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Leak Prevention in Underground Storage Tanks:

A State-of-the-Art Survey

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LEAK PREVENTION IN UNDERGROUND STORAGE TANKS: A STATE-OF-THE-ART SURVEY

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments, and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report reviews the state of the art of underground storage tank (UST) leak prevention technology and identifies areas for further research and development to aid in developing regulations for USTs as mandated by the Resource Conservation and Recovery Act as amended in 1984.

For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

Thomas R. Hauser, Director
Hazardous Waste Engineering Research Laboratory

ABSTRACT

The overall objectives of this study were to examine the structural design and operational practices associated with underground storage tank (UST) systems in the context of preventing leaks from such systems and identify areas for further research and development to advance the technology.

UST systems are conceptually simple. Many standards, guidelines, and recommended practices for the design and operation of these systems are currently promulgated by several professional and industrial organizations. However, many of these procedures have overlapping requirements and there is no way of confirming how widely they are understood or followed in the field. Consequently, there is a need for a cohesive and coordinated set of rules and standards that apply to various types of UST systems, including those that store chemicals, and for further work to assess and improve operating practices, including spill prevention and leak detection methods and devices.

Other recommendations derived from this study include: (1) establishing a national data base to provide information on failure rates and mechanisms and their correlation to design, engineering, installation, and operation practices and corrective actions; (2) assessing the effectiveness of cathodic protection methods, their interaction with the environment, and the performance of retrofitting existing USTs; (3) developing compatibility protocols for the selection of appropriate materials of construction and long-term protection; and (4) developing methods to assess the life expectancy of both new and existing systems and to extend their useful life.

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ABBREVIATIONS

ACI	American Concrete Institute
ANSI	American National Standard Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing Materials
AWWA	American Water Works Association
FRP	Fiberglass-reinforced plastic
MEK	Methyl ethyl ketone
NACE	National Association of Corrosion Engineers
NFPA	National Fire Protection Association
RCRA	Resource Conservation and Recovery Act
SSPC	Steel Structure Painting Council
STI	Steel Tank Institute
UL	Underwriters Laboratories
UST	Underground storage tank
VOC	Volatile organic compound

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SECTION 1

INTRODUCTION

BACKGROUND

Protecting the nation's groundwater resources from contamination by regulated substances* that leak+ from underground storage tank (UST) systems has emerged as a major issue on the nation's environmental agenda and for valid reasons. More than 50 percent of the nation's population draw drinking water from underground resources (1). There are between 2 and 3.5 million underground tanks buried across the nation, of which some 100,000 tanks are estimated to be presently leaking, and some 350,000 are expected to leak within the next 5 years (2). The immensity of the problem becomes all the more apparent with some additional statistics (2-6):

- Almost 90 percent of existing underground tanks are made of steel that are unprotected against environmental deterioration -- principally corrosion;
- More than one million existing USTs are 16 years or older;
- A recent analysis of over 12,000 leaks, approximately 65 percent of which are from retail gasoline station incidents, indicated mean and median tank system ages of 17 years at the time of the leak;
- An unknown, but presumably large, number of abandoned tanks -- with no information on their size, location, content, and ownership -- is strewn across the nation. (For example, some 28,000 abandoned tanks are estimated to exist within New York State);
- The fate and transport of regulated substances in water-bearing soil strata are complex phenomena. The potential for contamination of groundwater a significant distance from the leak source and over an extended period of time exists.
- Remediation and restoration of land and groundwater resources contaminated by underground leakage of regulated substances are a costly undertaking, with costs, in some instances, running into the millions.

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*Regulated substances are those defined in Section 101 (14) of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, and petroleum, including crude oil or any fraction thereof which is liquid at 60°F, and 14.7 pounds per square inch absolute pressure.

+In this report, the word "leak" is used to denote all types of unauthorized releases.

Accordingly, the need to improve leak prevention methods is evident. The first step in any improvement strategy is to assess the problem and evaluate solution options. This report is just such a step. Its purpose is to examine the structural design and operational practices of UST systems in the context of leak prevention and identify areas for further research and development to advance leak prevention technology. Specifically, the report:

(1) Reviews structural design, corrosion protection, installation, testing, and operational practices;

(2) Examines the available statistical information on the demographics of leaks;

(3) Presents a summary of the most dominant failure mechanisms, viz., corrosion, and other causes of leaks;

(4) Describes the applicable codes and standards for design, installation, and operation of UST systems; and,

(5) Identifies gaps and deficiencies, and recommends topics for future research.

FACTORS AFFECTING LEAK PREVENTION

System Characteristics

Preventing leaks in UST systems requires the consideration of several factors (Figure 1). These factors include UST system characteristics, elements of the solution scheme, and other factors such as time, cost, regulations and standards.

The characteristics of the system that influence leak prevention strategies and options include:

- Age of installations -- New installations, old but known installations, abandoned installations;

- Ownership -- Large industrial owners, small industrial/business owners, local governments;

- Products stored -- gasoline and petroleum products, chemicals;

- Size of installation and quantity of fluid stored.

Age of installation--

The age of an UST system greatly influences the solution option. In a new installation, leak prevention technology is designed and engineered into the system. In an old, but known, installation, on the other hand,

