329

UNDERGROUND LEAKAGE OF FLAMMABLE & COMBUSTIBLE LIQUIDS 1977

NFPA

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See Official NFPA Definitions at the back of this pamphlet.

Recommended Practice for Handling

Underground Leakage of Flammable and Combustible Liquids

NFPA 329 — 1977

1977 Edition of NFPA 329

This Recommended Practice was prepared by the Sectional Committee on Maintenance and Repair, approved by the Flammable Liquids Correlating Committee, and adopted by the National Fire Protection Association at its 1977 Fall Meeting held in November 1977 in Atlanta, GA.

Origin and Development of NFPA 329

This Recommended Practice is an update of the Recommended Practice on Leakage from Underground Flammable and Combustible Liquid Tanks, NFPA 329 — 1972 edition.

This Recommended Practice replaces the 1972, 1965 and 1964 editions and a manual on this subject issued in 1959. The manual was preceded by a report (NFPA 30B) on the same subject which was withdrawn from publication in 1950.

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*Recommended Practice for Handling

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CHAPTER I

Introduction

The purpose of this Recommended Practice is to provide a guide for the safe and efficient handling of flammable and combustible liquids when, for whatever reason, they are found unconfined and unwanted. For the proper installation of underground tanks, see the Flammable and Combustible Liquids Code, NFPA 30.

The Problem

Flammable liquids (those having a flash point *below* 100°F) and combustible liquids (those having a flash point at or *above* 100°F) are used by the millions of gallons daily and, of necessity, are stored and handled in locations immediately adjacent to structures, facilities, and people. These liquids include chemicals, cleaning fluids, motor gasolines, diesel fuel and heating oils. Motor gasolines are the most widely used of these liquids and they are commonly stored underground at service stations.

In spite of constant effort to maintain and operate storage and transfer equipment properly, accidents do happen, equipment does fail, and people do make mistakes that sometimes permit the escape of these liquids. Leaks may develop from corrosion, or be caused by mechanical damage, or some liquid may be spilled during transfer. Generally, the amount of liquid lost is small and it is dissipated by evaporation or is otherwise assimilated before it creates a serious problem. However, it occasionally happens that some flammable or combustible liquid finds its way into an underground facility, such as a basement, utility conduit, sewer, or well. Whether or not it creates an immediate hazard will depend on many things, such as how much liquid or its vapor is involved, where it is found, how it is confined, possible sources of ignition, etc. But, because a flammable or combustible liquid unconfined in the ground can move from place to place, any indication that such liquids have escaped into the ground must be considered as a potential, if not immediate, hazard.

Cooperation and Responsibility

The responsibility for proper handling of a suspected escape of flammable or combustible liquids, or a potential hazard from such an escape, will fall upon various individuals and organizations. The successful handling of these problems will depend upon the best possible cooperation between them.

One of the prime purposes of this guide is to provide a basis for this cooperation. Because of the almost infinite variables involved, it can't be a rule book in the strict sense of the word. It can, however, provide a definite course of cooperative action that will ensure the most effective use of skills and equipment, the fairest assessment of responsibility, and will result in the best possible protection of life and property. A positive, cooperative attitude of anyone potentially involved will benefit everyone, regardless of the final results. Lack of cooperation could result in inadequate protection of life and property.

Since leakage of flammable liquids, especially such liquids having low flash points, is a fire problem, necessary steps to be taken will normally be under the jurisdiction of the fire officials. It therefore becomes important for such officials to understand the many facets of the problem, and to secure the cooperation of interested groups as outlined above.

Recent developments, problems and attitudes have now also involved health and environmental officials. When dealing particularly with water pollution and the more persistent slow or non-evaporating combustible liquids, the concern of these officials may be paramount.

The location of leaks, testing of tanks and piping, removal of leaky tanks and removal of liquid in the earth will require equipment and facilities which may be more available to the industries involved than to the public authorities. In addition, much of the work is not the responsibility of the fire department or other agencies, but rather is the responsibility of the owner of the leaking equipment.

Regardless of the willingness of individuals or companies to cooperate with governmental agencies during an emergency, the agencies should recognize that they should officially request such cooperation.

When tanks are to be removed, or other work done on private equipment, or on private property, such as holes being dug, this work must be authorized by the owner. Such authorization generally is easy to secure if the work has been requested by officials. In some cases, these requests may of necessity be in the form of a written order. Regardless of conditions, leadership and a close spirit of cooperation should be established by the responsible agency.

In addition, those in industry having special qualifications in dealing with leakage should be called upon for help and guidance. Their knowledge and experience should merit careful consideration.

This guide is intended for the information of all organizations and persons involved.

CHAPTER II

Procedure When Life or Property May Be in Danger

The need for cooperative effort by many individuals and organizations is stressed in the introduction preceding this chapter. Good judgment must be used in assembling the various groups. Always seek assistance in the interests of safety, but avoid creating unnecessary alarm or unwarranted interruption of normal activities. Owners, operators or others becoming aware of a hazardous condition should notify the fire department, police, or other proper authority. However, make every reasonable effort to determine the degree of the problem. Excessive alarming, such as may be caused by unwarranted evacuation or publicity, can create more hazard than the original problem. Good judgment applied to the following step-by-step guide will materially improve the chances for successful results.

The potential that unconfined flammable or combustible liquids exist underground will normally become known by discovery of one of the following conditions:

1. Combustible or flammable liquids or their vapors are reported in:

a. Normally inhabited subsurface structures such as basements, subways, and tunnels;

b. Other subsurface structures such as sewers and utility conduits;

c. Groundwater such as drawn from wells, on or in surface water, or emerging from cuts or slopes in the earth.

2. User reports loss of stock or presence of water in the storage facility. *Each condition requires different handling:*

Condition 1-a

NORMALLY INHABITED SUBSURFACE STRUCTURES SUCH AS BASEMENTS, SUBWAYS, AND TUNNELS.

This condition implies a strong potential hazard to life or property and immediate steps must be taken to protect the public from the danger of explosion and fire.

Eliminating Sources of Ignition

Smoking or other sources of ignition should not be permitted in the suspected area. Lights and other electrical switches should not be turned on or off and extension cords should not be removed from outlets. Such action may create a spark capable of igniting flammable vapors. Use only those switches located well away from the contaminated area to cut off electrical power, which may require the electric utility to make a remote cutoff.

After the presence of flammable vapors has been verified, the electric and gas services to the building, where possible and feasible, should be disconnected or cut off outside the structure. The shutting off of the gas service outside of the building removes the fuel from pilot lights and gas burners, which may be sources of ignition.

No one should enter the contaminated area except as described in "Entering the Area." Where liquids or vapor within or above their flammable range are found in a building, the building should not be entered, and evacuation of building occupants, at least in areas exposed, should be ordered. Construction and layout as well as occupancy are factors to be considered in ordering evacuation. Traffic should be stopped through tunnels and subways until qualified personnel determine there is no danger of explosion or fire.

Entering the Area

The presence of flammable vapors in a building is generally reported because of an odor. Most persons can detect gasoline vapor in concentrations as low as .005 percent. However, smell cannot be relied upon to determine the type of vapor or its concentration. The use of a combustible gas indicator is the only practical, positive method to determine the presence and extent of a flammable vapor concentration.

To enter an area in which there is an undetermined concentration of some unknown vapor is to risk the possibility of fire or explosion. Entry should not be made until the vapor concentration has been checked with a combustible gas indicator. Portable combustible gas indicators are reasonable in price and are recommended for use by all fire departments. If the fire department does not have such an indicator, arrangements should be made for securing one or more from utilities, oil companies or others who may have them available. A trained operator should use the combustible gas indicator, which must be well maintained.

Also an additional life hazard may exist because of toxic vapors or insufficient oxygen. If these conditions are suspected, instruments to detect toxic vapors or insufficient oxygen should be used.

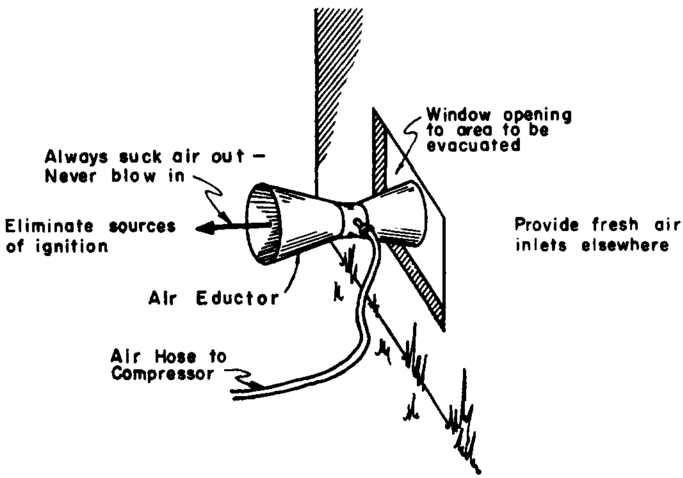
Use the combustible gas indicator continuously to determine the range of vapor concentrations in the affected area. If areas of vapor concentration above 50 percent of the lower flammable limits (LEL on indicators) are exposed to a source of ignition, leave the area and evacuate everyone within the danger zone. Ventilate the area to remove or reduce the flammable vapors and thus reduce the fire or explosion hazard. As soon as the flammable vapor has been reduced below 50 percent of the lower flammable limit, entry may be made to locate and eliminate the source of vapor. Wear self-contained breathing apparatus when entering. Do not rely on filtering or chemical masks as asphyxiation is likely due to lack of oxygen.

