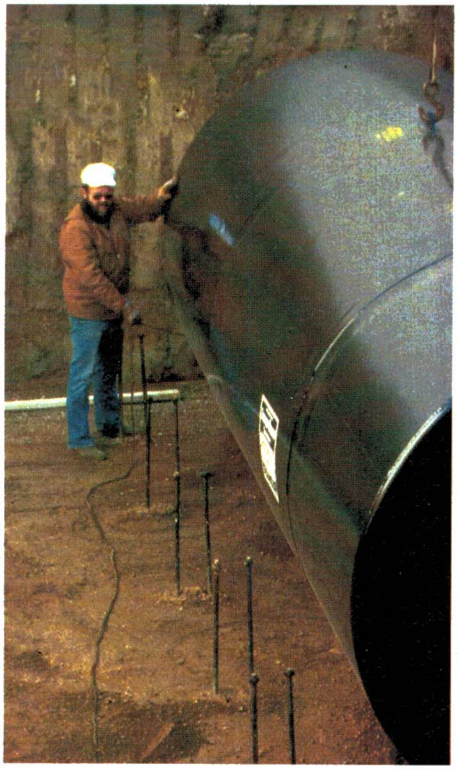

New regulations make it wise to either eliminate undergound storage tanks or provide them with facilities for leak detection. If they do leak, your company may be required to remove contaminants from the soil — a process that can be unbelievably expensive.

UNDERGROUND STORAGE TANKS
POTENTIAL FOR ECONOMIC DISASTER

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In 1984, Congress amended the Resource Conservation and Recovery Act (RCRA), and gave the U.S. Environmental Protection Agency (EPA) broad new areas to regulate, together with unusually specific legislative directives. Among the new items that the Congress targeted for regulation were underground storage tanks, in effect changing the way such tanks must be managed.

Consider this scenario: A chemical process industries (CPI) plant supervisor follows the new regulations and obtains a permit for a RCRA regulated underground-storage tank. When the tank is tested, a leak is found. Depending upon the contents of the tank and the size of the leak, this leak may be treated as a "release to the environment," which must be reported to the National Response Center.

If the leak has not been cleaned up to "background" levels by the time the state environmental agency becomes involved, the state may decide that "disposal" has taken place and that a portion of the plant must now be listed as a waste disposal site.

The plant could then be required to provide a waste-site closure plan, to hold public hearings, to place deed restrictions on the plant property, and finally to provide a bond that would cover the cost of closing the site and also sampling and analyzing the groundwater for up to 30 years.

The threat is real. One mechanical-equipment manufacturer that we know has a large vacant building for sale. The building comprises over 250,000 ft^2 of clean manufacturing space and one small area used for equipment degreasing and cleaning.

A prospective buyer wanted to acquire the building but insisted on excavation and removal of the underground storage tank and piping used for the cleaning solvent. A cracked elbow in the drain line leading to the tank had allowed solvents to leak into the groundwater and spread under the manufacturing building. The original owner still has his building, and has spent over $300,000 to date for investigation and site cleanup. The cleanup is not yet complete.

RCRA — A brief overview

When Congress amended the RCRA Regulations in late 1984, it added provisions to control the underground storage of hazardous substances along with hazardous wastes. If an underground tank contains a RCRA hazardous waste, a hazardous substance, or petroleum, it falls under EPA's Underground Storage Tank Program. Hazardous substances are defined by the spill control regulations (Comprehensive Environmental Response Compensation and Liability Act or CERCLA in 40CFR, 300–302*).

These regulations cover a wide variety of process chemicals. The 1984 RCRA Amendments define a "regulated substance" as all hazardous substances and "petroleum, including crude oil or any fraction thereof that is liquid at standard conditions of temperature and pressure 60 degrees fahrenheit and 14.7 pounds per square inch absolute." The Amendments excluded the regulation of hazardous wastes because they are already regulated under Subtitle C of RCRA (40CFR, 260–261).

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*CFR = Code of Federal Regulations. The citation is to Title 40 of the Code, Parts 300 to 302.

Congress was very specific in defining just what types of tanks, and tank systems, fall under the RCRA Amendments. An aboveground tank that does not have more than 10% of its volume (including piping) underground is *excluded* from the underground tank regulations. (But note that, by this definition, a 5,000-gal tank sitting wholly atop the ground but having 1,400 ft of 3-in. buried pipe or 350 ft of 6-in. buried pipe is considered an underground storage tank!)

Other tanks excluded from regulations include (a) noncommercial farm tanks (those serving botanical research groups, timberlands, nurseries, etc.) and residential petroleum tanks smaller than 1,100 gal; (b) on-premises heating oil tanks; (c) septic tanks; (d) tanks associated with pipelines already regulated under pipeline safety acts, (e) surface impoundments of any type (lagoons, ponds, etc.); (f) storm water or wastewater collection systems; (g) flowthrough process tanks including sumps; (h) oil or gas production facility pipelines and liquid traps; and (i) storage tanks located in a basement, mine shaft or tunnel, only if the tank is not lying on the floor. However, it should be noted that if the basement has an impermeable finished floor, the tank may bear directly on the floor.

Any underground storage tanks that have been in operation since Jan. 1, 1974 or that have been removed from service since that date should have been registered with the "designated" state environmental agency by May 8, 1986. [A list of designated state agencies can be obtained by calling the RCRA-Superfund Hotline at 1 (800) 424-9346.] The designated authority for registration varies from state to state. According to one government estimate, about 25% of all underground storage tanks may still be unregistered.

