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LEAK DETECTION

DEPARTMENT OF THE ARMY
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UTILITIES

LEAK DETECTION

1. Purpose. The purpose of this Public Works Technical Bulletin (PWTB) is to transmit current information on active and passive leak detection technology for water, fuel, energy pipe and storage tank systems for implementation at Army installations.

2. Applicability. This PWTB applies to all U.S. Army Public Works activities involving the use of water, fuel, energy pipe and storage tank systems.

3. References.

a. AR 420-49-02, Facilities Engineering Utility Services, 28 May 1997.

b. Army Regulation (AR) 200-1, Environmental Protection and Enhancement, 21 February 1997.

c. U.S. Code of Federal Regulations (CFR), Title 40, Part 280, Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks (UST), Vo. 53, No. 185, 23 September 1988.

4. Discussion.

a. The consequences of utility system leaks are more noticeable now than in the past because of increasing requirements for environmental protection and emphasis on energy and water conservation. Leaks of fuels, other petroleum products and chemicals are a serious hazard. Leaks in water distribution systems waste water, energy and system capacity. Unfortunately it is not unusual for a water distribution system to have leakage rates of 20%. These factors highlight the growing importance of leak detection.

b. This PWTB provides an evaluation of current leak detection technology applicable to water, fuel and energy pipe systems and provides lessons learned. The lessons provide insights into selection of appropriate leak detection technologies, installed either as post-construction system additions or during construction. The attached document provides detailed information on the leak detection technology and application.

5. Point of Contact. Questions and/or comments regarding this subject should be directed to the technical POC:

U.S. Army Engineer Research and Development Center
Construction Engineering Research Laboratory
ATTN: CEERD-CF-M (Dr. Vincent Hock)
2902 Newmark Drive
Champaign, IL 61822-1072
Tel. (217) 373-6753
FAX: (217) 373-7222
e-mail: v-hock@cecer.army.mil

FOR THE COMMANDER:

Dwight a Beranek

DWIGHT A. BERANEK, P.E.
Chief, Engineering and Construction Division
Directorate of Civil Works

Encl

ACTIVE AND PASSIVE LEAK DETECTION TECHNOLOGY FOR WATER, FUEL, ENERGY PIPE AND STORAGE TANK SYSTEMS

GUIDANCE

ACTIVE AND PASSIVE LEAK DETECTION TECHNOLOGY FOR WATER, FUEL, ENERGY PIPE AND STORAGE TANK SYSTEMS GUIDANCE

1. Introduction

A single gallon of gasoline can render a million gallons of water non-potable. The cost of effecting leak repairs is approximately proportional to the amount of trenching needed to access the leak. Passive leak detection can provide leak location to within a 6 inch radius of the actual leak location. The use of this technology can save critical time when detecting and locating a leak, and minimize unproductive trenching for repairs.

The U.S. Army maintains approximately 20,000 underground storage tanks (UST) and pressurized underground pipelines to store and deliver petroleum and other chemicals. According to the U.S. Environmental Protection Agency, approximately 25% of these are leaking. The average clean up cost of a petroleum leak is estimated by U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) to be $193K, ranging higher where ground water is contaminated.

The U.S. Army also maintains 3,000 miles of steam and High Temperature Hot Water (HTHW) distribution lines. A leak repair in these energy lines can cost in the range of $2-15K per leak, due in large part to the multiple trenching required to locate the source.

The objective of this PWTB is to publish lessons learned, based on the evaluation of passive leak detection technology applicable to water, fuel and energy pipe systems. The lessons provide insights into selection of appropriate leak detection technologies, installed either as post-construction system additions or during construction.

The U.S. Army Corps of Engineers has reported[1] that the most likely technology for reliable and cost effective detection of fuel leaks in underground piping systems is manufactured by Arizona Instruments Inc., followed by the Tracer Research ALD 2000 system (continuous monitoring), and finally the various cable systems (with the constraint that they must be installed in double walled piping systems).

Leak detection technologies applicable to water and energy pipe systems were researched through vendor information, but no installed systems were found in the DoD.

2. Regulations

The U.S. Naval Facilities Engineering Service Center has reported upon the pertinent regulations that apply to petroleum leaks[2]. The key points are summarized here, please refer to the original

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[1] Timmins, J., Weber, R.A., Hock, V.F., **Summary of Findings and Survey Results for Leak Detection Sensors for Water, Fuel and Energy Piping Systems**, USACERL Report XX, 10 Sep 1997.

[2] Lefave, J.P., Karr, L., **Underground Pipeline Leak Detection and Location Technology Application Guide**, Naval Facilities Engineering Service Center, Report UG-2028-ENV, April 1998.

report for a more detailed treatment of the regulatory subject as it applies to airport hydrant systems, USTs, ASTs, and their associated piping.

a. Federal Environmental Protection Agency Regulations

Federal regulations require >release detection= for underground storage tanks (USTs) and their associated piping. Federal regulations also defer the release detection requirement indefinitely (Section 280.10 c and 280.10 d of Ref. 2[3]) for field-constructed USTs, emergency power generator fuel tanks, and airport hydrant fuel distribution systems. Release detection methods that satisfy the Federal requirement for existing UST systems are discussed at Sections 280.41 and 280.43 (for tanks), and Section 280.44 (for piping) (Ref. 2[3]). The options for release detection for pressurized piping are:

(1) Automatic line leak detection
(2) Annual line tightness testing
(3) Monthly monitoring of soil vapor, groundwater, or the interstitial space of a double walled pipeline.

Automatic line leak detectors must be able to detect leaks of 3 gallons per hour at a pressure of 10 psig within an hour. The annual tightness test must be able to detect a leak rate of 0.1 gallon per hour. Other methods are also allowed if they can detect a 0.2 gallon per hour leak rate, a release of 150 gallons in a month, or are approved by the implementing agency (Ref. 2[3] Section 280.43(h)).

b. State Regulations

Contacts at the State (or Territorial) regulating offices are available to answer leak detection questions. A list of contacts can be found at *http://www.epa.gov/OUST/states/statcon1.htm*. California, Florida, and Texas have special leak detection requirements. California=s requirements are governed by the California Code of Regulations, Title 23, Sections 2640 et.seq. Florida=s requirements are governed by Florida Administrative Code, Rule 62-761, Underground Storage Tank Systems, and Rule 62-762, Aboveground Storage Tank Systems. Texas= requirements are governed by the Texas Administrative Code, Chapter 334, Underground and Aboveground Storage Tanks. Table I provides a summary of the regulatory requirements for airport hydrant systems, USTs, ASTs, and their associated piping.

c. Regional Regulations

Certain localities may impose regulations that differ from Federal and State requirements. Consult your local EPA office for more information on regional requirements.