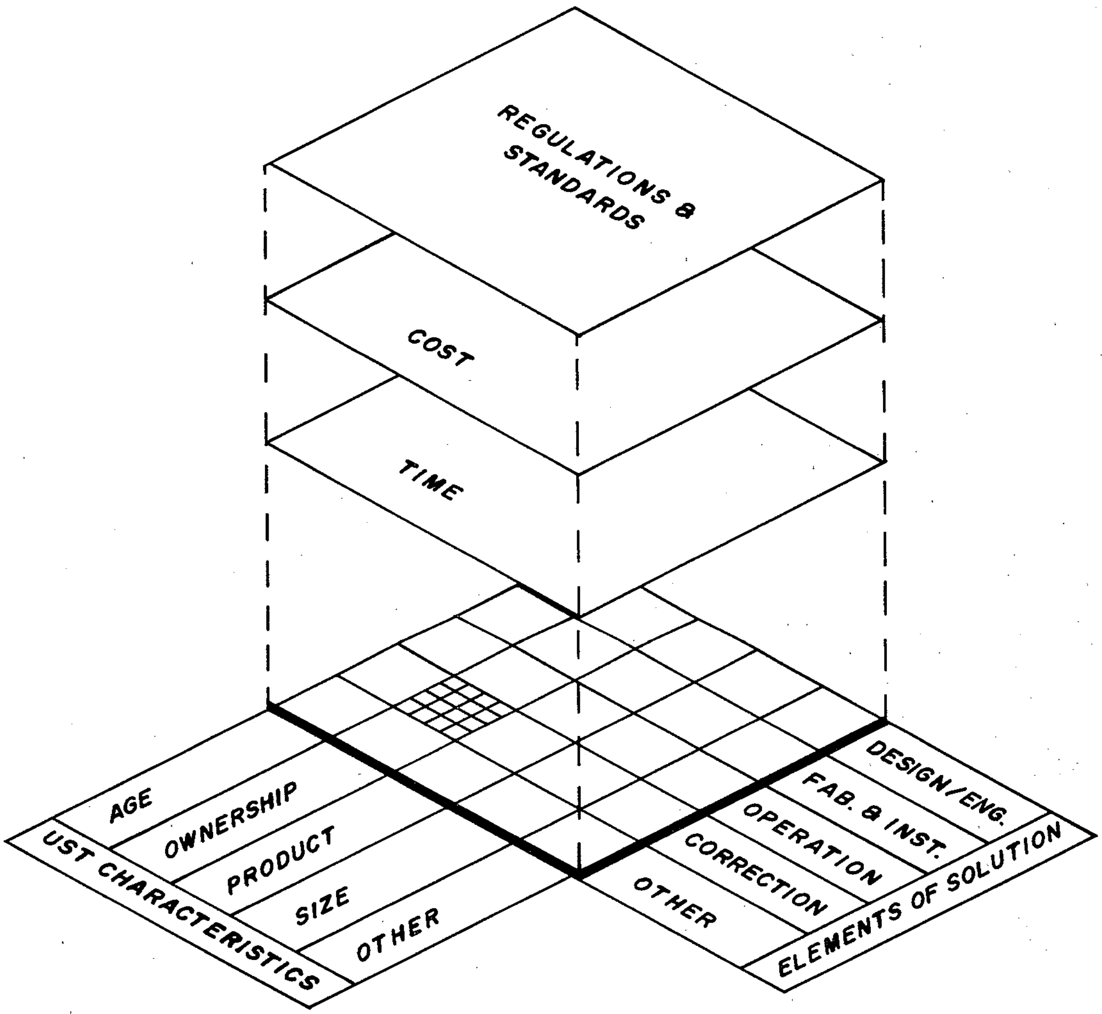

Figure 1. Dimensions of leak prevention.

it is a reactive step that requires system monitoring, retrofitting, remediation and restoration. In an abandoned installation, problem identification is most significant in the solution scheme. Being prepared to solve a problem even though it is not clearly defined thus becomes a prudent strategy in this case. Material, personnel, and organizational resources to detect leaks, to determine their sources, and to contain and remediate the environmental damages should be the focus of the prevention strategy. An appropriate analogy is the fire prevention and firefighting strategies found in communities across the nation.

Ownership--

The owners of underground storage tank systems greatly influence the effectiveness of leak prevention strategy. Large industrial owners generally have the technical, managerial, and financial resources to employ the most effective active and reactive leak prevention strategies. Moreover, large owners have the economic incentive to minimize product losses from underground systems and avoid risks of heavy financial losses resulting from potential lawsuits. It can be reasonably concluded, that cost reduction, generic research, improvements and advancement of the technology, and wide dissemination of such advancements are the most significant needs of this ownership group.

Small owners* from industrial and business sectors, local governments, school boards and others present a different set of needs. This group usually lacks the financial resources and organizational strength to develop their own methods, products, and procedures to prevent and remediate leaks. The smaller the owner the less likely they are to have in-house technical capabilities to discern the causes and effects of leaks, and to apply effective prevention methods. This group's needs are likely to include: (1) recognition and understanding of the dimensions of the problem; (2) proven and reliable methods, products, and procedures for solution; (3) a qualified, trained, and price-competitive technical labor pool; and (4) incentives and rewards that compel them to apply leak prevention programs continually.

Products stored--

By far the largest class of products stored in UST systems is gasoline and other petroleum products. Understandably, the primary focus of leak prevention investigations thus far has been UST systems that store these products. The problem, however, extends far beyond this. The list of regulated substances includes 698 chemicals which are stored in USTs in varying quantities. For example, in California (9) close to 500 regulated chemical substances, most commonly sodium hydroxide, sulfuric acid, toluene, acetone, and methyl ethyl ketone (MEK), are stored underground. The differences in the physical and chemical properties,

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*Small owners as used in this report are independent oil companies, gas station owners, and oil jobbers, municipalities, small fleet owners, etc.

toxicity, transport, and fate characteristics of such chemicals and petroleum products require different approaches and strategies for leak prevention.

Size of installation--

The size of UST installations has a significant influence on leak prevention strategy. Leak rates from large installations are likely to be higher than from smaller installations, and thus the potential for environmental damages will most likely be higher. Size differences also present unique problems and opportunities with regard to materials of construction, design, inspection procedures, leak monitoring, repair, maintenance, and replacement schedules.

Elements of the Solution Scheme

The objective of a leak prevention program is to insure the integrity of the containment boundaries throughout the useful life of the system; avoid or minimize accidental spills and overflows; provide early warning of impending leaks; and prevent products from spreading should they leak. These tasks require three necessary but sufficient steps:

1. Proper design, engineering, fabrication, and installation;
2. Correct operation;
3. Appropriate corrective actions through inspection, repair, and maintenance.

Design and engineering--

As the first step in leak prevention, proper design and engineering of an UST system should follow a high level of standard engineering practices, which include:

- o Understanding the forces and environmental factors that impair the containment boundaries;
- o Applying valid principles of mechanics and other engineering sciences to develop proper configurations and layouts;
- o Selecting appropriate materials of construction to withstand the forces of the system and environment;
- o Providing appropriate means to control, monitor, maintain, repair, and replace the systems once they are built;
- o Insuring a desired level of quality in all aspects of the work by implementing acceptable standards.