Ventilating the Area

Natural ventilation by opening doors and windows may be adequate. Grounded mechanical exhaust ventilating equipment may be required to remove vapors from all areas, particularly from low, confined spaces. Use fans driven by motors approved for Class I, Group D locations, hand-driven fans, or air eductors to remove vapors. (See Fig. 1.) Eliminate sources of ignition near the exhaust outlets. Provide openings for free entry of fresh air, but never force air into the area. A water hose with the nozzle set in a spray pattern may be used for ventilating the area when set in a window and discharging outwardly.

Locating Seepage into Building

When the area has been made safe for entry, it may be examined to determine the source of the flammable vapors. If the place or places of entry of the liquid or vapors can be determined,



EXHAUST VENTING

Fig. 1

appropriate steps should be taken to seal off such places. Untrapped drains, dry traps, pipes or other openings through floors or foundations are common sources of liquid or vapor entry into a building. Check any gas pipes in the area; the flammable vapor may be fuel gas. If this appears to be the source, call the gas company.

Preventing Seepage into Buildings

Entrance of vapors or liquids through drains, pipes, or other openings may be stopped by plugging such openings. Sewer pipes may be the source of entry. If only vapor is entering through a sewer pipe, it may be because the trap is dry. Filling the trap with water is an effective means of blocking further gas or vapor entry.

The nature of seepage may be such that it cannot be effectively stopped from the inside of the structure. In this case an intercepting hole or trench, holes for pumps, or well points may be used outside the contaminated structure, between it and the suspected source. (See Chapter VI for details.)

Condition 1-b

OTHER SUBSURFACE STRUCTURES SUCH AS SEWERS AND UTILITY CONDUITS.

Liquids or vapors in such structures imply a potential for explosion or fire but, generally, a low potential of hazard to life and property other than to the structure involved. If the detection of flammable or combustible liquids or their vapors indicates an unusual condition wherein vapors are escaping from the sewer or conduit into an area similar to Condition 1-a, or if the proximity to other structures or facilities is such that an explosion or fire would be relatively as serious as Condition 1-a, then proceed with the guides of 1-a in addition to the following procedures.

Contact those directly responsible for the facility involved: the municipal sanitary department or highway or street department for sewers; for conduit, the electrical, telephone and gas companies' engineering departments. Normally, the maintenance and engineering departments of such organizations will be well equipped to take charge of the situation; police, if needed, may be asked to keep the public clear of the danger areas. The fire department may be needed to assist in fire control and purging. Those involved with the storage and handling facilities of flammable and combustible liquids that may be the source of the problem should offer all possible assistance. (See NFPA 328, *Flammable Liquids and Gases in Manholes and Sewers*, and Chapter V of this guide for further details.)

Entering the Area

Basically the same as for Condition 1-a; however, the flammable vapors in a sewer or conduit may not originate from flammable liquids. They may be vapors from overheated insulation, sewer-generated gases, fuel gases, or industrial gases. Consequently, special instruments, equipment and skills may be needed. The guidance of the utility owning and operating the facility should be solicited and followed.

Ventilating the Area

Some type of grounded mechanical ventilating will normally be required. Use explosionproof equipment if the vapors are drawn out. Remove all sources of ignition from the vicinity of vapor exit.

It may be that water flushing is the better means of purging the area of flammable vapors. For example, the generation of sewer gas may be stopped or significantly reduced by this method. In a similar fashion, flammable and combustible liquids may be removed from the area.

In any case, follow the guidance of the owner or operator of the facility as he will be most familiar with its characteristics and the consequences of any action taken.

Locating the Seepage

Assist the facility owner in any way practicable. See Chapter V for information on tracing liquids underground.

Preventing Continued Seepage

Because of the length of sewers and conduits it is often better to take advantage of these facilities for the collection and removal of flammable or combustible liquids until the source is found and cut off. However, if the points of entry are limited in number and concentrated, interception by a hole or a trench, well holes, or well points may be better methods. (See Chapter VI for details.)

If entry of liquid or vapor into the conduit or sewer is to be stopped, and the inside of the facility is not accessible, probe or drill alongside the facility to determine the extent of its exposure to the saturated soil. Uncover the exposed area and caulk the facility from the outside.

Condition 1-c

GROUNDWATER SUCH AS DRAWN FROM WELLS, ON OR IN SURFACE WATER, OR EMERGING FROM CUTS OR SLOPES IN THE EARTH.

These liquid seepages on water will often be more of a problem because of pollution than as an explosion or fire hazard. However, until the source of the flammable or combustible liquid is found and stopped and all liquid and vapor safely removed, there is a potential hazard of explosion or fire.

Wells

When flammable or combustible liquids are found in well water, stop pumping and avoid any source of ignition around well houses and water storage tanks until vapor concentrations are checked. Turn power off outside any well house or similar trap that may collect vapors from the well or stored water.

If vapor concentrations are below 50 percent of the lower explosive limit, pumping may be resumed if desirable for purging. (See Chapter VI for details.)

Surface Water

When flammable or combustible liquids are found on surface water or water emerging from hillsides or cuts, concentrations may develop in ditches or collection points that may create an explosion or fire hazard. Normally, the amount of flammable or combustible liquid found on the surface water will be in such a thin layer that it does not create a fire hazard. This is the case when the liquid is dispersed into small bubbles or pools, or when only color patterns are visible on the surface of the water.

However, if the entire surface of the water is covered, or there are large pools in the order of 20 ft. or more across, a fire hazard does exist. If this occurs in an inhabited area or along a street or highway, and the police and fire department are not present, they should be called. Traffic should be stopped and the public kept away from the area. If large amounts of vapor are being generated, check the wind and remove all sources of ignition within at least 100 ft. downwind of the source. It is unlikely that vapors will be in the flammable range farther than 100 ft. away. However, if large amounts are involved, and the air is relatively still, a combustible gas indicator should be used to determine the extent of the hazardous area. Its use is desirable in any event if flammable liquids are involved.

Normally, the only effective means to stop further accumulation will be to find the source and stop it. (See Chapters V and VI.) It may be desirable to construct dikes or dams to prevent further spreading of the liquids or of contaminated water.

Floating booms can be used on flowing water to hold the contaminating liquid. (See Chapter VI for details.)

Once the source of flammable or combustible liquids is stopped, evaporation or normal dispersal and dilution will often be the best means of removal. Burning off under controlled conditions with fire-fighting equipment available may be permissible, or collection with adsorbents or skimming devices may be necessary. (See Chapter VI for details.)

Condition 2

USER REPORTS LOSS OF PRODUCT OR PRESENCE OF WATER IN STORAGE FACILITY.

An inventory loss, or water in tanks, does not directly imply a hazard of fire and explosion. Check the immediate vicinity for any signs of escaping liquid; if any exist, apply Conditions 1-a, 1-b, or 1-c, as appropriate. Otherwise, proceed in accordance with Chapter IV, Testing for Underground Leaks.

CHAPTER III

Primary Search for the Source

Once all necessary precautions have been taken to protect life and property, the next most important step is to determine the source of the flammable or combustible liquid and prevent any further escape.

Generally, the source of a flammable or combustible liquid will be relatively near the location of the discovery of unconfined liquids or vapors. However, liquids can travel blocks or even miles underground through porous soil or rock, trenches filled with porous soil, alongside pipes or conduits, or in sewer pipes. Consequently, the area from which an escaped liquid could have come may be remote and extensive, and include many facilities storing and handling flammable or combustible liquids. If a check of potential sources (see page 16 for check list) immediately adjacent to, or within a few hundred feet of, the discovery does not reveal an obvious or possible source, organize a general search of the area.

Obtain (or sketch) a map of the area, mark each facility found on the map, and record all the information obtained in a notebook. Good data, well organized, will prove invaluable in subsequent efforts to solve the problem.

Organize teams of as many qualified persons as are needed and available to conduct the search. A very efficient method is to assign two-man teams (with one man representing the local public authority) to specific areas on the map. Begin with the nearest and most obvious potential sources and work out from the point of discovery, concentrating on moving uphill, upstream of underground water flow, or upstream of sewer or conduit flow.

Quite often the source can be found by inquiry or simple inspection. Begin with the "Primary Search." If this fails to discover an obvious or very likely source within the first few hours, it is advisable, while the Primary Search continues, to begin testing equipment for concealed leaks at the closest and most probable sources (see Chapter IV) and to take the first steps in tracing underground liquids (see Chapter V).

Primary Search Procedure

Flammable or combustible liquids will escape into the ground from one of two principal sources: (a) liquid has been spilled during transfer and has run into a sewer or soaked into porous soil; or (b) a leak has developed in storage, transporting or handling equipment.

Use the list below to check for spills or other possible sources by asking questions and by a careful inspection of premises and equipment. Unless an obvious source is found, substantial enough to account for the seepage, do not stop the search at the first sign of a potential source. First impressions can be misleading.

Liquids may travel slowly underground or may not move at all until the water table rises. As a result, there can be a considerable time lapse between the occurrence of a leak or spill and the report of finding liquid or vapor. Record all history or evidence of potential sources regardless of how long ago they occurred; do not eliminate any potential sources on the basis of time, until data is available and the analysis of that data justifies elimination.

