UNDERGROUND LEAK STUDY

PROPRIETARY

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UNDERGROUND LEAK STUDY

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UNDERGROUND LEAK STUDY

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INTRODUCTION

The subject of underground leaks at service stations is one of growing concern to petroleum marketers. Large sums of money, time, and effort are exhausted on a continuing basis in the location and correction of leaking tanks and lines.

The purpose of this study is to review the major problem areas as we know them, consolidate available data on each area, develop alternative solutions to each problem, evaluate the alternatives, and draw general conclusions which should provide guidelines for the solutions of specific field problems. Some of the areas are conspicuously lacking in basic research, and these will be pointed out as we progress through the study. They will be further accented in the final section, which deals with areas needing additional study.

Underground leaks occur for one of three reasons:

(1) Corrosion;
(2) Rupture;
(3) Loose Fittings.

Loose fitting and rupture failures occur as a result of several easily definable situations. Faulty installation in which fittings are not properly secured, failure to replace temporary bung covers, and improperly backfilled trenches are primary causes for this type of problem. Violent natural phenomena, such as earthquakes, result in massive shifts in the sub-soil which can easily loosen fittings and/or rupture lines and tanks. More subtle soil movements, such as those along natural fault lines without an actual quake, fill settlement (particularly in the tank hole), and subsidence can cause problems; and maintenance personnel should keep a wary eye out for tell tale signs, notably heaving and/or settlement in paved and unpaved areas, shifts in fill locations, and canting or shifting of aboveground equipment. Care in installation or at least recognition of these unusual situations which might have resulted in a leak should substantially reduce the likelihood and magnitude of these types of leaks. However, the nature of leaks resulting from corrosion is such that the continued process makes the instantaneous point in time at which failure occurs imperceptible. Thus corroding tanks and lines probably exhibit the highest potential danger to the environment and most extensive long range costs.

Corrosion can be prevented; but to understand how, we must understand what corrosion is and how it works.

CORROSION

Basic Principles

Very simply, corrosion is the deterioration of a material through electrochemical reaction between the material and its environment. The chemical change at the material surface is accompanied by the transfer of electrical energy.

Every metal has an inherent tendency to return to a more stable compound, that is, to corrode. In most instances, this tendency is directly proportional to the potential, or voltage, of the material. Certain materials have a greater potential than others and, therefore, a greater tendency to corrode. This difference in potentials is the driving force of corrosion. Table I shows the voltage relationships between the various metals.

If two dissimilar metals are connected by a conducting wire, and if they are immersed in a conductive solution (electrolyte), as shown in Figure 1, the metal with the higher (more negative) electrode potential (anode) will corrode to the metal with the lower (less negative) electrode potential (cathode), until the difference in potential is eliminated. Thus, we say that the higher potential electrode is anodic to the lower potential electrode (cathode).

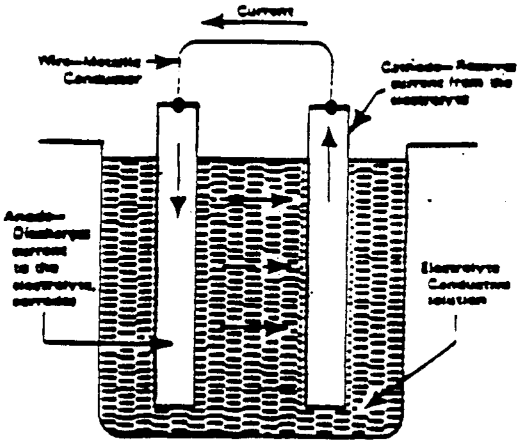

Figure I - Galvanic, or Voltaic Cell

As indicated above, there are four basic elements necessary to the corrosion process. There must be an anode, a cathode, an electrolyte, and an electrical connection to complete the circuit. Not all of the elements will always be easily identifiable; but if corrosion is taking place, all of the elements are present.

The example above is representative of a bi-metallic corrosion cell. There are three other types of corrosion cells which occur in practice. They all must still include the four basic elements, but the configuration may vary from that of the bi-metallic cell illustrated above.

A corrosion cell can also exist between electrodes of the same metal or between electrode areas in the same metal. The essential

TABLE 1

ELECTROMOTIVE SERIES OF METALS

Metal	Reference Ion	Standard Electrode Potential
		Volts
Lithium	Li^{+}	− 2.96
Rubidium	Rb^{+}	− 2.93
Potassium	K^{+}	− 2.92
Strontium	Sr^{++}	− 2.92
Barium	Ba^{++}	− 2.90
Calcium	Ca^{++}	− 2.87
Sodium	Na^{+}	− 2.71
Magnesium	Mg^{++}	− 2.40
Aluminum	Al^{+++}	− 1.70
Beryllium	Be^{++}	− 1.69
Manganese	Mn^{++}	− 1.10
Zinc	Zn^{++}	− 0.76
Chromium	Cr^{++}	− 0.56
Iron *(ferrous)*	Fe^{++}	− 0.44
Cadmium	Cd^{++}	− 0.40
Indium	In^{+++}	− 0.34
Thallium	Tl^{+}	− 0.33
Cobalt	Co^{++}	− 0.28
Nickel	Ni^{++}	− 0.23
Tin	Sn^{++}	− 0.14
Lead	Pb^{++}	− 0.12
Iron *(ferric)*	Fe^{+++}	− 0.04
Hydrogen	H^{+}	0.00
Antimony	Sb^{+++}	+ 0.10
Bismuth	Bi^{+++}	+ 0.23
Arsenic	As^{+++}	+ 0.30
Copper *(cupric)*	Cu^{++}	+ 0.34
Copper *(cuprous)*	Cu^{+}	+ 0.47
Tellurium	Te^{++++}	+ 0.56
Silver	Ag^{+}	+ 0.80
Mercury	Hg^{++}	+ 0.80
Palladium	Pd^{++}	+ 0.82
Platinum	Pt^{++++}	+ 0.86
Gold *(auric)*	Au^{+++}	+ 1.36
Gold *(aurous)*	Au^{+}	+ 1.50

This table is taken from Table I in " Corrosion Control Guide" Vol. I 1968, by E.G. Sellers.

requirement is that one electrode or electrode area be anodic with respect to the other electrode or electrode area; that is, one part of the metal must have a greater potential or tendency to ionize than another part of the metal. Some examples are:

(1) Impurities such as slag inclusions are generally cathodic to the base metal;

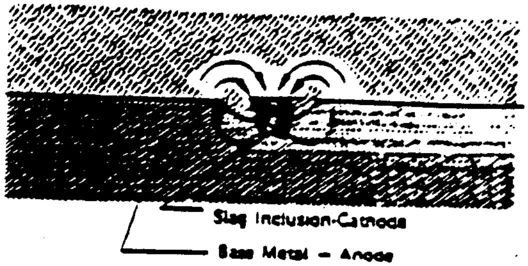

Figure 2

(2) Welds may be anodic to the base metal;

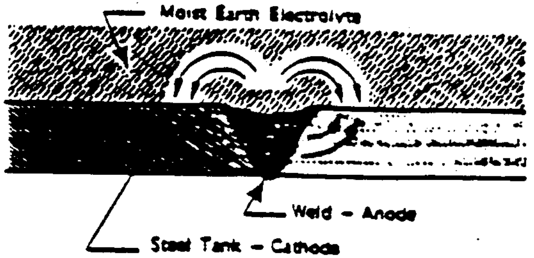

Figure 3

(3) Stressed steel is anodic to unstressed steel;

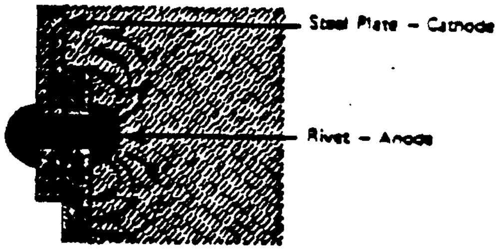

Figure 4

(4) Surface scratches or cuts are anodic to the base metal;

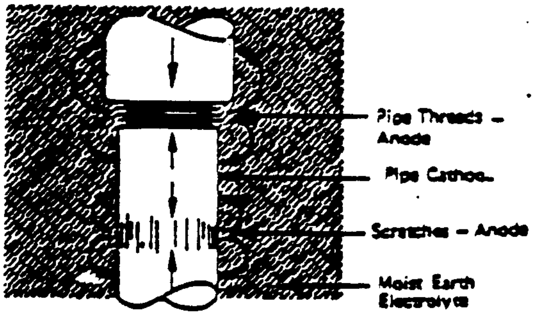

Figure 5

(5) Millscale is cathodic to bare steel;

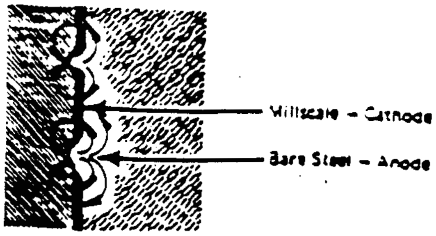

Figure 6

(5) New steel is anodic to old steel.

