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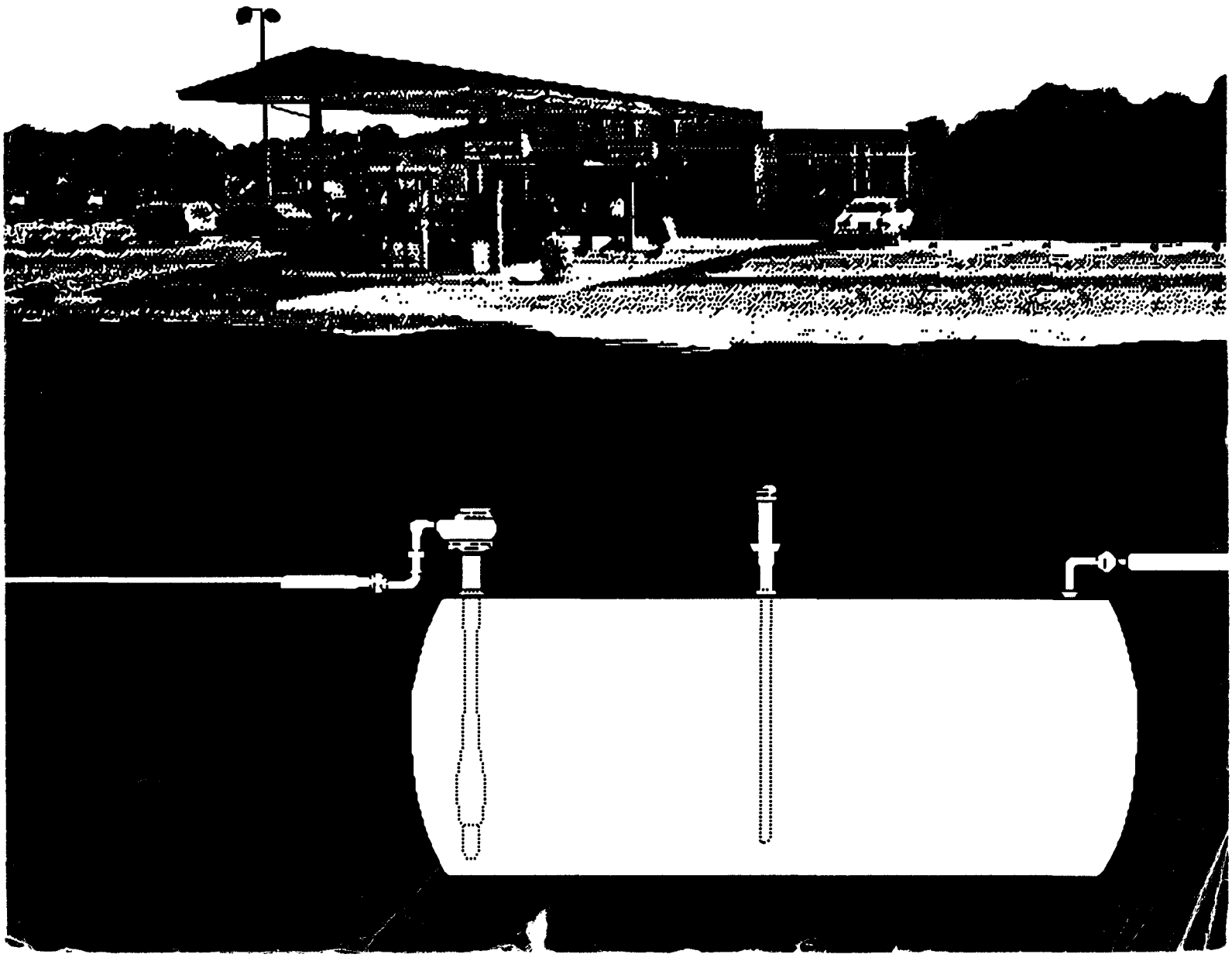

UNDERGROUND MOTOR FUEL STORAGE TANKS:

A NATIONAL SURVEY

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The research on underground storage tanks contained in this report represents the joint efforts of several organizations and many individuals. The project team met separately to refine the study design, analyses, and approach to data interpretation. The names of the principal authors and the contributions of the various organizations are summarized below.

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EXECUTIVE SUMMARY

Background and Objectives - The U.S. Environmental Protection Agency's Office of Toxic Substances (OTS) conducted a national survey of underground motor fuel storage tank systems. This study was conducted in support of the EPA's Office of Underground Storage Tanks, which has responsibility for implementing the requirements of the 1984 Amendments to the Solid Waste Disposal Act. The results of the survey are presented in this report.

The primary objectives of the national survey were to provide estimates of: (1) the total number of underground motor fuel storage tanks; (2) the number of establishments with underground motor fuel storage tanks; (3) the number of tanks that leak; and (4) characteristics of tanks and tank establishments. These tank and establishment characteristics were analyzed in a search for possible correlations with leak status (i.e., whether or not a tank system leaks) and leak rate. In addition, OTS conducted an evaluation of the use of inventory reconciliation analysis as an indirect method of detecting and measuring leaks.

Scope - The target universe included the following kinds of establishments if they had motor fuel stored in underground tanks: (1) fuel-related establishments, including business, government and military (establishments which store fuel for retail sales or transportation services including gas stations, trucking companies, auto dealers, marinas and other industry groups using or dispensing motor gasolines, diesel fuel, aviation gasoline, and jet fuel); (2) large establishments in non-fuel-related industries (establishments which store fuel for purposes such as company vehicles and private fleets); and (3) farms. The

survey excluded: tanks storing heating oil, used motor oil, chemicals, hazardous wastes and sewage; tanks which are above or partially above ground, abandoned or nonfunctional tanks; private non-business tanks; bulk storage tanks; and tanks which do not dispense fuel to end users.

Data Collected - Survey data collection was conducted with a national probability sample of 890 establishments, with a total of 2,445 tanks. A subsample of 218 establishments was selected for physical tank testing, and at those sites there were 433 tank system tests that yielded conclusive results.

Three different primary data collection efforts were used in this survey. In-person interviews were conducted with tank establishment operators in order to collect a variety of information such as the type of business, type of fuel stored, number of tanks, and tank characteristics (such as capacity, age, material of construction). The second type of data collection involved fuel inventory data which were provided by establishment operators and analyzed to evaluate inventory reconciliation techniques as an indirect method of detecting and measuring leaks. The third data collection effort involved physical tank system tightness tests at a representative subsample of establishments.

Response Rate - A rigorous quality assurance program was implemented at every stage of the survey. Response rate for the interview with tank owner/operators was 99 percent, which is very high. The tank testing phase achieved an excellent cooperation rate of 95 percent; even after allowing for untestable tanks, the tank testing response rate remained at a high level of 85 percent. For the inventory data collection, 78 percent of those contacted provided complete or partially complete data. However, only 41 percent produced data that were sufficiently complete and

accurate to be used in the inventory reconciliation analysis of this study.

Terminology - Several terms are important to the understanding of the survey's results and are thus defined here. The estimates apply to the tank system which includes the underground vessel together with all connecting distribution lines, vent and fill pipes and connections. Manifolded tank systems consist of two or more tank systems which are joined together. Whether or not a tank system passed the tightness test is determined by a statistical decision rule applied to the physical measurement data. This decision rule involves the null hypothesis that the tank system is tight. This test has a 5 percent risk of falsely declaring a test failure, and a 5 percent risk of not detecting a failure at 0.10 gallons per hour. The actual test failures could be due to product loss anywhere in the tank system -- in the vessel, lines, pipes, or bungs.

Major Findings - Following are the major findings of this study. The estimates given are subject to sampling error and nonsampling error. The ranges in parentheses following the estimates represent 95 percent confidence limits for the estimates due to sampling error. These national estimates are for the contiguous United States.

1. There are an estimated 796,000 (503,000-1,090,000) individual motor fuel storage tanks in the United States.

   - 158,000 (35-453,000) of these are on farms.

2. The above tanks are located at an estimated 326,000 (296,000-356,000) establishments.

   - 79,000 (58,000-100,000) of these are farms.

   - The estimated mean of number of tanks per establishment is 2.4 (1.6-3.2), overall, which varies from 1.9 for large establishments that are not in a fuel-related business to 3.5 for gasoline stations.

3. Under test conditions, an estimated 35 percent (30-40%) of the non-farm underground motor fuel storage tank systems, including manifolded systems, did not pass the tightness test. This represents an estimated 189,000 (153,000-226,000) tank systems. Using a different test criterion (i.e., the commonly used NFPA 0.05 gallon per hour cutoff) rather than the statistical significance test used above leads to a very similar estimate (33%) of tanks not passing the tightness test with an estimated 44 percent total classified as "uncertifiable" (i.e., 44% = 33% test failures plus 11% untestable tanks and inconclusive test results which are also counted as uncertifiable in most commercial tests). Of the physical tank system tests attempted, 5 percent were untestable with the method used because of unusual system configurations or large interferences.

4. The percentage of fiberglass and steel tank systems that did not pass the tank tightness test were about the same. Steel tanks, which comprise an estimated 89 percent of all underground motor fuel storage tanks, show little increase in the percentage of tank systems not passing the test as they age except for the oldest tanks (over 20 years), for which the percent increases substantially. There is a much smaller sample of fiberglass tanks, so no comparison by material was possible for the tanks aged 20 or more years, but fiberglass and steel tank systems have no significant difference in percent not passing the test at comparable ages. These findings should not necessarily be interpreted as causal effects of age and tank material. Such statistical associations could be caused by other associated variables.

5. This report presents many descriptive statistics on the characteristics of underground tanks and the facilities or establishments at which they are located. For example, based on the national sample estimates:

   - Thirty-one percent of establishments with underground storage of motor fuels also store waste oil underground;
   - Fourteen percent of establishments have one or more abandoned tanks on site;
   - Seventy-eight percent of establishments used clean sand, pearock, or peagravel to backfill around tanks;
   - Twenty-nine percent of establishments are required to have tank operating licenses;
   - Sixty-nine percent of establishments believe they are insured for non-catastrophic leaks;
   - Eleven percent of underground motor fuel tanks are fiberglass;
   - Twenty-one percent of tanks are installed partially or completely below the water table;
   - Twenty-three percent of tanks are in manifolded systems; and
   - The mean age of tanks is 12 years.

6. The statistical analysis did not identify any single explanatory variable (such as age of tank, type of material, or fuel type) that is strongly correlated with tightness test results. Additional multiple regression and logistic models were developed which suggested the possible influence of a few variables, but their ability to predict the test outcome was weak, as described in the appendices of this report. Soil characteristics were not among the variables analyzed because they were not available in the data base during this study. Soil data more recently developed by EPA and General Software Corporation are described in the appendices of this report.

7. There is only limited agreement between inventory analysis methods and tightness test outcomes on a tank-by-tank basis. It is possible that a longer period than 28 days of inventory data might improve the level of agreement. While each of three inventory methods provided roughly similar overall estimates for the percent of tank systems that might leak, there were substantial disagreements among the inventory methods as to which tank systems leak.

   - It is very difficult to obtain accurate and usable inventory data. Owners and operators had trouble following even simple inventory data collection procedures. The 78 percent response rate was achieved only after extensive followup efforts. It is not that inventory control does not work, it is just that the successful execution of it is difficult to achieve.

   - EPA feels that the failure of the inventory analyses as part of the survey was a result of human error and inconsistency and we do not view it as a basic failing of inventory methods.

8. For the tank system tightness tests, EPA initially conducted an extensive evaluation program to test existing methods, then selected one of these, modified it to improve its accuracy, and characterized its field performance. The method used by EPA has stated procedures to identify and correct for potential interference problems which commonly occur in the field and which can otherwise invalidate the test results. These interferences include tank end deflection, temperature effects, water table and vapor pockets. With the modified method, EPA was able to detect a 0.10 gallon/hour leak with 95 percent probability while correctly identifying a tight system with 95 percent probability.

   None of the existing test methods evaluated by EPA could consistently and reliably achieve detection of the 0.05 gallon/hour leak rate specified by the NFPA 329 "Recommended Practices for Underground Leakage of Flammable and Combustible Liquids, 1983." This conclusion is based entirely on the data collected during EPA's evaluation program since supporting data which had been requested from the test companies to document their performance claims were not received.

While some methods can provide reliable results under some specific conditions, most of them do not take definitive steps to deal with the commonly occurring interference problems previously mentioned. EPA believes that in general the field performance of existing test methods could be improved by:

- training field crews to identify interference problems;
- developing stated procedures to deal with interference problems; and
- increasing frequency and duration of data collection.

In any case, it is important that those who must rely on the results from these methods be informed about their performance characteristics. If valid performance data on a method do not exist, they should be generated. If they do exist, they should be made available to those who are potential users.

Simply put, EPA believes that there are problems with existing tank system tightness tests. EPA believes these problems are correctable and for this survey EPA chose a method, modified it to deal with these problems and was able to improve the accuracy over existing methods.

SECTION 1

INTRODUCTION

The National Underground Storage Tank Survey was designed to provide estimates of the number of underground motor fuel storage tanks and the number of establishments with such tanks, the number and percent of tank systems that leak, and characteristics of tanks and tank establishments. Tank and establishment characteristics were analyzed in a search for possible correlations with leak status (whether a tank is leaking) and leak rate. The survey sample was a national probability sample of establishments in the U.S. (except Hawaii and Alaska) that had underground motor fuel storage tanks (not abandoned).

The survey consisted of a series of information-gathering procedures which included an in-person interview, inventory data collection, tank tightness testing, and secondary data abstracting. This report presents national estimates for statistics based on data collected in the interview phase of the survey, analysis of the inventory data collection, and results of the tightness testing phase.

The tank and establishment characteristics data presented in this report were collected through in-person interviews conducted by Westat field interviewers using the "Underground Storage Tank Survey Establishment Operator's Questionnaire" (see Appendix F for a facsimile of this questionnaire). The results reported here are based on interviews conducted during visits to 890 establishments. As a part of the tank tightness test fieldwork (at a subsample of establishments), certain tank and establishment characteristics were also collected by the Midwest Research Institute tank tightness test field crews. This

information was checked against interview data and discrepancies resolved by telephone recontact and checking the hard data from both sources. The tank system leak data in this report were collected by on-site tank system and manifolded tank system tests conducted by Midwest Research Institute field crews using a modified PetroTite procedure.

I. DEFINITION OF KEY TERMS

For the purposes of this survey, an establishment is defined as any site or location where underground storage tanks are being used to store and dispense motor fuel for business, commercial, government, and, in a few instances, farm purposes. The term "tank system" refers to an individual underground storage tank vessel plus the lines and equipment that are connected to that vessel. At some establishments, two or more tanks are linked together by piping in "manifolded tank systems." Manifolded tank systems often present special data collection problems. For inventory reconciliation and sometimes for tank tightness testing, it was necessary to collect data at the "manifolded tank system" level rather than for the individual tank systems. For example, when two manifolded tanks have one meter, inventory data must be collected for the manifolded system as a whole in order to compare meter data to stick data. In physical tank tightness tests, tanks in manifolded systems were not isolated for testing when, for example, they were joined by inaccessible lines. In the interview procedure it was possible to collect data (such as age, size, construction material) on an individual tank basis.

Our analytical approach has been to report results at the smallest unit of analysis, whenever possible. Thus, interview-collected characteristics and national estimates of the numbers and types of tank establishments and tanks (in Section 9) are

reported for individual tank systems rather than for "manifolded tank systems." Similarly, leak status and leak rate analyses will be based on the smallest available unit tested. Thus, for tanks in manifolded systems that were separated and tested individually, leak rate and status will be reported for individual tank systems rather than for the tanks combined into a manifolded tank system leak rate and status. However, for those manifolded tank systems that were not separated for testing, the leak status and rate reported are the manifolded tank system test status and rate. The text for each table defines the unit of analysis used in the table.

II. TYPES OF TANKS COVERED BY THE UNDERGROUND STORAGE TANK SURVEY

The Underground Storage Tank Survey was limited, for practical and regulatory reasons, to underground tanks that store and dispense motor fuel prior to end use by business, commercial and government establishments. **This limitation excludes** tanks used to store materials other than motor fuels such as chemicals, waste-water, hazardous waste, heating oil, and used or waste oil. Also excluded by definition are motor fuel storage tanks that are at private residences, above-ground or partially buried tanks, and all motor fuel tanks at bulk storage facilities that do not dispense fuel to end users. Tanks that are abandoned or empty were also excluded from consideration. **Included** within the scope of the survey are tanks that are owned and operated by private businesses, public and government institutions, military facilities, and farms. The initial step of the data collection effort was to determine, for a random sample of establishments, whether they in fact had an active underground motor fuel storage tank as defined above. If so, the establishment (and its tanks)

were considered **eligible for the survey**, and the main questionnaire was administered.

As a result, the sample includes such establishments as gasoline stations, airports, marinas, rental car agencies, fleets of trucks or company cars, bus companies, fire stations, parks, police stations, and many other types of establishment.

III. LIMITATIONS OF THE DATA PRESENTED IN THIS REPORT

As in any research report of this type, there are limitations in the study's scope and methods which should be understood by all who interpret and use the results of the study. The major limitations are summarized below as caveats which must be kept in mind by the reader.

A. Sample Frame Limitations

Because of practical and economic considerations, the sample was drawn from those establishments most likely to have the types of underground tanks described above (Subsection II). All establishment types and industries were covered except small (less than 20 employees) businesses in non-fuel-related industries. As a result, the study would not have counted any underground motor fuel tanks in small businesses, private homes, and less relevant industry sectors. In other words, it is possible that the number of underground motor fuel tanks in the nation is somewhat greater than our estimate. However, we would expect roughly similar leakage experience in uncovered business establishments, based on the relatively constant percentage of tanks leaking across the different sectors studied.

B. Owner/Operator Responses

The tank and establishment characteristics data presented in this report were collected by Westat interviewers during an in-person interview with establishment owners and operators. The accuracy of these data is limited by the knowledge of the responding owner/operator.

A substantial number of owner/operators responded "don't know" to interview questions about certain tank characteristics such as the age of the tank or the material of construction. Because the information may prove useful in regulatory development, we have included information on the percentage of "don't know" responses when this was substantial.

C. Inventory Data

Reconciliation of inventory records received from respondents was evaluated as a secondary, more economical method of detecting tank system leaks and estimating tank system leak rates. Inventory data were analyzed by Warren Rogers Associates, Inc. (WRA), using proprietary inventory reconciliation analysis software. Alternative methods were also explored. Some limitations to the usefulness of the inventory data are related to the ability of the owner/operator to accurately collect it. Because many tank managers do not normally maintain such inventory records they often produced error-prone data, which could not be analyzed. This occurred frequently in establishments which had fairly inactive tanks (fuel was dispensed only once or twice a week) and when the volume of fuel in a tank was very low. Very accurate measurements were needed for the WRA analysis. A less demanding analytical protocol might

have been able to use a higher proportion of the inventory data received.

D. Line, Vessel, and Equipment Leaks

Based on tank test methods used in this study, it was generally not possible to distinguish between leaks occurring in the tank vessel and leaks occurring only in lines or equipment such as fill pipes, manways, vent pipes, distribution lines, joints and bungs. Leak tests of distribution lines in isolation from their tanks were possible for about one-third of the tested tanks found to be leaking. (A distribution line test was always attempted but could not be completed in many cases.) The distribution line leak data are analyzed in Section 8. Elsewhere in this report, no distinction is made between tank vessel leaks and distribution line leaks or other non-vessel leaks. A leak anywhere in the system is reported as a tank system leak. Also, for manifolded systems of more than one tank where the tanks were not separated for testing, the entire system was tested and a reported leak could be in any of the tanks or in any associated line, pipe, fitting, joint, or other equipment.

E. Test Conditions Versus Operational Conditions

The tank tightness test conditions include some circumstances which are not always present during normal tank operations. Specifically, during the test tanks were overfilled (i.e., tanks were filled as were the associated fill pipe and additional testing apparatus to permit measurements) such that the net pressure at the tank bottom was 4 psig. The test procedure compensates for hydrostatic pressure when the water table is above the bottom of the tank by increasing the height of

overfill. As a result of the overfilling, tanks that leak only near or at the top of the tank or in lines, pipes, or joints not normally filled with fuel might not always (or might never) be leaking in normal operations if the tank is kept less than full. The impact of increased leak rate because of test pressure is less of a problem than leaks at non-operational locations because the test pressure is small, and test leak rates have been adjusted downward to correct to typical operating pressures. (Section 8 discusses the typical fill levels reported in the interview phase and their effects on leak status statistics, and also describes the leak rate adjustment procedures.)

F. Interpretation and Adjustment of Tank Tightness Test Data

Many factors affect the reliability of tank tightness test data. The most important factor is temperature effect. Because the volume of fuel in a tank varies with temperature change, it was necessary to measure temperature changes directly and adjust results using a correction and smoothing process. These adjustment procedures required careful engineering and statistical review and data editing using engineering judgment to rule out suspect data. Some introduction of error is possible in such engineering judgments, but careful discarding of suspect data increased the overall validity of the findings. (Section 7 describes the data reduction procedures applied to the raw data.)

G. Untestable Tanks and Unreliable Test Data

The primary purpose of the tightness testing phase of the survey was to estimate the number and proportion of leaking tanks and to estimate the leak rates of those tanks. The degree to

which the test data fulfill the objectives of the survey is limited by the number of tanks for which responses were obtained. For approximately 10 percent of the tanks selected for testing, the tests were unsuccessful because the tank was untestable or the resulting test data were unreliable. Reasons for untestability included plumbing and piping problems and other installation factors, such as physical constraints on the placing of the test equipment in the tank. Reasons for unreliable tests included trapped vapor pockets in the tank vessel or lines, and unexplained temperature variations. For an additional five percent of the selected tanks, the leak rate could not be measured due to the great size and speed of the leak (although leak status was determined). Generally, leaks at a rate of three or more gallons per hour under test pressure could not be quantified by the test procedure.

IV. Overview of the Report

Chapter 2 presents the major findings from the interview and tank tightness test data as well as operational findings of interest in developing regulations. Chapter 3 describes the quality assurance program, with results given as appropriate in the subsequent chapters. Chapter 4 describes the sample selection and estimation procedures, Chapter 5 gives the field procedures for the questionnaire and inventory data collection, and Chapter 6 describes the tank tightness test data collection. Chapter 7 gives the tank testing data reduction process and quality assurance results, and Chapter 8 describes further statistical analyses applied which resulted in the final determination of whether a tested tank was leaking. The actual data are presented in tabular form in Chapter 9, together with the findings of some analyses designed to search for possible correlations between tank and establishment characteristics and

leak status of tanks. Chapter 10 presents the findings on inventory reconciliation techniques.

The Appendices provide further details supporting these discussions.

SECTION 2

CONCLUSIONS

I. ACCURACY OF ESTIMATES

A. Accuracy and Sampling Error

The major findings of this survey are the national estimates made from the data. These are presented in tabular form, along with statements based on the data. The numbers are statistically unbiased estimates based on a national probability sample, and represent a sample estimate of the result that would be obtained from a census of the target universe in which standard questionnaire data collection and physical tank testing was conducted for all tanks and establishments in the target universe. The size of the difference between sample results and results from such a hypothetical census are measured by sample variances estimated from the survey data. Thus, the accuracy of the figures can be objectively assessed as far as sampling error is concerned. Non-sampling error is discussed below.

Estimates are given together with 95 percent confidence limits in parentheses. These confidence limits are based on the sampling variances estimated from the survey data. (The estimation procedures are discussed in Section 4 and Appendix A.) The limits can be expressed as the following statements. For the first entry in Table 2-1 for the total of all establishments, which is 326 (296-356) thousand, one would say, "It is estimated with 95 percent confidence that the number of establishments with underground motor fuel storage tanks is between 296,000 and 356,000 establishments, with a point estimate of 326,000

Table 2-1. Estimates, by type of establishment, of the number of underground motor fuel storage tanks and the number of establishments with underground motor fuel storage tanks in the continental United States (95% confidence bounds in parentheses)

Type of establishment	Number of establishments with tanks (1,000's)	Number of tanks (1,000's)	Number of tanks per establishment	
			Mean	Median
Government and military	**45** (29-62)	**98** (69-128)	**2.2** (1.8-2.5)	**2** -
Gas stations owned by major petroleum companies	**33** (26-41)	**118** (87-148)	**3.6** (3.3-3.8)	**3** -
Gas stations owned by other companies	**58** (50-67)	**204** (174-233)	**3.5** (3.2-3.8)	**3** -
Other fuel-related establishments	**36** (30-43)	**77** (64-90)	**2.1** (1.8-2.4)	**2** -
Large non fuel-related estabments (with ≥ 20 employees)	**74** (55-93)	**142** (97-187)	**1.9** (1.6-2.2)	**2** -
Total for business and government establistments	**247** (220-275)	**638** (584-692)	**2.6** (2.4-2.8)	**3** -
Total for farms	**79** (58-100)	**158** (<453)	**2.0** (<5.0)	**1** -
TOTAL	**326** (296-356)	**796** (503-1,090)	**2.4** (1.6-3.2)	**3** -

establishments." This means that there is only a 5 percent chance that the actual value falls outside of this range. When an upper limit is given, as in the estimate of number of eligible tanks on farms in Table 2-1, where the entry is 158 (less than 453) thousand, this indicates that the lower bound of the confidence interval is a small number. The statement for this estimate would be, "It is estimated with 95 percent confidence that the number of underground motor fuel storage tanks on farms is less than 453,000, with a point estimate of 158,000." This means that there is only a 5 percent chance that the actual value is greater than the upper limit.

B. Non-Sampling Error

As in any data collection effort, non-sampling error is also present in these data. This type of error is not quantified in the confidence intervals but has been explored and reported on in several places in the report. Potential non-sampling errors include deficiencies in the sampling frame, respondent errors, physical test errors, and inventory recording and analysis errors. In this survey, one potential non-sampling error investigated in depth comes from the physical tank testing. Several parts of the report discuss the test method. Section 1, in particular, has reviewed the limitations in the interpretation of the results which stem from the testing method chosen. First, a leak detected by the test may represent a hole anywhere in the system of tank vessel and associated lines, pipes and fittings, or indeed a loose connection within this system. Second, it cannot be definitively determined from the data where the detected hole or loose connection is or when or whether a leak occurs under operating conditions. Section 8 offers two relevant pieces of information: Tanks do tend to be nearly or completely filled at delivery (so that holes or loose fittings at or near

the top of the tank would have occasion to leak in practice); and when distribution line tests were possible, the measured rate of the line leak accounted for very little of the measured tank system leak (so that detected leaks do not appear to be in the distribution lines). As is described in Sections 6 and 7, factors which could lead to difficulties with the physical testing such as uneven product temperature, change in temperature, erratic measurements, vapor pockets, and tank end deformation due to test pressure have been carefully accounted for in the the test procedure and subsequent data reduction process.

II. NATIONAL ESTIMATES

The major findings are given in Tables 2-1 through 2-3.

- Number of Establishments with Tanks -- Table 2-1 presents survey estimates of the number of underground motor fuel storage tanks and the number of establishments with such tanks, as well as the mean and median number of tanks per establishment, by type of establishment. The national estimate for the number of tanks is 796,000 with 95 percent confidence bounds of 503,000 to 1,090,000. This total includes farms. Since so few farms surveyed actually had underground motor fuel storage tanks (20 out of a sample of 600), further national estimates including farms could not be accurately made and therefore are not presented. The national estimate of business and government tank establishments is 247,000 (220,000-275,000) and the number of non-farm tanks is estimated to be 638,000 (584,000-692,000).

- Percentage of Tank Systems Judged to be Leaking under Test Conditions -- Table 2-2 shows the estimated number and percent of business and government tanks judged to be leaking under test conditions by establishment type, based on the physical tightness test results. Based on tested tank systems which yielded valid test results, an estimated 35 percent of tank systems are judged to be leaking under test conditions, with 95 percent confidence bounds of 30 to 40 percent.

Table 2-2. Estimated number and percent of tank systems[1,2] judged to be leaking under test conditions by establishment type (95% confidence bounds in parentheses)

Establishment type	Number of tank systems judged to be leaking (in 1,000's)	Percent of tank systems judged to be leaking (of tanks with conclusive test results)[3]
Government and military	**29** (5-54)	**36** (16-55)
Gas stations owned by major petroleum companies	**25** (11-38)	**32** (19-45)
Gas stations owned by other companies	**56** (40-71)	**30** (22-37)
Other fuel-related establishments	**35** (25-45)	**57** (43-71)
Large nonfuel-related establishments	**45** (19-71)	**33** (18-47)
Total	**189** (153-226)	**35** (30-40)

[1]In this table, tank test results are reported for individual tank systems unless the tanks were tested as a part of a manifolded tank system that was not broken apart. These manifolded systems are included in the table.

[2]Does not include farm tanks.

[3]Excludes tank systems for which test results were inconclusive. (Therefore the estimated number in this table, when divided by the estimated totals in Table 2-1, will not give the percentages shown here.)