Any owner or operator of underground storage tanks that are newly installed or removed, or of any existing tanks having hazardous substances or hazardous wastes put in them for the first time, must notify the designated state agency within 30 days of the tanks' change in status.

The "change in status" concept can be found to be confusing — especially when a tank may be used to store several chemicals. For example, in an ammonia plant, putting ammonia in an underground tank formerly used for propane storage would trigger the tank registration requirements. Another example would be a change of use from a process or sump tank to a storage tank for petroleum, hazardous wastes or hazardous substances would also require tank registration.

Financial responsibility

Congress also set up requirements for underground-tank monitoring and leak detection, and told EPA to establish financial responsibility standards for tank owners. These regulations have not yet been issued, but an examination of recent rules for underground hazardous-waste tanks suggests that the tank owner will be required to provide an insurance policy, bond or surety in an amount equal to the estimated cost of decontamination and disposal of the tank and its contents.

The cost estimate for the tank will include all chemical testing and certification of site closure by a professional engineer in the same manner that a hazardous-waste-management site is closed under current RCRA regulations. Depending on the nature and size of the tank, the cost of decontamination and disposal can easily exceed $20,000 per tank. If the tank or its piping has leaked and contaminated the ground, the closure cost could approach $30,000 –$50,000, or even go much higher. If groundwater contamination has occurred, a cleanup bill may easily exceed $250,000.

None of this liability is covered by commercial insurance carriers, nor will it be any time in the near future. Cleaning up after underground storage-tank leaks can pose a great financial liability for any company.

New construction standards

Congress allowed the installation of underground storage tanks after May 8, 1985, only: (a) if the tank will prevent releases due to corrosion or structural failure during the life of the tank; (b) if the material used in tank construction or tank lining is compatible with the substance stored; and (c) if the tank is cathodically protected, constructed of or clad with a noncorrosive material, or designed in a manner to "prevent the release or threatened release of any stored substance." A noncathodically-protected mild-steel tank may be installed in soils that have a resistance of at least 12,000 ohms/cm, (as determined by ASTM Test Method G57-78), provided that the tank meets the other requirements above.

The final regulations governing underground storage tanks are due to be issued in mid-1987. The potential impact of these regulations can be evaluated by examining existing and proposed ones. The July 14, 1986, Final Rule — Hazardous Waste Management System; Standards for Hazardous Waste Storage and Treatment Tank Systems, (51FR25422),* provides a good guide to what EPA is thinking.

A careful reading of these regulations reveals several things:

1. The use of underground tanks to store petroleum or hazardous substances will become much more expensive. The regulations will strongly discourage continued use of single-walled tanks, and encourage the construction of tanks that have spill containment systems.
2. EPA will rely heavily on visual detection of leaks. Any tank or piping that cannot be frequently visually inspected will require secondary containment and an alarm system capable of rapidly detecting a leak.
3. Prevention of leaks from tanks and pipelines will be a cornerstone of EPA's program.
4. Annual or semiannual tank inspection and testing may become mandatory.
5. Groundwater monitoring will be a required element of the underground-storage-tank program.
6. EPA will issue standards for underground-storage-tank design, and will require the certification of new construction.
7. A bond or surety will be required to ensure that tanks that have reached the end of their service lives are properly decontaminated and removed from service.
8. EPA will require a tank management plan that addresses operator training, emergency response procedures, and operation and inspection procedures.
9. All new underground-storage tanks will be required to meet new design standards that include: (a) corrosion protection, (b) use of noncorrosive backfill materials, (c) certifica-

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***Federal Register*, Vol. 51, p. 25422.

tion of tank compatibility with stored materials, (d) structural analysis of the tank design, and (e) a certification that the tank has been installed according to that design.

10. A bond or insurance policy must be obtained that will provide for cleanup of leaks or spills. While no specific figure has been established, EPA has been considering requiring a $1 million-per-occurrence policy for retail gasoline outlets. (EPA has been informed that, for gasoline tanks, environmental liability insurance is available at an annual cost of $2,000 per site. No such insurance is currently available for hazardous wastes or hazardous substances).

Fig. 1 provides an indication of how new and existing underground tanks may have to be designed or modified to meet the new tank standards.