Fabrication and installation--

System fabrication and installation must adhere to high standards of workmanship by:

- o Insuring quality of materials of construction;
- o Providing appropriate tools and instruments;
- o Hiring trained, qualified workers and providing appropriate supervision;

- Adopting proven methods of construction and verifying quality of workmanship.

Operations--

Correct operations of an UST system are necessary to prevent leaks and spills. Several steps are required:

- Establishing valid procedures for the range of operations: start-up, normal, upset, emergency, and shut-down conditions;
- Hiring qualified operators and providing them with proper training and tools for operation;
- Maintaining proper records of operation.

Corrective actions--

Appropriate corrective actions permit the identification and repair of potential failure before they become major problems. These actions require:

- Establishing appropriate schedules for inspection, repair, and maintenance;
- Providing proper personnel, tools, access, and facilities for corrective actions;
- Insuring quality of corrective actions to meet established standards.

Regulations and standards--

Regulations and standards enhance leak prevention by improving quality, uniformity, and interchangeability of products. Too much or too little regulation, and too early or too rigid standards, however, would inhibit innovation and technological growth. A conscious appreciation of these factors is essential in promoting leak prevention technology.

An equally compelling issue that applies to standards is user participation in and acceptance of the standard-making process. Much can be learned and applied to UST leak prevention from the successful history of voluntary standards that are applied by many industries in the U.S.

Other factors--

Cost is an overriding consideration in the selection of a leak prevention option. While prevention-at-any-cost may be an ideal solution, a rational decision process should include a consideration of acceptable risk. Cost minimization would therefore be a norm rather than an exception in the search for leak prevention strategies.

Time influences the choice of leak prevention strategies in many ways. Problems that are current and more immediate, e.g., unprotected tanks that are in place for 15 or 20 years, require more prompt attention than a newly installed tank. Research priorities are thus influenced by the time factor.

In the following sections, the implementation of these steps in UST systems is reviewed. Inadequacies of current practice are identified, and appropriate remedial research and development work that should be initiated is suggested.

SECTION 2

CONCLUSIONS

1. Leak prevention in UST systems can be achieved through improvements in design, engineering, fabrication, installation, operational practices, and corrective actions. Appropriate regulations and standards would enhance leak prevention technology. Too much or too little regulation and too early or too rigid standards, however, can inhibit technological growth. A conscious appreciation of these competing factors is essential to promote the technology.

2. The basic UST systems are conceptually simple, and include tanks, pipes, and accessories. Some newer designs also have a secondary containment system. The basic system parts are mostly made of carbon steel. Fiberglass-reinforced plastic (FRP) is used in many newer installations, particularly for tanks that store gasoline products. Flexible liners and concrete vaults are the two most-developed secondary containment concepts.

3. Hundreds of standards, guidelines, and recommended practices, many with overlapping requirements, are presently followed for the design and engineering of UST systems. Most of these documents apply to systems that store gasoline products. There is need for a cohesive, coordinated set of rules and standards that apply to various classes of UST systems.

4. The available statistical information does not provide a correlation of failure rates and failure mechanisms with different design configurations, materials of construction, soil conditions, and environmental and operational factors.

5. The effects of long-term exposure of materials of construction of UST systems to different types of products and outside soil and backfill materials are not known. There is a need to develop these data and protocols for selection of materials applicable to specific conditions.

6. Various agencies and institutions provide installation procedures and guidelines. However, at present there is no way to determine how well these procedures and guidelines are understood and followed by installers.

7. Efforts to improve operating practices should focus upon three areas: methods, equipment, and people. Adequacy of spill prevention methods, leak detection methods and devices, and operator training require special attention.

8. Corrective actions include inspection, maintenance and repair, retrofitting, and tank system closure. Methods and procedures to perform these tasks have been prepared by several agencies and professional groups. However, information is required to determine how well they are applied.

9. Retrofitting of existing tank systems with cathodic protection is one area that warrants special attention. Information on its applicability and effectiveness is lacking.

SECTION 3

RECOMMENDATIONS

As a result of this review, several topics have been identified and are recommended for further research to improve leak prevention technology. These topics are presented below in order of their priorities.

1. Establish a national data base that will provide more refined and detailed information on failure rates and mechanisms and their correlation to different design, engineering, installation, operation, and corrective action methods and procedures.

2. Establish organizational vehicles and mechanisms to integrate, improve, and develop standards and procedures applicable to UST systems.

3. Perform an in-depth assessment of cathodic protection methods, including: (1) the effects of backfill, water tables, types of anodes, and UST design configurations and details on the performance of cathodic protection, and (2) retrofitting existing USTs with cathodic protection.

4. Study the effects of long-term exposure of materials of construction with products stored, and with outside soil and backfill materials. Develop compatibility protocols for the selection of materials for construction and long-term protection of USTs.

5. Develop methods to assess the life expectancy of new USTs and the remaining life of existing USTs, and develop techniques to extend the useful life of new and existing USTs.

6. Assess and establish effective means to train and make available an adequate labor pool of installers, operators, inspectors, and testers of UST systems.

SECTION 4

DESCRIPTION OF UNDERGROUND STORAGE TANK SYSTEMS

A basic UST system has three subsystems: tanks, piping, and accessories. Tanks act as the primary containment for the product; piping conveys and transfers the product from one point to another within the system; and accessories -- pumps, valves, vapor vents, etc. -- control and regulate the flow of the product and operation of the system. A basic UST system at a retail gasoline station is shown in Figure 2.

Some modern USTs (those built mostly within the last five years) have a secondary containment boundary that envelops the part of the primary system that lies underground. The secondary containment acts as a barrier to prevent any product leaking from the impaired basic system from reaching the surrounding ground.

TANKS

Reports (2, 3) indicate that 89 percent of tanks in UST systems in the U.S. are made of steel, mostly carbon steel. A large majority of these steel tanks are unprotected against corrosion. For example, API estimates that almost 66 percent of the tanks owned by its members as of 1984 were made of unprotected steel (4).

Tanks that have corrosion protection include: steel tanks with internal and external coatings; cathodically protected steel tanks; fiberglass-reinforced plastic (FRP) tanks; and steel/FRP-bonded composite tanks. Tanks made of materials such as stainless steel, aluminum, and various plastics are used in specialized applications.