Table 2-3. Estimates by establishment type of mean and median leak rates among tank systems[1,2] judged to be leaking under test conditions (95% confidence bounds on the means in parentheses)

Establishment type	Mean adjusted leak rate (gph)[5]	Median adjusted[3] leak rate[4] (gph)
Government and military	**0.26** (0.06-0.47)	**0.27**
Gas stations owned by major petroleum companies	**0.42** (0.18-0.68)	**0.29**
Gas stations owned by other companies	**0.24** (0.13-0.34)	**0.28**
Other fuel-related establishments	**0.45** (0.20-0.71)	**0.32**
Large nonfuel-related establishments	**0.25** (0.14-0.36)	**0.14**
Total	**0.32** (0.24-0.39)	**0.25**

[1]In this table, tank test results are reported for individual tank systems unless the tanks were tested as a part of a manifolded tank system that was not broken apart. Results for manifolded systems are included in the table.

[2]Does not include farm tanks.

[3]Leak rates of leaking tank systems were adjusted to operating pressure.

[4]Calculation of median adjusted leak rate includes tanks judged to have unquantifiably large leaks.

[5]Calculation of mean adjusted leak rate includes only those tank systems judged to be leaking which had quantifiable leak rates.

- Percentage of Tank Systems Leaking Under Operating Conditions -- Under operating conditions, the percentage of tank systems that are leaking might be somewhat less. This could vary from 18 percent at a random point in time to 29 percent at the time of product delivery the way tanks are normally filled, and to 35 percent at the time tanks are filled if they are filled to capacity. (See further discussion in III below.)

- Leak Rates -- Table 2-3 presents the mean and median leak rate for tank systems judged to be leaking under test conditions by establishment type for business and government tanks. These leak rates have been adjusted to typical operating conditions (see Section 8). The mean leak rate for all business and government tanks is 0.32 gallons per hour with 95 percent confidence bounds of 0.24 to 0.39 gallons per hour. This is based on tank systems judged to be leaking which had quantifiable leak rates. Some tanks showed leaks too large to quantify so the estimated mean leak rate is conservative.

- Incidence of Underground Motor Fuel Tanks Among Various Types of Establishments -- The screening effort revealed a low incidence of underground motor fuel tanks for certain types of establishment. Twenty-four percent (19-28%) of fuel-related establishments (other than gas stations) have underground motor-fuel storage tanks. Thirteen percent (9-16%) of large establishments not in fuel-related establishments have eligible tanks. Three percent (2-4%) of farms have eligible tanks. **However, as is seen in Tables 2-1 and 2-2, a substantial proportion of the tank and tank establishment universe is found in these types of establishments** even though many such establishments do not have underground motor fuel storage tanks.

III. LEAK STATUS UNDER OPERATING CONDITIONS

Certain features of the tank testing method are different from typical operating conditions, especially the overfilling of the tank during the test.

It is certainly reasonable to ask whether some of the leaks detected under test conditions might have been due to holes near the top of the tank or in lines, pipes and fittings above normal fill levels. Data from the survey reveal that it is common practice to fill tanks to 100 percent capacity when product is delivered. In fact, 100 percent was the modal value for this variable, and the median of the reported average fill level was 83 percent of capacity. Thus, the data suggest that even holes near the top of the tanks would be subject to leaking, at least just after product delivery.

On the other hand, the average tank fill level just prior to delivery had a median value of about 20 percent of tank capacity. Therefore, as a rough approximation, a typical operating level might be midway between the high and low point, or 52 percent of capacity. If one were to further assume that holes were evenly distributed between the top and bottom of the tank, then an estimated 52 percent x 35 percent = 18 percent of the tank systems would be leaking on the average at any point in time under typical fill level conditions.[1] Furthermore, using average percent filled after delivery may be a conservative estimate of operational fill levels. When asked about the maximum gallons ever stored, most respondents reported 100 percent, and only one-quarter were below 92 percent full.

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[1]This is a rough approximation which could be refined by calculating highest and lowest fill levels for each tank separately, and then computing the median and mean fill levels as fuel is withdrawn. Fuel withdrawal rate could be assumed as uniform over time or simulated from inventory data. Finally, refinements could be made to account for the fact that the assumption of uniform leak distribution over the surface of the tank is not identical to uniform leak distribution over volume. However, since actual leak distribution is unknown, such refinements do not seem warranted at present.

In summary, if we are willing to assume that holes are uniformly distributed around the tank circumference (we have no data to verify this assumption), we could calculate that:

- Approximately 35 percent of the tank systems would be leaking if they were filled to capacity;
- If all tanks are ever filled to capacity during the year, then an estimated 35 percent of the tank systems in the country are leaking at one time or another during a year;
- Approximately 29 percent (.35 x .83) of tank systems are leaking just after the time of product delivery the way tanks are normally filled; and
- Approximately 18 percent (.35 x .52) of the tanks are leaking at a random point in time.

Based on a limited set of 43 leaking tank systems where it was possible to test the leak status of distribution lines separately, it was found that the distribution line leak rate makes up a very small portion of total tank system leak rate. Distribution line leaks made up a small portion of the total system leak rate.

IV. ESTABLISHMENT CHARACTERISTICS

Descriptive statistics for establishments include:

- Thirty-one percent (27-35%) of establishments with underground storage of motor fuels also store waste oil underground.
- Fourteen percent (11-17%) of establishments with in-use underground motor fuel storage tanks also have one or more abandoned underground storage tanks on site.

- Seventy-eight percent (73-83%) of establishments used clean sand, pearock or peagravel to backfill around tanks (one-quarter of owner/operators did not know the backfill material).

- Twenty-nine percent (21-37%) of establishments are required to have tank operating licenses (whether this was required was not known by 16% of owner/operators).

- Sixty-nine percent (64-75%) of establishments believe they are insured for non-catastrophic leaks (22% of owner/operators did not know the answer to this question).

V. TANK CHARACTERISTICS

Other descriptive findings include:

- The mean age of eligible business and government tanks is 12 years (11-13 years). The mean capacity is 5,405 gallons (5,026-5,783 gallons).

- Forty-two percent (37-46%) of business and government tanks store unleaded gasoline, 33 percent (30-36%) store leaded gasoline and 21 percent (17-26%) store diesel fuel. The remaining tanks store aviation fuel, jet fuel, gasohol or other products used as motor fuel.

- Eleven percent (7-15%) of tanks with known construction material are fiberglass.

- Twenty-one percent (17-25%) of tanks with known positions in relation to the water table are partly or completely below the water table (tank owner/operators do not know this status for one-third of tanks).

- Twenty-three percent (18-27%) of tanks are part of a manifolded system.

- Five percent (3-6%) of tanks for which the owner/operators knew whether cathodic protection was installed do have such protection (tank owner/operators did not know the answer to this question for 13% of tanks; it is unlikely that such a system would work well if the operator were unaware of its existence).

- Twenty percent (14-26%) of tanks were installed by the owner/operators themselves (this is among the 54% of owner/operators who knew the identity of the installer).

VI. TANK CHARACTERISTICS ASSOCIATED WITH LEAKS

Statistics describing tank systems judged to be leaking under test conditions include:

- Fifty-seven percent (46-67%) of tank systems storing diesel fuel are judged to be leaking under test conditions, while 18 percent (9-26%) of tank systems storing leaded gasoline are judged to be leaking under test conditions. Thirty percent (26%-41%) of tank systems storing unleaded gasoline are judged to be leaking under test conditions. These differences in percent leaking by fuel type could be due to some other variable associated with fuel type. No conclusion should be drawn about the effect of fuel type without further research.

- Fifty-four percent (39-68%) of tanks in manifolded systems are judged to be leaking under test conditions, while 31 percent (26-36%) of single tank systems are judged to be leaking.

- Thirty-one percent (15-48%) of fiberglass tank systems (i.e., tank systems in which the tank is made of fiberglass although lines, pipes, and fittings may not be) are judged to be leaking under test conditions. This figure is quite similar to the proportions of steel tank systems judged to be leaking, whether bare (uncoated) with 32 percent (14-49%), or coated, with 38 percent (30-46%).

- Steel tanks, which comprise 89 percent of all underground motor fuel storage tanks, show little increase in percentage of tank systems judged to be leaking as they age except for the oldest tanks (over 20 years of age) for which the percent judged to be leaking increases substantially to 58 percent (29-77%). No fiberglass tanks over 20 years old were found in our sample, so percent judged to be leaking cannot be compared across material type for this age category. Fiberglass and steel tank systems show similar

proportions judged to be leaking for the younger age categories. For example, among tanks less than five years old, 38 percent (11-65%) of steel tank systems are judged to be leaking and 26 percent (<77%) of fiberglass tanks are judged to be leaking. The broad confidence bounds are due to the small sample sizes (46 and 7 tank systems tested, respectively). Furthermore, for tanks between five and 20 years old, the percent of tank systems judged to be leaking under test conditions are similar for fiberglass tank systems and steel tank systems.

The statistical analysis did not identify any single explanatory variable (such as age of tank, type of material, or fuel type) that is strongly correlated with either leak status or tank system leak rate. Additional multiple regression and logistic models were developed which suggested the possible influence of a few variables, but their ability to predict leak status or leak rate was weak, as described in Section 9, Subsection VI, and Appendix I. Soil characteristics were not among the variables analyzed because they were not available in the data base during this study. Soil data more recently developed by EPA and General Software Corporation are described in Appendix H.

VII. OPERATIONAL FINDINGS

A. Tightness Test Method Development

There were a number of possible tank system testing methods commercially available at the time of the survey. OTS modified an existing method in order to improve the reliability for the survey (see MRI draft report, November 7, 1985 for OTS, "Development of a Tank Test Method for a National Survey of Underground Storage Tanks," which is summarized in Appendix C).

B. Establishment Manager Cooperation and Inventory Participation in the Field Interview Phase

Participation in the field interview phase of the survey was nearly 100 percent overall. As indicated in Table 2-4, 99.3 percent of all eligible respondents completed interviews. The highest response rate among the sample segments was among the large establishments where 100 percent of the eligible establishments provided interview data.

It is very difficult to obtain accurate and usable inventory data. Owners and operators had trouble following even simple inventory data collection procedures. The 78 percent response rate was achieved only after extensive followup efforts. About 90 percent of these respondents required technical assistance to collect the inventory data. This contrasts with the 60 percent of owner/operators who responded "yes" to the questionnaire item, "Do you reconcile your stick inventory with your book inventory?" The lowest inventory data response rate was from the farm sample, where only 35 percent of all eligible farms provided inventory. Of all eligible respondents, 16 percent have not yet provided any inventory. Problems that establishment operators encountered in keeping inventory records are described in detail in Section 5.

C. Tightness Test Cooperation

The physical tank testing response (cooperation) rate was 95 percent and complete, usable results were obtained from 85 percent of the subsample of tank systems and manifolded tank systems. Test results were judged reliable in about 89 percent of the tank systems and manifolded tank systems where tests were

Table 2-4. Field interviewing and inventory response rates

	Farms	Large establishments	Fuel-related establishments*	Total
A. Number of eligible establishments	20	76	800	896
B. Response rate (percent of eligible respondents who completed interview)	95%	100%	99.4%	99.3%
C. Refusal rate (percent of eligible respondents who refused interview)	5%	0%	0.6%	0.7%
D. Inventory response rate (percent of eligible respondents who returned inventory)	35%	79%	78.8%	77.8%
E. Inventory refusal rate (percent of eligible respondents who refused to record inventory)	30%	1.3%	1%	1.7%
F. Percent of establishments delinquent in returning inventory	20%	11.8%	16.4%	16.1%
G. Percent of establishments for which inventory measurements are impossible	15%	7.9%	3.8%	4.4%

*including government and military establishment

attempted. Approximately 5 percent of the tank systems and manifolded tank systems where tests were attempted were not testable for technical reasons which are discussed in more detail in Section 6. Table 2-5 presents the tightness test completion rates for the survey.

The testing methods used in the survey required that the tank be out of service for one day and be filled to capacity at the start of the test. Difficulties in arranging for a fuel delivery, scheduling an acceptable test time, or physical problems with the tank and with its associated plumbing add significantly to both the time required and the cost of physical testing. Severe operational difficulties requiring excavation were encountered in about 14 percent of the tanks. More details on these problems appear in Section 6.

Table 2-5. Tank testing completion statistics

	Single tank or manifolded tank systems	Total number of individual tanks at these systems
A. Number selected for tightness testing	484	561
1. Percent of out of scope of survey[1]	0.8%	0.7%
2. Percent at sites refusing to participate	5.0%	4.8%
B. Number of tests attempted	456	530
1. Percent untestable for technical reasons	5%	5%
2. Percent for which test results were unreliable or inclusive	6%	5%
3. Percent with reliable, conclusive test results	89%	90%
	100%	100%
C. Response rate for estimates of the percentage of tank systems that are leaking[2]	85%	86%

[1]Became out of scope after the interview phase (for example, went out of business).

[2]These response rates are the number of reliable test results out of the eligible cases selected. From the figures presented above, they can be calculated as (0.89 x 456)/((1.0 - 0.008) x 484) = 0.85 and (0.90 x 530)/((1.0 - 0.007) x 561) = 0.86.

SECTION 3

QUALITY ASSURANCE APPROACH

Rigorous quality assurance (QA) procedures were applied to all stages of the survey to ensure that the data are of known quality. These procedures are detailed in two QA Plans[1]; one covering the overall survey and one dealing specifically with tank testing. This section provides a brief overview.

In addition to the procedures outlined here and detailed in the QA plans, the survey was audited by EPA QA personnel. This involved site visits, productivity and response rate monitoring, and QA audits and reviews of home office processing procedures.

Data quality is assessed by its representativeness, completeness, accuracy, precision and comparability. The sample of establishments and their underground storage tanks must be representative of the population of establishments and tanks about which inferences are to be made. A complete, or almost complete, set of data must be collected; otherwise, its representativeness, accuracy and precision will be compromised. Accuracy (lack of bias) and precision must be sufficiently high so that confidence can be placed in the numerical value of the results. The methods employed must be well documented and allow

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[1] LUST Quality Control Procedures, National Survey of Underground Storage Tanks, Quality Assurance Plan, Westat, July 12, 1985; and National Survey of Underground Storage Tanks Draft Quality Assurance Program Plan for the Office of Toxic Substances, Midwest Research Institute, June 7, 1985.

results. The methods employed must be well documented and allow comparison of the results with other relevant studies. The succeeding pages outline procedures used at each stage of the study to assess and maximize data quality. Quantitative measures of data quality are presented in the appropriate sections throughout the report.

I. DEVELOPMENT OF SAMPLING FRAME AND SAMPLE SELECTION

The objective of the survey is to provide national and regional estimates of the number and proportion of underground motor fuel storage tanks that leak, and to investigate characteristics of leaking tanks. To achieve this objective, the information collected must be representative of storage tanks throughout the country. Representativeness was ensured by careful development of the sampling frames and methods of sample selection.

The entire contiguous United States was divided into Primary Sampling Units (PSUs) consisting of counties or groups of counties with a minimum number of gas stations and other fuel-related business establishments. A probability sample of PSUs was drawn, and sample summary statistics were compared with summary statistics calculated from the entire frame to check that the random selection procedure had been applied correctly.

Section 4 and Appendix A detail the construction of frames and sample selection for the fuel establishment, large establishment and farm samples. In each case, checks were made between frame and sample summary statistics.

II. PREPARATION OF QUESTIONNAIRES AND INTERVIEWS

Versions of the questionnaire and inventory recording forms were pretested, both informally and in extensive formal pretests. The questionnaire, together with an instruction booklet, was sent to the respondent prior to the interview to allow the respondent to look up information not immediately available and thereby improve the quality (accuracy and completeness) of the response. Questionnaire packages were sent by certified mail to provide a record of receipt.

Interviewers were carefully selected and underwent a five-day training session that included instruction at both Westat and MRI in Kansas City. They were provided with a detailed interviewer's manual that explained project and administrative procedures, and provided item-by-item specifications for the questionnaire.

III. INTERVIEWING

One or more interviewers were assigned to each PSU. They received call records and labels for each of their assigned cases, and were to complete a questionnaire for each eligible case. All survey materials for completed work were sent to the home office weekly. Call records for ineligible as well as eligible cases had to be returned with the reason for ineligibility clearly marked on the call record. Interviewers were required to make weekly progress reports by telephone.

In addition to questionnaire administration, interviewers were responsible for conducting a meter accuracy test, reviewing inventory procedures with the respondent, and collecting other information on the location and nature of the establishment. The measured meter errors were used to adjust the meter sales figures to give actual quantities dispensed each day. This, in turn, reduces the incidence of false-positive results from inventory reconciliation analyses when quantity dispensed is compared to stick readings. Review of inventory procedures was aimed at improving the respondent's ability to understand and correctly complete the inventory recording forms.

Interviews from the field were checked for completeness, given a final interview status code, and logged into an automated receipt control system. Refusals to comply with this mandatory survey were reported directly to EPA's Office of Enforcement and Compliance Monitoring. Most refusals eventually complied, and the overall response rate was 99.3 percent. Approximately 78 percent of the eligible establishments furnished complete or partial inventory data. Difficulties in gathering inventory data are discussed in Section 5.

Initially, replacements for ineligible (i.e., out of scope because no below-ground tanks, no motor fuel, etc.) fuel establishments were selected after their ineligible status had been determined. An unexpectedly high ineligibility rate of about 50 percent made this procedure impractical. Subsequently, the lists were oversampled, and the interviewers screened for eligibility in the field. This made replacement errors less likely.

IV. DATA TRACKING

An automated receipt control system was developed to maintain a record of the status of each data type for each establishment. The data types and activities logged into the system include:

- Certified mail cards - date received;
- No tank certifications - date received;
- Interview status - Complete, Partially Complete, Ineligible, etc., with appropriate dates;
- Contact name, mailing address and telephone number;
- Prompt call status - date of call to prompt for inventory records;
- Inventory status - Complete, Partially Complete, Refused, etc.;
- Tightness test flag - establishments selected for tightness testing;
- Tightness test status - Complete, Partially Complete, Refused, etc.;
- Map status - Availability of soil and hydrogeologic data; and
- Final status - Computed from the above status fields.

The system enabled the survey to be monitored on a continuous basis by providing document control and producing various lists and reports. Discrepancy reports indicating missing data types, such as missing inventories or missing "No

Tank" certification, provided measures of the completeness of the survey.

V. SELECTION OF ESTABLISHMENTS FOR TIGHTNESS TESTING

The frame was developed from the information in the receipt control system and checked against manual records before drawing the sample. Weighted and unweighted summaries of the sample were calculated to check that the sample of 198 establishments was drawn correctly from the 876 eligible business and government establishments. All 20 farms were scheduled for testing.

Notification packages were sent to each selected establishment with a request for a return receipt. Four to seven days after the mailing, each respondent was called to verify that the package had arrived and that the testing procedure was understood.

VI. TIGHTNESS TESTING

A. Training Tightness Teams

To assure that testing conducted by the several tank testing crews would produce accurate and reliable results, a formal training program was conducted prior to the beginning of the testing program. All of the crew members participating in the training were employees of O.H. Materials, Inc. or Double-Check,

Inc. and had been trained and certified by Heath Consultants (the manufacturer of the testing equipment) prior to the training for the national survey. The two main objectives of the training were to assure that all crews would follow the same test procedures, and to provide advanced tank testing training.

The MRI field data analysts who accompanied each tank testing crew received a four day training session that covered procedures for collecting data, preparation of site diagrams, computer operations, and data transmission. The analyst's training sessions included hands-on practice experiences in data entry, data transmission and recordkeeping.

It was necessary to add six additional test teams at approximately halfway through the testing program. The test crews were subcontracted through Protanic, Inc, and were selected based on their past performance records, and years of experience. The added crews were trained in the testing protocols by on-site trainers or by sessions held via telephone, and the test crews were teamed with experienced MRI data analysts who monitored the testing procedures. All data collected by the added test teams received extra verification review by Protanic and MRI staff prior to entering the data in the analysis files.

B. Instrument Calibration

The Petro-Tite equipment used to collect the leak rate data includes a thermistor in a probe that is inserted into the fuel tank to monitor fuel temperature and a thermal sensor box which provides an absolute temperature measurement within three degrees

Fahrenheit. The electronic circuit in the thermal sensor box was checked each time the equipment was set up (on site) to assure that the circuit detected a simulated temperature change to within approximately 0.003 degrees Fahrenheit, before the equipment was used in the test.

Thermistors, glass thermometers and barometers used to collect ancillary environmental information such as air temperature, barometric pressure, and surface and subsurface temperature were calibrated at MRI prior to field use, and the calibration data were entered as a part of the project file.

C. Field Inspections

Site visits to tank test operations were conducted by the MRI project leader, the MRI quality assurance coordinator, the field coordinator, and EPA staff. The purposes of the site visits were to evaluate the test protocols, and to assess the performance of the field crews.

D. Data Management and Analysis

A computerized receipt control file was used to track the test data. As the data were processed and reported, that stages of the process were entered into the receipt control file. Weekly reports were printed for project management and reporting.

The tank test data were entered into a portable computer in the field, using a thoroughly tested data entry program. These data files were transmitted to MRI by telephone, where they were stored on disks. The hard copy of the data on the original Petro-Tite sheets, the field copies of the disk files, and the data collected on ambient conditions was sent to MRI on a weekly basis. The field disk files were compared to the transmitted disk files using a computer utility program, in order to detect any transmission errors. All of the data elements to be used in subsequent leak analyses were printed out and hand checked against hard copy.

The data file for each test was hand checked for measurement problems and outliers, which were eliminated prior to the analysis of the file to determine test status and leak rate. Each tank test analysis was checked individually to ensure that the formulas for calculating the leak rate and standard error were correct. Leak rate, test status, and environmental data were abstracted from hard copy and computer files, and coded, keyed, key-verified, and edited prior to being merged with the questionnaire analysis file.

E. The Retest Program and Results

Three types of retesting were carried out to investigate different sources of variation in the test results. Back-to-back retests (on the same day and by the same crew) were conducted to investigate the stability of test results over time. A leak simulation retest was used to check the accuracy of the test in a situation with a constant leak of known rate. "Complete retests"

were independent tank tests usually conducted on different days with different crews from the original test, and involving rescheduling the test and refilling the tank.

A detailed analysis and discussion of the retest data is reported in Section 7 and Appendix D of this report.

VII. DATA HANDLING AND MANAGEMENT

Questionnaires were batched in groups of ten and tracked through the entire survey processing operation. Rules for coding and editing were published in a Coding Manual that was updated periodically to include new codes. Coding problems were referred to a supervisor for resolution. Inventory records were reviewed prior to coding so that missing or incorrect information could be recovered or corrected by a phone call to the respondent as soon after receipt as possible. Approximately 90 percent of respondents received prompt or data retrieval calls in an effort to obtain complete and accurate data on both the questionnaires and inventory records. All coded questionnaires were verified by the coding verifier.

All data were key-punched and then key-verified by a second operator and transferred by telephone link to EPA's NCC computer facility at Research Triangle Park in North Carolina. The data were machine edited to check that each data element is in range, that skip patterns were correctly followed, and that answers to related questions are consistent. Errors were corrected and the edit program rerun until no more problems were found. Frequency distributions and various tables were generated to check on data

quality. These allowed outliers to be identified and checked to ensure that they are "true" values.

Careful coding and data entry procedures ensure that the final data files accurately represent the information collected by the survey.

VIII. DATA ANALYSIS

National estimates of number of establishments with tanks, number of tanks, percentage of leaking tanks and leak rates were obtained using the methods described in succeeding sections. Where appropriate, the estimates are accompanied by confidence bounds or standard errors to indicate precision. Confidence bounds are narrowest (i.e., the estimates are most precise) for estimates based on data from the entire survey. Estimates based on subsets of the data (e.g., data from individual regions or for tanks of a particular age) have broader confidence intervals.

SECTION 4

SAMPLE DESIGN, ESTIMATION OF SAMPLE WEIGHTS AND VARIANCES

The national probability sample for the Underground Storage Tank survey was drawn in a three-stage sample design that involved sampling establishments from establishment frame lists within 34 survey sites which had been sampled to represent six survey regions. Data were collected from the sampled establishments using several data collection techniques. All sampled establishments were first screened to determine survey eligibility, that is, whether they had an underground motor fuel storage tank. At eligible establishments, the owner or operator of the tank was interviewed in person and instructed in the completion of 30-day inventory records. A sub-sample of the eligible establishments was selected for physical tank tightness testing.

This section reviews the target universe of the survey and then describes the three stages of sampling: Primary Sampling Units (PSUs) or survey sites; establishments for questionnaire and inventory data collection; and the sub-sample of eligible establishments for physical tightness tests. In brief, the sample consisted of 34 PSUs in which 2,218 establishments were sampled. Of these, 896 establishments were eligible for the survey, (i.e., had underground motor fuel storage tanks that were not abandoned) and 890 cooperated with the interview phase. Two hundred eighteen were selected for physical tank testing, which was accomplished at 202 establishments. The section concludes by describing the methods used to calculate the final weights used in making national estimates from the survey and to estimate the sampling error of those estimates. Appendix A gives more details

on these subjects, and Appendix G gives a detailed account of the farm sample.

I. SCOPE OF THE SURVEY

The scope of the Underground Storage Tank survey was limited, for practical and regulatory reasons, to underground tanks used to store and dispense motor fuel for business, commercial and government use. This limitation excludes materials other than motor fuels that may be stored in underground storage tanks, such as chemicals, waste water, hazardous waste, heating oil, and used or waste oil. Also excluded by definition are motor fuel storage tanks that are at private residences, above-ground or partially buried tanks, and all motor fuel tanks at bulk storage facilities that do not dispense fuel to end-users. Tanks that are abandoned or empty were also excluded from consideration. Included within the scope of the survey are tanks that are owned and operated by private businesses, public and government institutions, military facilities, and farms.

As a result, our sample includes such establishments as gasoline stations, airports, marinas, rental car agencies, fleets of trucks or company cars, bus companies, and many other establishments. For practical reasons for list building and screening costs, small establishments (with fewer than 20 employees) in industries not judged to be fuel-related were not included in the survey. Table 4-1 is a list of the industries that <u>were</u> judged to be fuel-related. For these industries all establishments were included in the listing process.

Table 4-1. Selected SIC codes for fuel tank establishments frame

SIC code	Description
4010	Railroads, switching and terminal companies
4110+	Local and suburban passenger transportation companies (includes airport transportation, ambulance and limousine services)
4121+	Taxicab companies
4131+	Intercity highway transportation services
4140+	Passenger transportation charter services (includes bus charter, rentals and tours)
4151	School bus companies
4170	Passenger transportation terminal and service facilities
4210+	Trucking companies
4231+	Motor freight terminals
4469A	Marinas
4511	Air transportation, certificated carriers
4521+	Aircraft charter, rental and leasing -- non-certificated carriers
4582A	Airports
4582B+	Aircraft maintenance services
4583	Airport terminal services
5511+	Auto and truck dealers (new and used)
5521+	Used car dealers
5541+	Gasoline service stations
7512+	Passenger car rental and leasing agencies
7513+	Truck rental and leasing agencies
7519+	Utility and house trailer rental agencies
7992+	Public golf courses
7997B+	Golf and country clubs

II. SAMPLE DESIGN AND SITE SELECTION

A. Sample Design

The contiguous U.S. (forty-eight states plus the District of Columbia) was divided into six survey regions based on broad soil and climatic characteristics. Table 4-2 lists the states which comprise each region. Six Primary Sampling Units (PSUs) were drawn from each region, except for the Mountain region, where four were drawn. The PSUs consist of counties or groups of counties with a minimum count of gas stations and the fuel-related establishments (see Table 4-1). They were sampled within the survey regions on the basis of probability proportional to this count.

Once the 34 survey sites (consisting of 76 counties) were drawn, establishment lists for sampling were constructed for each county. In order to construct the lists, the target universe was divided into three sectors:

1. Fuel-related establishments -- Establishments which by the nature of their business are likely to have underground motor fuel storage tanks. The industries in this category are listed in Table 4-1 and include gas stations, trucking companies, airports, marinas, and others. Government and military establishments with underground motor fuel storage tanks were also part of this sector.

2. Large establishments (20 or more employees) in other industries -- Although the nature of their business would not suggest the presence of underground motor fuel storage tanks; by virtue of their size, these large establishments may have such tanks.

3. Farms were listed and sampled separately -- (See Appendix G for detailed discussion of the farm sample.)

Table 4-2. Six regions for the National Survey of Underground Fuel Storage Tanks

1 -- Northeast

Maine
New Hampshire
Vermont
Connecticut
Massachusetts
Rhode Island
New York
New Jersey
Pensylvania
Maryland
Delaware
Virginia
West Virginia
Washington, D. C.

2 -- Southeast

Kentucky
Tennessee
Arkansas
Louisiana
Mississippi
Alabama
Georgia
North Carolina
South Carolina
Florida

3 -- Midwest

Wisconsin
Minnesota
Iowa
Missouri
Illinois
Indiana
Ohio
Michigan

4 -- Central

North Dakota
South Dakota
Nebraska
Kansas
Oklahoma
Texas

5 -- Mountain

Montana
Wyoming
Idaho
Nevada
Utah
Colorado
Arizona
New Mexico

6 -- Pacific

Washington
Oregon
California

Separate samples were drawn from the three frames thus established, since they were expected to yield widely varying eligibility rates.

The fuel establishment sample was drawn by region, with equal probability of selection within each region. To reach the target of 800 survey-eligible establishments in this sector, 1,618 establishments were sampled for screening. The large establishment and farm samples were drawn on an equal probability basis nationwide. Six hundred establishments were drawn from each of these frames and the survey-eligible establishments kept.