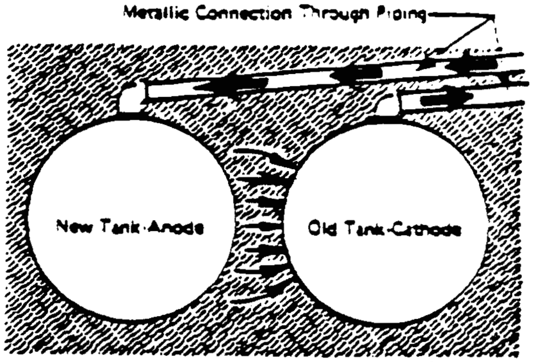

Figure 7

The third type of corrosion cell is created by dissimilar environments at the two electrodes. Dissimilar environments alone will provide a voltage. Significant factors which affect the environment are:

(1) Variations in oxygen concentration (Figs. 8-11);

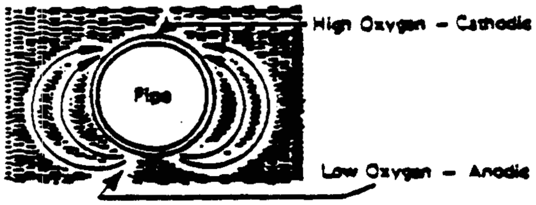

Figure 8

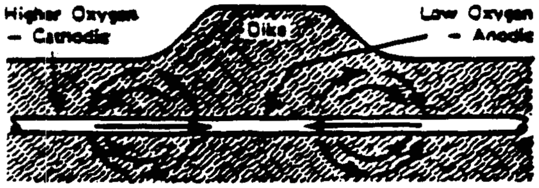

Figure 9

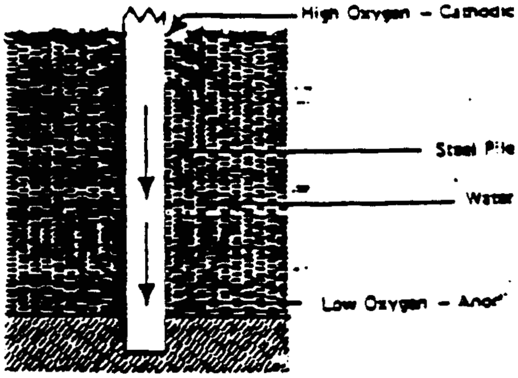

Figure 10

(1) Continued:

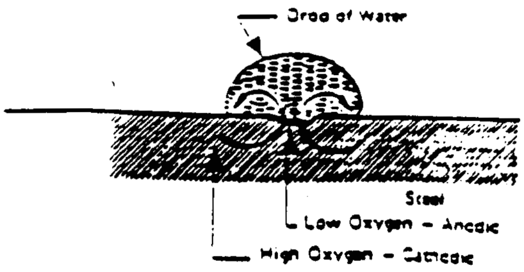

Figure 11

(2) Variations in the pH of the electrolyte;

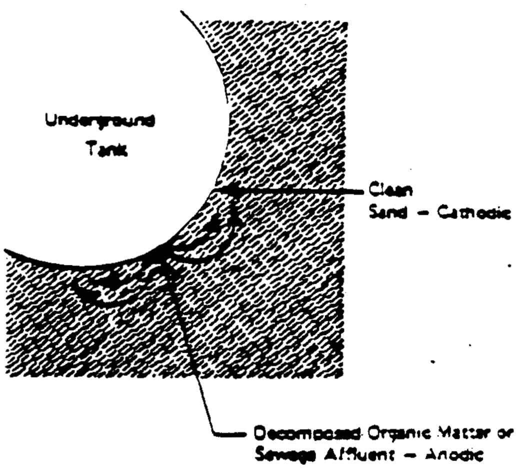

Figure 12

(3) Differential electrolyte concentration;

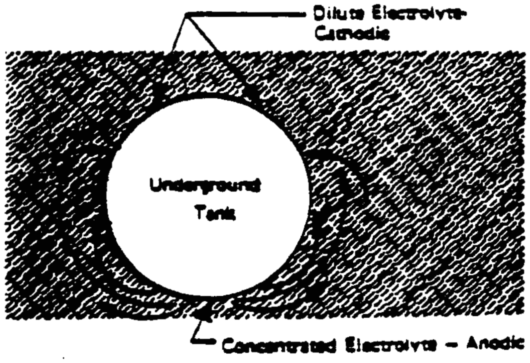

Figure 13

(4) Temperature differentials of the electrolyte.

Finally, stray current cells can exist when the structure is subjected to current from some external source. A prime example would be stray current from direct current electric operations such as subways or railroads leaving the tracks and using an underground pipeline as a secondary conductor back to the power source (See Figure 14). The point of entry of the current into the pipeline is cathodic, so no damage occurs. At the point of exit, however, the pipe acts as an anode and corrodes in direct proportion to the magnitude of current flow. Because the magnitude of the current in this electrolytic cell is generally so much greater than that of typical galvanic cells, the failure of an underground structure subjected to stray current corrosion can be rapid and extensive.

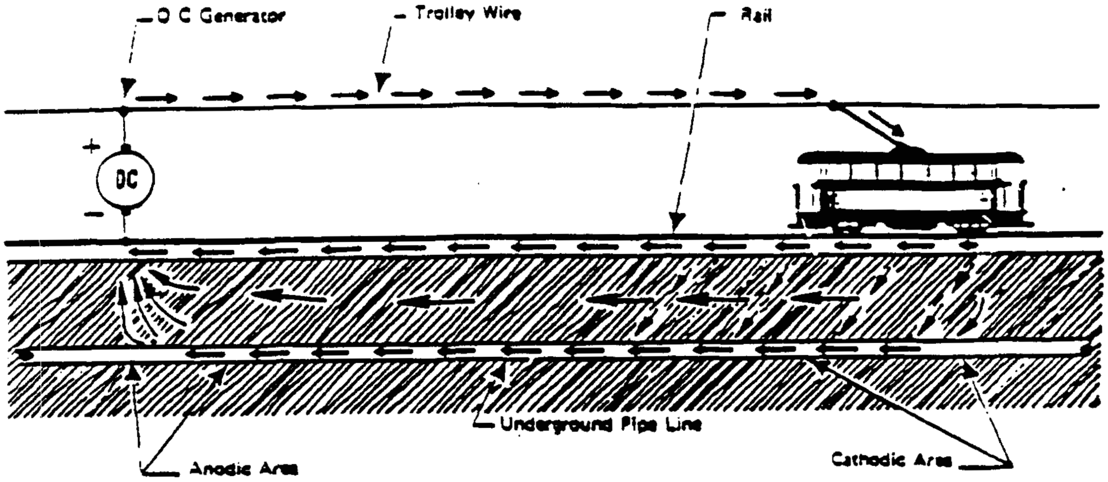

Figure 14

Up to this point, we have been talking in general terms about the corrosion process and how it occurs. The remaining piece of the picture concerns the rate of corrosion, and why a metal will corrode at different rates in different situations.

You will recall that we defined corrosion as an electrochemical reaction between the material and its environment. The corrosion cell is an electrical circuit in which the potential difference in the two electrodes causes a current flow from the anode through the electrolyte to the cathode, then back to the anode through the metal conductor. The magnitude of the current flow in the cell determines directly the rate of corrosion at the anode and is controlled by Ohm's Law, the basic relationship of all electrical circuits. Ohm's Law states that the potential in volts is equal to the product of the current in amperes and the circuit resistance in ohms. Therefore, the electrical current in a galvanic cell is determined by the open circuit electrical potential between the two electrodes and the total ohmic resistance of the cell electrical circuit.

Since the resistance to electron flow through the anode, cathode, and metallic connection is usually negligible, the effective circuit resistance of most cells is through the electrolyte and at its interfaces with the two electrodes.

The importance of the ohmic relationship will become apparent in the following pages when we talk of soil as the electrolyte in our practical corrosion cell, and how variations in soil characteristics greatly affect a structure's tendency to deteriorate.

This has been a very brief and necessarily non-technical treatment of the corrosion process. An excellent study has been done under MERP 5704, Corrosion Control, if an expanded technical background is desired in the subject. For this study, however, the foregoing brief introduction should suffice.

UNDERGROUND ENVIRONMENT/EQUIPMENT RELATIONSHIP

There is a variety of systems available for use in the fabrication of underground service station equipment. Each is being used to some degree, and we have a substantial quantity of empirical data available to evaluate each of them, particularly with respect to their relative susceptibility to failure under varying environmental situations.

Underground Tanks

The two basic materials being used for underground tanks are steel and fiberglass reinforced plastic (FRP). Steel tanks are factory coated with an asphaltic enamel or other inexpensive coating, unless a more elaborate coating is specified. These represent the extremes in initial cost, and a variety of systems applied to the steel tank afford the engineer a full range of variously effective mitigating systems for use in differing environmental situations.

Steel tanks can be treated with any number of coating systems to insulate the steel surface from the environment. Common coatings include epoxies, heat or solvent tapes, and fiberglass reinforced plastic.

Cathodic protection systems operate on the principle of superimposition of direct current on the corrosion cell so that the structure is transformed into the cathode of the cell. There are two types of cathodic protection. In the sacrificial anode system, a magnesium or zinc electrode is coupled to the structure and the natural current produced protects the structure at the sacrifice of the anode. An impressed current cathodic protection system uses an artificial power source to make the tanks cathodic to the surrounding environment.

The STIp3 System is a pre-engineered cathodic protection system which incorporates a coal tar epoxy coating with a sacrificial magnesium anode attached to each end of a steel tank.

Each system has its advantages and disadvantages. FRP tanks are, of course, inert; thus, there is never a possibility of failure from corrosion. They are guaranteed to last twenty years if installed properly. However, limited production points make availability costly due to freight requirements, and their base cost is considerably above the cost of steel.

The STIp3 System is designed for installation in soils having a resistivity of 2000 ohm-cm or greater. It is almost as costly as FRP, and also carries a twenty year guarantee. However, the guarantee is pro rated over the eleventh through twentieth years. Distribution is currently very limited geographically, precluding the possibility of use on other than a very localized basis. The guarantee is voided if failure occurs in soils having a resistivity less than 2000 ohm-cm, and the dynamic nature of soil resistivity would make such a situation possible, even if the resistivity at the time of installation were acceptably higher than 2000 ohm-cm. The major physical drawback results from possible anode damage or loss of electrolyte contact resulting from tank end flexure.

Individually designed cathodic protection systems are considerably less costly to install than the STI-P3 System, but a continuing monitoring requirement to verify the system validity makes maintenance something of a problem. The impressed current system has the advantage of voltage regulation above the limits of the sacrificial anode system. It can also be utilized to protect all underground and aboveground metallic structures at the location. However, the impressed current system must be carefully engineered to insure that other nearby structures are not affected adversely by cathodic interference.

Simple coating systems are sufficient only in those areas where corrosion has never been a problem, and tests indicate no adverse conditions. Holidays in the coating, variable coating thicknesses, dents and scratches all create potential differences in the tank, and adverse environmental characteristics could cause accelerated deterioration of the equipment.

Fiberglass coated tanks offer an inert, highly effective system for corrosive environments. The primary disadvantages result from high cost and limited production points, but toughness and ease of on-site repair of damages make this an attractive alternative for specialized applications. These tanks are guaranteed for five years, but there appears to be no reason why they cannot last as long as FRP tanks.

Glass Armor fiberglass tank lining offers an alternative to replacement of failed or corroded tanks. Tanks are de-gasified, manholes cut, and the interiors cleaned and sandblasted, and an epoxy lining is applied by spraying a thickness of 1/8" to 1/4" of an epoxy resin over the tank interior. The process is faster and slightly less expensive than tank replacement, and it offers the added advantage of minimal physical disruption of service. The system is guaranteed for 10 years from date of installation.