1. Possible sources to check:

a. Gasoline service stations.

b. Automotive garages or agencies.

c. Fleet operators such as taxicab companies, dairies, bakeries, municipal garages, etc.

d. Contractors or equipment dealers who may store fuels on their premises.

e. Fuel distributors that supply service stations or commercial users.

f. Heating oil distributors.

g. Cleaning establishments.

h. Chemical companies.

i. Industrial plants that may use and store flammable or combustible liquids.

j. Airports and marinas.

k. Check public records, make inquiries about any high-pressure petroleum or gas lines in the area. They may be marked with signs at street and railroad crossings.

l. Any abandoned flammable or combustible liquid tanks.

m. Any other properties on which flammable or combustible liquids may be stored.

2. Questions to ask:

a. Has there been a spill during loading or unloading?

b. Any storage or handling equipment leaking, or has there been a leak? Check for excavations that may have damaged underground facilities or give evidence of repairs.

c. Has any maintenance work involved release of liquids from tanks, pipes, or equipment?

d. Has there been any odor or sign of liquids where they should not be?

e. Are inventory and use records kept?

f. Has water been found in the storage facility?

g. Is there any knowledge of an accident in the area that may have released liquid from tank trucks, barrels, or large fuel tanks? (A check with local police may be in order.)

h. Ask about the age of underground facilities. If subsequent equipment checks are made, the older equipment is suspect as a leaking source because of corrosion.

i. Have any pumping problems been experienced?

If inquiry fails to disclose any potential source, ask the owner or operator for his cooperation in checking his equipment and the area around his premises. If he refuses because he does not own the equipment, contact the owner for his cooperation. If necessary, governmental authority such as exercised by fire officials, may be used to obtain such cooperation.

3. Checking equipment:

a. Check the area around fill pipes where liquid is transferred from truck to tank for signs of frequent spills. Saturated and darkened soil, stained concrete, or disintegrated asphalt indicates repeated spills that may accumulate underground.

b. Check the area around aboveground tanks for similar signs that may indicate a leak or overfilling.

c. Check any exposed piping for signs of leaks.

d. Check pumping equipment for leaks. It is advisable to use a combustible gas indicator when checking pumps/dispensers of the type used in service stations. Open the cover of the unit just far enough to insert the indicator probe into the bottom area. Opening the cover wide may provide sufficient ventilation to give such a low reading as to indicate no leak. Also, check the hose and nozzle.

e. If a remote pumping unit is used, check its housing or pit with a gas indicator before opening and then open for visual check for signs of leaks.

f. Check automotive repair areas for signs of waste liquids being dumped into floor drains or sumps.

4. Checking the area:

If all equipment seems to be in order and there is no obvious sign of spilling or dumping into sumps or sewers, check around the grounds and adjoining areas.

a. Look for signs of dumping waste liquids on the ground.

b. Check nearby streams and bodies of water for signs of flammable or combustible liquids.

c. Check vegetation in the area for any indication of damage by spillage, dumping or contaminated ground water.

d. Using a combustible gas indicator, check sewers and other underground cavities such as telephone and utility conduit manholes for presence of vapors and make visual inspection for signs of foreign liquids on water surfaces.

e. Check nearby excavations and steep cuts or natural slopes below the potential source for signs of liquid coming through the soil.

When leaks in equipment are discovered, ask the user and owner to stop use of the equipment until the leak is repaired. Pump out liquid in storage if it is still escaping through the leak.

If large spills have been reported or there are indications that there has been repeated dumping or spilling of flammable or combustible liquids into sewers or on the ground, ask those involved to modify their operations to prevent recurrence.

Be reasonable and fair; recognize that small spills may inadvertently occur and that a very small amount of petroleum liquid (just one cup of gasoline, for example) on a wet pavement will spread over a large area, appearing to be a more severe spill than it actually is. Spills on the surface that spread out will dissipate rapidly and are not likely sources of underground contamination. The significant spills are large spills that can flow to points of access to underground structures or areas of porous soil, or repeated smaller spills that immediately flow into structures or soak into soils.

If an obvious source, or one or more likely sources, has been found and further escape of liquids eliminated, further search may be temporarily suspended to determine if, in fact, the located source(s) is the cause of the problem. While removal and protective measures are taken, monitor and record the flow of liquid, the amount of liquid, and the vapor concentration at those locations where the problem exists. If there is a distinct and continuous decrease it may be assumed that the source(s) has been found and further contamination eliminated. The decrease may not show up immediately; it may, in fact, require days or weeks to remove liquid that has accumulated underground or for it to dissipate. Refer to Chapter V, Tracing Liquids Underground, to determine how much time may be required before a decrease at the monitoring point may be expected.

If, after a reasonable length of time as determined with the reference above, the supply of liquid to the threatened area does not stop or show definite decrease, further investigation should be conducted simultaneously along two paths. These two paths also should be followed if no source is found.

One is a test of flammable or combustible liquid storage and handling equipment in the vicinity of the contaminated area; the other is to trace the liquid underground from its point of discovery. Tracing is conducted to determine the extent of the contamination, the direction of flow, and any potential more remote source(s). Tests on underground equipment are performed to determine definitely whether or not they are a source. (See Chapter IV, Testing for Underground Leaks, and Chapter V, Tracing Liquids Underground.)

CHAPTER IV

Testing for Underground Leaks

Tests to determine the tightness of underground liquid handling equipment will have to be conducted when:

1. The search procedures of Chapter III or the tracing procedures of Chapter V indicate a probable or likely leakage source, but the actual cause is not determined from surface observation;

2. There is a suspicion of a leak because of reported stock losses;

3. There is a report of the accumulation of water in a tank.

Review all data previously gathered to determine the most efficient method or methods of testing. There are several quick and simple tests described in this chapter that may reveal a leak under certain circumstances. If one of these preliminary tests does not reveal the source of a suspected leak, it cannot be concluded that the liquid-handling system is tight, but the possibility of quickly solving the problem will often warrant the limited effort involved before a precise Final Test is undertaken. (See page 31.)

One or more of these preliminary tests would be particularly desirable if precise final test equipment is not immediately available. If such equipment is available, time and labor costs may be reduced by immediately making a Final Test.

Regardless of the testing procedure involved, keep in mind that liquid-handling equipment should be tested in a condition as close as possible to normal operating condition, particularly equipment which is underground or otherwise concealed. There are several important reasons for this.

1. Uncovering and exposing can very easily cause a leak which did not previously exist and its discovery might imply the problem is solved when, in fact, it is not.

2. Responsibility resulting from unconfined liquids or vapors underground might be falsely placed by a leak created by uncovering and removal activity.

3. Uncovering underground liquid-handling equipment is costly and time consuming and is not justified without valid reasons to suspect leakage.

4. Excessive pressures or tests by nonrepresentative liquids may indicate leaks where none existed or conceal leaks where one, in fact, exists.

Action Preliminary To Testing

Before actual equipment testing is undertaken, review the results of the Primary Search in Chapter III. This review may reveal information that will eliminate the need for further testing or this information will be useful in making further tests.

Ensure that spills or deliberate disposal are not the leakage source, keeping in mind the possible transit of liquids by trenches and underground water. (See Chapter V.)

Recheck stock records for indications of loss; but do *not* jump to conclusions. Meters may be off calibration causing only a paper loss, not a physical loss.

Temperature change may falsely indicate a loss. The volume of petroleum products is highly sensitive to temperature change. A drop of one degree Fahrenheit will shrink 1000 gallons of gasoline by 0.6 gallons. This may at first seem small but consider a typical example. In the spring, the ground will still be relatively cool from the preceding cold weather, while liquids stored and transported aboveground may be relatively warm.

A typical underground storage tank may handle 20,000 gallons in one month. If, on the average, this liquid cooled 5° F after delivery, stock records will show a loss of $5 \times .6 \times 20 = 60$ gallons. Ten degrees cooling would appear as a 120 gallon loss for 20,000 gallons handled, and 240 gallons loss for 40,000 gallons handled. Obviously, a temperature increase would have the opposite effect and could actually conceal a physical loss.

Finally, theft may be the cause of reported stock loss.

Consequently, further checking must be performed before a facility is implicated on book stock losses alone. Check meters for calibration. Check relative temperature of delivered and stored product during the period in question. Check for the possibility of theft.

Checking Stock Records

A careful check of stock records will be very helpful in determining the course of further investigation.

1. If the reason for the check is a report of loss of stock but no liquid or vapor has been reported in unexpected locations:

a. Loss due to meters out of correct calibration, loss by contraction due to lower temperatures, or theft would indicate that a hazard need not be expected. Further testing is not necessary;

b. If not solved as in (a), evidence of a stock loss requires further testing to determine the cause. It also indicates that a potential hazard may develop from the escaped liquids and a check of the surrounding area should be made for signs of contamination. (See pages 18–19.)

2. If the reason for the check is discovery of escaped liquids or vapors found underground:

a. Evidence of stock loss strongly implies the source has been found but subsequent checks to determine how the loss has occurred must be made before definite conclusions can be drawn;

b. Loss partially or totally explained by off-calibration meters, temperature shrinkage or theft cannot be considered as conclusive evidence that the site in question is not a source. Records are often incorrect or inadequate; unless another source is found and considered to be a satisfactory solution to the problem, other tests must be performed to draw definite conclusions.

When a review of the Primary Search Procedure (see page 15) fails to reveal a probable source, any leak that may exist is probably underground, and testing of the liquid-handling equipment is required.

Many methods have been devised to test for leakage. Recent extensive studies and experience have clarified their effectiveness and limitations.

Air Testing

Pressure tests with air shall not be used on tanks. Such tests are not likely to detect a leak that is below the liquid level in the tank. Also, with air testing there is severe danger of causing a tank rupture, or expulsion of contained liquid through normal openings.