After the eligible establishments were determined, a sub-sample was drawn for tank tightness testing. All eligible farms were selected for this testing since so few (20) farms were eligible. For the fuel-related and large establishments, the two samples were combined and an equal probability sample drawn from each region. All tanks at sub-sampled establishments were to be tested.

B. PSU (Site) Selection

Once the six survey regions were defined (Table 4-2), a master list of PSUs was developed. For each of the 3,111 counties in the contiguous U.S., several counts were developed. The 1981 County Business Patterns (CBP) data base supplied figures for the number of gas stations, other fuel-related establishments, and establishments in other industries with 20 or more employees. A report prepared by Versar for the EPA (Leaking Underground Storage Tanks Containing Engine Fuels, draft, March 1984) supplied estimates for the number of gas stations on a state-wide basis, based on figures from Petroleum Marketing News (PMN). These counts included all retail outlets for branded

gasoline, i.e., convenience stores and other outlets as well as gas stations. The CBP county totals for gas stations were adjusted upwards to sum to the PMN totals. These adjusted counts were added to the CBP other fuel-related establishment totals to get a fuel establishment count for each county. Minimum PSU counts were established by region (so that a sampled PSU would be sure to have enough establishments to list and sample). Counties with fewer fuel establishments than these minima were grouped together to form multi-county PSUs. The 3,111 counties yielded 1,362 PSUs.

Within each survey region the PSUs were sorted by urban versus rural, then by state and finally by PSU measure of size (count of fuel establishments). Six PSUs were selected from each region (four in Region 5 -- Mountain) with probability proportional to measure of size. The resulting 34 sampled PSUs are made up of 76 counties. Twenty-three PSUs are urban and eleven rural, and together they form a probability sample representing the entire contiguous United States.

III. ESTABLISHMENT FRAME CONSTRUCTION AND SAMPLE

A. Frame Construction

Since lists of establishments with underground motor fuel storage tanks do not exist, it was necessary to create establishment frame lists for each of the 34 PSUs. As described above, the target universe of all establishments with underground motor fuel storage tanks was divided into three segments. The first segment consisted of establishments which, by the nature of their business, were considered fairly likely to have such tanks. This segment, called the "fuel-related establishments" segment,

contained gas stations, trucking companies, bus services, auto dealers, marinas, golf courses, airports and other industry groups that use large amounts of motor fuel or dispense it to the public. (See Table 4-2 for a list of these industries.) Also included in this segment were government and military establishments with underground motor fuel storage tanks.

The second sample segment, the large establishment segment, consisted of establishments in all nonfuel-related industries (i.e., those industries excluded from the first segment) that have 20 or more employees. This segment was designed to provide estimates of the number of large, nonfuel-related establishments that have underground motor fuel storage tanks to service company vehicles and private fleets.

The third sample segment consisted of farms. Recent census of agriculture statistics indicate that about half of the more than two million farms in the United States have on-farm motor fuel storage, but no information existed on how much of this fuel storage was in underground tanks. This segment was designed to provide estimates of the number of farms that have underground motor fuel storage tanks to service farm equipment.

To construct the first list of fuel-related establishments, several sources and methods were used. A listing of all establishments with a primary or secondary Standard Industrial Classification code appearing on the list in Table 4-1 was purchased from National Business Lists. By specifying firms with a fuel-related SIC code as the secondary code, we included such establishments as convenience stores which also sell gasoline. This list was supplemented by adding any establishments with such a code as their primary or secondary code appearing on the large establishments list, purchased from another source. To complete the fuel establishments sampling frame, lists of government

(Federal, State and local) and military establishments with eligible tanks were needed. The Department of Defense provided lists of military tank locations in the sampled PSUs to the EPA. The civilian government list was constructed using a telephone contact and network approach for the government officials serving the sampled PSUs at the local, State and Federal levels. The frames for all 34 PSUs had about 34,000 entries.

The large establishment list was purchased from Dun and Bradstreet. All establishments in the 76 counties with 20 or more employees were purchased from the Dun's Market Indicators list, a very complete business listing. As noted above, all establishments on the purchased list with a fuel-related primary or secondary SIC code were removed from the large establishments frame and clerically compared with the existing fuel establishments frame. If they were not already on that frame they were added to it. About four percent of the final fuel establishments frame came from the Dun and Bradstreet list. All establishments with an agricultural SIC code were also removed from the large establishments frame and added to the farm frame if not already there. In this way, the particular establishments were on the correct frame and duplication between frames was ruled out. The final count for the large establishments frame in the 34 PSUs was about 68,000 establishments.

The farm frame was provided to the EPA by the U.S. Department of Agriculture (USDA). As noted, it was supplemented by the (very few) farm establishments found on the purchased Dun and Bradstreet list of large establishments. About 31,000 farm owners and operators were listed on the farm frame for the 34 PSUs.

B. Establishment Sample Draw

The fuel establishment sample was drawn by survey region. The total sample size of 800 eligibles was allocated among the six regions in proportion to their count of fuel-related establishments in the 1981 County Business Patterns data. Based on initial field results of 50 percent eligibility, the target sample sizes were approximately doubled. Within each region an equal probability sample was drawn. Table 4-3 gives the counts of sampled cases by region.

The large establishments and farms were both sampled on an equal probability basis nationwide. Six hundred of each were sampled, with only the eligibles remaining in the survey. Because so little was known regarding incidence of underground motor fuel storage tanks in these sectors, the initial sample size was fixed rather than the final number of eligibles being fixed.

Table 4-4 shows the results of screening the initial sample. Eight hundred fuel establishments and 76 large establishments were eligible for the survey (in business and operating an underground motor fuel storage tank). Of these, 871 provided questionnaire data. In addition, 20 of the 600 sampled farms had underground storage tanks. As indicated in Appendix G, about half of all farms report motor fuel storage, but only about 10 percent have more than 1,000 gallons of storage capacity. For these small amounts of fuel, above ground storage is often a reasonable alternative.

Table 4-3. Initial sample sizes for fuel establishment, large establishment and farm samples by survey region

Survey region	Fuel establishments	Large establishments	Farms
1 Northeast	449	158	11
2 Southeast	415	116	88
3 Midwest	325	142	324
4 Central	194	68	142
5 Mountain	75	29	33
6 Pacific	160	87	2
Total	1,618[1]	600	600

[1]Subsequent fieldwork determined that six of the sampled fuel establishments were duplicates.

Table 4-4. Number of eligible cases for fuel establishments, large establishments, and farm samples by survey region

Survey region	Fuel establishments	Large establishments	Farms
1 Northeast	225	21	0
2 Southeast	197	18	3
3 Midwest	161	13	5
4 Central	92	7	5
5 Mountain	42	4	4
6 Pacific	83	13	0
Total	800[1]	76	20[1]

[1]Five fuel establishments and one farm refused at the interview phase of the survey.

IV. SUB-SAMPLE OF ELIGIBLE ESTABLISHMENTS FOR PHYSICAL TANK TIGHTNESS TESTS

Since so few farms screened had underground motor fuel storage tanks, it was decided to physically test all such tanks at all eligible farms. At the time of sample allocation, it was estimated that there would be at most 50 tanks at eligible farms, so that number was set aside for farm tank tests.

This left a target number of 450 tanks or manifolded tank systems to be tested in the business and government sector (fuel and large establishments). The 450 were allocated to the six survey regions in the same proportions as the original establishment sample allocation, except that a minimum number, 40, were allocated to Region 5, the smallest region, before allocating the remainder to the other five regions. As each region was completed by the interviewers, a list of eligible government, fuel-related establishments and large establishments in the questionnaire sample was constructed, with the number of tanks or manifold tank systems for each establishment listed. At the time of sub-sampling it was assumed that a manifolded tank system (two or more tanks connected by various lines and pipes) would be physically tested as one unit. Therefore the sub-sample was drawn on that basis. During the actual testing, some such systems were isolated, and the individual tanks (and associated lines) were tested separately. Thus, the total number of possible tank tests is more than the number of tanks or tank systems reported here but less than the total number of tanks at these establishments.

The sub-sample of tanks to be tested was drawn on an establishment basis, with all tanks at a given establishment tested. The establishment list for a given region was sorted by number of tanks or tank systems, then PSU, and then fuel-related

and government versus large establishment. The target number of establishments to select was calculated from the list, which included initial sampling weights, and the target tank sample size, using the weighted average number of tanks per establishment. An equal probability sub-sample of establishments was then drawn from the list. Table 4-5 shows the target number of tank tests and the number of establishments sub-sampled with the number of tanks or tank systems at the sub-sampled establishments.

V. CALCULATION OF FINAL SAMPLE WEIGHTS AND VARIANCE ESTIMATION

A. Calculation of Final Sample Weights

1. Questionnaire Weights for Business and Government Establishments

The final questionnaire weights for establishments sampled with fuel-related SICs other than gas stations were based on a ratio adjustment of the initial sample weights for all such screened establishments to 1982 County Business Patterns (CBP) counts of these SICs followed by a nonresponse adjustment among the eligible other fuel-related establishments to account for the few nonrespondents. (By the time final weights were being calculated, the 1982 data were available.) The adjustments were made by survey region. The ratio adjustment served to calibrate the initial sample to CBP estimates of the number of establishments with one of the fuel-related SICs in each region. The sum of the weights of the eligible cases is the survey estimate of the number of such establishments with eligible tanks, by region. The nonresponse adjustment assures that the

Table 4-5. Summary of business and government establishment subsample[1] for tank tightness testing, by region

Region	Target number of tank systems[2] to subsample for business and government sectors	Number of business and government establishments subsampled	Number of business and government tank systems[1] at subsampled establishments
1 Northeast	115	51	112
2 Southeast	110	47	111
3 Midwest	90	38	86
4 Central	50	23	52
5 Mountain	40	17	43
6 Pacific	45	22	46
Total	450	198	450

[1]All eligible farm underground motor fuel storage tanks were assigned for tightness testing. There were 20 eligible farms with 35 tanks.

[2]In allocating and drawing the subsample of establishments for tightness testing, a manifold tank system was counted as one unit. Some such systems were separated for physical testing.

weighted results based on questionnaires received equals the estimates based on screening results.

The gas stations were weighted in the same way. First the initial sample was ratio-adjusted by region to CBP totals for gas stations (SIC code 5541). The sum of the weights of eligible cases then estimates the number of gas stations with eligible tanks, by region. A nonresponse adjustment again assures that the weighted results based on questionnaires received will equal the estimates based on screening.

The sample sector of establishments with 20 or more employees in industries not otherwise sampled (the large establishments) was weighted the same way as the gas stations and other fuel-related industries. The CBP totals of establishments of this size in all but the selected fuel-related SICs were used for a region-by-region ratio adjustment of the initial sample. The weighted eligible large establishments then estimate the number of such establishments with eligible tanks in the country, by region. Since all eligible large establishments participated in the interview phase of the survey, no nonresponse adjustment was needed.

No national statistics are currently available to estimate the number of individual government agencies with underground motor fuel storage tanks, which is the universe our frame was built to cover. Therefore no ratio adjustments can be made. Nonresponse adjustments were made to account for the small amount of nonresponse among government establishments.

2. Physical Test Result Weights, Business and Government Establishments

After calculating final questionnaire weights for all responding business and government establishments as described above, the sampling weights for establishments chosen for physical testing were adjusted to sum to the estimated totals for four establishment types (government, gas station, other fuel-related, and other industry) by region. This adjustment was made by an iterative raking procedure,in which the weights were adjusted first to regional totals, then to establishment-type totals, then readjusted to regional totals, and so forth, until no further adjustment was needed. (This took five and a half iterations to achieve.)

A final adjustment was made for tank test result weights. The weight for the individual tank or tank system test would be equal to the establishment physical test weight, except that some tanks were not tested. Thus, a "tank nonresponse" adjustment was made to the tank weights to account for the untested tanks.

3. Farm Questionnaire and Physical Test Weights

Due to the distribution of farms within the survey regions (both overall and in our sample) and the low yield of eligible farms from the screening, the survey regions have been consolidated into three areas for calculating final weights for farms. (See Appendix G for a more detailed discussion.) These are: (1) East (combines survey regions Northeast and Southeast); (2) Midwest; and (3) West (combines survey regions Central, Mountain, and Pacific). Total counts of farms for these areas were obtained from the 1982 Census of Agriculture and used to

form ratio adjustments for eligible farms. Due to one refusal among farms, a nonresponse adjustment was also made.

Since so few farm tanks were tightness tested (21 of 35 -- most not tested were smaller than 1,100 gallons), no weighted estimates will be presented for that data, and hence no final weights were calculated for physical test results for farm tanks.

B. Variance Estimation

National estimates from the survey are based on a sample of cases rather than a complete census of the nation's underground motor fuel storage tanks, so they are subject to variability termed sampling error. This is due to the fact that drawing several samples would result in different sets of establishments being interviewed and different national estimates. Since the sample was drawn on a probability basis, it is possible to use the survey data to estimate the magnitude of this sampling error. Due to the complex nature of the sample design, this variance is not easily expressed as a simple mathematical formula. It has therefore been estimated by a more empirical approach.

The method of variance estimation used in this survey is termed the jackknife approach. Essentially, a series of sub-samples of the survey data known as replicates are created. Using the same series of steps given above for the full sample, each replicate is given weights which can be used to create national estimates based on that replicate. The variance of the replicate estimates of the statistic from the full sample estimate estimates the sampling error of the statistic.

In this report the sampling error is generally reported in terms of 95 percent confidence bounds. These are interpreted as

being the numeric range which one can be 95 percent confident includes the true value of the statistic. It is centered on the full sample estimate and its width is determined by the estimated sampling error of the statistic.

SECTION 5

FIELD PROCEDURES -- QUESTIONNAIRE AND INVENTORY

Interviewing fieldwork for the Underground Storage Tank Survey began December 2, 1984. A staff of eight Westat field interviewers was trained to collect data from establishments selected in 34 PSUs nationwide. The interviewing phase concluded on June 29, 1985. This chapter includes some details about the field procedures, inventory data collection and followup procedures used for the survey. Interview and inventory response rate statistics are reported. The detailed summary of the fieldwork is found in Appendix B.

I. WESTAT SCREENING PROCEDURES

The sample of 600 farms and 600 large establishments was pre-screened for survey eligibility by telephone. Telephone interviewers contacted the owner or operator of the farm or business and asked if there were any underground tanks used to store motor fuel at the establishment. All establishments that could not be reached by telephone were included in the interviewer assignment lists to be located and screened in the field.

Establishments selected from the fuel-related sample frame (such as gas stations, government facilities, and trucking facilities) were screened for survey eligibility by the field interviewers.

After the screening procedures were complete, survey materials were mailed out, beginning with all sampled establishments in Survey Region 6 (West Coast). Each establishment was sent a survey package (Appendix F) including an introductory letter, a copy of the survey questionnaire, an instruction booklet, and forms for collecting tank inventory data. The owner or operator was to review the materials to prepare for the next phase of the survey in which a Westat field interviewer visited the establishment and conducted an in-person interview with the respondent. Packages were mailed according to the schedule of the field interviewer so that the respondent received the materials two weeks prior to the interviewer's arrival on site. This gave the respondent time to prepare for the in-person interview.

II. DATA COLLECTION PROCEDURES

The first phase of fieldwork in a PSU was the field screening of the fuel-related sample of establishments. Establishments were found to be ineligible for the survey for various reasons; most commonly, they had no underground motor fuel storage tanks, they were out of business, they were out of area or scope of the survey, or the only tanks at the establishments were abandoned (i.e., out of service permanently). In-person interviews where scheduled with the owners or operators of all eligible establishments within each PSU. When an owner or operator refused to participate in the survey, the interviewer informed the respondent that EPA would be notified, and contacted a Westat field director immediately. An attorney with EPA's Office of Enforcement and Compliance Monitoring was then notified by Westat and necessary action was taken. Questionnaire and inventory refusal rates are discussed in Subsection III.

After the field interviewer arrived at the establishment site, the data collection procedures began with the administration of the Operator's Questionnaire (Appendix F). The respondent received a copy of this questionnaire in the survey package and was to have completed it prior to the interview. The questionnaire gathered basic data about the establishment, its operating characteristics and its tanks.

The interviewer then reviewed the inventory forms and procedures with the respondent. The inventory record-keeping procedure involved taking and recording dipstick readings and meter readings (if the dispensers were metered) for 30 days. Any deliveries made during that time period were also recorded. The interviewer checked to see that the inventory forms were being filled out correctly and that all tank and meter numbers on the forms and in the questionnaire corresponded to one another. If previously collected inventory records were used, the interviewer made sure 30 complete readings were provided.

Once all inventory sheets were reviewed and tank and meter numbers verified, the interviewer checked the accuracy of all dispenser meters using a five-gallon Certified Standard Weights and Measures Calibration Can. Five gallons of fuel was pumped into the test can and by reading the level of fuel according to the measuring gauge on the front of the can, the interviewer was able to determine the calibration ratio that would correct for any error in the meter. The inventory records were adjusted prior to inventory reconciliation analysis to account for the meter error.

After the meter accuracy check, the interviewer measured the diameters of all tank fill pipes, determined whether or not there

were drop tubes present inside the fill pipes and, if present, whether the drop tube was permanent or removable. This data was collected to aid tank testing crews in preparing for tightness tests at selected establishments.

Before leaving the site, the interviewer located the underground storage tanks on U.S. Geological Survey maps, which were provided for each PSU in the survey. The interviewer also evaluated the overall status or attitude of the on-site interview by answering debriefing questions.

III. FIELD INTERVIEW DATA COLLECTION STATISTICS

Table 5-1 contains data collection statistics for the field interview portion of the survey. It covers statistics on interview and inventory response and refusal rates.

A. Interview Response Rate

The interview response rate for this mandatory survey is nearly 100 percent overall, as well as for each sample segment. Out of 2,800 establishments contacted, 896 had underground motor fuel storage tanks, and were therefore eligible for the survey. Of those, 890 or 99.3 percent completed interviews. The highest response rate among the sample segments was among the large establishments, where 100 percent of the eligible establishments provided interview data.

Table 5-1. Field interviewing and inventory status statistics

	Farms	Large Estab-lishments	Fuel Estab-lishments	Total
A. Number sampled	598[1]	600	1,612[2]	2,810
B. Number contacted	596	596	1,608	2,800
C. Number of establishments contacted that have tanks ("eligibles")	20	76	800	896
D. Number of interview responses	19	76	795	890
E. Response Rate (percent of eligible respondents who completed interview	95%	100%	99.4%	99.3%
F. Number of interview refusals	1	0	5	6
G. Refusal rate (percent of eligible respondents who refused interview)	5%	0%	0.6%	0.7%
H. Number of inventory responses (includes both complete and partial complete)	7	60	630	697
I. Response rate (percent of eligible respondents who returned inventory)	35%	79%	78.8%	77.8%
J. Number of inventory refusals	6	1	8	15
K. Refusal rate (percent of eligible respondents who refused to record inventory)	30%	1.3%	1%	1.7%
L. Number of delinquent inventory responses	4	9	131	144
M. Number of establishments for which inventory measurements are impossible	3	6	31	40

[1] 600 farms were sampled. Two farms were found to be duplicates in the telephone pre-screening.

[2] 1,618 fuel establishments were sampled. Six were found to be duplicates in the field screening.

B. Certification of No Tank Status

Since many of the sampled establishments had been selected based on being in an industry expected to have underground motor fuel tanks, a verification program was undertaken for establishments which responded to the initial contact by stating that they had no eligible tanks (i.e., non-empty, underground, and storing motor fuel). For Region 6, the West Coast, which was the first region fielded, the field interviewer went to each of these establishments in person to visually confirm the statement and to get the owner or operator's signature on the "Certification Statement for Establishments Without Tanks" (a copy of which appears in Appendix F). This experience showed that those respondents initially stating they had no tanks were correct. For the remainder of the survey, the personal visits were not made to all such respondents, but they were all asked (by mail) to sign and return the no tank certifications. Signed statements were received from 80 percent of the "no tank" ineligible respondents.

C. Inventory Response Rate

Nearly 78 percent of the eligible establishments have furnished complete or partial complete inventory data. Even this relatively low response rate (compared with other parts of the survey) was achieved only after extensive edit and followup efforts by Westat's survey staff and finally a stern warning letter from EPA. Sixteen percent of the eligible establishments have not yet provided inventory records. It was impossible for 4.5 percent of the eligible establishments to keep inventory records.

D. Problems Encountered in Recordkeeping

A majority of establishment operators were unable to provide inventory data that was useable for inventory reconciliation analysis techniques without technical assistance. Establishment operators received detailed written instructions on inventory recordkeeping procedures, and on-site training was provided by the survey interviewers.

Nevertheless, almost 80 percent of the operators supplied inventory data sets that were incomplete or incorrect, initially. Extensive mail and telephone recontacts were made to the operators to attempt to capture the missing information and correct the problems. Eventually about half of the responding establishment operators were finally able to provide inventory records complete enough for analysis.

These experiences suggest that many establishment operators lack skill, training and/or motivation to correctly follow inventory recordkeeping procedures. Problems encountered with inventory records are listed in Table 5-2.

IV. FOLLOWUP PROCEDURES

Followup procedures were implemented to complete interviews which could not be completed during the time the interview team was working in a PSU and to make sure as many eligible establishments as possible returned useable inventory data.

A "clean-up" interviewer followed behind the field interviewers to complete interviews that could not be scheduled

Table 5-2. Problems encountered in inventory recordkeeping

Major problem areas	Percent of establishments with this problem
1. Meter sales and gallons used as calculated from stick readings and deliveries are equal (respondents adjusted out the daily variances)	19%
2. Did not provide inventory for the total 30 days	15%
3. Did not use the form correctly such that data was unusable	8%
4. Carried readings down from closing to opening (tanks without meters)[1]	7%
5. Did not provide enough complete readings (some stick or meter readings missing)	6%
6. No inch-to-gallons conversions provided	4%
7. Inconsistent conversions (from inches to gallons)	4%
8. No meter readings provided	3%
9. No stick readings provided	3%
10. Problems with delivery records	2%
11. Reported readings greater than tank capacity	1%

[1]For tanks without meters, the inventory recording procedure involves sticking the tank before and after each inactive period. This procedure is counter-intuitive to most respondents, who cannot understand the value of measuring and recording what they regard as measurement error in the second reading. Most respondents using "Tank Without Meter" forms have, therefore, measured the level in the tank only after each use (before each inactive period), and have (incorrectly) carried the readings to the "after" columns.

SECTION 6

TANK TESTING FIELD PROCEDURES

The field testing phase of the national survey required collecting descriptive information from each test site, conducting tightness tests on the tank systems and associated piping, and collecting ancillary environmental data. MRI managed the field testing and data acquisition, developed and maintained the test schedule, and served as the primary contact with the establishment owner/operator (o/o). The three-person field teams were comprised of an MRI field data technician and a two-person tank test crew provided by a commercial tank testing firm under subcontract to MRI. The tank test crews were provided by O.H. Materials, Inc., Double Check Company, Inc., and Protanic, Inc. This section describes the procedures used to accomplish the field data collection. A more detailed description of the field testing procedures may be found in MRI's Test and Analysis Plan.[1]

I. PRE-TEST PREPARATIONS

Preparations for field data collection at each establishment were initiated soon after the site identification and survey questionnaire results were received from Westat. The questionnaire responses and site diagrams were reviewed and a preliminary test date was assigned for each site. Tests were scheduled to maximize efficient use of the field teams and to complete the

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[1]"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.

survey as expeditiously as possible. Key scheduling considerations were the geographic locations of the sites, the number of tank systems at each establishment, and any special problems related to tank testing anticipated from the survey questionnaire results. Because up to three tank systems could typically be tested each work day at a single establishment, one day was allocated for sites with three or fewer tank systems. Similarly, two days were allocated for sites with four or more tanks. However, as testing three systems in a single day generally required significant overtime, consecutive three-system days were avoided where possible. Days were also incorporated into the schedule for makeup tests.

As soon as possible following assignment of a preliminary test date, the o/o was contacted by phone to arrange the test appointment. The testing and data collection program were fully explained and a mutually agreeable test date was established. The o/o was also instructed how to file compensation claims to EPA for costs incurred due to closure for testing.

The key requirements of the tightness testing were that the system be removed from service during the test and that the tanks be completely filled. Several gallons of additional product were also required to top off the tank during testing. If the o/o was unable to arrange product delivery to accommodate the test requirements, assistance was provided in the form of contacts to the appropriate fuel supplier.

The field crew assigned to a specific site contacted the establishment o/o by phone or visit approximately two days prior to the scheduled test date. This contact served to confirm the test date, confirm that the establishment would be ready for testing, and answer any additional questions from the o/o.

II. SITE DESCRIPTION INFORMATION

A site inspection was conducted at each establishment during the test visit prior to or during setup of the tank system test equipment. The purpose of the inspection was to provide an accurate-detailed record of the layout of the establishment, tank system configurations, and environmental features that may be related to system failure or leakage. This information was recorded in the form of overall site sketches, detail sketches for each tank, and a table of critical features. The site sketches recorded the layout of tank systems and dispensers as well as locations of buildings, roads and pavements, power lines, and waterways. Color instant print photographs were taken to supplement descriptions contained in the sketches. The following details were recorded on a critical features data form for each tank system:

Survey ID No.
Tank number
Product type
Number of dispensers
Tank size
Size of fill pipe
Size of gauge pipe
Size of stick pipe
Drop tube - permanent or removable
Delivery system - pressure, suction
Depth of tank from grade
Surface over tank
Presence of overhead power lines
Presence of nearby waterways

III. TANK SYSTEM TIGHTNESS TESTING

After the evaluation of a number of tank tightness test methods (see Appendix C), it is clear that none of the standard

test methods evaluated in the program can consistently and reliably achieve detection of the 0.05 gallon per hour leak rate specified by the NFTA 329 "Recommended Practices for Underground Leakage of Flammable and Combustible Liquids, 1983." This conclusion is based entirely on the data collected during the method selection phase of the program, since supporting data which was requested from the test companies to document their performance claims was not received. EPA modified, for use in the survey, one of the tank test methods to improve the accuracy of the test results.

While some methods can provide reliable results under some specific conditions, there are many situations which commonly occur in the test environment (such as the presence of a water table) which can invalidate the test results. Unless the test crew takes specific steps to identify these conditions, the reported results may be either misleading or incorrect. Most test methodologies currently in use fail to take definitive steps to identify one or more of these problem areas. The test results obtained must therefore be suspect to the degree that these factors are not recognized. The effects can be substantial and cannot be generally evaluated from the test data after the test crew has left the test site.

One of the major objectives of the program prior to the national survey was to identify and characterize a test method suitable for use on the program. A modification of the Petro-Tite method was developed and characterized for this purpose. This method was selected as the method with the most consistent approach to identifying potential problems and taking action to correct for them. It was judged to provide the most consistenyly reliable data for the national survey. It has stated procedures to identify and correct for tank end deflection, temperature effects, water table, and vapor pockets. EPA modified the method

in three ways in order to improve accuracy: (1) the test time and sample frequency were increased; (2) the temperature correction algorithm was improved; and (3) statistical hypothesis testing procedures were applied to the data to determime leak status.

A. System Test

1. Method Description

The Petro-Tite tank test measures product loss from the tank system by monitoring the change in product level in an elevated standpipe. Apparent volume changes are corrected for expansion and contraction caused by product temperature changes during the test to produce a net volume change. The net volume change over time is equivalent to the leak rate. The key features of the Petro-Tite method are that the test is conducted with the tank overfilled into an elevated standpipe and that the product is circulated during the test. The reference level in the standpipe is set to maintain a hydraulic pressure, or fuel head pressure, of 4 psig on the bottom of the tank in excess of any back pressure caused by groundwater at a level above the tank bottom. The purpose of conducting the test at an elevated pressure is to increase the probability of detecting small leaks, to mitigate masking of leaks by groundwater back pressure, and to stabilize end cap deformation. The product is circulated during the test to produce and maintain temperature homogeneity.