Product Lines

Product lines are usually galvanized steel or FRP. The FRP, because it is inert, needs no protective system; the galvanized steel, however, is subjected to the same conditions as underground tanks, and it may be protected by wrapping, coating, or cathodic protection.

Cost considerations, after an initial learning curve situation for the handling and installation of FRP, favor the FRP in all cases except where the soil conditions are totally non-corrosive. In those instances where no protection is required on the piping, the costs for the two systems are about the same. The FRP has one major disadvantage. It is subject to fracture and puncture failure if not installed properly, and care must be taken to assure that stakes are not driven into trench areas and that the pipe is not subjected to extreme pressure in the interim between installation and proper backfill and surfacing. Freeze and thaw conditions may be slightly more damaging to FRP than galvanized steel, but proper depth of installation should preclude any serious problems.

Environmental Classification of Soil

There are many factors inherent to the soil which affect the corrosion process. Since the soil is the electrolyte in our underground corrosion cell, variations in its ability to carry current, differences in composition (heterogeneity), and other factors directly affect the rate of decay of the anodes of the cell and mitigation measures required. Some of the factors are discussed below.

Resistivity is resistance per unit measure. It represents the ohms of electrical resistance through a cubic centimeter of the electrolyte and is expressed as ohm-centimeters. As the primary variable in the total circuit resistance, the electrolyte resistivity becomes the principal factor controlling cell current and corrosion rate. Consequently, resistivity is considered the most definitive characteristic for evaluating the corrosiveness of natural electrolytes.

The pH value of the electrolyte indicates its relative acidity or alkalinity, providing a valid indication of the chemistry involved. The more acid the electrolytic solution, the more corrosive its nature. Natural salt solutions are generally less corrosive than acid solutions, but more corrosive than alkaline solutions.

These two characteristics, resistivity and pH, are generally sufficient evidence as to soil corrosiveness, but there are some other measurements which may prove helpful in an analysis.

Moisture level is a good indicator of corrosiveness of the soil. While there is enough moisture almost universally present to support limited electrolytic activity, the amount of activity which can be supported is proportional to the amount of moisture present. Thus, saturated soil will be more aggressive than damp soil.

Differential characteristics of the soil offer another indication of corrosiveness. You will recall that these dissimilar environments alone will create a potential difference, regardless of metal dissimilarities.

Some soil bacteria create, through their life processes, conditions which are quite conducive to galvanic corrosion. Measurement of sulfides in the soil and the level of oxygen are good indicators of the presence or absence of these bacteria.

Table 2 can be used effectively to determine the relative aggressiveness of a soil for which these measurements have been taken. A word of caution should be inserted here, however. While the Aggressiveness Index is generally indicative of corrosiveness of a sample, the individual measurements must be considered also. An Index of 9 indicates a "less aggressive" soil, but if 8 of the 9 points were due to a pH of less than 3, it would indicate a highly aggressive soil.

In general, a low pH or the presence of sulfides is characteristic of a highly aggressive soil.

Table 2

Evaluation of Underground Environments

I. Basic Characteristics

		Points
Soil Resistivity	< 300	12
	300 – 1,000	10
	1,000 – 2,000	8
	2,000 – 5,000	6
	5,000 – 10,000	3
	10,000 – 25,000	1
	> 25,000	0
Soil pH	< 3	8
	3 – 5	6
	5 – 6.5	4
	6.5 – 7.5	2
	7.5 – 9	1
	> 9	0
Soil Moisture	Saturated	3
	Wet	2
	Damp	1
	Dry	0

II. Differential Characteristics

		Points
Resistivity (ratio of extremes)	> 1:10	3
	> 1: 5	2
	> 1: 3	1
	< 1: 3	0
Soil pH (Difference in pH value)	> 3	2
	1.5 – 3	1
	0 – 1.5	0

III. Indicators of Bacterial Activity

Redox Potential (mv.)	Negative (–)	4
	0 – 100	3
	100 – 400	1
	> 400	0
Sulfides	Positive	4
	Trace	2
	Negative	0

IV. Classifications of Aggressiveness

Index – Sum of Selected Point Values

> 12	Highly Aggressive
10 – 12	Aggressive
7 – 9	Less Aggressive
4 – 6	Mild
< 4	Innocuous

Taken from Table 4 in "Corrosion Control Guide", Vol. 1, 1968, by E. G. Sellers.

Environment/Equipment Relationship

It should be obvious that the service life of the equipment is directly related to the aggressiveness of the environment and the mitigating measures taken to counteract that aggressiveness. In fact, data accumulated throughout the Regions of the United States indicates the following approximate correlation between unprotected equipment service life and the aggressiveness of the electrolyte:

Electrolyte Classification	Criteria	Equipment Service Life (Unprotected Steel)
Highly Aggressive	Index > 12, or Resistivity < 2000, or Soil pH < 3, or Sulfides present	1-3 years, widespread failure
Aggressive	Index = 10-12, or Resistivity = 2000-5000, or Soil pH = 3.0-5.0	3-5 years, widespread failure
Less aggressive	Index = 7-9, or Resistivity = 5000-10,000, or Soil pH = 5.0-7.5	5-10 years, localized failure
Mild	Index = 4-6	10-15 years, localized failure
Innocuous	Index < 4	> 15 years, very localized failure

TABLE 3

EQUIPMENT SERVICE LIFE AS A FUNCTION OF ELECTROLYTE AGGRESSIVENESS

The service lives indicated are, of course, only estimates based on prior experience, and the use of such a table should be limited to such preliminary analyses as comparative DCF tabulations between alternative storage and transfer systems. Although definitive studies have not been carried out as to the type of distribution that failures follow, externally caused failures appear to meet the criteria of and possess the qualities of the Poisson Distribution. (It is not the intent of this paper to offer a treatment on discrete statistical distributions, so readers not familiar with this statistical model are referred to any introductory text[1] on probability and statistics for verification that the model is valid.) The service lives indicate the average for the classification of electrolyte.

Internal Corrosion

The reader will note that the relationships in the preceding section are limited to externally caused corrosion failures. Internally caused corrosion failures must be treated as an entirely different problem. While the ingredients of the failure must by definition be identical to those inherent in external corrosion, differing physical characteristics of the model result in corrosive situations which may be greatly exaggerated or retarded relative to a similar situation in an externally corrosive environment.

Certain areas seem to be faced with a high incidence of internal corrosion as a primary cause of structure failure. Those failures appear to be distinguished from external corrosion caused failures in several respects:

(1) The average age of tanks failing from internal corrosion is higher (17 years) than those failing from external corrosion (14 years) in the same geographical area;

(2) The highest incidence of internal corrosion (indeed, the only recognized significant incidence) occurs in areas currently using or recently discontinuing use of brass-tipped gauge sticks;

(3) Small tanks register a higher incidence of internally attributed failures;

(4) Failure occurs predominately in tanks in Exxon Extra service;

(5) Failure from internal causes occurs most commonly in the immediate vicinity of the fill tube and along the bottom of the tank;

(6) The only recognized significant incidence of internal corrosion has been recorded in the geographical area with the oldest marketing facilities and the smallest average tank size.

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[1] A good reference text is: "Introduction to Probability and Statistics," by Lindgren and McElrath, Macmillan Company, 1959.

This empirical evidence leads to the following observations regarding internal corrosion:

(1) Failure from internal corrosion occurs in older tanks and facilities, indicating that internal corrosion proceeds at a generally slower rate than external corrosion. Consequently, in an externally corrosive environment, the failure will normally come from without, while an innocuous or less aggressive external environment will result in failures from internal causes;

(2) The use of tank gauge sticks with tips of metal result in acceleration of internal corrosion under the fill tube. If the metal is brass or other metal which is below steel on the electromotive series (see Table 1), a corrosion cell is set up every time the tank stick touches the tank bottom. Every contact between the stick and the tank shell results in a transfer of metal from the stick to the shell, setting up a bi-metallic couple. The steel corrodes to the brass, and the impingement from the next gauging breaks away the existing corrosion cell to bare steel, and the process is repeated. If the stick is tipped with a metal which is above steel on the electromotive series, the mere impingement from continuous gaugings stresses and abrades the tank's shell, setting up a corrosion cell between the smooth metal and the abraded metal;

(3) The use of smaller tanks results in a higher internal corrosion rate due to the increased frequency of delivery. Depending on the filling rate, product entering the tank can stir up bottom water and sludge layers, causing impingement on the tank in areas above the water line. Any naturally formed protective film can be damaged and pitting action can occur;

(4) The predominance of failures in tanks in Exxon Extra service may be attributed to a higher frequency of filling due to heavier sales, or it may result from the formulation of the gasoline. The product itself may present a corrosive environment in certain areas due to the level of metal particles, dissolved water, oxygen, and other impurities in the gasoline;

(5) The predominance of failure at the fill tube and along the tank bottom results from several factors:

    (a) Flushing action is most concentrated in these areas;
    (b) Highest oxygen and moisture concentrations occur along the tank bottom;
    (c) Sludge deposits settle to the tank bottom;
    (d) Tools and other debris gravitate to these areas;
    (e) Impingement is most likely under the fill tube.

Additionally, there are some other explanations for the internal corrosion phenomenon. The following have been described in other studies:[2]

(6) Anerobic bacteria provide an environment conducive to corrosion in five ways:

(a) Destruction of protective coatings;
(b) Formation of hydrogen sulfide;
(c) Production of acids;
(d) Formation of galvanic cells;
(e) Oxidation of ferrous iron.

(7) Atmospheric pollution, especially when it involves sulfur dioxide, can be a significant factor in corrosion;

(8) Humidity above a critical level can result in a mild form of corrosion;

(9) Tank bottom slope and dents and irregularities caused during installation can cause the formation of pockets to permanently trap tank bottom water, resulting in areas of concentrated attack.

The extent of internal corrosion has been reported as widespread in certain areas and virtually non-existant in others. This wide range of reported severity may be attributable to one or more of several explanations. The first, and most obvious, concerns the ability and desire of field personnel to distinguish between externally and internally caused failures. It seems highly unlikely that an entire Region would escape all internal corrosion, but it is completely feasible that failed tanks might be inspected from the outside only, resulting in a failure to recognize an internal problem. Additionally, prior to the inception of the maintenance center concept, retail districts were handling much of their own work, particularly in the upgrading of storage to current requirements. Thus, many replaced tanks were not inspected by the engineer, and no record of their status at removal was made.

