Field Evaluation Study of Automatic Tank Gauging Systems, Electronic Line Leak Detection Systems, and Mechanical Line Leak Detectors

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PREFACE

This report was produced by Ken Wilcox Associates under contract to the California State Water Resources Control Board, agreement Number 00-240-550-0. Jeff Wilcox conducted the field work and drafted the final report, Dr. J. D. Flora provided the statistical analyses of the data, and Ken Wilcox and Marcel Moreau provided project oversight and review of the final report.

Ken Wilcox Associates wishes to thank Shahla Farahnak and Erin Ragazzi of the SWRCB for their significant contributions toward fostering development of this project. Several SWRCB staff also contributed substantially in the preparation of the final report. These include Scott Bacon, Laura Chaddock, and Donielle Jackson.

Ken Wilcox Associates wishes to thank the following for providing invaluable assistance in the completion of this project:

- Local Agency inspectors who helped locate facilities for inclusion in this study.
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EXECUTIVE SUMMARY

Beginning in 2002, the State Water Resources Control Board (State Water Board) staff conducted a comprehensive evaluation of the effectiveness of underground storage tank (UST) and piping systems, and associated leak detection equipment. The evaluation includes: a field-based research project to determine the frequency and source of releases from single and double-walled UST systems (May 2002), a field evaluation of leak detection sensors (August 2002), and this field evaluation of automatic tank gauges (ATGs) and line leak detectors (LLDs).

California's UST population of approximately 41,000 tanks currently consists of roughly 11% single-walled systems, most of which rely on ATGs and LLDs as the primary means of leak detection in tanks and piping respectively. There are two primary types of LLDs: mechanical line leak detectors (MLLDs) and electronic line leak detectors (ELLDs). This study was conducted to:

- Determine the effectiveness of ATGs, ELLDs, and MLLDs in detecting leaks,
- Compare field performance of ATGS and LLDs with the results of third-party evaluations conducted in a controlled setting,
- Observe and assess field testing procedures used by service technicians during the annual monitoring equipment certification that is required by California law,
- Recommend ways of improving the operational effectiveness of ATGs and LLDs.

Both Federal and California regulations require that LLDs undergo functional testing on an annual basis. LLD functional testing is typically done at the 3-gal/hr level in California, although many ELLDs are capable of detecting leaks of 0.2-gal/hr and 0.1-gal/hr. Neither Federal nor California regulations require annual testing of ATGs using simulated leaks.

General Findings

- ATGs and LLDs detected leaks in a majority of the facilities tested, although the overall leak detection performance of the ATGs and LLDs was somewhat less than the federal Environmental Protection Agency (EPA) requirement of 95% probability of detection.
- Missed detections varied depending on the type of equipment being tested. Problems observed in this field evaluation included improper installation and programming of equipment, poor or infrequent testing of equipment, tampering with monitoring equipment, and interference of UST components with leak detection equipment.
- The observed probability of false alarms for ATGs and LLDs was better (less) than the federal EPA's requirement of 5%.
- Annual testing of monitoring equipment was beneficial to maintaining effective leak detection, but regulations for testing leak detection equipment are ambiguous and there is a lack of standardization in functional test procedures.

Findings for ATGs

The probability of false alarm was estimated at zero percent, less (better) than specified in the EPA performance requirements. The overall probability of detection of a leak of 0.20-gal/hr was estimated as 86%, somewhat less than the 95% prescribed by the EPA performance standards. The probability of detection was significantly associated with the product in the tank, the material or type of construction of the tank, and the size of the tank. The probability of detection was 95% for tanks of 8,000 gallons and less, 84% for tanks from 8,000 gallons to 25,000 gallons, and was only 63% for tanks of 26,000 gallons up to 50,000 gallons. Older ATGs had a lower probability of detection than newer ones, but the difference was not statistically significant.

Findings for MLLDs

The estimated probability of false alarm for MLLDs was zero, less (better) than specified by the EPA performance standards. The overall probability of detection of a 3-gal/hr leak rate was estimated as 63%, but 76% of the MLLDs detected a leak rate of 5-gal/hr, and 88% detected leak rates up to 10-gal/hr. There was little information about the age of the MLLDs, but among those whose age could be determined, the older ones had a significantly lower detection rate for 3-gal/hr, but were about the same as the newer ones at 5-gal/hr. This suggests that either the older units were not calibrated as well, or that their detection level decreases with age if they are not recalibrated frequently.

Findings for ELLDs

The estimated probability of detection for ELLDs was 71% at the 3-gal/hr level and 76% at the 5-gal/hr level. A specific problem was identified when a Veeder-Root ELLD was used with a F.E.Petro turbine, leading to a failure of the ELLD to detect the 3-gal/hr leak rate. A maintenance bulletin had been issued earlier pertaining to this issue, but evidently it had not been implemented fully. With this corrected, the probability of detection of 3-gal/hr should increase substantially.

The overall probability of detection was estimated to be 80% for the 0.1-gal/hr leak rate. The overall probability of detection at the 0.2-gal/hr leak rate was estimated to be 70%. Nearly all of the missed detections were traced to an improper installation. Among those ELLDs that were correctly installed, the probability of detection was 96%.

The probability of detection was significantly associated with product, as the detection of leaks of diesel was significantly lower. The relatively small number of tests with diesel product, however, indicate that caution should be taken when interpreting the data.

The probability of detection was also significantly associated with type of line, in that flexible lines had a significantly lower probability of detection.

Recommendations

Based on the findings of this evaluation, Ken Wilcox Associates proposes the following recommendations to improve ATG and LLD leak detection performance and to improve the functional testing of ATGs and LLDs during annual inspections.

1. Periodic functional testing of leak detection equipment during annual monitoring inspections is important to effective and reliable leak detection.
2. Continue to require LLD functional testing during annual monitoring inspections, but more clearly outline the testing requirements. Current functional testing is done at the 3-gal/h level or greater depending on the LLD manufacturer's recommendations. Specific leak simulation rates and testing procedures should be defined in California regulations for all LLDs.
3. Clearly define a position on functional testing of ATGs. ATG functional testing could be improved by outlining specific testing procedures.
4. Clearly define a position on functional testing of ELLDs at the 0.2-gal/hr and 0.1-gal/hr levels.
5. Work with leak detection equipment manufacturers to establish guidelines for equipment used to simulate leaks.
6. Work with OSHA and the Office of the State Fire Marshall to establish minimum safety guidelines for leak simulation fittings.
7. The State Water Board should work with leak detection equipment manufacturers to promote manufacturer's training courses that include hands-on use of leak simulation equipment, an understanding of what constitutes a leak, and an ability to test several types of leak detectors that are functionally different.
8. The State Water Board and leak detection equipment manufacturers should aid local regulators in improving their understanding of what constitutes effective testing of leak detection equipment by training regulators on the content of the guidelines recommended above.

INTRODUCTION

Although secondary containment has been required for most UST systems installed in California since January 1, 1984[1], many older single-walled UST systems remain in service throughout the State. A 2006 State Water Board survey of local regulatory agencies found that approximately 11% of California 41,000 UST systems have a single-walled tank and/or single-walled piping. The vast majority of these single-walled UST systems use automatic tank gauges (ATGs) and line leak detectors (LLDs) as their primary means of leak detection. For these UST systems, the performance of ATGs and LLDs is a critical factor in the early detection of releases of hazardous substances into the environment.

Federal and California regulations require all methods of leak detection be third-party certified prior to their use for meeting leak detection compliance requirements.[2] A majority of third-party evaluations are conducted in a laboratory under controlled conditions using EPA evaluation procedures.[3] While the controlled conditions allow evaluators to create an environment that is more difficult for ATGs and LLDs to conduct leak tests than would normally be present, with laboratory testing, it is not possible to test for all of the variables that might be encountered in the field.

California regulations require that all UST monitoring equipment be tested and certified annually by a qualified technician.[4] Testing and certification are often witnessed by an inspector from one of the 104 local government agencies throughout the state that implement the UST regulations. Most annual inspections include testing LLDs for their ability to detect leaks of 3-gal/hr or larger. ATGs are not normally functionally tested and LLDs are not tested at the 0.2-gal/hr or 0.1-gal/hr level.

Because of the reliance on ATGs and LLDs by a significant percentage of California's UST population, a study was conducted to evaluate ATG and LLD functionality, check the adequacy of field-testing procedures, and determine if ATGs and LLDs perform consistently with the performance estimated in their third-party certifications. The State Water Board contracted with Ken Wilcox Associates (KWA) to conduct the field-study, which involved simulating leaks in operating USTs and pipelines to determine the effectiveness of ATGs and LLDs. Since much of the study was conducted during annual monitoring inspections, it was also possible to check the adequacy of the field-testing procedures used by technicians.

The field study was conducted between March 2002 and July 2003. Data was collected from 106 facilities. A total of 104 ATG tests, 177 ELLD tests, and 82 MLLD tests were performed. Testing was done at facilities where the equipment was already present and in use by the tank owner/operators. A variety of types of facilities were included in the study, including gas stations owned by independent owners and major oil companies, fleet-fueling facilities, emergency generator facilities, an airport, and military fueling facilities.

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[1] California Health and Safety Code, Chapter 6.7, Section 25291(a).

[2] 40CFR Part 280, Subpart D, and California Code of Regulations, Title 23, section 2643.

[3] "Standard Test Procedures for Evaluating Leak Detection Methods," EPA/530 UST-90/001-7, March to October 1990. Seven different procedures were developed for different leak detection methods and released between March and October 1990.

[4] California Code of Regulations, Title 23, Section 2638.

1.0 SCOPE OF WORK

1.1 Objectives of the Field-Study

The purpose of this study was to determine the performance of Automatic Tank Gauging Systems (ATGs) and Line Leak Detectors (LLDs) operating in real world environments. ATGs and LLDs undergo third-party certification testing under controlled conditions to determine if they can meet the performance requirements specified by the U.S. EPA. This study involved simulating leaks in operating USTs and pipelines in the same way that leaks are simulated for third-party certification testing. The study attempts to answer the following questions:

- Are leaks of the size specified in regulations being detected at the required rates?
- Is equipment performance consistent with third-party evaluations?
- Why does equipment fail to detect leaks?
- What can be done to improve the field performance of leak detection equipment?

During the study, the following additional questions were raised:

- Are appropriate procedures and equipment being used by technicians to conduct annual testing of leak detection equipment?
- Are the training and/or certification requirements adequate for technicians who test leak detectors as part of California annual monitoring inspections?
- Do regulators at state or local levels have an adequate understanding of leak detection equipment and field-testing procedures?
- Are procedures in place to minimize the safety hazards associated with testing leak detection equipment, particularly on pressurized pipelines containing gasoline?

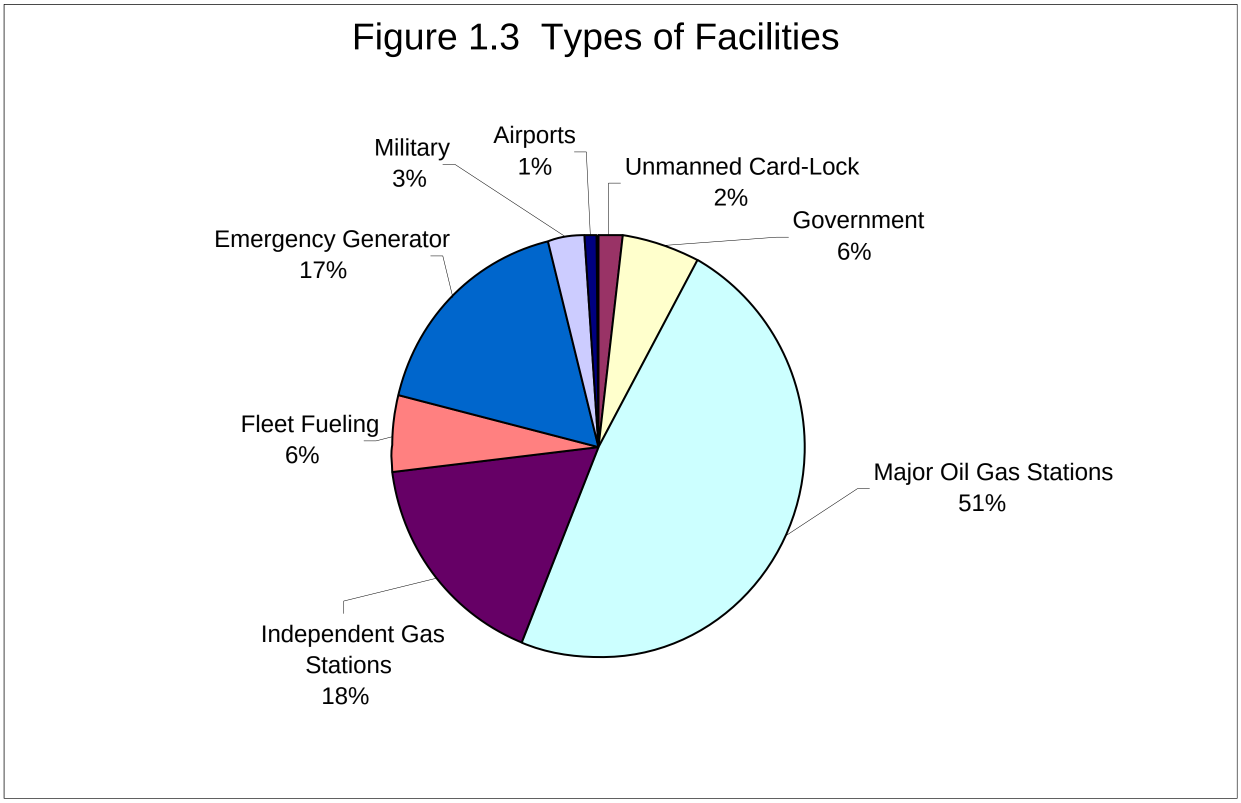
This report attempts to answer or make recommendations to all of the questions listed above.

1.2 Facility Selection Process

Originally, the main criterion in selecting facilities was the type of leak detection equipment present at the facility. One goal of the study was to include as wide a variety of makes and models of leak detection equipment as possible. Limited access to UST facilities, however, did somewhat restrict the variety of equipment included in the study. Access to facilities was primarily made through local agency regulators during annual monitoring inspections and by contacting tank owners directly. Often, the type of leak detection equipment present could not be determined prior to arrival at the facility.

1.3 Types of Facilities

Of the 106 facilities that were included in this study, 51% were retail gas stations owned by major oil companies and 18% were retail gas stations owned by independent marketers. Other types of UST facilities were also included, such as fleet fueling facilities, emergency generator facilities, military fueling facilities, airports, unmanned card-lock facilities, and government facilities. Figure 1.3 shows the distribution of facilities in this field evaluation by facility type.



1.4 Geographic Location

The study covered 21 counties. Table 1.4 lists the counties where facilities in this study are located.

Table 1.4 California Counties where Testing was Conducted.

County	
Alameda	San Diego
Contra Costa	San Francisco
Lake	San Joaquin
Los Angeles	San Luis Obispo
Marin	San Mateo
Mendocino	Santa Barbara
Monterey	Santa Clara
Orange	Solano
Riverside	Sonoma
Sacramento	Ventura
San Bernardino	

1.5 Scheduling and Coordination of Field Testing

A variety of organizations were contacted before and during the field-study. Major oil and independent oil companies were contacted directly and through the Western States Petroleum Association (WSPA) and the California Independent Oil Marketer's Association (CIOMA). Local agency regulators were contacted in every jurisdiction in California, requesting help in locating and accessing facilities for inclusion in the study. UST service and maintenance companies were also contacted.

A majority of the sites were tested during the required annual monitoring system certification and inspection. Annual monitoring system certification requires that each leak detection component be tested for functionality by a qualified technician. KWA staff accompanied local agency regulators and/or service company personnel who were performing inspections and certification.

In many cases, KWA staff tested the line leak detection equipment for its ability to detect a 3-gal/hr leak, which is one of the requirements of the annual monitoring certification. In some cases, KWA staff observed the technician's testing of the line leak detection equipment and recorded data from his equipment. In cases where the facility was equipped with an ELLD, KWA attempted to test the ELLD's ability to detect a 0.2-gal/hr or 0.1-gal/hr leak as well as the 3-gal/hr leak. If the facility was equipped with an ATG that was being used for monthly monitoring at 0.2-gal/hr, KWA often tested this as well.

1.6 Data Collection Process

Data was collected in the field between March 2002 and July 2003. KWA staff used several forms to record information about the leak detectors, the leak simulations, and the UST facility. Whenever possible, printouts were obtained from the consoles of ATGs and ELLDs to document their setups and their testing histories.

KWA developed a website and database to track results of the field study throughout the project. Completed field data forms were entered into a database throughout the project from a standard web browser interface. This aided the project greatly in that the data was constantly updated and made available to all of the project's team members as soon as it was typed into the database. Printouts from leak detection equipment, scheduling of test sites, and contact information for facilities and regulators was also made available on the website. This aided the field crews in that information about upcoming and potential test sites was easily available at all times during the project.

All of the sites were tested directly by, or under the supervision of, KWA staff, each of whom has more than 10 years of experience simulating leaks to test leak detectors. Each test conducted by KWA staff was performed using leak simulation equipment that was functionally identical to that used in third-party certifications.

1.7 Limitations of Data Collection

Site Access Limitations

KWA did not have the authority to include sites in the study without permission of the site's owner/operator. It was therefore necessary to obtain permission of tank operators, regulators and maintenance companies before access to facilities could be obtained. Obtaining site access was challenging; some oil companies were very helpful in allowing site access while others were strongly opposed to being included in the study at all. Some regulators were also very helpful in helping KWA obtain site access and in locating facilities with equipment that was of specific interest.

Equipment Manufacturer and Model Limitations
While the study included test data from several different models from 11 different manufacturers, there were a number of models and manufacturers that were not included in the study. Model and manufacturer limitations were a result of limited site access and an inability to locate specific models and manufacturers. Regulators, maintenance companies, leak detection manufacturers, oil companies and petroleum organizations were contacted throughout the study in an attempt to locate as diverse a population of leak detector types as possible.

Additionally, 48 percent of the sites included in the study were from major oil companies that granted KWA permission to collect data during annual monitoring inspections. Some of the major oil companies that provided access to their facilities have standardized their leak detection equipment to a single manufacturer. While having access to major oil facilities was helpful to the study, it also prevented the study from collecting data points that were completely random.

Double-Wall Tank and Piping Limitations
One objective of the study was to determine if ATGs and LLDs were capable of correctly identifying leaks at facilities that were using this equipment for compliance purposes. In most cases, facilities using ATGs for compliance purposes are equipped with single wall tanks and/or single wall piping. For several years all new stations in California have been required to be constructed with double-wall tanks and piping, so many of the facilities that were available for inclusion in the study had double-walled tanks and piping. Such stations were either not included, or were tested with the knowledge that the leak detectors were being used by the tank operators for inventory control and/or supplemental leak detection, not for regulatory compliance purposes.

0.2 and 0.1-gal/hr Line Leak Detector Limitation
One objective of the study was to determine if ELLDs could correctly identify 0.2-gal/hr and 0.1-gal/hr leaks in the field. A number of ELLDs that were tested did not have an option of conducting 0.2-gal/hr or 0.1-gal/hr tests. These systems were primarily installed on double-wall piping that used sump and dispenser pan sensors to meet compliance requirements. The ELLDs were present for redundancy purposes to protect against catastrophic leaks.

1.8 Leak Simulation Procedures

KWA staff was present during every test included in this report. With a few exceptions, KWA staff conducted all of the leak simulations that were done to determine if leak detectors were correctly identifying leaks. There were a few tests in which KWA recorded the results of leak simulations done by technicians during annual monitoring inspections. In these cases, KWA staff observed the procedures used by the technicians and determined if they were appropriate for inclusion in the study.

The leak simulation procedures used were those described in the EPA's standard procedures for evaluating leak detection methods.[5] Leaks were induced in the tank and pipeline prior to the start of a leak detection test. Leaks were maintained at rates specified by the EPA protocols for the duration of the test. At the completion of the test, the results were recorded and the final induced leak rates were calculated.

The procedures required for simulating leaks in tanks and in pipelines are quite different and require different types of equipment. A detailed description of the procedures and equipment used to simulate leaks is provided below.

1.8.1 ATG Leak Simulations

Leak rates of 0.2-gal/hr were introduced into tanks in cases where the ATG was being tested. Tank leak simulations were generated using special equipment designed by KWA. Figure 1.8.1 contains a schematic of the equipment used to generate tank leak simulations. Leaks were induced using a peristaltic pump that removed product from the tank at a uniform rate of approximately 0.2-gal/hr for the duration of a leak detection test. A piece of flexible tubing connected to the peristaltic pump was positioned in the product of the tank by dropping it into the fill-tube of the tank. The leak was introduced and calibrated to approximately 0.2-gal/hr using a graduated cylinder and a stopwatch. As fuel is removed it is captured, in a graduated cylinder or on a balance, so that the volume can be measured. The final leak rate is then calculated from the volume of fuel removed over the time period of the test.

Once the leak was established, KWA staff manually initiated a leak test by programming the ATG console to start a test. The leak was then maintained and monitored for the duration of the leak test. At the completion of the leak test, printouts of the results were obtained whenever possible, and a final induced leak rate was calculated. All test results and leak simulation data were recorded on the field data forms.

The peristaltic pump setup for simulating leaks is the same type of equipment that KWA has used to evaluate numerous ATGs for third-party certifications. KWA has evaluated all of the equipment tested in the field study at some level using leak simulation equipment that was functionally identical to that used in the field study. This made it possible to directly compare some of the field study results with some of the third-party certification results.

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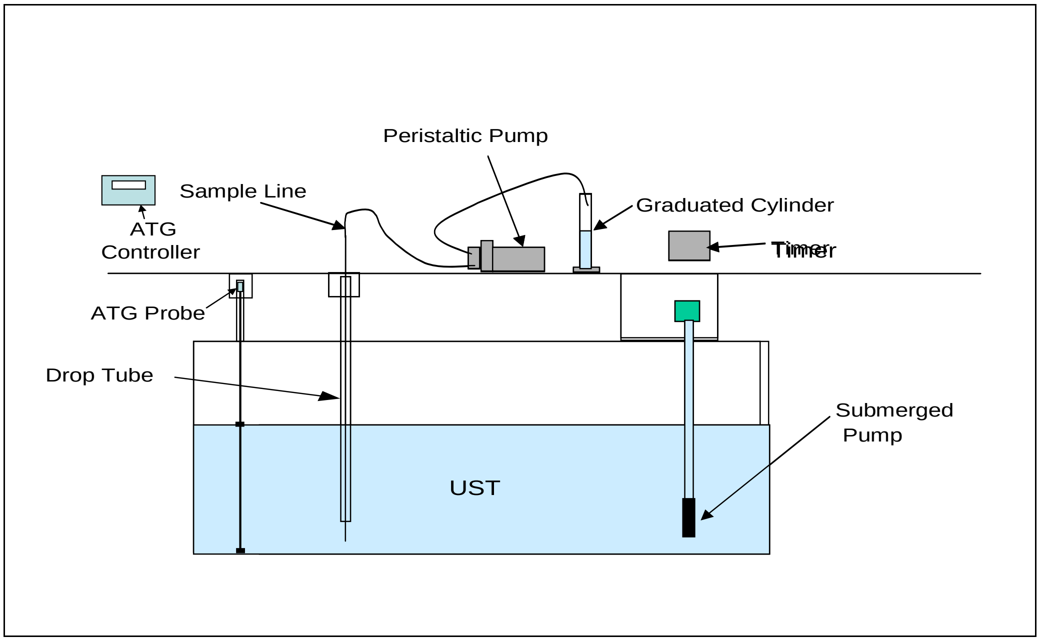
[5] EPA standard leak detection evaluation protocols are available online at http://nwglde.org/protocols.html

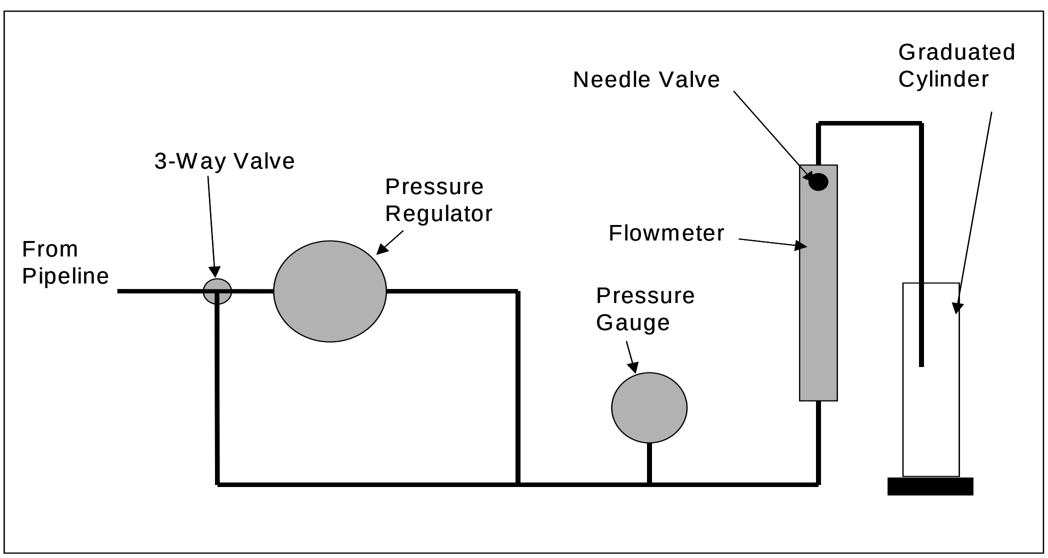
Figure 1.8.1 Schematic of Leak Simulator for ATG Testing



1.8.2 LLD Leak Simulation Procedures

Leak rates of 3-gal/hr were induced in the pipeline for all of the LLDs included in the study. Additionally, in some cases where ELLDs were present, leaks of 0.2-gal/hr and/or 0.1-gal/hr were induced. Pipeline leaks were generated using the LS-2003, a test apparatus designed by KWA for simulating pipeline leaks. Figure 1.8.2 contains a schematic of the LS-2003.

Figure 1.8.2 Schematic of Pipeline Leak Simulation System



The equipment that KWA used to generate leaks in the pipelines was normally installed in the shear valve beneath a dispenser. Once the equipment is connected to the pipeline, fuel comes into the simulator to a three-way valve. To calibrate the system, the fuel passes through a pressure regulator where the pressure is reduced to 10 psi to calibrate the 3.0-gal/hr at 10 psi leak. The flow rate is set using the needle valve and fuel is collected in the graduated cylinder for one minute. This flow rate was set to 189 ml per minute for a 3.0-gal/hr leak. After calibration, the three-way valve is changed to bypass the regulator so that the pressure at the needle valve is now pump pressure. The increase in flow can be seen on the flow meter.

After the test apparatus is connected and the specified rate is calibrated, the leak detector test sequence was initiated. The steps required to initiate a leak test vary greatly depending on a number of factors, including the following:

- Which MLLD or ELLD is installed
- Whether or not the station is configured to blend products at the dispenser.
- Whether the ELLD controls the turbine's on/off cycle or not
- Whether or not the ELLD monitors line pressure or flow to determine if a leak is present.

All MLLDs use essentially the same operational procedures, which are much different than those of ELLDs. ELLDs also have different operational procedures depending on specific makes and models. It is necessary to have significant experience with the operational principles of pipeline leak detectors to test them correctly. Each of KWA's staff has more than 10 years of experience testing line leak detectors and this proved to be very important in assuring that the pipeline leak detectors were properly tested for the field study. Briefly summarized, the procedures for testing a pipeline leak detector are as follows:

1.8.2.1 Installation of the Leak Simulator

1. Turbines are powered down and locked out at the breaker box and on the pump controllers. The pressure in the line is reduced to zero.
2. Quick connect fittings are installed in the shear valves beneath the dispensers
3. Turbines are powered back on.
4. High pressure hosing is connected to the shear valve on one end and the KWA LS-2003 on the opposite end.

1.8.2.2 Conducting an ELLD Test

The methods used to conduct an ELLD test differ with the operating principles of each manufacturers design. For small leaks the test may take up to several hours to complete. In general the following procedures are followed.

1. Leak rates are calibrated to 3-gal/hr, 0.2-gal/hr or 0.1-gal/hr.
2. For systems that conduct a test when the dispenser is turned off the technician will first activate the dispenser and turn it off after a few seconds of operation.
3. The technician then observes the pressure behavior without a leak.
4. For a correctly operating ELLD a "pass" message should be indicated on the controller.
5. Leak results from the leak detector are recorded when the leak test is finished.

6. A leak is then introduced into the line using the leak simulator.
7. A second test is conducted by again activating and deactivating the dispenser.
8. For a correctly operating system, a "fail" message should be indicted on the controller.
9. For systems that conduct a test while the dispenser is activated, the technician will activate the dispenser and leave it on until the test is completed.
10. For a tight line a "pass" should be indicted on the controller.