Air testing of piping is not as hazardous as for tanks, but it may be inconclusive. A liquid pressure test with instrumentation that will detect pressure loss and measure volume loss per time period is much more reliable and gives conclusive results.

Air tests of tanks or piping containing flammable or combustible liquids should not be required by regulations or ordinances and should be discouraged in practice.

Water Testing

Tests involving the addition of water to a tank may be useful under certain conditions if contact with the stored liquid is acceptable. Total substitution of the stored liquid with water should be used only for extreme cases. Water is difficult and sometimes impossible to use in cold weather; it will not detect leaks of less viscous liquids, and contamination of the storage and dispensing system can be a major problem.

Testing Underground Facilities

Using the information gained from the Primary Search Procedure, (see page 15), use the following tests in a logical process of elimination. For example, if water is reported as entering a tank, or if the tanks are old and corrosion is known to exist in the area, make the preliminary checks on the tanks first. On the other hand, if pumping troubles are reported, the piping is suspected and preliminary tests should be performed on underground piping first.

The tests described on the following pages are listed in approximate order of ease of performance, the easiest being first. The sequence should be varied to fit the circumstances, as noted in the preceding paragraph.

Checking Underground Pipe

Check for:

a. Recent digging, driveway repair, or other work in the area which may have damaged undergound lines.

b. Any recent repairs that may have been made indicating a previous leak or perhaps creating a leak due to faulty work.

c. Any evidence of shifting ground, such as frost heave, which may have damaged lines.

d. Soft spots in asphalt paving indicating solvent action of liquids or vapor.

If information on the location of liquid underground has been compiled by methods described in Chapter V, Tracing Liquids Underground, review this information for possible patterns that may indicate a specific pipe is likely to be the source. It may be advisable to drive or drill additional holes to define more definitely where the liquids are and how they are flowing. (Review in particular the information in connection with Figure 11 in Chapter V.)

The test to be used on piping will depend on the method used to move or pump the stored liquid.

Suction Line Testing

If the pump used in moving the liquid is above ground the supply pipe operates under vacuum or suction and certain pumping characteristics indicate either a leaking check valve or a leaking pipe. If there is a leak, air will enter the pipe as liquid drains back into the tank through the check valve or through a pipe leak into the ground. The presence of air will be indicated by the action of the pump in the first few seconds of operation after an idle period. If the pump is equipped with a meter and cost/quantity display device such as is found in a gasoline service station, pumping of air is indicated by the display wheels skipping or jumping. Other indications of air in the suction line are:

a. The pump is running but not pumping liquid.

b. The pump seems to overspeed when first turned on and then slow down as it begins to pump liquid.

c. A rattling sound in the pump and erratic liquid flow indicates air and liquid are mixed.

If any of the preceding conditions indicate a leak in the suction line, the check valve should be inspected first. Some check valves are located close to the pump inlet, others are mounted in the underground pipe just above the tank, and some may be on the end of the suction stub inside the tank. Some of those valves located in the pipe above the tank can be inspected and repaired from the surface of the ground through a special extractor mechanism installed with the valve. If not, or if the valve is inside the tank, it may be necessary to dig down to the tank to check the valve or disconnect and seal off the pipe for a pressure test. (See page 25.)

Generally, digging down to the check valve or tank should be delayed until other more easily performed surface tests have failed to reveal the leak. If there is any doubt that the check valve seats tightly, repair it, replace it or seal it off. Then repeat the pumping test and if air is still entering the suction line, it may be assumed the pipe is leaking underground and it should be exposed for inspection. Dig carefully to avoid damage to the pipe which might make it impossible to verify whether a leak actually existed prior to uncovering.

If the pumps do not exhibit the symptoms of a leak as described above but there is still reason to suspect a pipe leak; or, if a complete system check has been performed and it is now necessary to isolate and check the piping system, individual pipe runs may be isolated and pressure tested.

Pipe Line Tests with Liquid

1. Disconnect the supply pipe at the dispensing unit so that the upstanding open end may be observed. (This may require removing the dispenser to one side.)

2. Fill the upstanding pipe to the top with the liquid being dispensed. Wait for any air bubbling to stop and refill as necessary.

3. Observe the liquid level for approximately 15 minutes. If the level drops steadily, either the check valve is leaking or there is a leak in the pipe line. Inspect the check valve, make sure it is tight or isolate the pipe from it with a cap.

4. Repeat the test for additional 15-minute periods. If the level again drops, there is probably a leak in the line and it must be uncovered and inspected.

5. As an alternate to steps 1 through 4, the pipe may be pressure tested at 50 psi or greater. If the pressure drops more than 5 psi per minute, it indicates the probability of a leak in the pipe. Also the amount of liquid required to be added to maintain the test pressure in the pipe will give a quantitative indication of the size of the leak. A leak of .05 gal. per hour is considered by most authorities as the limiting criterion.

Pipe Line Tests with Air (NOTE: This test may not be conclusive.)

1. Drain the line of all flammable liquid to avoid possible forcible expulsion.

2. Isolate the section between the dispenser or pump and tank with pipe caps or check valves. If the check valve on the tank end of the pipe is used, be sure the tank is open to atmosphere to avoid applying pressure to the tank if the valve leaks.

3. At a convenient point in the piping provide fittings to supply air, to release air and to attach a pressure gage.

4. Provide an air pressure gage reading to 50 psi or 100 psi with a minimum 3 in. gage face to clearly show pressure variation.

5. As air pressure is first applied, carefully check for leaks at fittings with soap solution and any indications air is leaking into the tank. (This can be detected by listening for the sound of bubbling at the tank fill pipe.)

6. When all exposed fittings are determined to be tight and there is no evidence of air leaking into the tank, raise the pressure to a minimum of 50 psi. There may be some initial pressure loss due to

temperature change and any loss observed in the first 15 minutes should be restored. After this first restoration of pressure, any subsequent pressure drops exceeding 10 psi in 15 minutes indicates a leak and the pipe must be uncovered for visual inspection.

Discharge Pipe Line Testing (Pipe under pressure from remote pump.)

Quite often pumps are located in the tank, or, on some rare occasions, just above the tank but remote from the dispensing devices. In such cases, the pipe to the dispensing equipment operates under pressure. A leak in this line will cause rapid loss of pressure after the pump is turned off. This can be checked in the following manner:

At the dispenser end of the pipe, close the emergency shutoff valve at the base of the dispensers or close any valve upstream of any hose to hold pressure at the dispenser end. The pump end can be sealed off by setting the check and relief valves in the head of the pump. The check valve is readily accessible in the manhole over the pump, and most are equipped with a screw or bolt supplied for the specific purpose of positively seating these valves for line checking. Install a pressure gage in the line (a minimum 3 in. dial with maximum 60 psi range should be used to clearly show graduations of 1 psi.) Generally, the best location for the gage is in the emergency shutoff valve under the dispenser where ¼ in. or other small size plugs are installed for this purpose. Start the pump, note the maximum pressure (generally 25 to 35 psi), seat the check valve, turn off the pump and observe any pressure drop. If the pressure drops more than 5 psi per minute, it indicates the probability of a leak in the line. Repeat the test at least once to ensure against compression of entrained air. Any pressure drop less than 5 psi per minute is inconclusive as it may be caused by cooling or a small valve leak. Uncover the pipe for visual inspection if the test continues to indicate a leak.

If the preceding tests do not reveal a leak, they should not be considered as conclusive and underground piping must be included in the Final Test described on page 31.

Checking Underground Tanks

Review the information obtained from the Primary Search described in Chapter III. Ask about, observe, and note in particular:

a. Method of filling tanks — Damaged fill pipes, poorly maintained tight-fill connections or hose couplings, driver carelessness, or even overemphasis on full deliveries may cause some of the product to be spilled around the pipe when a delivery is made. Particularly, check fill pipes installed under manhole covers. On night deliveries in which the tank is filled into the fill pipe a warmer underground product temperature can cause considerable overflow due to expansion before dispensing begins the following day;

b. Any evidence of ground settlement around tanks and any sign of work that may have damaged the tank or its fittings;

c. History of past or recent work on the tanks or attached piping;

d. The presence of excessive amounts of water in the tank and any history of past water removal. (Use water-finding paste on the gage stick.) Ascertain, if possible, if the water increases during periods of heavy rainfall and remains constant or diminishes during dry spells. Also, if possible, ascertain the depth of the water table, i.e., the static level of the ground water, by using an easily drilled, probed or excavated area close to the tank(s) or some existing undrained opening;

e. The age of the tank; in particular, as it relates to the history of corrosion in the vicinity;

f. The location and flow of liquid found underground by gas sensors or visual inspection. It may be advantageous to drive or drill additional holes to develop more detailed information.

Use this information to guide subsequent inspection and testing.

When Water is Reported to be Entering a Tank

a. Check the fill pipe to ensure that water is not entering through a loose fill cap.

b. Check the surface area around vent lines for evidence that water may be entering by this route. Standing water over vent lines may be the source. Note this possibility for future use.

c. If no explanation, except a possible leak, is found for water in the tank, carefully record the depth of water by water-finding paste, and tightly close and lock the fill cap. After 8 to 12 hours, remove the cap and again check for water. If the rise in 12 hours exceeds ½ in., close and lock the cap and check for another 8 to 12 hours. If the rise in the second period closely matches that of the first period, a leak is probable. A rise of less than ¼ in. in 8 hours is inconclusive due to the inability to measure the water level closer than to within ¼ in. Longer test periods will have to be used to determine definitely if a leak does, in fact, exist. Best results will be obtained if the water depth is less than 3 in. at the beginning of the test.