The Petro-Tite tank test equipment is shown in Figure 6.1. A probe, inserted into the fill tube, consists of the circulation pump inlet and discharge tube and a thermistor assembly. The probe is sealed in the fill tube with an air bladder seal. The

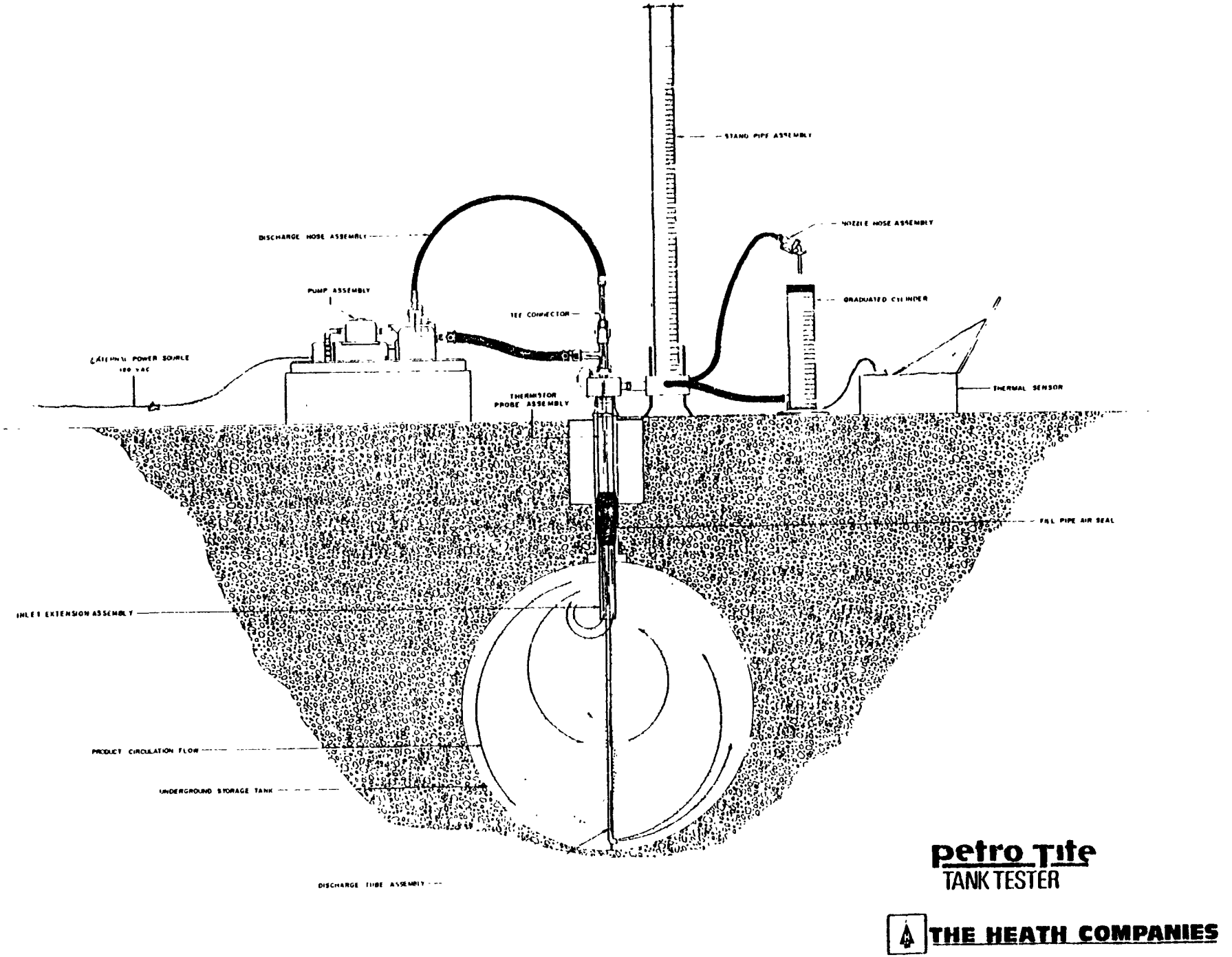

Figure 6-1. Test equipment

circulation pump withdraws product from the fill pipe and discharges it through a jet nozzle located near the bottom of the tank. The nozzle is directed at a 45-degree angle down the longitudinal axis of the tank to produce a swirling circulation. The thermistor is located at the pump inlet and is connected to an electronic thermal sensor module to provide temperature readout. The standpipe is connected to the probe and also to a graduated cylinder. During the test, the product level in the standpipe is readjusted to the reference level using the graduated cylinder. The volume of product added to or removed from the standpipe to reach the reference level is measured from the cylinder by difference, i.e., volumes in the cylinder are read before and after raising the standpipe level to the reference mark.

2. Method Operation

At the beginning of the test, the probe and thermistor units were installed into the fill pipe and the circulation was initiated. A small bore hole was drilled near the tank, preferably in the tank backfill, to determine if and at what level the water table was above the bottom of the tank. The density and temperature of the fuel product was determined with a hydrometer and a thermometer. The product temperature and density were used to determine the thermal expansion coefficient for the fuel from physical properties tables prepared by the American Petroleum Institute. The product density and depth to the water table were used to determine the standpipe reference levels.

The standpipe and graduated cylinder were installed and product was added to the standpipe to a "high" level reference level to place a pressure of 5 psig on the tank bottom. Product was periodically added to maintain this level until the rate of

change indicated that end cap deformation had stabilized. Then, the level was lowered to the "low" level to place 4 psig on the tank bottom. This was the reference level for the leak rate test.

The product level in the standpipe was readjusted to the reference level at 5-minute intervals. The volume of product in the cylinder before and after releveling were recorded on the test data sheet. Fuel temperature readings were made and recorded on the test data sheet at 5-minute intervals. These data were also entered into a LOTUS 123 (tm) spreadsheet file on a portable microcomputer. The test was conducted for 2 h with readings at 5-minute intervals. The tank system leak rate was calculated using the volume change, temperature data, tank volume, and thermal expansion coefficient of the product. At the conclusion of the system test, a line test was conducted. After completion of the line test, the equipment was removed from the tank.

Where possible, the entire tank system was tested as a single unit. This included vent lines, distribution lines, and, in the case of multiple tanks manifolded into a single system, all tanks and syphon lines. However, in cases where vapor pockets were found or the piping layout was not well known, tanks were isolated and tested separately. Isolation of tanks from associated piping generally required excavation to expose the top of the tank.

Vapor pockets were also indicated in several single tank systems. Vapor pockets were suspected when the standpipe level fluctuated in an apparent haphazard manner. This was typically caused by vapor trapped in manway or piping on the top of the tank. In cases where vapor pockets were indicated, the top of the tank was exposed by excavation and air bleed valves were

installed on manway and bung covers. The vapor was bled from the filled tank and normal tank tightness test was conducted. Identification of vapor pocket problems and the need for excavation could not be identified until the tank test was attempted. Hence, testing tanks with vapor pocket indications generally required at least two test days.

3. Performance Characteristics

The performance characteristics of the Petro-Tite test method were empirically determined during the survey by examining the variance within specific tests, and between retests on 34 pairs of data. The total variance was found to be 0.00264 gal^2/h^2 which represents a standard error of $\pm$ 0.0514 gallons per hour. This procedure is covered in Appendix D of this report.

B. Line Tests

Tightness testing was conducted on the distribution lines where possible. The system requirements for conducting a line test are a suitable connection at the delivery end of the line to install the test unit and a check valve in good working order. The check valve, typically installed at the inlet of the distribution line in the tank (foot valve) or in the line just above the tank (angle check valve), prevents product in the line from draining back into the tank. Hence, the location of the check valve determines the portion of line subjected to the test.

1. Method Description

The Petro-Tite line test system pressurizes the system with product and measures the volume of product required to maintain the reference pressure. Lines for pressure and suction distribution systems are tested in a similar manner, although the test pressure differs. A diagram of the line test system is shown in Figure 6.2. The test unit is connected to the delivery end of the distribution line and the line is pressurized using a foot operated pump to 15-30 psig for suction lines or 30-80 psig for pressure lines. This pressure closes the check valve to prevent fuel loss back to the tank. The pressure is monitored using the gauge and the pressure restored periodically. The volume of product required to restore the reference pressure is recorded.

2. Method Operation

The line test was conducted at the conclusion of the tank system test, before the tank test equipment was removed. Air was bled from the line and the test unit was connected to the distribution line. Product was pumped into the line to achieve the required pressure. The product level in the tank test standpipe was monitored simultaneously to determine if the foot valve was functioning properly. If product loss from the line was observed as a volume increase in the tank test standpipe, the check valve was considered leaking and the line test was inconclusive. If possible, the check valve was replaced and the test repeated.

The line set pressure was monitored and restored using the test pump at 15-minute intervals. The product level in the graduated reservoir was recorded before and after each pressure restoration. The total product volume added during the 1-h test

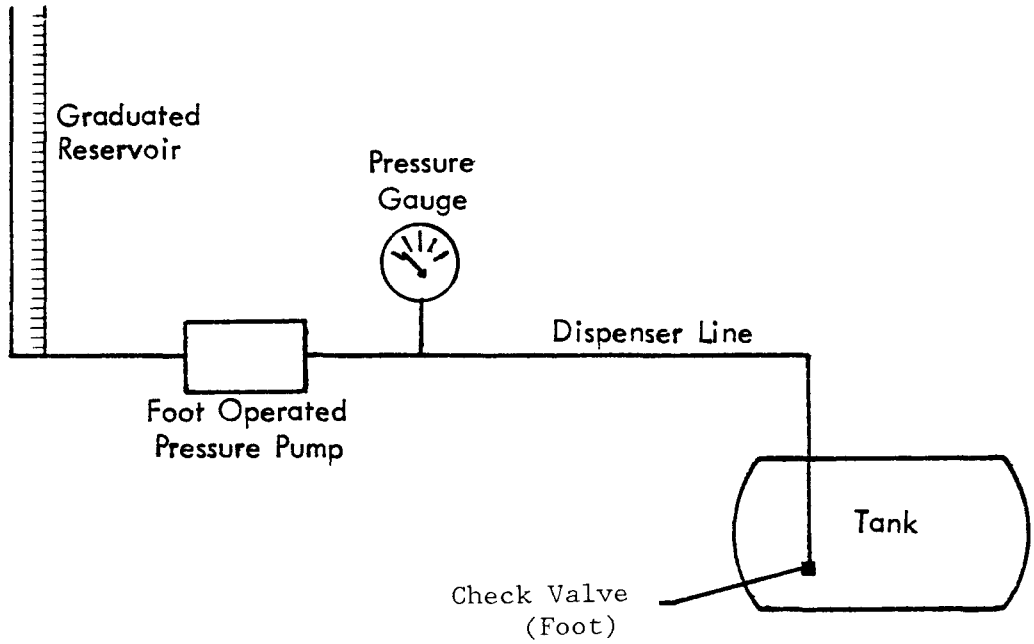

Figure 6-2. Line test equipment

(a total of four 15-minute interval readings) was reported as the line leak rate. If the volume required to restore pressure is less than 0.025 gallons per hour for suction lines or 0.010 gallons per hour for pressure lines, the line is considered to be tight. Volumes greater than these indicate that the line is leaking or an invalid test.

3. Performance Characteristics

The performance characteristics of the line leak detector have not been verified by independent measurements. However, expert users of the device have stated its tolerance to be at least ± 0.0005 gallons per hour when used on a typical delivery line.

The average standard error of line tests conducted on the national survey was of the order of 0.001 gallons per hour. This is more than an order of magnitude more sensitive than the threshold leak rate.

Four situations can occur which can cause volume changes. These are: leaks (or a bad check valve); changes in the liquid temperature in the line; line expansion or stretching due to the high pressure; and compression or shrinkage of air vapor present in the line. All of these produce characteristics which can be recognized by experienced personnel.

The two problems which caused the large number of line leaks to be declared invalid were bad check valves and air pockets. Ninety-one tests were declared to be invalid for these reasons. In order to complete the testing on the 77 systems with bad check valves, it would have been necessary to excavate the top of the tank in most cases. This was beyond the scope of survey.

At the conclusion of the line test, the pressure on the line was released and the product allowed to flow back into the graduated reservoir. The bleed back volume was also measured. A bleed back volume of greater than 0.050 gal indicated air in the line and the test was considered inconclusive. The test was repeated after air was bled from the line. If the repeat test also had excessive bleed back, the test was considered inconclusive.

IV. ENVIRONMENTAL DATA COLLECTION

General environmental data were also collected during the tank system and line testing. These data included the following:

Ambient air temperature
Surface temperature above the tank
Subsurface soil temperature
Barometric pressure
General climatic conditions
Water table level.

These data were collected to provide a record of any external temperature and pressure conditions that may have an effect on the operation and results of the system and line tightness tests.

All environmental data except the water table level were recorded hourly during the test visit. The water table was typically determined by drilling a bore hole through the tank backfill material to the depth of the tank bottom. If water was not encountered at that depth, it was recorded as being lower. Anecdotal information concerning seasonal or other periodic fluctuations were recorded as available. The ambient air tem-

perature was measured using a mercury-in-glass thermometer. Surface temperature was also measured with a mercury thermometer placed on the surface at grade level over the tank. A thermistor inserted into the bore hole previously drilled to determine water level was used to monitor subsurface soil temperature. Barometric pressure was measured with an aneroid barometer. General climatic conditions, based on the observations of the field technician, were recorded in common climatic terms such as: light and variable winds, foggy, light rain, or sunny.

V. Tightness Testing Field Experience

A. Test Completion

A summary of the tests completed is presented here. There were 485 manifolded tank systems from which 560 tanks were selected for tightness testing. However, about 10 percent were not tested because they were found to be out of scope or untestable for technical reasons, or testing was refused by the facility owner/operator. Out-of-scope tank systems consisted of a closed fuel service station, small tank systems on farms (i.e., less than 1,100 gallons), and one system at an establishment that had been misclassified. Technical problems included several unused tank systems containing a residual sludge and tank systems installed that did not permit access to install an air bleed valve when vapor pockets were indicated. Some of the latter cases included tank systems without bungs on the top and tank systems installed under a building. A tank system installed under a hospital helicopter emergency landing pad was considered untestable due to the lack of an alternate landing location. The final refusal rate was 3 percent.

B. Technical Problems

A summary of the technical problems encountered in tank system and distribution line testing is presented in Table 6-1. Fuel delivery problems and vapor pockets were the most disruptive to the test schedule. Coordination of fuel delivery scheduling with the test schedule was a significant part of the test preparation effort. In spite of extensive preparation, failure of the supplier to deliver product as scheduled caused delays in 19 tests. Vapor pockets were indicated in 21 tests. These required exposing the top of the tank by excavation and installation of air bleed valves.

Many of the other problems involved features requiring resolution to permit installation of the test equipment or mitigation of vapor pockets. Permanent drop tubes, vapor recovery systems, and pumps were removed and remote fill pipes were excavated and disconnected to facilitate installation of the test equipment. Manifolds were disconnected to mitigate vapor pockets and to allow separate testing of individual tank systems in some manifolded tank systems. Failure of foot valves was a frequent problem encountered during distribution line testing. Also, excessive bleed-back volumes, indicating air in the distribution line, caused 14 line tests to be considered unreliable.

Table 6-1. Technical problems summary

Problem	Number[1]
Fuel delivery	19
Vapor pockets	21
Permanent drop tubes	17
Vapor recovery systems	6
Pump	2
Remote fill pipe	2
Manifolds	14
Other	23
Foot valve failure	77
Excessive bleed-back volume	14

[1]More than one problem could be encountered in a given test. Hence the total number of problems is greater than the number of tests with any problem.

SECTION 7

TANK TESTING DATA REDUCTION AND QUALITY ASSURANCE (RETEST) RESULTS

This section describes the statistical data reduction process whereby the raw data generated by physical tank tightness tests in the field were converted into estimates of volume change rates under test conditions for tank systems (vessels plus piping). It then gives results of the quality assurance retests which help in judging the overall accuracy of the physical test and data reduction process. Note that throughout this Section of the report, quantitated volume change rates are given as measured under test conditions and are not adjusted from test pressures to operating pressures.

I. DATA COLLECTION AND REDUCTION

A. Data Collection and Transmission

Raw data of volume and temperature change at five-minute intervals were collected for a two-hour period during the physical test, as described in Section 6. These data were collected in handwritten form on the data sheets normally used by Petro-Tite, and were also entered onto a spreadsheet using a mini-computer at the field site. Data were transmitted from the spreadsheet to MRI by telephone for timely analysis. The diskettes and hard-copy data sheets were shipped to MRI on a weekly basis. The telephone transmission was checked against the diskette, and the diskette against the hard copy to ensure that the correct raw data were entered in the working spreadsheet

file, which was then used to estimate volume change rates and their (within-test) variability.

B. Standard Data Reduction

Several statistical analysis methods for reduction of the tank test data were considered for use on the national survey. The test method produced a volume change measurement at five-minute intervals. The other measurement recorded at five-minute intervals was a temperature measurement. The temperature was recorded as a cumulative reading -- the tank temperature -- while the volumes were recorded as differences. In order to make the temperature and volume data comparable, they had to be put in the same form. Either both must be changes or both must be cumulative.

As a result of the considerations of the types of analyses available (see Part III of Appendix D for discussion of possible methods) and the advantages and disadvantages of each, a standard analysis was designed. For the standard analysis, the estimated volume change due to temperature change and the observed total volume change were both expressed in cumulative form, beginning at zero for the start of the test. A straight line through the origin was fit to the temperature-related volume change data by least squares. The predicted values of this line were calculated and used as a smoothed temperature correction for the observed volume changes. The data were plotted and inspected visually for outliers or deviations of the temperature data from linearity. Any questionable data were checked in detail or considered for special analysis.

If no problems with the data were found, the predicted values from the smoothed temperature line were used as the tem-

perature correction. This smoothed temperature correction was subtracted from the observed volume data for each time point. The resulting differences were divided by the time interval to obtain a series of volume change rates expressed in gallons per hour, typically based on a five-minute interval. The arithmetic mean of these rates was calculated and used as the estimate of the volume change rate. In calculating the variance n-1 was used as the divisor, where n is the number of terms in the mean. The result was divided by n to form the variance of the mean. The square root of this is the within-test standard error reported before adjusting for between-test variation. See Part V of Appendix D and Part I of Section 8 for a discussion of the between-test variance.

C. Special Analyses

A number of data set features called for a different or more detailed analysis than that described above. These were dealt with on an individual basis. Occasionally apparent outliers were found. These were checked against the raw data and the test log to see if there was any physical reason for them. A few tests had thermistor boxes fail during the test for some reason (rain, FM interference). These generally gave temperature data that appeared as outliers. When outliers were found and a physical reason identified, the aberrant data were removed from the analysis. This generally required smoothing over the missing data by interpolation. If errors were identified, they were corrected and the analysis redone.

The typical data showed a consistently increasing temperature, generally linear. A smaller proportion of the data sets showed linearly decreasing temperature. Some data sets showed evidence of temperature increase that was curvilinear. If

this curvilinearity appeared or was suspected, a test for curvilinearity was done by fitting both a linear and quadratic to the temperature data by least squares (through the origin). If the quadratic improved the fit significantly, the curvilinear fit (using both linear and quadratic terms) was used for smoothing.

A few cases were found where both temperature and volume were not only non-linear, but also not moving consistently in one direction. Provided that they showed the same pattern, analysis proceeded. In this event, a five point moving mean was used to smooth the temperature data. Equal weights were used. This resulted in the loss of four data points; two at the start and two at the end of the test.

Some tests showed volume change rates that were initially increasing rapidly in curvilinear fashion, while the temperature changes were quite linear. The volumes typically increased rapidly for the first few observations, then slowed. This was interpreted as relaxation or tank deformation. The apparent relaxation appeared to follow an exponential curve and to approach the temperature change rate as an asymptote. However, the constant of this differed by tank. The rate of relaxation may be related to the nature of the soil in backfill and water conditions. When this was identified, the initial points exhibiting this relaxation of the tank deformation were deleted before analysis.

D. Criteria for Invalid Data

A few of the data sets from the tank tests were judged invalid based on the analysis of the data. This occurred infrequently (in 6% of test results).

There were a number of criteria for declaring a data set to be invalid. The most common was that the data showed a volume increase even after adjusting for temperature. Since the test method places pressure on the tank, a volume increase cannot occur from inflow of water. Data that showed volume increases after temperature adjustment that exceeded levels that could be reasonably attributed to the variability of the measurement process were judged to be invalid tests. The reason for this is that such an apparent volume increase with no explanation could be eclipsing a small actual volume loss or leak. Generally any tank that showed a volume gain rate of more than 0.1 gallons per hour after temperature adjustment was judged to be an invalid test. The most likely explanation for such tests is that those tanks had trapped vapor pockets.

As described in Section 8 (Part III) and Appendix D (Part VII), at the next stage of analysis, some additional tests were judged to be invalid due to a measured inflow that was excessive when compared with its estimated total standard error, even though the inflow was not as large as 0.10 gallons per hour.

A variety of other data features led to the conclusion that the test was invalid. A few instances were found where the temperature as recorded fluctuated erratically during the test while the volume measurements were relatively stable. If the temperature data were so erratic as to preclude a temperature adjustment, then the test was declared to be invalid.

One or two tests showed both temperature and volume measurements that were erratic and did not appear to track together. These tests were also judged invalid. Such behavior may have been caused by incomplete tank deformation, followed by relaxation, combined with mixing problems. No valid volume change rate could be estimated.

II. RETEST RESULTS

Three types of retests were conducted as part of the national survey of underground storage tanks. One was a back-to-back retest, conducted immediately after the original test used to estimate the volume change rate. The second was a leak simulation test also conducted immediately after the original test. The third type was a complete retest conducted on a different day and generally by a different crew. Each of these types of second testing estimates a different source of variation possible in the tank tests. The leak simulation and back-to-back retests estimate variation of the overall measurement procedure from one two-hour period to the next, with the same set-up, crew, day of the week, and so on, while the complete retests measure variation between tests as well. The initial test result in each case was used as the data for the survey estimate. When the test and retest results differed, the results were examined to discover reasons for the differences. This led to the discovery of the repairs that had been made in two cases. The primary purpose of the quality assurance program was to measure the overall performance of the test, which was accomplished. A list of all of the retests appears in Appendix D, as does a list of the simulated leak retests. A table summarizing the estimates of bias (lack of accuracy) and standard deviation (precision) based on each type of test is presented as Table 7-1. We discuss these three types of quality assurance retests in more detail below.

A. Leak Simulations

The leak simulation tests were conducted after the original test was concluded. Generally they were only conducted when the original test indicated that the tank was tight or had a small estimated volume change. The volume rate used for leak

Table 7-1. Retest results (volume change rates measured under test conditions, not adjusted to operating pressure)

Type	Mean difference (gallons per hour)	N	Variance $(gph)^2$	Mean squared error $(gph)^2$	Standard deviation (gph)	Root mean squared error (gph)
Leak simulation	-0.00891	11	0.00066	0.00074	0.0257	0.0272
Back to back	0.00629	14	0.00053	0.00057	0.0231	0.0239
Retests	0.00297	34	0.00254	0.00255	0.0504	0.0505

simulation was on the order of 0.1 gallons per hour, so a large observed volume change would overwhelm it.

The purpose of the leak simulation tests was to document that the testing method could detect leaks of known size in tanks that appeared to be tight. In addition, use of the leak simulation allows for an estimate of the accuracy of the test as well as its precision. The accuracy refers to the ability of the test to measure a known volume change, while the precision of the test refers to its ability to reproduce measured rates.

Thirteen leak simulation tests were conducted. Two of these were conducted on tanks that had estimated volume rates that indicated that the tanks were probably leaking (as evidenced by the observed volume changes). These tests were excluded from the analysis because variability is known to increase for leaking tanks.

Three rates were calculated from leak simulations. The first was a baseline rate for the tank. This was estimated during the regular tank test. While the leak simulation was conducted, a measured rate was estimated. This is the rate observed by the testing method during leak simulation. It is presumed to be composed of the tank rate plus the simulated rate. The simulated rate is calculated by collecting product drawn from the tank at a constant rate, weighing it on a triple beam balance, and converting the weight to volume at the temperature of the product in the tank. The difference between the observed rate during the simulation and the baseline rate provides an estimate of the simulated rate. The difference between this and the actual simulated rate can be used to assess the accuracy of the test.

The average difference between the measured rate and the simulated rate was -0.00891 gallons per hour, based on the 11 leak simulations where the tank was not estimated to be leaking (see Table 7-1). Recall that these rates are reported as observed under test conditions and not as adjusted for test pressure. The difference between the measured rate and the simulated rate is interpreted as an estimate of bias. The variance of the differences about their mean provides an estimate of precision. This variance was estimated to be 0.00066 gallons per hour squared. The mean squared error (MSE) is a measure which incorporates both types of error--accuracy and precision. It is calculated as the sum of the bias squared plus the variance. In this case it was 0.00074 gallons per hour squared.

The bias is clearly not significant in that it does not differ significantly from zero ($t = -0.347$, 10 degrees of freedom). As a result, the variance and the mean squared error are nearly identical. A measure of variation often used is the standard deviation (or root mean squared error if bias is present), which is the square root of the variance (or MSE). This measure has the advantage that its units are the same as the measurement, gallons per hour. The standard deviation (estimating within-test variation)was estimated to be 0.0257 gallons per hour for these data.

B. Back-to-Back Retests

Back-to-back retests were conducted on a total of 18 tanks, which includes the 13 tanks with leak simulations. The purpose of the back-to-back retests was to estimate the stability of the test method. That is, to ensure that the volume change estimate did not differ markedly if based on the succeeding two hours after the test.

As with all of these tests, variability is expected to be larger if the initial leak rate or volume change is larger. For this reason, the results of the back-to-back retests are presented here for the 14 tests with volume change rates less than 0.1 gallons per hour in absolute value. Retest results for tanks with larger volume rates were more variable but generally consistent. (See Appendix D, Part IV for a discussion of these retests.)

The average difference between the original and retest for the 14 tests with small volume changes was 0.00629 gallons per hour. The variance estimate was 0.00053 gallons per hour squared, giving a mean squared error of 0.00057 gallons per hour squared. The corresponding standard deviation was 0.0231 gallons per hour and the root mean squared error estimate was 0.0239 gallons per hour (not adjusted for test pressure). The mean difference was not significantly different from zero ($t = 0.272$, 13 df).

C. Complete Retests

The complete retests consist of revisits to the site on a different day. Typically this includes a different crew and involves rescheduling and refilling the tank. The complete retests incorporate all of the features of a tank test and so include all the sources of error including potential difference from crew to crew (including differences between sets of testing equipment) and differences due to weather conditions, nearby traffic, day of the week, etc. In addition, there is a possibility that the tank is different at the time of the retest. In fact, two of the retests originally scheduled were canceled when it was found that the tanks had been repaired between the

initial test and the scheduled retest. In addition, two retests were performed and it was then discovered that the tanks had been repaired between the initial test and retest. These data are also not included as they would measure an additional source of variation which is not of interest (i.e., repair). Two other retests were performed on tanks that were initially determined to have large vapor pockets. These two tanks were retested later and on retesting were again found to have large vapor pockets. The results of the test and retest for these tanks with vapor problems agreed qualitatively; however, the numerical agreement was not close. The reason for this may be that the vapor pocket trapped in the tank was of different size. There were also different ambient conditions that would affect the vapor differently. For these reasons, the vapor retests were not included in the estimate of the variance from the retests.

The mean difference from the set of 34 relevant retests was 0.00297 gallons per hour. The variance of the difference was 0.00254 gallons per hour squared, giving a mean squared error of 0.00255 gallons per hour squared. The standard deviation of the differences for these 34 retests is 0.0504 gallons per hour and the root mean squared error is also 0.0505 gallons per hour. The mean difference is not significantly different from zero ($t = 0.059$, with 33 df).

D. Results

The retest data analysis showed no evidence of bias in the test methods. All three retest schemes had very small estimates of bias which were not significantly different from zero. Given the historical leak cut-off of 0.05 gallons per hour, bias of less than 0.01, as was found in all three data sets (less than

0.005 in the largest set) is not of practical concern, in addition to not being statistically significant.

The variability, or magnitude of the measurement error of the physical test can also be assessed using these data. Both the back-to-back retest and the leak simulations estimated within-test standard deviations on the order of 0.025 gallons per hour. The complete retest data gave a standard deviation of 0.05 gallons per hour for the total variability of volume change rate estimates. As is discussed in Section 8, Part I, the difference is probably due to a between-test component of variation which is measured by the retests but not by the back-to-back or leak simulation tests.

In summary, the physical test is <u>accurate</u> (not significantly biased) and has a known precision (total standard error of an estimated volume change) of 0.05 gallons per hour (measured at test pressure and not adjusted to operating pressure). That this standard error coincides with the historical cut-off value for declaring a leak is an interesting coincidence.

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 into 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:

- 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
- 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%

[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.

Table 8-2. Estimated percentage of underground motor fuel storage tank systems judged to be leaking under test conditions in the U.S., business and government sectors, based on NFPA .05 gallons per hour criterion

	Using NFPA .05 gallons per hour criterion	
Leak status of tank systems[1]	At test pressures[2]	Adjusted to typical operating conditions[3]
Percent judged to be leaking under test conditions[4]	42%	33%
Percent judged to be not leaking under test conditions	58%	67%

[1]In both columns, 6.4 percent of tanks tested had an inconclusive result. This includes cases where the data were judged unreliable and cases with a measured inflow of greater than 0.05 gallons per hour, indicating a vapor pocket or other problem with the test. These cases are not included in the base on which the percentages are figured.

[2]The test procedure resulted in a small pressure, 4 psi, at the bottom of the tank.

[3]Leak rates were adjusted to typical operating conditions only for those tank systems initially judged to be leaking.

[4]Includes cases with unquantifiably large leaks as well as with measured leak rates greater than 0.05 gallons per hour.

arbitrary 0.05 gallons per hour and does not examine the estimated leak rate relative to its standard error.

In summary, this report uses a statistical test to distinguish leaking and tight tank systems. The test has a five percent probability of false alarm, while running on average a five percent risk of failing to detect leaks of 0.10 gallons per hour or larger. Furthermore, the use of other statistical test criteria described above would not substantially alter the overall results.

IV. ASSESSING THE UTILITY OF TESTING FOR LEAKAGE BY FILLING TANKS TO CAPACITY

When tank systems were tested for leaks, the process involved filling the tank to capacity and then observing the resulting leak rates, if any. A concern arising from this approach is the extent to which this procedure reflects the general status of tank storage. For example, if it is the case that tanks are seldom filled to capacity, the discovery of leaks in the tops of tanks using the specified testing procedure does not provide information with general application to real world situations. On the other hand, if tanks are filled to capacity or near-capacity routinely, the testing procedures are appropriate.