Steel Tanks

The design, construction, and installation of underground steel tanks usually follow one or more of the following standards:

- Underwriters Laboratories (UL) Inc. UL 58, Steel Underground Tanks for Flammable and Combustible Liquids (7);

- National Fire Protection Association (NFPA). NFPA 30, Flammable and Combustible Liquids Code (8);

- American Petroleum Institute (API) Publication 1611. Service Station Tankage Guide (9);

- API Publication 1615. Installation of Underground Petroleum Storage Systems (10);

FRP tanks are normally designed to conform to one or more of the following standards:

- o <u>UL Standard 1316</u>. Standard for Glass-Fiber-Reinforced Plastic Underground Storage Tanks for Petroleum Products (12);
- o <u>NFPA 30</u>. Flammable and Combustible Liquids Code (8);
- o <u>NFPA 31</u>. Standards for Installation of Oil Burning Equipment (13).

<u>Steel/FRP Bonded Tanks</u>

Steel/FRP bonded tanks are constructed of an inner shell of steel and an outer layer of FRP fused together by a polyester resin bond. The tanks have the advantage of the strength and stiffness of steel and the corrosion resistance of FRP.

PIPING

Pipes used in USTs are made of a variety of materials:

- o Carbon steel
- o Cast iron
- o Stainless steel
- o Galvanized steel
- o Rubber, plastic, or epoxy-lined steel
- o Plastic
- o Fiberglass-reinforced plastic

Carbon steel pipes are compatible with petroleum; however, they are susceptible to corrosion. On the other hand, cast iron pipes resist corrosion well and can be used to carry concentrated acids. They are brittle, however, and can break on impact or shock. Both carbon steel and cast iron are relatively inexpensive.

Stainless steel pipes offer considerable corrosion resistance and longer life, but they are expensive. Galvanized steel pipes provide some protection against corrosion, although areas where galvanizing has been impaired (e.g., through handling) are susceptible to corrosion.

Plastic-lined steel pipes combine the corrosion resistance of plastic with the structural strength of steel. These pipes are expensive compared with other types of steel pipes.

Plastic pipes, including FRP pipes, are used because of their superior compatibility with a wide range of chemicals and petroleum products. They are not susceptible to internal or external corrosion and do not induce galvanic corrosion when joined with metal structures. However, they are not structurally strong and are susceptible to failures when subjected to frost heaves, excessive weights, and pressures. They also are not suitable for complex piping layouts.

ACCESSORIES

Accessories in an UST system include valves, pumps, joints and fittings, and other components such as vapor recovery systems, overfill prevention systems, and leak monitoring ports.

Valves

Valves are used to control the flow of fluid, isolate sections of the system for maintenance, prevent backflow in pipelines, and relieve pressure in pipelines and tanks. Most valve designs are modifications of two basic types: gate valves for stopping and starting flow and globe valves for regulating flow. Other types of valves include (14,15) angle, ball, diaphragm, and control valves to regulate flow; plug valves to stop flow; check valves to prevent backflow; and safety valves to relieve pressures in the system.

Valve bodies are usually made of metal or FRP. Metals most commonly used include cast iron, bronze, nickel alloys, steel, stainless steel, aluminum, and titanium. Valve trim includes the internal part of the valve body that comes into contact with the stored liquid and is made of various alloys and plastics. It must retain its smooth finish for successful operation.

Selection of valve material is based on the following criteria (19):

- Resistance to corrosion;
- Resistance to erosion by suspended solids;
- Prevention of galling by dissimilar or hard materials;
- Prevention of deformation or distortion.

The selection is also based on the viscosity, corrosivity, temperature, and pressure of the liquid the valve is exposed to. For example, cast iron and bronze are used for applications at temperatures up to 260°C; nickel alloy steel is used in low-temperature applications for temperatures down to -57°C. FRP or plastic is used where chemical compatibility to the stored liquid is a primary design consideration.

Pumps

Pumps move stored liquid by any of the following methods:

- Centrifugal force
- Volumetric displacement
- Mechanical impulse
- Momentum transfer
- Electromagnetic force
- Gravity

Pumps normally used in UST systems are either suction type or submersible type. Suction pumps are either centrifugal, rotary, or reciprocating and are located at grade or at the product dispenser. Submersible pumps, usually centrifugal, are mounted inside the tanks.

Selection of a pump depends on the following factors (15,16):

- o Characteristics of the fluid stored (temperature, viscosity, vapor pressure, specific gravity);
- o Desired capacity in gal/min;
- o Static suction head;
- o Static discharge head;
- o Size, length, and type of pipe, hose, fitting, etc.

Most leakage in pumps occurs at the seals. Pumps seals are of two types: packing or mechanical. Neither has a clear advantage over the other, but the type of applications may dictate the selection of a certain seal. Packing seals are comprised of fibers of cotton, asbestos, jute, Teflon, silicon, or resins pressed between the two mating surfaces of the pump where sealing should occur to provide a leak-tight fit. In mechanical seals, the mating surfaces are kept in leak-tight contact by springs. Packing seals can be tightened while the pump is in operation; mechanical seals cannot.

Joints and Fittings

Joints and fittings connect various parts of a piping system. Joints and fittings commonly used are:

- o Couplings and unions to join two pieces of pipes;
- o Elbows and tees to change pipe direction;
- o Reducers and expanders to change pipe diameters;
- o Plugs and caps to terminate a pipe;
- o Tees, Ys, and crosses to join two or more streams together;
- o Expansion joints to prevent thermal stresses, eliminate noise and vibration, and compensate for misalignment;
- o Swing joints to give the pipeline rotational flexibility and reduce torsional stresses that can result in pipe failure.

Other Components

Overfill prevention systems are designed to prevent spills at the product delivery transfer connection from the tank truck to the underground storage tanks. These systems automatically shut off flow to the underground tank at a level at which the delivery, including drainage from the delivery transfer hose, is completed without overfilling the tank. "Quick-disconnect" couplings are used on the end of discharge hoses. The liquid released during disconnection is allowed to collect in the spill container surrounding the fill pipe.