The above tests are not conclusive if the water table is above the top of the tank, as water could be entering around pipe connections into the tank top or through unused plugged or capped openings in the top of the tank which are not watertight. Also, if water is entering the tank at these top openings it is not significant from the standpoint of tank leakage. Likewise, these tests are not conclusive if the tank is full, or substantially full, of product.

In fact, water may not enter the tank if the level of product is at or above the level of the water table outside the tank. These tests are relatively effective if the tank is practically empty and the water table is high but still below the tank top. A tank partially below the water table can have water enter, or lose product, through the same leak depending on the relative levels of the ground water and the product in the tank.

If a leak is indicated and equipment is available for a Final Test, make such test (see page 31) before uncovering the tank. If the test equipment is not available, dig down to the junction of the vent line with the tank, break the connection and seal one end of the vent pipe. Using the other end for access, test for a leak with 50 psi of air pressure. A drop exceeding 5 psi per minute indicates the vent line may be the source of water. A drop less than 5 psi in one minute indicates that an insignificant amount of water could be entering via the vent line.

Uncover the remainder of the tank fittings and inspect for leakage. If no leaks are found in the tank fittings, the leak must be in the tank itself and the tank must be uncovered for inspection.

Checking Tank Bottoms

Two tests can be made easily and with very limited equipment to check for relatively large leaks along the bottom of the tank. Failure to find a leak by these tests does not indicate a tight tank, but if they do reveal a leak, the Final Test becomes unnecessary. Circumstances will determine the advisability of using these tests; it may be that they can be run while waiting for equipment for the Final Test. Perhaps the situation may require that the Final Test be run as soon as possible.

1. Checking the Tank Bottom Under the Fill Tube

Experience has shown that many tanks develop leaks in a narrow band along the bottom. This is because small amounts of water condense out of most liquids, settle in the tank bottom and sometimes cause corrosion from the inside. Often this internal corrosion will be aggravated under the fill pipe or gage hole as protective rust is removed by liquid flow against the tank bottom or the impact and movement of the gage stick.

To test for this, make a probe by driving a finishing nail into the end of a gage stick leaving about ¾ in. protruding. Check for a hole in the tank bottom under the fill or gage hole by probing or "feeling" the bottom with the nail head. This test requires a little technique, but it is quickly acquired and has been quite successful.

2. Checking the Internal Corrosive Zone of the Tank Bottom

The bottom for the full length of the tank can be checked with water if it is practical for the stored liquid to come in contact with water. Add water to the tank to a depth of about 3 in. There must be at least 2 ft. of petroleum liquid above the ground water table to overcome any outside pressure from ground water. If the water table is near or above the top of the tank, this method will not work. Carefully gage and record the water level with finding paste, replace and lock the fill cap. Periodic checks may be made at intervals of 4 to 12 hours. If water is lost at a rate exceeding ½ in. in 12 hours, a leak is indicated. If the loss is between ¼ and ½ in. in 12 hours, repeat the test for another 12 hours to verify the loss. Verification justifies uncovering and inspecting the tank. A loss less than ¼ in. in 12 hours is inconclusive due to measurement accuracy and the more sensitive Final Test must be made.

Standpipe Testing

The following procedure will be useful where it is desired to check the tightness of any underground storage tank and its connected piping for gross leaks. It is not adequate for detecting small leaks nor for determining that a tank system is tight due to the many variables discussed in the Final Test.

On suction systems, this connected piping would include the fill pipe, vent pipe, and piping up to and including the dispensing pump. On remote pumping systems, this connected piping would include the fill and vent pipes, and any suction piping. There will be no need to uncover the tank or piping unless leakage is indicated.

Equipment for making the test is simple and is commercially available or may be readily assembled from the following materials:

1. A piece of clear plastic pipe or standard weight steel pipe approximately four feet long, three inches or four inches in diameter, threaded on both ends. For repetitive use, the steel pipe should be equipped with a boiler gage glass close to the upper end. If this is not readily available, readings of sufficient accuracy can be made by measuring from the top of the pipe down to the flammable liquid level with a measuring tape or ruler;

2. Threaded bell reducer (or coupling and bushing) to connect the test pipe to the fill opening of the tank;

3. Five gallon capacity safety cans.

The following procedure is applicable to the equipment described.

1. If two or more tanks are connected with siphons, all tanks so connected must be filled.

2. Remove fill pipe cover and, if necessary, remove the fitting onto which it screws, exposing the pipe thread on the fill pipe. By means of a coupling, the bell reducer or bushings attach the test pipe to the fill opening. Threads must be in good condition and must be made up product-tight, using pipe dope if necessary. Tightly cap the fill pipe of all other tanks connected to test tank by siphons, as all tanks so connected will be tested as a unit.

3. Pumps to which this particular tank siphon is connected must be temporarily taken out of service, blanked off or disconnected. If the vent line from this tank is manifolded to that from any other tank, the vent line must be disconnected and capped; if the vent line serves this tank only, it need not be disturbed for the present.

4. Fill the test pipe by pouring product in the top until the level is close to the top of the gage glass, or within a few inches of the top of the test pipe. Make a preliminary inspection to see that there is no leakage at the point where the test pipe connects to the fill pipe of the tank, at the pump, or at any other point where piping is exposed.

5. Maintain the level of liquid in the standpipe within 3 in. of the top by adding measured quantities of liquid as often as is necessary to prevent the level from dropping below the midpoint of the standpipe. Proceed with steps 7 and 8 as necessary to isolate the leak if:

a. Thirty minutes after first filling the standpipe the rate of addition of liquid exceeds 0.8 percent of the capacity of the tank in one hour or;

b. One hour after first filling the standpipe the rate is less than 0.8 percent but more than 0.1 percent of the capacity of the tank in one hour and is constant for a period of at least two hours.

If the rate of addition of liquid is decreasing each hour for several hours after first filling the standpipe, the true condition of the tank may be masked by the variables discussed in the Final Test. The tank system must then be tested by the Final Test or uncovered for inspection. If the liquid rises in the standpipe and liquid has to be removed rather than added, the change of volume in the tank systems is due to temperature changes as discussed in the Final Tests and may be masking a leak. The tank system will have to be tested by the Final Test or uncovered for final inspection.

6. It will be noted that the tests to this point include not only the tank but also the fill pipe, vent line, and suction piping up to and including the pump.

7. Pump product out of the tank through the service station pump to lower the liquid level to the top of the tank. Uncover the tank and disconnect, and cap the suction connection of the tank. Refill the test pipe and repeat the test. If no leakage is indicated, the leak must be in the suction line. If the leakage persists, it must be either in the tank or vent piping, and another step will be necessary.

8. Pump out product to lower the level in the test pipe, then disconnect and cap all piping at the top of the tank. Refill the test pipe and repeat the test. If leakage still persists, then it is the tank that is leaking and appropriate steps must be taken for repair, removal or abandonment (see *Flammable and Combustible Liquids Code*, NFPA 30, Appendix C, Abandonment or Removal of Underground Tanks). When two or more tanks have been tested as a unit, this test must be made on each tank individually.

Final Test

The Final Test will conclusively determine whether or not an underground liquid storage and handling system is leaking. Any testing devices used for the Final Test shall be capable of detecting leaks as small as .05 gals. in one hour, adjusted for variables, a limiting criterion widely accepted by most authorities.

The principle of the test is to directly measure the amount of liquid lost. To detect a leak anywhere in the complete underground storage and handling equipment, the tank and all piping are filled and the net volumetric change in a given period of time is measured. If the *net* change exceeds .05 gals. per hour, in all probability a leak exists somewhere in the tank or piping. The piping is then isolated for further check (see pages 24–26). If the piping is tight, then the tank must be uncovered for inspection.

A testing device for the Final Test can be an assembly of equipment, instruments and recording forms developed to control or measure all of the variables encountered, and thereby determine net volume losses due to leakage. Since these tests cannot be performed without the equipment, the details of the assembly, procedure and recording are not included here, but are completely covered in the manual accompanying the testing devices.

The test is designed to account for all the variables that will affect a measurement of .05 gals. per hour. An understanding of what these variables are and how they are handled is essential to effective performance of the test.

The Effect of Temperature

Liquids expand with an increase in temperature and contract with a decrease in temperature. Fig. 2 lists the thermal coefficient of expansion for some of the more common flammable and combustible liquids.

Thermal Expansion of Liquids	Volumetric Coefficient of Expansion per Degree
Acetone	0.00085
Amyl acetate	0.00068
Benzol (benzene)	0.00071
Carbon disulfide	0.00070
Ethyl ether	0.00098
Ethyl acetate	0.00079
Ethyl alcohol	0.00062
Fuel Oil	0.0004
Gasoline	0.0006
Methyl alcohol	0.00072
Toluol (toluene)	0.00063
Water — at 68° F	0.000115

Fig. 2

Note that a temperature decrease of only .02° F in one hour in a 6,000 gal. tank containing gasoline would cause a volumetric decrease of .02° x .0006 x 6,000 gals. = .072 gals. which exceeds the .05 gals. considered to indicate a leak. If this temperature change was not detected and accounted for in a test, a leak would be assumed where none existed. And in a like manner, if the temperature increased, a leak could be concealed by volumetric expansion if the temperature change was not detected.