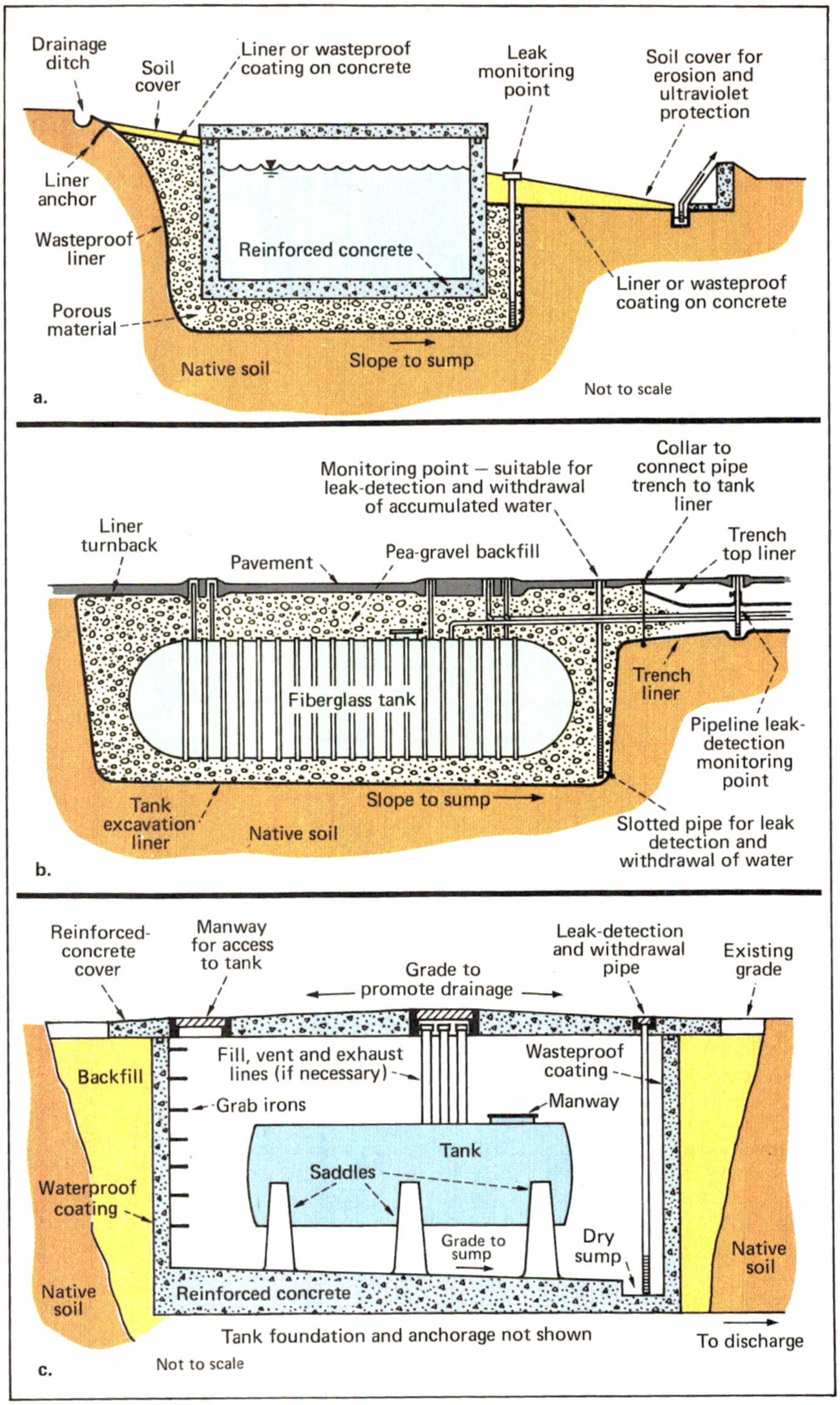

Figure 1 — Some ways in which new tanks may have to be designed, or old ones modified, in order to meet the new underground storage-tank standards

Leak detection

Underground-tank integrity testing, and the use of periodic groundwater monitoring, will be required on all underground-tank systems. It is important for the person responsible for managing an underground tank system to be aware of the limitations and strengths of the various leak detection and groundwater monitoring systems.

Several types of leak detection systems are available for underground tanks. Some are better than others because of their reliability, cost, or ease of use. Some of the leak detection systems may produce a false sense of confidence about your tank. Those interested in learning about tank testing methods should obtain "Underground Tank Leak Detection Methods — A State of the Art Review," NTIS Publication No. B86-177155.*

A tank either leaks or it does not. Even a very small leak represents a potentially large liability. Just because most of the tank-testing methods indicate that your tank is apparently nonleaking, you should not feel secure. The present EPA and American Petroleum Institute standard for nonleaking underground tanks is 0.05 gal/h — or about 3.15 cm^3/min. On a daily basis, this is only 1.2 gal, but it is large enough to cause major aquifer contamination and major cleanup expense.

The tank system piping should be checked separately from the tank if possible. Loose fittings and cracked piping will show up as a leaking tank unless they are independently inspected or tested.

Tank testing

Table I presents a brief overview of the commercially available volumetric-type tank testing systems, and summarizes some of their limitations. These systems all claim to be able

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*Available from NTIS (National Technical Information Service), 5285 Port Royal Rd., Springfield, VA 22161.

to accurately measure a change in tank volume due to a very small leak; they do not claim to locate the leak.

Three of the four types of systems listed rely on a change in level of the working fluid in the tank. The buoyancy systems use a sensitive balance and the apparent change in buoyancy of a float to track the volume change within a tank. The manometric systems measure the change in pressure due to a change in fluid depth; the level-change systems measure the direct change in level — usually in a standpipe or in some other location where the apparent loss in liquid will be easily measurable.

The pressure-based tank testing systems are semivolumetric; they require an empty tank and rely on the change in pressure of the gas in the tank to determine a leak rate for the test fluid. From the Bernoulli equation, the approximate size of the opening can be calculated and related to an equivalent leak rate based on the viscosity of the tank's liquid.

As noted, the volumetric systems can determine the size of the leak but not the location. For some of the nonvolumetric systems listed in Table II, the manufacturers claim to be able to determine both the leak rate and the location. Acoustical systems using either pressure or vacuum to generate a detectable sound may ultimately prove very accurate, but they are not yet commercially available.

The "Tankology" system triangulates the sound of bubbles entering the tank from a vacuum leak. The gas detector systems use the diffusive properties of helium or other tracer gases to locate a leak. Helium is so diffusive that it will penetrate cement or asphaltic pavements covering the tank. Manufacturers of these systems claim that they can determine the size and location of an underground tank leak by determining the helium concentration at the pavement above it. The tracer gas is sensed by a mass detector or gas chromatograph on the surface, or in monitoring wells around the tank.

Table III lists several other types of leak detection systems that will confirm a leak but will not determine its location or size.

The underground tank, its piping and the soil in which the tank and piping reside, make up a dynamic interactive system. Fig. 2 indicates some of the variables that can influence an underground-storage-tank leak test.