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[3] U.S. Code of Federal Regulations (CFR), Title 40, Part 280, **Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks (UST)**, Vo. 53, No. 185, 23 September 1988.

Table I. Regulatory Requirements Summary
(from Ref. 4, Lefave and Karr)

		Airport Hydrant Systems	**UST and Associated Pressurized Piping**	**AST And Associated Pressurized Piping**
Federal		(Deferred)	Same as tank (deferred for field constructed USTs); After 22 December 1998, secondary containment (for piping), *AND* Automatic Line Leak Detector required (3 gal/hr at 10 psig). Option for approval of alternate release detection methods.	No requirement, unless piping is >10 percent of total volume, which makes the entire system a UST.
California		Same as UST>>	Hourly (3.0 gal/hr) when pressurized *AND* Monthly (0.2-gal/hr) or Annual (0.1-gal/hr at 150 percent operating pressure)	No requirement, unless piping is >10 percent of total volume, which makes the entire system a UST.
Texas		Same as UST>>	Hourly (0.2-gal/hr) *AND* Annual Tightness Test (0.1-gal/hr at 150 percent of operating pressure)	<< Same as UST.
Florida (Current reg=s)	Thru 1999	Same as UST >>	Annual Tightness Test	<< Same as UST.
	After 1999	Same as UST >>	In-Line Leak Detector (0.3-gal @ 10 psig) *OR* Quarterly Pressure Test	Hydrant & bulk product piping (3-inch+ diameter.): << same as USTs; Other piping upgrade with secondary containment.
Florida (Proposed)		Same as UST >>	Annual Tightness Test *OR* Monthly Release Detection system	Hydrant & bulk product piping: Annual tightness test.

3. Technology Overview

There are eight main technologies in use for the detection of liquid leaks, each associated with physical phenomena which occurs either at a leak site or in the system due to the leak:

a. Gas sniffing systems detect changes in chemical concentration, and require the leak to provide changes in concentration which are detectable above normal, naturally occurring chemical levels.

b. Cable systems involve laying a cable in probable leak sites and monitoring for changes in the cable=s impedance, conductivity or (in the case of fiber optic cables) the refractive index, to determine when the cable comes in contact with a liquid.

c. Acoustic systems rely on noise produced by turbulent liquid flow through the leak to detect leaks in piping systems. Two sensors mounted either temporarily or permanently to the pipe can locate the leak in relation to the sensors.

d. Infrared methods rely on the difference in temperature between the piping system and surrounding soil to provide a thermal signature which can be observed by special imaging equipment.

e. Magnetic flux leakage detection systems (also known as a >pigs=) are instruments which identify and record information about pipeline anomalies such as corrosion pits, mechanical damage, dents, mill defects, wrinkle bends, hard spots, and hydrogen blisters. A pig must be launched with the pipeline completely evacuated and requires special launch and recovery stations.

f. Temperature compensated volumetric testing systems measure the volume of liquid that must be added to a piping system to maintain a constant pressure, thus providing the flow rate of a leak (or leaks) in gallons per hour.

g. Pressure point analysis systems detect pressure waves caused by the sudden onset of a leak in a pipeline.

h. Supervisory Control and Data Acquisition (SCADA) systems rely on process control sensors to detect discrepancies in the performance of the system which could indicate a leak. One subset of the SCADA system category (which is often used as a stand-alone leak detection system) is Level Monitoring, which can be used only in closed systems which allow an accounting system to detect losses. The other SCADA subsystem (which can also be used as a stand-alone system) is Mass Flow measurement methods, which rely on various physical phenomena to obtain accurate measurements of the total mass flow between two points on a pipeline. Irrespective of the portion of the SCADA system utilized as the detection system, each requires the use of a computer, sensor data acquisition, and an analysis algorithm to evaluate the sensor data and produce a leakage determination.

Each technology mentioned has a detection sensitivity associated with the system it is used with. These eight technologies are evaluated further in Appendix A in terms of the phenomena exploited, their system applicability, and their advantages and disadvantages when applied to the detection of leaks in a buried pipe system responsible for carrying liquids.

4. Technology Selection Criteria

Implementation of a leak detection and location (LDL) system is a tradeoff between cost and performance. Many variables should be considered when selecting LDL equipment. These considerations are listed in Table II and are discussed in this section. Further information on these LDL methods is contained in the Appendices of this report.

a. Soil Conditions: Soil conditions can affect LDL technology performance. For example, tracer gas migrates more quickly in dry, porous soil than in wet soil. Acoustic techniques may also be affected by the type of soil around the pipeline. Tidally influenced salt-water environments pose special corrosion problems for pipelines. When researching leak detection equipment, always consider the soil conditions.

b. Water Table: Some LDL techniques don=t work well if the pipeline runs below the water table or the high tide level. Tracer techniques are less effective if the pipeline is under water, because leaking tracer gas may be washed away before it reaches a sensor. Or, the tracer may migrate and be detected by another sensor, thus indicating a leak in the wrong location.

c. Condition of Pipeline: The age and condition of a pipeline are important considerations when selecting leak detection equipment. Static pressure testing techniques require modern high-quality valves, so that a leaky pipeline can be distinguished from a leaky valve. Older small diameter pipelines containing sharp bends may be unsuitable for pigging.

d. Operations: Certain LDL techniques can be affected by routine operations. For example, temperature compensated pressure tests must be conducted when a pipeline is >quiet=, which may require temporary suspension of operations. Acoustic techniques can be disturbed by vibrations generated from heavy traffic in the surrounding area. Pressure point analysis techniques may be hampered by fuel facility operations.