In order to assess the extent to which tanks are utilized in their full capacity, an analysis of the average proportion of each tank utilized before and after delivery of a motor fuel for storage (as reported by tank owner/operators in the questionnaire) was undertaken for the nearly 2,300 cases on which such data was available. Just before delivery, the median average proportion of a tank utilized was 20 percent, with the

75th percentile being 33.3 percent and the 25th percentile at 10 percent. The most frequent or modal value is 25 percent. Thus, on average, the product stored within tanks is allowed to drop to a rather low level before delivery of a further supply. After delivery, the median average proportion of the tanks' capacities utilized jumped to 83.3 percent, with the 75th percentile at 97.5 percent and the 25th percentile at 62.7 percent. Thus, 25 percent of the tanks were filled over 97.5 percent full. The most frequent or modal value was 100 percent.

Respondents were also asked the largest amount their tank was ever filled. Responses to this question had a median value of 100 percent. The 25th percentile was 92 percent full. Thus, the majority of tanks are filled to capacity at some time, and most tanks have filled nearly to capacity.

Such sample estimates suggest that a substantial number of the tanks surveyed routinely utilized all or most of their storage capacity, consequently exposing virtually all of a tank's surface area to the possibility of being a potential source of a leak. It is therefore reasonable to employ a testing procedure which involved filling a tank to capacity in an effort to detect possible sources of leakage.

V. ASSESSING THE CONTRIBUTION OF DISTRIBUTION LINE LEAKS TO MEASURED TANK SYSTEM LEAKS

A. Comparison of Leaking Tanks with Valid Distribution Line Tests With Those Whose Distribution Lines Were Not Tested

In assessing the potential proportion of measured tank system leaks[5] which might be attributed to distribution line leaks, a subset of our representative sample of tank systems was analyzed. This subset was first restricted to single tank systems judged to be leaking and with quantified leak rates, of which there are 110 in the data set. Although distribution line tests were attempted for all tested tanks, such tests often failed due to bad check valves, bleed-back or other problems (see Section 6). Thus, valid distribution line tests with quantified leak rates were available for only 43 of the 110 quantified leaking tank systems. Before analyzing the data obtained from the completed valid distribution line leak tests, it is important to consider the issue of the extent to which they may differ from tanks where valid distribution line test results were not obtained. For example, is there evidence that the ability to complete valid distribution line tests was linked to the type of fuel stored in the tanks, the material used in the construction of the tanks, etc? Cross-tabulations comparing the distributions of those leaking tank systems with valid line leak data and those without across categories of variables with potential impact were examined in conjunction with tests of association, such as the chi-square test, where appropriate.

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[5]Recall that a "tank system leak" refers to a determination of a leak based on the physical test. The leak could actually be in the tank vessel or any of the associated lines, pipes, or fittings.

Variables for which there was evidence of a difference in the distribution between those leaking tank systems with completed valid tests and those without included: type of establishment (government sites had a higher than expected valid completion rate), material of construction (fiberglass had a lower than expected valid completion rate), and type of delivery system (pressure pumps had a lower than expected valid completion rate). Comparisons between the group with valid data and that without on the actual measure of leak rate indicated no significant differences between their average values, although the leak rates for those tank systems with incomplete tests were significantly more variable than those without.

B. Consideration of Distribution Line Leakage as a Proportion of Total Measured Leakage

The finding of a leak during testing can be attributed to a distribution line leak, a vessel leak, both, or some other leak(e.g., fill pipe, vent pipe, manway fitting, etc.) For the 43 cases known to have leaks and for which valid distribution line leak data was obtained, an examination of the proportion of each total measured leak attributable to a distribution line leak was undertaken. In doing this, it was necessary to adjust the line leak rate values to the system test pressure, taking account of differences in tank diameters and the type of pump used (suction or pressure). (Appendix D, Part VI, described this adjustment.)

Of the 43 cases, in only one case (2.3%) was the proportion of the system leakage attributable to the distribution line more than 25 percent. In fact, leakage in the distribution line accounted for less than 10 percent of the leakage for 38 of the

43 cases (88.4% of the cases) and for less than two percent of the measured leakage for 23 of the 43 cases (53.5% of the cases). Thus, at least for those cases in which valid leak rate measurements could be obtained, leaks in the distribution lines account for very little of the total measured leakage.

VI. PERCENT OF TANK SYSTEMS LEAKING UNDER OPERATING CONDITIONS

Certain features of the tank testing method are different from typical operating conditions, especially the overfilling of the tank during the test.

It is certainly reasonable to ask whether some of the leaks detected under test conditions might have been due to holes near the top of the tank above normal fill levels. Data from the survey reveal that it is common practice to fill tanks to 100 percent capacity when product is delivered. In fact, 100 percent was the modal value for this variable, and the median of the reported average fill level was 83 percent of capacity. Thus, the data suggest that even holes near the top of the tanks would be subject to leaking, at least just after product delivery.

On the other hand, the average tank fill level just prior to delivery had a median value of about 20 percent of tank capacity. Therefore, as a rough approximation, a typical operating level might be midway between the high and low point, or 52 percent of capacity. If one were to further assume that holes were evenly distributed between the top and bottom of the tank, then an estimated 52 percent x 35 percent = 18 percent of the tank systems would be leaking on the average at any point in time

under typical fill level conditions.[6] Furthermore, using average percent filled after delivery may be a conservative estimate of operational fill levels. When asked about the maximum gallons ever stored, most respondents reported 100 percent, and only one-quarter were below 92 percent full.

In summary, if we are willing to assume that holes are uniformly distributed around the tank circumference (We have no data to verify this assumption.), we could calculate that:

- Approximately 35 percent of the tank systems would be leaking if they were filled to capacity;
- If all tanks are ever filled to capacity during the year, then an estimated 35 percent of the tank systems in the country are leaking at one time or another during a year;
- Approximately 29 percent (.35 x .83) of tank systems are leaking just after the time of product delivery the way tanks are normally filled; and
- Approximately 18 percent (.35 x .52) of the tanks are leaking at a random point in time.

Because of the nature of the test procedures used (i.e., overfilled tanks), we might be concerned about the possibility that a large portion of the leaks could be near the top of the tank and its associated pipe fittings. If that were the case, test results in this study could overstate the percentage of

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[6]This is a rough approximation which could be refined by calculating highest and lowest fill levels for each tank separately, and then computing the median and mean fill levels as fuel is withdrawn. Fuel withdrawal rate could be assumed as uniform over time or simulated from inventory data. Finally, refinements could be made to account for the fact that the assumption of uniform leak distribution over the surface of the tank is not identical to uniform leak distribution over volume. However, since actual leak distribution is unknown, such refinements do not seem warranted at present.

tanks leaking under operating conditions. While we do not have information in our study on the location of the leaks, an American Petroleum Institute report (API letter of March 27, 1981 from F.B. Killmar to Mr. Paul J. Sausville, P.E. Chief, Northeast Sector Wastewater Management Bureau, New York State Department of Environmental Conservation) provides some relevant statistics. This API report found that among all 318 leaking tanks, only 4.4 percent had leaks limited to the upper one-third of the tank. Even though the API study was based on volunteer reports from leaking tank inspections rather than a representative probability sample, these findings seem to strongly dispel any concern that leaks are predominantly or disproportionately close to the top of the tank. As a result, the 18 percent estimate given above for percentage of tanks leaking at a random point in time under operating conditions may be an underestimate.

SECTION 9

STATISTICAL ANALYSIS

I. NATIONAL ESTIMATES OF THE NUMBERS OF UNDERGROUND MOTOR FUEL STORAGE TANKS AND ESTABLISHMENTS WITH UNDERGROUND MOTOR FUEL STORAGE TANKS

In the continental United States (i.e., excluding Alaska, Hawaii, and the trust territories) there are an estimated 796,000 underground tanks currently being used for the storage of motor fuel at an estimated 326,000 business, government and farm establishments. Table 9-1 shows the estimated number of tanks and establishments with tanks (as well as the mean and median number of tanks per establishment) overall and within the business/government stratum and the farm stratum. Overall there are an average of 2.4 tanks per establishment with such tanks, and a median of three tanks per establishment.

Among the business and government establishments (based on analysis of the combined fuel establishment and large establishment strata), there are an estimated 638,000 underground motor fuel storage tanks in use at approximately 247,000 establishments. The average number of tanks per establishment for the business and government sample is 2.6 tanks. The median number of tanks per establishment is three. (The sample strata are described in detail in Section 4 of this report.)

According to survey estimates, there are approximately 158,000 underground motor fuel storage tanks in use on about 79,000 farms, or an average of 2.0 tanks per farm with underground motor fuel storage tanks. The median number of tanks

Table 9-1. Estimates of the number of underground motor fuel storage tanks and the number of establishments with underground motor fuel storage tanks in the continental United States (95% confidence bounds in parentheses)

Type of establishment	Number of establishments with tanks (1,000's)	Number of tanks (1,000's)	Number of tanks per establishment with tanks	
			Mean	Median
Business & government	**247** (220-275)	**638** (584-692)	**2.6** (2.4-2.8)	**3** -
Farms	**79** (58-100)	**158** (< 453)	**2.0** (< 5.0)	**1** -
Total	**326** (296-356)	**796** (503-1,090)	**2.4** (1.6-3.2)	**3** -

per farm is one tank. Because of the small sample size for farms, the resultant large sampling weights, and the associated broader confidence bounds, the farm sample was not combined with the samples of fuel and large establishments in the succeeding analyses. For a detailed discussion of the farm sample, see Appendix G of this report.

A. Estimates by Survey Region of the Number of Underground Motor Fuel Storage Tanks and Establishments

The survey sample was stratified to provide estimates for six predefined survey regions. Table 9-2 lists the six survey regions and shows the estimated number of tanks and establishments with tanks, plus the mean and median number of tanks per establishment, within each of the regions. The Northeast survey region has the highest estimated number of tanks (186,000) and establishments (69,000). The survey region with the smallest number of tanks is the Mountain region, with an estimated 36,000 tanks at 14,000 establishments. The average number of tanks per establishment is 2.6 tanks, and ranged from a high of 2.7 tanks per establishment in the Northeast to a low of 2.3 tanks per establishment for the central region. The median number of tanks per establishment for all regions combined is three. The Northeast, Mountain, and Pacific survey regions each have a median of two tanks per establishment. In the Southeast, Midwest, and Central survey regions the median number of tanks per establishment is three.

Table 9-3 displays the estimates of the number of underground motor fuel storage tanks and establishments with motor fuel

Table 9-2. Estimates, by survey region, of the number[1] of underground motor fuel storage tanks and the number of establishments with underground motor fuel storage tanks in the continental United States (95% confidence bounds in parentheses)

Survey region	Number of establishments with tanks (1,000's)	Number of tanks (1,000's)	Number of tanks per establishment with tanks	
			Mean	Median
1 Northeast	**69** (52-86)	**186** (175-198)	**2.7** (2.1-3.3)	**2** -
2 Southeast	**48** (39-58)	**126** (106-147)	**2.6** (2.4-2.8)	**3** -
3 Midwest	**53** (39-67)	**139** (108-170)	**2.6** (2.4-2.9)	**3** -
4 Central	**27** (15-39)	**63** (43-84)	**2.3** (2.0-2.6)	**3** -
5 Mountain	**14** (12-17)	**36** (23-49)	**2.5** (2.1-2.9)	**2** -
6 Pacific	**35** (29-42)	**87** (58-116)	**2.4** (2.0-2.9)	**2** -
Total	**247** (220-275)	**638** (584-692)	**2.6** (2.4-2.8)	**3** -

[1] Does not include farms or tanks at farms.

Table 9-3. Estimates, by type of establishment, of the number[1] of underground motor fuel storage tanks and the number of establishments with underground motor fuel storage tanks in the continental United States (95% confidence bounds in parentheses)

Type of establishment	Number of establishments with tanks (1,000's)	Number of tanks (1,000's)	Number of tanks per establishment with tanks	
			Mean	Median
Government and military	**45** (29-62)	**98** (69-128)	**2.2** (1.8-2.5)	**2** -
Gas stations owned by major petroleum companies	**33** (26-41)	**118** (87-148)	**3.6** (3.3-3.8)	**3** -
Gas stations owned by other companies	**58** (50-67)	**204** (174-233)	**3.5** (3.2-3.8)	**3** -
Other fuel-related establishments	**36** (30-43)	**77** (64-90)	**2.1** (1.8-2.4)	**2** -
Large non fuel-related estabments (with ≥ 20 employees)	**74** (55-93)	**142** (97-187)	**1.9** (1.6-2.2)	**2** -
Total	**247** (220-275)	**638** (584-692)	**2.6** (2.4-2.8)	**3** -

[1] Does not include farms or tanks at farms.

storage tanks as they are distributed by type of establishment. Establishment types include:

- Government and military establishments, including state, local and federal facilities;
- Gas stations (SIC code 5541) owned and/or operated by major petroleum companies (according to the establishment manager);
- Gas stations (SIC code 5541) owned by other companies;
- Other fuel-related establishments (i.e., transportation related industries); and
- Large non-fuel-related establishments (with 20 or more employees).

Gasoline stations without regard to ownership account for about half (321,000) of all tanks. but a little over a third (92,000) of the total number of establishments with tanks. Of the five establishment types, gasoline stations owned by other (i.e., non-major) companies account for the largest number of tanks (203,000). The other fuel-related establishments have the smallest share of tanks (an estimated 77,000) and establishments (an estimated 36,000). The large non-fuel-related establishments category has the highest estimated number of establishments with tanks (74,000 establishments), and has second highest estimated number of tanks (142,000). The average number of tanks per establishment, which is 2.6 for establishments of all types, ranges from a high of 3.6 for gas stations owned by major petroleum companies, to a low of 1.9 for the large non-fuel-related establishments. The median number of tanks per establishment is three for both of the categories of gas stations, and two for the non-gas station categories.

II. CHARACTERISTICS OF ESTABLISHMENTS WITH UNDERGROUND MOTOR FUEL STORAGE TANKS

There are an estimated 247,000 government and business establishments that use underground tanks to store motor fuel. Table 9-4 displays the estimated number, the 95 percent confidence bounds for the estimates, and the percentage distribution of the type of establishment, within region. The differences in the distribution of establishment types within the survey regions are described in Section 9.II.A. In addition, specific establishment characteristics were analyzed by region and establishment type, and are displayed in Tables 9-5 and 9-6. These tables are discussed in Section 9.II.B.

A. Distribution of Types of Establishments within Survey Region

The distribution of establishment types is relatively similar across the six survey regions, although there are some differences, particularly in gas station ownership type in certain regions. While gas stations owned by major petroleum companies account for 13 percent of the establishments across all regions, 23 percent of the establishments in the Pacific region were gas stations owned by major petroleum companies. In contrast, the lowest proportion of gas station establishments owned by major petroleum companies (8%) occurs in the mountain regions. Gas stations owned by other companies (i.e., not owned by major petroleum companies) account for 24 percent of the establishments in all survey regions, but for only 11 percent of the establishments in the Pacific survey region. The Midwest survey region has the highest proportion (29%) of gas stations owned by other companies.

Table 9-4. Estimates of the number and percent of establishments with underground motor fuel storage tanks[1] across establishment types for the six survey regions[2] (95% confidence bounds on number of establishments in parentheses)

Survey region	Government and military establishments	Gas stations owned by major petroleum companies	Gas stations owned by other companies	Other fuel-related establishments	Large non-fuel-related establishments	Total
Northeast						
Number:	13,000	7,000	17,000	11,000	21,000	69,000
% in region:	19%	10%	24%	16%	31%	100%
95% conf. bounds:	(< 27,000)	(3,000-11,000)	(13,000-20,000)	(6,000-16,000)	(13,000-29,000)	(52,000-86,000)
Southeast						
Number:	7,000	7,000	11,000	6,000	17,000	48,000
% in region:	15%	15%	23%	12%	35%	100%
95% conf. bounds:	(2,000-13,000)	(4,000-11,000)	(9,000-14,000)	(4,000-8,000)	(5,000-28,000)	(39,000-58,000
Midwest						
Number:	10,000	7,000	16,000	8,000	12,000	53,000
% in region:	19%	14%	29%	15%	23%	100%
95% conf. bounds:	(6,000-15,000)	(3,000-12,000)	(12,000-20,000)	(4,000-12,000)	(4,000-29,000)	(39,000-67,000)
Central						
Number:	6,000	3,000	7,000	4,000	7,000	27,000
% in region:	24%	11%	25%	15%	29%	100%
95% conf. bounds:	(4,000-9,000)	(1,000-5,000)	(4,000-10,000)	(3,000-5,000)	(< 15,000)	(15,000-39,000)
Mountain						
Number:	3,000	1,000	4,000	2,000	4,000	14,000
% in region:	20%	8%	28%	15%	29%	100%
95% conf. bounds:	(2,000-3,000)	(< 3,000)	(1,000-7,000)	(1,000-3,000)	(3,000-5,000)	(12,000-17,000)
Pacific						
Number:	5,000	8,000	4,000	6,000	12,000	35,000
% in region:	15%	23%	11%	16%	35%	100%
95% conf. bounds:	(2,000-9,000)	(6,000-10,000)	(0-8,000)	(5,000-6,000)	(7,000-19,000)	(29,000-42,000)
All survey regions						
Number:	45,000	33,000	58,000	36,000	74,000	247,000
% all regions:	18%	13%	24%	15%	30%	100%
95% conf. bounds:	(29,000-62,000)	(26,000-41,000)	(50,000-67,000)	(30,000-43,000)	(55,000-93,000)	(220,000-275,000)

(1) Does not include farms.
(2) Percents are calculated prior to rounding.

The Central region has the highest proportion of government and military establishments, with 24 percent compared to 18 percent for all regions. The Midwest survey region has a slightly lower percentage of large non-fuel-related establishments, with 23 percent compared to 30 percent for all regions. The proportion of other fuel related establishments is nearly identical across regions.

B. Selected Establishment Characteristics, Analyzed by Region and by Establishment Type

Selected establishment characteristics were analyzed by region and by establishment type for the establishments with underground motor fuel storage tanks. These analyses were based on a file of 876 establishments, weighted to represent 247,000 establishments. The percent of establishments exhibiting each of the selected characteristics is displayed in Table 9-5 (by region) and Table 9-6 (by establishment type).

1. Establishments with Underground Waste Oil Tanks

Overall, 31 percent of the establishments have underground waste oil tanks on site. Most owner/operators knew whether or not their establishments have waste oil tanks (over 99%). The Central and Southeast regions have the smallest percentage of establishments with underground waste oil tanks (24% and 25% respectively) and the Pacific region has the largest percentage (43%). Among establishment types, gas stations of both types have higher percentages of underground waste oil tanks than other establishment types. More than half (59%) of the gas stations

Table 9-5 Estimates, by survey region, of the percent of establishments with underground motor fuel storage tanks[1] with selected characteristics (95% confidence bounds in parentheses)

Survey region	Percent of establishments with waste oil tanks	Percent of establishments with abandoned tanks	Percent of establishments where clean sand or pearock used as backfill	Percent of establishments required to have tank installation permits	Percent of establishments required to have tank operating licenses	Percent of establishments with insurance to cover sudden motor fuel spills	Percent of establishments with insurance to cover non-sudden motor fuel spills
1 Northeast	30% (21-39%)	11% (7-16%)	82% (75-89%)	59% (19-98%)	25% (2-48%)	80% (68-92%)	63% (47-79%)
2 Southeast	25% (20-29%)	15% (8-22%)	78% (65-91%)	49% (45-53%)	22% (16-28%)	79% (69-90%)	64% (59-69%)
3 Midwest	32% (28-38%)	16% (7-25%)	88% (75-100%)	52% (34-69%)	31% (17-34%)	75% (63-87%)	65% (56-74%)
4 Central	24% (10-38%)	17% (4-30%)	63% (54-70%)	37% (11-64%)	15% (3-26%)	73% (52-94%)	63% (41-86%)
5 Mountain	32% (22-42%)	15% (5-25%)	72% (53-90%)	62% (40-84%)	34% (14-53%)	96% (96-97%)	94% (88-99%)
6 Pacific	43% (29-58%)	9% (6-12%)	65% (52-77%)	78% (63-94%)	49% (35-62%)	92% (87-98%)	89% (81-98%)
Total	31% (27-35%)	14% (11-17%)	78% (73-83%)	56% (44-69%)	29% (21-37%)	81% (76-86%)	69% (64-75%)

[1] Does not include farms.

Table 9-6. Estimates, by establishment type, of the percent of establishments with underground motor fuel storage tanks[1] with selected characteristics (95% confidence bounds in parentheses)

Type of establishment	Percent of establishments with waste oil tanks	Percent of establishments with abandoned tanks	Percent of establishments where clean sand or pearock used as backfill	Percent of establishments required to have tank installation permits	Percent of establishments required to have tank operating licenses	Percent of establishments with insurance to cover sudden motor fuel spills	Percent of establishments with insurance to cover non-sudden motor fuel spills
Government and military	17% (11-23%)	11% (6-16%)	76% (70-82%)	33% (18-47%)	11% (3-20%)	70% (59-81%)	65% (54-77%)
Gas stations owned by major petroleum companies	59% (47-67%)	4% (1-7%)	92% (86-99%)	87% (75-99%)	55% (47-62%)	78% (69-86%)	70% (60-81%)
Gas stations owned by other companies	46% (38-54%)	22% (16-29%)	89% (84-93%)	61% (44-76%)	36% (24-48%)	84% (79-89%)	65% (55-75%)
Other fuel-related establishments	29% (23-36%)	13% (8-17%)	76% (68-85%)	60% (43-76%)	32% (20-44%)	80% (73-87%)	73% (67-80%)
Large non fuel-related establishments	16% (6-26%)	14% (6-21%)	66% (51-80%)	59% (42-75%)	20% (6-33%)	88% (80-95%)	73% (65-81%)
Total	31% (27-35%)	14% (11-17%)	78% (73-83%)	56% (44-69%)	29% (21-37%)	81% (76-86%)	69% (64-75%)

[1] Does not include farms.

owned by major petroleum companies have underground waste oil tanks, and 46 percent of the gas stations owned by other companies have underground waste oil tanks. Government and military establishments and large non-fuel-related establishments have the smallest percentage of establishments with underground waste oil tanks, with 17 percent and 16 percent respectively.

Approximately 98 percent of the establishments that have underground waste oil tanks have only one of these tanks. Altogether, there are an estimated 78,000 underground waste oil tanks at establishments that also have underground motor fuel tanks. (This estimate does not include waste oil tanks that may be at establishments that do not have underground motor fuel storage tanks, since those establishments were not surveyed.)

2. Establishments with Abandoned Underground Tanks

Approximately 14 percent of the establishments that have in-use underground motor fuel storage tanks also have one or more tanks on site that have been abandoned (i.e., are no longer in use, and have not been removed.) Again, most owner/operators (95%) knew whether their establishment had such a tank on site. Across regions the percentages of establishments with abandoned tanks is similar, ranging from a high of 17 percent in the Central region to a low of 9 percent in the Pacific region. A more striking difference can be seen in the percentages of establishments with abandoned tanks across establishment types. Only 4 percent of the gas stations owned by major petroleum companies have abandoned tanks, while 22 percent of the gas stations owned by other companies have abandoned tanks.

Nearly 70 percent of the establishments with in-use motor fuel tanks that have abandoned underground tanks have only one

abandoned tank, but the number of abandoned tanks in the survey sample ranges from one tank to ten tanks per establishment. Overall, there are an estimated 53,000 abandoned underground tanks at establishments that have in-use underground motor fuel storage tanks. (Note that the estimates provided in this section are based only on establishments with in-use underground motor fuel storage tanks. The numbers and percentages given here do not include abandoned tanks at establishments that do not have in-use underground motor fuel storage tanks.)

3. Establishments with Clean Sand or Gravel as Tank Backfill

Overall, 78 percent of the establishments claim to have used clean sand, pearock or peagravel for backfill around their tanks. (This estimate is based on the three-quarters [74%] of owner/operators who knew the backfill material.) The remaining 22 percent used excavation soil, rubble, clay and combinations including these materials to fill around their tanks. In the Central and Pacific regions a lower percentage of establishments used the clean sand/clean gravel backfill (63% and 65% respectively), while in the Midwest the percentage using this type of backfill was higher (88%). A higher percentage of both types of gas stations used clean sand/clean gravel backfill. Among gas stations owned by major petroleum companies, 92 percent used clean sand/clean gravel as backfill, while among gas stations owned by other companies 89 percent used this type of backfill. Only 66 percent of the large establishments used clean sand/clean gravel as backfill.

4. Establishments Required to Have Tank Installation Permits

Operators of 56 percent of the establishments with underground motor fuel storage tanks did not know whether the establishment was required to obtain a permit for the installation of the underground tanks. Among those who did know, 56 percent said they were required to obtain such a permit. The Central region has the lowest percentage of establishments reporting a required installation permit (37%) while the Pacific region has the highest percentage (78%). Among gas stations owned by major petroleum companies, where this question was answered, 87 percent said they were required to have installation permits. However, among government and military establishments, where this question was answered, the owner/operators said an installation permit was required for only 33 percent of the establishments.

5. Establishments Required to Have Tank Operating Licenses

Whether the establishment was required to have an operating license was known by 84 percent of responding owner/operators. At these establishments, only 29 percent of the establishments overall are required to have tank operating licenses, according to the establishment operators. Differences in the proportions of establishments required to have licenses are noticeable across survey regions and establishment types in patterns similar to the differences in percentages of establishments required to have installation permits. Again the Pacific survey region has the highest percentage of establishments requiring licenses (49%, or two thirds more that the overall percentage), and the Central

survey region has the lowest (15%, or about half of the overall percentage.) Only 11 percent of the government and military establishments are required to have operating licenses, while 55 percent of the gas stations owned by major petroleum companies have such licenses.

6. Establishments with Insurance Coverage for Sudden Motor Fuel Spills

Among all regions and establishment types, 81 percent of establishment operators who answered this question believe they have insurance to cover damage to people or property caused by sudden motor fuel spills. Most (85%) did answer the questionnaire item. The Mountain region has the highest percentage of establishments with sudden spill coverage, with 96 percent of the establishment operators claiming to have this type of coverage, closely followed by the Pacific region, with 92 percent of the establishment operators claiming to have this type of coverage. Among the five establishment types, government and military have the lowest percentage of establishments covered for sudden spills (70%) and large non-fuel-related establishments have the highest percentage covered, with 88 percent of the establishment operators claiming to have this type of coverage.

7. Establishments with Insurance Coverage for Non-sudden Motor Fuel Spills (Including Leaks)

A total of 69 percent of the establishment operators who answered this item believe that their establishments have insurance to cover damage to people and property caused by non-sudden spills of motor fuel (such as tank system leaks). (Since

this type of insurance coverage is not yet common, this belief may be unfounded.) A slightly lower number (78%) answered this item than answered the "sudden spills" question. A higher percentage of the operators in the Mountain and Pacific regions believe that their establishments are covered by insurance for non-sudden motor fuel spills (94% in the Mountain region and 89% in the Pacific region). There was very little difference in the percentage of operators claiming non-sudden spill coverage across establishment types.

III. CHARACTERISTICS OF UNDERGROUND MOTOR FUEL STORAGE TANKS

There are an estimated 638,000 underground motor fuel storage tanks at business and government establishments in the continental United States. Table 9-7 shows the numerical and percent distribution of these tanks by survey region and establishment type. The differences in these distributions across survey region are described in Section 9.III.A below. Selected tank characteristics, including tank age, tank capacity, products held in the tank, and various installation characteristics, were also analyzed by survey region and by establishment type. The results of these analyses are reported in Tables 9-8 through 9-15, and are discussed in Section 9.III.B.

A. Distribution of Tanks by Type of Establishment within Survey Region

As is shown in Table 9-7, tanks at government and military establishments account for 15 percent of all of the underground motor fuel tanks. This proportion is about the same across all

Table 9-7. Estimates of the number and percent of underground motor fuel storage tanks[1] across establishment types for the six survey regions[2] (95% confidence bounds on number of establishments in parentheses)

Survey region	Tanks at government and military establishments	Tanks at gas stations owned by major petroleum companies	Tanks at gas stations owned by other companies	Tanks at other fuel-related establishments	Tanks at large non-fuel-related establishments	Total
Northeast						
Number:	25,000	29,000	61,000	27,000	44,000	187,000
% in region:	14%	16%	33%	14%	24%	100%
95% conf. bounds:	(2,000-49,000)	(9,000-50,000)	(48,000-74,000)	(18,000-35,000)	(20,000-68,000)	(175,000-198,000)
Southeast						
Number:	17,000	24,000	40,000	12,000	33,000	126,000
% in region:	14%	19%	32%	9%	26%	100%
95% conf. bounds:	(9,000-25,000)	(12,000-37,000)	(31,000-50,000)	(6,000-17,000)	(14,000-52,000)	(106,000-147,000)
Midwest						
Number:	26,000	25,000	52,000	16,000	20,000	139,000
% in region:	19%	14%	29%	15%	23%	100%
95% conf. bounds:	(14,000-37,000)	(9,000-40,000)	(39,000-65,000)	(9,000-24,000)	(2,000-39,000)	(108,000-170,000)
Central						
Number:	13,000	10,000	23,000	9,000	9,000	63,000
% in region:	20%	15%	37%	14%	14%	100%
95% conf. bounds:	(8,000-18,000)	(4,000-15,000)	(11,000-36,000)	(7,000-10,000)	(< 19,000)	(43,000-84,000)
Mountain						
Number:	7,000	4,000	13,000	5,000	7,000	36,000
% in region:	20%	11%	36%	13%	20%	100%
95% conf. bounds:	(3,000-11,000)	(< 11.000)	(2,000-24,000)	(4,000-6,000)	(3,000-11,000)	(23,000-49,000)
Pacific						
Number:	10,000	26,000	14,000	8,000	28,000	87,000
% in region:	12%	29%	16%	10%	33%	100%
95% conf. bounds:	(2,000-19,000)	(20,000-31,000)	(1,000-27,000)	(7,000-10,000)	(3,000-53,000)	(58,000-116,000)
All survey regions						
Number:	98,000	118,000	204,000	77,000	142,000	638,000
% all regions:	15%	18%	32%	12%	22%	100%
95% conf. bounds:	(69,000-128,000)	(87,000-148,000)	(174,000-233,000)	(64,000-90,000)	(97,000-187,000)	(584,000-692,000)

[1] Does not include farms.
[2] Percents are calculated prior to rounding.