Air pockets in a tank will expand or contract at a rate different from that of the tank liquid and may cause erroneous indications either way. The volume of the air pockets are affected principally by temperature and barometric pressure.

Most groundwater is around 55°F, and if the tank liquid is not in thermal equilibrium with the groundwater, the liquid temperature in the tank may change, giving false indications. A high groundwater level may cause pressure changes on the tank that can mask a leak.

Tank deformations during the test can create apparent leaks or mask leaks. Anything that tends to make the tank change shape can cause a potential error. Fortunately, most of these errors occur rapidly and give large indications of volumetric changes. Improper bedding, end-wall deflections, and unusual surface loadings (heavy trucks) can all interfere with the tank leak test.

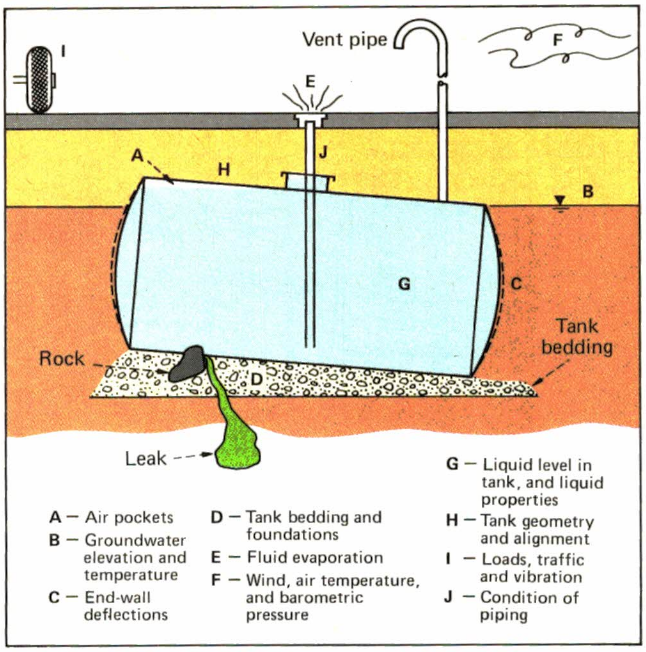

Figure 2 — Plan and elevation of a monitoring-well system

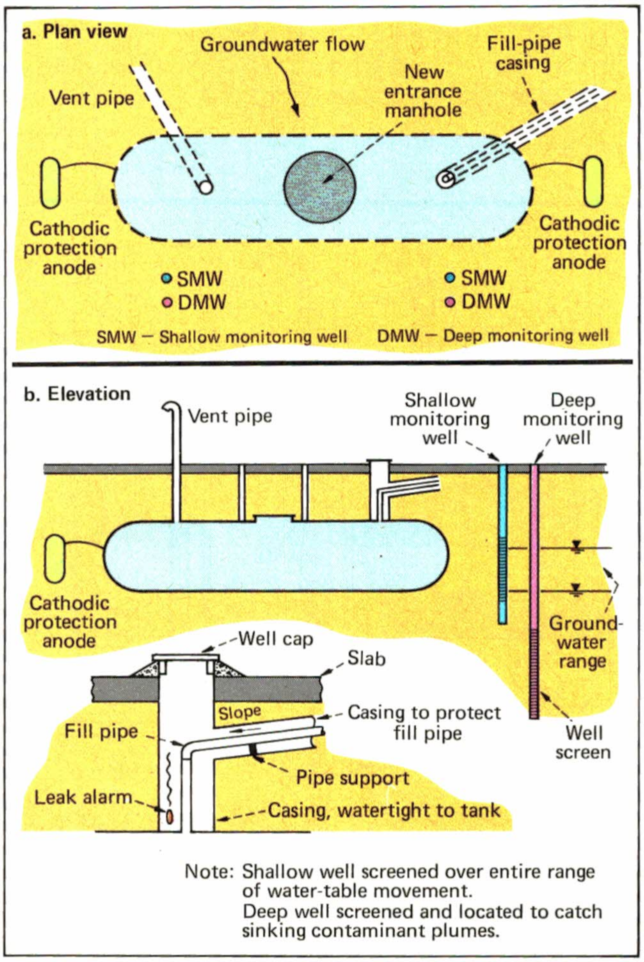

Figure 3 — Many factors influence leak tests on underground tanks

One occasionally overlooked factor is the tank pressure during the test. An extra 4 ft of water head on a 48-in.-dia. tank can cause a net change in pressure of 3,133 lb on the end-wall — creating a deflection that would cause a volume change of 150–200 cm³ — about the magnitude of a 0.05 gal/h leak.

Fluid evaporation during the test can also falsely indicate a tank leak. Wind, air temperature and barometric conditions can affect the tank-fluid's evaporation rate. The temperature of an underground tank will frequently vary in direct proportion to the temperature of the air.

A change in liquid temperature of even a few tenths of a degree can mask a leak or falsely indicate one. For example, benzene has a thermal coefficient of expansion of 0.00071. A temperature change of 0.02°F in a 5,000-gal tank during a 1-h test could change the apparent liquid volume in the tank by about 0.071 gal — which is slightly larger than an allowable tank leak. In many tanks, temperature stratification of the tank liquid must also be considered. Almost all of the tank-testing companies have a system to measure tank temperature within 0.01°F, and to compensate for thermal stratification within the tank.

If the tank is not level, and if the tank test method measures a level change in a partially full tank, the change in the volume of the tank per increment of depth may involve some careful evaluation.