e. Time Monitoring: Some LDL methods provide leak detection 24 hours a day (continuous monitoring). Other methods provide a >snap shot=, or assessment of the pipeline condition at that moment. Regulators may require that a snap shot technique be employed at specified time intervals to implement an effective leak control program.

f. Spatial Resolution: Leak detection and location techniques provide different levels of spatial resolution. When properly applied, pigging, cables, and acoustic techniques can accurately locate leaks. However, the accuracy of tracer leak location is a function of the spacing between sampling points. Static pressure testing techniques don=t locate leaks at all. Sometimes the best way to solve leak detection problems is to first identify a leak with one technique, such as pressure testing, and then locate it with another technique, such as tracers.

g. Leak Rate Resolution: Some leak detection techniques, such as temperature compensated pressure testing, provide a volumetric measure of the leak rate. Other techniques, such as product sensitive cables, indicate where fuel has been detected, but not how much fuel is present.

h. Ease of Retrofit: Most underground piping systems have been in service for many years. It is therefore important to address whether a LDL technology can be applied to an existing pipeline. Some techniques, such as temperature compensated pressure testing, can be easily applied on most pipelines, new or old. The hardware associated with these techniques is not an integral part of the pipeline system and can brought to the pipeline by a contractor who performs the test. However, these systems can be made a part of the fueling system, if that is determined to be cost effective.

5. Cost Data

Table II. Cost Data for Surveyed Field Installed Leak Location Systems
(from Ref. 3, Timmins, Weber and Hock)

Leak Detection System	Cost Data Source	Installation Cost	Equip. and Constr. Materials	Maintenance Cost (Annual)	Length of Pipline in feet	Total Cost in first Year	Total Cost Per Foot
Soil Sentry 12XP Pipeline and AST Environmental Monitoring System	Site Costs Pensacola NAS (Based on 26,400')	$274,000		$300	26,400	$274,300	$10.39
AZI Soil Sentry (Tracer Research Tracer Tightness used on storage Tanks - not included in cost data)	Site Costs Ellsworth AFB (Based on 7908')	$104,000	$40,000	$300	7,908	$144,300	$18.25
Soil Sentry 12XP Pipeline and AST Environmental Monitoring System	Manufacturer Estimate (Based on 1000')	$15,500	$10,750	$995	1,000	$27,245	$27.25
Tracer Research: ALD 2000	Manufacturer Estimate (Based on 5,000')	$134,941		$25,883	5,000	$160,824	$32.16
Raychem: Trace Tek (Quote by Tracer Research)	Manufacturer Estimate (Based on 5,000')	$113,000		$8,000	5,000	$121,000	$24.20
PermAlert: PAL-AT Leak Detection System	Manufacturer Estimate (Based on 5,000')	$49,246			5,000	$49,246	$9.85
Vista Research: Model LT100	Manufacturer Estimate (Based on 1,000')	$42,000			1,000	$42,000	$42.00
Hansaconsult: TCS Tightness Control System	Manufacturer Estimate (Based on 1,000') and Converted to US Dollars	$66,000			1,000	$66,000	$66.00
Argus Technologies	Manufacturer Estimate (Based on 5,280')	$209,457			5,280	$209,457	$39.67

This table was derived from questionnaires were to both installations and vendors to determine applicable current pricing on maintenance, installation, and materials costs for the system types being surveyed. Table II illustrates the relative breakdown of the cost data obtained. Vendors were supplied with a hypothetical piping system 1000 ft long, carrying JP-8 in a single wall pipe buried 4 ft. beneath grade. DoD installations were asked to include similar system descriptions with installation and maintenance cost data for their individual systems.

6. Implementation Guidance

To achieve sufficient performance from a leak detection system, the pipeline should first be verified for integrity before having a continuous monitoring system installed and tested. The leak detection system must also be relatively maintenance free and inexpensive to operate. None of the systems surveyed or researched provide the optimal level of leak detection on their own. Leak detection in underground piping systems is a multifaceted problem, which requires several technologies to achieve a satisfactory solution.

The aspects of leak detection which are and will continue to be the most critical are leak location and magnitude. A highly sensitive system which monitors infrequently does little to protect the user from the high costs resulting from a major discharge. A system which monitors continuously but is only able to detect major discharge events puts the user at the same risk level.

Of the leak detection systems investigated, the most promising technology for reliable detection of fuel leaks in underground fuel piping systems appears to be the gas sniffing systems. This technology has proven its ability to detect numerous hydrocarbons from natural gas, hydraulic fluid, or JP8. However, the system is not applicable to water or energy pipe systems, and current systems are susceptible to water invasion.

The AZI leak detection and location system seems to have a good potential. It provides sufficient sensitivity to detect smaller leaks and has the ability to continuously monitor the piping system. The AZI system can also provide leak location to within 10 ft. with 20 ft. well spacing. The AZI system could be feasibly made impervious to water by the addition of the Argus Technologies proprietary sensor tube, which is selectively permeable. Because the AZI system draws a vacuum on the sensor tubing, the rate of diffusion of concentrated hydrocarbons could be increased enough to reduce the idle time required, and still provide a system that continuously monitors the site.

Tracer gas systems also have good potential. These systems are suitable for intermittent pipeline integrity tests and do not depend on prior knowledge of the pipeline condition. These systems are based on the detection of a unique marker gas introduced into the product carried in the pipeline and detected through gas chromatography. They are not useful for potable water piping systems due to the toxicity of the marker gas.

The technology used in cable systems appear to be useful for both energy pipe systems and new potable water systems which incorporate double wall piping. There are also cables available for the detection of hydrocarbon liquids, which makes this technology applicable to fuel, water, and energy pipe systems.

Table III lists the various leak detection and location technologies discussed in this bulletin, and indicates their relative suitability to various field applications under different conditions.