It is sometimes proposed that this problem can be overcome by filling the tank 10 or 12 hours before a test run, on the assumption that the product temperature will stabilize. Extensive tests have shown that this is seldom if ever true. When liquid is added to fill a tank for testing, it will often require several days for the liquid to stabilize to ground temperature, which in itself is constantly changing. The rate of temperature change in the first day or two will generally be in the range of .02° F per hour to .25° F per hour. Obviously, the test must be capable of detecting any very small temperature changes if it is to be conducted in a reasonable length of time.

Another temperature effect that must be recognized and accounted for is temperature stratification or temperature "layering." Fig. 3 illustrates how temperature may vary in a typical underground tank after cool product has been added to warmer product already in the tank.

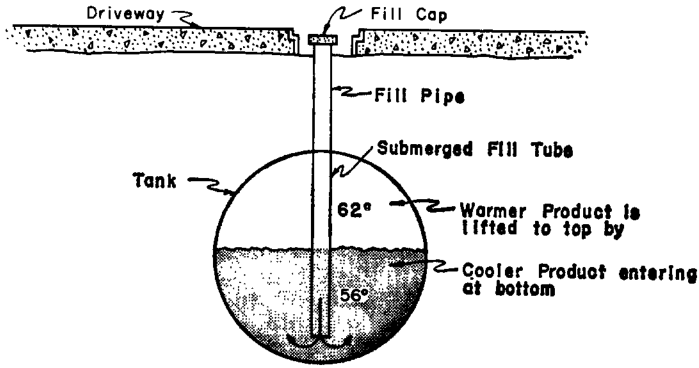


Fig. 3

Temperature measurement must include a method for averaging any differences in temperature because the rate of change will not be the same. If the product in the ground prior to filling is at or close to ground temperature (62° F in Fig. 3) its rate of change will be nil. However, the temperature of the liquid added to fill the facility will immediately begin to change toward the temperature of the ground (56° F to 62° F in Fig. 3). The rate of temperature change in this case would probably average about .12° F per hour. If a 4,000 gal. tank was half full prior to filling for the test, this would mean an average change of .06° F per hour or a volume expansion of .06° x .006 x 4,000 gal. = .14 gal. per hour; almost 3 times the minimum leak criteria. In this case, a leak of .15 gal per hour or 3.6 gal. per day would be concealed by temperature rise.

The Effect of Pressure

Measuring very small volumetric changes in a storage facility requires the filling of that facility to a point abovegrade where volumetric measuring equipment can be used. This increase in height of liquid increases the pressure inside the underground tank over the normal operating pressure. This is illustrated in Fig. 4.

In a 6 ft. diameter tank the average pressure on the end or "head" of a tank full of typical gasoline is .98 pounds per square inch. If the tank is buried 3 ft. under the driveway (typical for most gasoline tanks), the average pressure on the head will increase to approximately 2.95 pounds per square inch when the fill pipe and standpipe are filled to 3 ft. abovegrade. The increase of approximately 1.95 psi in the average pressure exerts an additional force on the end or "head" of the tank of about 8,000 pounds, or 4 tons.

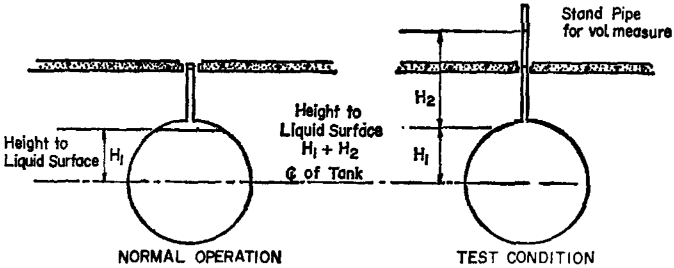


Fig. 4

Most tank ends[1] of the type normally used underground are made of ¼ in. thick steel plate and will deflect outward as pressure inside the tank increases. (See Fig. 5.)

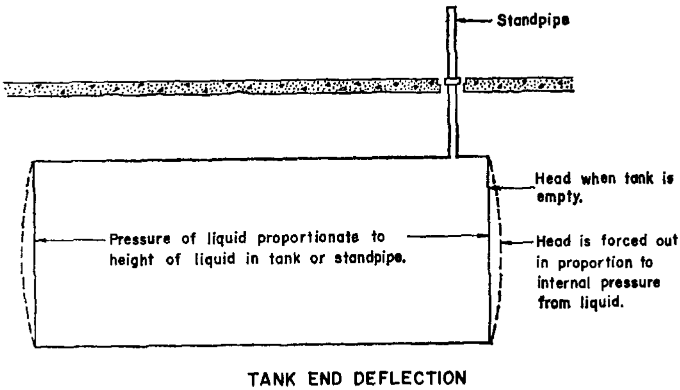


Fig. 5

If the tank is located aboveground and the heads are not supported in any way, it is possible to predict the amount of movement that will result from any given change in pressure and, when the amount of movement is known, the resulting increase in volume of the tank can be calculated. However, when tanks are located underground they are subject to an infinite variation in support from the surrounding soil, and it is not possible to predict how much movement will take place. Very solid soil may provide close to full support, but normally soils will consolidate to some degree, particularly if they are wet thereby allowing tank expansion and end deflection.

[1] Although most fiberglass tanks have oval or spherical ends, the same phenomenon of expansion will occur due to flexure between the ribs on the sides of the tank.

Extensive study and testing have revealed that in almost all cases tank movement significant to the test for leaks will occur. It will not occur suddently because of the time required to consolidate the soil. Under a constant increased pressure it will normally take several hours for the tank to stabilize. The table in Fig. 6 shows the volume increase as a result of various degrees of movement in the tank ends. The figures underlined are the maximum normally encountered with underground steel tanks; the last figure in each horizontal row is the maximum possible for the tank size in that row.[1]

Apparent Loss of Liquid Volume in Gallons
Due to Increased Pressure in a Tank

Outward Deflection at Center of Head in Inches

Tank Dia. Inches	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1
48	.49	.98	1.47	1.95	2.44	2.93	3.42					
64	.87	1.74	2.61	3.48	4.35	5.22	6.10	6.97				
72	1.10	2.20	3.31	4.41	5.51	6.62	7.72	8.82	11.0			
84	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	15.0	18.0	21.0	
96	1.96	3.91	5.87	7.82	9.77	11.75	13.70	15.65	19.6	23.5	27.4	31.3
102	2.21	4.42	6.65	8.25	11.06	13.30	15.50	17.70	22.6	26.6	31.0	35.4
120	3.06	6.12	9.18	12.25	15.30	18.4	21.4	24.5	30.6	36.7	42.8	49.0

Fig. 6

In summary, three major factors must be accounted for in the Final Test to determine the presence or absence of a leak in an underground liquid storage facility.

1. The gross volume change in a given period of time.
2. The temperature change of the liquid in that period of time.
3. The movement of tank ends as pressure is increased.

[1] Compatible figures are not yet available for fiber glass tanks. Latest data indicates that expansion due to side flexure may exceed that for flexure of steel tanks.

CHAPTER V

Tracing Liquids Underground

The "Underground," as referred to in this booklet, consists of an almost infinite variety of rocks and soils, tunneled, pierced and trenched by man-made structures and pipes. All these provide paths for movement of liquid underground. Flow of liquid in tunnels, sewer pipes, and open trenches is obvious and relatively easy to trace by observation and vapor testing. Flow in soil and rocks is a complicated matter. A few basic principles will provide an understanding that will often prove sufficient to solve many problems of tracing the source of unconfined liquids. Even though such basic understanding may prove inadequate for a particular problem, it is essential to select and coordinate the particular expert skills necessary to solve the more complex problems.

Background

The principal characteristic that permits liquids to enter, and accumulate or flow through soil or rock is porosity or, simply, the space or "voids" between the particles that make up the soil or rock. The size of the voids in soil will vary from large in gravel, through small in sand and top soil, to essentially zero in fine, dense clay. Rock almost never has large voids but sandstones and limestones have voids similar to a fine sand.

Rate of flow through soils and rocks depends largely on the size of the voids; with large voids (gravel) the flow can be several feet per minute; medium voids (sand) will provide several feet per hour; and fine voids (shale or sandstone) may be as slow as one foot per day.

The term used to express this rate of flow is "pervious." A very pervious soil will permit fast liquid flow; a relatively "impervious" soil will permit only very slow flow. When the word impervious is used alone, it implies no flow; thus glass is impervious to the flow of water.

Porosity does not insure a pervious condition. If the pores of a rock are not interconnected, the rock will be impervious.

Crystalline rocks, such as granite and marble, are essentially impervious in their solid state but these rocks often have fractures or cracks that do permit flow. Rate of flow through rock fractures will vary from large continuous cracks which will act like a pipe, to very small irregular cracks which may result in flows similar to fine sand.

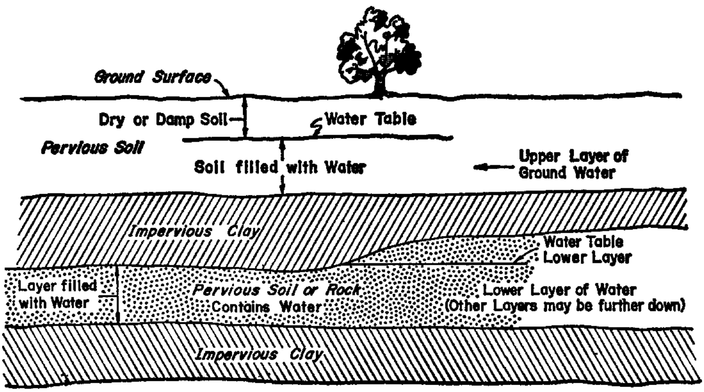


Fig. 7

Almost all flammable and combustible liquids are lighter than water and consequently they will float on water unless they are water soluble. When these liquids escape into the ground they will normally flow down to the water in the ground and there move with that water. An understanding of groundwater flow is essential to trace flammable and combustible liquids underground.