Note: For correctly operating systems, a zero leak rate test and can be used to help estimate the probability of a false alarm.

1.8.2.3 Conducting an MLLD Test

Mechanical line leak detectors are used to detect larger leaks of 3-gal/hr and larger. These tests are generally short, taking only a few minutes to conduct. The procedure is the same for all mechanical leak detectors.

1. Leak rates are calibrated to 3-gal/hr at 10 psi.
2. The dispenser was then activated and the technician observed the pressure behavior without a leak. For a correctly operating MLLD, the pressure should rise rapidly to the metering pressure for a few seconds, and then open to the full flow position.
3. A leak was then introduced into the system using the leak simulator. The rate was set at 3-gal/hr at 10 psig.
4. A second test was then conducted with the leak. For a correctly operating leak detector, the pressure would rise to the metering pressure and remain there indefinitely.
5. Monitor the pressure during the test until the leak is either detected or a pass is obtained.
6. If the leak was not detected, the technician conducted larger leaks up to 10-gal/hr to estimate the threshold of the MLD.
7. Leak results from the leak detector are recorded when the leak test is finished.

1.8.2.4 Completion of the Testing

1. Turbines are powered down at the breaker box and on the pump controllers.
2. Quick connect fittings are removed from the shear valves beneath the dispensers.
3. Turbines are powered back on.

Before leaving the site, the technician should check to verify that the dispenser is operating properly and will deliver fuel. If no fuel is delivered, check the shear valve to make sure that it has not been inadvertently tripped.

The LS-2003 uses the same technology that KWA has used in numerous third-party certifications, making it possible to directly compare the field study results with the third-party certification results. Differences between the LS-2003 and equipment used for certifications are mainly related to packaging the equipment in a durable case to make it portable and rugged for use in the field.

1.9 Data Analysis

Much of the data analysis was done using the procedures contained in the EPA's standard protocols[6]. The protocols contain statistical procedures for evaluating the performance parameters of leak detection equipment based on the results of evaluating the leak detector in a test tank or pipeline. To the extent appropriate, the results of the field study were statistically analyzed using the EPA's procedures. These statistical procedures were applied to the entire set of data and to a variety of subsets of data. The results of these calculations are contained in Section 3 and Appendix II of this report.

[6] EPA standard leak detection evaluation protocols are available online at http://nwglde.org/protocols.html

2.0 DISCUSSION OF LEAK DETECTION EQUIPMENT TESTED

2.1 Automatic Tank Gauging (ATG) Systems

ATGs typically consist of a console located inside of a building and a probe located in a UST. The console typically includes a display, printer, and audio/visual alarms. The probe typically measures product level and temperature information and transmits this information to the console. ATGs typically conduct leak detection testing by measuring product level and temperature information during times that the UST is not in use.

There are numerous makes and models of ATGs commercially available. Different ATG makes and models have different operational principles and different procedures for conducting leak tests, and it was therefore necessary to test each ATG accordingly. Manuals were often referenced to determine the correct operational procedures for the ATG and to determine how to obtain detailed test results from the ATG. For example, some models of ATGs run tests for a set period of time while other models vary the length of the test depending on the tank size or other conditions, requiring a leak simulation for different lengths of time. Other differences include the information that is provided on the printouts containing the leak detection results. Some models would only print pass or fail while others would print the leak rate. It was sometimes possible, however, to obtain a leak rate from models printing only pass or fail by accessing a diagnostic mode of the ATG.

Although there are several types of ATG probes, all but 2 of the ATGs in this study were the same type of probe: magnetostrictive probes which consisted of a fuel float, a water float, multiple temperature sensors spaced from top to bottom of the probe, and an electronic board to collect and transfer the data to the ATG controller. These probes are capable of detecting level changes of 0.001 inches and sometimes less. Temperature measurements are within 0.01 deg F or less. The probe supplies this level and temperature data to a processor, which converts the information into temperature corrected volume, usually gallons. The temperature-corrected volume changes are tracked over time to estimate leak rates. These systems are generally capable of reporting a large amount of information including inventory reports, delivery reports, leak test histories, theft, and shift change information.

2.2 Mechanical Line Leak Detectors (MLLD)

MLLDs are capable of detecting leaks of 3-gal/hr or greater. They typically are installed in the head of the submersible pump. When a leak is detected by an MLLD, the flow of product into the pipeline is limited to 3-gal/hr, making fueling of vehicles impractical. UST operators are alerted of a possible leak by customer complaints of slow fuel flow. There are currently three manufacturers of MLLDs. Each manufacturer produces several different MLLD models, all of which are functionally similar. All of them are limited to the detection of a leak of 3-gal/hr, sometimes referred to as the hourly test

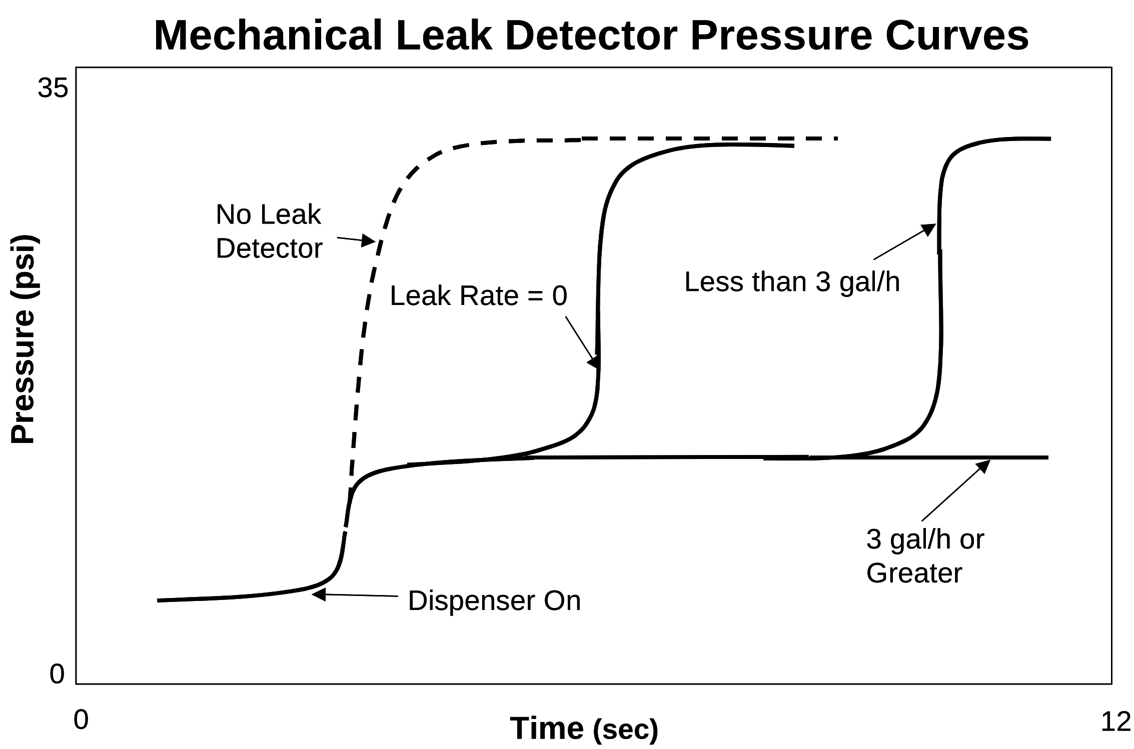
MLLDs conduct their tests in several steps with different flow rates and pressures during each step. The successful testing of these devices must take into account these steps, which are shown graphically in Figure 2.2. These steps are:

1. The initial flow of approximately 3-gal/min into the line raises the pressure to around 10-15 psig.

2. The metering position where the flow into the line is metered at approximately 3-gal/hr.

3. The full flow position at full pump pressure that is reached if no leaks are present.

Figure 2.2 Pressure Curves for MLLD



Step one occurs when the dispenser is activated. The pressure rises rapidly to the metering pressure of around 10-20 psi. The flow rate during this step is approximately 3-gal/min.

Step two occurs when the pressure reaches the metering pressure. In this position, fuel is metered into the line at a rate of 3-gal/hr. If there is a leak of 3-gal/hr or greater, the pressure will remain at the metering pressure indefinitely. If the pump is activated during the metering phase, the leak detector will return to the lower initial position and dispensing will be limited to a slow flow of around 3-gal/min.

Step three occurs if there is no leak. The pressure will rise slowly over the next few seconds until the leak detector opens to the full flow position. Normal dispensing can then occur. Timers within the dispenser prevent the dispensing of fuel until the metering process has had time to reach the open position.

For any tests to occur the initial pressure in the line must drop below the reset pressure, usually between one to four psig depending on the model and condition of the leak detector. If the initial pressure is greater than the reset pressure no test will be conducted when the dispensers are activated. In fact this is often the case when the line is tight and there is no thermal contraction due to a cold climate. In some instances where the leak detector is well below the dispenser, the head pressure at the leak detector may be higher than the reset pressure. In this case the leak detector will not operate and no leak of any size will ever be detected.

2.3 Electronic Line Leak Detection Systems (ELLD)

ELLDs are capable of detecting leaks of 3-gal/hr, 0.2-gal/hr, and 0.1-gal/hr. They typically include a console capable of displaying and printing information, and a sensor that is installed in the head of the submersible pump or elsewhere in the pipeline. The console typically includes a display, printer, and audio/visual alarms. The sensor measures pipeline information, which is used by the console to determine if a leak is present. ELLDs are capable of providing positive pump shutdown and audible/visual alarms when a leak is detected. There are two fundamentally different types of ELLDs: Those based on pressure decay, and those based on volume change at constant pressure. Almost all systems are capable of conducting hourly tests of 3-gal/hr, monthly tests of 0.2-gal/hr, and annual tests of 0.1-gal/hr. Some ELLDs are built into ATG systems and can be programmed to operate from the leak detector console, while others are stand alone devices.

The primary problem with detecting leaks at low flows is that the leak detectors are susceptible to false alarms caused by thermal contraction. Cooling product in a pipeline will contract, which can be mistakenly interpreted by the ELLD as product lost through a leak. The less sophisticated systems handle this by waiting a preset amount of time before conducting a leak test. This time must be long enough, usually several hours, to allow for the effects of temperature change to dissipate.

To distinguish between the pressure decay caused by a leak and pressure decay resulting from thermal contraction requires multiple measurements over a period of time. The effects of a leak are constant while the effects of thermal decay vary as the pipe system reaches equilibrium with the surrounding environment. For example the pressure decay time caused by a leak for an initial pressure to a lower pressure will be the same while thermal decay times for the same pressure interval will change over time. Therefore, ELLDs typically run a test sequence until consistent decay times are obtained or the pressure stays above the lower pressure for an extended time period.

2.3.1 Pressure Decay ELLD Systems

Pipeline leaks are often detected by monitoring the change in pressure over time. The line is first pressurized by the turbine. A check valve in the pump keeps the pressure in the line. For some systems, the functional element in the turbine serves as the check valve.

The ELLD then monitors the pressure behavior. This can range from simple systems that monitor pressure after a fixed, long stabilization period (up to six hours) to a sophisticated system that attempts to shorten the test to a minimum time (as short as 15 minutes) by correcting for temperature effects.

Pressure decay systems usually cycle the pump on and off one or more times during the test, depending on the test conditions. The same leak simulation system is used as with the MLLDs. The operator should observe the pressure during the cycling process until a leak is detected or the system passes the test.

2.3.2 Constant Pressure ELLD Systems

Volume based systems operate at constant pressure during testing. The turbine continues to run during the entire test period. The sensor in this case is a sensitive flow measurement device located in the leak detector. As fuel leaks from the line, the meter measures the rate at which the leaked fuel is replaced in the line. It will continue to monitor until the leak rate is steady, or until no loss of fuel is detected. The pressure will remain constant (with the normal fluctuations as the turbine runs) during these tests. The pump will shut off if a leak is detected or the line is found to be tight.

2.3.3 Regulatory Requirements for Pipeline Leak Rates

Before tests are conducted it is important to understand the various leak rates that are specified in the regulations for testing pipeline systems. Table 2.3.3 summarizes the various requirements for hourly, monthly, and annual testing.

Table 2.3.3 Summary of Leak Requirements for ELLD Pipeline Testing

Test Type	Calibration Pressure	Conduct Test At	Leak Rate at Operating Pressure
Hourly (3-gal/hr)	10 psi	Operating Pressure	Varies as square root of line pressure ratio
Monthly (0.2-gal/hr)	Operating Pressure	Operating Pressure	0.2-gal/hr
Annual (0.1-gal/hr)	1.5 Times Operating Pressure	Operating Pressure	0.082-gal/hr

For hourly testing, the leak rate of 3-gal/hr is specified at 10 psi. It is therefore required that the leak simulation system be capable of setting a leak of 3-gal/hr at this pressure. After calibration is completed, the leak rate changes as the pressure in the line changes. The actual rate at operating pressure is given by the equation

$$\text{Operating Leak Rate} = 3.0 * (P_1/10)^{0.5}$$

where the Operating Leak Rate is the leak rate at the pump operating pressure and P_1 is the operating pressure of the line. For a system operating at 30 psi, the actual leak rate would be

$$\text{Operating Leak Rate} = 3 * (30/10)^{0.5} = 5.2\text{-gal/hr}$$

For monthly monitoring, the leak rate is set at 0.2-gal/hr at the actual pump operating pressure of the line being tested.

For annual testing it is not practical to produce a line pressure of 1.5 times the operating pressure without an additional pump. For the test, the leak rate is converted from 1.5 times the operating pressure to the actual operating pressure using the equation

$$\text{Operating Leak Rate} = 0.1 * (P_1/1.5*P_1)^{0.5} = 0.082\text{-gal/hr}$$

3.0 TEST RESULTS

Section 3 presents the results of the tests that were run on the Automatic Tank Gauges and line leak detectors. The basic question to be answered was whether these leak detectors operating in the field could correctly detect an induced leak. Because other characteristics of the installation (product, size, manufacturer, etc.) were recorded, it was possible to compare the percent of correct leak detection by some of these other factors. Such comparisons often led to small sample sizes.

Small sample sizes can give misleading results. For example if one category had 100 tests and correctly detected 90 (90% correct), it might appear better than a category that had only 3 tests and correctly detected only two of them (67% correct). However, in reality there might be no difference. In addition, often several factors are related. A statistical test, called the chi-squared test, can be used to determine if apparent differences are statistically significant. A more detailed discussion of this is in Appendix II. For these reasons, it would be a misuse of the data to conclude that an apparent difference in detection rates by a given factor was caused by that factor.

The federal performance standard for ATGs is it to operate at no more than a 5% false alarm rate (indicating a leak when none exists), with at least a 95% probability of detecting a leak of 0.2-gal/hr or greater. This performance must be achieved during the third-party equipment evaluation under a standardized set of test conditions. In the field operation of ATGs, tests may be run under conditions different than those encountered during the third-party evaluation testing. Consequently, actual field performance may not be the same as the performance standards. This study attempts to estimate the observable field performance and to see if the field performance differs from the performance estimated in the EPA evaluation or from the EPA standards. This study concentrated on determining the ATGs' ability to detect a leak of 0.2-gal/hr. While some tests with a zero leak rate were run, the results of the present study are targeted toward identifying the ATGs' ability to detect a leak. However, enough tests with a zero leak were run to estimate the overall probability of a false alarm. The procedures used to analyze the data were taken from the EPA protocol "Standard Test Procedures for Evaluating Leak Detection Methods: Automatic Tank Gauging Systems" EPA/530/UST-90/006, March 1990. A summary of these calculations has been provided in Appendix II.

Line Leak Detectors (LLDs) for pressurized piping are required to meet various standards, depending on regulatory requirements applicable to the UST system being monitored. All are required to detect a large leak rate of 3-gal/hr (at 10 psi, or an equivalent rate at a different pressure), referred to as an hourly test. In addition, LLDs are required to detect a leak rate of 0.2-gal/hr (at operating pressure) with a probability of at least 95% (and a false alarm rate of no more than 5%) when used for monthly monitoring. In some cases, an annual test is used, in which case the LLD must be able to detect a leak rate of 0.1-gal/hr (at one and one-half times the operating pressure) with a probability of at least 95% (and a false alarm rate of no more than 5%). Again, these performance standards are in reference to a defined set of tests under specified test conditions. In the field operation of LLDs tests may be run under conditions more extreme than those of the evaluation testing. The purpose of this study is to estimate how much the performance in the field differs from that of the evaluation testing. As with the ATGs, testing of LLDs concentrated on their ability to detect a simulated leak of a specified leak rate. No tests were run in the tight condition.

3.1 Automatic Tank Gauging Systems (ATG)

A total of 20 models of ATGs from 9 different manufacturers were included in the field study. Approximately two-thirds of the ATGs tested were manufactured by Veeder-Root. This distribution resulted in part from market share, and in part from the voluntary participation of the facilities. It cannot be viewed as representative of the California population. Figure 3.1a has the distribution of ATGs tested by manufacturer. The data are tabulated in Table 3.1a.

Figure 3.1a ATGs Tested, by Manufacturer

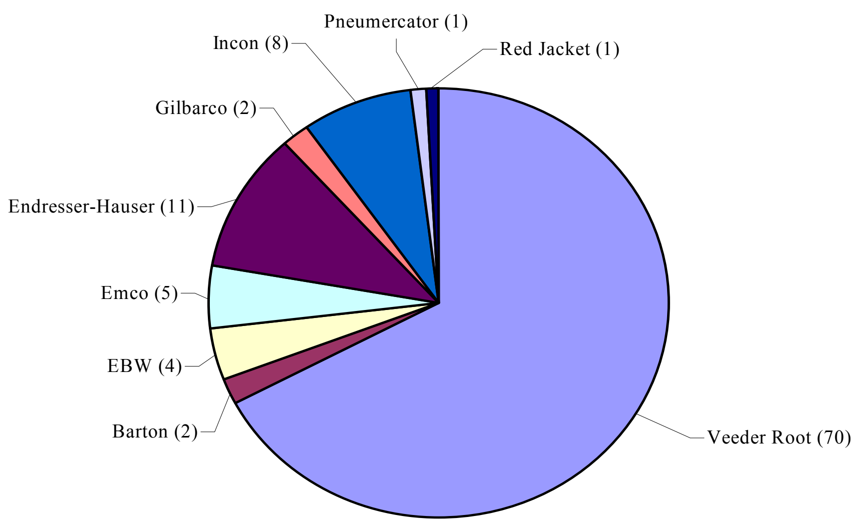


Table 3.1a ATGs Tested, by Manufacturer

Manufacturer	Number	Percent of ATGs	Valid Tests	% Correct	% Leaks Detected
Barton	2	1.92	0	-----	-----
EBW	4	3.85	2	50	50
Emco	5	4.81	1	100	100
Endresser-Hauser	11	10.58	11	73	57
Gilbarco	2	1.92	2	100	100
Incon	8	7.69	8	75	67
Pneumercator	1	0.96	0	-----	-----
Red Jacket	1	0.96	1	0	0
Veeder-Root	70	67.31	54	93	90
Total	104		79	86	81

Figure 3.2a has the distribution of ATGs tested by specific model and Table 3.2a has the data on specific models of ATG tested.

Figure 3.2a ATGs Models Tested

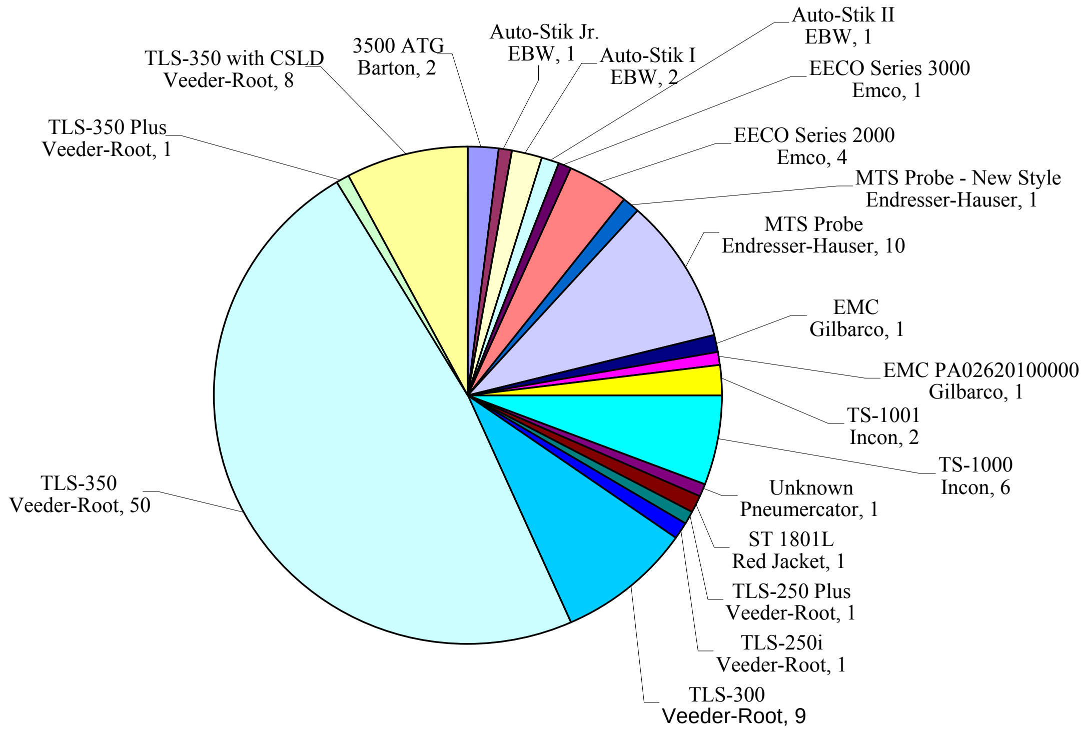


Table 3.2a ATG Models Tested

Manufacturer	Model	Number	Percent
Barton	3500 ATG	2	1.92
EBW	Auto-Stik Jr.	1	0.96
EBW	Auto-Stik I	2	1.92
EBW	Auto-Stik II	1	0.96
Emco	EECO Series 3000	1	0.96
Emco	EECO Series 2000	4	3.85
Endresser-Hauser	MTS Probe - New Style	1	0.96
Endresser-Hauser	MTS Probe	10	9.62
Gilbarco	EMC	1	0.96
Gilbarco	EMC PA02620100000	1	0.96
Incon	TS-1001	2	1.92
Incon	TS-1000	6	5.77
Pneumercator	Unknown	1	0.96

Red Jacket	ST 1801L	1	0.96
Veeder-Root	TLS-250 Plus	1	0.96
Veeder-Root	TLS-250i	1	0.96
Veeder-Root	TLS-300	9	8.65
Veeder-Root	TLS-350	50	48.08
Veeder-Root	TLS-350 Plus	1	0.96
Veeder-Root	TLS-350 with CSLD	8	7.69
Total		**104**	

The ATGs were tested by simulating a 0.2-gal/hr leak from the tank in which the ATG was installed. Once the leak rate was established, the ATG was programmed to begin a test. In a number of cases a test was run on one tank in the tight condition (no induced leak) while the same make/model ATG was tested on a neighboring tank with a leak simulation. This provided a number of tight tests that could be used for calculating the probability of false alarm (PFA) and the probability of detection (PD). Tests were run until completion, when the test result was printed by the ATG. In many cases, the ATG printed only a summary result such as "PASS" or "FAIL." When possible, the ATG was put into a diagnostic mode to retrieve the leak rate estimated during the test for comparison with the actual induced leak rate. In a number of cases the ATG reported an "INVALID" test. This response could occur when a delivery had occurred shortly before the initiation of a test. "Invalid" results were included in this study in the "Other" category. Results in the "Other" category generally indicate that the ATG was functioning correctly, but the conditions were not acceptable for it to complete a test at the time of the inspection. Thus, while the ATG appeared to be working correctly, it was not possible to verify that it would correctly identify a simulated leak.

3.1.1 Overall ATG Results

104 ATG tests were conducted, of which 79 gave valid test results. Of the 79 valid tests, 58 had induced leaks and 21 were conducted with the tank in the tight condition. 68 of the 79 valid results (86%) correctly identified the tight tank or simulated leak condition. The ATG result was stated as correct on all 21 of the 21 tight tests, or 100%. This is equivalent to a 0% false alarm rate, meeting the EPA specification of a PFA of 5% or less. This does not mean that there would never be a false alarm. The 95% confidence upper bound on the false alarm rate is 13.3%.

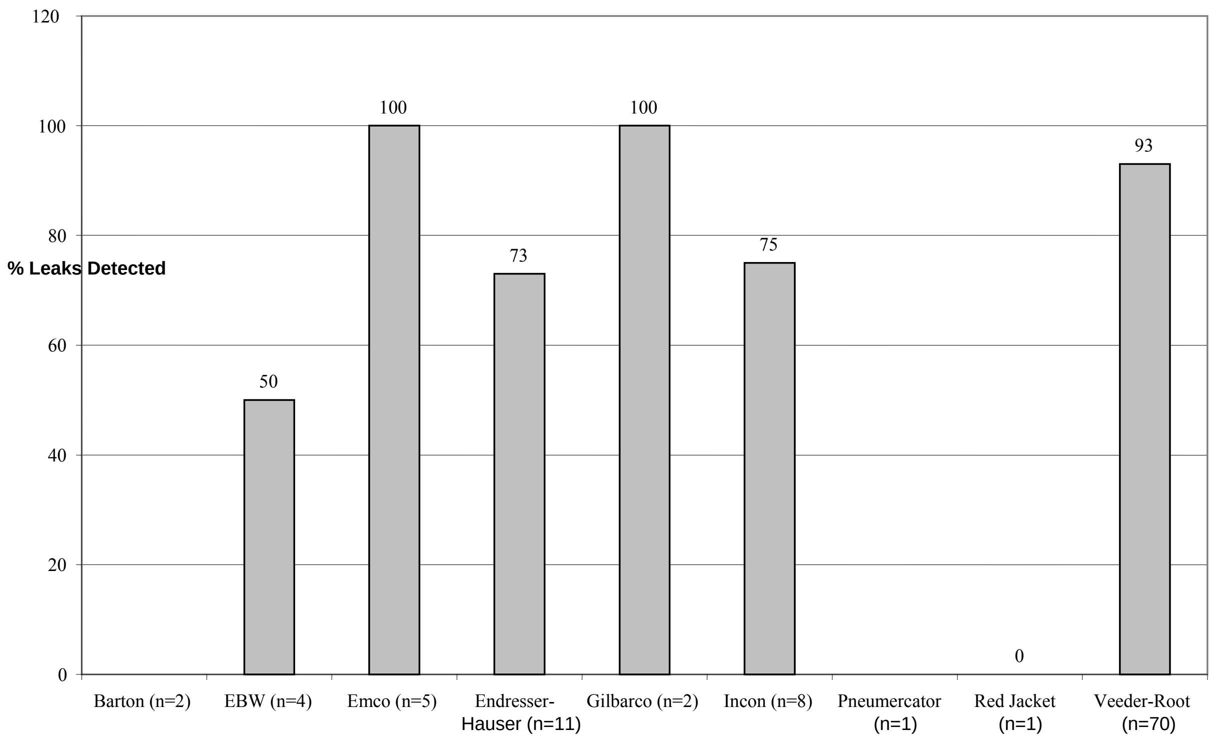
Among the valid tests, the ATG correctly detected 47 of 58 tests (81%) conducted with induced leaks. Although the intent was to induce a leak rate of 0.2-gal/hr, some of the actual induced leak rates were less than the standard of 0.2-gal/hr. In fact, only 43 of the induced leaks were 0.2-gal/hr or more, which is the size of leak that is required to be detected with 95% probability. Of the 43 valid tests with leak rates of at least 0.2-gal/hr, 36 (84%) were correctly detected, This rate is close to the overall detection rate of 81%, so the fact that some induced rates were a little less than the standard did not appreciably affect the results.

3.1.2 ATG Results by Manufacturer

The number of valid tests conducted for most manufacturers was so small that the estimated proportions of correct detection are subject to very wide errors. Only one manufacturer, Veeder-

Root, had enough systems with valid tests so that reliable statistics could be calculated. Table 3.1a (page 16) has the number of valid ATG tests conducted by manufacturer and the percent of correct results. Figure 3.1.2 has the percent of correct leak detections by manufacturer.

Figure 3.1.2 Leak Detection Rate (%) by ATG Manufacturer



3.1.3 ATG Results by Other Factors

Several other variables were recorded about the ATG tests. These included the age of the system (when known), the product level at the time of the test, the size of the tank, the material of the tank, whether the tank was single or double-walled. The probability of detecting a simulated leak of about 0.2-gal/hr can be compared on each of these factors. The proportion of correct leak detections for each of these factors is presented in Tables 3.1.3a through 3.1.3b below.