The current practice of tank removal only when an emergency exists does not lend itself to proper inspection and analysis of failures, and, historically, such a program has maintained a rather low priority relative to construction and other programs. Consequently, unavailability of time for proper analysis, as well as lack of incentive, results in a sketchily documented file regarding internal versus external corrosion.

Thirdly, in areas with highly aggressive external environments, failure from external causes occurs so rapidly that the slower internal corrosion goes unnoticed by comparison.

Finally, in areas where a severe problem is recognized, wholesale mitigation practices, such as fiberglass reinforced plastic tanks and lines, are pursued, resulting in the elimination of internal as well as external corrosion.

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[2] Notably, "Report No. 7, Investigation of Internal Corrosion of Steel Fuel Storage Tanks," The Hinchman Company, 1970.

As a closing note on internal corrosion, the Region which reported the most severe problems in this area is using Glass Armor fiberglass tank linings extensively for correction of system failures. Consequently, the interiors of the tanks which fail are inspected closely, and evidence of internally caused failures is naturally more apparent. It is not clear at this time whether this evidences a more serious problem in the other areas of the country, or whether it indicates an overemphasis in the single Region reporting extensive internal problems.

TESTS FOR SYSTEM TIGHTNESS

A large number of underground leak detection systems is produced and available for use in petroleum marketing facilities. Each of the concepts in use in these tests will be discussed and analyzed in the following pages, but a valid discussion of system tightness testing must begin not with the physical test but rather with the procedures necessary to determine that a test is warranted.

Pretesting Procedures

The first step necessary in the effective and timely detection, correction, and control of underground leaks at service stations is the implementation and proper maintenance of a valid inventory and stock control system. There are many such systems in use[3], and most major oil companies will make an appropriate accounting system available to their operators, but the key is the implementation and proper maintenance of the system. It must be used continuously, consistently, and conscientiously if its full value is to be realized. A properly maintained system will detect leaks or possible leaks before they become a major problem, thus resulting in smaller product losses, less costly cleanup, and less extensive equipment repair and/or replacement.

Although the formats of the various systems differ, there are certain procedures common to all valid systems. Physical and book inventories must be reconciled periodically, and differences must be accounted for. The following procedures are necessary, but not sufficient, to the successful implementation of any valid system:

(1) Tanks should be gauged and meters read at the opening and closing of business, at change of shift, and before and after product delivery;

(2) Tanks should be checked for water weekly, before and after product delivery, and after a thaw;

(3) Meter accuracy should be checked with a standard 5 gallon test can weekly;

(4) Truck compartments or meters should be checked before and after every delivery; and,

(5) Inventory should be balanced against sales at the close of business and after product delivery.

Losses from leaks can be more quickly detected and further reduced by regular inspection of visible parts of dispensing equipment, pursuit of sources of noticeable vapor odor, or recognition of a continuous operation of remote pumping units, or other mechanical abnormality.

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[3] See Appendix IV.

If the operator is diligent in his application of these procedures, he should have no difficulty discovering a suspected leak in the system. He should then fill out a check list such as the one in Appendix I. This verification that all other avenues have been explored evidences that a mechanical test of the system is warranted.

It should be pointed out here that, without a proper accounting procedure there is no way of isolating the problem evidenced by the loss, and an expensive system tightness test is merely a shot in the dark. To be used effectively, the test must be preceded by an elimination, by record analysis, of all other possible causes both of a controllable and uncontrollable nature. If this is not the case, the magnitude of discovered leaks cannot be assessed, thus complicating immeasurably any necessary cleanup operations.

Available Equipment

It is generally accepted that the most sensitive, quantititative, and simple system tightness testers are based on the measurement of changes in the level of liquid in the tanks. However, other concepts merit discussion and will be evaluated concurrently with those units based on the liquid level measuring method.

The Kent-Moore Tank Tightness Tester was developed in cooperation with the API to support improved techniques associated with NFPA 329 - "Underground Leakage of Flammable and Combustible Liquids."[4] It is based on the concept of using a standpipe to directly measure liquid loss by leakage. The two major variables which simulate and conceal leakage in the system, temperature variation and stratification and pressure-volume relationships, are compensated for by use of sophisticated appurtenate equipment. A circulating pump mixes the product in the tank to eliminate the stratification of the product and a temperature sensing and reading instrument monitors temperature change to an accuracy of less than 0.02°F. A schematic showing Kent-Moore's operation is shown in Figure 15. Various charts, conversion tables, and forms enable the tester to determine the magnitude of product loss and gain independent of temperature and tank volume related variations. The total equipment package is compact enough to be stored and transported in the trunk of a full size passenger car, and the total testing time is usually 5 to 6 hours. The cost of a complete unit is approximately $2,500.

Esso Research & Engineering Company has developed a simplified automated system which is based on the Kent-Moore technique.[5] This automated leak volume monitoring system (ALVOMS) eliminates the need for operator collection of data and calculation by automatically compensating for volume changes caused by temperature changes and displaying the corrected ΔV values on a strip chart recorder. The need for manual addition or withdrawal of product to the standpipe to maintain the test level is also eliminated through the use of a weight reservoir and self-priming suction pump. As the volume in the weight tank changes to compensate for variations in standpipe level, the weight change is correlated to product temperature variations and results in a temperature corrected

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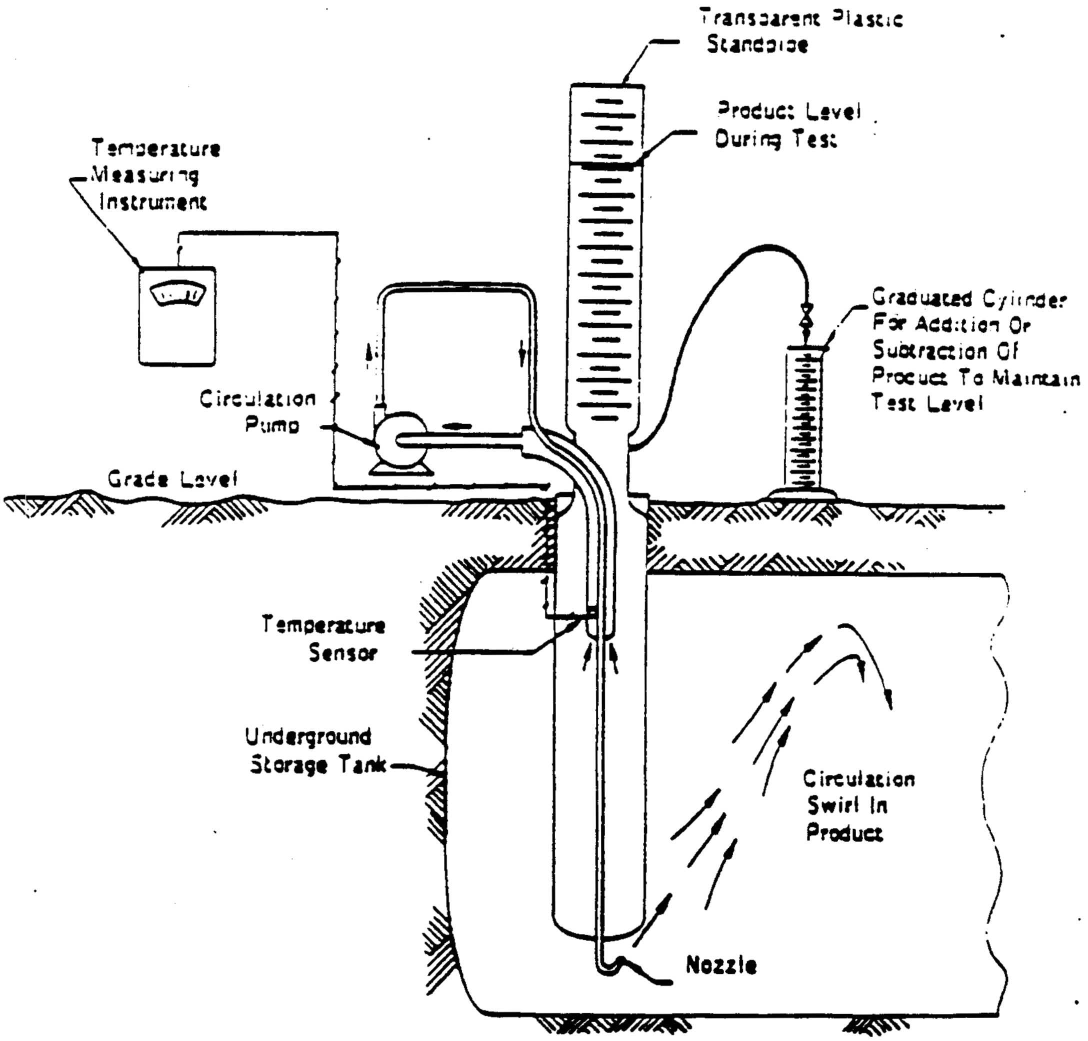
[4] See Appendix II for complete text of NFPA 329.

[5] The full report has been published as: "Leak Testing of Buried Product Storage Tanks," MERP #7006, 1972.

Figure 15

KENT-MOORE TANK TIGHTNESS
TEST - SCHEMATIC DIAGRAM



Taken from MERP #7006, "Leak Testing of Buried Product Storage Tanks," 1972, by N. O. Cross and J. L. Thompson.

ΔV display on the strip chart recorder. ALVOMS is billed as more accurate, less time consuming, and more versatile than the conventional Kent-Moore System. ALVOMS operation is depicted in the schematic of Figure 16 and Figure 17 shows a possible packaging arrangement. The cost of such a system is projected to be less than $2,000.

There are two methods in use for sonic testing of tankage for leaks or probable leaks. The most common method utilizes a probe which is held against the area under test. The equipment emits an ultrasonic pulse which passes through the material and is reflected off the remote surface back to the probe. The measured time interval between the transmission and reflection of the pulse is then converted into metal thickness. The requirement that the probe be held against the test area appears to limit this procedure to aboveground containment facilities. To utilize it below ground would require excavation, degasification, and provision for a manhole. However, some limited use may be found for pitting checks in unique installations.

The other sonic method for testing underground systems for leaks works on the concept of detecting leaks by the unique vibrations created by air going through an orifice. Testing is done from above ground, by immersing the probe in the product through the fill, with no disruption to service or excavation at the test location. The Jamie Corporation of Cincinnati, Ohio, is currently refining the process, and this method appears to hold great promise for a fast economical procedure for leak detection.