Vapor recovery systems prevent hydrocarbon vapor from escaping into the atmosphere during delivery of product into service station underground storage tanks or during product dispensation. Vapors generated during delivery operations are forced to the top of the delivery tank. The vapor release during dispensation is minimized by appropriate design of the nozzles and hose connections at the product dispensation islands and by adding vapor return lines to the underground tanks.

SECONDARY CONTAINMENT

Secondary containment retains leaks from a basic UST system, aids their detection, and facilitates their cleanup (17-19). Secondary containment can be accomplished in two ways: (1) by building a barrier between the basic system and the surrounding ground with flexible membrane liners, a concrete vault, clay liners, or soil sealants; or (2) by using a double-wall structural configuration for tanks and pipes. Systems constructed of these materials can be "fully lined," "partially lined," or "unlined" (11). In a "fully lined" system, the entire tank excavation and pipe trench are lined with either flexible membrane liners, concrete vaults, or clay/soil liners before backfilling. The backfill can then be maintained in a dry or wet condition. In a "partially lined" system, double-walled tanks are used with liners (flexible membrane, concrete, or clay/soil) enclosing only the pipe trench. "Unlined systems" are double-walled tanks, pipes, and fittings, thereby obviating the need for additional liners. However constructed, all secondary containment systems require one leak monitor; double-walled tanks require one monitor for each tank.

Flexible Membrane Liners

Flexible membrane liners are made of polymeric materials manufactured in sheet form. Polyester elastomer, high-density polyethylene, epichlorohydrin, and polyurethane products have been used for a variety of UST system applications, including the storage of petroleum products. Flexible membrane liner materials with bases of polyvinylchlorides, chlorinated polyethylenes, neoprene, ethylene propylene diene monomer, butyl rubber, and chlorosulfonated polyethylene are used for the storage of compatible chemicals, but are inappropriate for petroleum product storage because of their poor resistance to hydrocarbons (17). Flexible membrane liners must be compatible not only with the stored product but also with the surrounding soil and groundwater. They should also be resistant to bacterial deterioration.

A fully lined system in which the entire tank excavation pit and pipe trenches are lined with a continuous flexible membrane liner is shown in Figure 3. Two variations of this concept are: (1) a dry system in which both the tank excavation pit and pipe trenches are kept in a dewatered, dry, state; and (2) a wet system in which the tank excavation pit is kept wet with aqueous saturated backfill, and the pipe trenches are kept dry.

Concrete Vaults

Vaults made of reinforced concrete can be constructed on site to house one or more storage tanks and associated piping. As concrete is a porous material, all concrete vaults must have an internal lining or coating to make them leakproof. Concrete vaults are structurally stable and durable; however, they are brittle and subject to cracking. A typical concrete vault secondary containment system is shown in Figure 4.

Clay Liners and Soil Sealants

Clay liners and soil sealants are relatively inexpensive secondary containment methods. They are both generally used in UST systems that store chemicals. Although some clays may effectively contain petroleum products, they are generally considered unsuitable because of their susceptibility to dessication by hydrocarbons. Natural soils can be made impermeable by treating them with either sealants (e.g., sodium bentonite) or cements (e.g., hydrated Portland cement). However, sealants are susceptible to reactions with groundwater, and may rapidly degrade when exposed to hydrocarbons. The long-term performance of clay liners and soil sealants is not well established.

Double-Walled Tanks and Pipes

Double-walled tanks and pipes are essentially a tank within a tank, and a pipe within a pipe, respectively. The outer walls act as an additional containment boundary in the event of leaks in the primary inner walls. The annular space between the two walls is monitored for leaks. Double-walled tanks are available in steel, fiberglass, and composites of steel and fiberglass. Double-walled pipes are not available commercially on a large scale.

Double-walled UST systems allow near-conventional installation practices and easy replacement of individual tanks and pipe sections. However, there are disadvantages, including: fabrication difficulties at tank and pipe interfaces and other connections; a requirement to have one leak monitor for each tank or pipe section; an inability to protect against product spills and tank overfills; and difficulty in preventing corrosion in the annular space between the tank and pipe walls.

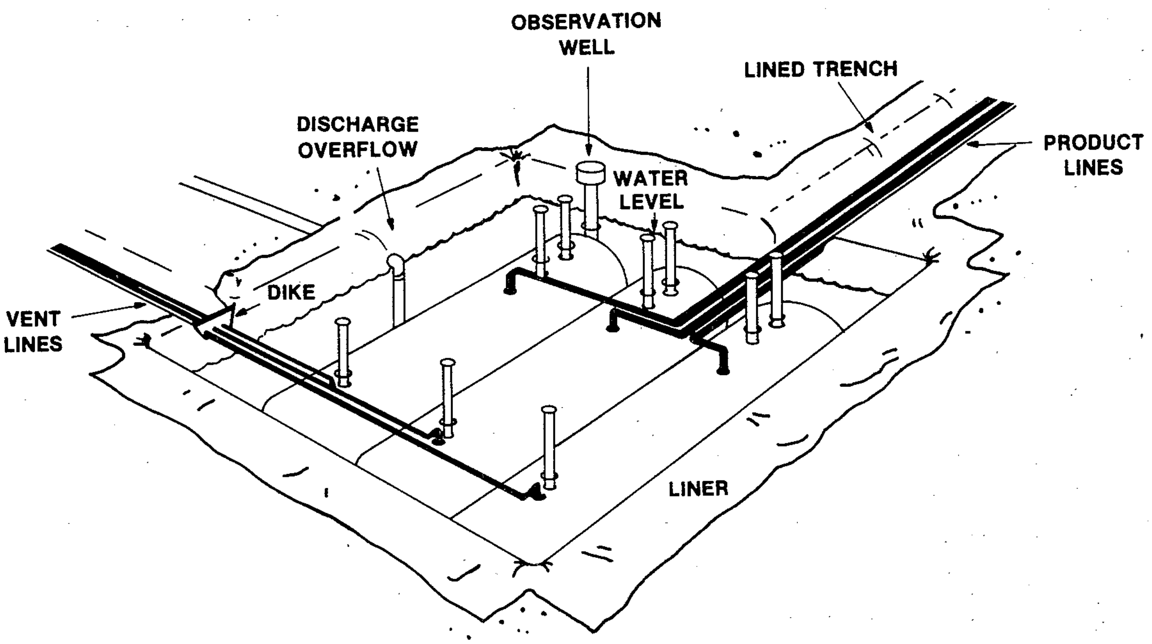

Figure 3. Secondary containment using a flexible membrane. (Adapted from (2).)