Table 9-8. Estimates, by survey region, of the mean and median age (in years) of underground motor fuel storage tanks[1] (95% confidence bounds about the mean in parentheses)

Survey region	Mean tank age (in years)	Median tank age (in years)
1 Northeast	12 (11-13)	12
2 Southeast	12 (11-14)	11
3 Midwest	12 (11-14)	11
4 Central	12 (9-15)	10
5 Mountain	11 (9-14)	11
6 Pacific	12 (7-18)	11
Total	12 (11-13)	11

[1] Does not include tanks at farms.

Table 9-9. Estimates, by establishment type, of the mean and median age (in years) of underground motor fuel storage tanks[1] (95% confidence bounds about the mean in parentheses)

Type of establishment	Mean tank age (in years)	Median tank age (in years)
Government & military	12 (10-14)	9
Gas stations owned by major petroleum companies	12 (9-14)	11
Gas stations owned by other companies	14 (13-16)	13
Other fuel-related establishments	12 (10-13)	11
Large non-fuel-related establishments	10 (9-12)	7
Total	12 (11-13)	11

[1] Does not include tanks at farms.

Table 9-10. Estimates, by survey region, of the mean and median capacity (in gallons) of underground motor fuel storage tanks[1] (95% confidence bounds about the mean in parentheses)

Survey region	Mean tank capacity (in gallons)	Median tank capacity (in gallons)
1 Northeast	**4,583** (3,662-5,503)	**4,000**
2 Southeast	**5,744** (4,931-6,557)	**6,000**
3 Midwest	**5,710** (5,064-6,357)	**5,000**
4 Central	**5,176** (4,751-5,601)	**4,000**
5 Mountain	**5,866** (5,711-6,020)	**5,000**
6 Pacific	**6,180** (4,954-7,406)	**6,000**
Total	**5,405** (5,026-5,783)	**4,000**

[1] Does not include tanks at farms.

Table 9-11. Estimates, by establishment type, of the mean and median capacity (in gallons) of underground motor fuel storage tanks[1] (95% confidence bounds about the mean in parentheses)

Type of establishment	Mean tank capacity (in gallons)	Median tank capacity (in gallons)
Government & military	**4,342** (3,059-5,626)	**2,000**
Gas stations owned by major petroleum companies	**6,821** (6,120-7,522)	**6,000**
Gas stations owned by other companies	**5,093** (4,513-5,674)	**4,000**
Other fuel-related establishments	**5,687** (4,963-6,410)	**4,000**
Large non fuel-related establishments	**5,261** (4,374-6,149)	**4,000**
Total	**5,405** (5,026-5,783)	**4,000**

[1] Does not include tanks at farms.

Table 9-12. Estimates, by survey region, of percent of underground motor fuel storage tanks[1,2] that stored specified fuel types within the prior year (95% confidence bounds in parentheses)

Survey region	Percent of tanks that store leaded gasoline	Percent of tanks that store unleaded gasoline	Percent of tanks that store diesel fuel	Percent of tanks that store aviation fuel	Percent of tanks that store gasohol	Percent of tanks that store other types of motor fuel
1 Northeast	28% (19-36%)	48% (36-59%)	23% (13-32%)	2% (1-3%)	0%[3]	< 1% (< 1%)
2 Southeast	33% (30-36%)	39% (34-44%)	23% (18-29%)	2% (1-3%)	2% (1-2%)	2% (1-4%)
3 Midwest	36% (40-42%)	36% (27-46%)	20% (6-34%)	3% (< 6%)	3% (< 6%)	2% (1-4%)
4 Central	33% (31-36%)	39% (28-49%)	23% (16-30%)	3% (1-5%)	1% (< 3%)	1% (< 3%)
5 Mountain	34% (23-45%)	36% (27-44%)	25% (19-31%)	5% (3-8%)	0%[3]	0%[3]
6 Pacific	37% (33-41%)	46% (32=59%)	16% (4-28%)	1% (< 4%)	0%[3]	0%[3]
Total	33% (30-36%)	42% (37-46%)	21% (17-26%)	2% (1-3%)	1% (0-2%)	1% (1-2%)

(1) Does not include tanks on farms.
(2) Row percent may sum to more than 100 percent because some tanks were used to store more than one fuel type during the 12 months prior to the survey.
(3) No tanks were found in this region's sample storing this type of fuel. Hence, no confidence bounds were estimated.

Table 9-13. Estimates, by establishment type, of percent of underground motor fuel storage tanks[1,2] that stored specified fuel types within the prior year (95% confidence bounds in parentheses)

Establishment type	Percent of tanks that store leaded gasoline	Percent of tanks that store unleaded gasoline	Percent of tanks that store diesel fuel	Percent of tanks that store aviation fuel	Percent of tanks that store gasohol	Percent of tanks that store other types of motor fuel
Government and Military	34% (27-41%)	27% (22-31%)	29% (25-32%)	6% (1-11%)	1% (< 2%)	4% (< 8%)
Gas station owned by major petroleum companies	33% (30-36%)	60% (57-62%)	6% (4-9%)	0%[3]	3% (< 6%)	0%[3]
Gas station owned by other companies	36% (33-38%)	50% (46-55%)	13% (9-17%)	0%[3]	1% (< 3%)	1% (< 2%)
Other fuel-related establishments	24% (20-29%)	33% (25-40%)	28% (22-35%)	11% (8-14%)	< 1% (< 1%)	3% (0-6%)
Large non-fuel-related establishments	33% (25-41%)	29% (20-38%)	38% (30-45%)	1% (< 2%)	0%[3]	0%[3]
Total	33% (30-36%)	42% (37-46%)	21% (17-26%)	2% (2-3%)	1% (0-2%)	1% (1-2%)

(1) Does not include tanks on farms.
(2) Row percents may sum to more than 100 percent because some tanks were used to store more than one fuel type during the 12 months prior to the survey.
(3) No tanks were found in this establishment type storing this type of fuel. Hence, no confidence bounds were estimated.

Table 9-14. Estimates by survey region of the percent of underground motor fuel storage tank systems[1] with selected installation characteristics (95% confidence bounds in parentheses)

Survey region	Percent of tank systems that are fiberglass	Percent of tank systems that are bare steel (i.e. not coated)	Percent of tank systems that have cathodic protection	Percent of tank systems that are installed partially (or completely) below water table	Percent of tank systems that are covered by a paved surface
1 Northeast	10% (4-16%)	5% (2-9%)	4% (2-7%)	21% (13-29%)	73% (55-91%)
2 Southeast	10% (5-15%)	10% (4-17%)	3% (1-5%)	17% (11-23%)	71% (63-80%)
3 Midwest	12% (< 25%)	12% (8-16%)	5% (3-8%)	25% (21-29%)	65% (44-85%)
4 Central	16% (2-29%)	8% (4-12%)	< 1% (< 1%)	12% (2-21%)	74% (62-86%)
5 Mountain	12% (8-15%)	8% (< 17%)	17% (3-30%)	27% (14-40%)	72% (66-79%)
6 Pacific	10% (1-20%)	38% (8-68%)	3% (< 7%)	26% (6-45%)	90% (83-97%)
Total	11% (7-15%)	12% (7-17%)	5% (3-6%)	21% (17-25%)	73% (66-80%)

[1]Does not include farm tanks.

Table 9-14. (Cont'd) Estimates by survey region of the percent of underground motor fuel storage tank systems[1] with selected installation characteristics (95% confidence bounds in parentheses)

Survey region	Percent of tank systems that are in a manifolded system	Percent of tank systems that are connected to a pressure pumping delivery systems	Percent of tank systems that have metered dispensing systems	Percent of tank systems that were self-installed	Percent of tank systems that were 2nd-hand when installed
1 Northeast	29% (18-41%)	26% (10-43%)	96% (93-100%)	13% (0-27%)	5% (2-7%)
2 Southeast	22% (15-28%)	29% (25-32%)	88% (83-93%)	25% (17-33%)	6% (1-11%)
3 Midwest	21% (14-27%)	31% (22-40%)	90% (86-94%)	18% (8-28%)	2% (1-4%)
4 Central	18% (9-26%)	25% (13-37%)	89% (81-97%)	44% (22-67%)	7% (< 14%)
5 Mountain	12% (< 23%)	42% (39-45%)	87% (83-91%)	6% (< 18%)	3% (< 6%)
6 Pacific	22% (8-35%)	24% (14-34%)	88% (76-100%)	22% (3-42%)	1% (< 2%)
Total	23% (18-27%)	28% (22-34%)	91% (88-93%)	20% (14-26%)	4% (2-6%)

[1]Does not include farm tanks.

Table 9-15. Estimates by establishment type of the percent of underground motor fuel storage tank systems[1] with selected installation characteristics (95% confidence bounds in parentheses)

Type of establishment	Percent of tank systems that are fiberglass	Percent of tank systems that are bare steel (i.e. not coated)	Percent of tank systems that have cathodic protection	Percent of tank systems that are installed partially (or completely) below water table	Percent of tank systems that are covered by a paved surface
Goverment and military	6% (2-10%)	15% (8-22%)	7% (3-11%)	27% (19-34%)	46% (33-58%)
Gas stations owned by major petroleum companies	24% (14-34%)	7% (3-12%)	5% (2-9%)	24% (14-34%)	95% (92-99%)
Gas stations owned by other companies	9% (3-14%)	10% (6-15%)	5% (1-8%)	21% (12-29%)	84% (74-94%)
Other fuel-related establishments	8% (4-11%)	9% (2-15%)	3% (< 7%)	33% (20-46%)	68% (60-77%)
Large non-fuel-related establishments	10% (2-18%)	17% (< 38%)	2% (< 5%)	10% (< 20%)	61% (51-71%)
Total	11% (7-15%)	12% (7-17%)	5% (3-6%)	21% (7-25%)	73% (66-80%)

[1]Does not include farm tanks.

Table 9-15. (cont'd) Estimates by establishment type of the percent of underground motor fuel storage tank systems[1] with selected installation characteristics (95% confidence bounds in parentheses)

Type of establishment	Percent of tank systems that are in a manifolded system	Percent of tank systems that are connected to a pressure pumping delivery systems	Percent of tank systems that have metered dispensing systems	Percent of tank systems that were self-installed	Percent of tank systems that were 2nd-hand when installed
Goverment and military	14% (7-22%)	9% (3-16%)	87% (83-90%)	44% (29-60%)	6% (3-9%)
Gas stations owned by major petroleum companies	24% (16-31%)	58% (47-70%)	100% (99-100%)	10% (1-19%)	1% (< 2%)
Gas stations owned by other companies	24% (17-31%)	32% (26-39%)	98% (96-100%)	9% (4-14%)	1% (< 2%)
Other fuel-related establishments	30% (21-39%)	22% (16-31%)	84% (80-88%)	17% (6-28%)	2% (1-4%)
Large non-fuel-related establishments	21% (8-35%)	14% (3-24%)	80% (71-89%)	20% (8-31%)	10% (4-15%)
Total	23% (18-27%)	28% (22-34%)	91% (88-93%)	20% (14-26%)	4% (2-6%)

[1]Does not include farm tanks.

of the survey regions, ranging from 12 percent in the Pacific region to 20 percent in the Mountain and Central regions. The distributions of tanks at gas stations in the two ownership groups show differences particularly in the Pacific survey region. While 18 percent of the tanks in all survey regions are found at gas stations owned by major petroleum companies, in the Pacific survey region, 29 percent of the tanks are at this type of establishment. The Mountain survey region has the lowest proportion of tanks in this group (11%). And while 32 percent of the tanks in all survey regions are found at gas stations owned by other companies, in the Pacific survey region only 16 percent of the tanks are at gas stations owned by other companies. Tanks at large non-fuel-related establishments account for 33 percent of the tanks in the Pacific survey region, and 14 percent of the tanks in the Central survey region, while they account for 22 percent of the tanks across all survey regions.

B. Selected Tank Characteristics, Analyzed by Region and by Establishment Type

Selected tank characteristics, including tank age, tank capacity, type of motor fuel held in the tank, and installation characteristics, were analyzed by survey region and by establishment type. These analyses are based on a file of 2411 tanks, weighted to represent the national estimate of 638,000 tanks. The results of the analyses of these characteristics are displayed in Table 9-8 through Table 9-15.

1. Tank Age

Tank age was calculated by subtracting the year of installation from the year of interview (1985). If a tank was used (i.e., second-hand) when it was installed, the age of the tank at installation was added to the number of years since installation, to obtain tank age. All information required to compute tank age was present for 69 percent of the tanks surveyed. Tables 9-8 and 9-9 are based on these tanks. They show the mean (or average) age of tanks and the median (or 50th percentile) age of tanks in years, by survey region and establishment type. For tanks in all survey regions, the average age is 12 years, and the median age is 11 years. The average age within survey regions was also 12 years for all regions except Mountain, where the average age was 11 years. The median tank age also was similar for all survey regions.

More differences appear when the average age of tanks is compared across types of establishments. Table 9-9 shows that tanks at gasoline stations owned by other companies (i.e., those not owned by major petroleum companies) tend to be older than tanks at other types of establishments. The mean age of tanks at gas stations owned by other companies is 14 years (compared to a mean of 12 years, overall) and the median age of these tanks is 13 years (compared to a median of 11 years overall). Large non-fuel-related establishments appear to have newer tanks than other establishments, with an average tank age of 10 years, and a median tank age of 7 years.

2. Tank Capacities

Average and median tank capacities also varied within survey regions and establishment types, as may be seen in Tables 9-10 and 9-11. (Nearly all tanks, over 99%, had known capacity.) Across all survey regions and establishment types, the average tank size is 5,405 gallons, and the median tank size is 4,000 gallons. Tanks in the Pacific survey region tend to be larger, with an average tank size of 6180 gallons and a median tank size of 6000 gallons. Tanks in the Northeast survey region tend on average to be smaller, with a mean tank capacity of 4,583 gallons, and a median capacity of 4000 gallons.

Tanks at gas stations owned by major petroleum companies tend to be larger, with an average capacity of 6,821 gallons (compared to the national average of 5,405 gallons), and a median capacity of 6,000 gallons (compared to the national median of 4,000 gallons.) The establishments with the smallest tank capacity are the government and military establishments, where the average tank size is 4,342 gallons and the median tank size is 2,000 gallons.

3. Type of Motor Fuel Stored

Tables 9-12 and 9-13 show the estimates, by survey region and by type of establishment, of the percent of underground tanks that were used to store specific motor fuel types during the prior year. All tanks had data on fuel type. There is not much variation in the percent of tanks that store leaded gasoline across survey regions. For all survey regions together, 33 percent of the tanks store leaded gasoline, and the proportions within survey regions range from a low of 28 percent in the

Northeast region to a high of 37 percent in the Pacific region. Unleaded gasoline is stored in 42 percent of the tanks overall. The regions with the lowest percentage of tanks that store unleaded gasoline are the Midwest and Mountain, each with 36 percent. The region with the highest percentage of tanks that store unleaded gasoline is the Northeast with 48 percent. Diesel fuel is stored in 21 percent of the tanks nationally, but in a slightly lower percentage of tanks in the Pacific survey region (16%).

Tanks that store aviation fuel account for about two percent of the tanks in the continental United States, while tanks that store gasohol and tanks that store other fuel types and fuel blends each account for about one percent of the tanks in the country. Regional variations among these products do not appear to be meaningful.

Some variation in the types of fuels stored within establishment types is expected, since different types of establishments use fuels for different types of vehicles. A smaller percentage of government and military tanks are used to store unleaded gasoline (27%) than the national percentage of 42 percent. Among gas stations, the percent of tanks that store unleaded gasoline is substantially higher that the national percentage, but interestingly enough, the percentage is higher for gas stations owned by major petroleum companies (at 60%) than it is for gas stations owned by other companies (at 51%). Although it is risky to draw any conclusions from such small subsamples, it is not surprising that government and military establishments and other fuel-related establishments account for the majority of tanks that store aviation fuel. (These two categories of establishments include the government and public sector airfields, airports and air services.)

4. Material of Construction

Overall, 11 percent of the underground motor fuel storage tanks in the continental United States are fiberglass. This information was known for 92 percent of tanks, and the estimate of 11 percent fiberglass is based on those with known material of construction. The percent distribution is nearly equal for all survey regions (ranging between 10% and 12% in each region) except for the Central survey region, where the percentage of fiberglass tanks is just slightly higher (16%). There are more striking differences in the percentages of tanks that are fiberglass within establishment types. The percentages of fiberglass tanks at gas stations that are owned by other companies, other fuel-related establishments, and large non-fuel-related establishments are all close to the national percentage of 11 percent. (These establishment types have 9%, 8%, and 10% respectively.) Only 6 percent of the tanks at government and military establishments are fiberglass, while 24 percent of the tanks at gas stations owned by major petroleum companies are fiberglass.

Steel tanks comprise 89 percent of the underground motor fuel storage tanks nationally. According to establishment operators, the majority (about 85%) of steel tanks are coated, based on tanks for which this question was answered. (However, establishment operators did not know if the tanks were bare or coated for 39% of the tanks, and the material of construction was unknown for 8% of the tanks.) Among tanks reported to be coated, the coating material was not reported for 7 percent of the tanks. Among tanks for which the coating material <u>was</u> reported, 58 percent were coated with asphaltic material, 34 percent with coal tar epoxy, and the remainder with urethane (2%), "black coating" (2%), fiberglass/epoxy (1%) or other coatings with less than 1

percent each (and totaling 2% of responses) such as double-wrapped tar tape, red oxide, paint, jenite (creosote and asphalt), tar paint, rust primer and anti-rust paint, etc.

Based on available data, it is estimated that 12 percent of the tanks nationally are bare (uncoated) steel tanks. These bare tanks are found in differing proportions throughout the country. Only five percent of the tanks are reported to be bare steel in the Northeast survey region. However, 38 percent of the tanks in the Pacific survey region are reported to be bare steel. The remaining four survey regions are much closer to or equal to the national proportion.

The variations in the distributions of tanks that are bare steel across establishment types are less pronounced. The lowest percentage is found among gas stations owned by major petroleum companies, where 7 percent of the tanks are reported to be bare steel. Large non-fuel-related establishments have the highest percentage of bare steel tanks, with 17 percent. However, the percentages for all establishment types are within five percentage points of the overall percentage.

5. Cathodic Protection

Only five percent of all tanks were reported to have cathodic protection systems of any type installed to protect them against corrosion, based on the 87 pecent of tanks for which this question was answered. Within survey regions, 17 percent of the tanks in the Mountain survey region were reported to have cathodic protection. There are no other particularly noteworthy divergences from the national proportions across other survey regions or across establishment types.

6. Water Table Level

Establishment operators were asked to indicate how each of the tanks at an establishment were situated in relation to the water table ("completely above", "partially above and partially below", or "completely below"). Establishment operators were able to provide information on the water table level for about 70 percent of the tanks surveyed. Based on the tanks for which responses were given, 21 percent of the tanks are reported to be installed partially or completely below the water table. This percentage varies somewhat across regions, with only 12 percent of the tanks in the Central survey region installed in or beneath the water table. In the Mountain survey region, the highest percentage of tanks (27%) are reported to be installed in or beneath the water table.

Among establishment types, large non-fuel-related establishments have the lowest percentage of tanks reported to be installed in or beneath the water table, with 10 percent. The other fuel-related establishments reported 33 percent of tanks installed partially or completely below the water table. Government and military establishments also have a slightly higher percentage, with 27 percent of tanks at these establishments reported to be installed in or beneath the water table.

7. Surface over the Tank

About 73 percent of the tanks nationally are covered by a paved surface. (Paved surfaces are defined here to include

asphalt surfaces, concrete surfaces and surfaces that are made of these materials in combination. They exclude surfaces that are "paved" with gravel or crushed rock. Surface over the tank was known for nearly all tanks -- over 99 percent.) Among the survey regions, the Pacific region has the highest percentage of tanks that are covered by a paved surface, with 90 percent of tanks reported to have this trait. The Midwest survey region has 65 percent of its tanks covered by a paved surface, and this is the lowest proportion among regions. The remaining four regions are all within 2 percentage points of the national percent.

Among establishment types, gas stations have the highest percentage of tanks covered by paved surfaces, with 95 percent of the tanks at gas stations owned by major petroleum companies covered by paved surfaces, and 84 percent of the tanks at gas stations owned by other companies covered by paved surfaces. Government and military establishments have the lowest proportion of tanks under pavement, with 46 percent. Tanks that are under unpaved surfaces may or may not have the same amount or type of traffic over the tank as tanks under paved surfaces. However, tanks under paved surfaces will be more costly to excavate and rebury, should there be a need to remove, replace or repair them.

8. Manifolded Systems

Twenty three percent of all tanks are in manifolded tank systems. (This was known for 99.9% of tanks surveyed.) Manifolded systems were defined, for the purposes of this survey, as two or more underground motor fuel storage tanks that are joined together by pipes or lines prior to the dispenser meters. The average number of tanks per manifolded system is 2.36. The survey region with the highest percentage of tanks in manifolded

systems is the Northeast, with 29 percent of tanks in such systems. The Mountain survey region has the lowest percentage of tanks in manifolded systems, with 12 percent. The remaining four regions are all slightly lower than, but very close to the national percentage, ranging from 18 percent to 22 percent.

Other fuel-related establishments have a somewhat higher percentage of tanks in manifolded systems (30%). The establishment type with the lowest percentage of tanks in manifolded systems was the government and military establishments with 14 percent.

9. Types of Pumping Systems

The majority of tanks are reported to be connected to suction pumping systems, based on the 95 percent of tanks for which type of pumping system was known. Overall, 28 percent of the tanks were reported to be connected to pressurized delivery systems. All survey regions were close to the national percentage on this trait, except the Mountain survey region, where 42 percent of the tanks were reported to be connected to pressurized delivery systems. Also, more than half (58%) of the pumping systems at gas stations owned by major petroleum companies are pressurized, which is nearly twice the national percentage. Government and military establishments and large non-fuel-related establishments have much lower percentages of tanks connected to pressure pumping systems, with 9 percent and 13 percent respectively.

10. Metered Dispensing Systems

It is virtually impossible to conduct inventory reconciliation monitoring on tanks that are connected with dispensing systems that do not have meters to record the total amount of fuel dispensed from the tank. Fortunately, 91 percent of the tanks nation-wide have metered dispensing systems, based on 99.8 percent of tanks for which this question was answered. The percentages within each survey region are all within five percentage points of the national percent of tanks with dispenser meters. Some variation in the percentage of tanks with dispenser meters can be seen across establishment types. Nearly all tanks at gas stations (100 percent at gas stations owned by major petroleum companies and 98 percent at gas stations owned by other companies) have metered dispensing systems. The remaining three establishment types are all slightly lower than the national percentage of tanks with metered dispensing systems. Large non-fuel-related establishments have the lowest percentage, with 80 percent of the tanks at this type of establishment connected to metered dispensing systems.

11. Self-Installed Tanks

The identity of the tank installer was known for over half (54%) of tanks surveyed. Based on these tanks with known installers, establishment owners reported that 20 percent of underground motor fuel storage tanks were self-installed (i.e., installed by the establishment or its owners.) However, this percentage varies both across survey region and across establishment type. Percentages of tanks that were self-installed across survey region range from a high of 44 percent in the Central survey region to a low of 6 percent in the Mountain

survey region. Among establishment types, 44 percent of the government and military tanks were self-installed, which was the highest percentage among the establishment types. The establishment types with the lowest percent of self-installed tanks are the gas stations owned by other companies (with 9% self-installed) and gas stations owned by major petroleum companies (with 10% self-installed).

12. Secondhand Tanks

A small percentage of the tanks surveyed were secondhand when they were installed at their current location, based on the 81 percent of tanks for which this information was ascertained. It is estimated that four percent of the tanks nationally were installed secondhand. (As explained above, if a tank was secondhand when installed, its total age was calculated to include its age at the time it was installed.) Because of the small percentage of tanks with this trait, it is risky to draw many conclusions about the percent distribution of this trait within survey regions and establishment types. It may be noted with some caution that a higher percentage of tanks at large non-fuel-related establishments (10%) were secondhand tanks, while a lower percent of tanks at gas stations in both ownership categories and tanks in the Pacific survey region (about 1% for each category) were secondhand.

IV. LEAK STATUS OF UNDERGROUND MOTOR FUEL STORAGE TANKS

A total of 439 individual and manifolded tank systems at business and government establishments were tested as a part of the physical tank testing phase of the survey. The analyses in this subsection are based on two related data files. The first

is the file of 412 individual and manifolded tank systems for which there are conclusive test results. The second data file consists of the 383 conclusive test results which refer to single-tank systems. The sample of individual and manifolded tank systems, is analyzed in tables where the characteristics being examined apply to entire systems, whether they consist of individual tanks and their lines, or manifolded tanks and their lines. The sample of individual tank systems, is analyzed in tables where the characteristics being examined apply to individual tanks in systems rather than manifolded tanks in systems (such as, for example, tank capacity.)

A. Leak Status of Tank Systems within Survey Regions and Establishment Types

Detailed analyses are given below for the leak status distribution of tank systems. On an establishment basis, an estimated 117,000, or 36 percent, of establishments have one or more tank systems judged to be leaking under test conditions. This is comparable to the percentage on a tank system basis.

Within the continental United States 35 percent of the underground motor fuel storage tank systems at business and government establishments are judged to be leaking under test conditions, based on all tests with conclusive results. The distributions of percentages of leaking tank systems across survey regions and establishment types are displayed in Tables 9-16 through 9-18. The estimated number of tank systems judged to be leaking is 189,000. This excludes tank systems for which test results were inconclusive. (Therefore, this estimated number, when divided by the estimated total number of tanks, will not give the percentage shown.)

Table 9-16. Estimated number and percent of tank systems [1,2] judged to be leaking under test conditions within each survey region (95% confidence bounds in parentheses)

Survey Region	Sample size[3]	Number of tank systems judged to be leaking (in 1,000's)	Percent of tank systems judged to be leaking
1 Northeast	98	57 (37-77)	39% (32-45%)
2 Southeast	104	42 (19-65)	36% (22-50%)
3 Midwest	82	34 (22-46)	28% (19-37%)
4 Central	48	26 (14-38)	46% (22-70%)
5 Mountain	39	11 (3-18)	33% (17-48%)
6 Pacific	41	20 (11-30)	28% (18-38%)
Total	412	189 (153-226)	35% (30-40%)

[1]In this table tank system test results are reported for single tank systems unless multiple tanks were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are included in this table.

[2]Does not include farm tanks.

[3]Includes all tank systems with conclusive test results. Excludes tank systems for which test results were inconclusive.

Table 9-17. Estimated number and percent of tank systems[1,2] judged to be leaking under test conditions within establishment types (95% confidence bounds in parentheses)

Type of Establishment	Sample size[3]	Number of tank systems judged to be leaking (in 1,000's)	Percent of tank systems judged to be leaking
Government and military	55	29 (5-54)	36% (16-55%)
Gas stations owned by major petroleum companies	62	25 (11-38)	32% (19-45%)
Gas stations owned by other companies	155	56 (40-71)	30% (22-37%)
Other fuel-related establishments	64	35 (25-45)	57% (43-71%)
Large non-fuel-related establishments	76	45 (17-71)	33% (18-47%)
Total	412	189 (153-226)	35% (30-40%)

[1]In this table tank system test results are reported for single tank systems unless multiple tanks were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are included in this table.

[2]Does not include farm tanks.

[3]Includes all tanks with conclusive test results. Excludes tanks for which test results were inconclusive.