The Red Jacket Underground Tank Validator (UTV) is a liquid level monitoring device with extremely high sensitivity (±0.001") to changes in liquid level. However, no provision for mixing to eliminate temperature stratification in the tank and no compensation for temperature-related volume changes make the need for such accuracy questionable. It may be that the limited duration of the test (about two hours) is felt to preclude volume changes due to temperature variation, but the high sensitivity of the monitoring equipment would certainly register temperature-related volume changes of an extremely small magnitude. It appears that some modification of this equipment is necessary before it can be used effectively.

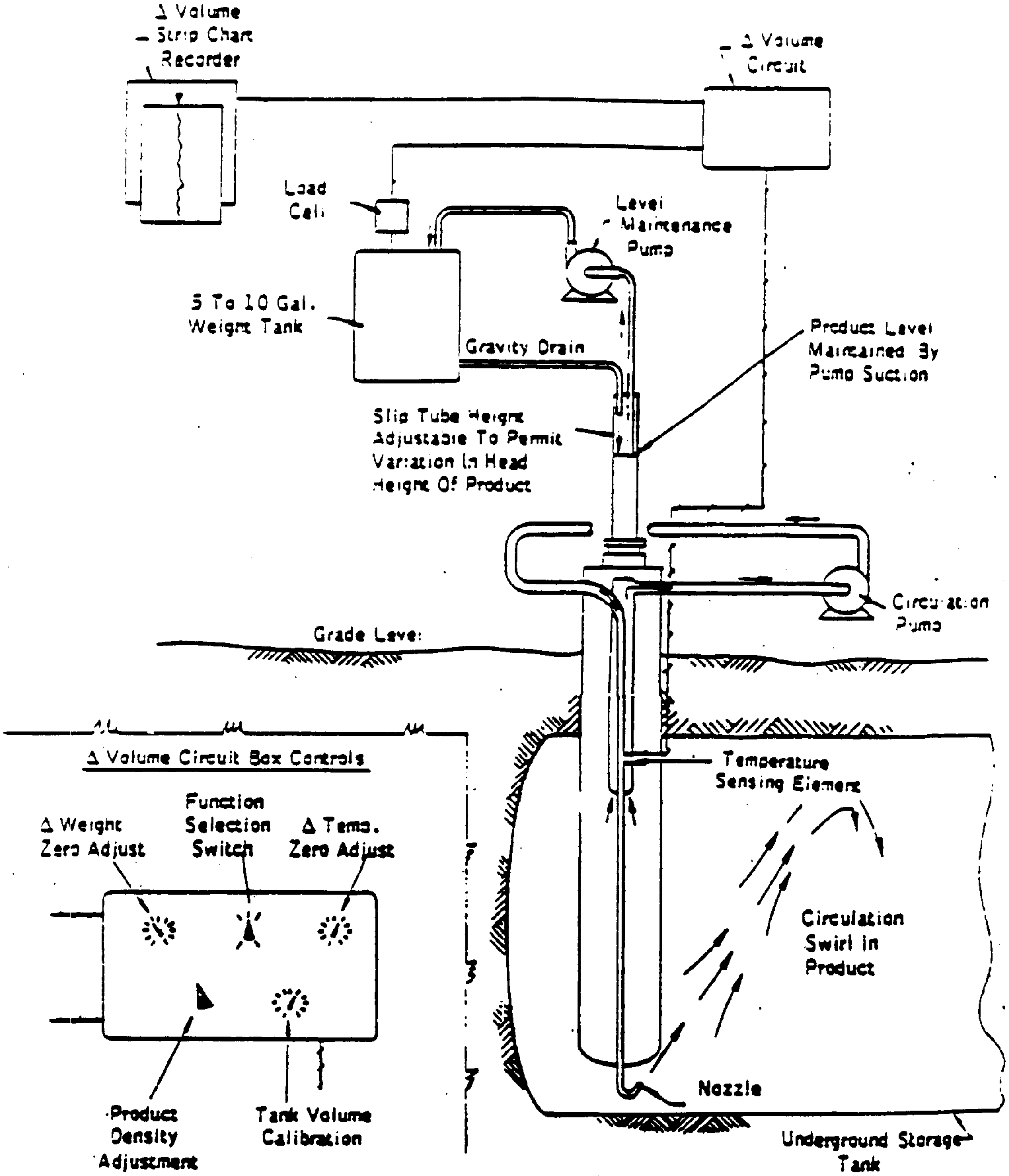
The Red Jacket leak detector is based on the principle of detecting flow past the submerged turbine pump (STP) check valve. In practice, this involves an automatic test for leakage commencing when the last operator on the dispenser circuit is turned off. The system logic causes the STP to continue operating for a test cycle of two to three minutes, during which time flow of product past the STP check valve caused by a line leak is detected by a transducer. The system is a low cost ($75), easily retrofittable unit which is currently being installed on all STP's purchased by Exxon USA. While sensitivity is well above the API requirement of 0.05 gph, the units have proven valuable in detecting a number of leaks due to loose fittings and other construction related problems.

Evaluation

The Kent-Moore Tank Tightness Tester is a system tester accepted by most interested agencies and associations, including NFPA and API, as

Figure 16

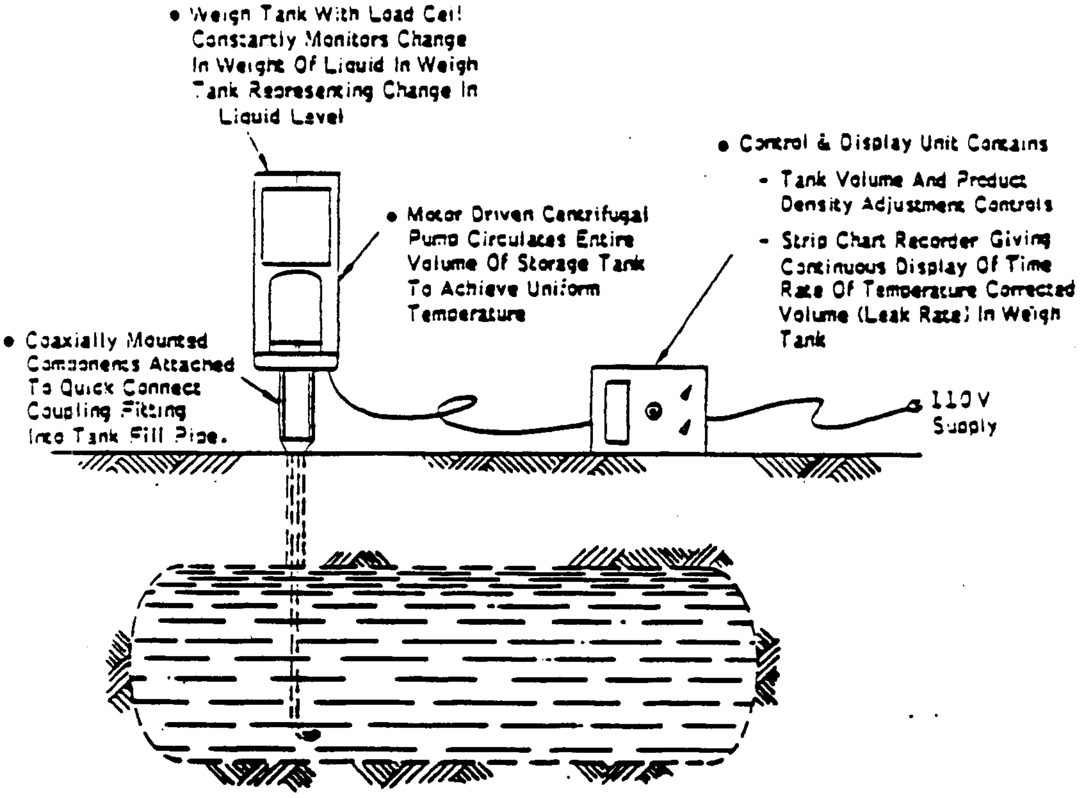
MODIFIED KENT-MOORE TANK TIGHTNESS TEST - SCHEMATIC DIAGRAM



Taken from MERP #7006, "Leak Testing of Buried Product Storage Tanks," 1972, by N. O. Cross and J. L. Thompson.

Figure 17

AUTOMATED LEAK VOLUME MONITORING SYSTEM (ALVOMS) FOR UNDERGROUND STORAGE TANKS



Taken from MERP #7006, "Leak Testing of Buried Product Storage Tanks," 1972, by N. O. Cross and J. L. Thompson.

meeting all criteria for early accurate detection of tank failure.[6] We will first evaluate the Kent-Moore system, therefore, and use it as a standard against which we can measure the relative effectiveness and value of the other systems.

The Kent-Moore System costs about $2,500. The test of a tank takes five to six hours due to the need to eliminate temperature stratification and allow time for tank end bulging to stabilize. Once the test begins, it is necessary to take readings each 30 minutes, and calculate temperature adjusted volume changes for the test duration, usually three to four hours. During the test, the system must be isolated and out of use. The tester is extremely reliable and accurate, easily measuring to the established sensitivity criterion of 0.05 gph, but the need for manual calculations at intervals throughout the test provides substantial possibility for human error in the results.

The Esso Research & Engineering Company variation on the Kent-Moore System has the added advantage of more reliable results through automated temperature compensation and standpipe test level maintenance. This virtually eliminates the possibility of miscalculation and false detection or concealment of a leak. The system is designed to be packaged in a much less bulky method, and set-up should require less time than Kent-Moore. The projected cost of less than $2,000 is an added advantage at no sacrifice of accuracy. The automation makes the test less busy and simpler to operate, in fact making possible the testing by any mechanic or semi-skilled laborer. Economies can result from freeing the tester from the calculation and monitoring of the apparatus. It is reasonable to assume that this would make possible the performance of other routine maintenance during the testing sequence, thus utilizing otherwise unproductive time.

The contact probe sonic tester does not appear to have significant value in the testing of underground storage. The necessary preparation (excavation, degasification, etc.) is time consuming, costly, and disruptive to business, and, in the final analysis, the probe will not be much more effective in pinpointing existing leaks than the naked eye. Its real value lies in the discovery of potential failures, through the measurement of metal thickness, and is much more suitable to testing of aboveground facilities.

The ultrasonic tester, produced by the Jamie Corporation, still needs refinement before it will achieve the reliability level of Kent-Moore. When tested against the Kent-Moore tester in Ohio, it falsely detected leaks in a tight tank, probably due to some interference which was unrelated to the tank under examination. It appears that a more sophisticated noise filtering system may be required before a practical validity can be established. However, the concept appears to have considerable merit.