<u>Age of ATG System</u>
The recorded ages ranged from less than one year up to 10 years. Many of the systems were missing data on age. The results were grouped into new (one year or less) and old (more than one year old up to 10 years old). There was no significant difference in the overall percent correct between the new and old ATG. The difference in the percent of leaks detected (88% compared to 67%) did not quite reach statistical significance at the 5% level (chi-squared of 1.92 compared to the critical value of 3.84). However, there were a large number of ATG systems with unknown age, so this finding is not definitive. ATGs with unknown age had intermediate results, but were close to the results for new ATGs. Eighty-five percent (85%) of the leaks were

detected in by ATG with unknown age compared to 77% of the leaks detected when the age of the system was known. The results by age of system detection rates by age are tabulated in Table 3.1.3a and displayed in Figure 3.1.3a. Figure 3.1.3a shows the percent of correct decisions for tight tests and for simulated leak tests. There is no difference at the 5% confidence level therefore no conclusions can be drawn regarding tanks of unknown age.

Figure 3.1.3a ATG Leak Detection by Age of System

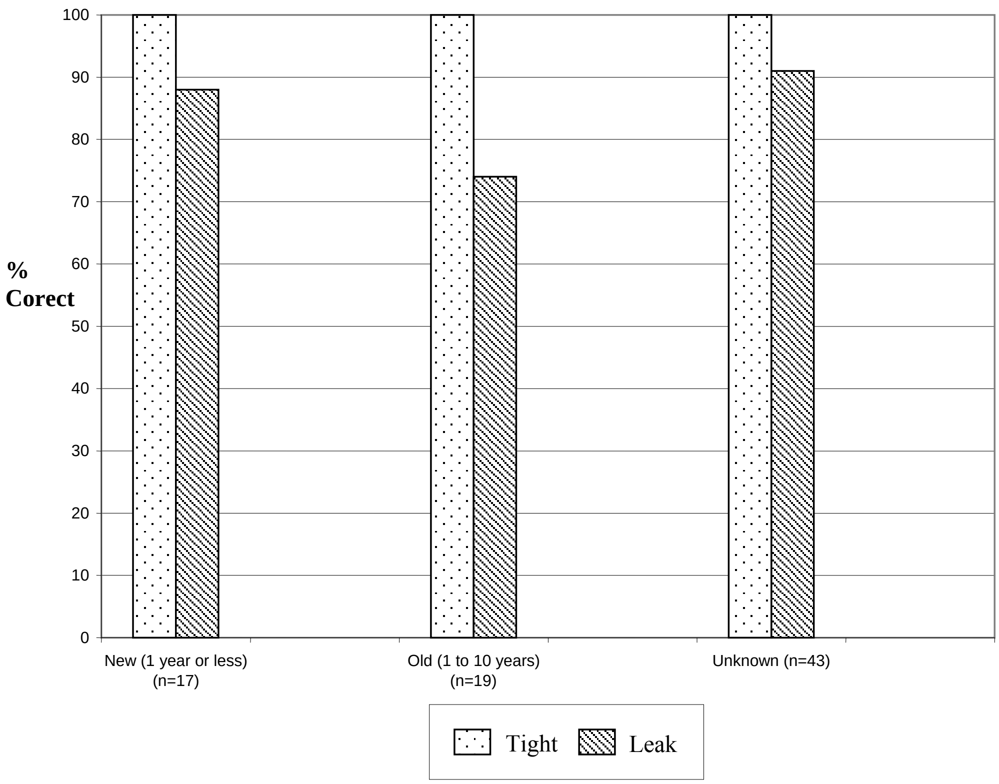


Table 3.1.3a ATG Test Results by Age

Age of ATG system	Number of Zeros	PFA	No. of Leaks	PD	No. Valid Tests	Percent Correct
New (1 year or less)	1	0%	16	87.5% (14/16)	17	88% (15/17)
Old (1 to 10 years)	4	0%	15	66.7% (10/15)	19	74% (14/19)
Unknown	16	0%	27	85.2% (23/27)	43	91% (39/43)

Product Stored in the UST

The ATG systems were used on several different products. The products encountered included several grades of gasoline, diesel fuel, and two types of jet fuel. The results by product are given in Table 3.1.3b and are displayed in Figure 3.1.3b. There was only one tank with aviation gasoline. However, there is an apparent difference in performance when used on jet fuel, JP-5 or JP-8. These tanks with jet fuel were quite large, ranging from about 26,000 gallons up to 50,000 gallons. It may be that the performance was affected by the tank size rather than the product.

Figure 3.1.3b ATG Leak Detection by Product

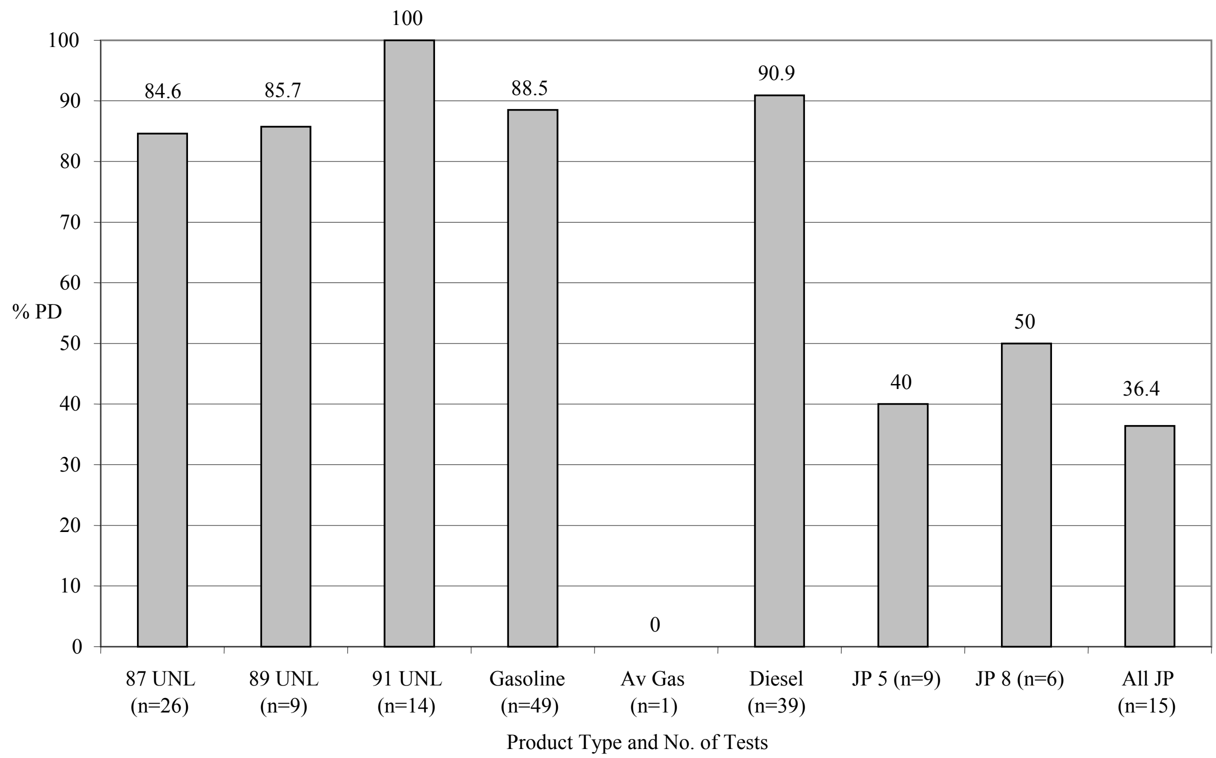


Table 3.1.3b ATG Leak Detection by Product

Product	N	N Leak Simulations	N Detections	N Valid	Zeros	PFA	PD
87 UNL	26	13	11	14	1	0	84.6
89 UNL	9	7	6	8	1	0	85.7
91 UNL	14	6	6	7	1	0	100.0
Gasoline	49	26	23	29	3	0	88.5
Av Gas	1	1	0	1	0	---	0.0
Diesel	39	22	20	36	14	0	90.9
JP 5	9	5	2	7	2	0	40
JP 8	6	4	2	6	2	0	50.0
All JP	15	9	4	13	4	0	44.4

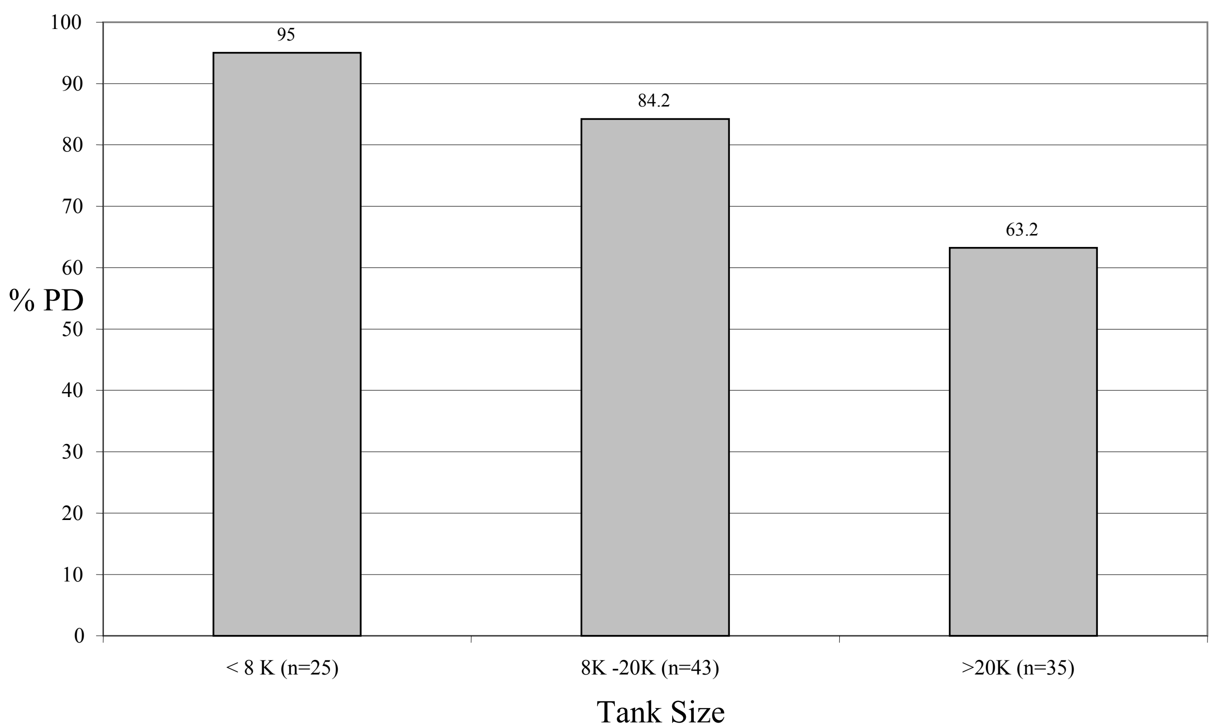
Size of UST

The size of the tank may affect the performance of the ATG. This is particularly true since many ATGs have only been tested for use on tanks up to about 20,000 gallons or so. Sixty-nine of the ATG tests were done on tanks of 20,000 gallons or less. The remaining 35 tests were done on tanks from 26,000 gallons up to 50,000 gallons. Table 3.1.3c and Figure 3.1.3c have the test results for the tanks grouped into three size categories. The small tanks were taken as less than 8,000 gallons, medium sized tanks were from 8,000 gallons up to 20,000 gallons, and large tanks were 26,000 gallons and larger. The rate of detection shows a trend decreasing as the size of the tank increases. If all tanks of sizes 20,000 gallons and smaller are considered together, the detection rate among those tanks is 89.7%.

Table 3.1.3c ATG Leak Detection by Tank Size

Tank Size	N	N Valid	N Leaks	N Detected	Zeros	PFA	PD
< 8 K	26	21	20	18	1	0	95.0
8K -20K	43	25	19	16	6	0	84.2
>20K	35	33	19	12	14	0	63.2

Figure 3.1.3c Leak Detection Rate by Tank Size



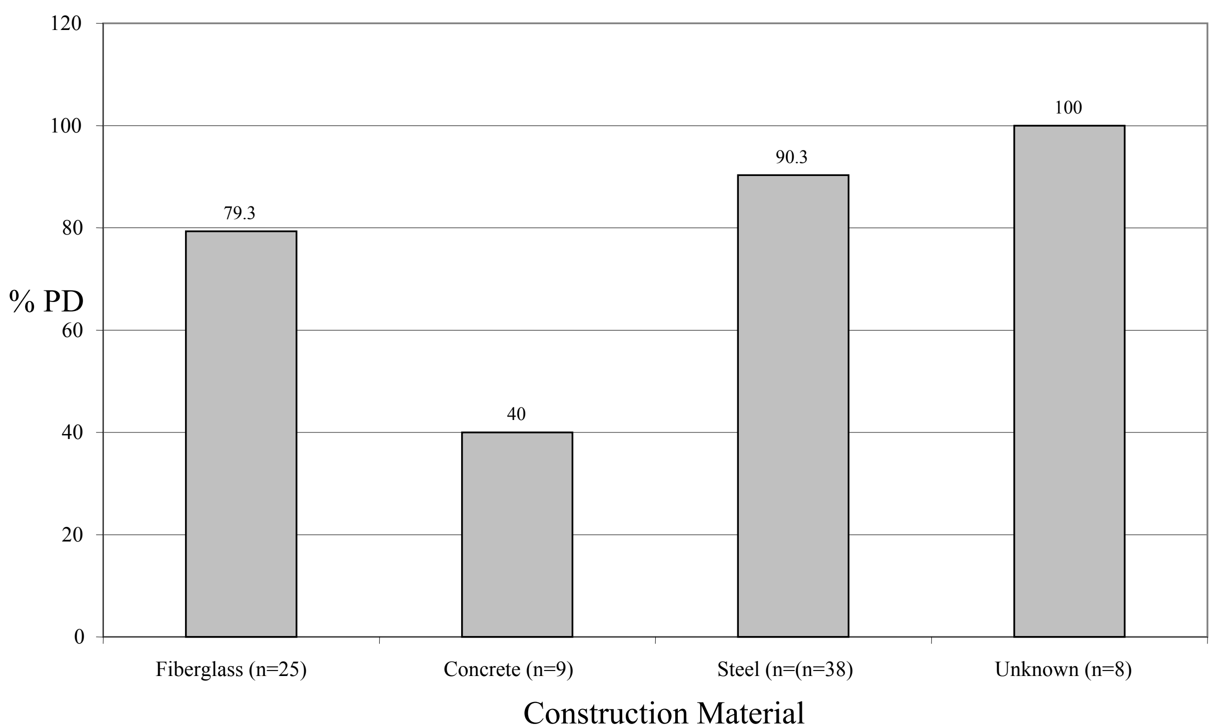
Tank Material

There were several types of tanks encountered during field testing. Most common were fiberglass and steel, with a few tanks of unknown material. There were also concrete tanks with a fiberglass liner and Plasteel tanks (steel tanks lined with a plastic outer coating. The Plasteel tanks were combined with the steel tanks.) The concrete tanks were generally vertical cylinders instead of the more common horizontal cylinders. The test results by type of tank material are shown in Table 3.1.3d and Figure 3.1.3d. The results were better for steel than for fiberglass and the detection rates were quite poor for the concrete tanks. However, the concrete tanks were all either 26,000 gallons or 50,000 gallons, so these were large tanks, which may explain the results. That is, the large (26,000 gallon and above) tanks were also all concrete and contained jet fuel. Leak detection was not as good on these tanks, but this could be due to any of these three factors or to some combination of them.

Table 3.1.3d ATG Leak Detection by Tank Material

Tank Material	N	N Valid	N Leaks	N Detected	Zeros	PFA	PD
Fiberglass	49	33	29	23	4	0	79.3
Concrete	9	9	5	2	4	0	40.0
Steel	38	31	20	18	11	0	90.3
Unknown	8	6	4	4	2	0	100.0

Figure 3.1.3d ATG Detection Rates by Tank Material



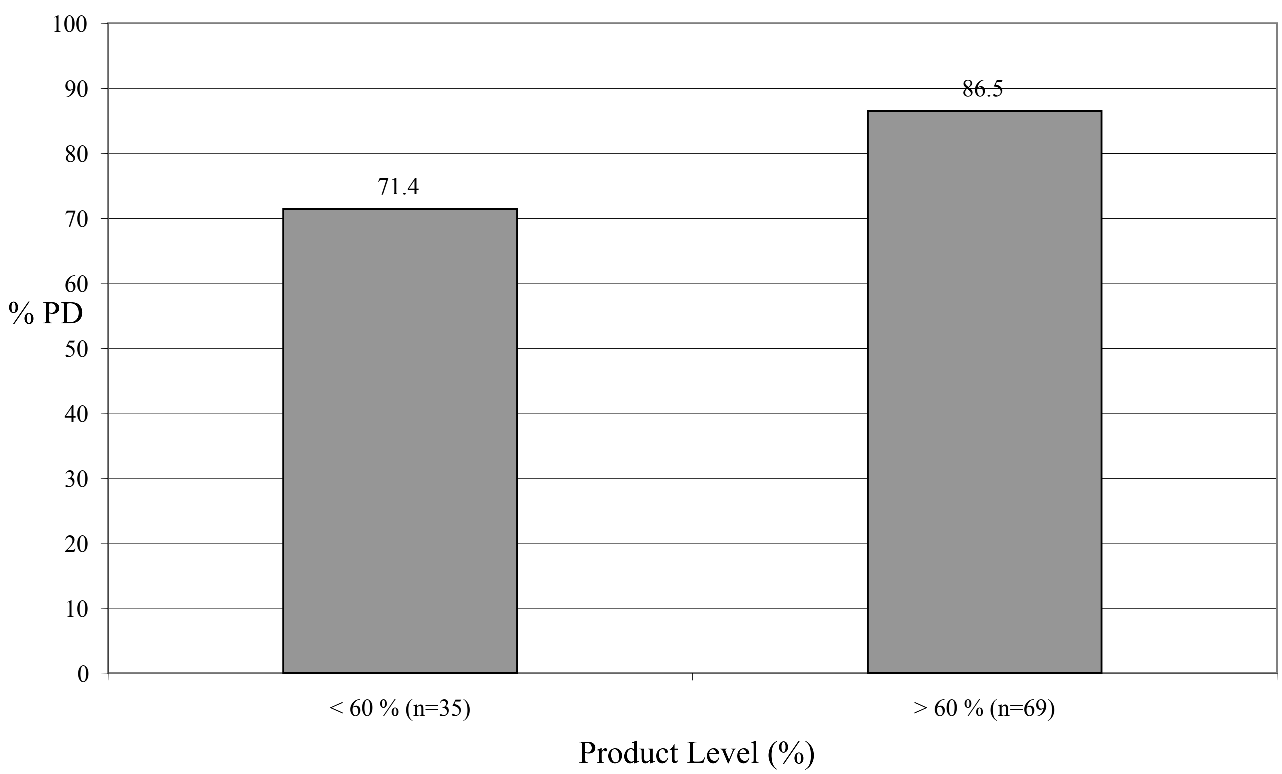
Product Level

Table 3.1.3e and Figure 3.1.3e have the performance of the ATG tests by the product level in the tank at the time of the test. Tanks are generally horizontal cylinders, meaning the surface area changes dramatically as product level varies from the small tank bottom or top sections to the larger center sections. Detecting leaks is generally more difficult when the product level is in the larger center area of the tank because the liquid level changes less for a given product volume lost. In spite of this phenomenon, there was no significant difference in performance. The PFA rates observed for high and low product levels were both zero. The detection rate was 71% when the product level was below 60% and was 87% when the level was above 60%.

Table 3.1.3e ATG Performance by Product Test Level

Product Level	N	N Valid	N Leaks	N Detected	Zeros	PFA	PD
< 60 %	35	27	21	15	6	0	71.4
> 60 %	69	52	37	32	15	0	86.5

Figure 3.1.3e ATG Detection Rates by Product Level



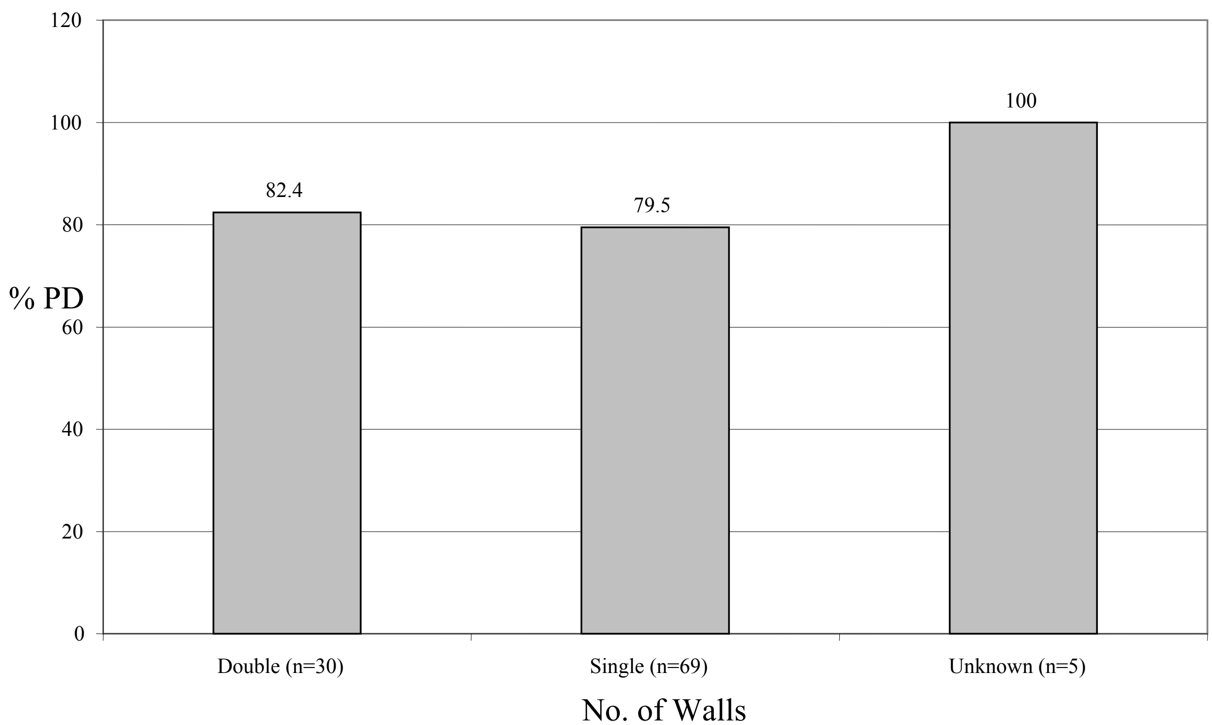
Single and Double-walled Tanks

Table 3.1.3f and Figure 3.1.3f have ATG results by number of tank walls. Most of the tanks tested (69) were single-walled. There were 30 double-walled tanks and the number of walls was unknown for 5 tanks. There was very little difference in the leak detection rate for single-walled tanks (80%) compared to double-walled tanks (82%). Three tanks with an unknown number of walls had valid tests, both of which detected the leak.

Table 3.1.3f ATG Results by Number of Tank Walls

Walls	N	N Valid	N Leaks	N Detected	Zeros	PFA	PD
Double	30	20	17	14	3	0	82.4
Single	69	56	39	31	17	0	79.5
Unknown	5	3	2	2	1	0	100.0

Figure 3.1.3f ATG Performance by No. of Tank Walls



3.1.4 Comparison to Third-party Evaluation Results per EPA Protocols

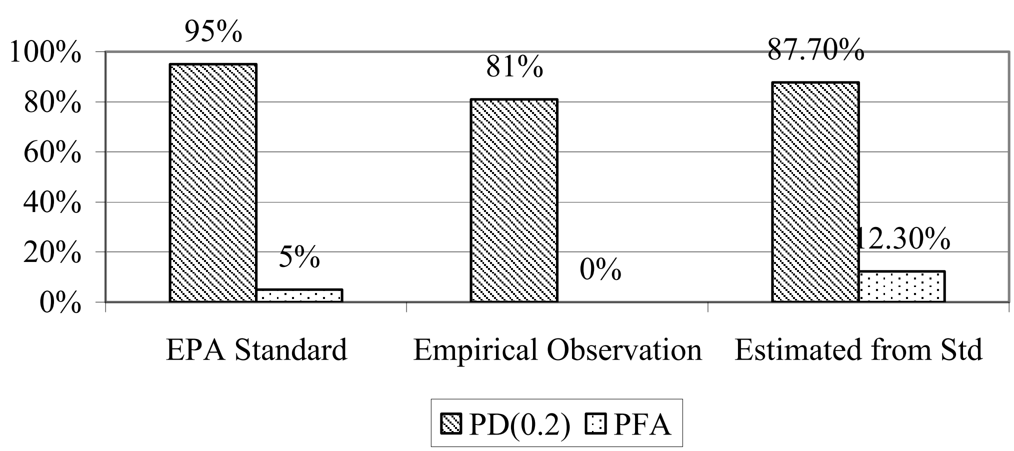
Federal and California regulations require that all leak detection equipment, including ATGs, be evaluated by an independent third-party testing organization in accordance with recognized protocols designed to determine if the equipment is capable of meeting minimum performance standards. While many of the test conditions during third-party evaluations are more rigorous than those typically present in real-world environments, there are numerous real-world variables that cannot be accounted for during third-party evaluations. One objective of this study was to compare ATG functionality under field conditions with the specifications outlined in their third-party certifications.

Third-party evaluation in accordance with EPA protocols provides an estimate of the performance of an ATG by comparing the measured leak rate of the ATG to the simulated leak rate. The standard deviation of these differences is used with a statistical model to estimate the probability of a false alarm and the probability of detection based on the t-distribution. The same approach can be used with the ATG tests that provided a measured leak rate.

For this comparison, some tests were dropped because the ATG indicated an invalid result. The ATG gave various reasons for an invalid test, including too great a temperature change, too recent a delivery, etc. After eliminating such tests, there were 79 tests with valid leak rate estimates. Using these 77 valid tests, the standard deviation of the difference between the measured and simulated leak rates was calculated to be 0.086-gal/hr. Based on this calculated standard deviation and an assumed threshold of 0.1-gal/h for declaring a leak, the estimated probability of detecting a leak of 0.2-gal/hr is 88% and the estimated probability of a false alarm is 12%. These performance estimates based on the standard deviations differ somewhat from the rates estimated by counting the number of false alarms (zero percent based on zero out of 21) and the number of detected leaks (81% based on 47 out of 58).

The observed performances differ from the EPA performance standards of 95% PD and 5% PFA. The observed false alarm rates are lower than the EPA performance, but so are the rates of detecting [a simulated] leak of 0.2-gal/hr. The comparison is shown graphically in Figure 3.1.4.

Figure 3.1.4 Comparison of Performance to EPA Standards



There were a number of differences in the conditions during the field tests compared to the standard conditions during the EPA evaluation. These differences included temperature conditions, product level, time since delivery, size and type of tanks. In particular, some ATG were tested in tanks larger than those used in the EPA evaluation, and even larger than the size of tank they were approved for. In addition, there were a few systems tested in the field that had not been through an EPA evaluation. Given the variety of conditions for these field tests, the results are not extremely different from the EPA standards. It should be noted that the ATGs met the EPA performance standards when used in tanks of 8,000 gallons or less, and were close to meeting the leak detection performance (90% PD and 0% PFA) for all tanks up to 20,000 gallons.

There were enough tests conducted on three manufacturer's ATGs that a reliable standard deviation could be calculated. These data are shown in Table 3.1.4, which includes the name of the company, the number of tests, the estimated standard deviation, and the estimated PFA and PD based on these data. The two right hand columns show the estimated PFA and PD based on counts from the data. All of the makers had an empirical PFA much smaller than that predicted from their standard deviation, using a threshold of 0.1-gal/hr. The estimated PD for the Veeder-Root systems agreed quite well. However, the other two had somewhat smaller probabilities of detection based on the counts than estimated from the standard deviation.

Table 3.1.4 Statistics and Estimated Performance by Manufacturer

Manufacturer	N	SD	Estimated PFA (%)	Estimated PD (%)	Observed PFA (%)	Observed PD (%)
Veeder-Root	54	0.0808	11.07	88.93	0.0 %	89.74%
Endresser-Hauser	11	0.0933	15.45	84.55	0.0 %	57.14%
Incon	8	0.0913	15.48	84.52	0.0 %	66.67%

3.2 Electronic Line Leak Detection Systems (ELLD)

ELLDs usually have at least two modes of operation. One mode of operation is designed to detect a gross leak of 3-gal/hr and operates whenever the dispensing stops and starts again. Operation in this mode typically takes only a few seconds. A second mode of operation is designed for monthly monitoring at a leak rate of 0.2-gal/hr and may take an hour or more. Some ELLDs have a third mode of operation designed to detect a leak rate of 0.1-gal/hr, which could satisfy annual line testing requirements. This test mode to detect a leak of 0.1-gal/hr typically takes multiple hours. More detailed results for each leak rate follow.