Table I — Summary of volumetric tank testing systems

Operating principle	Common tradenames or type	Manufacturer's claimed sensitivity (if known), gal/h	Special requirements
Level change	Ethyl Tank Sentry	0.02 – 0.05	No deliveries for 24 h before test
	Heath Petro Tite	0.02 – 0.05	Full tank
	Kent More	0.02 – 0.05	Full tank
	Standpipe	0.02 – 0.05	Full tank
	Mooney	0.02 – 0.05	Fill tank at least 2 h before test
Manometric systems	ARCO HTC Systems	0.05	Adjust tank to 2/3 full
	Ainley Tank Tegrety	0.02	Fill tank evening before test
	Ethyl Tank Sentry		No deliveries for 24 h before test
	EZY-Check Leak Detector	<0.01	Fill tank 4 h before test
Buoyancy change	Leak Locator Test	0.05	Full tank
	Tank Auditor	0.03	None
Pressure testing	Air pressure	Gross	Empty tank and seal ports
	Helium	Very very small	Empty tank and seal ports

Table II — Nonvolumetric leak detection systems

Operating principle	Common tradenames or type	Manufacturer's claimed sensitivity (if known), gal/h	Special requirements
Acoustic triangulation of sound	Tankology	Unknown	Tank ports sealed and tank placed under vacuum
Helium mass detector	Varian Leak Detector; Smith and Dennison; Leybold-Heraeus	Detect leak of 0.005-in. dia	Tank filled with helium. Leak detected from surface by special mass detector
Tracer gas	TRC Rapid Leak Detector	Unknown — believed very small	May use helium or other tracer gas

Table III — Other leak-detection methods

Type of detection method	Limitations
Inventory monitoring	Volumetric meters and gages not sensitive to losses
Monitoring wells	Properly developed and screened wells can be used to detect gases escaping from tanks. Several wells are required.
Conductivity systems	Use changing conductivity to detect leaking products. This can be a reliable early-warning system.
Collection pumps	Rely on a perforated pipe to collect leakage from beneath tanks

Surface vibrations, traffic, and pavement type and condition can all affect the tank test.

Vibrations can create standing or pressure waves in the tank that make level measurement within the tank difficult. Such vibrations can be caused by traffic in the area.

One important item that can influence the test is the condition of the tank's piping. Improperly tightened joints, broken elbows, and broken or cracked pipes can all be the major source of a leak. In a recent tank-testing survey we conducted on over 300 underground storage tanks, we found that about 20% were leaking. Almost half of these had piping leaks.

Nonvolumetric testing systems

Acoustic leak-detection systems may be affected by noise and vibration, making the operator unable to hear the leak bubbling into the tank. Acoustic systems can also be affected by both the groundwater level and the soil type. In a vacuum test, clay or soil fines could plug the leak from outside the tank.

Helium and tracer gas testing is very good, but quite expensive. A helium mass-detection system costs around $20,000, and is a relatively sensitive piece of equipment; a good gas chromatograph properly fitted for leak detection is almost as expensive. Both these instruments require frequent recalibration and maintenance.

A nonvolumetric tank-testing system using an ultrasonic analyzer to detect a high-frequency noise generated by a vacuum leak appears promising as a leak detection method, but it is not yet commercially available.

Other leak-detection methods

U-tubes, sumps and wells are often used to detect underground tank leaks. These methods are reliable but only work if the leaking product finds its way to the well or sump.

The U-tube and sump systems must be constructed prior to tank installation; monitoring wells can be installed after the tank is in place. U-tube and sump systems may be very good for a chemical product heavier than water but are less effective for a floating product. The reverse is often true for the monitoring-well system (see Fig. 3).

It will require at least three wells to determine the direction of the groundwater flow around a tank. Wells located too far away from the tank or improperly screened can miss the leak in the tank — especially if the liquid is denser than water.

With all passive monitoring systems, the leakimg material must first reach the system and then someone must collect and analyze a sample. The delay between sampling and receipt of analytical results can be several weeks. Some rapid detection systems on the market detect a leak by measuring a change in conductivity of the groundwater. Most of the systems are designed for gasoline and other fuels, and measure a conductivity change in a thin layer on the groundwater surface; they can work very well if enough leaking product is present.

Vapor detection systems for monitoring underground tanks may become important because vapor moves faster through the ground than water; no vapor detection systems are commercially available.

Planning an underground tank test

Before you test an underground tank, ask yourself several questions:

What am I going to do with the information I gain? Does my plant's management understand the need to test the tanks and is it ready to take the actions that may be needed if the tanks are found to be leaking or if there is a major underground contamination problem?

If you suspect, for any reason, that your underground storage tanks may be leaking, ask yourself whether you should postpone the testing until the last date that testing may be legally required, or whether you should try to save money by starting to clean up the underground contamination plume before it gets bigger. (The impact of month or two delay may not be significant in reducing the cost of cleanup for a leak that has been going on for several years.)

Select tank-testing contractors carefully. Many testing companies are new in the business and many will be out of business in a few months. A few firms and testing systems have been around for several years. Depending upon the tank testing system you select, experience may be the deciding factor in choosing between equally well qualified contractors.

Look at the tank-testing contractor's review and reporting practices. Does the field technician provide the certification on the tank or are the data reviewed by someone with more experience, to see whether there are any errors. Will the contractor come back and retest if its data do not make sense? Will you be supplied with the raw data, as well as with its evaluation?

Determine what the contractor is certifying or attesting to. Few contractors will attest to more than the results of the test, allowing you to draw your own conclusions. If the contractor will warrant that your tank is leakfree, and back up his statements with a bond, so much the better. We doubt that anyone presently in the business will. In actuality, you are asking the contractor to look at the tank and report on its tests — it can draw conclusions from the tests, but if it incorrectly interprets the test results, you are worse off then before, because now you have a false sense of confidence about your tank system.