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[6] It should be cautioned that not all fire departments accept the Kent-Moore Test because it is not always understood. Some field orientation may be advisable in order to gain more widespread acceptance with volunteer and part-time personnel. Pressure testing should be strongly discouraged as an acceptable tank testing method as it is unreliable and can be extremely dangerous.

The Red Jacket Underground Tank Validator (UTV) will need to correct is basic shortcomings, lack of temperature correction capability and lack of provision for eliminating temperature stratification, before it can become a valid alternative to the Kent-Moore System. These disadvantages make leak concealment and/or simulation entirely too possible.

The Red Jacket leak detector is a valuable line checking device which should be used in all new installations. It should substantially reduce product loss and pollution from line leaks through immediate detection and correction. Although it detects only those leaks of a magnitude of 1.5 gph or greater, the cost is half that of the more sensitive Gilbarco unit.

Based on the foregoing, it appears that existing technology limits the field of valid system testers to the Kent-Moore Tank Tightness Tester and E.R.&E.'s ALVOMS. Since the ALVOMS is not yet in production, current testing should be done by the Kent-Moore method, as outlined in NFPA 329 - "Underground Leakage of Flammable & Combustible Liquids, 1972" on pages 30-34, and in accordance with the manufacturer's operation manual. Assuming a production run cost competitive with the Kent-Moore Tank Tightness Tester, however, the ALVOMS would be the more attractive alternative. Earliest production would appear slated for Fall, 1974.

DETERMINING LEAK PROBABILITY

The electro-chemical process of corrosion is a predictable phenomenon. Given a known environmental situation, the rate of deterioration of a test sample can be determined with pinpoint accuracy. Unfortunately, in actual practice, the environment is not precisely known due to its heterogeneity. An infinite number of different environments may be present in any field location, resulting in a varying aggressiveness and thus a corrosion rate which differs over different sections of the anodic structure. Consequently, one can never be certain that the sample taken exhibits the worst condition at the location under consideration.

However, this heterogeneity which is so apparent on a microscopic level loses its identity quite readily on a macroscopic basis. In most geographic areas, the natural environment can be considered homogeneous over a limited range, and an environment which has been found to be of a corrosive nature at a given location can be assumed preliminarily to exhibit that same characteristic at other locations in the same general geographic area.

Correlation Between Environment and Structure Life by Geographical Area

Due to this heterogeneity over widespread areas, there are several sources of very good structure life data available to the engineer. First, county soils reports often cover areas in close proximity to the site under investigation, and preliminary approximations as to the aggressiveness of the soil can be determined from these general studies.

Company and industry experience in the area can be a valuable source of information regarding both structure life and necessary mitigation measures. Transmission and pipeline companies run extensive tests prior to and subsequent to line installation, and their data will indicate such input as stray currents, pH, and resistivity along the pipeline path.

Local soils experts and corrosion engineers are often familiar with specific locations and conditions which may affect an installation. They can also sometimes offer information regarding the virginity of the soil and the nature of any fill on the site.

Finally, the engineer can make necessary tests or contract the performance of tests in order to determine necessary mitigation measures. Pertinent tests and their performance are covered in detail in MERP #6704, "Corrosion Control, Implementation, Section III, Evaluation of Service Station Conditions."

From the data gathered from these sources, it may be possible to determine within a reasonable tolerance, the service life of an unprotected structure and what mitigation measures are required. This determination of approximate service life is basic to the adoption of a valid program of leak control.

Once the expected service life is determined, a variety of alternatives is available for new installations, and a slightly different set of alternatives is available for existing structures. These involve testing and monitoring procedures and replacement criteria options.

Testing Frequency

At existing locations, the frequency of testing can be increased with the age of the installation. There are two criteria which control the frequency and the age at which testing begins. First, the anticipated service life, which is based upon the aggressiveness of the environment and in-place mitigating systems, indicates when the system can be expected to fail. Second, the type of location and the relative hazards associated with a leak will have a bearing on when accelerated testing should begin. For example, the problems involved in a leak into a navigable waterway may dictate that a facility adjacent to this type of location would begin accelerated testing early in the life of the facility. A consumer account in a rural area, however, might not require testing until the expected life has been reached.

The monitoring of an in-place mitigation system may also be more frequently performed as the system approaches the expected duration of its useful service. The effectiveness of cathodic protection systems must, of course, be monitored regularly through their lives, but additional testing may prove feasible in the latter stages of service.

The state of the art of leak protection and corrosion mitigation has currently progressed to the point where the life of a newly installed facility, with proper pre-installation testing and analysis and proper installation, can be quite accurately forecasted. Therefore, the underground system can be designed for a useful life compatible with the anticipated life of the facility. As a result, new installations can be programmed for testing both later in their lives and at less frequent intervals than facilities constructed in an era of less knowledge concerning corrosion.

Replacement Prior to Failure

There are certain types of locations which require more drastic action as they near the end of their useful lives. They include locations for which an underground leak has a high probability of causing substantial adverse publicity. Among these types of locations are: sites adjoining navigable waterways; those where contamination of wells or other underground waters is probable in the case of a failure; facilities used in aircraft fuel service; and locations where the accumulation of liquids or vapors might result in an explosive condition in subways, basements, or other subterranean enclosures.

In these types of locations, it might be wise to pursue a program of periodic facility replacement as systems approach the anticipated end of their service lives. If the situation, in fact, does warrant such drastic measures, it would be well to consider replacement with an inert system, or one exhibiting a fully protective characteristic.

Definitive recommendations will be made in the Conclusions and Recommendations Sections.

IDENTIFYING THE LEAK SOURCE

When a leak does occur, it is normally discovered as a result 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 of these conditions requires certain steps which are necessary to the protection of life and property, and which should be carried out prior to any further action. A word of caution should be inserted here, however. Avoid creating unnecessary alarm or unwarranted interruption of normal activities. Make every reasonable effort to determine the magnitude of the problem before notifying authorities. Excessive alarming, such as that which may be caused by unwarranted evacuation or publicity, can create more hazard than the original problem. In short, use good judgment in all action taken.

Condition (1) (a) is normally the most hazardous situation. Smoking and other forms of ignition should be eliminated from the suspected area. Electric and gas service should be cut off at a location remote from the area to avoid sparking. Occupants should be evacuated and unauthorized personnel should not be allowed to enter.

Ventilate the area by opening doors and windows and use grounded mechanical ventilators to exhaust the area of vapors.

After rendering the building safe for entry, try to locate the source of entry into the structure and block the source. If this is not possible, well points, trenches, or holes for pumps may be necessary outside of the structure to block the entry.

Conditions (1) (b) and (1) (c) present a normally less hazardous situation, the latter often producing more of a pollution problem than a danger to life and property. However, the same initial precautions should be taken until explosivity and toxicity are definitely eliminated as potential hazards.

Condition (2) does not imply directly a hazard of fire and explosion. The immediate area should be checked for signs of escaping fluids. If any exist, apply the proper protective measures outlined above. Otherwise, apply proper testing procedures to verify the tightness of the system. These procedures are expanded in detail in NFPA No. 329-72, Chapter II, for the interested reader.

After the initial safety precautions have been applied, the source of the flammable or combustible liquid must be discovered and corrected.

Primary Search

The primary search, as outlined in NFPA No. 329-72, Chapter III, consists of an elimination process where most, if not all, non-contributory locations are eliminated from suspicion. This procedure, briefly, is as follows.

Canvas all local operations upstream of the discovery which are potentially responsible for the leak. Try to determine from conversation and visual inspection if there has been a spill of product lately, a recent maintenance or repair call which may have disturbed the underground facilities, any noticed odor or other sign of liquids where they should not be, water in the tanks, etc. If this fails to identify any potential source, ask for permission to check the equipment and the area around each suspect facility.

Tracing Liquids Underground

When the field has been narrowed down as far as possible, it may be necessary to test one or more facilities for underground leaks. If no definitive results can be reached and the flow of liquid does not stop, it is then necessary to trace the liquid underground with the help of geologists, authorities, and industry members. The nature of liquid flow underground is such that the source may be a great distance away, and elaborate studies may be necessary to place the fault.

Of some assistance may be laboratory tests, such as chromatography and spectography. Dyes are sometimes helpful, but are limited physically by leaching and bleaching over longer distances.

NFPA No. 329-72, Chapters III & V, cover this subject matter in much greater detail. It is apparent, however, that the location of the source of the product is still very much an art, and considerable research is needed in this area.[7]

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[7] See Appendix III for additional treatment of tracing liquids underground.

CORRECTING THE PROBLEM

The discovery of an underground leak unquestionably indicates a problem at a location, but it does not necessarily indicate the extent of the problem. It could mean as little as an isolated corrosion cell, a loose fitting, or a mechanical seal failure; or it could mean as serious a situation as a highly corrosive environment, severe fault activity, or general backfill failure, with the entire system approaching failure. How, then, does the engineer determine what corrective measures are warranted? First, an examination of the failure, if possible, should be made. It is sometimes possible to determine if the failure is caused by an isolated cell or if it is widespread by visual examination.

The environment must be re-evaluated to determine if a less aggressive situation has become more aggressive, and the degree of aggressiveness must be evaluated. Changes from prior evaluations should be noted and their causes investigated. This information should indicate the condition of the balance of the system with some degree of accuracy, allowing the engineer to select the proper corrective measures from the alternatives discussed below.

Replacement Limited to Failed Structure

In situations where the failure is determine to be localized in nature, it may prove advantageous to limit replacement to the structure that failed. This may mean replacing a single tank, hoist, or underground line. If this is the decision that has been made, there are several alternatives to consider.

The failed structure can be replaced on a like-for-like basis, e.g., steel for steel, fiberglass for fiberglass, etc. Before selecting this alternative for an existing steel installation without current cathodic protection, however, it should be remembered that a potential difference exists between new steel and old steel, and galvanic action may be induced between the new structure and the existing portion of the system.

That portion of the system that failed can be replaced with fiberglass reinforced plastic. This offers an inert situation which will not result in the corrosion cell illustrated above, but it may cause problems if the system is currently cathodically protected. The replacement could throw the c.p. system out of balance or cause a break in the system by acting as a dielectric coupling. Special handling and recognition of this situation will alleviate this potential problem.

In the event that widespread damage is anticipated prior to the end of the productive life of the facility, it may be justifiable to cathodically protect the system, or any part of it, subsequent to replacement of the member which failed. This offers an extended life to the existing system as well as the opportunity to utilize the most economical material for the replacement of the failed portion.