3.2.1 Overall ELLD Results at 3.0-gal/hr

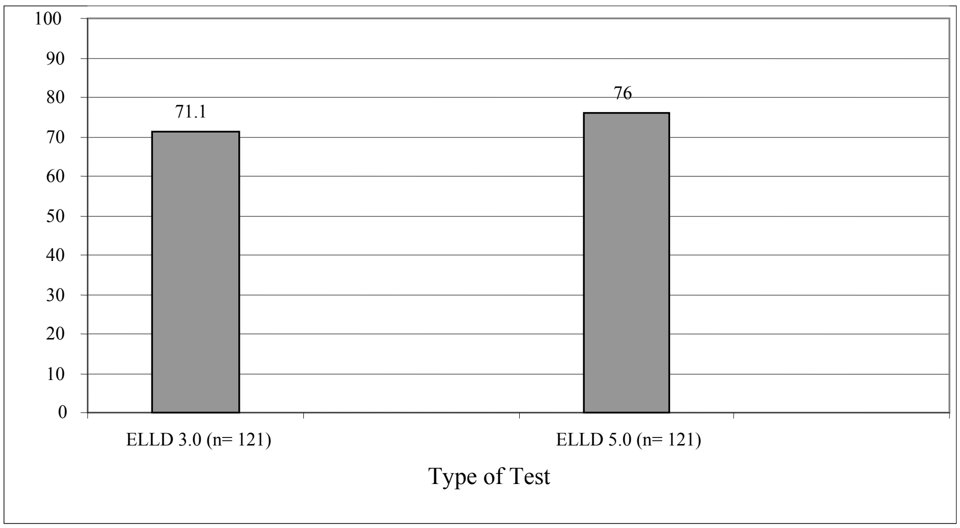
A total of 121 ELLD systems were tested in the 3-gal/hr mode, including six models from four manufacturers. Overall, 86 of 121 ELLD tests (71%) at 3.0-gal/hr were successfully detected. When the leak rate was increased to 5-gal/hr, 92 of 121 (76%) ELLD successfully detected the leak. 101 of 121 (83%) of the systems detected a leak at some rate less than about 11-gal/hr, the maximum that could be simulated. There were 20 tests that missed the 3-gal/hr leak rate but did not have their detectable leak rate determined.

Figure 3.2.1 and Table 3.2.1 show the overall result of the ELLD tests in terms of the percent of leaks detected by the type of the leak test. For comparison, the overall detection rate of the mechanical leak detector is also shown.

Table 3.2.1 Overall ELLD Results at 3.0-gal/h

Test Type	Tests	Detections	Percent
ELLD at 3.0-gal/hr	121	86	71.1
ELLD at 5.0-gal/hr	121	92	76.0

Figure 3.2.1 Overall ELLD Performance at



3.2.2 ELLD Results at 3.0-gal/hr, by Manufacturer

ELLD testing included four manufacturers. Figure 3.2.2a has the distribution of ELLD tests conducted, by manufacturer. The numbers shown are the number of tests conducted on each manufacturer's system. Detection rates for each manufacturer are shown in Figure 3.2.2b and Table 3.2.2. Although Gilbarco had a 100% detection rate, this was based on very few cases (only 2 or 3).   Overall, differences by manufacturer are not very pronounced.

Figure 3.2.2a ELLD Systems by Manufacturer

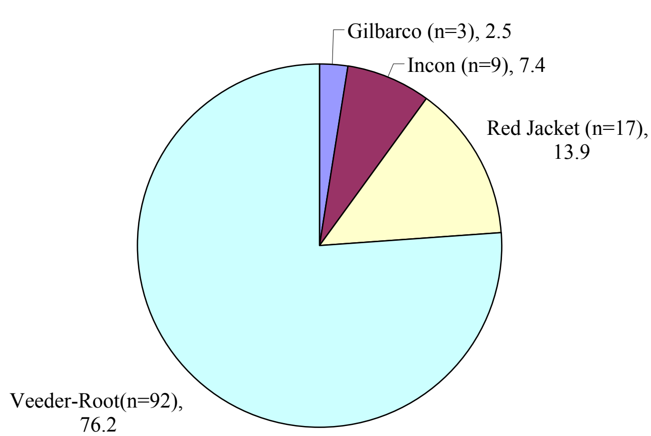
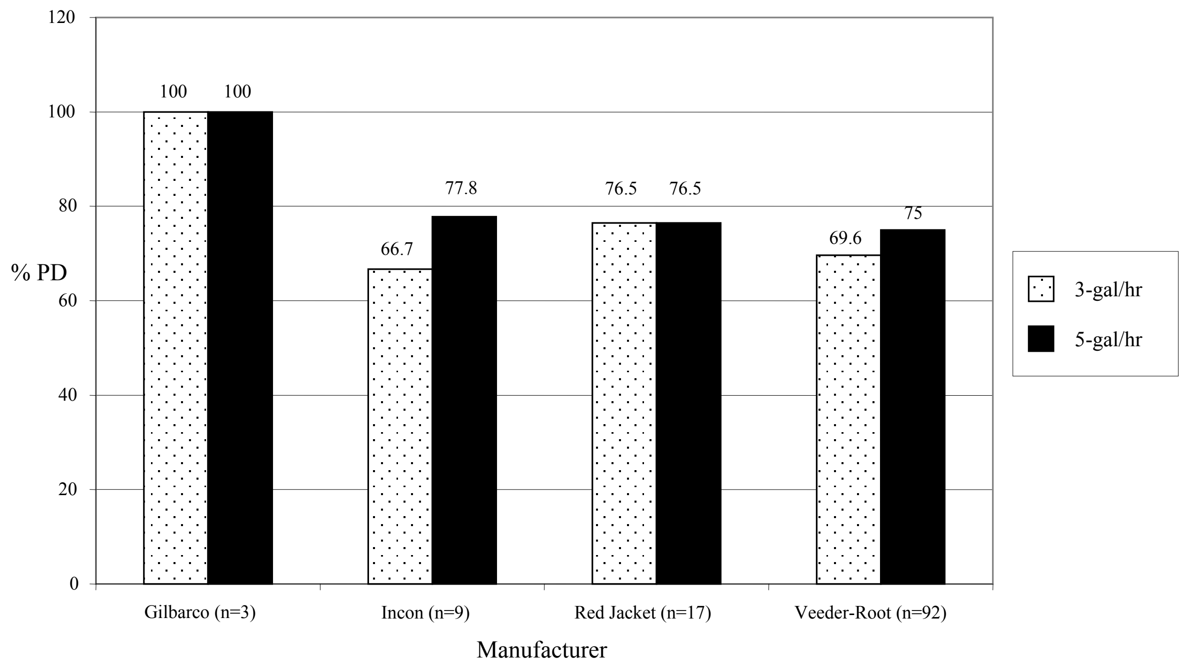


Table 3.2.2 ELLD Systems Tested by Manufacturer and Detection Rate

Make	N	% Dist	PD @ 3-gal/hr	Pd @ 5-gal/hr
Gilbarco	3	2.5	100.0	100.0
Incon	9	7.4	66.7	77.8
Red Jacket	17	13.9	76.5	76.5
Veeder-Root	92	76.2	69.6	75.0
Total	121	100.0	71.1	76.6

Figure 3.2.2b ELLD Detection Rates at 3 and 5-gal/hr by Manufacturer



3.2.3 ELLD Results at 3-gal/hr by Other Factors

Several other variables were recorded about ELLD tests. These included characteristics of the piping (length, material, number of walls) and type of pump used to move product from the tank to the dispenser. The probability of detecting a simulated leak of 3-gal/hr can be evaluated based on each of these factors. The proportion of correct leak detections for each of these factors is presented in the following Tables.

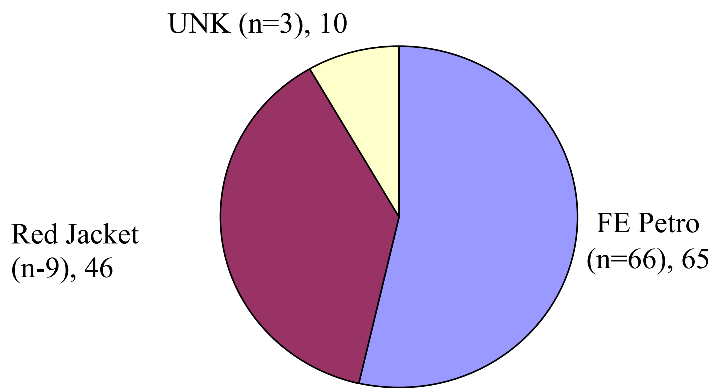
Turbine Pump Manufacturer

The ELLD systems were combined with different makes of turbine pumps, which move product from the tank to the dispensers. The distribution of ELLD tests by turbine manufacturer is shown in Table 3.2.3a and Figure 3.2.3a. Only two manufacturers of turbines were encountered in this study, FE Petro and Red Jacket, although there were some tests with unknown maker of the turbine.

Table 3.2.3a ELLD Tests @ 3-gal/hr, by Turbine Manufacturer

Turbine	N	Percent
FE Petro	65	54
Red Jacket	46	38
UNK	10	8
Total	121	100

Figure 3.2.3a Distribution of ELLD Tests by Turbine Manufacturer



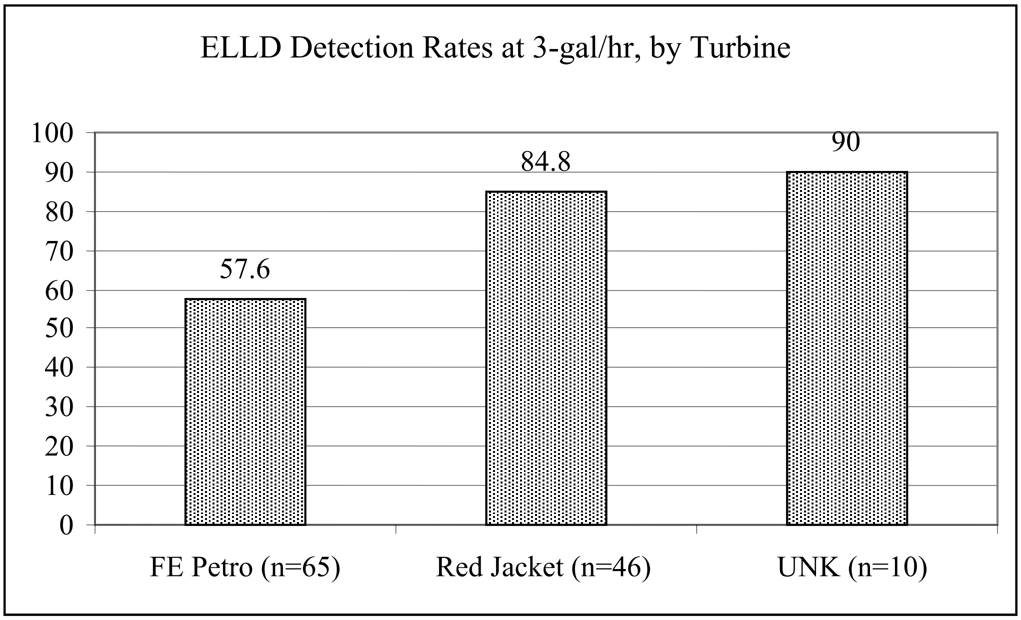
For the 3-gal/hr leak rate, a substantial difference in performance was found associated with turbine manufacturer. This is illustrated in Figure 3.2.3b, which shows the detection rate by simulated leak rate and by turbine manufacturer. Note that for the 3-gal/hr leak rate, the detection rate was 85% for ELLDs with Red Jacket turbines but considerably less, 58%, with FE Petro turbines. This difference was statistically significant at the 5% significance level.

Most of the missed detections were a combination of a Veeder-Root PLLD with a FE Petro turbine pump. This can be seen in Figure 3.2.3b, which has detection rates by combination of ELLD maker and turbine. The FE Petro turbine has been found to have a siphon jet assembly that sometimes fails, which can cause the Veeder-Root PLLD to fail to detect a leak. Veeder-Root has issued a maintenance bulletin on this, but results of this field study seem to indicate that some systems have not been checked.

Table 3.2.3b ELLD Detection Rates at 3-gal/hr, by Turbine

Turbine	Pd @ 3-gal/hr	N =
FE Petro	57.6	65
Red Jacket	84.8	46
UNK	90.0	10

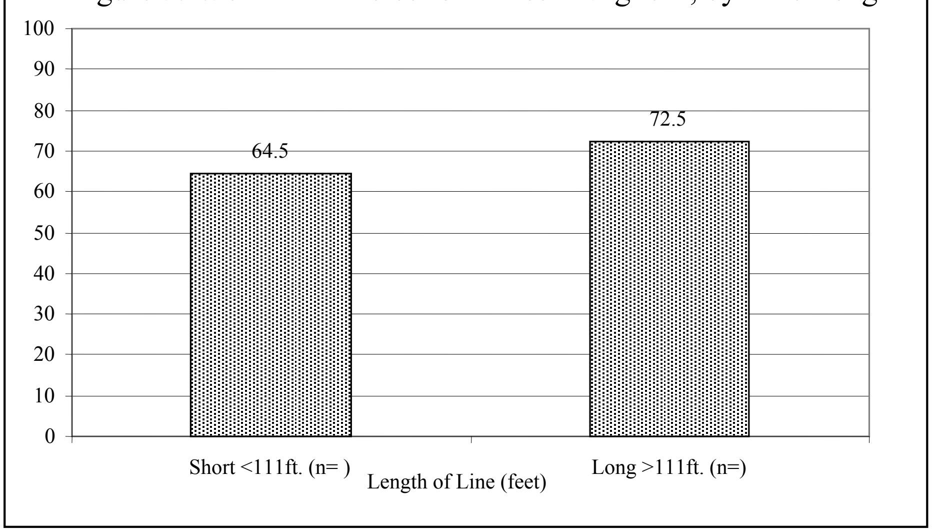
Figure 3.2.3b ELLD Detection Rates at 3-gal/hr by Turbine Type



Length of Piping Being Monitored

The detection rates were considered in relation to the length of the line. The lines were divided into short (less than 110 feet) and long (more than 110 feet). Figure 3.2.3c displays the results. Somewhat surprisingly, higher detection rates were found for the longer lines.

Figure 3.2.3c ELLD Detection Rates at 3-gal/hr, by Line Length



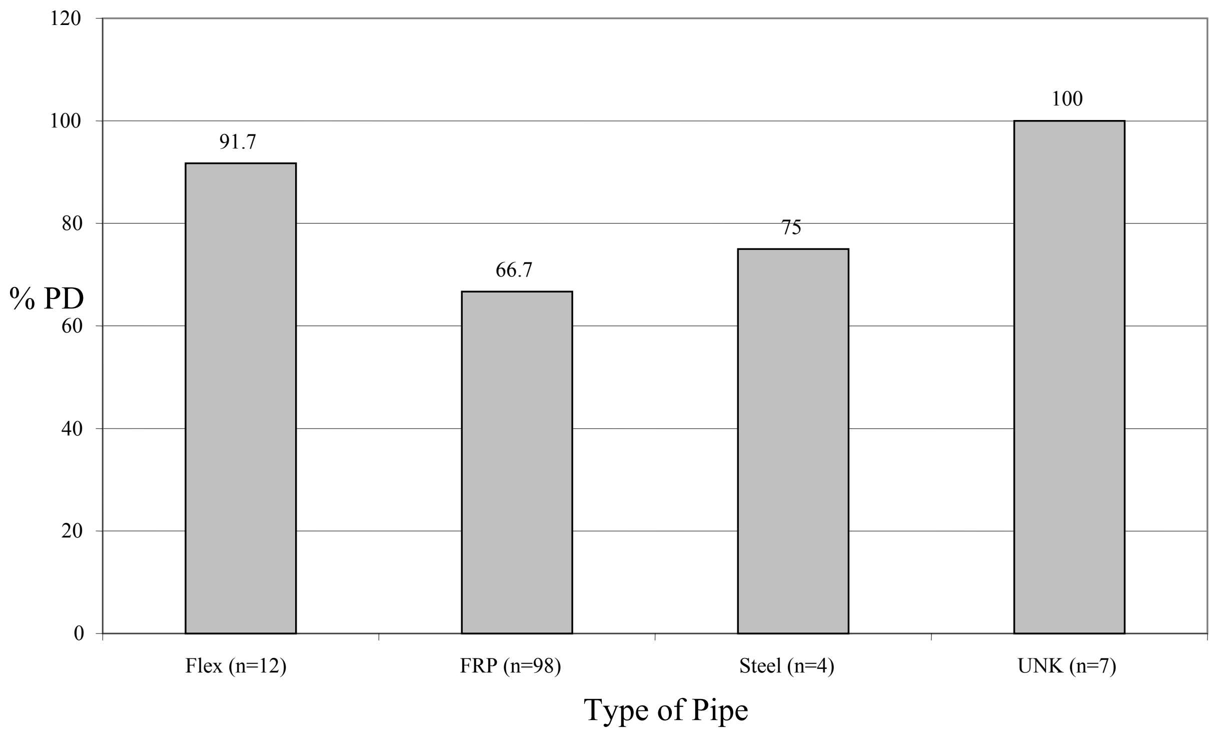
Piping Material

Three types of piping material were encountered in this study: flexible polymer, rigid fiberglass, and rigid steel. There were also 7 lines where the piping material could not be identified, which were classified as "unknown." The detection rates were calculated separately for each of these material types. Somewhat surprisingly, the detection rate was highest on flexible polymer piping. The results are shown in Table 3.2.3c and Figure 3.2.3d.

Table 3.2.3c ELLD Detection Rates at 3-gal/hr, by Material

Material	Pd at 3-gal/hr	N
Flex	91.7	12
FRP	66.7	98
Steel	75.0	4
UNK	100.0	7

Figure 3.2.3d ELLD Detection Rate at 3-gal/hr by Pipe Material



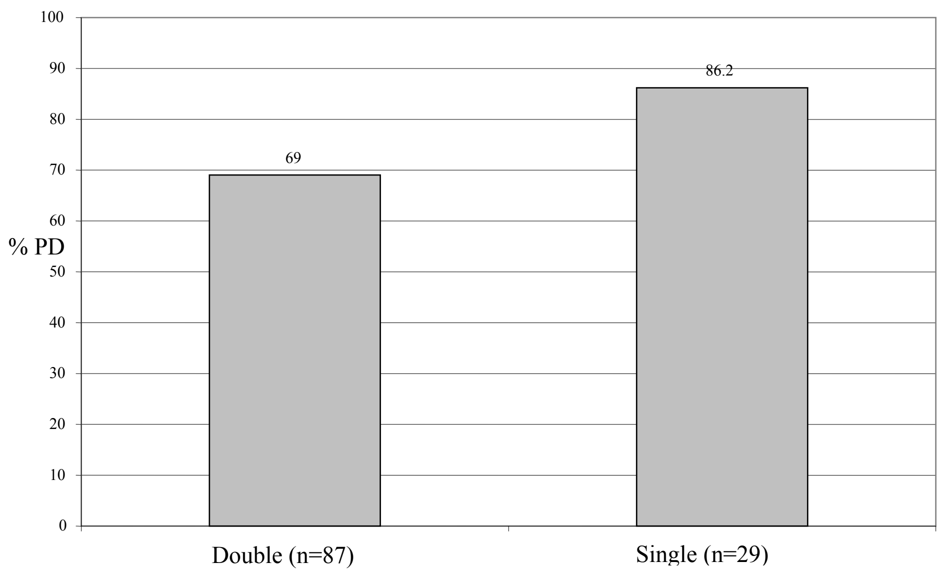
Single and Double-walled Piping

The type of piping, single or double walled, was also investigated in relation to the detection rate. In general, ELLD systems performed better on the single-walled pipes when testing to the 3-gal/hr leak rate. One possible reason for the difference in detection rates between the single and double walled pipes is that the line leak detectors were not the primary means of detection, since most of those systems monitored the interstitial space. Consequently the systems may not have received the normal maintenance or the attention that they receive when they are the primary means of leak detection as they are for single walled pipe systems. The detection rates are in Table 3.2.3d and are displayed in Figure 3.2.3e.

Table 3.2.3d ELLD Detection Rate at 3-gal/hr, by Number of Walls

Walls	Pd @ 3-gal/hr	N
Double	69.0	87
Single	86.2	29

Figure 3.2.3e Number of Pipe Walls



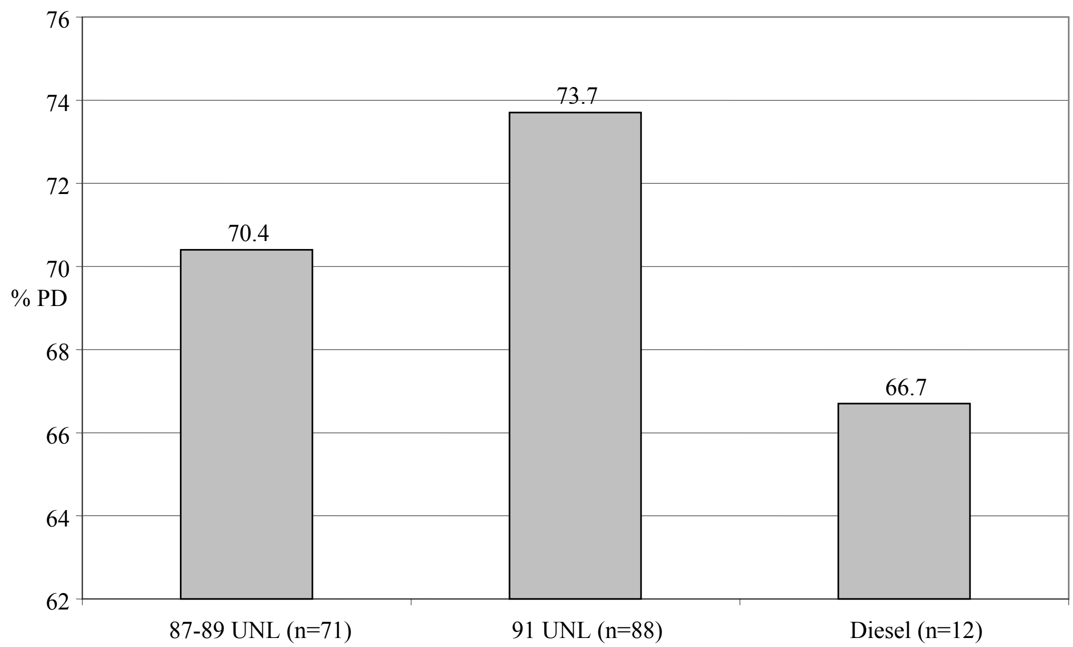
Product Stored in Piping

The detection rates for different products in the line were investigated. The rates for each size of leak are in Table 3.2.3e. They are also displayed in Figure 3.2.3f. Only a small difference in detection rate was observed between diesel, and differences between different grades of gasoline were not significant.

Table 3.2.3e ELLD Detection Rate at 3-gal/hr, by Product

Product	LR 3	N
87-89 UNL	70.4	71
91 UNL	73.7	88
Diesel	66.7	12

Figure 3.2.3f ELLD Detection Rates at 3-gal/hr by Stored Product



3.2.4 ELLD Results for Precision 0.2-gal/hr and 0.1-gal/hr Tests

A total of 20 tests were attempted in the annual (0.1-gal/hr) mode. One of these tests was aborted by a service mechanic who dispensed product. On another system, the tester was unable to get the system into the 0.1 test mode despite a lengthy consultation with the manufacturer. At one site, three lines were tested as the system was installed. On checking the set-up configuration, it was found that the line length was programmed incorrectly. The programmed length was changed and the three lines were retested. Only the first results were included. This left a total of 15 valid tests, of which 12 correctly detected the induced rate of 0.1-gal/hr. This is an overall detection rate of 80%.

Table 3.2.4 Manufacturers of ELLD Systems Tested at the 0.1-gal/hr Rate

Vendor	N	Percent
Veeder-Root	18	90
EBW	1	5
Gilbarco	1	5

A total of 35 tests were attempted in the 0.2-gal/hr or monthly mode. Two of these tests were aborted by fueling operations. Four additional tests were repeated tests on the same lines tested before, but after re-programming the ELLD. These four tests were dropped from analysis so that the data would represent the condition of the electronic line leak detectors as found in the field. Of these remaining 29 tests, the induced leak was correctly detected in 21 of the tests, for an overall detection rate of 72.4%.

The largest difference (which was significant at the 5% level) was by line length. The shorter lines had the lower detection rate (57.1% compared to 100%), which was unexpected. The 8 cases where the ELLD failed to detect the induced leak are worthy of some comment. There was only one case where the ELLD was set up correctly, but missed the detection. For two of the tests it was found that the ELLD had been wired around and so could not test. Another site had a conflict with another pump and could only test if the other pump was quiet. One ELLD was incorrectly programmed and so did not test correctly. One site had three lines, but only 2 were programmed into the ELLD. Finally, one test was conducted on a new line with lots of trapped air and gave an incorrect result. Thus, the most common problem was some sort of incorrect installation, which accounted for 6 of the missed detections, 7 if the new line with trapped vapor is also considered an installation problem. If these were excluded, the ELLD correctly detected 21 of 22 induced leaks, or 95.5% when correctly installed and programmed.

There were several other factors that could affect the results. These included the product in the line, the length, the line material, single or double walls, the turbine, and the manufacturer.

Two factors in particular were found to be associated with different detection rates. When the type of line, flexible or rigid, was considered, the ELLD systems on the flex lines only detected the induced leak a third of the time, while the rigid lines (FRP, steel, and unknown) detected the leak 82.6% of the time. There were only 6 tests on flex lines, so this result may be viewed with some caution. However, the difference was statistically significant at the 5% level.

The other factor that was statistically significant at the 5% level was the product in the line. The ELLD correctly detected the leak only 30% of the time (3 out of 10) on diesel lines, while it correctly detected the leak about 95% of the time (18 out of 19) on the gasoline lines.

There were some other differences that were large enough to be interesting, but did not reach statistical significance. For example, the ELLD did not seem to do as well on double-walled pipe as on single-walled pipe. However, since double-walled pipe usually does not rely on the ELLD for leak detection (usually the interstitial space between the walls is monitored), these tests may have failed to detect the leak because they were not set up or programmed correctly.

3.2.5 Comparison to Results of Third-party Evaluation per EPA Protocol

Federal and California regulations require that all leak detection equipment, including ELLDs, be evaluated by an independent third-party testing organization in accordance with recognized protocols designed to determine if the equipment is capable of meeting minimum performance parameters. While many of the test conditions during third-party evaluations are more rigorous than those typically present in real-world environments, there are numerous real-world variables that cannot be included during third-party evaluations. One objective of this study was to compare ELLD functionality under field conditions and compare this with the specifications outlined in their third-party certifications.

The EPA performance standards specify that the ELLD systems must be capable of detecting a leak of 0.2-gal/hr with a probability of at least 95% when operating in the monthly monitoring mode. The false alarm rate is specified to be less than 5%. No information is available in this study on the false alarm rate. Testing concentrated on simulating leaks to determine if the system could detect them.

Overall, the ELLD systems testing at the 0.2-gal/hr simulated leak rate detected the rate in 21 of 29 valid tests, or 72%. Of the 8 tests that failed to detect the simulated rate, 7 were found to have been incorrectly installed or set up. Of the 22 cases where the ELLD was installed and correctly set up, the leak was correctly detected in 21 of these or 95.4%. Thus, when correctly installed and programmed, the ELLD appeared to detect the 0.2-gal/hr leak rate consistently with the EPA performance standard.

When operated as an annual test, the ELLD systems must be capable of detecting a leak of 0.1-gal/h with 95% probability. Again, a false alarm rate of 5% is specified. When tested with a simulated leak rate of 0.1-gal/h, 12 of 15 valid tests detected the leak for a rate of 80%. While this is somewhat lower than the required detection rate of 95%, the number of tests was too small for this result to differ significantly at the 5% significance level from 95%. Thus, although the estimated rate is lower than the EPA standard of 95%, it is still consistent with that standard.

There is no specific detection criterion for ELLD systems designed to detect a 3-gal/hr leak. These systems are supposed to be capable of detecting a 3-gal/hr leak within an hour. In general, third party evaluators have tested ELLD systems operating in this mode to determine if they can detect a 3-gal/hr leak rate with a 95% probability of detection. Most evaluations have indicated this performance. The overall detection rate of a 3-gal/hr leak by the ELLD systems was only 71%, substantially less than the EPA standard. A number of the systems that failed to detect the 3-gal/hr leak were tested at successively larger leaks and were found to detect a leak at a somewhat larger rate, which ranged from 3.34 to 8.94 and averaged 6.01-gal/hr. In fact, 92 out of 101 tests with detectable leaks found a leak rate of 5-gal/hr or less. One hundred and one of the 121 tests or 83% found some detectable leak.