Table 9-18. Estimates by survey region and establishment type of percent of underground motor fuel storage tank systems [1,2,3] judged to be leaking under test conditions (95% confidence bounds in parentheses)

Survey region	Establishment type: Government and military	Gas stations owned by major petroleum companies	Gas stations owned by other companies	Other fuel-related establishments	Large non-fuel related establishments	All establishment types
1 Northeast	60% (40-80%)	50% (50-50%)	31% (19-43%)	44% (4-85%)	32% (12-52%)	39% (32-45%)
2 Southeast	17% (0-34%)	55% (43-66%)	29% (20-37%)	60% (37-83%)	36% (0-73%)	36% (22-50%)
3 Midwest	0%[4]	12% (0-39%)	31% (12-51%)	68% (49-88%)	0%[4]	28% (19-37%)
4 Central	29% (0-76%)	40% (27-53%)	41% (12-70%)	60% (40-80%)	75% (38-100%)	46% (22-70%)
5 Mountain	60% (36-84%)	0%[4]	18% (0-52%)	38% (33-42%)	50% (12-88%)	33% (17-48%)
6 Pacific	20% (0-61%)	29% (18-39%)	0%[4]	50% (0-100%)	30% (0-75%)	28% (18-38%)
All regions	36% (16-55%)	32% (19-45%)	30% (22-37%)	57% (43-71%)	33% (18-47%)	35% (30-40%)

[1]In this table tank system test results are reported for single tank systems unless multiple tanks were tested as part of a manifolded tank system that could not be broken apart. These manifolded tank systems tested together are included in this table.

[2]Does not include farm tanks.

[3]Includes all tanks with conclusive test results. Excludes tanks for which test results were inconclusive (sample size = 412 cases).

[4]No eligible sampled establishments of this type were found in this survey region, so the percent and confidence bounds on it were not estimated.

As is shown in Table 9-16, the Central survey region has the highest percentage of leaking tank systems, with 46 percent. The regions with the lowest percentage of leaking tank systems are the Midwest and the Pacific, each with 28 percent. The Northeast survey region has the highest estimated number of leaking tank systems (57,000) while the Mountain survey region has the lowest estimated number (11,000).

Table 9-17 shows the number and percent of tank systems judged to be leaking by establishment type. Fuel-related establishments other than gas stations have the highest percentage of leaking tank systems, with 57 percent judged to be leaking. Gas stations owned by other companies have the lowest percentage of tank systems judged to be leaking, with 30 percent, but account for the largest estimated number (56,000) of tank systems judged to be leaking.

The percent of tank systems judged to be leaking under test conditions within each category of establishment type and survey region is displayed in Table 9-18. Small sample sizes within many of the cells of this table result in wide confidence bounds and some difficulty in interpretation. The five cells with the highest percentages of tank systems judged to be leaking were government and military tank systems in the Northeast and Mountain survey regions, tank systems at other fuel-related establishments in the Midwest and Central survey regions, and large non-fuel-related establishments in the Central survey region. The five cells with the lowest percentages of tank systems judged to be leaking were government and military tank systems, tank systems at gas stations owned by major petroleum companies, and tank systems at large non-fuel-related establishments in the Midwest survey region, tank systems at gas

stations owned by major petroleum companies in the Mountain survey region, and tank systems at gas stations owned by other companies in the Pacific survey region.

B. Characteristics Associated with Leaking Tanks

Selected tank characteristics, including tank age, tank capacity, type of motor fuel held in the tank, and installation characteristics were analyzed by tank system leak status. The results of these analyses, including the sample size, estimated number of tank systems leaking, and percent of tank systems leaking, are displayed in Tables 9-19 through 9-23.

1. Tank Age and Material

Table 9-19 shows the estimated number and percent of tank systems that are judged to be leaking under test conditions within five categories of tank age. While overall, 35 percent of tank systems are judged to be leaking, 57 percent of the tank systems that are more than twenty years old are judged to be leaking under test conditions. However, tank systems that are thirteen through twenty years old form the age category with the smallest percentage leaking. Note, however, that this difference does not appear to be statistically significant. Each of these arbitrary age categories accounts for a similar number of leaking tank systems, ranging from an estimated 22,000 tank systems to 27,000 tank systems.

Table 9-19A provides a more detailed look at percent judged to be leaking broken down by both age and tank material. There

Table 9-19. Estimated number and percent of tank systems[1,2] judged to be leaking under test conditions within tank age categories[3] (95% confidence bounds in parentheses)

Tank age categories	Sample size[4]	Number of tanks judged to be leaking (in 1,000's)	Percent of tanks judged to be leaking
< 5 years old	**54**	**27** (4-51)	**38%** (19-57%)
5-8 years old	**52**	**25** (13-38)	**35%** (23-47%)
9-12 years old	**57**	**26** (9-42)	**36%** (20-52%)
13-20 years old	**56**	**22** (8-35)	**30%** (15-45%)
> 20 years old	**36**	**26** (14-37)	**57%** (39-75%)
Age unknown	**128**	**50** (21-79)	**29%** (19-39%)
Total	**383**	**177** (139-214)	**35%** (30-40%)

[1]In this table, tank system test results are reported for single tank systems. Tanks tested as a part of a manifolded tank system that was not broken apart are not included in the table.

[2]Does not include farm tanks.

[3]Tank age, as calculated from year of installation and age at installation (if second-hand), was missing for 128, or 33% of the tanks.

[4]Includes all individually tested tank systems with conclusive results. Excludes tank systems for which test results were inconclusive, and tank systems tested as part of a manifolded tank system.

Table 9-19A. Estimated number and percent of tank systems[1,2] judged to be leaking under test conditions, by age and material of tank construction[3] (95% confidence bounds in parentheses)

Tank material and age categories	Sample size	Number of tanks judged to be leaking (in 1,000's)	Percent of tanks judged to be leaking
Steel:			
< 5 years old	46	23 (< 47)	38% (11-65%)
5-8 years old	44	21 (12-30)	38% (24-45%)
9-12 years old	46	18 (5-31)	31% (13-49%)
13-20 years old	51	22 (8-35)	33% (17-50%)
> 20 years old	35	26 (14-39)	58% (39-77%)
Fiberglass:			
< 5 years old	7	2 (< 5)	26% (< 77%)
5-20 years old	20	10 (< 20)	36% (17-55%)

[1]In this table, tank system test results are reported for single tank systems. Tanks tested as a part of a manifolded tank system that was not broken apart are not included in the table.

[2]Does not include farm tanks.

[3]Respondents were unable to provide age or material of construction for 33 percent and 8 percent, respectively, of tested tanks.

Table 9-20. Estimated number and percent of tank systems [1,2] judged to be leaking under test conditions within tank capacity category (95% confidence bounds in parentheses)

Tank Capacity	Sample size[3]	Number of tank systems judged to be leaking (in 1,000's)	Percent of tank systems judged to be leaking
≤ 1100 gallons	**82**	**29** (13-45)	**23%** (13-34%)
1101 to 3999 gallons	**58**	**21** (9-32)	**27%** (18-37%)
4000 to 4999 gallons	**61**	**30** (11-49)	**39%** (24-55%)
5000 to 5999 gallons	**17**	**13** (3-24)	**61%** (35-86%)
6000 to 7999 gallons	**50**	**25** (4-45)	**37%** (14-60%)
8000 to 9999 gallons	**33**	**15** (2-28)	**34%** (11-58%)
10,000 to 11,999 gallons	**60**	**34** (17-51)	**45%** (29-62%)
≥ 12,000 gallons	**22**	**11** (3-19)	**43%** (30-57%)
Total	**383**	**177** (139-214)	**35%** (30-40%)

[1]In this table tank system test results are reported for single tank systems. Tank tested as a part of a manifolded tank system that was not broken apart are not included in the table.

[2]Does not include farm tanks.

[3]Includes all individually tested tank systems with conclusive results. Excludes tank systems for which test results were inconclusive, and tank systems tested as part of a manifolded tank system.

Table 9-21. Estimates by fuel types stored during the prior year of the number and percent of tank systems[1,2] judged to be leaking under test conditions (95% confidence bounds in parentheses).

Fuel types stored during prior year	Sample size[3]	Number of tank systems judged to be leaking (in 1,000's)	Percent of tank systems judged to be leaking
Leaded gasoline	130	32 (15-49)	18% (9-26%)
Unleaded gasoline	171	72 (53-91)	33% (25-41%)
Diesel fuel	97	73 (48-99)	57% (47-67%)

[1]In this table tank system test results are reported for single tank systems unless multiple tanks were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are not included in the table.

[2]Does not include farm tanks.

[3]Includes all tank systems with conclusive test results. Excludes tank systems for which test results were inconclusive.

Table 9-22. Estimated number and percent of tank systems[1,2] judged to be leaking under test conditions for single tanks and tank systems in manifolded systems (95% confidence bounds in parentheses).

	Sample size[3]	Number of tank systems judged to be leaking (in 1,000's)	Percent of tank systems judged to be leaking
Single tanks systems (not manifolded)	**338**	**140** (105-174)	**31%** (26-36%)
Tanks in manifolded systems	**74**	**50** (19-80)	**54%** (39-68%)
Total	**412**	**189** (153-226)	**35%** (30-40%)

[1]In this table tank system test results are reported for single tank systems unless multiple tank systems were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are included in this table.

[2]Does not include farm tanks.

[3]N1 = Tank systems with conclusive test results. Excludes tank systems for which test results were inconclusive.

Table 9-23. Estimates number and percent of tank systems[1] judged to be leaking under test conditions for tank systems with selected installation characteristics (95% confidence bounds in parentheses).

Installation characteristics	Sample size[2]	Percent of systems judged to be leaking	Number of systems judged to be leaking (in 1,000's)
Fiberglass tanks	30	31% (15-48%)	12 (1-24)
Bare (uncoated steel) tanks	33	32% (14-49%)	14 (0-28)
Coated steel tanks	192	38% (30-46%)	97 (65-128)
Tanks with cathodic protection installed	10	60% (0-100%)	9 (< 25)
Tanks installed partially or completely below the water table	40	47% (25-69%)	23 (9-36)
Tanks covered by a paved surface	263	39% (32-45%)	136 (103-198)
Tanks connected to a pressure pump delivery system	71	41% (27-55%)	37 (21-52)
Tanks with metered dispensing systems	351	36% (31-40%)	164 (130-198)
Tanks that were self-installed	42	23% (31-40%)	14 (3-26)
Tanks that were 2nd-hand when installed	13	52% (26-78%)	9 (4-14)
National totals[3]	383	35% (30-40%)	177 (139-214)

[1]Does not include farm tanks.

[2]Includes all individually tested tank systems with conclusive results. Excludes tank systems for which test results were inconclusive, tanks tested as part of a manifolded tank system.

[3]Since the categories overlap, the national totals are given to provide a reference point, not as the total of the rows alone.

is some indication that the oldest steel tanks (> 20 years old) may have a higher proportion leaking than younger steel tanks. A comparison of percent judged to be leaking by tank material cannot be made for tanks more than 20 years old, since no fiberglass tanks that old were found in the survey. For age categories where a comparison can be made by tank material, no significant differences appear.

2. Tank Capacity

While the percentage of tank systems judged to be leaking under test conditions nationally is 35 percent for all tested tank systems, there is some variation in the percentage across size categories. Table 9-20 displays the estimated number and percent of tank systems judged to be leaking under test conditions within eight arbitrary size categories. The percentage of tank systems judged leaking is somewhat lower than the national percentage in the two smallest size categories. An estimated 23 percent of the tank systems that are 1100 gallons or less are judged to be leaking, and 27 percent of the tank systems ranging in size from 1101 to 3999 gallons are judged to be leaking. The size categories with the largest percentages of tank systems that are judged to be leaking are systems with tanks that are 5000 to 5999 gallons, with 61 percent; systems with tanks that are 10,000 to 11,999 gallons, with 45 percent; and systems with tanks that are 12,000 or more gallons, with 44 percent. The size categories with the largest estimated numbers of leaking tank systems are those systems with tanks that are 10,000 to 11,999 gallons, and 4,000 to 4,999 gallons.

3. Type of Motor Fuel Stored

There were interesting differences in the leak status of tank systems depending upon the type of motor fuel they had stored during the prior year, as may be seen in Table 9-21. Among tank systems that store unleaded gasoline the percent leaking under test conditions is 33 percent which is nearly the same as the national percentage. However, among tank systems used to store leaded gasoline, only 18 percent, or about half of the national percentage, are judged to be leaking. Among tank systems storing diesel fuel, the percent judged to be leaking is 57 percent, or nearly two-thirds more than the national percentage. Very small numbers of tank systems used to store other fuel types such as aviation fuel and gasohol were tested, so reliable estimates of leak status can not be provided for tanks storing these fuel types.

4. Manifolded Systems

A somewhat higher proportion of the tank systems that are part of a manifolded tank system are judged to be leaking under test conditions, as is displayed in Table 9-22. Among tank systems that are a manifolded system of two or more tanks, or are individually tested members of such a system, 54 percent of the tank systems are leaking, compared with single tank systems, where 31 percent of the tank systems are leaking.

5. Material of Construction

Single-tank systems with tanks made of fiberglass, coated steel and bare (uncoated) steel were analyzed separately, with

the results displayed in Table 9-23. The percent of tank systems judged to be leaking under test conditions within each category of material of construction was nearly the same as the overall percent: compared to 35 percent of tank systems judged to be leaking overall, 31 percent of the systems with fiberglass tanks are leaking, 32 percent of the systems with bare steel tanks are leaking, and 38 percent of the systems with coated steel tanks are leaking. Systems with coated steel tanks account for the majority of all tank systems, and therefore not surprisingly account for the largest number of tank systems judged to be leaking within construction material type.

6. Cathodic Protection

Only a small percentage (about 5% nationally) of tank systems have cathodic protection, and a small number of these systems were tested. The results of these tests for ten systems with cathodic protection are displayed in Table 9-23 and show that 60 percent of cathodically protected tank systems are estimated to be leaking. However, the confidence bounds on this estimate are not tight. In fact, the 95 percent confidence limits range from 0-100 percent. A tighter bound can be constructed by requiring a lower confidence: for example, the 50 percent confidence bounds are 33-87 percent.

This result should not be taken to imply that cathodic protection, when properly installed, maintained, checked by the local establishment operator, and covering the entire tank system is not an effective leak prevention system in principle. However, it does raise a question that would bear further investigation, namely, how feasible it is to achieve the above conditions in practice. A possible explanation for the high proportion judged to be leaking among cathodically protected tank

systems is that such protections are only judged worth the installation expense for tank systems believed to be at high risk of leaking. Thus, the figure would be more a description of the tank system universe to which cathodic protection is applied than a measure of what would happen were it to be adopted on a wider basis.

7. Water Table Level

Systems with tanks that are installed in or beneath the water table may be more susceptible to corrosion than tanks that are installed above the water table. Based on an analysis of forty tank systems with tanks reported to be installed in or beneath the water table, it is estimated that 47 percent of the tank systems with tanks installed in or beneath the water table are leaking under test conditions. This is a somewhat higher percentage than the national percentage of 35 percent of systems leaking.

8. Surface over the Tank

Tank systems with tanks that are covered by a paved surface might be expected to be more protected than tank systems with tanks that are not covered by pavement. However, 37 percent of the tank systems with tanks covered by paved surfaces were judged to be leaking under test conditions, which is nearly identical to the overall percentage of tank systems that are leaking (35%).

9. Type of Pumping System

Conclusive test results were obtained for 71 tanks with pressure pumping delivery systems. The results of the analysis of these tests are displayed in Table 9-23. Under test conditions, 41 percent of tank systems that include a pressure pumping delivery system are judged to be leaking. This percentage is only slightly higher than the overall percentage (35%) of tank systems that were judged to be leaking.

10. Metered Dispensing Systems

As shown in Table 9-23, based on tests of 351 tank systems, 36 percent of tanks systems with metered dispensing systems are judged to be leaking under test conditions. This percentage is nearly identical to the overall percentage of tanks judged to be leaking.

11. Self-Installed Tanks

Forty-two of the tank systems for which conclusive test results are available were reported to be installed by the establishment itself. The leak status of these self-installed tank systems is displayed in Table 9-23. Among self-installed tank systems, 23 percent were judged to be leaking, which is twelve percentage points lower than the overall percentage of 35 percent.

12. Secondhand Tanks

About 4 percent of the tanks overall were secondhand when installed. Thirteen systems with secondhand tanks were included in the tank testing program and provided conclusive test results, which are displayed in Table 9-23. Based on this small number of conclusive tests, 52 percent of the systems with secondhand tanks were found to be leaking under test conditions.

V. LEAK RATES OF UNDERGROUND MOTOR FUEL STORAGE TANK SYSTEMS

This section provides an analysis of the estimated mean and median leak rates for tank systems that were judged to be leaking under test conditions. Analyses of mean (average) leak rates are based only on those tank system test results which provided valid system leak rates. Tank systems with leak rates that were coded by the test crew as "unquantifiably large" are excluded from the calculations of the mean leak rates. These comprise 20 percent of the tank systems judged to be leaking. The largest quantified leak rate (after adjustment) was 3.04 gallons per hour. Tank systems that were judged to be leaking and have unquantifiably large leaks were included in the analyses to derive the median leak rates, however. The leak rates reported in this section, whether mean or median, are rates in gallons per hour as adjusted to operating pressures. The adjustment procedure is described in detail in Section 8 and Appendix D of this report.

Each table describes in footnotes the set of test results each column is based on. The medians are based on more cases than the means, since the unquantifiably large leaks are included in calculating the median but not in calculating the mean. Further, some tables include results from manifolded systems not

separated for testing, and others, based on characteristics of individual tanks (such as tank age), do not. The total mean and median leak rates are different in these two groups. The overall mean leak rate, based on all quantified tank systems judged to be leaking (118 cases) is 0.32 gallons per hour (0.24-0.39 gallons per hour). The mean for the tests which are of single tanks and associated piping (109 cases) is 0.31 gallons per hour (0.23-0.39 gallons per hour). The median leak rate for all tests (149 cases) is 0.25, while the median for single tank system tests (138 cases) is 0.21.

Mean leak rates for tanks with quantified leak rates are calculated as the weighted arithmetic mean, using sample weights, which allows us to project from the sample to the universe. It is presented as a commonly used and well understood measure of "average" value. However, the mean has two drawbacks which the median does not suffer from: data from unquantifiably large leaks cannot be incorporated in calculating the mean (which biases the mean towards zero); and a single large quantified value can affect the mean greatly (pulling it away from zero), while having no impact on the median. The median is the "middle value" -- i.e., half the values are larger, and half are smaller (including the unquantifiably large leaks at the large end of the scale). It is calculated on an unweighted basis. In a data set with a non-symmetric distribution and significant outliers, the mean and median measure different things, and a discrepancy between them indicates skewness or outliers in the data, which should be kept in mind in undertaking any interpretation.

The overall mean leak rate for tanks leaking under test conditions is 0.32 gallons per hour, and the median leak rate is 0.25 gallons per hour. The distribution of observed leak rates (adjusted to operating conditions) of the 149 tank systems judged

to be leaking is shown below. Note that the intervals are not of equal width.

Interval	Proportion of test results in interval
Up to 0.0549	11%
(0.0550-0.149)	30%
(0.150-0.249)	10%
(0.250-0.349)	5%
(0.350-0.449)	5%
(0.450-0.549)	5%
(0.550-1.49)	10%
Quantified, >1.49	3%
Unquantifiably large	21%

A. Mean and Median Leak Rates within Survey Regions and Establishment Types

Within survey regions, mean leak rates for leaking tank systems ranged from a low of 0.24 gallons per hour for the Northeast survey region to a high of 0.48 gallons per hour for the Central survey region (Table 9-24). The Midwest and Pacific survey regions have the lowest median leak rates (of 0.13 gallons per hour) and the Mountain survey region has the highest median leak rate (0.44 gallons per hour) followed closely by the Central survey region with 0.41 gallons per hour.

Within establishment types, leaking tank systems at government and military establishments, gas stations owned by other companies and large establishments have leak rates that range between 0.24 and 0.26 gallons per hour, which is below the overall average of 0.32 gallons per hour (Table 9-25). Leaking tank systems at gas stations owned by major petroleum companies

Table 9-24. Estimates by survey region mean and median leak rates among tank systems[1,2] judged by be leaking under test conditions (95% confidence bounds in parentheses)

Survey Region	Sample Size (N3)[5]	Mean adjusted[3] leak rate (gph)	Sample size (N4)[5]	Median[4] adjusted leak rate (gph)
1 Northeast	29	0.24 (0.23-0.26)	38	0.22
2 Southeast	28	0.30 (0.17-0.43)	39	0.34
3 Midwest	23	0.32 (0.06-0.57)	26	0.13
4 Central	17	0.48 (0.26-0.71)	22	0.41
5 Mountain	9	0.34 (0.27-0.41)	12	0.44
6 Pacific	12	0.33 (0.02-0.69)	12	0.13
Total	118	0.32 (0.24-0.39)	149	0.25

[1]In this table tank system tests results are reported for single tank systems unless the tanks were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are included in this table.

[2]Does not include farm tanks.

[3]Leak rates of leaking tank systems were adjusted to operating pressure.

[4]Calculation of median adjusted leak rate included tank systems judged to have unquantifiably large leaks.

[5]N3 = Number of tank systems judged to be leaking under tests conditions that had quantifiable leak rates.

N4 = N3 + those tank systems judged to be leaking under test conditions that had unquantifiably large leaks.

Table 9-25. Estimates by establishment type of mean and median leak rates among tank systems [1,2] judged to be leaking under test conditions (95% confidence bounds in parentheses)

Establishment Type	Sample size (N3)[5]	Mean adjusted[3] leak rate (gph)	Sample size (N4)[5]	Median[4] adjusted[3] leak rate (gph)
Government and military	14	0.26 (0.06-0.47)	20	0.27
Gas stations owned by major petroleum companies	18	0.42 (0.18-0.68)	21	0.29
Gas stations owned by other companies	30	0.24 (0.13-0.34)	46	0.28
Other fuel-related establishments	33	0.45 (0.20-0.71)	36	0.32
Large non-fuel related establishments	23	0.25 (0.14-0.36)	26	0.14
Total	118	0.32 (0.24-0.39)	149	0.25

[1]In this table tank system tests results are reported for single tank systems unless the tanks were tested as a part of a manifolded tank system that was not broken apart. These tank systems are included in this table.

[2]Does not include farm tanks.

[3]Leak rates of leaking tank systems were adjusted to operating pressure.

[4]Calculation of median adjusted leak rate includes tank systems judged to have unquantifiably large leaks.

[5]N3 = Number of tank systems judged to be leaking under test conditions that had quantifiable leak rates.

N4 = N3 + those tank systems judged to be leaking under test conditions that had unquantifiably large leaks.

and other fuel-related establishments have mean leak rates that are higher (0.42 and 0.45 gallons per hour respectively) than the overall average. Leaking tank systems at large non-fuel-related establishments have a median leak rate that is lower (at 0.14 gallons per hour) than the overall median rate of 0.25 gallons per hour.

B. Mean and Median Leak Rates for Tank Systems with Selected Characteristics

Tables 9-26 through 9-30 below display analyses of the mean and median leak rates for leaking tank systems with selected characteristics. The characteristics include tank age, tank size, type of product held in the tank, and various installation characteristics.

1. Mean and Median Leak Rates within Tank Age Categories

Table 9-26 shows the mean and median leak rates for the tanks judged to be leaking under test conditions. Leaking tanks that are less than five years old and leaking tanks of unknown age have the highest mean leak rate (0.46 gallons per hour). Leaking tanks that are less than five years old also have the highest median leak rate.

The lowest mean and median leak rates were found among leaking tanks that are five to eight years old and leaking tanks that are more than 20 years old.

Table 9-26. Estimated mean and median leak rates among tank systems[1,2] judged to be leaking under test conditions within tank age categories. (95% confidence bounds in parentheses)

Tank Age Categories	Sample size (N5)[5]	Mean adjusted[3] leak rate (gph)	Sample size (N6)[5]	Median[4] adjusted[3] leak rate (gph)
< 5 years old	**14**	**0.46** (0.20-0.71)	**21**	**0.71**
5-8 years old	**17**	**0.14** (0.09-0.18)	**20**	**0.11**
9-12 years old	**20**	**0.27** (0.12-0.42)	**21**	**0.18**
13-20 years old	**10**	**0.22** (0.10-0.34)	**18**	**0.52**
> 20 years old	**17**	**0.15** (0.11-0.20)	**21**	**0.16**
Age unknown	**30**	**0.46** (0.21-0.71)	**36**	**0.39**
Total	**109**	**0.31** (0.23-0.39)	**138**	**0.21**

[1]In this table tank system test results are reported for single tank systems. Tank systems that were tested as a part of a manifolded tank system that was not broken apart are not included.

[2]Does not include farm tanks.

[3]Leak rates of leaking tank systems were adjusted to operating pressure.

[4]Calculation of median adjusted leak rate includes tank systems judged to have unquantifiably large leaks.

[5]N5 = Number of tank systems judged to be leaking under tests conditions that had quantifiable leak rates.

N6 = N5 + those tank systems judged to be leaking under test conditions that had unquantifiably large leaks.

Table 9-27. Estimated mean and median leak rates among tank sytems [1,2] judged to be leaking under test conditions within tank size categories. (95% confidence bounds in parentheses)

Tank Size Categories	Sample Size (N5)[5]	Mean adjusted[3] leak rate (gph)	Sample size (N6)[5]	Median[4] adjusted[3] leak rate (gph)
≤ 1100 gallons	16	0.14 (0.08-0.21)	21	0.10
1101 to 3999 gallons	13	0.26 (0.09-0.43)	16	0.18
4000 to 4999 gallons	18	0.20 (0.13-0.28)	24	0.21
5000 to 5999 gallons	6	0.15 (0.11-0.18)	10	0.23
6000 to 7999 gallons	10	0.35 (-0.07-0.77)	17	1.24
8000 to 9999 gallons	8	0.53 (0.30-0.76)	12	0.89
10,000 to 11,999 gallons	28	0.30 (0.18-0.43)	28	0.12
≥ 12,000 gallons	10	0.83 (-0.05-1.72)	10	0.37
Total	109	0.31 (0.23-0.39)	138	0.21

[1]In this table tank system test results are reported for single tank systems. Tank systems that were tested as a part of a manifolded tank system that was not broken apart are not included.

[2]Does not include farm tanks.

[3]Leak rates of leaking tank systems were adjusted to operating pressure.

[4]Calculation of median adjusted leak rate includes tank systems judged to have unquantifiably large leaks.

[5]N5 = Number of tank systems judged to be leaking under test conditions that had quantifiable leak rates.

N6 = N5 + those tanks judged to be leaking under test conditions that had unquantifiably/large leak.

Table 9-28. Estimates by fuel types stored during the prior year of the mean and median leak rates among tank systems[1,2] judged to be leaking under test conditions (95% confidence bounds in parentheses)

Fuel types	Sample size[5] (N3)	Mean adjusted[3] leak rate (gph)	Sample size (N4)[5]	Median[4] adjusted[3] leak rate
Leaded gasoline	120	0.22 (0.14-0.31)	24	0.22
Unleaded gasoline	42	0.36 (0.25-0.47)	60	0.49
Diesel fuel	50	0.27 (0.17-0.37)	56	0.14

[1]In this table tank system test results are reported for single tank systems unless the tank systems were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are not included in the table.

[2]Does not include farm tanks.

[3]Leak rates of leaking tank systems were adjusted to operating pressure.

[4]Calculation of median adjusted leak rate includes tank systems judged to have unquantifiably large leaks.

[5]N3 = Number of tank systems judged to be leaking under test conditions that had quantifiable leak rates.

N4 = N3 + those tank systems judged to be leaking under test conditions that had unquantifiably large leaks.

Table 9-29. Estimated mean and median leak rates among tank systems[1,2] judged to be leaking under test conditions for tanks in manifolded systems and single tanks. (95% confidence bounds in parentheses.)

Tank type	Sample Size (N3)[5]	Mean adjusted[3] leak rate (gph)	Sample size (N4)[5]	Median[4] adjusted leak rate (gph)
Single tanks (not manifolded)	93	0.27 (0.20-0.35)	109	0.16
Tanks in manifolded systems	25	0.49 (0.22-0.75)	40	0.71
Total	118	0.32 (0.24-0.39)	149	0.25

[1]In this table tank system test results are reported for single tank systems unless the tanks were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are included in the table.

[2]Does not include farm tanks.

[3]Leak rates of leaking tanks were adjusted to operating pressure.

[4]Calculation of median adjusted leak rate included tank systems judged to have unquantifiably large leaks.

[5]N3 = Number of tank systems judged to be leaking under test conditions that had quantifiable leak rates.

N4 = N3 + those tank systems judged to be leaking under test conditions that had unquantifiably large leaks.

Table 9-30. Estimated mean and median leak rates among tank systems[1,2] judged to be leaking under test conditions for tanks with selected installation characteristics. (95% confidence bounds in parentheses.)

	Sample Size (N5)[5]	Mean adjusted[3] leak rate (gph)	Sample size (N6)[5]	Median[4] adjusted leak rate (gph)
Fiberglass tanks	110	0.42 (0.22-0.61)	10	0.14
Bare (uncoated steel) tanks	8	0.60 (0.12-1.08)	10	0.39
Coated steel tanks	55	0.26 (0.19-0.32)	75	0.23
Tanks installed partially or completely below the water table	16	0.49 (0.09-0.89	19	0.20
Tanks covered by a paved surface	79	0.29 (0.22-0.37)	100	0.20
Tanks connected to a pressure pump delivery system	23	0.25 (0.12-0.39)	29	0.18
Tanks with metered dispensing systems	101	0.32 (0.23-0.40)	129	0.22
Tanks that were self-installed	9	0.26 (-0.05-0.56)	11	0.13
Total	109	0.31 (0.23-0.39)	138	0.21

[1]In this table tank system test results are reported for single tank systems. Tanks that were tested as a part of a manifolded tank system that was not broken apart are not included.