Table III. LDL Suitability to Application

	Utility																																									
	Potable Water													Petroleum											High Temp Hot Water										Sewage							
	Material					Backfill			Water Table			Pressure		Material			Backfill			Water Table			Pressure		Material		Backfill			Water Table			Pressure		Material		Backfill			Water Table		
LDL Technology	Cast Iron	Transite	Copper	Plastic	Steel	Sand	Gravel	Clay	Below Pipe	Above Pipe	Varies	0 – 10 psi	Above 10 psi		Aluminum		Sand	Gravel	Clay	Below Pipe	Above Pipe	Varies	0 – 10 psi	Above 10 psi	Steel	Copper	Sand	Gravel	Clay	Below Pipe	Above Pipe	Varies	0 – 10 psi	Above 10 psi	Concrete	Cast Iron	Sand	Gravel	Clay	Below Pipe	Above Pipe	Varies
Gas Sniffing														X	X	X	X	X	X	X			X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X		
Cable	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X		
Acoustic	X		X		X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
Infrared																									X	X	X	X	X	X		X	X	X								
Magnetic Flux Leakage	X				X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
Temp. Compensated Volumetric	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X								
Pressure Point Analysis	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X								
SCADA	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

APPENDIX A

Detailed Technology Descriptions

Detailed Technology Descriptions

1. *Gas Sniffing*

Technology: Electro-chemical sensors are calibrated to background concentration levels of the particular compound of interest. In some situations this compound can be an additive to the liquid to make detection feasible. Sensors are located or transported to a suspected leak location, where readings are taken and compared with threshold values to determine either a >leak= or >no leak= condition.

Use: These sensors are commonly used with Volatile Organic Compounds (VOCs) which produce highly localized concentrations of vapor when a leak occurs. They can also be utilized with tracing gases, which are introduced into the system.

Installation: Some gas detection equipment can be installed permanently and remotely monitored, however, the most frequent configuration is a hand-held unit which is used in surveys.

Advantages: This system is good for some liquids, such as petroleum products, which produce vapor that can permeate through the soil covering the pipe system and produce an area of concentration sufficient for detection around the leak location.

Disadvantages: Leaks of liquids with varying ambient concentrations, such as water, can easily be masked by the background noise. It is also not possible to chemically detect the presence of a water leak without adding a marker compound to the liquid. This would not be acceptable for potable water distribution systems, as the tracing additives are sometimes toxic.

2. *Cable Systems*

Technology:

(1) Impedance Mismatch - A cable with a permeable outer shield is excited with a known frequency. Because the dry cable has a known impedance and length, when a leak changes the dielectric properties at a particular location within the cable, it creates an impedance which can be located along the length of the cable by signal attenuation and phase measurements.

(2) Conductivity - Two conductors (generally stainless steel) are woven into a specially treated cable or ribbon. When a conductive liquid forms a continuity path between the two wires, a leak condition is indicated and can signal an alarm.

(3) Refractive Index - A fiber optic cable is given a coating that interacts with a contaminant. In the presence of the contaminant, the light passing through the fiber is affected, providing a means of detecting and locating the contaminant.
Use: This technology is used to detect aqueous leaks or (with special polymers) leaks of fuel, solvents, electrolytes, acids, and bases. The cable can be installed during construction in limited access applications, or, as in the case of computer room floors and other accessible areas, installed after the fact.

Installation: The cable is installed in locations where leaking fluid is likely to accumulate. The cable is run along the bottom annulus of double walled pipe and terminated at monitoring stations. For area applications, the cable is laid in a serpentine pattern. In multi-branch pipe systems, individual cables can be run from branching junctions.

Advantages: This system can be sensitive to different types of liquids and can be easily installed. It can be used in piping systems as well as in storage tanks. The system presents a >leak= or >no leak= indication.

Disadvantages: After exposure to water or fuel, the cable may need to be replaced. System design allows for false indications depending on initial designed sensitivity.

*3. **Acoustic Methods***

Technology: Acoustic leak detection methods rely on piezoelectric transducers to translate pressure waves generated by fluid escaping the piping system into an electrical signal. The system generally consists of a piezoelectric (a crystalline material which produces a voltage potential when stressed) transducer and an amplifier/signal conditioning unit. The operator then makes a >leak= or >no leak= determination. Research is currently investigating the permanent installation of transducers on a piping system at specific locations to continually monitor the system=s condition.

Use: This technology can be applied to any system which is carrying fluids under pressure.

Installation: For permanent or semi-permanent installation, transducers are connected to piping junctions acoustically via waveguides (metallic connections which conduct vibrations efficiently from the pipe to the transducer). The monitoring system then acts as either a data logger or a remote unit, both of which maintain a record of the acoustic activity in the pipe system within acoustic range by storing the acoustic signals received above a set threshold in either volatile memory or by transmitting them to a central computer. Portable units are used in a search pattern over the piping system, which may include direct acoustic coupling to the system where it is accessible through manholes or vents.

Advantages: Leak location can be determined to within several feet or even within fractions of an inch, depending upon the location of the pipe and its surroundings. Because the system can be used to scan a piping system, the cost to detect a leak in a large system is only dependent on the man-hours required to cover the system.

Disadvantages: The system can give false positives due to flow noise around valves and other geometry changes. The system can also give false negatives due to noise interference from the surroundings. Systems which depend upon operators to evaluate the signals require an experienced operator.

4. ***Infrared Imaging***

Technology: Infrared inspections are performed with a video camera capable of recording infrared radiation. The camera records the temperature differential and the images are processed to show the different temperatures in a color spectrum. Data can be videotaped for future review and processing.

Use: These systems are generally used on piping systems which can produce significant thermal signatures through several feet of earth. This limits them to use with piping systems which transport liquids significantly above the surrounding ambient ground temperature, such as heating water or steam.

Installation: These systems are used for surveys only. When conditions permit, the system or suspect locations within the system are scanned for leak indications.

Advantages: The advantages of this system are that it can be used to scan large areas at a time and does not require any excavation. The infrared technique is especially useful for surveying heating and cooling distribution piping systems.

Disadvantages: The disadvantages of this process are that it cannot be used for any piping system that does not present a temperature differential.

5. ***Magnetic Flux Leakage (Pigging)***

Technology: Magnetic flux leakage detection is done with instruments which identify and record information about pipeline anomalies such as corrosion pits, mechanical damage, dents, mill defects, wrinkle bends, hard spots, and hydrogen blisters. Magnetic flux is sent into the pipe by the pig, and anomalies cause leakage of the magnetic flux into the ground. Data is recorded for future review and processing.