Some of the tests for which the ELLD failed to detect the leak were found to be caused by faulty installation or programming. Several of the failures to detect were found to occur in a combination of an FE Petro turbine and a Veeder-Root PLLD system. The FE Petro turbine has a siphon jet assembly that can fail, causing the PLLD to miss leaks. Veeder-Root has issued maintenance bulletins to correct this problem. It appears that some of these systems could be programmed to use a lower threshold in the 3-gal/hr test mode and then could find a leak of 3-gal/hr. However, the overall rate of detection of some large leak of 83% was significantly lower than the EPA standard of 95%.

3.3 Mechanical Line Leak Detectors (MLLD)

There are three primary manufacturers of MLLD systems, each of which manufactures several models. This study attempted to include a sample of the MLLD makes and models commonly used. Table 3.3a has the MLLD systems included in this study, by manufacturer and model. Figure 3.3a shows the percent of MLLD tests by manufacturer. Figure 3.3b shows the percent of MLLD tests by specific model.

Table 3.3a MLLD by Manufacturer and Model

Manufacturer	Model	Number	Percent
FE Petro	MLD	12	14.6
	Unknown	1	1.2
FE Petro Total		13	15.9
Red Jacket	FX	3	3.7
	FX1V	10	12.2
	FX2V	2	2.4
	FX-Diesel	1	1.2
	Unknown	1	1.2
Red Jacket Total		17	20.7
Vaporless Manufacturing, Inc.	99 LD 2000	29	35.4
	LD 2000	20	24.4
	Unknown	3	3.7
Vaporless Manufacturing, Inc. Total		52	63.4

Figure 3.3a MLLD Systems by Manufacturer

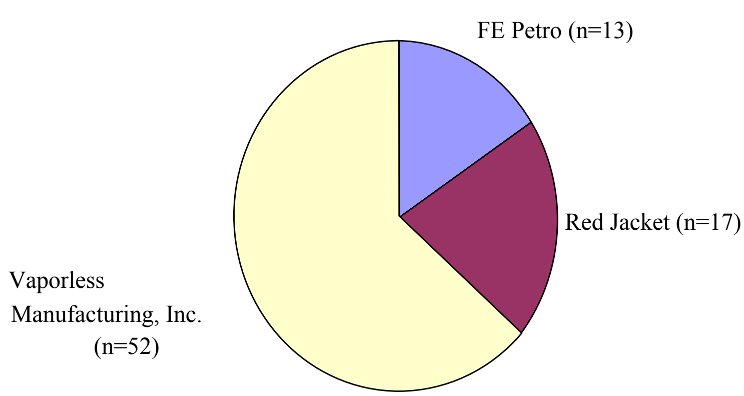
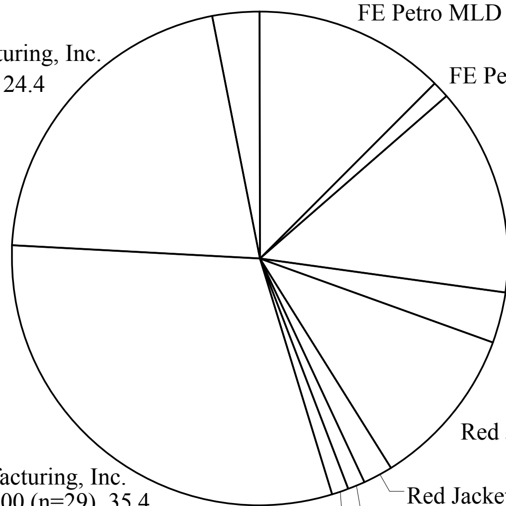


Figure 3.3b MLLD Tests by Model



3.3.1 Overall MLLD Performance

A total of 82 tests of MLLD systems were conducted. Each of the 82 MLLDs tested correctly moved into leak sensing position when the system pressure dropped, and each initiated a line test when the pump was activated.   A "no-leak" test was run on each MLLD to determine that it was functioning, and none of these 82 no-leak tests gave a false alarm. Of the 82 MLLDs tested with a simulated leak, 52 (63%) detected an induced leak at a rate of the regulatory standard 3-gal/hr or less. Of the 30 MLLD systems that failed to detect the leak rate of 3-gal/hr, 20 were able to detect leaks between 3 and 10-gal/hr. 10 of these 20 MLLDs (50%) detected a leak rate of between 3 and 5-gal/hr, while the other 10 (50%) detected a leak rate of between 5 and 10-gal/hr. Overall, 72 systems (87.8%) detected a leak rate of 10-gal/hr or less. These data are tabulated in Table 3.3.1 and displayed in Figure 3.3.1.

Figure 3.3.1 Overall MLLD Detection Results

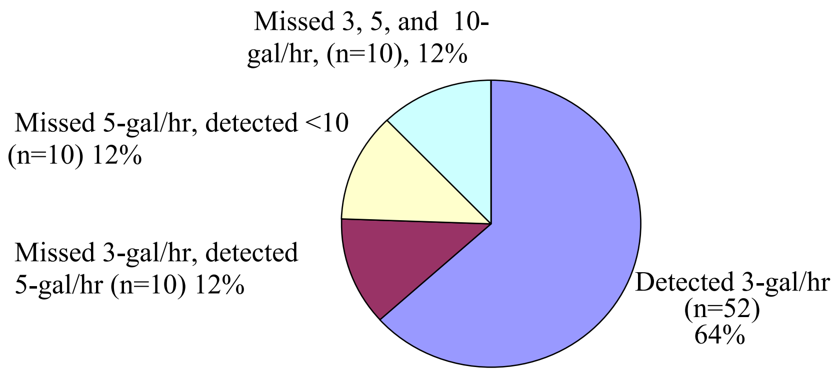


Table 3.3.1 Overall MLLD Detection Results

Result	Percent	N
Detected 3-gal/hr	63.4	52
Missed 3-gal/hr, detected ≤5-gal/hr (n=10)	12.2	10
Missed 5-gal/hr, detected ≤10	12.2	10
Missed 3, 5, and 10-gal/hr	12.2	10
Total	100.0	82

3.3.2 MLLD Results by Manufacturer

Three different vendors of MLLD systems have been tested. The leak detection rates for these three vendors varied from 58% up to 77% when the systems were tested at the regulatory standard of 3-gal/hr. Differences in the MLLD detection rate have been found by a number of line characteristics as well as by the MLLD make and model. Since the size of the line and other factors seem to affect the performance of the MLLD systems in the field, it is possible that the apparent differences by manufacturer could be the result of a differential association of these factors with the systems installed by one manufacturer. Results of detection of a 5-gal/hr leak rate are also shown. The results by vendor are tabulated in Table 3.3.2 and shown in Figure 3.3.2.

Figure 3.3.2 Leak Detection Results by Manufacturer

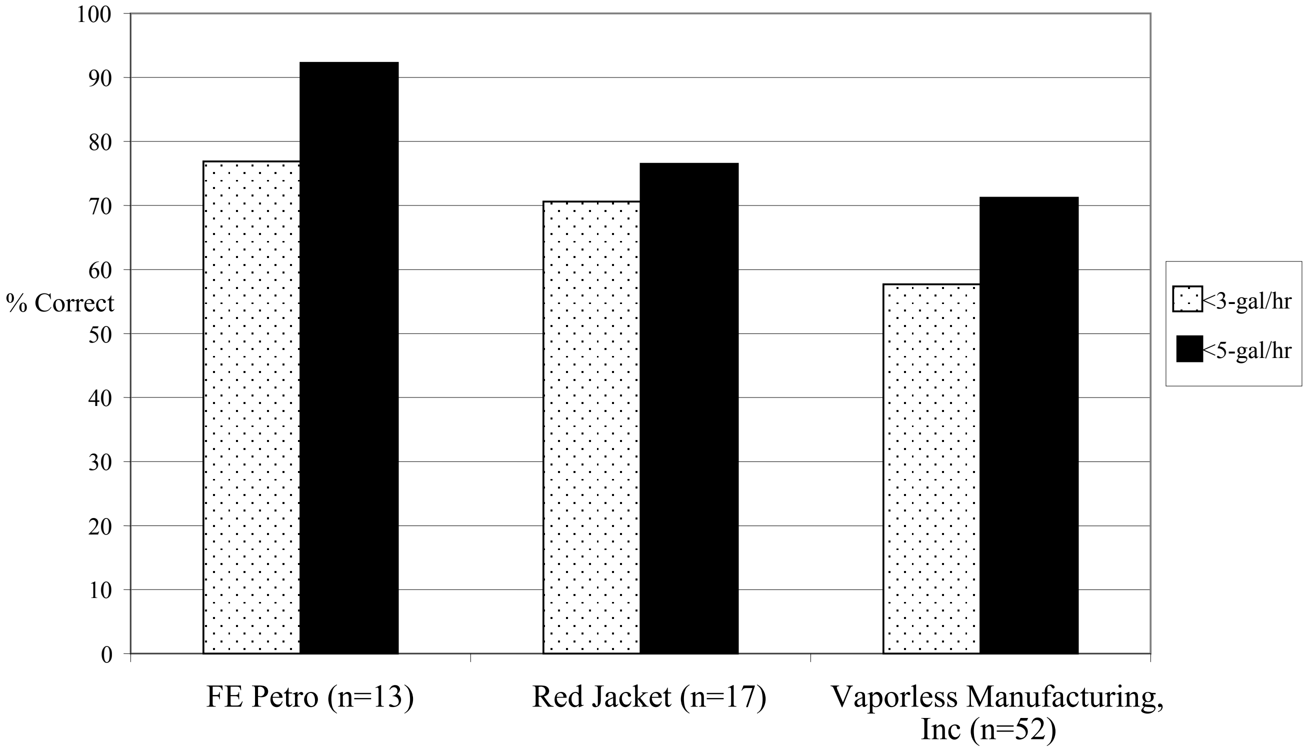


Table 3.3.2 MLLD Results by Manufacturer

Manufacturer	Correct	Detect 3-5-gal/hr	N	Percent Correct	% Detect < 5-gal/hr
FE Petro	10	2	13	76.9	92.3
Red Jacket	12	1	17	70.6	76.5
Vaporless Manufacturing, Inc.	30	7	52	57.7	71.2

3.3.3 MLLD Results by Other Factors

Several other variables were recorded for the MLLD tests. These included age of the MLLD, characteristics of the piping (length, material, number of walls), and type of pump used to move product from the tank to the dispenser. The probability of detecting a simulated leak of 3-gal/hr can be compared on each of these factors. The proportion of correct leak detections for each of these factors is presented in the following Tables. Some interesting differences in detection rates appeared, although in some cases the small number of tests for some groups means that these results should be interpreted with caution.

<u>Age of MLLD</u>

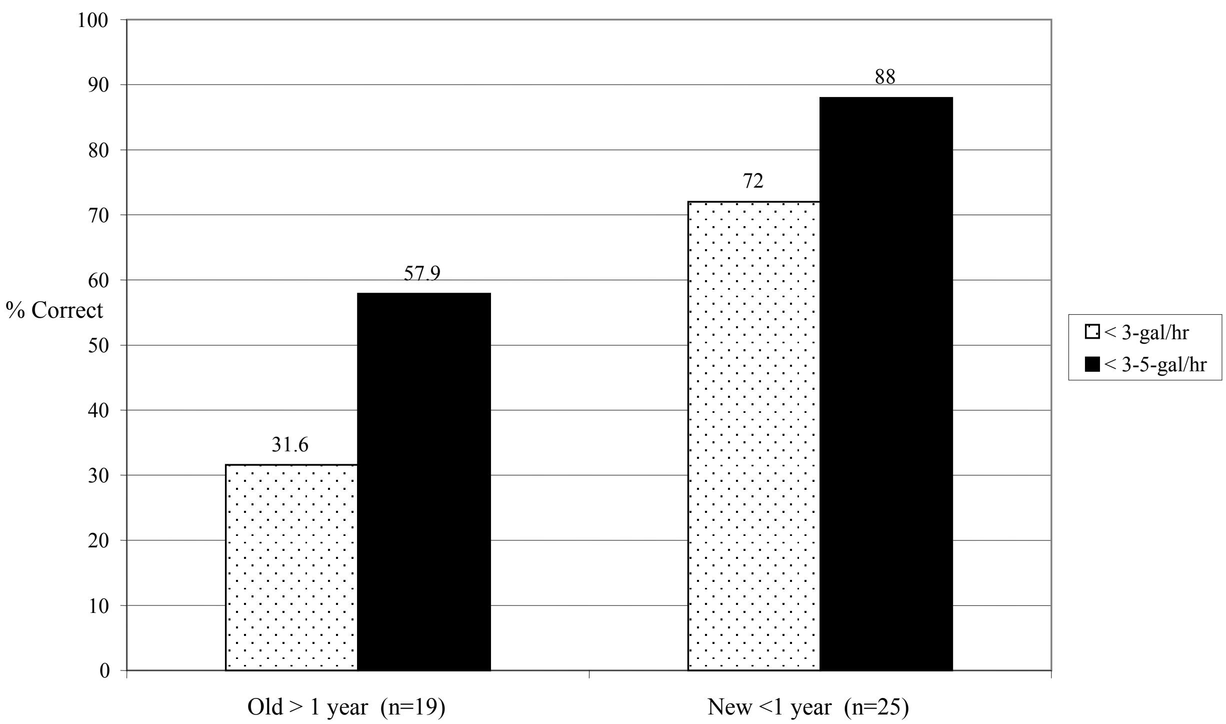
The age of the MLLD system was difficult to determine, and most of the 82 tested were of unknown age. To get information on the age of the system, the serial number on the system was recorded when possible. For Vaporless Manufacturing, it was possible to determine the date of shipment of the unit from the serial number. This data was compared with the test date and an age was imputed. Using the best available information on the age, 44 of the tests were conducted on systems with an age that could be estimated. In many cases a new unit was installed concurrently with the testing.

The systems were classified as "new" if they were one year old or less and "old" if they were older than that. The data on age are presented in Table 3.3.3a. Figure 3.3.3a has the leak detection results by age. As expected, older MLLDs showed a lower rate of detection than newer MLLDs.

Table 3.3.3a Leak Detection Results by Age of MLLD

Case	LD<3	LD 3-5	N	% LD<3	% LD3-5
Old	6	5	19	31.6	57.9
New	18	4	25	72	88.0
Total	24	9	44	54.5	70.5

Figure 3.3.3a Leak Detection Results by Age



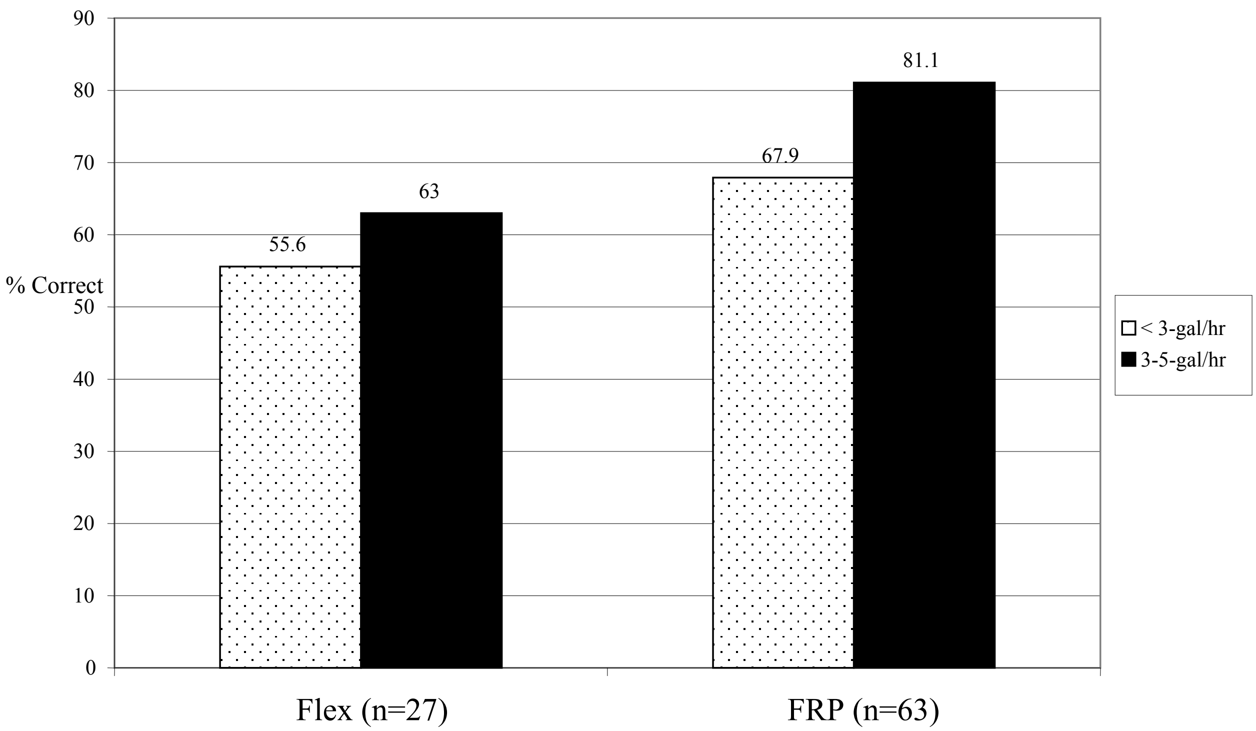
Piping Material

MLLD systems react to pressure changes in a piping system, so the degree to which piping expands when pressurized can impact MLLD performance. Only two types of material were found in this study: rigid fiberglass (FRP) and flexible polymer. (Two of the tests were performed on pipelines of unknown material.) The results by different materials are shown in Table 3.3.3b. The results are displayed graphically in Figure 3.3.3b.

Table 3.3.3b MLLD Leak Detection by Pipe Material

Material	#LD<3	#LD<5	N	% LD<3	%LD<5
Flex	15	17	27	55.6	63.0
FRP	36	43	53	67.9	81.1
UNK	1	2	2	50.0	100.0

Figure 3.3.3b MLLD Leak Detection Results by Pipe Material



Single and Double-walled Piping

California regulations require that LLDs on single-walled piping must shut down the turbine pump when a leak is detected or the LLD is disconnected. These requirements are met by ELLDS only, not MLLDs. Accordingly, no data was available for MLLD performance on single-walled piping.

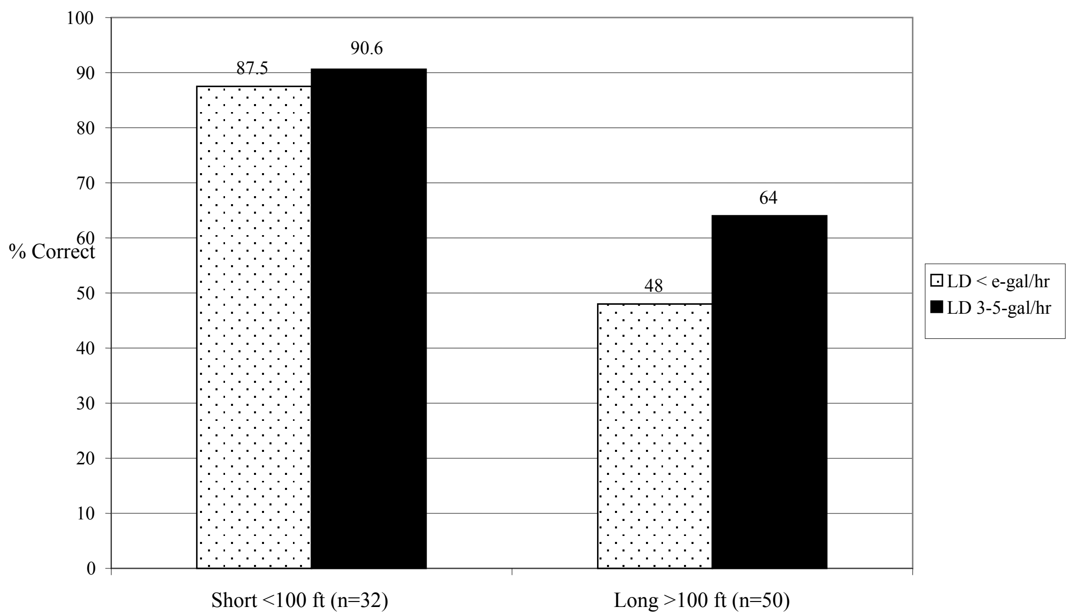
Piping Length

The length of the pipelines was classified as short if the pipeline was less than 100 feet in length. Piping 100 feet in length or greater was classified as long. The long pipelines ranged up to 350 feet. The detection rate at 3-gal/hr was significantly higher for the short pipelines than for the long ones, 87.5% compared to 48.0%. The difference in detection rates for 5-gal/hr leaks was somewhat smaller, but still important (90.6% for short lines compared to 64% for long lines). The results are tabulated in Table 3.3.3c and shown graphically in Figure 3.3.3c.

Table 3.3.3c MLLD Results by Line Length

Line Length	LD < 3	LD <5	N	% LD <3	% LD <5
Short (<100 ft.)	28	29	32	87.5	90.6
Long (>100 ft.)	24	32	50	48.0	64.0

Figure 3.3.3c MLLD Leak Detection Results by Length of Pipeline



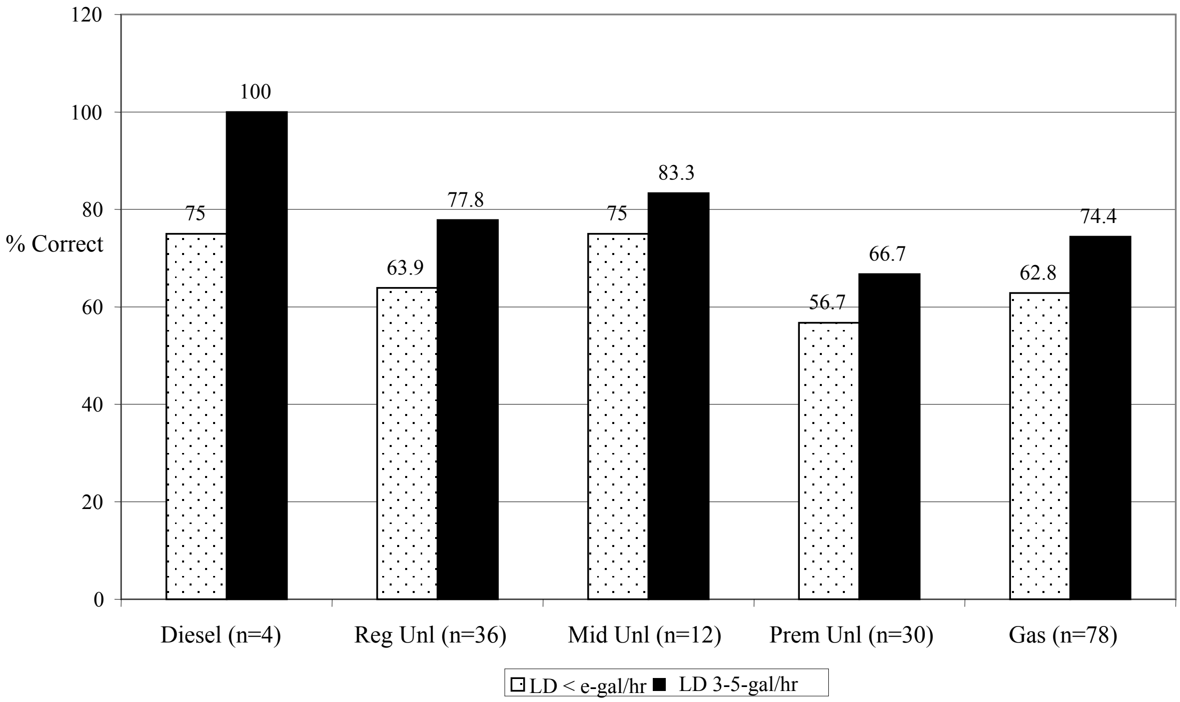
Product Stored

The product in the lines was classified into diesel, regular unleaded (87 octane), mid-grade unleaded (89 octane), and premium unleaded (91 or more octane). Only 4 lines contained diesel, so the results for diesel are not significant. Among lines with gasoline, the MLLD systems with mid-grade product had the highest detection rate, but the fewest tests. The data are in Table 3.3.3d and are displayed in Figure 3.3.3d.

Table 3.3.3d   MLLD Detection Rates, by Product

Product	#DL<3	#DL <5	N	% DT<3	%DT<5
Diesel	3	1	4	75.0	100.0
Reg Unl	23	5	36	63.9	77.8
Mid Unl	9	1	12	75.0	83.3
Prem Unl	17	3	30	56.7	66.7
All Unl	49	9	78	62.8	74.4

Figure 3.3.3d MLLD Detection Rate by Product Stored



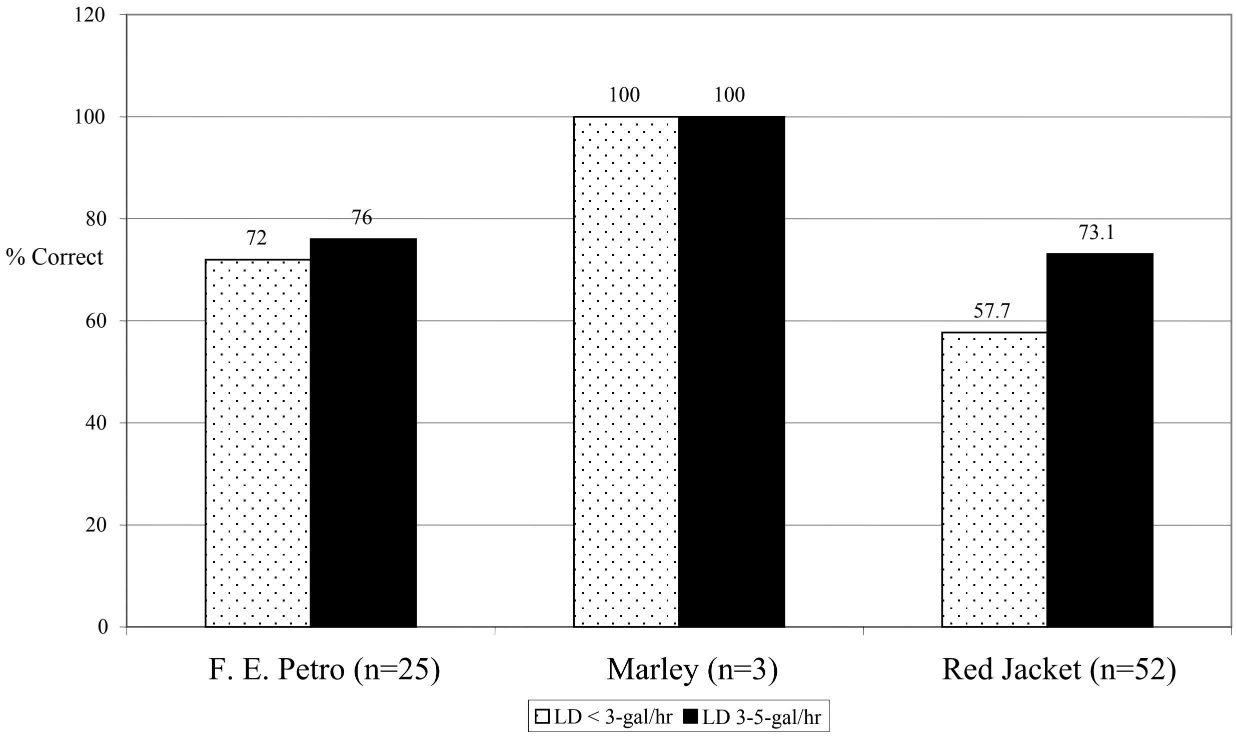
Turbine Pump Manufacturer

MLLDs are typically installed in the head of the turbine pump, and they respond to changes in line pressure generated by the pump. It stands to reason that pump operation could impact MLLD performance. There were 3 manufacturers of turbine pumps encountered in this study, and results of MLLD performance with each of these manufacturers' pumps are tabulated in Table 3.3.3e and shown graphically in Figure 3.3.3e.