Tank testing is probably the least expensive factor in tank management (unless the plant's purchasing agent is allowed to select the tank-testing contractor on the basis of the lowest costs.) When writing a tank-testing contract engineering input is needed to ensure that the contractor is supplying you with the data you need. A typical tank test may cost from \$300 to \$2,500 per tank, depending upon the tank system, the test method and the amount of technician's time required.

Test preparation

When you have finally scheduled the tank testing crew and confirmed its arrival date, make sure that you:

1. Provide the crew with a list of plant safety rules well before the test — especially if your plant's Safety Department requires that all personnel be clean shaven or be able to wear a respirator.

2. Inform the plant Safety Department so that it can provide safety briefings and have line or security personnel available to escort the contractor.

3. Notify the Maintenance Departments and Plant Operations well in advance of the tests. Plant Operations will need to reschedule production around the tank. Plant Maintenance will need to supply plumbers and electricians, jackhammers for pavement breaking, and concrete or asphalt for pavement patching.

4. Determine what is needed by the tank contractor and where the crew can gain access to the tank.

Some contractors may require that all tank piping be uncovered; others may want the tank empty; others may want a series of holes drilled through the pavement to help pinpoint leaks. Find out whether the contractor needs the area around the tank to be relatively free from vibration (traffic may have to be rerouted, or a local compressor may have to be shut down during the tests).

If the tank is to be tested in a full condition, schedule tank deliveries well in advance of the contractor's needs, and make sure that a drum or two of extra liquid is on hand to allow the contractor to top off the tank.

Alternatively, if the tank is to be tested in an empty condition, you may want to have it visually inspected and desludged prior to the testing.

5. Arrange for someone to work with the contractor on the day of the test, and inspect and document the work. You may need confirmation that the contractor was there, and photo-

graphic evidence of the condition of the tank at the time of the test.

6. Make sure that the tank piping has been inspected, tested, and plugged at the appropriate points. Tank piping is frequently a source of leaks.

7. Make needed upgrading changes during the planned service interruption. If you intend to install cathodic protection, it may be convenient to do it while the tank is out of service. In the future, all underground tanks and piping may have to have leak detection systems.

Test results

Let us say that you have received your tank-test results from the contractor and found out that the tank may be leaking — what do you do now? If you are in doubt, take it out!

The money you will spend on replacing the tank and rebuilding the tank vault may appear large; but in comparison with the cost of assessment and remedial action for a leaking tank, it is small.

Assessment and remediation

After you have repaired or replaced your leaking underground storage tank, you will need to initiate a program of contaminant assessment. The objectives of the assessment program should be to: determine the type of contamination present, measure the concentrations of constituents, estimate the extent of contamination, and determine the hydrogeologic properties of the subsurface materials. This information will be used in designing a recovery system.

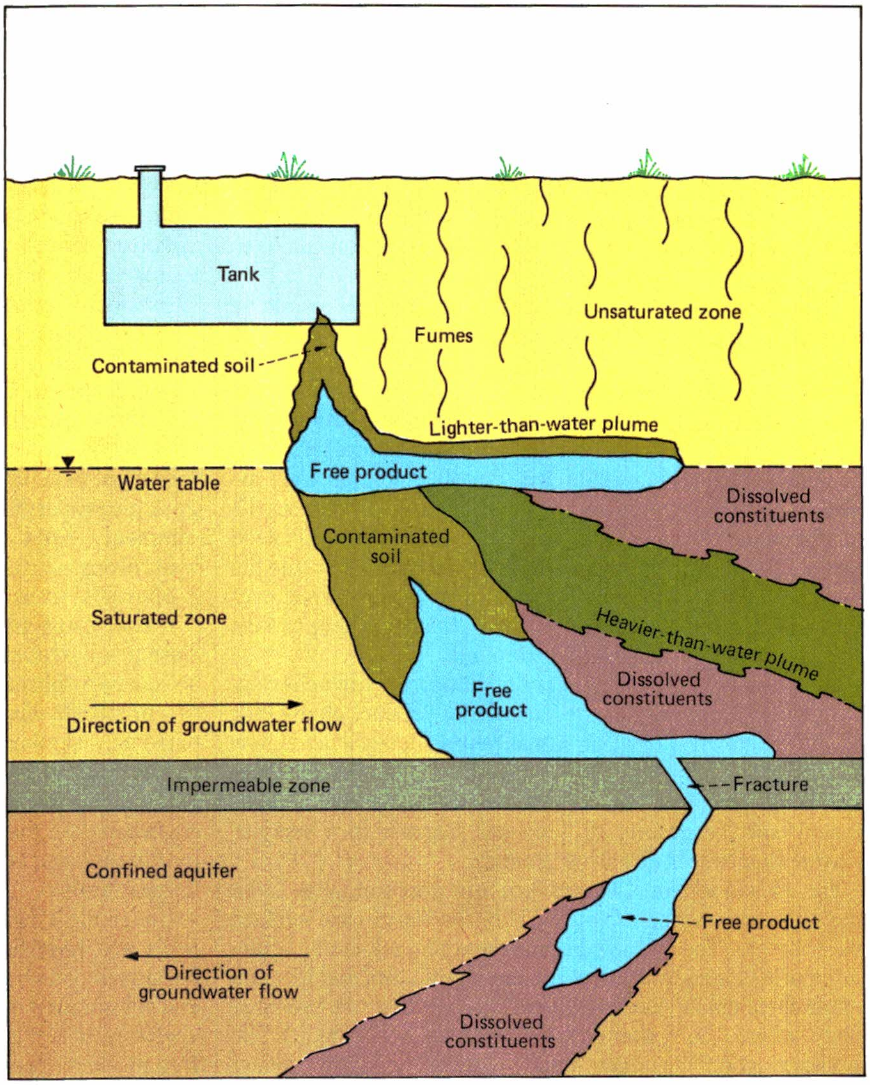

Figure 4 — How subsurface geology can affect dispersion of underground-tank leaks

An assessment program should recognize four phases of environmental contamination: contaminants adsorbed onto soil, free product floating on (or sinking below) the water table, dissolved constituents in the groundwater, and vapor phase (fumes) in the unsaturated zone (Fig. 4).