Use: These systems are only used for piping systems which are made of steel or cast iron. Anomalies can be located with an accuracy of ± 0.1% of the distance measured, and the minimum detectable pit ranges from 5 to 10% of the pipe wall thickness.

Installation: These systems are used for surveys only. The magnetic tape produced by the pig is examined for conditions associated with leaks.

Advantages: The advantages of this system are that it can be used to scan large areas at a time and does not require any excavation.

Disadvantages: A pig must be launched with the pipeline completely evacuated and requires special launch and recovery stations. Pipeline diameters and bend radii must be large enough to accommodate the pig.

6. ***Temperature Compensated Volumetric Testing***

Technology: Temperature compensated volumetric testing systems measure the volume of liquid that must be added to a piping system to maintain a constant pressure, thus providing the flow rate of a leak (or leaks) in gallons per hour. The temperature compensation is important, because thermally induced volume changes can either mask a small leak (causing missed detection) or be mistaken for a small leak (causing a false alarm). Thus, this type of testing must not be confused as being the same as conventional pressure testing.

Use: This type of testing can be applied to any piping system, made of any material. It is also applicable to any type of liquid, be it aqueous or petroleum based.

Installation: The equipment must be plumbed into the piping system under test.

Advantages: The measurement is highly accurate, capable of finding leak rates of less than the regulatory limit of 0.1 gallon per hour.

Disadvantages: The measurement takes 2 hours to complete, and the piping system must be taken out of service during the measuring period. Also, there is no way to determine the location of the leak

7. ***Pressure Point Analysis***

Technology: Pressure point analysis systems detect pressure waves caused by the sudden onset of a leak in a pipeline. Since this systems deals with the internal liquid, external factors such as ground water, previous contamination, or location of the pipeline (above or below ground) have no effect on performance.

Use: This system can be applied to pressurized pipelines ranging from 3 to 42 inches in diameter, regardless of material of construction. It is also applicable to any type of liquid, be it aqueous or petroleum based.

Installation: The pressure detectors are plumbed directly into the pipeline.

Advantages: The sensors can be spaced miles apart, unless special conditions like steep hills exist, when a sensor must be placed at the top of the hill.

Disadvantages: Flow noise can mask a leak indication (leak detection limited to 0.5 to 2% of the flow), and normal operation (such a valve movement) can also imitate leaks. The size of the leak which can be detected also depends upon pipeline volume (0.05 gph leaks detectable in 5,000 gallon systems, 0.1 gph leaks detectable in 17,000 gallon systems, and 3.0 gph leaks detectable in 116,000 gallon systems).

8. *SCADA Systems*

Technology: Supervisory Control and Data Acquisition (SCADA) systems use sensors to convert physical phenomena (such as pressure, temperature, flow rates, and density) into electronic signals which can be interpreted by the control system. SCADA systems rely on the combination of sensor inputs to determine the state of the system, which is then used to modify the control inputs to bring the system (heat distribution, petroleum delivery, etc.) to the desired state. Complete information about the liquid system is precisely determined at the sensor locations.

Use: SCADA systems control large networks of piping systems for the delivery of value-added liquids. These systems are monitored by a central processor, which uses the inputs from remote monitoring locations to account for the total volume of liquid. SCADA is applicable to potable water distribution systems as well as hot water heat distribution and Heating Ventilation and Air Conditioning (HVAC) systems. The nature of the monitoring system allows the incorporation of volumetric leak detection, as well as energy leak detection, over the entire piping network.

Installation: The multiplicity of the sensors required for an effective leak detecting SCADA system is easily implemented into new construction. Post-construction installation of a SCADA system limits sensor placement to accessible locations, when some, if not all, of the aforementioned sensors can be incorporated into the leak detection system, depending upon the particular installation requirements of each sensor. The sensors are then linked through telemetry to a central monitoring location and supervised by a host computer.

Advantages: The sensor inputs at adjacent measurement locations can be used to determine leak locations as well as leak rates. The time frame required to detect and locate a leak in the system is dependent on the frequency with which the system is sampled.

Disadvantages: The cost of sensors and data communication equipment necessary for implementing a SCADA system on a large piping system is prohibitive.

9. *Level Monitoring (SCADA sensor)*

Technology: Level monitoring uses high precision storage tank liquid level measurements to determine the volume of liquid contained in each tank of the system. In a closed system, the volume should be constant for a given pressure and temperature when there is no leak present in the system. Any variation in the level generates an alarm that something is out of specification for the system. Sensors can be float switches, of either capacitance or continuity type.

Use: Recirculating heating water distribution systems can recover and reuse water used to carry heat energy to the various distribution points. Also, any petroleum distribution system which goes to a static state for suitable length of time would be a candidate for liquid level monitoring for leak detection. In general, any liquid piping system which can be held in a static state for a sufficiently long period of time (based on total system volume), is a candidate for liquid level monitoring.

Installation: These systems can be designed into the construction of the system or added at a later time. The installation of a level monitoring system requires either a continuous reading probe or discrete level probe to be installed in each tank within the closed system, as well as the necessary monitoring wiring.

Advantages: The implementation of this system for leak detection is relatively inexpensive. Cost of implementation is directly related to the accuracy required for the particular system to detect leaks of a specific rate.

Disadvantages: Liquid level monitoring requires the system to be in a static state for a period of time which is dictated by the resolution of the sensors and the volume of the system. A large volume system would require extremely precise measurement sensors which would be subject to noise, or an excessively lengthy static state holding period to detect small leaks in the system.

*10. **Magnetic Induction Flow Meters (SCADA sensor)***

Technology: Magnetic induction flow meters rely on the conductive properties of the liquid. The flow passes through a magnetic field and this produces a voltage difference over the cross-section of the flow area. This voltage is proportional to the (average) flow velocity. By knowing the conductivity of the liquid, the strength of the magnetic field, and the cross-sectional area, the flow velocity can then be determined by measuring the potential.