Table 3.3.3e MLLD Results by Turbine Manufacturer

Turbine	LD<3	LD<5	N	% LD <3	% LD <5
F. E. Petro	18	19	25	72.0	76.0
Marley	3	3	3	100.0	100.0
Red Jacket	30	38	52	57.7	73.1

Figure 3.3.3e MLLD Results by Turbine Manufacturer



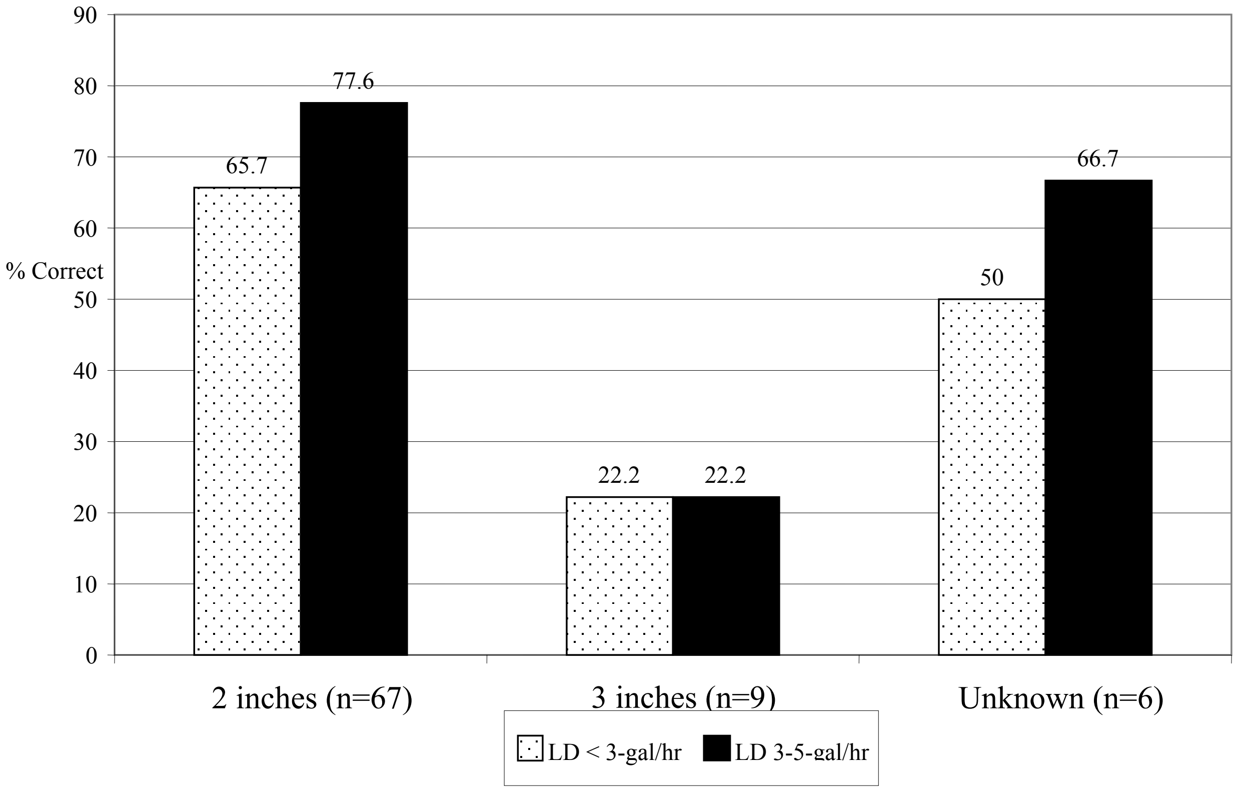
Diameter of Piping

Most of the lines with MLLD systems were 2 inches in diameter. There were two that were one and one-half inches in diameter, 9 that were 3 inches in diameter, and 6 that were of unknown diameter. The MLLD systems detected about 66% of the 3-gal/hr leaks in the smaller lines, while they only detected 22% of the leaks in the 3-inch lines. While the number of larger, 3-inch, lines was small, this is a fairly dramatic difference and suggests that the MLLD systems may have a problem with the larger lines. The data are tabulated in Table 3.3.3f and graphed in Figure 3.3.3f.

Table 3.3.3f MLLD Results by Line Diameter

Line Diameter	# LD < 3	# LD < 5	N	% LD < 3	% LD < 5
2 inches	44	52	67	65.7	77.6
3 inches	2	2	9	22.2	22.2
Unknown	3	4	6	50.0	66.7

Figure 3.3.3f MLLD Detection Percentage by Line Diameter



3.3.4 Comparison of Results to Third-party Evaluations

Federal and California regulations require that all leak detection equipment, including MLLDs, be evaluated by an independent third-party testing organization in accordance with recognized protocols designed to determine if the equipment is capable of meeting minimum performance parameters. While many of the test conditions during third-party evaluations are more rigorous than those typically present in real-world environments, there are numerous real-world variables that cannot be included during third-party evaluations. One objective of this study was to compare MLLD functionality under field conditions and with the specifications outlined in their third-party certifications.

The EPA regulations did not specifically include a required probability of detection or probability of false alarm for MLLD systems, or for testing to the "hourly" test of 3-gal/hr. Most of the MLLD systems were evaluated according to the EPA line leak detection tests protocol. All of these systems are qualitative in that they do not report a leak rate, but merely indicate whether or not a gross leak was detected.

Most of the EPA evaluations indicated a 100% detection rate in the laboratory testing, combined with an estimated 0% false alarm rate. The findings in the field show a detection rate that is less than that reported in the evaluations, but a zero false alarm rate was observed. There may be a number of explanations for this. The systems in the field are required to be recalibrated on an annual basis, and it is not clear whether this was actually done. Systems in the field may not be maintained as well as needed. It is possible that the field testing may have been done under more severe conditions than the evaluation. However, these tests are generally not much affected by environmental conditions, so this seems unlikely to be the explanation. Since most of the systems in the field that did not detect the leak rate at 3-gal/hr did detect a somewhat larger leak rate (87.8% detected a rate of 10-gal/hr or less), it suggests that the systems that failed to detect the 3-gal/hr leak may not have been correctly calibrated.

3.3.5 Comparison of the 3-gal/hr and 0.2-gal/hr test results

A comparison of some interest is that of the 3-gal/hr (hourly) test to the 0.2-gal/hr (monthly) or the 0.1-gal/hr (annual) line tests. If the results of the 3-gal/hr test accurately predict the performance of the other tests, then functionality of the ELLD can be checked using the 3-gal/hr performance test. This is important, because the 3-gal/hr test can be done quite quickly, while the 0.2-gal/hr and 0.1-gal/hr tests require substantially longer times of the line out of service in order to complete the tests.

The data for comparison were somewhat limited. A total of 27 lines had both the 3-gal/hr and the 0.2-gal/hr test. Only 13 lines had both the 3-gal/hr and the 0.1-gal/hr test. Some of the lines, where taking the line out of service did not pose a hardship, had all 3 tests done.

Table 3.3.5a contains the data for comparing the results of the 3-gal/hr test and the 0.2-gal/hr ELLD line test on those lines that had both tests done. One site with 3 lines was found to have the ELLD programmed incorrectly for the line length and other parameters. The results in Table 3.3.5a for these 3 lines are after the programming was corrected. As can be seen in Table 3.3.5a, the results agreed on 22 out of 27 tests (82%). Further, it is possible that the 3 tests that gave invalid or inconclusive results might have given the correct result if they had been run again after the conditions stabilized. There is no data about false alarms in this study because the lines were all tested with an induced leak.

The ELLD systems correctly detected a leak of 0.2-gal/hr on 19 of the 21 (90.5%) lines where they correctly detected the 3-gal/hr leak. If the invalid test is dropped, the result is 19 out of 20 or 95%. There was a scattering of disagreements as can be seen in the table. This suggests that a test of the ELLD line leak detection system at the 3-gal/hr that shows that the system correctly detects the leak would indicate that the system would also function correctly in detecting leaks of 0.2-gal/hr.

Table 3.3.5a Comparison of 3-gal/hr and 0.2-gal/hr ELLD Results (after reprogramming)

3-gal/hr / 0.2-gal/hr	Detect (0.1-gal/hr)	Missed (0.1-gal/hr)	Invalid (0.1-gal/hr)	Total
Detect (3-gal/hr)	19	1	1	21
Missed (3-gal/hr)	1	1	2	4
Invalid (3-gal/hr)	0	0	2	2
Total	20	2	5	27

Table 3.3.5b contains the data for comparing the results of the 3-gal/hr test and the 0.1-gal/hr ELLD line test on those lines that had both tests done. One site with 3 lines was found to have the ELLD programmed incorrectly for the line length and other parameters. The results in Table 3.3.5b for these 3 lines are after the programming was corrected.

Table 3.3.5b Comparison of 3-gal/hr and 0.1-gal/hr ELLD Results (after reprogramming)

3-gal/hr / 0.1-gal/hr	Detect (0.1-gal/hr)	Missed (0.1-gal/hr)	Invalid (0.1-gal/hr)	Total
Detect (3-gal/hr)	9	0	2	11
Missed (3-gal/hr)	1	1	0	2
Invalid (3-gal/hr)	0	0	0	0
Total	10	1	2	13

There were 13 lines which had both a 3-gal/hr and a 0.1-gal/hr leak test. Of these, 11 detected the 3-gal/hr leak. Of these 11, 9 (82%) detected the 0.1-gal/hr leak. Two (18%) gave an invalid or inconclusive result when tested at 0.1-gal/hr. It is possible that the inconclusive results might have correctly identified the 0.1-gal/hr leak if tested again under different conditions as would be done in practice.

Thus, when programmed correctly, 82% of the systems that correctly detected a 3-gal/hr leak also found a 0.1-gal/hr leak. The others were inconclusive and might have detected the 0.1-gal/hr leak on a subsequent test.

Thus, based on the data in the study, if an ELLD is tested at the 3-gal/hr leak rate and detects it, there appears to be at least a 90% chance that it would also correctly detect a leak of 0.2-gal/hr and at least an 80% chance that it would correctly detect a 0.1-gal/hr leak. If lines with inconclusive results were retested, these probabilities would increase.

4.0 RECOMMENDATIONS

Based on the results of field testing, Ken Wilcox Associates issues the following recommendations to improve the overall effectiveness of ATG and line leak detection systems.

4.1 Functional Testing of Leak Detectors

A periodic functional test of tank and line leak detectors is important for effective and reliable leak detection. In cases where the leak detector is the primary method of leak detection to prevent line leaks of 3-gal/hr or larger, annual monitoring inspections and functional testing are crucial to maintaining effective and reliable leak detection. During the study, some line leak detectors were observed that were neither installed nor operating correctly. Periodic testing should be conducted to demonstrate that these line leak detectors are operational and that they can detect the appropriate leak rate.

Periodic functional testing of automatic tank gauging systems should become standard. This testing should include simulating a leak of about 0.2-gal/hr to demonstrate that the ATG can detect a leak. Annual functional testing would seem reasonable, although another periodic test could be applied. Such testing should determine whether or not the ATG was installed correctly.

4.2 Leak Simulation Standards

A standard practice for simulating leaks to test leak detectors needs to be approved by the state of California to provide a standard document that technicians and regulators can refer to. The understanding of leak detector functionality and of what constitutes a leak needs to be vastly improved. Common misconceptions exist amongst technicians and regulators as to what constitutes a leak and how a leak detector should be tested.

4.3 Technician and Regulator Training and Certification Requirements

During the study, it was observed that different service companies had different procedures for testing the functionality of the 3-gal/hr line leak detectors. Furthermore, the different service technicians had different understandings of what constituted a leak and how leak detectors should be tested. Different regulators also had different interpretations of the leak and how the line leak detectors should be tested. The understanding of leak detector functionality and of what constitutes a leak needs to be vastly improved. Common misconceptions exist amongst technicians and regulators as to what constitutes a leak and how a leak detector should be tested.

Training of technicians and regulators needs to be improved with respect to testing leak detectors. Very little understanding of the principles of leak simulation equipment was present amongst regulators. Numerous cases in which the technician improperly tested a leak detector were observed. In most cases that were observed during the field study, the regulator observing the technician performing the test had no understanding of the leak simulator’s operations or what was required. The lack of understanding is attributed to a lack of standards for field-testing and for equipment used in field-testing.

4.4 Leak Simulation Equipment Performance Requirements

Equipment that is used by technicians during third-party evaluations also needs to be improved. In many cases, the equipment used in annual monitoring inspections was not adequate enough to perform even a basic check of leak detector functionality. Furthermore, unsafe equipment was observed in several cases (See Case Study 9 in Appendix I).

5.0 CONCLUSIONS

For most leak detection modalities, the probability of detecting the leak of specified size in the field operations was estimated to be somewhat less than the 95% specified by the EPA regulations. However, in most cases, although the estimated rate of leak detection was somewhat less, it was not statistically significantly less than the 95% specified by EPA. The false alarm rate was only estimated for ATGs and MLLDs . Among the tests conducted with a zero leak rate, no false alarms were observed. Consequently, for ATGs and MLLDs, the false alarm rate was estimated as less (better) than the 5% rate specified by EPA.

California regulations require all leak detection equipment to be functionally tested and certified by an authorized service technician on an annual basis. Most of the data included in this report was collected from facilities that are inspected annually. Much of the data was even collected during routine annual testing and certification. It is important to note that federal regulations and other state UST programs do not require annual certification of monitoring equipment. The ATG and LLD performance reported in this report would likely differ from that in locations where there is no required annual certification of monitoring equipment.

5.1 ATG Testing

A number of ATG systems were found that were not being used for leak detection, since that was being accomplished by monitoring the interstitial space of a double-walled tank. These systems may not be maintained as well as those actively used for leak detection.

Overall, 86% of the valid ATG tests gave correct results. About 81% of the ATG tests with simulated leaks correctly detected the 0.2-gal/hr leak rate. No false alarms occurred among 21 tests with no simulated leak, so the estimated false alarm rate was zero percent.

Some ATG installations were found in tanks that exceeded the size for which the ATG had been certified. Some were found used in vertical-cylinder concrete tanks, which were field-constructed. The performance in these oversized and field-constructed tanks was worse than in the other tanks.

A number of factors were found to be associated with the detection rate of the ATG systems. These included the product (Lower percent detection was observed for jet fuel than for diesel or gasoline), the tank size (Lower percent detection was observed for tanks over 20,000 gallons), and worse detection was observed for concrete tanks than for fiberglass or steel tanks. The tank material—steel, fiberglass, or concrete—was confounded with the tank size, so it is unclear which of these factors affected the results.

To the extent that age could be determined, the age of the ATG did not appear to be associated with its performance.

Most of the ATG systems were made by one manufacturer, and had a somewhat better leak detection rate than the rest of the ATG systems.

Some of the associated testing interfered with testing the ATG. This included changes in product level, removal and replacement of ATG probes prior to the test, etc. In some cases, the ATG appeared to function correctly, but returned an "invalid" or "inconclusive" result for the test. This means that the system software determined a condition (for example, too recent a delivery or too rapid a temperature change) that led it to invalidate the test. While this meant that the system was not demonstrated to detect a leak, it also appeared to function correctly.

5.2 ELLD Testing

Electronic line leak detectors (ELLD) were all tested in the "hourly" (3-gal/hr) mode. In addition, many were tested in the monthly (0.2-gal/hr) mode and some in the annual (0.1-gal/hr) mode.

Overall, about 71% of the ELLD systems correctly detected the hourly leak rate of 3-gal/hr. This was slightly greater than the detection rate of about 63% for the MLLD (mechanical) systems.

Many of the failures of the ELLD systems to detect a leak of 3-gal/hr were found to be associated with an installation problem in that the system was not installed or programmed correctly. In addition, one combination of ELLD system and turbine was found that had an unusually large failure rate. This was traced to a failure of a particular part in the turbine. While the ELLD manufacturer has issued maintenance bulletins attempting to correct this, it does not appear that these have been acted upon appropriately.

In the annual (0.1-gal/hr) test mode, 80% of the systems tested detected the leak. While this appears low, it was not statistically significantly different from the 95% detection rate specified by the EPA performance standards. This was probably due to the small number (15) of valid tests.

In the monthly (0.2-gal/hr) test mode, the ELLD system correctly detected the leak in 21 of 29 valid tests or 72.4%. All but one of the missed detections was associated with an installation problem. Of the systems correctly installed and programmed, 21 of 22 or 95.5% correctly detected the simulated leak. This suggests that the systems did well when installed and programmed correctly. A test of the function of the ELLD would have detected many of the incorrect installations.

5.3 MLLD Testing

Overall, 63% of the MLLD systems tests correctly found the 3-gal/hr simulated leak. Many more detected a leak at a somewhat higher rate. Among the tests for which the detectable leak rate was determined, 87.8% detected a rate up to 10-gal/hr. These results suggest that some of the MLLD systems were not adjusted correctly. An adjustment or improved calibration might improve the detection of the 3-gal/hr leak rate. There were no false alarms observed among 82 tests, so the estimated false alarm rate was zero percent.

APPENDIX I – ANALYSIS OF FIELD DATA, SUMMARIZED BY SUB-GROUPS

This appendix contains limited test data, insufficient for reliable statistical analysis, but indicative of possibly interesting topics for future study.

1. ELLD data for 0.01-gal/hr leaks
2. ELLD data for 0.02-gal/hr leaks
3. Comparison of results from 0.2-gal/hr and 3.0-gal/hr tests

The scope of this study's work included analyzing field data by a variety of subsets. The intent of the detailed analysis was to identify specific factors that affect field performance of ATG and LLD systems. In many cases, data subsets were not large enough to yield statistically valid results. However, there may still be interest and value in analyzing data by subsets where the number of data points is not large enough for statistically valid results. The data subsets shown in this appendix cannot be relied upon to draw conclusions about the performance of leak detection equipment, but may be useful in identifying areas of focus for future field studies. Most of the data in this appendix is from the 0.1-gal/hr and 0.2-gal/hr pipeline tests. In most cases there was sufficient data from the 3.0-gal/hr tests to draw reliable conclusions.

ELLD Data for 0.10-gal/hr Leak Tests

The data for the 0.10-gal/hr line tests have been summarized below in Table I-1. This data has also been presented in the bar graphs following the table. In most cases, few reliable conclusions can be supported.

Table I-1. ELLD 0.1-gal/hr Results by Different Factors

Factor	Number of Tests	Successful Detections	Detection Percentage
Product Stored			
Regular Unleaded	8	8	100.0
Premium Unleaded	5	4	80.0
All gasoline	13	12	92.3
Diesel	2	0	0.0
Piping Length			
Short (<110 ft.)	7	4	57.1
Long (>110 ft.)	8	8	100.0
Piping Diameter			
1.5 inches	3	2	66.7
2 inches	12	10	83.3
Piping Material			
Flexible	3	2	66.7
Fiberglass	12	10	83.3
Piping Wall			
Double	8	7	87.5
Single	7	5	71.4
Turbine Manufacturer			
FE Petro	5	4	80.0
Red Jacket	5	3	60.0
Unknown	5	5	100.0

Figure I-1. ELLD Detection Rate at 0.1-gal/hr, by Stored Product

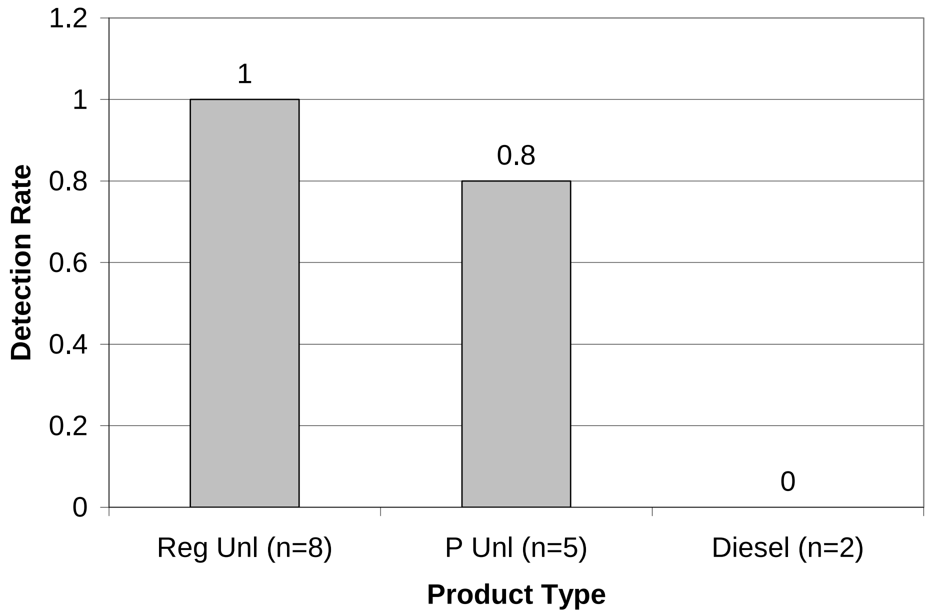


Figure I-2. ELLD Detection Rate at 0.1-gal/hr, by Line Length

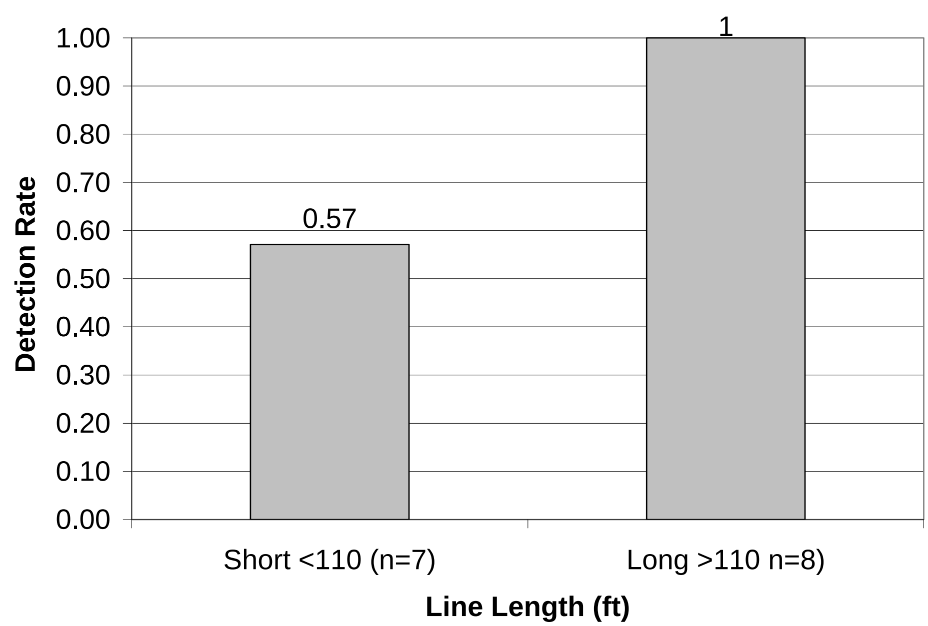


Figure I-3. ELLD Detection Rate at 0.1-gal/hr, by Line Diameter

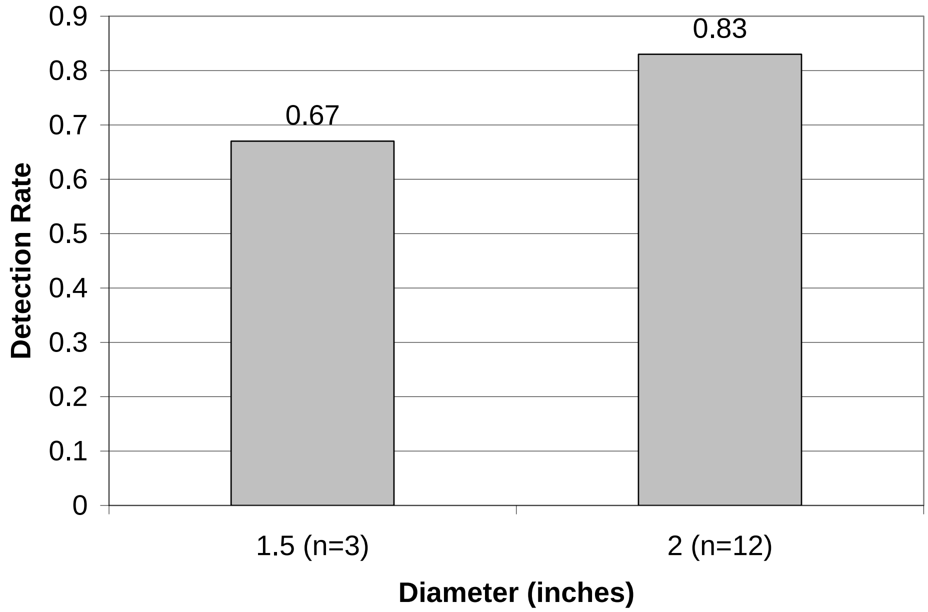


Figure I-4. ELLD Detection Rate at 0.1-gal/hr, by Pipe Material

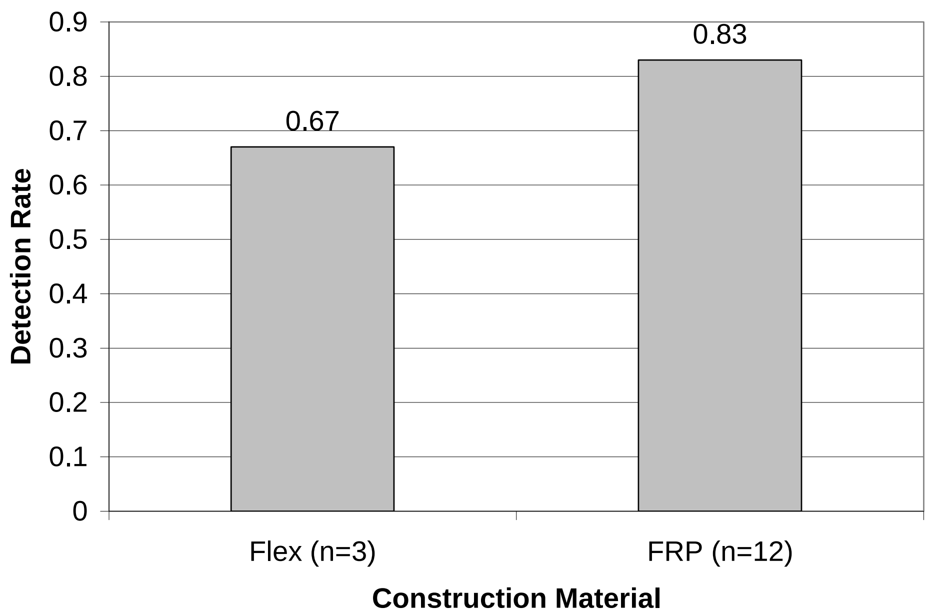


Figure I-5. ELLD Detection Rate at 0.1-gal/hr, by Single- or Double-Walled Pipe

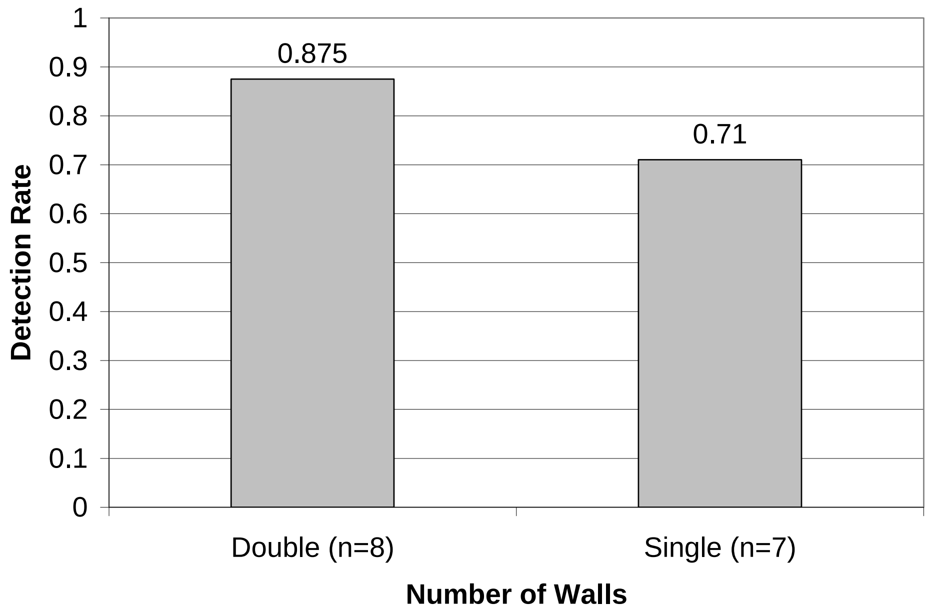


Figure I-6. ELLD Detection Rate at 0.1-gal/hr, by Turbine Manufacturer

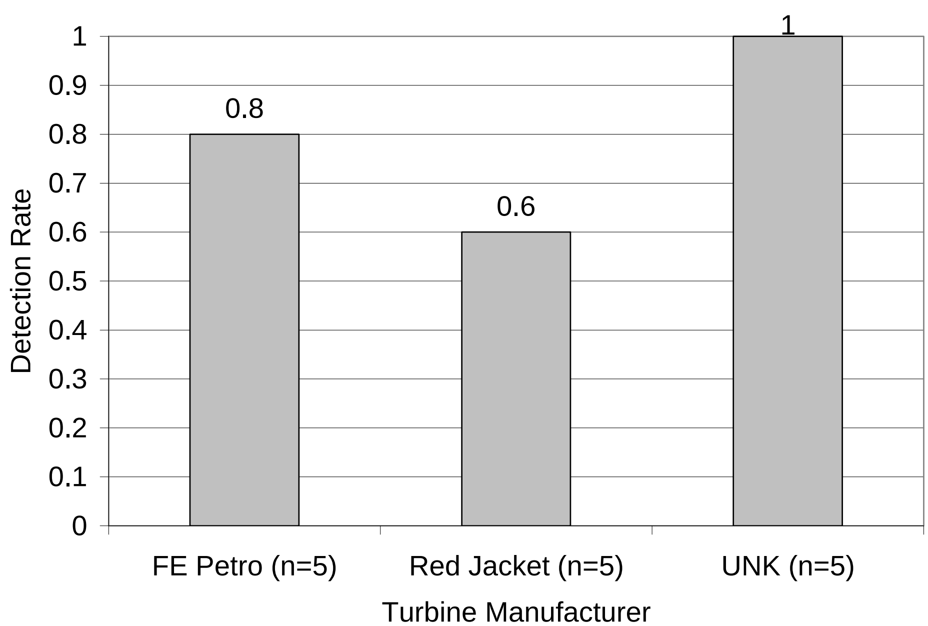


Table I-2. Distribution of ELLD Tests at 0.1-gal/hr, by Make and Turbine Combination