Product released from a leaking underground storage tank will migrate downward under the force of gravity until it encounters the water table, where it will then flow with the groundwater. In the unsaturated zone above the water table, some product will be absorbed onto the soil particles and some product will be retained in the pore space between the soil particles by capillary action. The concentration of the contaminants in the unsaturated zone of the soil depends on the soil's sorptive capacity (principally the percentage of clay minerals) and the soil capillarity, which is largely a function of the soil's grain size.

In a soil having low sorptive capacity and capillarity, such as an unsaturated, clean medium- to coarse-grained quartz sand, only small amounts of contaminants are likely to be left in the pore spaces between individual sand grains. In a fine-grained soil having a large percentage of clay minerals, capillary action and soil adsorption can retain a significant quantity of contaminants. If the soil is later saturated, by a rise in the water table, product stored in the pore spaces may be released, causing reappearance of free product. A decline in the water table may "smear" product onto previously unaffected soil

Below the water table, contaminants are retained by soil adsorption only. Contaminated soil is likely to be found anywhere free product has been; the contaminated soil may act as an apparent secondary source of product if underground conditions are right.

When it encounters the water table, escaped free product from an underground storage tank will move with the local groundwater (Fig. 4). Chemicals with a specific gravity less than 1 will float atop the groundwater, while those with a specific gravity greater than 1 will sink, leaving behind a long trail of contaminated soil.

The free-product plume in the soil has the highest concentration of contaminants, but generally is of limited area; adsorption and capillary-pore-space retention retard the migration of the free-product plume. Particularly viscous products may completely block off the pore spaces and seal off any conduits of migration. Lighter-than-water free-product plumes are generally easy to detect. Heavier-than-water free-product plumes may be less so, especially if conduits of flow, or vertical joints, exist in the soil or rock formations, thus allowing the free product to migrate downward (see Fig. 4).

The primary objective of a remediation program should be recovery of the free product, as it is a source of contaminated soil, dissolved constituents and fumes.

The groundwater may dissolve some of the free product, creating dissolved-contaminant plumes. These plumes have the viscosity of water, and the contaminants in them move by advection. Contaminants in the dissolved plume may be present at trace levels, well below the parent compound's solubility in water. In the case of gasoline, the dissolved contaminants may include benzene, toluene and xylene, as well as ethylene dibromide and lead. These compounds may not be present in the groundwater in the same proportions that they exist in the parent compound.

Dissolved-constituent plumes do not necessarily behave in the same manner as does the parent free-product plume. For example, the wood-treating agent pentachlorophenol is normally mixed with diesel fuel and will form a lighter-than-water free-product plume. However, dissolved pentachlorophenol (specific gravity of 1.98) will migrate in a sinking, heavier-than-water dissolved plume.

The dissolved constituents are the contaminants most likely to enter water-supply wells or discharge into surface water bodies. The dissolved-constituent plumes can be attenuated or changed by adsorption, biodegradation and groundwater chemical interactions. (Chemical interactions are most likely where the contaminant is primarily inorganic.) The capillary action that may inhibit migration of pure product plumes occurs only in the unsaturated soil zone, but because the dissolved constituent plume is mostly water, capillary action does not retard its movement.

Due to their large volume and areal extent, dissolved plumes are often difficult to remedy by recovery techniques. Also, unless the parent contaminated soil and free-product plumes are completely remediated, dissolved constituents will persist, regardless of the amount of remedial activity.

The fumes (or vapor phase of contamination) are the unsaturated-zone (the zone above the water table) equivalent of the dissolved-constituent phase. The vapor-phase contaminants travel much faster than do the water-borne contaminants. There are a number of cases in which gasoline fumes detected in the foundations of a nearby building provided early indication of a leaking underground gasoline tank.

Because of the volatility of the products, and the low rate of soil pore-space air movement with respect to that above the surface, the vapor phase can accumulate concentrations of contaminants many times higher than the lower explosion limit. Excavations in and around a leaky underground storage tank that contained gasoline or highly flammable chemicals needs to be performed with some caution, as explosive pockets may exist in the soil.

The primary transport mechanism of vapor contamination appears to be gaseous diffusion. A dissolved-contaminant plume may move feet per day, whereas vapor-phase contamination may move tens of feet per day, or feet per hour. Because of the structure of the soil and its pore spaces, the migration path and extent of a vapor phase is very difficult to predict. Vapor-phase contamination is derived primarily from free product or heavily-contaminated soil because the dissolved contaminant concentrations are generally so low that their contribution to the vapor is insignificant.

As stated earlier, one of the objectives of an assessment program should be to determine which of the four types of contamination (contaminated soil, free product, dissolved constituents or vapor phase) are present. Other equally important objectives of the assessment include measurement of the concentrations of contaminants, estimation of the extent of contamination, and determination of the hydrogeologic properties of the soil matrix. Several techniques are commonly used in assessment: visual inspections (site walkthroughs),soil test borings, monitoring-well installation, geophysical measurements and vapor detection.