Replacement of Selected Portions Beyond Portion Which Failed

In isolated instances, the potential liability of additional leaks, the age of the facility, relatively low incremental cost of underground work, or other considerations may dictate that the entire system be replaced at the time of the emergency repair work. A location this critical would probably demand the special treatment of fiberglass or full cathodic protection, but a like-for-like replacement criterion could be envisioned if the economics of replacement were weighted heavily by high costs of getting to the job or the need for special equipment. This type of installation would necessarily parallel a grass roots installation and be governed by the same guidelines, except that empirical evidence of a problem at the location now exists, and certainly some mitigation measures would be in order.

Repair of Portion Which Failed

As alternative to replacement of failed tanks, the engineer has the option of repairing the failed structure, which has certain advantages over replacement. Minimum disruption of business and no interference with the underground galvanic balance are major advantages to this process, and the ability to closely inspect the failed tank without the removal of it offers close visual evidence of the probable condition of the rest of the system. This process, coupled, where necessary, with cathodic protection of the balance of the system, can often offer the least costly solution to the problem.

CLEANING UP LEAKS

One of the areas most in need of continuing research concerns the recovery and cleanup operation following a product loss. Removal and disposal methods will depend on the liquid involved and the area contaminated, each type of operation requiring different hazard reducing steps.

There are two groups of liquids that we must be concerned with. Volatile liquids are those which readily vaporize at ambient temperatures. Among these are solvents and gasolines. Non-volatile liquids include the heating oils and food processing oils. They do not vaporize readily.

In general, purging a facility of volatile liquids is primarily a matter of ventilation, while non-volatile liquids must be collected and picked up or flushed away with water.

Areas requiring removal procedures can be categorized into four major classifications:

(1) Normally inhabited subsurface structures:

  (a) Basements and similarly confined areas;
  (b) Subways, tunnels, and mines;

(2) Normally uninhabited substructures:

  (a) Utility conduits;
  (b) Sewers;

(3) Water surfaces;

(4) The soil:

  (a) Surface;
  (b) Subsurface.

The following discussion will briefly cover each of these categories.

Normally Inhabited Subsurface Structures

As was indicated in the section on Identifying the Leak Source, this situation is normally the most hazardous condition. In the case of flammable and combustible liquids in basements and other confined areas, the quantity of liquid will normally be very small. If the liquid is volatile, ventilate the area by opening doors and windows and use grounded mechanical ventilators to exhaust the area of vapors. Small remaining amounts of liquid should be picked up with rags or commercial absorbents. Complete the operation by flushing out basement sumps and floor drains with water and washing down contaminated surfaces. In rare cases of large volumes of volatile liquids, pumping or bailing operations may be required.

For non-volatile liquids in basements, use absorbents and pumping and bailing techniques. Separate water mixtures in barrels by settling and syphoning off the water.

Subways, tunnels, and mines differ from basements in three important respects. First, they will have greater exposure to the public. Second, there will normally be greater exposure to sources of ignition. Finally, there is much greater exposure to underground seepage. Consequently, greater caution must be exercised, more thorough monitoring is required, and a maximum cooperative effort must be affected with the authority responsible for the facility. Beyond these safeguards, however, procedures should be essentially the same as for basements.

Normally Uninhabited Substructures

Removal and disposal methods for utility conduits are different from those discussed earlier for three principal reasons:

(1) Normally, concentrations will be higher because early discovery and preventive measures are unlikely;

(2) Access is limited to manholes at infrequent intervals;

(3) Exposure and danger to the public are greatly reduced.

Cleanup should consist of separating contaminants from water in settling tanks or drums by gravity to avoid downstream contamination of drainage facilities.

Sewers offer an effective method for collection of contaminants from a surrounding area. Due to the impracticality of sealing off all entry points, however, removal constitutes a continuing effort until the entire area is purged. Skimming facilities provide effective recovery if the contaminated stream cannot be diverted to a separator. Booms and weirs can be used to facilitate the skimming effort by backing the contaminant up to offer a more easily recoverable film.

Water Surfaces

Contamination of water surfaces should be resolved in the manner discussed above for sewers.

The Soil

Underground soil contamination often proves to be the most difficult situation to resolve. A knowledge of the local geography is basic to the solution of this type of condition, strongly suggesting the retention of a geologist familiar with the area. Because the contaminant will gravitate downward through porous soils until it reaches an impervious layer or the water table, some knowledge of local soils and water table level is essential to the collection of the liquid.

Once the depth and direction of flow of the flammable liquid are determined, several alternatives become available for consideration. If the contaminated stratum is shallow, the best recovery method involves digging a trench to intercept the liquid, and lining the downstream side of the trench with an impervious barrier. The contaminant can then be pumped out as it percolates to the trench.

Deeper contaminated strata require the use of well points in lieu of trenches. A widespread contamination may require several wells. Each well may then be skimmed until the contaminant is exhausted.

NFPA No. 329-72, Chapter VI, covers this subject matter in much greater detail. As mentioned at the beginning of this section, however, additional research is sorely needed in the removal and disposal of contaminating liquids.

CONCLUSIONS AND RECOMMENDATIONS

It is obvious from the foregoing study that there is no single best solution to a particular problem. Many factors, including geography, local codes, and agency preferences, influence the decision in all cases. Consequently, the following recommendations include approved alternative solutions for each discussed situation, citing the preferred treatment first, then each of the other alternatives, in the order of preference (disregarding factors such as cost, because of geographical variation).

Classification of Installations

Typically, installations fall into one of four categories based on the consequences of an underground failure. The reader will note that these risk classifications vary from those in the MERP Corrosion Manual, AP IAlb. The differences result from a change of emphasis since the publication of the Corrosion Manual in September, 1968.

(1) Group I - This group includes those facilities at which tank leaks would exhibit the most critical public hazard. Included are those locations where leakage might result in explosive conditions in occupied or congested areas. Locations in the vicinity of basements or subways fall into this group. Equally critical are the facilities adjacent to navigable waterways where a leak might be particularly damaging to the environment or costly to clean up. This is particularly true in light of recent legislation calling for the automatic imposition of substantial fines upon the owners and/or operators of facilities which fail resulting in spills into certain navigable waterways.

(2) Group II - Classified here are those installations which might not present the most critical situation, but do offer a greater incentive for insuring against premature failure and prolonging the life of the underground system. Included are facilities in the vicinity of sewers, streams, and utility conduits where leakage might be widely distributed and constitute a significant hazard to life and property. Also included as Group II locations are aircraft fueling facilities and underground storage at bulk plants.

(3) Group III - These are the average underground installations where no unusual incentive for corrosion protection exists. Until recently, this included the bulk of our underground storage; but investment trends indicate that this group is and will continue to be declining in size in favor of the Group I and Group II locations defined above.

(4) Group IV - This group contains those facilities for which there is less incentive for corrosion control. The locations are characteristically designed for a ten year rather than twenty year life. They are typically contract dealer and consumer accounts in outlying areas.

These simple groups will suffice for the installation of new facilities, but there are certain subgroups which must be defined for existing facilities. The risk groups must be further divided into the following classifications in order to analytically determine the proper mitigation measures, if any, for each facility.

(1) Subgroup a - This classification includes all facilities which have a history of underground failure and which also are expected to remain in the chain for ten years or more.

(2) Subgroup b - These locations have a leak history and are anticipated to remain in the chain for more than five but less than ten years.

(3) Subgroup c - Included here are short remaining marketing life facilities (less than five years) with a history of underground leaks.

(4) Subgroup d - These locations have no history of leaks and have been in service for 15 years or more.

(5) Subgroup e - This group includes locations with no history of leaks and in the 10-15 year age bracket.

(6) Subgroup f - These facilities have been in service for less than 10 years and have no history of underground leaks.

The following recommendations are presented in the sequence one would normally apply them at a given location, beginning with the installation of the new facility and continuing through the various stages in its service life.

New Underground Storage/Delivery Systems

The first step necessary in the installation of a new underground system is the proper evaluation of the existing environment. The best and most accurate method of evaluation is through the physical tests described in the MERP Corrosion Manual, Im IIIB, and includes tests for resistivity, pH, and other basic data. These tests can be conducted by the engineer or a professional testing firm, and an Aggressiveness Index can be developed (See Table 2). However, not all areas require these formalized testing procedures. An area history of innocuous soil may be sufficient evidence of soil conditions, if the site is undisturbed native soil; likewise, an area with a history of highly aggressive conditions may warrant protection of the substructures without further testing. Generally speaking, however, environments which do not show an extremely mild or highly corrosive history should be tested physically as the initial step in the development plan.

Regardless of the area history, possible sources of stray currents must be investigated at every new site. High voltage lines, gas transmission facilities, electrical and telephone conduits, manufacturing and fabricating operations, and train and trolley lines in the immediate area must be considered as sources of stray currents, and necessary precautions taken. If tests indicate the presence of stray currents, a qualified corrosion engineer should be retained to determine the best mitigation measures.

When the Aggressiveness Index has been determined, the locations should be classified as to risk group. The selection of equipment for underground use can then be made from Table 4.

Subsequent to the selection of equipment, the primary consideration, as it pertains to the underground leak problem, is one of constant diligence during implementation. This point cannot be overstressed. Attention to specification is the most important single item, particularly with regard to backfill and testing for system tightness prior to coverup. The reader's knowledge now concerning the basic corrosion cell and the electromotive series impresses the necessary preclusion of foreign objects from contact with any of the components of the underground system.

Necessary checking and monitoring schedules should be set up through use of a suspense system. In the case of cathodic protection systems, validations should be performed annually, or more often if a signal device indicates circuit failure. Other systems require no set inspection, but file data concerning environmental agressiveness should indicate the anticipated service life of the equipment, and this information should be utilized in the scheduling of late life verification of systems. These, of course, are practical testing minimums, and more stringent local codes would necessarily take precedence.

Existing Underground Storage/Delivery Systems

The facility which has been in service for some period of time becomes a much more complex problem than a new installation for several reasons. Past practices in the field characteristically did not involve soils investigations, so most existing facilities have files which are incomplete as far as environmental variables are concerned. Additionally, Region data is not kept, typically, on underground leaks as a separate maintenance category; therefore, an accounting of those facilities with a leak history is not readily available. Thirdly, facility age may not be easily determined due to partial replacement of facilities, expansion and addition of tankage, and failure to remove replaced facilities from the books. Consequently, the development of the information necessary to classify the locations into the subgroups detailed above will require some initial effort. However, this effort is necessary to the successful implementation of the following program.