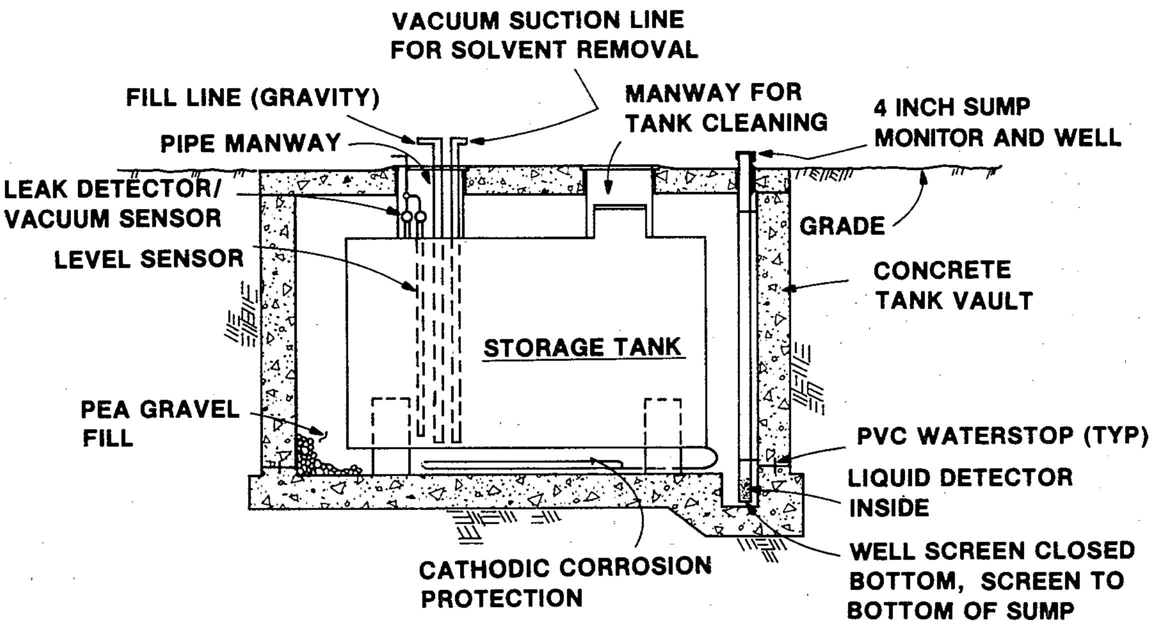

Figure 4. Secondary containment using concrete walls. (Adapted from W.D. Bellamy and R.B. Brummett. Designing for Underground Tanks. Pollution Eng., Nov. 1986, p. 24.)

A comparative evaluation of different types of secondary containment system components is presented in Table 1.

DISCUSSION

The descriptions of the system configurations and design details given in the preceding paragraphs, although not exhaustive, provide an indication of the state of the art of UST structural design technology. In order to assess the adequacy of these design concepts, an understanding of their performance histories, and failure locations and causes are required. Information on type of product released, type and age distribution of a leaking system and the influence of secondary containment, materials of construction and corrosion-prevention systems is also required. Unfortunately, the quality and completeness of failure data in the USTs are limited. The most comprehensive and current statistical information on leaks -- subsurface and underground releases -- is provided in a recent EPA report prepared by Versar, Inc. (3). The report contains an analysis of 12,444 documented leak incidents in all 50 states. Key findings of the Versar study are summarized below.

- 10,300 (83 percent) of the reported 12,444 leaks occurred at UST facilities covered under Resource Conservation and Recovery Act (RCRA) Subtitle I.

- About 65 percent of the reported releases involved retail gasoline stations; commercial establishments accounted for 11 percent of the releases; manufacturing facilities, 5 percent; municipal facilities, 4 percent; and the remaining facility types accounted for 15 percent of the total.

  The reasons for the high proportion (65%) of the reported releases from gasoline stations as compared to the proportion (48%) of retail gasoline station tanks in the total tank population have not been determined.

- 95 percent of all reported leaks occurred at operating facilities; the remaining 5 percent involved abandoned facilities.

- Gasoline accounted for more than 70 percent of the reported volume of leaked products.

- Of the 25 reported leaks that released 50,000 gallons or more of product, 14 involved gasoline, 5 heating oil, 4 diesel fuel, 1 aviation fuel, and 1 unspecified substance. Eleven incidents occurred at gasoline stations and the rest at commercial transportation and manufacturing facilities, military facilities, and other locations.

- Only 10 percent of the leak incident reports specified the age of the tank system. The available data, however, indicated the mean and median tank age for the nation as a whole to be 17 years. Except in the Southwest region (New Mexico and Arizona), the mean age ranged

TABLE 1. SUMMARY ASSESSMENT OF SECONDARY CONTAINER COMPONENTS

Secondary Containment for	Major Advantages	Major Disadvantages
TANK PROTECTION		
Double Wall	-Near conventional installation -Backfill contamination unlikely -Easy monitoring of annular space for primary containment failure and outer shell failure -Allows individual tank replacement	-Piping interface may be difficult -One monitor per tank -Depending on material, may require corrosion protection in annular space -Depending on material, weight and increased dimensions may require special transport and heavy duty cranes -Does not in itself provide for tank overfill or detection
Dry Hole Lined with Flexible Membrane	-Large capacity -One monitor for all tanks -Provides overfill and spill protection	-Significant installation training/inspection -Testing difficult -Future liner repair -Backfill contamination cleanup -Difficult to maintain dryness -Difficult to monitor product in soil in small quantities -Seams if field applied are difficult to seal
Wet Hole Lined with Flexible Membrane-	-Large capacity -One monitor for all tanks -Leak prompts system shutdown -Secondary containment system continuously monitored -Provides overfill and spill protection -Isolates failure	-Significant installation training/inspection -Future liner repair -Maintenance of water level -Backfill contamination cleanup -Seams if field applied are difficult to seal -Disposal of excess water