Use: Can be used for all liquids flowing in pipes, providing that the conductivity of the liquid is known. These sensors, as with all mass flow sensors, are generally used as an accounting system to detect the loss of material between monitoring locations. These sensors can only identify the section of piping in which there is a leak.

Installation: These sensors rely on precise flow measurements for determining mass flow rates. The sensors are housed in a short section of pipe which is installed in the piping system at locations where the system will maintain a positive pressure and flow continuity. For post-construction installation, a section must be cut from the existing pipe, the exposed ends flanged, and the magnetic inductive monitoring section installed.

Advantages: The sensors are relatively inexpensive and are very accurate.

Disadvantages: There are velocity restrictions which depend on the liquid being pumped.

*11. **Calorimetric Flow Meters (SCADA sensor)***

Technology: These flow sensors utilize the calorimetric principal to determine flow velocity at a certain point in the flow field. The flow is locally heated and then the temperature is sensed a short distance downstream. Based on the thermal permitivity (the temperature dependent rate at which thermal energy propagates through a given medium) of the material, the temperature differential indicates the flow velocity. Assumptions on flow field profile are then used to calculate the volumetric flow rate from which the mass flow rate can be determined for a liquid of known density.

Use: Can be used for a wide range of viscosities and for high solids content, as in sanitary applications.

Installation: These sensors operate using assumptions about the profile of the flow in the piping system, which are similar to the assumptions made for the magnetic inductive mass flow sensors. They are similarly housed to magnetic inductive sensors and must be installed in the same fashion. Because the temperature must be measured at at least one location, there are components which are intrusive to the local flow field.

Advantages: Highly accurate flow detection.

Disadvantages: The main disadvantage is precisely controlling the temperature at the sensor. Fouling of the sensor could be a problem, depending on the liquid being transported in the piping.

12. ***Ultrasonic Flow Meters (SCADA sensor)***

Technology: By utilizing time-of-flight measurements of wave propagation or Doppler shift of the ultrasonic signal, the average flow velocity can be determined using two piezoelectric transducers, one a >sender= and the other a >receiver=.

Use: Ultrasonic flow meters can be used for a wide range of materials from sewage to ammonia, nitrogen, natural gas, air, acids, heavy oils, or desalinated water.

Installation: These systems can be attached to the exterior of the pipe in configurations which minimize the effects of a non-uniform flow field across the area being monitored. The location must correspond to a (preferably straight) section of pipe, which will maintain a consistent flow field during monitoring.

Advantages: The ultrasonic sensor systems have high measuring accuracy, no pressure loss or flow obstructions, low power consumption, and can be purchased in intrinsically safe versions for explosive environments.
Disadvantages: The initial cost of the signal processing equipment can be prohibitive.

Table A-I. Performance Characteristics of LDL Technologies
(from Ref. 4, Lefave and Karr)

Parameter	Temperature Compensated Pressure Test	Tracers	Pigging	Sensitive Cable	Fiber Optic Cable	Acoustic Emission	Pressure Point Analysis
Soil Conditions	No Effect on LDL Performance	Works Best in Highly Permeable Soils	No Effect on LDL Performance	No Effect on LDL Performance	No Effect on LDL Performance	Sensitive to the Acoustic Properties of the Surrounding Soil	No Effect on LDL Performance
Water Table	No Effect on LDL Performance	High Water Table and Saturated Soils Reduce Effectiveness	No Effect on LDL Performance	Sensitive to Water Intrusion to Cable	Sensitive to Water Intrusion to Cable	Sensitive Soil Moisture Content	No Effect on LDL Performance
Condition of Pipeline	Leaking Valves Prevent Accurate Testing	No Effect on LDL Performance	No Effect on LDL Performance	No Effect on LDL Performance	No Effect on LDL Performance	No Effect on LDL Performance	Leaks Present at Installation Will Not Be Detected.
Operations	Sensitive to Fueling Operations	Tracer Gas Must Be Dissolved in Fuel Throughout Pipeline	No Effect on LDL Performance	No Effect on LDL Performance	No Effect on LDL Performance	Sensitive to Noise Generated by Facility Operations	Sensitive to Vibrations and Fuel Operations at the Facility
Time Monitoring	Snap Shot	Snap Shot	Snap Shot	Continuous	Continuous	Snap Shot	Continuous
Spatial Resolution	Poor	Dependent Upon Sample Spacing	Good	Good	Good	Good	Good
Leak Rate Resolution	Good	Low	Low	Low	Low	Low	Good
Ease of Retrofit	Easy	Moderate	Depends on Configuration of Pipeline	Difficult	Difficult	Moderate	Easy

APPENDIX B

Field Survey Results

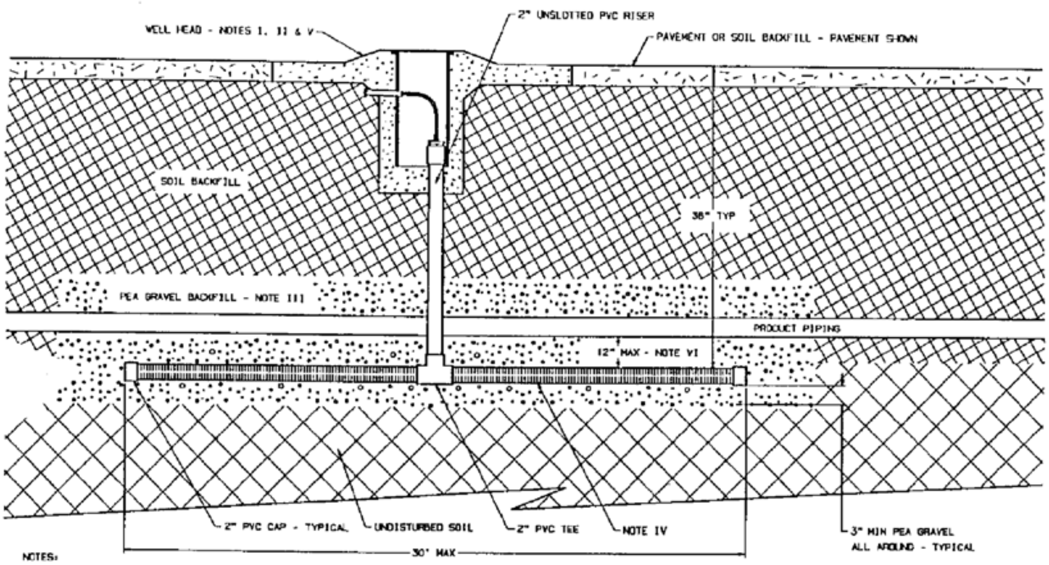
Field Survey Results

Site visits resulted in the accumulation of a great deal of useful information on the installation and operation of several commonly used leak detection and location systems. The most common systems encountered were the gas sniffing systems, configured either to detect hydrocarbons directly or to detect the presence of trace levels of a marker gas. The other systems surveyed consisted of cable systems and volumetric SCADA type systems. To date, CERL has performed 8 site surveys:

1. Pensacola NAS [14 inch JP5 line monitored by an Arizona Instruments hydrocarbon vapor detector],
2. Anchorage Airport [10 inch JP8 line monitored by a Hansa Consult pressure step system],
3. Elmendorf AFB [2 inch mogas and diesel lines monitored by Permalert cable systems],
4. North Island NAS [8 inch diesel line used in verification of a Vista Reasearch volumetric temperature compensation system],
5. Travis AFB [14 inch JP8 line monitored by an Argus Technologies hydrocarbon vapor detection system],
6. Ft. McCoy ANG [4 inch and 8 inch JP8 lines in a single conduit monitored by a Raychem cable system],
7. Whiteman AFB [18 inch JP8 line monitored by a Tracer Research marker gas system], and
8. Ellsworth AFB [18 inch JP8 line monitored by an Arizona Instruments hydrocarbon vapor detector].

Two leak detection systems manufactured by Argus Technologies were surveyed, and neither was functional. The system at Whiteman was abandoned in favor of the Tracer Research system when the quoted repair price of the Argus system exceeded the installation cost of the new Tracer Research system. The system installed at Travis AFB was installed concurrently with the pipeline to specifications by the pipeline construction contractor. MSgt. Torres indicated the system had yet to perform to the manufacturer=s specifications. The literature received from the company contained several performance evaluation documents from both foreign and domestic organizations. The system is based on sound scientific principals, however the system cannot be recommended due to two factors; 1) The time required for a given minimum leak to diffuse into the sensor requires the system to remain idle for so long that a leak of dangerous magnitude could remain undetected long enough to create a significant spill and 2) the system=s apparently unreliable performance.

AZI systems were surveyed at two sites, Pensacola NAS and Ellsworth AFB. This system has proven itself in the field, with its major drawback being the susceptibility of the system to water invasion and the resulting inability to monitor some sections of the piping system. In addition, experience has shown that the remote operation capabilities of the system can be a liability. Specifically, a lightning strike at the Pensacola NAS disabled several monitoring stations for several days. Another drawback to the AZI system is locating the leak source. At the Pensacola installation, the sensor tubes cover 20 ft. of pipeline per sensor well - see Figure B-1. This means that a leak indication can be located to within only 20 ft. of its source. The detection levels for a given leak rate are also dependent on the installation of the system, particularly the backfill surrounding the sensor tubing and pipeline. AZI recommends a minimum percolation value that must be obtained by the backfill in order for the system to perform to its minimum concentration detection levels. AZI claims a lower detection limit for gasoline of 150 ppm and 60 ppm for JP4, but does not give levels for either JP5 or JP8. Depending on soil types and ground water conditions, the system may be a viable solution for detection of fuel leaks, however, it is not applicable to water or energy pipe systems.



NOTES:

I. REFER TO THE OTHER DRAWINGS IN THIS SERIES CONTAINED IN THE INSTALLATION MANUAL FOR FURTHER INFORMATION REGARDING INSTALLATION OF THE SYSTEM.

II. CONCRETE SEAL MUST EXTEND AT LEAST 2" FROM THE WELL ENCLOSURE TO PREVENT SURFACE DRAINAGE INTO THE WELL. IF REQUIRED, THE CONCRETE SEAL MAY BE UNDERGROUND (THE ENCLOSURE MUST REMAIN AT LEAST 2" ABOVE GRADE).

III. PEA GRAVEL MUST BE CLEANED, NATURALLY ROUNDED AGGREGATE WITH A MIX OF PARTICLE SIZE OF NOT LESS THAN 1/8", OR MORE THAN 3/4".

IV. 2" MIN SCHEDULE 40 PVC WELL SCREEN OR 2" MIN SCHEDULE 40 PVC WITH SLOTS .030"±.010", 1/2" MAX APART EXTENDING FOR 1/3 OF THE PIPE CIRCUMFERENCE AND LOCATED ALONG THE ENTIRE HORIZONTAL LENGTH.

V. REFER TO DRAWING 7200-0024 (WELL HEAD INSTALLATION) FOR ADDITIONAL WELL HEAD INSTALLATION INFORMATION.

VI. PROBE SHOULD BE LOCATED PARALLEL TO AND WITHIN 12" OF PRODUCT PIPING. PROBE SHALL AT THE SAME DEPTH OR BELOW PRODUCT PIPING. TOTAL DEPTH IS DETERMINED BY PRODUCT PIPING. THE POROSITY OF THE PEA GRAVEL AND SOIL DURING WETTEST CONDITIONS SHALL ALLOW 1.5 LITERS/MINUTE OF AIR TO BE DRAWN FROM THE SAMPLE WELL HEAD WITHOUT CAUSING A VACUUM EXCEEDING 8" OF WATER.

HORIZONTAL VADOSE WELL IN BACKFILL 70000161

Figure B-1. AZI Model Twelve-X installation schematic

The Tracer Research system was used at Travis AFB before the installation of the Argus Technologies system. The Tracer system was considered too maintenance intensive after several of the probe wells were damaged by construction and grounds maintenance equipment. However, the same type of wells are used at Whiteman AFB and have not experienced the same rate of attrition. The 20 ft. well spacing of the Tracer Research system allows leak location to within 10 ft. of the source by comparison of relative concentration levels. The deficiency of the Tracer Research system is similar to that of the Argus Technologies system, in that it is not a continuous monitoring system. Leaks of dangerous magnitude can exist undetected until the next scheduled testing date.