Water is almost universally found underground at some level in soil or rock. It may be in very limited quantities and only "dampen" the soil. But when it fills all the voids and "saturates" the soil or rock up to a certain level, it becomes similar to water in a pail and establishes a definite top, referred to as the water table.

Figure 7 illustrates that this ground water may occur in several layers underground. A porous layer between two nonporous layers may be completely filled or it may be only partially filled and have its own water table. The primary concern with unconfined flammable and combustible liquids is with the uppermost layer and its water table. However, other layers must be recognized because even though they may be very deep at one location, they may be near the surface and hence the top layer at other locations. (See Fig. 8.)

All groundwater, with the exception of narrow bands along the seacoasts, comes from rain or snow falling on the surface and flowing down into the soil. Fig. 8 shows that at any given location, the water may have come from rain or snow on the surface immediately above (nos. 2, 8, and 11); or it may have flowed underground for long distances through pervious soil or rock from a point where the pervious layer (no. 6) "outcrops" or comes to the surface. Water from rain and snow may also flow to lakes and rivers and then into underground layers (no. 10).

Water tends to seek its own level underground just as it does on the surface as it flows through the soil. However, water flowing underground will not flow as fast as water on the surface because of the interference or resistance of the particles in the soil. This has the effect of steepening the slope of the water table (Fig. 8, layer 2) because the water does not move through the soil to lower levels as fast as it fills the soil at the higher elevation. The same effect is shown in layer 10, where the lake is supplying water to the pervious soil. Expressed in another way, pressure is required to overcome the resistance to flow, and the increase in elevation of the water table provides the necessary pressure.

The height or elevation of the water table will not only depend on how fast the water flows out of the strata, but also on how fast it is fed into the strata by rain or melting snow. When no water is being added, the water table will drop as water flows out at springs and is taken out by wells, or "wicks," through dry soil to eventually evaporate into the air. When water is being added faster than it flows out, the water table will rise. This rise and fall can be several feet in a few days as the weather changes from wet to dry, or from dry to wet.

In summary, the principal factors important to tracing unconfined liquids underground are:

1. Most flammable and combustible liquids float on water.

2. When unconfined in the ground, these liquids will float on the top or water table of the groundwater and move with that water.

3. Groundwater will flow through pervious soil or rock toward lower elevations. Flow rate will vary from several feet per minute to only one or two feet per day.

4. Groundwater may be trapped underground and be stationary as if in a lake.

5. The top or water table will be level with no flow but slope down in the direction of flow when flow occurs.

6. The water table will rise and fall (in some cases several feet in a few days) depending on supply by rain or melting snow.

The following examples illustrate how these principles are applied to tracing flammable and combustible liquids.

Fig. 9 shows the effect of the slope of underground strata on the direction of flow of liquids. A and B show identical surface conditions. A four-story apartment building is approximately midway in the block, between two streets 400 feet apart. The surface of the ground slopes up from left to right at a 5 percent grade, placing the

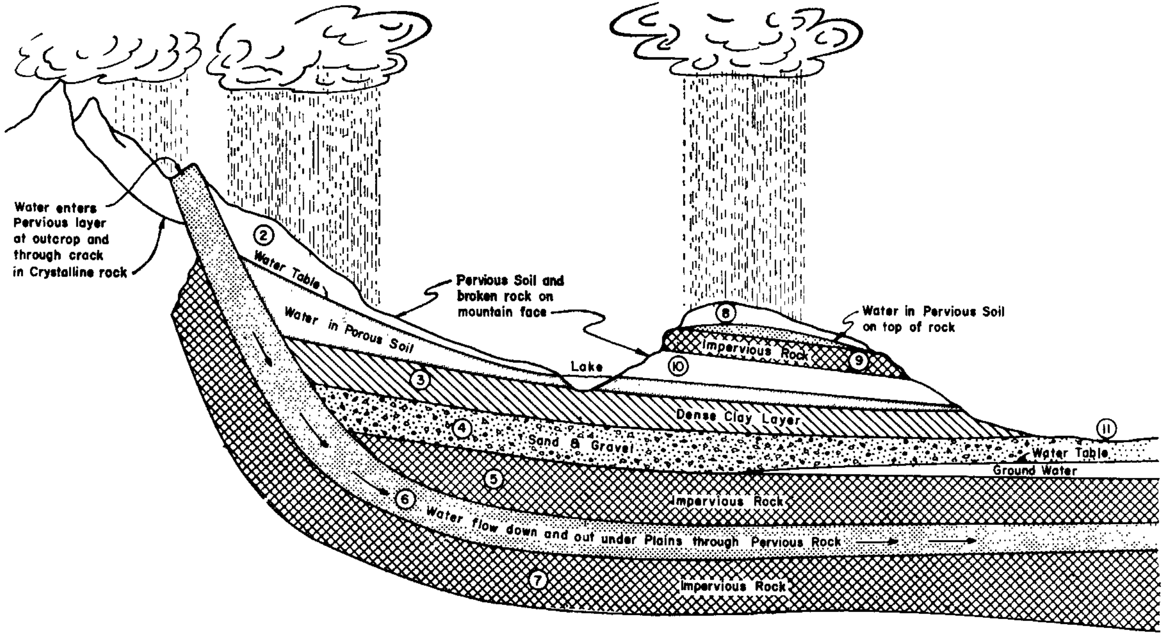
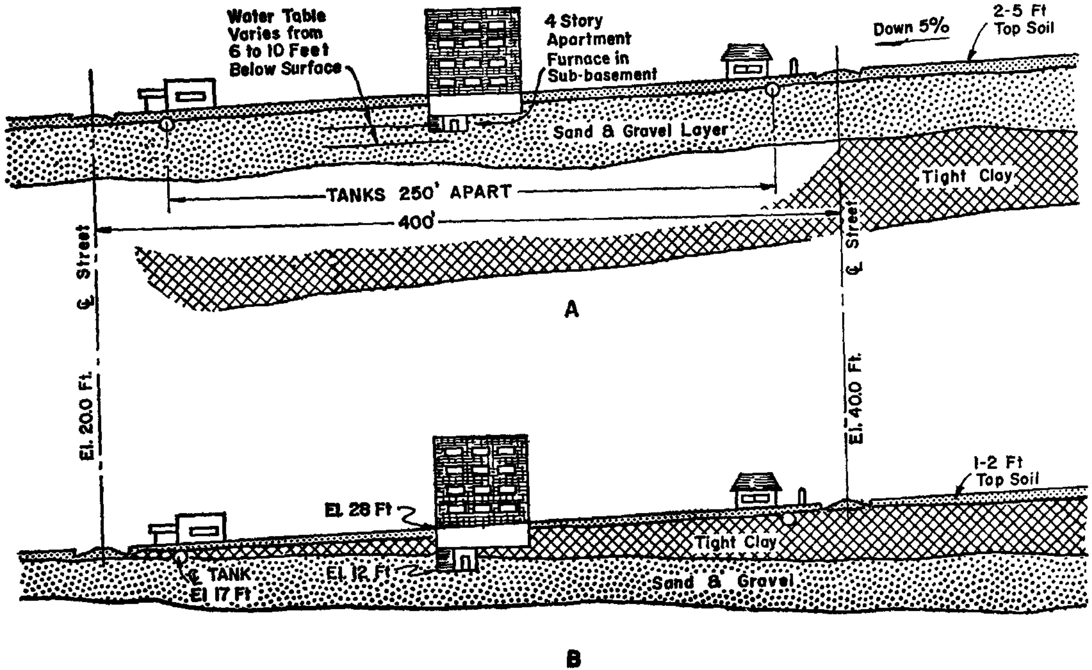

Water enters Pervious layer at outcrop and through crack in Crystalline rock
2
Water Table
Water in Porous Soil
Pervious Soil and broken rock on mountain face
Lake
8
Water in Pervious Soil on top of rock
Impervious Rock
9
10
3
Dense Clay Layer
4
Sand & Gravel
11
Water Table
Ground Water
5
Impervious Rock
6
Water flow down and out under Plains through Pervious Rock
7
Impervious Rock

Fig. 8



Water Table Varies from 6 to 10 Feet Below Surface
4 Story Apartment Furnace in Sub-basement
Down 5%
2-5 Ft Top Soil
Sand & Gravel Layer
Tight Clay
TANKS 250' APART
400'
℄ Street
El. 20.0 Ft.
℄ Street
El. 40.0 Ft.
A
El. 28 Ft
1-2 Ft Top Soil
Tight Clay
℄ TANK El 17 Ft
El. 12 Ft
Sand & Gravel
B

Fig. 9

elevation of the upper street (on the right) 20 feet higher than the lower street.

In Fig. 9-A, the underground strata follows the general slope of the surface and groundwater in the sand and gravel layer flows from right to left. Undèr these circumstances, if gasoline in liquid or vapor form was discovered in the subbasement of the apartment building, the source of that gasoline would most likely be from the service station on the right at the higher elevation, or from other tanks further up the hill.

However, Fig. 9-B shows an underground strata condition in which the station downhill is the most probable source. In this case, the water-bearing strata of sand and gravel slopes down from left to right, opposite that of the surface of the ground. Groundwater flow would also be from left to right and would carry gasoline escaping from the lower station to the basement of the apartment building.