Make / Turbine	N	Pct Detect	Distribution
Gilbarco / FE Petro	1	100.0	3.4
Gilbarco / Red Jacket	2	100.0	6.9
Incon / FE Petro	2	100.0	6.9
Incon / Red Jacket	6	66.7	20.7
Red Jacket / Red Jacket	2	0.0	6.9
Veeder-Root / FE Petro	7	71.4	24.1
Veeder-Root / Red Jacket	8	75.0	27.6
Veeder-Root / Unknown	1	100.0	3.4
Total	29		100

Figure I-7. ELLD Detection Rates at 0.1-gal/hr, by Make and Model

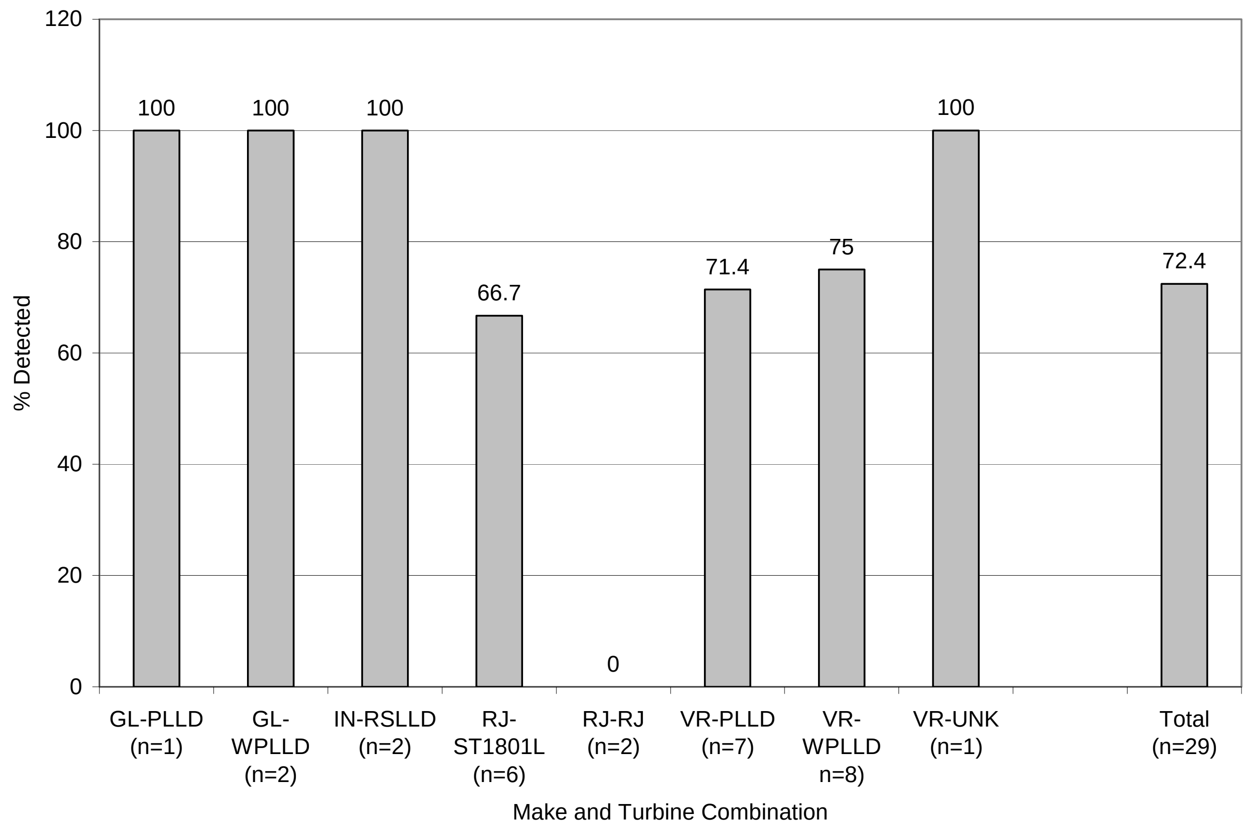
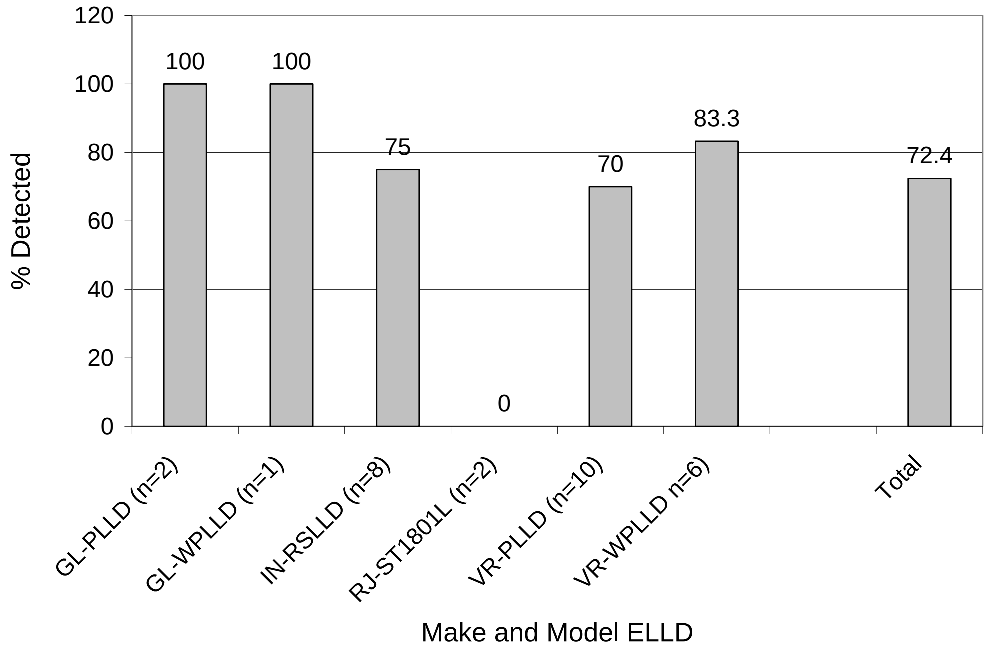


Table I-3. Distribution of Tests at 0.1-gal/hr by Make and Model Combination

Make / Model	Pct Detect	N	Distribution
Gilbarco / PLLD	100.0	2	6.9
Gilbarco / WPLLD	100.0	1	3.4
Incon / RSLLD	75.0	8	27.6
Red Jacket / ST1801L	0.0	2	6.9
Veeder-Root / PLLD	70.0	10	34.5
Veeder-Root / WPLLD	83.3	6	20.7
Total	72.4	29	100.0

Figure I-8. Distribution of Tests by Make and Model Combination



ELLD Data from 0.20-gal/hr Leak Tests

Table I-4 ELLD 0.2-gal/hr Detection Rates by Various Factors

Factor	Number of Tests	Successful Detections	Detection Percentage
Length			
Short (<110 ft.)	15	9	60.0
Long (>111 ft.)	14	12	85.7
Piping Material			
Flexible	6	2	33.3
Fiberglass	15	12	80.0
Steel	4	3	75.0
Unknown	4	4	100.0
Piping Walls			
Double	9	5	55.6
Single	20	16	80.0
Turbine Manufacturer			
FE Petro	15	10	66.7
Red Jacket	13	10	76.9
UNK	1	1	100.0
Product Stored			
87-89 UNL	11	10	90.9
91 UNL	8	8	100.0
All Gasoline	19	18	94.7
Diesel	10	3	30.0
ELLD Manufacturer			
Gilbarco	3	3	100.0
Incon	8	6	75.0
Red Jacket	2	0	0.0
Veeder-Root	16	12	75.0

The largest difference (which was significant at the 5% level) was by line length. The shorter lines had the lower detection rate (57.1% compared to 100%), which was unexpected. The 8 cases where the ELLD failed to detect the induced leak are worthy of some comment. There was only one case where the ELLD was set up correctly, but missed the detection. For two of the tests it was found that the ELLD had been wired around and so could not test. Another site had a conflict with another pump and could only test if the other pump was quiet. One ELLD was incorrectly programmed and so did not test correctly. One site had three lines, but only 2 were programmed into the ELLD. Finally, one test was conducted on a new line with lots of trapped air and gave an incorrect result. Thus, the most common problem was some sort of incorrect installation, which accounted for 6 of the missed detections, 7 if the new line with trapped vapor is also considered an installation problem. If these were excluded, the ELLD correctly detected 21 of 22 induced leaks, or 95.5% when correctly installed and programmed.

Two other factors in particular were found to be associated with different detection rates. When the type of line, flexible or rigid, was considered, the ELLD systems on the flex lines only detected the induced leak a third of the time, while the rigid lines (FRP, steel, and unknown) detected the leak 82.6% of the time. There were only 6 tests on flex lines, so this result must be viewed with some caution. However, the difference was statistically significant at the 5% level.

The last factor that was statistically significant at the 5% level was the product in the line. The ELLD correctly detected the leak only 30% of the time (3 out of 10) on diesel lines, while it correctly detected the leak about 95% of the time (18 out of 19) on the gasoline lines.

There were some other differences that were large enough to be interesting, but did not reach statistical significance. These included the product in the line, the length, the line material, single or double walls, the turbine, and the manufacturer. Table 3.2.3.1 has the results of the comparison of detection rates for various factors. One additional example is that the ELLD did not seem to do as well on double-walled pipe as on single-walled pipe. However, since double-walled pipe usually does not rely on the ELLD for leak detection (usually the interstitial space between the walls is monitored), these tests may have failed to detect the leak because they were not set up or programmed correctly. The comparisons are also plotted in Figures 3.2.3.1 through 3.2.3.6.

Figure I-9. ELLD Detection Rate for 0.2-gal/hr, by Line Length

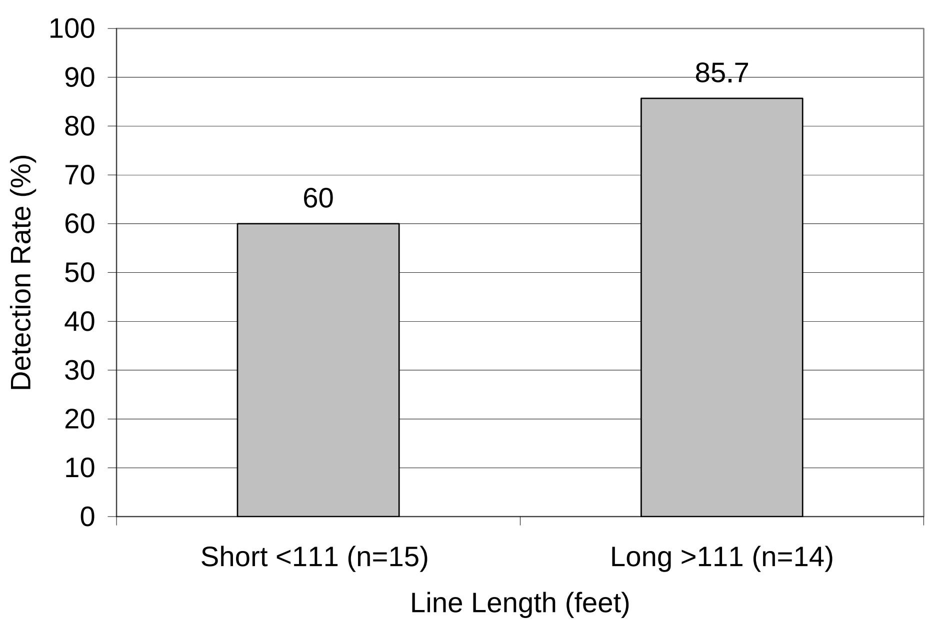


Figure I-10. ELLD Detection Rate for 0.2-gal/hr, by Pipe Material

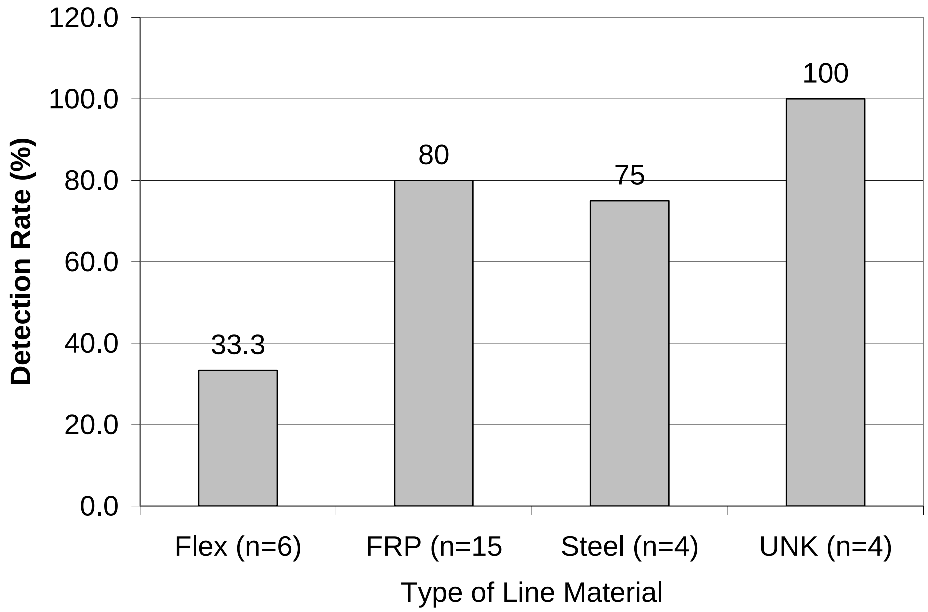


Figure I-11 ELLD Detection Rates for 0.2-gal/hr, by Single- or Double-Walled Pipe

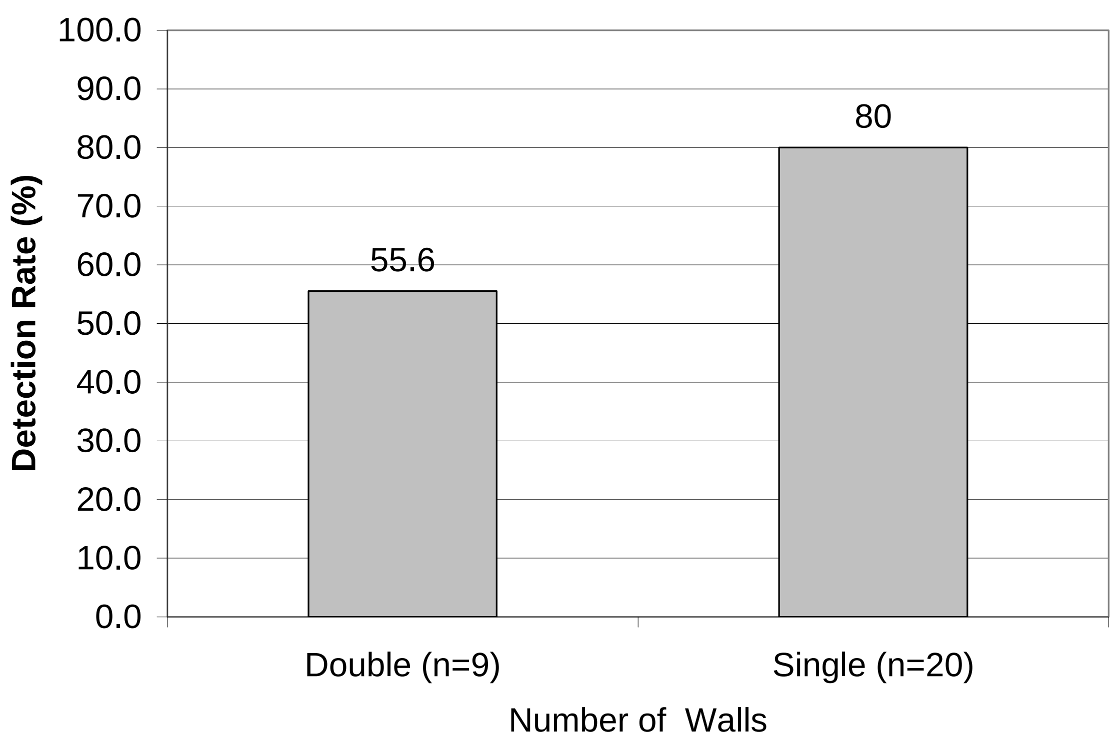


Figure I-12 ELLD Detection Rate for 0.2-gal/hr, by Turbine Manufacturer

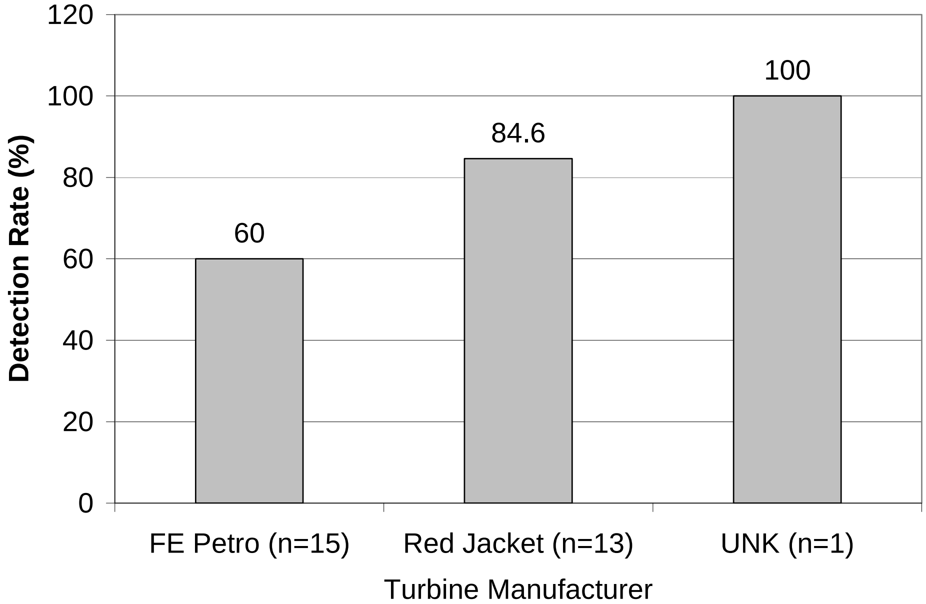


Figure I-13 ELLD Detection Rate at 0.2-gal/hr, by Product Stored

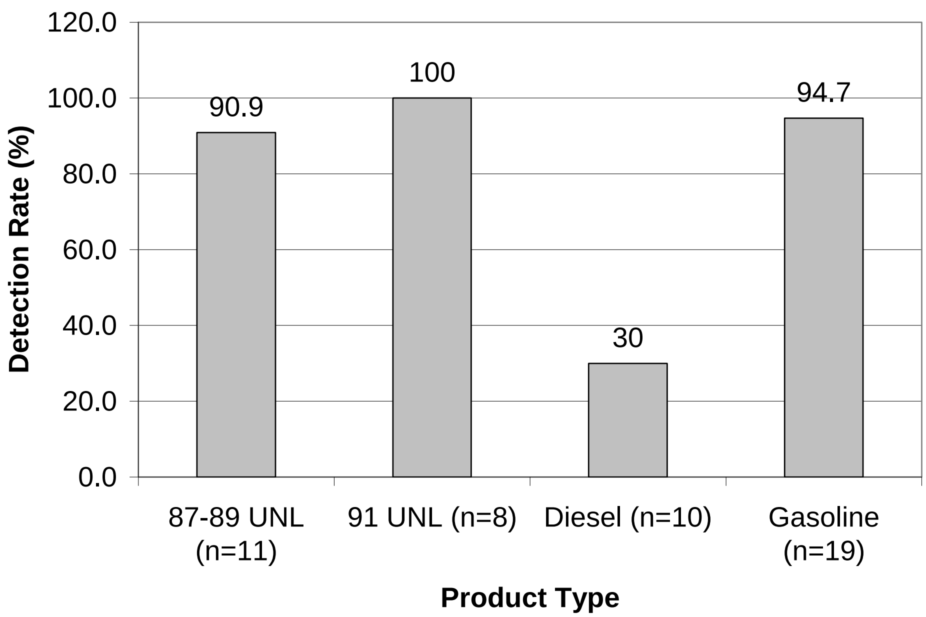
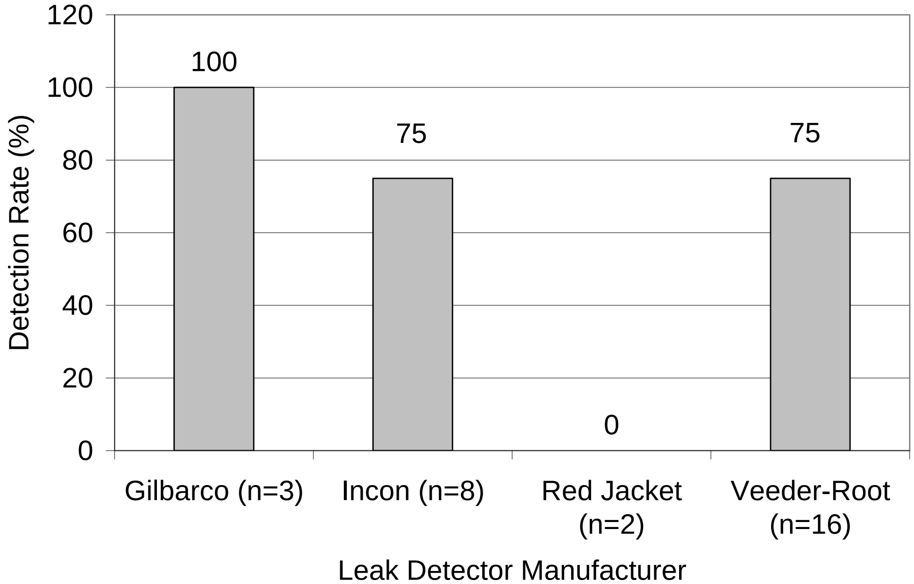


Figure I-14 ELLD Detection Rate at 0.2-gal/hr, by Manufacturer



Mechanical Line Leak Detector (MLLDs)

Seven combinations of MLLD make and turbine make were found, although only 4 had more than 10 tests. The results are displayed graphically in Figure 1-16. The most noticeable result is that the combination of a MLLD system made by Vaporless Manufacturing used with a Red Jacket turbine had an unusually low leak detection rate of less than 50%. This was also the combination with the largest number of tests. Possible follow-up could be an investigation by the vendors to determine if there is some partial incompatibility that could be contributing to this.

Table I-5. MLLD Percent Correct Detection by Manufacturer and Model

Make/Model	N	Detect <3-gal/hr	Detect <5-gal/hr	ND or >5-gal/hr
FE Petro MLD	13	76.9	92.3	7.7
Red Jacket FX	3	0.0	0.0	100.0
Red Jacket FX1V	10	80.0	90.0	10.0
Red Jacket FX2V	2	100.0	100.0	0.0
Red Jacket FXD	1	100.0	100.0	0.0
Unknown Red Jacket	1	100.0	100.0	0.0
Vaporless 99LD2000	29	55.2	72.4	27.6
Vaporless LD2000	20	70.0	75.0	25.0
Unknown Vaporless	3	0.0	33.3	66.7

Table I-5 has the rate of detection by the combination of make and model. These results are also displayed in Figure 1-17.