[2]Does not include farm tanks.

[3]Leak rates of leaking tank systems were adjusted to operating pressure.

[4]Calculation of median adjusted leak rate included tank systems judged to have unquantifiably large leaks.

[5]N5 = Number of tank systems judged to be leaking under tests conditions that had quantifiable leak rates.

N6 = N5 + those tank systems judged to be leaking under test conditions that had unquantifiably large leaks.

2. Mean and Median Leak Rates within Tank Size Categories

Table 9-27 shows the mean and median leak rates for eight size categories among tank systems judged to be leaking under test conditions. Systems with tanks that are 12,000 gallons or more in size have the largest mean leak rate (of 0.83 gallons per hour), and systems with tanks in the smallest size category (1100 gallons or less) have both the smallest mean leak rate (0.14 gallons per hour) and the smallest median leak rate (0.10 gallons per hour). The tank size category with the largest median leak rate is the 6000 to 7999 gallon category, where the median was 1.24 gallons per hour, due in large part to the fact that seven of the seventeen tanks tested in this category have unquantifiably large leaks.

3. Mean and Median Leak Rates by Types of Motor Fuel Stored

Table 9-28 shows mean and median leak rates for leaking tanks storing different types of motor fuels. Leaking tank systems that store unleaded gasoline have the highest mean (0.35 gallons per hour) and median (0.49 gallons per hour) leak rates. Leaking tank systems that store leaded gasoline have the lowest mean leak rate (of 0.22 gallons per hour), but leaking diesel tank systems have the lowest median leak rate (of 0.14 gallons per hour).

4. Mean and Median Leak Rates for Manifolded Tank Systems

Table 9-29 shows the mean and median leak rates for leaking tanks that are in single tank systems and those that are in manifolded tank systems. Both the mean and the median leak rates are higher for leaking tank systems that are manifolded. Leaking Tank systems that are manifolded have a mean leak rate of 0.49 gallons per hour (which is nearly 50% higher than the overall mean leak rate of 0.31 gallons per hour) and a median leak rate of 0.71 gallons per hour, which is nearly three times greater than the overall median leak rate of 0.25 gallons per hour.

5. Material of Construction

Table 9-30 shows the mean and median leak rates for leaking tank systems that have tanks which are fiberglass, bare (uncoated) steel, and coated steel. Leaking tank systems with tanks that are bare steel have the highest mean (0.60 gallons per hour) and median (0.39 gallons per hour) leak rates, but the category also has a small sample size. Leaking tank systems with coated steel tanks have the lowest mean leak rate, of 0.25 gallons per hour. Although there are a large number of tank systems with unquantifiably large leaks in this category, the median leak rate is only 0.23 gallons per hour.

6. Water Table Level

The mean leak rate for leaking tank systems installed in or beneath the water table is 0.49 gallons per hour, based on 16

tank systems tested (see Table 9-30). The median leak rate among these tanks is 0.20 gallons per hour.

7. Surface over Tank

As is shown in Table 9-30, the mean and median leak rates for tank systems where the tank is covered by a paved surface is nearly equal to the overall mean and median leak rates.

8. Mean and Median Leak Rates for Tank Systems with Pressure Pump Distribution Systems

Leaking tank systems with pressurized distribution systems have lower mean and median leak rates than leaking tank systems overall, as is shown in Table 9-30. The mean leak rate for tank systems with pressurized distribution systems is 0.25 gallons per hour, and the median is 0.18 gallons per hour.

9. Mean and Median Leak Rates for Tank Systems with Metered Dispensing Systems

Leaking tank systems that have metered dispensing systems have mean and median leak rates that are nearly identical to the overall mean and median leak rates. (See Table 9-30.)

10. Mean and Median Leak Rates for Tank Systems that Were Self-Installed

Table 9-30 shows the mean and median leak rates for leaking tank systems which were installed by the establishment itself. Only a small number of tank systems in this category were tested, in view of which the mean and median rates may be regarded as not substantially different from the overall means and medians.

VI. STATISTICAL ASSOCIATIONS OF LEAK STATUS AND LEAK RATE WITH OTHER VARIABLES

A. Introduction

In this section we present the results of statistical correlations found between leak status and each of 49 possible explanatory variables. Similarly, results are reported for leak rate.

In addition, multivariate and logistic models were developed to identify significant predictor variables. Because these models resulted in rather low predictive power, they are considered preliminary, and further research is required. These models and their development are detailed in Appendix I.

B. Simple Correlations

No single explanatory variable, among the 49 examined, had a strong correlation with either leak status or leak rate -- i.e., no correlation coefficient was larger than .34 (Table 9-31). The

Table 9-31. SIMPLE CORRELATION OF LEAK STATUS AND LEAK RATE WITH EXPLANATORY VARIABLES

Explanatory Variable	Meaning	Definition	Correlation[1] with Y1, Leak status (1 = Leak; 0 = No Leak)	Correlation[1] with Y2, Leak rate (gal/Hr), among leaking tanks[2]
X1	Gas Station	1 = Yes; 0 = No	-.08	-.06
X2	# Underground tanks	Number at facility	.12	.10
X3	Tank capacity	Gallons	.14	.34
X4	Average low fill level[3]	As fraction of tank capacity	-.05	-.07
$X5^2$	$(\text{Age of tank})^2$	in $(\text{years})^2$	.11	-.20
X6	Leaded gasoline	1 = yes; 0 = No	-.26	-.11
X7	Diesel fuel	1 = Yes; 0 = No	.24	-.08
X8	Aviation fuel	1 = Yes; 0 = No	.13	.07
X9	Gasohol	1 = Yes; 0 = No	-.07	0
X10	Other	1 = Yes; 0 = No	.08	.29
X11	Suction pump	1 = Yes; 0 = No	.003	-.12
X12	Depth buried	Inches from surface to top of tank	.10	-.006
X13	Water level	Inches from surface to water table[4]	-.15	-.005
X15	Tank tested	1 if tested after placed in service; 0 otherwise	.03	.01
X16	Years since test	Since most recent test	.06	-.21
X17	Tank material	1 = steel; 0 = fiberglass	.02	-.09
X18	Tank lined	1 = Yes; 0 = No	.07	.02
X19	Tank coated	1 = Yes; 0 = No	-.01	-.25
X20	Passive cathodic protection	1 = Yes; 0 = No	.10	.05
X21	Impressed current cath. protection	1 = Yes; 0 = No	0	0
X23	Other protection	1 = yes; 0 = No	-.08	0
X24	Previous tank leak	1 = Yes; 0 = No	-.05	-.04
X25	Previous line leak	1 = Yes; 0 = No	.05	.23
X26	Frequency of delivers	Number per year	-.05	-.003
X27	Sand fill	1 = Yes; 0 = No	.03	-.10
X28	Gravel fill	1 = Yes; 0 = No	.006	.16
X29	Concrete pad	1 = Yes; 0 = No	.07	-.09
X30	Packed earth pad	1 = Yes; 0 = No	.03	-.09
X31	Dist. to nearest tank or structure	(feet)	-.04	-.09

[1]Pearson's correlation coefficient; Kendall's Tau-B was also calculated for all Y1 correlations and found to be the same for nearly every variable.

[2]Using data only from individual leaking tanks with quantifiable leaks.

[3]*I.e., just before product is added.*

[4]At time of test.

Table 9-31. SIMPLE CORRELATION OF LEAK STATUS AND LEAK RATE WITH EXPLANATORY VARIABLES (Continued)

Explanatory Variable	Meaning	Definition	Correlation(1) with Y1, Leak status (1 = Leak; 0 = No Leak)	Correlation(1) with Y2, Leak rate (gal/Hr), among leaking tanks(2)
X32	Interaction: age & material	(X5) (1-X17)	-.03	-.07
X33	Interaction: gasohol & material	X9 (1-X17)	0	0
X34	Permit to install	1 = Yes; 0 = No	.12	.17
X35	Permit to store	1 = Yes; 0 = No	.02	.09
X36	Average high fill level(6)	As fraction of tank capacity	-.06	-.09
XT3	Average fuel delivery	in gallons (to one tank)	.15	.23
XT4	Max. ever stored	gallons	.11	.29
XT18A	Attached to other tank	1 = Yes; 0 = No	.22	.24
XT19	Tank proximity to water table	1 = above; 2 = partially above; 3 = below; 4 = other	.13	.28
XT20	Manway with tank	1 = Yes; 0 = No	.19	.13
XT36	Not self-installed	1 = Yes; 0 = No	.12	.12
XB5	Remote gauge	1 = Yes; 0 = No	-.005	.05
XB19	Log of deliveries	1 = Yes; 0 = No	-.03	.002
XC7	Any abandoned tank(5)	1 = Yes; 0 = No	-.03	.03
XC8	# Abandoned tanks	(coded as zero if none)	.12	-.09
XF1A	Corrosion prevention equip./ mat.	1 = Yes; 0 = No	-.02	-.12
XG2D	Trained to check pump	1 = Yes; 0 = No	.14	.24
XG2E	Trained to check line leaks	1 = Yes; 0 = No	.10	.18
XG2F	Trained to check leak prevention	1 = Yes; 0 = No	.10	.15
XG2G	Trained to check leak monitoring	1 = Yes; 0 = No	.15	.17

[5] At that facility.

[6] I.e., Just after product is delivered.

highest correlations with "leak status" (i.e., whether or not a tank is leaking) were found with the following variables:

Variable	Correlation Coefficient
Leaded gas	-0.26
Diesel fuel	+0.24
Tank manifolded	+0.22
Tank has manway	+0.19

Among leaking tank systems, the leak rate had stronger correlations. Eleven variables had a correlation coefficient larger than .20, as shown below:

Variable	Correlation Coefficient
Tank capacity	+0.34
Maximum ever stored	+0.29
Other fuel type	+0.29
Proximity to water table	+0.28
Tank coated	-0.25
Attached to other tank	+0.24
Trained to check pump	+0.24
Previous line leak	+0.23
Average fuel delivery (gal.)	+0.23
Years since tested	-0.21
$(\text{Age of tank})^2$	-0.20

The last variable in the list above is "age squared." It was used rather than "age" because of the non-linear relationship suggested by the plotted data. The sample size for most of these correlation coefficients is about 380. Due to missing data, some sample sizes are smaller, but all had a sample of 200 or more except X13 (N = 89), X16 (N = 72), and X18 (N = 173). Correlations with leak rate were calculated using all tanks that

were tested for leaks. Somewhat different correlations might be found if only leaking tanks were included.

While this represents a considerable number of variables with non-trivial correlations with leak status and leak rate, none of the correlations would be considered strong and, therefore, no single variable will have a strong predictive ability.

Some variables of possible interest, such as soil characteristics, were not included because they were not collected in this study. However, data were included on the back fill material where used (sand, gravel, etc.).

C. Multiple Regression and Logistic Models

Multivariate models were developed to explain leak status and leak rate in terms of various predictor variables. Although some statistically significant relationships were found, the overall predictive ability of the models was low. The models could account for only 8 percent of the variance in leak status and 20 percent of the variance in leak rate. Therefore, further research in this area is still required. Appendix I describes the model development method and specifies which variables were statistically significant. Logistic and regression models identified several of the same variables as significant.

SECTION 10

INVENTORY RECONCILIATION TECHNIQUES

I. INTRODUCTION

Analysis of properly collected motor fuel inventory data offers the potential for an inexpensive, readily available approach to detecting tank-product losses, including those resulting from leaking tanks and piping. Inventory data is collected typically at the close of each day of operation by the tank establishment operator, records (1) volume of fuel in each tank as measured by metering stick or gauge, (2) delivery volumes, and (3) dispensing meter readings. From these measurements, the volume of fuel metered through a tank system's dispensers is reconciled with the physical measurement (based on stick readings and delivery volumes) of product gone from the tank.

Rarely are these two measurements of volume of daily through-put (physical versus dispensing meter) numerically equal, even when there has been no loss of product. Rather, they will show some variance either as an "overage" (a numerical excess of product in the tank) or an "underage" (a numerical loss of product). Some part of the daily variance will be due to random errors of measurement; however, inaccurate gauging and metering devices add to the variance, as do temperature-induced product shrinkage and expansion, vapor loss, theft, and leakage of product from (or of water into) the system. To further complicate interpretation of inventory reconciliation data, several of the above factors may contribute both to overages and underages.

There are currently available several commercially developed computerized models which can be used to identify and quantify factors contributing to daily inventory variances. These models are proprietary and, in any case, are much too sophisticated to be implemented and interpreted by a typical tank owner or operator. To monitor inventory using these models, a tank owner must contract for the services of one of the firms which has developed such a model. To provide tank owners and operators with a simple, inexpensive procedure for monitoring inventory, EPA has developed a procedure based on counts of the number of negative daily variances (underages) in successive monthly periods.[1] Because of its simplicity, the EPA method would not be expected to be as accurate as the more sophisticated modeling techniques. Tank tightness test data and inventory reconciliation data collected during two phases of the National Survey of Underground Motor Fuel Storage Tanks make possible a determination of the extent of agreement between tank tightness tests and the various methods of inventory reconciliation analysis, as well as the extent of agreement among the latter.

At the time the inventory analysis was conducted, the survey had provided complete, properly-collected inventory data on 855 tank systems. While this represents only the first portion of the inventory returns, the inventory data collection and editing effort resulted in 41 percent of the attempted cases providing usable data. Of these 855 tank systems, 511 were analyzed using the inventory reconciliation model developed by Warren Rogers

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[1]USEPA, Office of Toxic Substances, "More about Leaking Underground Storage Tanks: a Background Booklet for the Chemical Advisory," (October 1984).

Associates.[2] In addition, in a smaller study, 18 tank systems were analyzed by Entropy Limited.[3] Tightness test results were available for 189 of the 855 tanks for which usable inventory data was available. The EPA inventory analysis method was applicable, in modified form, to all 855 tanks; modification was required since the EPA method was intended for application to on-going monitoring programs and not to a single set of one-time inventory data.[4]

The present section provides an analysis of the extent of agreement of the above inventory reconciliation methods with one another and with tightness-test results, based on data collected in the survey. In addition, we report the results of a small quality control study in which the various inventory approaches were applied to a simulated set of inventory data for five tanks. Mathematical techniques were used to simulate various combinations of stick error, leakage and theft for the five tanks. The results of the inventory analyses were then compared with the true condition of the hypothetical tanks which in this case, of course, was known exactly.

II. METHODS AND DATA

The survey protocol called for the collection of 30 days of inventory data on each tank or manifolded tank system at the

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[2]Warren Rogers Associates, Inc., "Inventory Reconciliation System," (undated)

[3]Entropy Limited, "Precision Tank Inventory Control," (1984).

[4]USEPA, Office of Toxic Substances, "More about Leaking Underground Storage Tanks: a Background Booklet for the Chemical Advisory," (October 1984).

sampled establishments. Many respondents were unable to supply proper inventory data (see Appendix B for details), with the result that complete, usable data was obtained for only 855 tanks or manifolded tank systems. Of these tanks, 511 were analyzed by Warren Rogers Associates (WRA). Eighteen of the 511 tanks were also analyzed by Entropy Limited (EL). Of the 439 tank systems in the tightness test (TT) sample, 189 had usable inventory data. Table 10-1 shows the available sample sizes for all possible pairwise comparisons between methods.

Table 10-1. Sample sizes for pairwise comparisons between methods

	EPA	WRA	EL	TT
EPA	855	511	18	189
WRA		511	17	106
EL			18	17
TT				439

The EPA-developed inventory analysis method is based on a simple count of the number of days for which the inventory reconciliation shows a negative variance, i.e., a numerical loss of product. An excess of days with negative variance over those with positive (or zero) variance may, under certain circumstances, be interpreted as a loss of product due to leakage or some other cause. The EPA method was developed and calibrated for application to an on-going monitoring program, in which cumulative month-by-month counts of negative variances would be compared with statistically-derived "action numbers" to determine whether there was evidence of a systematic deficit in inventory. Calculations indicated that the method would be effective in

detecting even relatively small leaks over a sufficiently long period of monitoring, at least when reasonably good inventory records were kept.[5] The method was not intended for application to a one-time collection of 30 days inventory and, indeed, would not be expected to detect smaller leaks based on such a small data set. For the present comparisons, the method was modified and the following decision rule adopted: A tank system is declared leaking if the 30-day record exhibits 18 or more negative daily variances. Calculations detailed in Appendix E, indicate that this rule has approximately a five percent false-positive (or "false alarm") rate. That is, there is a five percent chance that a tank system which is not leaking and whose inventory record is subject only to random stick measurement error, would be declared leaking. This is consistent with the definition of a leak adopted for the tightness test procedure, see Section 8. However, the modified EPA inventory analysis method has significantly poorer detection capability than tightness testing, even in optimistic scenarios where the inventory record is subject only to stick measurement error and not to other sources of discrepancy, such as delivery errors. For example, the chance of detecting a leak of 0.1 gallons per hour (2.4 gallons per day) in a typical tank is approximately 17 percent, as opposed to 95 percent for tightness testing. A detection capability of 80 percent or greater was obtained using the EPA method for leaks in excess of 0.37 gallons per hour (8.9 gallons per day). By substantially increasing the number of days of inventory data, an 80 percent detection capability would be possible for smaller leaks.

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[5] David C. Cox, "Performance of the Chemical Advisory Inventory Analysis Method Under Various Scenarios," Report from Battelle Columbus Laboratories to EPA under Contract No. 68-01-6721 (April 1984)

Both the WRA and EL procedures are proprietary, so that details of the methodology and decision rules are available only in sketchy form. A description of the methods, based on literature provided by their developers, is given in Appendix E. The literature mentioned is partly promotional in nature. Claims made therein have not been investigated or verified by EPA, except to the extent reported here, so that no endorsement of the methods should be inferred. In order to place the WRA and EL methods on the same footing as the EPA and tightness test approaches, it is important that the false positive rate of the WRA and EL methods also be five percent. According to the developers of these methods, the inventory analysis results they have provided meet this requirement.

The WRA, EL and tightness test methods occasionally fail to produce a definite conclusion as to whether a tank system is leaking or not leaking. This occurs for the inventory methods whenever the data is excessively noisy due, for example, to large stick errors or very frequent deliveries. For tightness tests, various physical problems may lead to an indeterminate test result (see Section 8.) Table 10-2 presents a breakdown of the results for each method. It is reasonable that the tightness test procedure reports the largest percent leaking; this method should have the best detection capability. Likewise, the EPA procedure should have the lowest percent leaking, as it does. In the next section, we examine agreement between the methods, i.e., the extent to which they agree, not just on percent leaking but on <u>which</u> tank systems are leaking and which are not leaking.

Table 10-2. Number and percent of tank systems judged to be leaking, judged not to be leaking, and providing inconclusive results for inventory methods and tightness testing

Method	Sample Size	Tank Systems Judged to be Leaking		Tank Systems Judged to be Tight		Tank Systems with Inconclusive Results	
		Number	Percent[1]	Number	Percent[1]	Number	Percent[1]
TT	439	152	35%	259	59%	28	6%
EPA	855	149	17%	706	83%	0	0%
WRA	511	160	31%	294	58%	57	11%
EL	18	4	22%	11	61%	3	17%

[1]May differ from national estimates because survey sampling weights are not considered here.

III. COMPARISON OF METHODS

In comparing two methods of deciding whether or not a tank system is leaking, one cannot focus simply on the degree of agreement between the predictions of the methods. To see why, consider two methods which give a correct prediction in 70 percent of cases. If the methods were completely independent, one would expect them to agree in 49 percent of cases, according to the rules of probability. This 49 percent represents the degree of agreement expected purely by chance and not due to any tendency for the methods to act in the same direction. In this example, agreement in significantly more than 49 percent of cases is required before one can conclude that the methods really are in substantial agreement. In this section, a statistic, K, is used to measure the agreement between methods above and beyond what is expected by chance.[6] The value K = 0 corresponds to purely chance agreement, while K = 1 means perfect agreement. Values of K between 0 and 1 may be interpreted on an ordinal scale, i.e., the larger K is, the better the agreement. Quantitative interpretation of K is more elusive, e.g., it is difficult to determine just how much agreement is represented by a value of, say, K = 0.5.

For each pairwise comparison between methods considered, we carry out a statistical test to determine whether there is sufficient evidence to conclude that K is positive, i.e., that there is more than chance agreement between the methods. In performing this test we have ignored inconclusive results for the various methods. We have also treated the data as if it were generated by a simple random sample of tank system, ignoring the

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[6]Yvonne M. M. Bishop, Stephen E. Fienberg and Paul W. Holland, "Discrete Multivariate Analysis: Theory and Practice," MIT Press, Cambridge, MA (1975)

survey sample weights. Tables 10-3 through 10-5 present comparisons between the tightness test, WRA and EPA.

The two inventory methods show agreement with each other beyond what one would expect by chance alone. However, each inventory method exhibits only chance agreement with tightness test results. This conclusion should be regarded as tentative since the sample sizes for even the overall inventory -- tightness testing comparisons reported here are not very large. More detailed analyses of the agreement between the methods would not be statistically meaningful. It is, however, worth pointing out that the agreement does not appear to be improved even if we restrict attention to large leaks (as measured by tightness testing). For example, consider quantifiable leaks exceeding 4 gallons per day. The EPA procedure found 6 out of 23 (26%), for which a comparison was possible, to be leakers; WRA found 4 out of 7 (57%) leaking.

Statistically meaningful comparisons with the EL results are not possible because of the very small number of tanks evaluated by Entropy. However, the data confirm the above two findings in a general way. Inventory methods agree with one another but not with tightness test results. The extent to which inventory and tightness testing may be measuring differing phenomena, as is suggested by these results, is not clear. It is possible that certain measured leaks may not represent operational leaks. For example, leaks at the very top of the tank would occur in a tightness test, but might not occur in practice if the tank were never filled to the top. Likewise, a phenomenon such as theft may be reported as a leak by the inventory methods while the tank system tests tight. The resolution of this question will require more detailed analyses of the survey data and, possibly, collection of longer series (more than 30 days) of inventory data.

Table 10-3. Comparison of EPA Inventory Reconciliation Method with Warren Rogers Associates Inventory Reconciliation Method

		WRA		
		Number of tank systems judged to be leaking	Number of tank systems judged to be tight	Inconclusive
EPA	Number of tank systems judged to be leaking	61	19	10
	Number of tank systems judged to be tight	99	275	47

Percent agreement = 74%

K = 0.36 (STATISTICALLY SIGNIFICANT)

Table 10-4. Comparison of EPA Inventory Reconciliation Method with Tightness Testing

		TT		
		Number of tank systems judged to be leaking	Number of tank systems judged to be tight	Inconclusive
EPA	Number of tank systems judged to be leaking	13	22	1
	Number of tank systems judged to be tight	37	102	14

Percent agreement = 66%

K = 0.09 (NOT STATISTICALLY SIGNIFICANT)

Table 10-5. Comparison of Warren Rogers Associates Inventory Reconciliation Method with Tightness Testing

		TT		
		Number of tank systems judged to be leaking	Number of tank systems judged to be tight	Inconclusive
WRA	Number of tank systems judged to be leaking	9	28	0
	Number of tank systems judged to be tight	11	38	5
	Inconclusive	5	8	2

Percent agreement = 55%

K = 0.02 (NOT STATISTICALLY SIGNIFICANT)

IV. QUALITY CONTROL SAMPLES

A limited quality-control study of the 3 inventory reconciliation methods was conducted in order to compare performance on a data set for which the true leak status could be unequivocally determined. Inventory data for a total of 5 tanks at 2 sites was generated using mathematical techniques to simulate various combinations of stick error, leakage and theft. To maximize realism, actual tank conversion charts were used to simulate the effect of random measurement error due to sticking the tank. The simulated data was provided blind to WRA and EL. Table 10-6 shows the scenarios simulated. Table 10-7 shows the results of the inventory analyses. In addition to EPA, WRA and EL, we have added a simple t-test. The test is a standard t-test with 29 degrees of freedom based on the 30 daily variances in the inventory record. For consistency with the other inventory methods, the false positive rate of the test is set at 5 percent.

Site 1 represents clean inventory data. There is no noise in the record other than random measurement error due to sticking the tank. The EPA method and the t-test correctly predicted leak status for both tanks. WRA detected the leak but also classified the non-leaker as a leaker. EL correctely classified the non-leaker but reported the leaker as inconclusive (accurately estimating the true leak rate, however).

Site 2 represent a more difficult test of the inventory methods. Stick measurement error is unusually large. Moreover, both the random pattern of theft in tank 2 and the relatively small leak (3 gallons per day) in tank 3 would be expected to be difficult to detect by any inventory method based on only 30

Table 10-6. Simulated quality control inventory data

Site 1

Tank	Size	Product	Description
1	10,000	Reg. unleaded	5 gals/day leak
2	10,000	Reg. leaded	No leak, stick error only

Readings to nearest 1/2" on dipstick -- typical random measurement error of 14-19 gallons

Site 2

Tank	Size	Product	Description
1	6,000	Reg. leaded	Stick error only
2	6,000	Prem. unleaded	Theft 15-20 gallons on 9 days
3	10,000	Reg. unleaded	Leak, 3 gals/day

Readings to nearest 1" on dipstick -- typical random measurement error is 20-25 gallons for 6,000 gallon tanks, 35-40 gals for the 10,000 gallon tank

Table 10-7. Inventory analysis of quality control samples

			EPA		WRA			EL			t-TEST	
Site	Tank	True Status	LS	NEG	LS	LR	Comments	LS	LR	Comments	LS	LR
1	1	L - 5 gals/day σ = 17 gals	L	19	L	8.4	Delivery discrepancies (2), Unexplained gains or losses (4), Large stick errors (1).	?	4.6	Thermal shrinkage, vapor loss reported	L	6.6
1	2	NL - Stick error only σ = 17 gals	NL	15	L	2.8	Delivery discrepancies (2), Large stick errors (2)	NL	-	Thermal shrinkage, vapor loss reported	NL	-
2	1	NL - Stick error only σ = 22 gals	L	18	L	11.1	Unexplained gains and losses (3), Large stick errors (1). Average stick error low.				NL	-
2	2	NL - Theft on 9 days/30, approx. 17 gals σ = 22 gals	L	19	L	10.3	Unexplained gains and losses (6). Average stick error low.				L	10.0
2	3	L - 3 gals/day σ = 40 gals	NL	13	NL	-	Unexplained gains and losses (1). Data quality code = 2, meaning results explained by frequent deliveries??				NL	-

Legend: LS = Leak status
LR = Leak rate
L = Leak
NL = No leak
NEG = Number of negative daily variances
? = Inconclusive
σ = Standard deviation of stick measurement error

days' data. (The change of detecting the 3 gallons per day leak using the EPA method is only about 10%.) Both EPA and WRA predicted that the tight tank was leaking and that the leaker was not; both found the theft case to be a leak, thus successfully detecting the negative trend in the inventory, although attributing it to the wrong cause. The t-test correctly evaluated the non-leaker but also got the other two tanks wrong. A surprising feature of both sophisticated methods (WRA and EL) was a tendency to find effects in the data which were not in fact present. Thus WRA found numerous unexplained gains and losses, delivery discrepancies and large stick errors, while EL found theoretical shrinkage and vapor loss. These spurious findings apparently tended to obscure the true status of the tank systems. It should be pointed out, of course, that a method of analysis tailored to perform well on real-world, noisy data will of necessity be less than optimal for unusually clean data such as we have here. Moreover, the simulated data does not reflect the effects of factors such as location and time-of-year that may be very important to account for in real data analysis. The results reported here must be interpreted in this light.

V. CONCLUSIONS

We have compared a number of inventory reconciliation techniques, with each other and with the results of tank tightness tests, using data from the survey, as well as a small set of simulated inventory records. The sample sizes, especially for inventory vs. tightness test comparisons, were somewhat small. Finally, the data were analyzed as if they were generated by a simple random sampling technique, rather than the sampling procedures actually used in the survey. Thus, the conclusions reported here

are tentative and require confirmation by further research. The major conclusions are:

- Results of inventory analysis methods and tightness tests exhibited only chance agreement;
- Inventory analysis methods agreed among themselves more than would be expected by chance; and
- On simulated data, all inventory methods were comparable in predictive power. However, the more sophisticated methods may have some tendency to "detect" noise in the data from effects that are not, in fact, present.

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16. Abstract (Limit: 200 words)

A nationally representative sample of 2,812 establishments were interviewed to determine the presence of underground motor fuel storage tanks. This sample represented establishments in fuel-related industries (1,612), large establishments in all other industries (600), and farms (600). A total of 890 of these establishments were found to have a total of 2,445 underground motor fuel storage tanks. Only 19 farms with 34 tanks were found. The following national estimates were made: there are 796,000 underground motor fuel storage tanks at 326,000 establishments in the Unisted States -- 158,000 of these are on 79,000 farms. A subsample of 218 establishments was selected for tank tightness testing, using a modification of a commercially available test. The method over-filled the tank system into a standpipe, and thus detected leakage anywhere in the system of tank vessel, pipes, lines, joints, and fittings. Among the non-farm establishments tested, the following estimates were made: 35 percent (189,000) of tank systems were judged to be leaking under test conditions; the average leak rate of those systems with quantifiable leak rate, adjusted for test pressure, was 0.32 gallons per hour; half the leaks among all systems judged to be leaking were 0.25 gallons per hour or less.

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