Table 1. SUMMARY ASSESSMENT OF SECONDARY CONTAINMENT COMPONENTS (Cont'd)

Secondary Containment for	Major Advantages	Major Disadvantages
Concrete Vault/ Encasement (Dry)	-Generally recognized -Structural stability and durability -Large capacity	-High cost -Not impermeable -Lacks plasticity (may crack) -Specially trained installers
<u>PIPE PROTECTION</u>		
Double Wall	-Easy leak monitoring -Backfill contamination unlikely -Isolates failure	-Piping interface experience in industry limited -Testing difficult -"Grade" problems due to pipe size, requires deeper tank hole -High cost -Difficult tank interface
Flexible Membrane Lined Trench	-Applicable to double wall and tank liner systems -Easy to monitor	-Significant installation training -Future liner repair -Backfill contamination
Concrete Lined Trench	-Applicable to double wall and tank liner systems -Easy to monitor	-Significant installation training -Future liner repair -Backfill contamination

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from 14 to 18 years. The mean age in the Southwest region was 28 years. The results seem to suggest that soil conditions in different regions of the country do not significantly affect corrosion rates and tank lifetimes. This is contrary to the generally held belief that a stronger correlation exists between soil condition and age-to-leak.

- The mean age of steel tanks that leaked was 17 years, FRP tank age was 5 years.

- The mean and median ages of leaks in pipes were 11 and 9 years, respectively.

- Steel tanks represent 81 percent of leak incidents, and fiberglass, 19 percent. It should also be noted that 89 percent of tanks in the UST population are made of steel and the rest FRP.

- More than half of the tanks that leaked ranged between 4,000 and 11,990 gallons in size. Analysis of the size distribution further showed that large tanks are as likely to leak as medium or small tanks.

- 43 percent of leaks were reported to occur in tanks. 18 percent occurred in pipes and 17 percent as a result of overfill.

- Structural failures caused by vehicle impact, ruptures caused by excessive pressure during tank tightness tests and ruptures due to improper excavation were the most commonly specified causes of leaks, followed by corrosion, loose fittings, improper installation, and natural phenomena. Relatively few of the structural failure incidents involved corrosion-related problems. The results strongly suggest that a program to minimize leaks in UST systems must address a variety of causes of structural failures in addition to corrosion-related releases.

The statistical information provided by the Versar study, although very valuable, does not permit a detailed analysis of failure mechanisms and failure rates that correlate to different design configurations, materials of construction, protective design concepts, soil conditions and environmental and operational factors.

SECTION 5

DESIGN AND ENGINEERING PRACTICES

Key factors that influence design and engineering of UST systems and their components are: properties of the products stored; mechanical forces imposed on the structural components; corrosion factors; properties of materials of construction; and applicable codes and standards.

PROPERTIES OF PRODUCTS

Physical, chemical, and hazard characteristics of the stored product are important considerations in the design of an UST system and its components. Critical characteristics include the product's physical state at storage temperature, melting point, boiling point, specific gravity, vapor pressure, explosivity, flammability, combustibility and corrosivity. Table 2 summarizes these properties for ten chemicals that are in liquid state at 20^{o}C. A more complete set of data for other chemicals is found in (20).

When products stored in an UST system comprise a mixture, the likely consequences of combining the constituent chemicals must also be evaluated. One tool that is widely used for determining these consequences is a chemical class compatibility matrix (21). The matrix is prepared by grouping chemicals into 38 classes based on similar molecular structure (classes 1 thru 31), and based on similar reactivity characteristics (classes 32-38). For example, mixing of caustics (class 10) with aldehydes (class 5) will generate heat. On the other hand, the consequences of mixing caustics with organic nitro compounds (class 24) include generation of heat and explosion. A clear understanding of such consequences of mixing chemicals is an essential first step in the proper design of UST systems that store chemicals.

MECHANICAL FORCES

Mechanical forces imposed on an UST system and its components include:

- o Dead loads due to product weight, self weight, weight of soil overlay, reaction forces, etc;
- o Live loads due to internal pressure, thermal expansion forces, vehicular traffic;
- o Environmental loads due to traverse and buoyancy pressures due to groundwater table, seismic load in earthquake-prone zones.

Very sophisticated design methods and analytical tools, e.g., finite element programs, are presently available to determine optimal configurations, dimensions and layouts of UST systems. However, the current design approach used in UST systems is largely based on manufacturers' specifications and requirements, and industry and professional standards. This approach is <u>not</u> unlike those employed in many other industrial designs.

TABLE 2. PHYSICAL AND CHEMICAL PROPERTIES OF SOME REGULATED SUBSTANCES (20,2)

Substance	Boiling Point °C	Specific[1] Gravity	Solubility[2] (mg/l) in H_2O	Vapor Pressure[3] (nm of Hg)	Hazard
1. Gasoline	60-199	0.72	NA	460-750	E,F
2. No. 2 Fuel Oil	260-350	0.85 (15/15)	515	28	E,F
3. Toluene	110.6	0.866 (20/4)	720 @ 16°C	20 @ 20°C	E
4. Tetrachloroethane	146.3	1.6 (20/4)	200 @ 20°C	74 (25)	E,F
5. Trichloroethylene	87.1	1456 (25/4)	100 @ 25°C	10 (32)	C
6. Tetrachloroethylene	121.2	1623 (20/4)	NA	15.8 (22)	NA
7. Methylene Chloride (Dichloromethane)	40.7	1.36 (20/4)	20,000	362.4	F
8. Cresols	191-202	1.03-1.047 (25/4)	19,900-25,100	38	C
9. Benzene	80.1	0.879 (20/4)	730 @ 20°C	80 @ 20°C	E,F
10. Styrene	146	0.903 (20/4)	280 @ 160°C	526	NA

1 Specific gravity at 20°C or as otherwise noted in parenthesis. Where stated, numerator is temperature of substance, denominator temperature of water, both in °C.
2 Solubility at 25°C or as otherwise stated.
3 Vapor pressure at 20°C or as otherwise stated.
4 All listed substances are toxic to humans at some concentrations.
E = Explosive
F = Flammable (flashpoint of less than 25°C)
C = Combustible (flashpoint of 25°C or higher)
NA - not available

CORROSION

Corrosion is one of the major causes of deterioration and failure of metallic underground tanks and pipes. Corrosion can occur both internally and externally. Internal corrosion is largely due to incompatibility of the stored product with materials of construction. External corrosion is primarily an electrical process in which a flow of electricity from the metal surface to the surrounding ground (which acts as the electrolyte) is induced under favorable conditions. The flow carries material, at the atomic level, that results in the thinning of the underground structure and causes its eventual failure. Factors that influence external corrosion are: soil resistivity; type and concentration of salts in the soil; presence of certain types of bacteria; temperature; permeability of surface film; presence of adjacent underground metallic structures, and stray underground electrical current. Among them, soil resistivity is the most important factor and is a function of moisture content, soil salt concentration, and temperature; the higher the values, the lower the resistivity of soil and the higher the possibility of corrosion.