If the water table is relatively shallow and if the tank is close to an excavation, trench or stream, the investigator can occasionally observe contaminants seeping into the excavation or stream directly. Where the depth to the water table is extremely shallow, as in some coastal areas or large river valleys, the free product may rise to the ground surface after heavy rainfalls or spring snow-melts. Vapor-phase contamination may sometimes be detected without specialized equipment in excavations or low areas adjacent to the leaking tank.

Under most conditions, soil test borings and monitoring wells are required for an assessment program. Soil test borings, in which a hole is advanced with an auger-type drill and soil samples are obtained with a split-spoon sampler, are useful in detecting the presence of contaminated soil and free product. The relative concentration of contaminants in soil can be estimated by visual inspection and odor of samples brought to the ground surface. When properly stored, the concentrations of contaminants in the soil samples can later be analyzed in the field or laboratory, using gas chromatographic techniques.

The thickness of the free-product plume is difficult to determine in a soil test boring because the drilling of the borehole significantly disturbs the plume. The areal extent of contaminated soil and free product can be determined by careful observation of both soil and water conditions and by plotting the data on an accurate site-map. Grain-size analyses of soil samples may also yield significant data on hydrogeologic properties, and for design of monitoring wells.

Installation of properly-designed monitoring wells can yield significant data on free-product and dissolved-constituent concentrations. Proper design of monitoring wells must consider placement, total depth, length of screened intervals, screen slot-size and methods of installation.

Monitoring wells installed upgradient of leaking underground storage tanks, side-gradient of the free-product plume, or down-gradient but beyond the free product plume, are all examples of improper placement. It is necessary to first determine, by literature search and field investigations, the direction of groundwater flow, so that the plume orientation can be determined, and the monitoring wells installed at locations that intercept the plume.

In the case of floating hydrocarbon products such as gasoline, it is necessary that the screened interval of the well span the range of the water-table fluctuations, so that free product can enter the well; monitoring wells having totally saturated screened intervals will not detect lighter-than-water free product plumes.

Similarly, monitoring wells at heavier-than-water plume-assessment sites must have sufficient depth to intercept a plume located at or near the aquifer bottom. Well screens with narrow slot widths (less than 0.020 in.) might not allow viscous products to enter the well. Monitoring wells should be designed and placed so that they have a high likelihood of intercepting a free-product plume, and should be designed to permit the collection of representative fluid samples.

Monitoring wells may also be used to determine aquifer properties such as hydraulic conductivity, transmissivity and hydraulic storage capacity. Hydraulic conductivity (the rate at which water flows through an aquifer cross-section of unit area under a unit gradient) is often estimated using slug-test procedures.

With the slug test, hydraulic conductivity is estimated from the rate of rise (slug-out test) or fall (slug-in test) of the water level in a well after a certain volume, or "slug" (generally, a 1.0- to 2.0-in.-dia. solid PVC pipe), is suddenly inserted or removed from a well. Calculations used to determine the coefficient of hydraulic conductivity (k) have been developed by Bouwer and Rice [*1*]. Conductivity has units of cm/s or ft/d.

Aquifer transmissivity is the rate of flow of water through a unit width of an aquifer under a unit gradient; it is equal to the product of the hydraulic conductivity and the thickness of the aquifer.

Transmissivity is often measured directly by aquifer testing. Here, a test well is pumped at a constant rate for a given time, and the resulting drawdown in the pumped well and in local observation wells is measured and recorded at specific time intervals. Measurements of water levels after the pump is stopped (aquifer recovery) are to check the pump test results.

Geophysical survey techniques that can detect electrical, magnetic, gravity or other anomalies in the subsurface may be low-cost alternatives to extensive drilling. Geophysical methods frequently used include resistivity and conductivity profiling, ground-penetrating radar, seismic reflection, magnetometry and metal detection. These methods may be limited by factors such as the suitability of the contaminant as a target (conductive contaminant plumes are good targets), the hydrogeologic setting, cultural "noise" (such as overhead power lines) and site access. Conductivity or resistivity methods are useful in locating conductive plumes; ground-penetrating radar may be good in sands but not in wet clays.

Vapor-phase-contaminant detection may be used to assess the extent of fumes and free-product contamination. Vapor detection can be accomplished through shallow hand-augured holes into the unsaturated zone with portable organic-vapor detectors or portable gas chromatographs. As with geophysics, vapor detection may provide a low-cost alternative to extensive drilling, but the results of both geophysical and vapor investigations should be verified and related to data obtained from monitoring-well installations.

After the four types of contamination have been identified and quantified by the assessment program, a corrective-action program may begin. Such a program should consist to two parts: elimination of the source, and cleanup of contaminants.

Source elimination may be achieved through tank removal, or replacement, tank and line modifications, or in-place tank closure. Old tanks are frequently replaced with new ones that feature leak-detection systems.

Corrective action may involve containing the plumes by slurry trench or sheet pile cutoff walls, creating hydraulic barriers around the site, excavation and removal of contaminated soil, pumping from plume recovery wells, and the like. Newer, less-tested methods include bacterial biodegradation, or fixation and stabilization by inorganic polymers. Whatever the method, it will be time-consuming and expensive.

In conclusion, we hope that we have convinced you that for the sake of your plant's economic well-being, you should consider either eliminating your underground storage tanks or installing the necessary containment facilities that are required to prevent the leak or loss of chemicals into the ground.

***Roy V. Hughson**, Editor*

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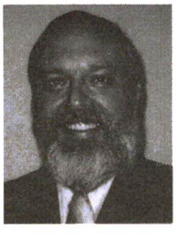

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