Two volumetric systems were surveyed - a pressure differential system by Hansa Consult and a temperature compensated volumetric system from Vista Research. The pressure differential system samples the pressurized pipe 75 times during a 20 minute test and then repeats at a higher pressure. The data is analyzed by a PC and the leak rate is calculated. The system is able to detect a leak rate of 1.5 gal/hour. The temperature compensated volumetric leak detection system from Vista Research utilizes a reservoir tank and precision measurements of the tank level to produce a temperature compensated volumetric curve at two different pressures. The testing protocol requires about 2 hours to complete and is capable of detecting leaks of 0.01 gal/hour.

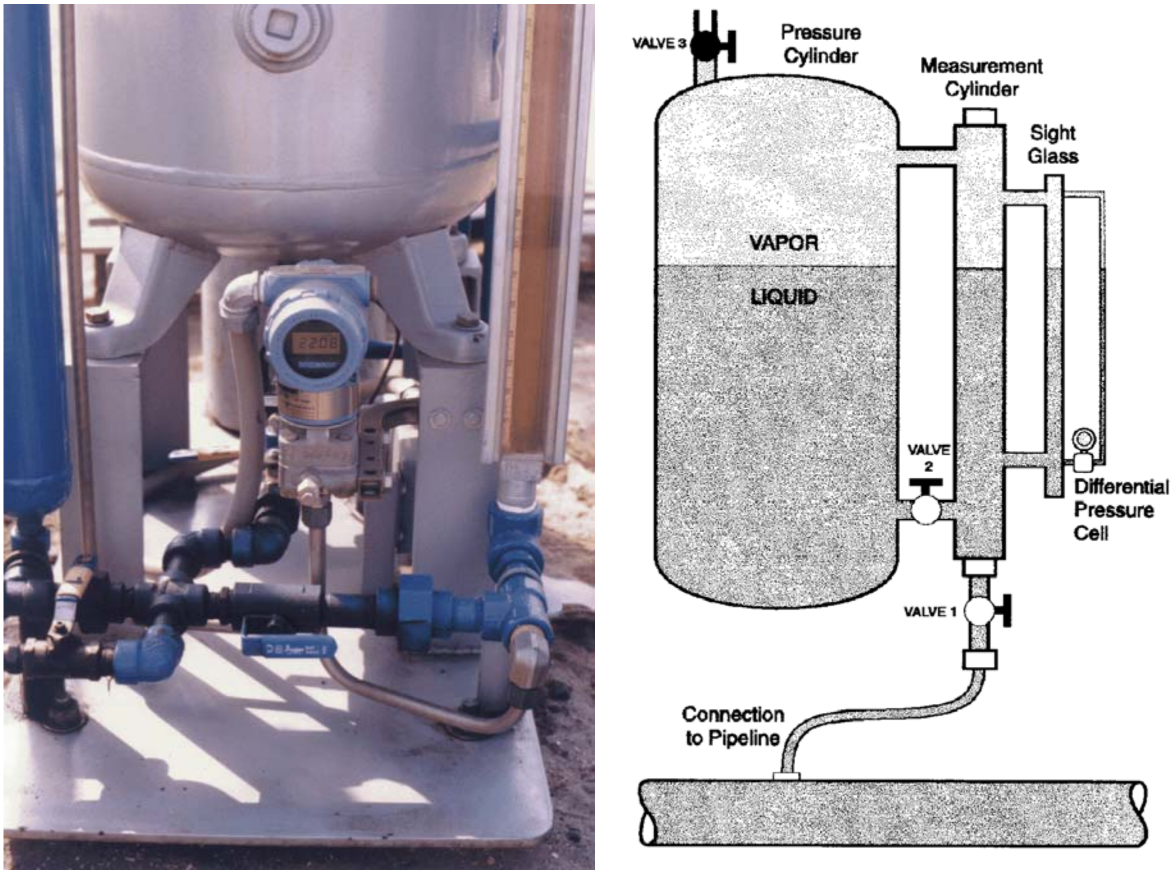
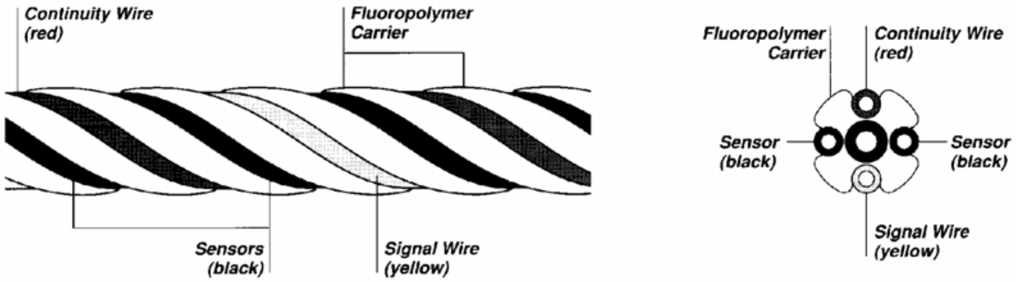


Figure B-2. A temperature compensated volumetric leak detection system

Two cable systems were also surveyed, one by Permalert and one by Raychem. Both cable systems were performing as advertised and one was indicating a water leak condition. The disadvantage of the cable systems is that they require replacement of any length of cabling which comes in contact with liquid. Also, they must be installed in a conduit pipe, effectively negating their applicability for an existing system and increasing the installation cost of a new system. The cable systems are ranked lowest in performance and cost. Water intrusion is a major problem for cable systems and since the cables must be protected, their use is limited to double-walled piping systems, which increases the initial cost of system installation and prevents retro-fitting existing systems.



Drawing not to scale

Cable diameter:	.240 inches nominal
Cable diameter with connector:	.510 inches nominal
Continuity and signal wires:	2 x 26 AWG with insulation of fluoropolymer
Sensor wires:	30 AWG with jacket of conductive fluoropolymer
Carrier:	fluoropolymer
Cable weight (50-ft length):	2 lbs

Figure B-3. Raychem TraceTek cable, typical of those used in a cable leak detection system