Figure –I-16. Results by Combination of Turbine and MLLD Make (at 3-gal/hr and 5-gal/hr)

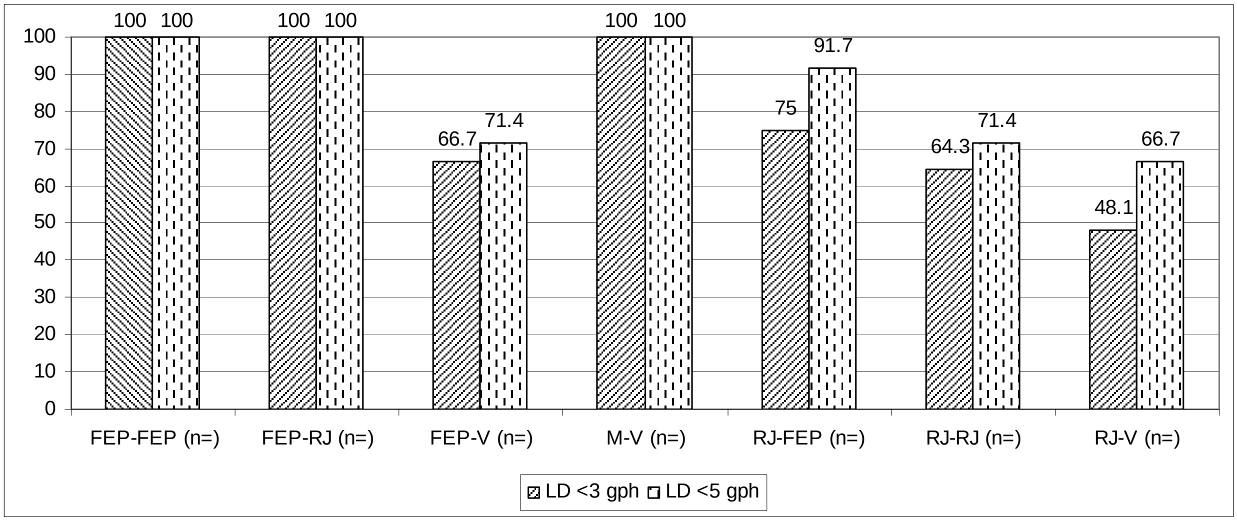
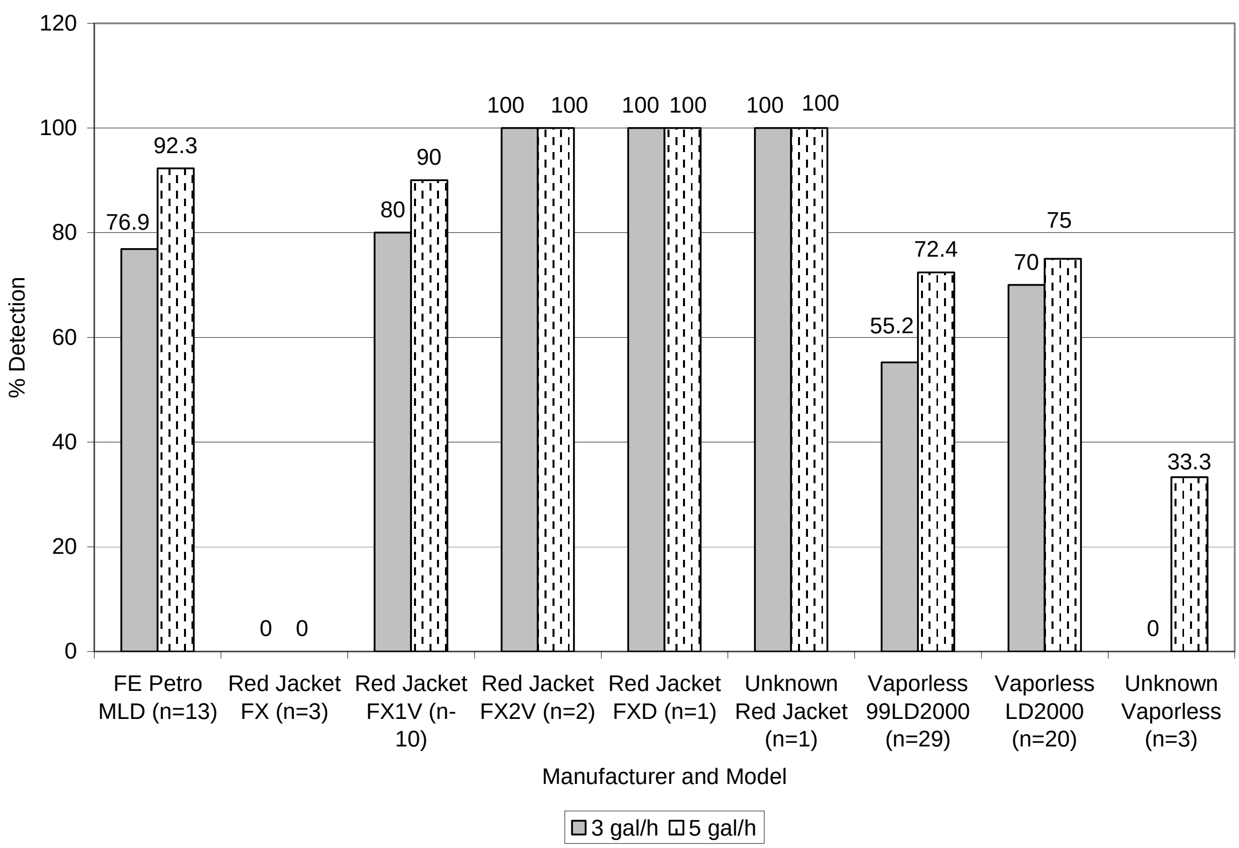


Figure I-17. Percent Correct Detection by Manufacturer and Model



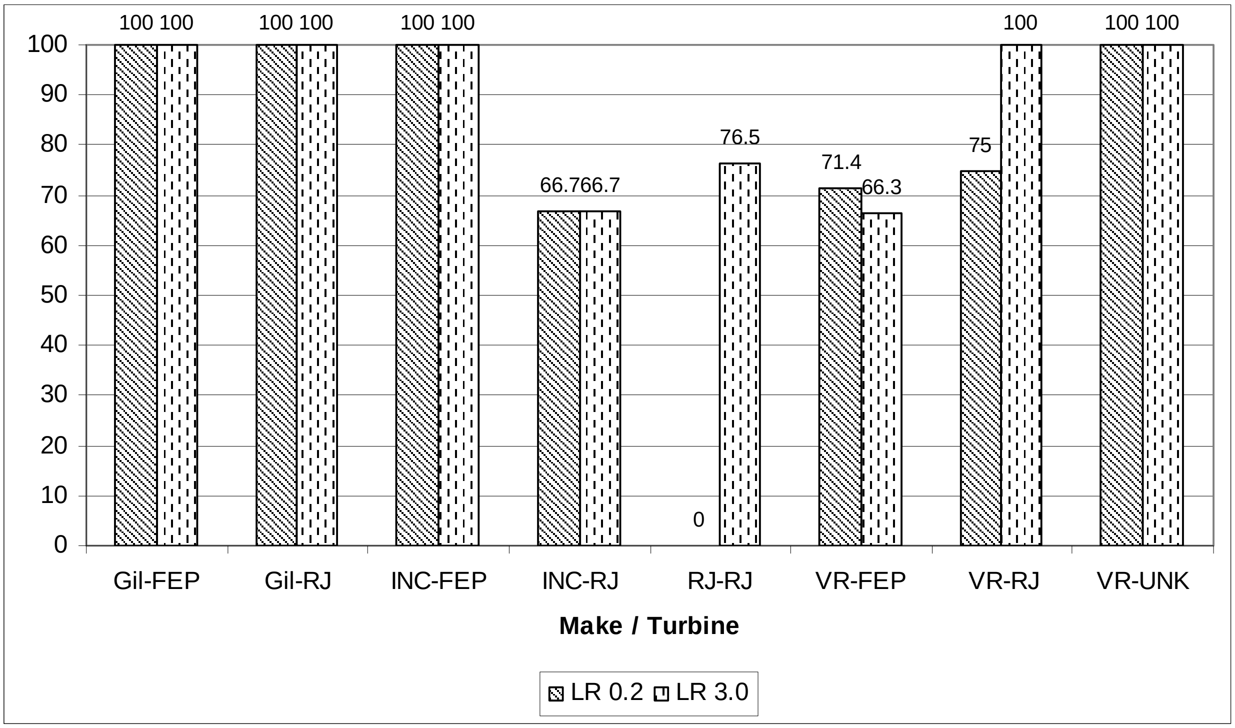
Detection of 0.2-gal/hr Leaks and 3.0-gal/hr Leaks by Manufacturer and Turbine

Table I-6 ELLD Test Results by Manufacturer and Turbine Combination

Make/Turbine	No. 0.2	LR 0.2	No. 3.0	LR 3.0
Gil-FEP	1	100.0	1	100.0
Gil-RJ	2	100.0	2	100.0
INC-FEP	2	100.0	3	100.0
INC-RJ	6	66.7	6	66.7
RJ-RJ	2	0.0	17	76.5
VR-FEP	10	71.4	61	66.3
VR-RJ	5	75.0	5	100.0
VR-UNK	1	100.0	10	100.0

Table I-6 has the number of tests and the rate of detection of 0.2-gal/hr leaks by the combination of the ELLD manufacturer and the turbine maker. The number of tests and rate of detection of the 3.0-gal/hr leaks are also shown. These data are displayed graphically in Figure I-18.

Figure I-18. ELLD Test Results by Manufacturer and Turbine Combination for 0.2-gal/hr and 3.0-gal/hr.



As noted in the body of the report, the difference in 3-gal/hr detection rates for Veeder-Root seems to be a result of a problem with a part in FE Petro turbine pumps. The data are displayed in Table I-6.

APPENDIX II - CALCULATION FORMULAS

The appendix provides additional information on the equations used to analyze the data in this report. These are the same equations used in the USEPA protocol for Automatic Tank Gauging Systems (ATGS's)

In addition to the basic results of whether or not a leak detector could detect the induced leak, a number of other characteristics of the tank system were recorded. These characteristics included information on the system size, material, manufacturer, product, etc. Since this information was available, it was interesting to compare results, such as detection rates, for these different characteristics. However, many of these characteristics may interact. For example, lines or tanks used with diesel may be of a different size than those used for gasoline. Thus, an apparent difference by product might be due to size, or an apparent difference by size might be due to product, or the difference might be due in part to each factor. There are more combinations of factors than there were tests run, so consideration of all of the possible factors jointly is not possible. Generally, only one factor at a time could be considered. Even doing this sometimes resulted in categories with very few cases. When the proportion of leaks correctly detected for different values of a factor are being compared, a statistical test, called the chi-squared test, can be used to determine whether or not apparent differences might be real or might just be due to random fluctuations. For comparing two detection rates, this test is described and illustrated in Appendix II.

When a small number of cases is available for some factor, care must be taken in interpreting the result. For example, if only one test was done, the percent of correct detections is either zero or 100%, If two tests were done, the percentage of correct detections can be zero, 50%, or 100%. Three tests would admit the possibility of zero, one-third, two-thirds, or 100% and so forth. Thus, the reader must be careful to consider the number of tests as well as the percent correctly detected.

Even if the number of tests is sufficiently large so that the difference is statistically significant, it does not necessarily follow that the characteristic being compared caused the difference. The characteristic, for example, fuel type, might appear to lead to a difference in results. However, if fuel type was also associated with another characteristic, such as size of tank or line, or type of line (such as flex or rigid), it might be this other characteristic that influenced the results, or it might be a combination of these two or still other characteristics that influenced the results.

It would be a mistake or a misuse of the data in this report to conclude that an apparent difference in detection rate by some factor was caused by that factor. This is particularly true when detection rates by manufacturers or by models of a leak detector are compared.

When a measured leak rate is reported, it can be compared to the induced or simulated leak rate on a quantitative basis. Let L_L denote the measured leak rate and let L_I denote the induced leak rate. Then the difference between the measured and induced result is given by equation 1.

$$d = L_L - L_I \tag{1}$$

The average of the differences between the measured and induced leak rates is calculated using Equation 2, where n is the total number of tests.

$$D = \sum_{1}^{n} \frac{d_n}{n} \tag{2}$$

The variance of the differences is calculated from equation 3.

$$Var = \sum_{1}^{n} \frac{(d_n - D)^2}{n-1} \tag{3}$$

The standard deviation is then obtained from equation 4 as the (positive) square root of the variance.

$$SD = (Var)^{1/2} \tag{4}$$

The bias of a leak detection method is the average of the difference between the measured and induced leak rates and is determined by equation 5 (which is the same as equation (2) with slightly different notation).

$$Bias = \sum_{1}^{n} \frac{L_L - L_I}{n} \tag{5}$$

The statistical significance of the bias can be tested using a t-test, with the t-statistic given by

$$T = (n)^{1/2}\, Bias/SD \tag{6}$$

Under the hypothesis that there is no significant bias, ***T*** would have a t-distribution with n-1 degrees of freedom. The (two-sided) critical value for a t-distribution (usually at the 5% significance level) is obtained from a table (or from a function in EXCEL). If the calculated absolute value of ***T*** exceeds the critical value, then the hypothesis of no bias is rejected and it is concluded that the leak detection method reports a consistently larger (or smaller) leak rate than the true or induced leak rate.

If a leak detection method has no statistically significant bias, then often the leak rate reported by the method is assumed to have an approximately normal (Gaussian) error distribution with a mean equal to the true leak rate. If the system (tank or line) being tested has no leak, then the measured leak rates (if done repeatedly over many times) would tend to be close to zero, some slightly positive and some slightly negative. Alternately, if a sample of measured leak rates from several systems (without leaks) is taken, the measured values or the differences between the measured and induced leak rates can be used to estimate the bias and the standard deviation of a measured leak rate. With the standard deviation of the leak rate, one can estimate the probability of a false alarm, PFA, or the probability of detecting a specified leak rate, PD.

To detect a leak rate of 0.2-gal/hr, a threshold of 0.1-gal/hr is often used, although this can vary by leak detection system and by manufacturer, based on the results of their evaluation. Using the threshold of 0.1-gal/hr, the PFA is given by (where the vertical bar, "|" denotes "given that")

$$\text{PFA} = \text{P}\ [\text{LR} > 0.1 | \text{true leak} = 0] \qquad (7)$$

$$\text{PFA} = \text{P}\ [\text{LR/SD} > 0.1/\text{SD}] \qquad (8)$$

$$\text{PFA} = \text{P}\ [T_{(n-1)} > 0.1/\text{SD}] \qquad (9)$$

Where $T_{(n-1)}$ is a random variable with the t-distribution with (n-1) degrees of freedom. Then the PFA can be calculated by looking up in a table of the t-distribution the probability that the t-statistic exceeds the calculated value given by 0.1/SD.

A similar approach can be used to calculate the PD for a given leak rate, R. The equations become

$$\text{PD} = \text{P}\ [\text{LR} > 0.1 | \text{ true leak=R}] \qquad (10)$$

If the true leak is R, then subtracting R from the measured values would give a leak or mean of 0.

$$\text{PD} = \text{P}\ [\text{LR-R} > 0.1\text{-R} \mid \text{true leak} = 0] \qquad (11)$$

Dividing by the standard deviation, we get

$$\text{PD} = \text{P}\ [(\text{LR-R})/\text{SD} > (0.1\text{-R})/\text{SD}] \qquad (12)$$

$$\text{PD} = \text{P}\ [T_{(n-1)} > (0.1\text{-R})/\text{SD}] \qquad (13)$$

So the PD can be found by looking up the value (0.1-R)/SD in a table of the t-distribution with n-1 degrees of freedom. (For further details, such as how to estimate the PFA and PD when the bias is significant, the interested reader is referred to the EPA Protocol for Evaluating ATGs.[7])

With data such as were obtained in the California study, a number of leak detection systems were tested by inducing a leak in the system and running a test. Then the test result (tight or leak indicated) was recorded. With this type of data the probability of detecting a leak (of a given size) is estimated directly as the proportion of the leak detection systems that correctly reported the leak.

In some cases, it is instructive to compare the detection rate under different conditions. For example, the leak detection rate of ELLD systems with gasoline could be compared to those with diesel as the product. Since each detection rate is a proportion, these can be compared using the chi-squared test. The calculations are illustrated using data from the report as shown in Table II-1. The chi-squared test is a statistical test used to test whether the proportion detected in each row (95% and 30% in the example table) is the same or whether these two proportions are statistically significantly different.

Table II-1. ELLD Detections by Product

Fuel	Detected	Missed	Total N	Proportion Detected
Gasoline	18	1	19	95%
Diesel	3	7	10	30%
Total	21	8	29	72%

Table II-2 is a general form of the table and is used to give the general formula for computing a chi-squared statistic from a two by two table. In Table II-2 the letter entries indicate the counts in each cell as illustrated in Table II-1. For example, A would represent 18, B would be 1, etc.

Table II-2. General Table

Group	Detected	Missed	Total
Group A	A	B	A+B
Group B	C	D	C+D
Total	A+C	B+D	A+B+C+D=N

The formula for computing the chi-squared statistic is given by

$$X^2 = N(AD-BC)^2 /[(A+B)(C+D)(A+C)(B+D)] \qquad (14)$$

In the formula, N is the sum of all four cells. Applying this formula to the example data in Table II-1, we find

$$X^2 = 29(18*7-1*3)^2/(19*10*21*8)$$

[7] Standard Test Procedures for Evaluating Leak Detection Methods: Automatic Tank Gauging Systems, U. S. EPA/530/UST-90/006, March 1990, Section 7.

From which we find that

$$X^2 = 13.745.$$

The 5% critical value from a chi-squared table with 1 degree of freedom is 3.84. If the computed chi-squared value exceeds this, then there is statistical evidence at the 5% significance level that the two proportions are different. This is clearly the case in this example. Alternatively a program or table of the chi-squared distribution could be used to calculate the significance of the computed value. In this example the calculated significance (using EXCEL) is 0.00021, or 0.021%, clearly highly significant.

Care must be exercised in interpreting this result. It might be that the ELLD systems worked differently for gasoline than for diesel. However, it is also possible that there are one or more other factors that are associated with the fuel type that explain the difference. For example, the diesel lines might have been longer, or constructed of different materials than the gasoline lines (flex instead of rigid), or there might have been different temperature conditions that contributed to the difference.

The chi-squared test can be used with larger tables that lead to degrees of freedom greater than one. For details of such calculations the reader is referred to any standard statistics text.

APPENDIX III – CASE STUDIES

A number of case studies are described that detail specific testing and/or problems that were identified during the field-study. Most facilities had leak detection equipment that was operating correctly. The cases described below have been included as examples of what regulators, technicians and tank operators can watch out for.

Case Study No.:	1
Site No:	78, 85
Type of Leak Detector:	Electronic Line Leak Detector (ELLD)
Leak Detector Make and Model:	Veeder-Root Pressurized Line Leak Detector (PLLD)
Line Size:	162-feet, 2-inch diameter (Site 78), 200-feet, 2-inch diameter (Site 85)
Line Type:	Double-wall fiberglass at both sites
Description:	PLLD would not detect 3-gal/hr leak due to a faulty siphon check valve on FE Petro submersible turbine pumps.

Two sites that were included in the study had Veeder-Root Pressurized Line Leak Detectors (PLLD) that failed to correctly identify 3-gal/hr leaks due to faulty siphon check valves present in FE Petro submersible turbine pumps. At both sites that this problem occurred; testing was done during the annual monitoring system certification. Technicians from a service and maintenance company were present at both sites. Veeder-Root was contacted following the testing and identified the source of the problem.

The siphon check valve in FE Petro submersible pumps is an inexpensive part that can be easily replaced. The presence of a faulty siphon check valve allows air to be pumped into the pipeline along with fuel whenever the submersible pump is activated. Air enters the submersible pump through the faulty siphon check valve and when the pump is activated, this air is pumped into the pipeline. Increased amounts of air enter the pipeline, the longer the turbine is not in use.

Air in the pipeline affects the PLLDs ability to detect leaks by masking their presence. The PLLD detects leaks by monitoring the pressure in the pipeline. If a leak is present, the pipeline will have a decrease in pressure that the PLLD can identify as a leak. If air is present in the pipeline, the pressure decrease occurs much slower than it would if no air was present.

When KWA arrived at the first site, the technician had already completed testing the PLLDs. Fittings were still present for attaching the leak detector testing so KWA proceeded to test the PLLD again. Two of the three PLLDs operated correctly but the third would not detect a leak. A bleed back test was done, which identified the presence of a large amount of air in the line. The technician had done a bleed back earlier and there had not been air in the line. The PLLD had worked correctly before as well. KWA later hypothesized that the turbine had not been used for a while before the KWA tests and air had probably seeped into the system.

The second site testing was similar to the first. KWA staff and the service technicians attempted to correct the problem, but were unsuccessful. The siphon check valve was not identified as the problem while at this site. Attempts at reprogramming the Veeder-Root console were also not successful in correcting the problem. A bleed back test was done on the line, which identified the presence of a large amount of air in the line. Attempts to remove this air were not successful and the technicians scheduled a follow-up visit for repair of the PLLD.

Case Study No.:	2
Site No:	45
Type of Leak Detector:	Electronic Line Leak Detector (ELLD)
Leak Detector Make and Model:	Veeder-Root Pressurized Line Leak Detector (PLLD)
Line Size:	241-feet, 2-inch diameter
Line Type:	Double-wall fiberglass
Description:	PLLD would not detect 3-gal/hr leak due to air trapped in an extra section of piping that was installed in case a new dispenser ever needed to be added.

One site included a Veeder-Root Pressurized Line Leak Detector (PLLD) that would not detect a leak due to the presence of air in the line. The air was in the line due to end caps that were left in place in case an additional dispenser needed to be added to the station. The station operator identified the presence of the end caps to KWA.

There were three PLLDs present at the facility, two of which worked correctly. Bleed back tests were conducted on all three pipelines to determine if air was present in them. The two lines on which the PLLDs worked correctly did not have air trapped in them. The PLLD that did not work correctly had a large amount of air trapped in the line.

Case Study No.:	3
Site No:	85
Type of Leak Detector:	Electronic Line Leak Detector (ELLD)
Leak Detector Make and Model:	Veeder-Root Pressurized Line Leak Detector (PLLD)
Line Size:	241-feet, 2-inch diameter
Line Type:	Double-wall fiberglass
Description:	PLLD would not detect 3-gal/hr leak due to the line length being incorrectly programmed into the Veeder-Root console.

Several sites had Veeder-Root Pressurized Line Leak Detectors (PLLD) that did not work correctly because an incorrect line length was programmed into the Veeder-Root console. The PLLD runs leak tests more quickly on shorter pipelines than on longer pipelines. If a line length that is shorter than the actual line is programmed into the console, the PLLD may fail to detect leaks.

The PLLD monitors the change in pressure in the line over time. Using the programmed line length and diameter in an algorithm, the change in pressure over time is correlated to a change in volume over time to determine if a leak is present or not. If the console is programmed for a shorter pipeline than the PLLD is installed on, it is possible that the PLLD will miss detection of a leak because the pipeline's pressure does not drop as quickly as the PLLD algorithm indicates that it should. If this occurs, the leak test will report a pass even when a leak is present in the pipeline. This was observed at several facilities included in the study. After programming the correct line length into the console, the PLLD should work correctly.

Case Study No.:	4
Site No:	97
Type of Leak Detector:	Mechanical Line Leak Detector (MLLD)
Leak Detector Make and Model:	Red Jacket FX and FX1
Line Size:	350-feet, 2-inch diameter
Line Type:	Double-wall Enviroflex flexible piping
Description:	Red Jacket FX and FX1 leak detectors would not detect 3-gal/hr leaks.

One facility included in the study had three Enviroflex flexible pipelines with Red Jacket FX Mechanical Line Leak Detectors (MLLD) on each pipeline. Testing was done during an annual monitoring system certification where a technician from a service and maintenance company and a local regulator were present during the testing.

None of the MLLDs would detect a 3-gal/hr leak. Measurements were done to determine what could be detected by the MLLDs and in all cases it was greater than 5-gal/h. Bleed back tests were done on each of the three lines and the amount of product retrieved was normal for these pipelines indicating that air was not trapped in the lines.

The technician that was present replaced two of the three MLLDs with new Red Jacket FX1 MLLDs during the testing. The two new MLLDs were tested but neither would detect a 3-gal/hr leak. The local regulator called for working MLLDs to be installed and tested within 10 days. The technician ordered new FE Petro MLLDs for installation at the facility.

Case Study No.:	5
Site No:	25
Type of Leak Detector:	Electronic Line Leak Detector (ELLD)
Leak Detector Make and Model:	Incon TS-LLD
Line Size:	53-feet, 2-inch diameter
Line Type:	Single-wall fiberglass
Description:	Of three TS-LLDs at this facility, two were hard-wired to keep pumps on which disabled their leak detection ability.

One facility included in the study had Incon TS-LLD Electronic Line Leak Detectors (ELLD) on three pipelines. Testing was done during an Annual Monitoring Inspection and a technician from a service and maintenance company and a local regulator were present during the testing. The facility was an independent gas station that had been in use for many years. The tanks and pipelines were single-walled. There were not sumps or dispenser pans present at the facility. The facility closed every night.

The Incon TS-LLD includes a faceplate with a readout that shows the number of days since the unit last had a passing 0.2-gal/hr line leak test. The three TS-LLDs were reading 00, 01 and 02 when we arrived at the site. This indicated that one unit had passed a test the day we were there, one had passed a test the day before, and one had passed a test 2 days ago. This was not normal for a station that is periodically closed. Normally, all three of the TS-LLDs should be reading 00.

The TS-LLD runs a 0.2-gal/hr test each day following fuel dispensing until it receives a passing test. If someone starts dispensing fuel during a test, the test will be aborted by the TS-LLD and it will restart the test when dispensing ends. If a station is closed at night, the TS-LLD will run leak tests while the station is closed and will normally receive a passing test sometime during the night. Test times range from 50 minutes to 8 hours. Testing will normally complete in 50 minutes unless there is a temperature differential between product in the piping and the ground temperature. In rare cases, at 24-hour stations that are extremely busy, a test might not complete every day. This was not the case with this facility.

Inspection of the TS-LLDs by the service technician revealed that two of the TS-LLDs were wired differently than they should have which disabled their leak detection abilities. The wiring was done in a way that caused the submersible turbine pumps to remain on at all times. It was hypothesized that the station operators had been rotating the faceplate from the one TS-LLD that was working correctly, which would result in the three faceplates reading 00, 01 and 02. The third TS-LLD was working correctly and identified a 3-gal/hr leak and a 0.2-gal/hr leak.

Case Study No.:	6
Site No:	99
Type of Leak Detector:	Electronic Line Leak Detector (ELLD)
Leak Detector Make and Model:	Veeder-Root Pressurized Line Leak Detector (PLLD)
Line Size:	110-feet, 1.5-inch diameter
Line Type:	Double-wall Environ flexible piping
Description:	Tank tester reported that PLLD would not detect leak in bio-diesel fuel after testing the PLLD during a new station's startup inspection. Testing for the study discovered a large amount of air in the pipeline, which when removed allowed the PLLD to operate correctly.

One facility included in the study was tested prior to the station opening. New Environ flexible piping had been installed to upgrade the facility. The county that the station was located in had done a startup test and had approved the station for opening. The station included three tanks and three pipelines. Two grades of unleaded gasoline and bio-diesel fuel were present at the facility. The station was equipped with a Veeder-Root TLS-350 and Veeder-Root Pressurized Line Leak Detectors (PLLD). KWA did testing for two days prior to the station opening while city building inspectors were completing inspections.

KWA obtained copies of the startup testing from the licensed tank tester who had done the testing. KWA was told that the PLLD on the pipeline containing bio-diesel fuel would not correctly identify a 3-gal/hr leak but that since bio-diesel was not a hazardous substance, the county regulators had approved the startup anyway.

KWA tested the three PLLDs at the facility and verified that the PLLD on the bio-diesel pipeline would not detect a 3-gal/hr leak. However, a bleed back test on this line indicated that a very large amount of air was trapped in the line. KWA pumped more than 100 gallons out of the line in an attempt to purge the air from the line. After the pumping was concluded, bleed back testing indicated that the air had been purged from the line and the PLLD worked correctly.

Case Study No.:	7
Site No:	60, 61, 66, 67
Type of Leak Detector:	Mechanical and Electronic Line Leak Detectors (MLLD and ELLD)
Leak Detector Make and Model:	Red Jacket FX1V (MLLD) and Red Jacket CPT (ELLD)
Description:	Technician incorrectly simulated pipeline leak when testing line leak detectors during Annual Monitoring Inspection.

KWA observed technicians generating pipeline leaks incorrectly. One technician was observed generating leaks much larger than the 3-gal/hr standard at 4 different facilities. Each of the four facilities was having an Annual Monitoring Inspection performed and the local regulator was present. The technician did not want KWA to perform tests until the oil company that owned the stations authorized it. At each facility, KWA repeatedly asked the technician to measure the leak rate that he had calibrated his equipment to so that the data could be included in the study. It was not until the third site that he agreed to let the leak rate be measured and it was found to be approximately 5-gal/hr. The technician had also told KWA that he did not need to calibrate his equipment more than once per day.

Because the technician had performed testing with a leak rate greater than 3-gal/hr, the leak detectors at these sites were not tested correctly. Environmental protection provided by the line leak detectors at these facilities is present, but it is not known if it is present at the required 3-gal/hr level. Additionally, the elevated leak rate used by the technician calls into question the data that KWA collected at these sites.

This was not the only technician that KWA observed who was simulating leaks incorrectly. Field testing standards, equipment used to simulate pipeline leaks, and training requirements are not defined as well as they could be. The examples below highlight the difficulties facing testing pipeline leak detectors.

- Federal regulations state that line leak detectors are to be tested according to the manufacturer's specifications. This has resulted in manufacturers publishing a variety of procedures that sometimes conflict with local laws. Some manufacturers have no published testing procedures or indicate that their leak detectors are "self-testing".
- Equipment used to simulate pipeline leaks is not defined at any level. Most technicians use homemade equipment built out of valves, gauges, regulators and fittings purchased at hardware stores. There are not third-party certification requirements for leak simulation equipment. This has created confusion amongst technicians and regulators. Regulators may be educated about the leak rate requirements, but the wide variety of equipment used to simulate leaks may make it difficult for them to understand if a technician is testing correctly.
- California law states that technicians must be certified by the manufacturer of the leak detector that they are testing. Certification requirements vary widely amongst manufacturers. Some manufacturers have classroom instruction that lasts for 3 days before an extensive written exam is taken. Other manufacturers require that you provide them with an address that they can send a certification card to.

Case Study No.:	8
Site No:	26, 41
Type of Leak Detector:	Automatic Tank Gauging System (ATG)
Leak Detector Make and Model:	EBW AutoStik I
Description:	EBW AutoStik I was approved by local regulators during Annual Monitoring Inspection although this ATG is not third-party certified and is not on the California LG-113 list of approved leak detectors.

Two sites included in the study had EBW AutoStik I Automatic Tank Gauging Systems (ATG) installed on single-wall tanks. Testing was done during an Annual Monitoring Inspection and a technician from a service company and a local regulator were present both times. In both cases, the regulator assumed that the ATG was listed on California's list of approved equipment (LG113). However, the AutoStik I was never third-party certified and both sites were therefore out of compliance. KWA did not realize that the EBW units were not third-party certified while at the sites and therefore KWA did not inform the regulators of this during the inspection.

Case Study No.:	9
Site No:	63
Description:	Technician conducting Annual Monitoring Inspection used air hose fittings to connect his leak detector tester to the pipeline. The air hose fitting came apart while the submersible turbine pump was running and a substantial amount of fuel was released onto the concrete.

In many cases during the study, KWA worked with service technicians during Annual Monitoring Inspections. This made it possible for KWA to observe testing methods and equipment used by technicians in the field. A variety of types of equipment were observed for generating pipeline leaks to test line leak detectors. There is not a third-party certification requirement for equipment that is used to simulate leaks to test line leak detectors. Training of technicians to do this type of testing also is not required.

Several of the service companies that KWA worked with during the study used homemade pipeline leak simulators that they built themselves. In several cases, the technician used air hose fittings to connect the leak simulator to the pipeline. These fittings are easy to use, can be obtained at any hardware store, and are inexpensive. They are not however safe to use for simulating leaks of gasoline on pressurized piping. There are readily available fittings that are double-shutoff and are designed for use with petroleum. KWA uses double-shutoff fittings and when unhooked, they do not allow product to come out of them.

At one facility where homemade equipment with air hose fittings was being used, KWA observed the fittings come apart when the submersible turbine came on. The fitting that came apart was on the end of a hose that was installed in the pipeline. The hose started whipping around uncontrollably and fuel began spraying everywhere. In a very short amount of time, a large amount of concrete was covered in gasoline that had been sprayed from the hose.