Note that if the sand and gravel layer was essentially level, groundwater flow could be in either direction depending on the extent and elevation of the sand and gravel layer beyond the area shown. In this case, flammable liquids stored either up or downhill from the apartment building could be the source.

One other condition illustrated in Fig. 9-A is the effect of a rising and falling water table. During the dry season, when the water table is below the subbasement floor of the apartment building, gasoline on the water table would not be discovered. But when the water table rises the gasoline will be lifted above the subbasement floor. There have been many cases where this was the cause of alternating discovery and disappearance of escaped gasoline due to a significant rise in the water table with each significant rain.

Fig. 10 illustrates another example of how underground water flow can be contrary to the surface slope of the ground. In this case, flammable liquids are stored in an underground tank a few hundred feet from, and 30 or 40 feet above, a small lake. From the surface, it would appear that an escape of liquids from this tank would show up in the lake. But, because the tank is in a pervious water-bearing layer that slopes away from the lake, wells at houses high above the service station are contaminated by the gasoline that has escaped.

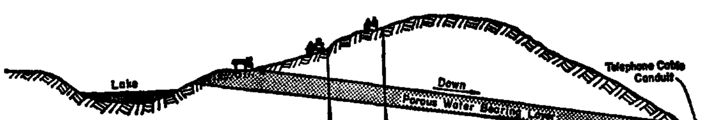


Fig. 10

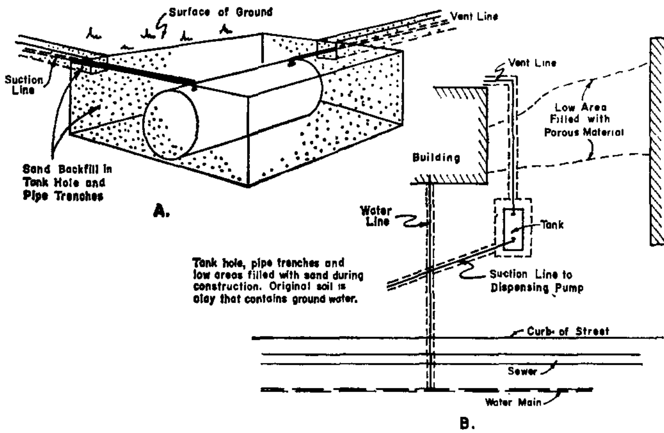


Fig. 11

Note also that if an underground leak existed unknown for a long period of time and there were no wells in the strata to discover contamination, the first discovery of escaped flammable or combustible liquids could occur in the telephone cable conduit on the other side of the hill from the service station, possibly several miles distant.

Fig. 11 illustrates other important effects of a rising and falling water table and the ability of trenches dug in relatively impervious soil but filled with sand or other porous material to act like interconnected piping. Fig. 11-A is a phantom view of a tank containing gasoline installed in a hole dug in clay and backfilled with sand. The suction and vent lines are likewise in trenches dug in clay and backfilled with sand.

Fig. 11-B is a plan showing the layout of tank installed next to a building with a basement. A water line to the building on the left is also a trench backfilled with sand as is the city water main and sewer. And, finally, a low area between the buildings was filled with sand and gravel during construction.

The "parent" or original soil is clay. A water table exists in the clay but has very little horizontal movement because of the resistance of the clay to flow. As a consequence, the water table rises and falls in direct response to supply of water from rain. During wet periods the water table will be within a foot of the surface and during dry periods will drop to or below the bottom of the tank hole.

It is easy to see how a leak in this tank could cause a collection of gasoline on a low water table in this hole much as if it were in an open square tank. Then, if rainfall raised the water table above the bottom of the pipe trenches, water with gasoline on top could flow along the sand-filled trenches much as it would through a pipe. At points where the trenches intersected other trenches or the sand and gravel fill between the buildings, the flow could find its way to the building or to the sewer or water main in the street.

Note that it will not necessarily enter the sewer pipe in the street. The water and gasoline may flow along the outside of the sewer or water pipe in the porous backfill of those pipe trenches and not appear until it comes to some point where it could leak into a manhole or sewer inlet.

Another condition illustrated by Fig. 11 is the potential for a flammable or combustible liquid to move without the aid of groundwater. If a severe leak occurred in the suction line, pure gasoline could flow along the trenches.

The principles and concepts discussed in the preceding pages point up the importance of knowledge about underground soil conditions and underground facilities when tracing the source of escaped liquids. It will not always be possible to obtain all the data desired but the effort should be made.

Test to Determine Underground Flow

The sequence of what to inspect and what test to use will depend to considerable degree on the circumstances of the problem, information gained from the Primary Search, and previous tests. Consequently, the following methods are not necessarily in the proper sequence for all conditions. They are, however, in an approximate descending order of importance. Tools are noted as they are needed.

1. On a sketch of the local area (Scale from 1 in. = 100 ft.) note underground facilities as illustrated in Figure 11-B and any geological data available. Be sure to include abandoned ditches and streambeds that have been filled and covered. Sources of information are:

a. Surface observation of manholes, fill pipes, pumps, vent risers, etc.

b. City engineer; sewer, water and street departments; highway engineer; city, state, and federal geological departments.

c. Utility companies.

d. Owners of the facilities and local residents. Do not overlook the old-timer who may have valuable knowledge of the area before it was built up.

e. Army mine detectors can be used to locate steel pipe if conditions warrant.

2. Information gathered to this point and plotted on the sketch may indicate that a certain nearby facility is a very likely source. If so, proceed with a test for leaks as described in Chapter IV. If not:

3. Check potential paths for liquid flow by:

a. Visual check in manholes, inlet boxes, wells, open trenches, exposed slopes or cuts, etc. Put samples of water in a glass bottle for close inspection to determine the possible presence of flammable liquids.

b. Use a combustible gas indicator to determine presence of vapors. To check underground porous backfill or pervious strata use a bar (¾ in. to 1 in.) and a sledge hammer to drive a hole to the level to be checked. A small hand-operated earth auger is very useful for this purpose. A larger auger, as used for power posthole digging, is also good and has the added advantage of providing a visual check and the opportunity to obtain both liquid and soil samples. This equipment is usually available from a state highway department. Maintain an accurate log of soil samples, and, in particular, note the top and bottom depths at which any soil samples have an odor indicating contamination. Retain representative samples of soil in vapor-tight containers.

c. Use a rod or stick with water-finding paste and a paste sensitive to the contaminating liquid to determine the water table elevation. Note these elevations on the sketch and determine the probable direction of flow.

If the potential of natural or sewer gas still exists at this point in the search, make particular note of indications by the combustible gas indicator relative to the location of sewer and gas lines.

When this testing has determined the probable direction from which the contamination is coming, extend the search upstream using these same methods to determine the next most likely source. Check on both sides of the direction of flow to determine its width.

As the area of search extends beyond the original sketch, obtain a smaller scale map or sketch, plot and record all data. As the area becomes larger, the data becomes more important to the search and subsequent disposal of contamination.

If the initial efforts, approximately one day's checking, fail to establish a clearly defined problem, additional expert help should be engaged. Ask industry for the assistance of experts who have had experience with these problems; and, whenever possible, obtain help from a local geologist familiar with local geology.

It is beyond the scope of this Recommended Practice to cover the problem in all its potential complexities; that is the purpose of seeking the assistance of experts. However, it will probably be advisable for those originally in charge to maintain control while the experts act as consultants and advisors. The following information will be helpful in understanding, appraising and coordinating the expanded effort.

When the investigation fails to locate an active source of seepage, it is possible that the product could be a residual accumulation from some previous equipment failure, spill, or improper disposal of petroleum product. Experience has indicated that many such residual deposits have existed and remained undetected over a long period of time before they became sufficiently large to make their presence known.

As the problem becomes more complex, other methods of testing and tracing may be helpful or suggested. However, both the advantages and disadvantages of these tests must be recognized if valid conclusions are to be reached.

Other Tracing Test Methods

1. Dye

The use of dye is often suggested as a means of tracing. The method is to add a strong dye to the stored liquid suspected of being the source and see if it shows up at the point of discovery. This is seldom successful for several reasons.

a. If only vapor is found at the discovery point, dye will be useless.

b. The dye may be leeched out or bleached by chemicals in the soil before it reaches the point of discovery.

c. If underground flow is very slow, too much time will be consumed in the tests.

d. It may very likely make the liquid tested unusable.

e. If it is used but does not appear at the point of discovery, it is not conclusive because of item b. It would be of benefit only if it did appear.

f. Dye may cause pollution of underground water supplies.

Dye is not a recommended method of tracing but may be used as one possible source of information in special cases.

Radioactive Tracers

Essentially the same points apply to radioactive tracers that apply to dyes, with the additional disadvantages of difficulty in handling and hazard of releasing a radioactive source to unknown area.

Chromatographic and Spectographic Identification of Components

The chromatograph and spectograph are instruments capable of detecting traces of elements in almost any compound. They can, for example, detect a trace of some element unique to a particular method of manufacture and therefore identify where the liquid originated. They can also detect the amount of an element involved. They are relatively inexpensive tests and only involve a sample of the product found at the point of discovery. These tests should be used in complex cases of products as a possible source of additional information. However, they may not be conclusive because some identifying element may be lost in the ground, or an element not in the original liquid may be picked up from the ground or from contact with buried materials.

Other Chemical Analysis

Any other chemical analysis is essentially the same as the chromatographic test and the same comments apply to both. One significant factor that may be determined by chemical analysis is the age of the contaminant.