The initial step required for existing facilities is the classification of each facility by Group (I-IV) and Subgroup (a-f). Once categorized in this manner, a logical procedure can be followed within each group. The end results will be the reduction of underground failures to 5-15% of the current annual rate by the completion of the program.

TABLE 4

TREATMENT SELECTION GUIDE FOR
NEW UNDERGROUND STORAGE/DELIVERY SYSTEMS

Environmental Index*	Risk Classification Group											
	I			II			III			IV		
	Tanks	Piping	Hoists	Tanks	Piping	Hoists	Tanks	Piping	Hoists	Tanks	Piping	Hoists
6	5	7, 11	17, 18	5	7, 11	17, 18	5	7, 11	17, 18	5	7, 11	17, 18
6-7	4 2	7 8	15 14	4 2	7 8	15 14	4 2	7 8	15 14	4 2	7 8	15 14
8	1 2	7 8	12 14	4 2	7 8	15 14	4	7	15	4	7	15
9	1 2	7 8	12 14	1 2	7 8	12 14	4	7	15	4	7	15
>9	1 2	7 8	12 14	1 2	7 8	12 14	1 2	7 8	13 14	1 2	7 8	13 14

*See Table 3 for additional criteria which may place an environment in a more aggressive classification.

Key to Treatment Numbers:

Tanks

1. Fiberglass Reinforced Plastic (FRP)
2. Cathodic Protection - Impressed Current (CPI)
3. FRP Coated
4. Cathodic Protection - Sacrificial Anode (CPS)
5. Wrapped or Coated Steel
6. Unprotected Steel

Piping

7. FRP
8. CPI
9. FRP - Coated Steel
10. Wrapped or Coated Steel
11. Galvanized Iron
12. Black Iron

Hoists

13. FRP - Coated
14. CPI
15. CPS
16. Wrapped
17. Coated
18. Unprotected

Existing locations must be identified as to the aggressiveness of their environments. Soil testing should be performed on each location according to the sequence indicated in Table 3. As each location is tested, it should be assigned a priority number based on anticipated remaining service life and risk group. Those systems which are anticipated to fail within one year would be assigned a priority of 1, failures expected in 1-2 years a priority of 2, etc. Mitigation measures should then be applied to locations in a priority group on the basis of risk group.

The only preventive maintenance mitigation system which is economically feasible for existing locations is an effective impressed current cathodic protection system. Specifications for such a system are detailed in the Corrosion Manual (M IVC). In general, if the tests indicate an Aggressiveness Index of six or more, protection is warranted. A check of the Aggressiveness Index against the approximate service lives of Table 3 will indicate how critical the timing of protection is.

Emergency Leak Correction

When a tank failure occurs, there are several approved methods of putting the facility back into operation. In order of preference, they are:

(1) Line the failed tank with Glass Armor, and install an impressed current cathodic protection system on the entire underground system.

(2) Replace the failed member with an FRP tank and install an impressed current cathodic protection system on the balance of the underground structures.

(3) Replace the failed member with a coated steel tank and install an impressed current cathodic protection system on the entire system.

The above recommendations limit replacement and repair to the failed structure. It may be desirable in certain extreme cases to go beyond the failed member and replace or repair tight tanks as well, due to extenuating circumstances.

If the failure is in the piping, there are two alternative solutions:

(1) Replace the entire line with FRP piping and install an impressed current cathodic protection system on the balance of the system.

(2) Replace the entire line with galvanized iron piping and install an impressed current cathodic protection system on the entire system.

TABLE 3

TESTING SEQUENCE AT EXISTING FACILITIES

Group Sub-Group	I	II	III	IV
a	1	2	7	16
b	3	4	14	17
c	5	6	15	18
d	8	9	19*	22*
e	10	11	20*	23*
f	12	13	21*	24*

*It may be determined locally that locations in these categories do not warrant testing, or that testing should be deferred for some period of time.

Here again, good judgement may require the replacement of structures which have not yet failed. However, in no case should less than the entire line which failed be replaced by splicing a new section into the existing line.

If a hoist fails due to corrosion, the replacement should be cathodically protected. In most cases, this can be accomplished by use of a sacrificial anode.

Testing for Leaks

The Kent-Moore Tank Tightness Tester is still the only reliable production model system validator on the market. E.R.&E.'s ALVOMS appears superior in packaging and in accuracy; but it will not be a valid competitor until it becomes available on the open market. Kent-Moore's unit could become more attractive if it incorporated some of ALVOMS' superior packaging ideas; but only a great price differential could bring it back to a competitive basis.

The Red Jacket Leak Detector should be installed on all new remote systems. Certain agencies (notably those requiring conformance to NFPA - 30) require the installation of a line check device such as the Red Jacket or Gilbarco Leak Detectors; but the cost of the Gilbarco model at this time makes it unattractive relative to Red Jacket's equipment. An investment of $60,000 to $75,000 in research and development could bring the unit cost down to a competitive level, however.

Due to the extremely dynamic nature of this industry, new and better equipment can be expected to reach the market on a continuing basis. Consequently, the engineer should keep himself abreast of new developments, and he should notify superiors of any promising equipment and methods.

Pressure testing of underground tanks should be strongly discouraged and only performed at the direct insistance of Fire Control officials.

Identifying the Leak Source & Cleaning Up Leaks

The definitive working guide to these problems today is NFPA 329, Underground Leakage of Flammable & Combustible Liquids, 1972, but much additional research is needed before we will be able to quickly and easily define and clean up a major product loss. No concepts appear to be available at this time, however, so no further MERP projects are proposed.

Accounting Procedures

The underground leak problem must be isolated in the accounting system in order that a meaningful analysis of a preventive maintenance program can be done. A separate expense category must be maintained, and the capital budget must show a line item for costs associated with underground leaks.

Bookkeeping Procedures

The individual location must be encouraged to keep records which will quickly spotlight possible leaks, and a check list such as that shown in Appendix I should be required prior to any physical tank test.

Further MERP Studies

Throughout the body of the paper, reference has been made to the need for additional research in various areas. This final section will address each of these areas and their most logical resolution.

(1) Underground Environment/Equipment Relationship - The further study necessary here is confined to the areas touching upon the Aggressiveness Index and internal corrosion. A MERP project on the latter is feasible, but the required time span and associated costs may prove prohibitive. Data gathering will be extremely time-consuming, and results may prove no better than those presented in this report. A fine-tuning of the Aggressiveness Index concept should be contracted through an outside firm specializing in soil characteristics, particularly corrosion control.

(2) Tests for System Tightness - The research needs outlined above for this topic should rightfully be handled through an industry group such as API. No further MERP studies are proposed, although a sequel to MERP #7006 is needed regarding production models of ALVOMS. Private research is being carried out along several avenues which should be monitored closely.

(3) Determining Leak Probability - A MERP study could combine this topic with the Aggressiveness Index concept study mentioned above. There does appear to be a feasibility to a prediction method which incorporates physical testing and reliable forecasting of service life.

(4) Identifying the Leak Source - Although methods in use today are cumbersome and unreliable, there does not appear to be a valid concept which offers any hope for improvement in the immediate future.

(5) Cleaning Up Leaks - The same situation exists for this aspect of the underground leak problem as for the identification of the source.

APPENDIX I

Date ____________

CHECK LIST FOR GASOLINE VARIATIONS

DISTRICT ____________ RETAIL STORE NO. ______ TERRITORY ________

The above store has had a reported Meter Balancing Report (MBR) loss in ________ gasoline of ________ gallons over the past ________ MBR's. A loss of this size indicates the potential of a very serious problem at this location, and it should be thoroughly investigated to determine the reason for the loss.

Please complete the following check list at your earliest convenience and return it to (Maintenance Center).

1. Check inventory records for the past 90 days for arithmetic errors and completeness.

   Date ____________ Finding ____________

2. Do the gallons sold check out with the money totalizer?

   Date ____________ Finding ____________

3. Do the daily tank stickings agree with the daily metered sales over the past 90 days? If not, to what extent do they vary?

   Date ____________ Finding ____________

4. **Are proper procedures used for receipt of gasoline? One of the following methods should be used (Check box of method currently used).**

   ☐ **a. Gauging of underground tanks before and after bulk delivery.**

   ☐ **b. Visually checking the quantity of gasoline in the truck on arrival and again for complete emptying before leaving.**

   ☐ **c. If delivery is by meter, check the meter readings before and after delivery.**

5. **Have any discrepancies been noted between volume actually received and manifest volume?**

5. (Continued)

If so, how were they found, when were they found, how was it reported, and what was the extent of the discrepancy?

Date ____________________ Finding ______________________________________

____

____

6. Are proper procedures used for gauging tanks (stick wiped clean prior to gauging, let stick slowly down into the tank, make sure the bottom of the tank is reached, wait a few seconds before removing stick, etc.)? Stick readings can vary ± 30 gallons.

Date ____________________ Finding ______________________________________

____

7. Are tank sticks the proper length?

Date ____________________ Finding ______________________________________

____

8. Does the size indicated on the tank chart agree with the size of the tank?

Date ____________________ Finding ______________________________________

____

9. Is there any visible evidence of leaks or spills around the pumps or tanks? (Turn on pumps or submerged pump when making check.) Be sure to look inside the pump panel around the impact valve.

Date ____________________ Finding ______________________________________

____

10. Check all meters for proper seals and signs of tampering; pay particular attention to the shaft connecting the meter with the computer.

Date ____________________ Finding ______________________________________

____

11. Check for signs of tampering with the 1/4" pipe plug in the impact valve.

Date ____________________ Finding ______________________________________

____

12. If none of the above have shown a significant probable cause for gasoline losses, request a meter calibration and record the results of the calibration below.

    Date ____________ Finding ____________________

    ____

    ____

13. If meters are calibrated properly, perform the following:

    a. Lock the fill caps.

    b. Notify the dispatcher that the fill caps are locked and request daylight deliveries.

    c. Carefully gauge tanks daily and check gauge readings against totalizer readings for 15 consecutive days. Record this information on a daily basis and note any variance. Remember that stick readings can vary ± 30 gallons.

    d. At the end of 15 days, unlock the fill caps and notify the dispatcher that the tanks are unlocked.

14. Return this check list and the attached daily tank gauging record to:

    ____

    ____

    ____

The above check list has been completed on (Date) ____________________.

Signed ____________________
Sales Representative

RDD:dw
7/30/73