External corrosion can be prevented by providing cathodic protection that forces the electric current to flow toward, rather than away from, UST components, or by selecting materials of construction that inhibit electric flow altogether. A detailed description of the corrosion process and preventive methods is given in Appendix A.

MATERIALS OF CONSTRUCTION

Materials used in UST systems include various types of metals and polymeric materials. Structural strength and compatibility with products and soil environment are two key factors that determine the choice of materials.

Most universally accepted standards for materials of construction are those developed by the American Society for Testing Materials (ASTM). Many industries accept the ASTM requirements by adoption or adaptation into their own standards. However, the scope of these standards and specifications does not necessarily include exposure to all hazardous chemicals listed as regulated substances. Specifications and guidelines proposed by manufacturers of UST system components are the standard tool that is presently used for the selection of appropriate materials of construction.

Structural strength and deformation characteristics of most materials of construction are well known; but data related to their compatibility with various chemicals and environmental conditions are less known. Two excellent references that provide guidelines for the selection of compatible construction materials for the containment of various chemicals are: <u>Corrosion Data Survey (22)</u> prepared by the National Association of Corrosion Engineers (NACE), and <u>Perry's Chemical Engineering Handbook (20)</u>.

NACE has also published standards and manuals for the proper coating/lining protection of tank interiors (23-25). Table 3 summarizes the applicability of various lining materials for six products that are among those commonly stored in UST systems.

CODES AND STANDARDS

Design and engineering of UST system components are presently based on standards and recommended practices established predominantly by professional, trade, and industrial organizations. These standards and practices represent a consensus of design and engineering approaches used by various manufacturers and technologists participating in the standard-making process. The basic approach used in these documents is what is generally termed as "design-by-rule" in which the "rules" specify the minimum acceptable design parameters, e.g., wall thickness, materials of construction, and coating and lining requirements.

For the purpose of design classificaton, UST systems may be grouped into:

- Atmospheric systems that operate essentially at atmospheric pressure;
- Low pressure systems that operate at pressures up to 15 psig;
- High pressure systems that operate at pressures higher than 15 psig.

Many documents provide technical standards, guidelines, and recommended practices that apply to these systems. As a broad generalization, most of the documents that apply to atmospheric systems are developed by the API, AWWA, and UL. Most standards and design guidelines that apply to lower-pressure systems are prepared by the API and the ASME. The ASME Boiler and Pressure Vessel Code, by adoption, is a legally binding standard in most states and local jurisdictions in the U.S. for the design, construction and operation of high-pressure systems. The API and the NFPA also have developed some codes pertinent to higher-pressure systems. A complete listing of codes and standards from these various organizations are given in Table 4. Some of the more pertinent industrial standards, and recommended practices used for the design and engineering of UST systems are:

Standard UL-58, Steel Underground Tanks for Flammable and Combustible Liquids (7)--Outlines requirements for cylindrical and horizontal atmospheric-type steel tanks for the storage of underground flammable and combustible liquids. It provides for tank design configurations, metal thicknesses, and construction materials. The standard also addresses details of design and fabrication, including shell seams, heads, head joints, bracings for unflanged and flanged bulkheads, and compartment tanks containing single and double bulkheads; pipe connections; size of pipe vent fittings; and internal pressure leak testing requirements. The standard recommends that the length of the tank be no more than six times its diameter.

TABLE 3. APPLICABLE LINING MATERIALS FOR SIX PRODUCTS STORED IN USTs

Lining Material	Products 1	2	3	4	5	6
Chlorosulfonated Polyethylene				X	X	
Chlorinated Polyester	X	X	X	X	X	
Epoxy			X		X	
Epoxy Resin Cement	X			X	X	
Furfuryl Alcohol				X	X	
Furnace Resin Cement	X				X	
Neoprene			X		X	
Phenolics	X	X				X
Phenolic Resin Cement	X				X	
Polyethylene					X	X
Polyester Reinforced					X	
Polyester Resin Cement	X				X	
Polyvinyl Chloride			X	X	X	
Rubber	X	X		X		
Teflon			X	X		
Urethane	X	X	X		X	
Vinyl			X			
Vinylidene Chloride	X				X	

Adapted from (25)

Product List

1. Gasoline
2. MEK
3. Potassium Hydroxide
4. Sodium Hydroxide
5. Sulfuric Acid (50%)
6. Toluene

TABLE 4. MAJOR TECHNICAL CODES APPLICABLE TO STORAGE SYSTEMS

Code No.		Title	Applicable Tank Types
API			
Spec.	12B	Bolted tanks for storage of production liquids	A
Spec.	12D	Field welded tanks for storage of product liquids	A
Spec.	12F	Shop welded tanks for storage of production liquids	A
RP	12RI	Setting, connecting, maintenance, and operation of lease tanks	A
Std.	510	Pressure vessel inspection code	L,H
RP	520	Design and installation of pressure-relieving systems in refineries	H
RP	521	Pressure relief and depression systems	H
Std.	526	Flanged steel safety relief valves	L,H
Std.	620	Design and construction of large welded, low-pressure storage tanks	L
Std.	650	Welded steel tanks for oil storage	A
Publ.	1587	Waste oil round-up	A
Publ.	1604	Abandonment or removal of used underground service station tanks	A
Bull.	1615	Installation of underground petroleum storage systems	A
Publ.	1621	Bulk liquid stock control at retail outlets	A
Bull.	1623	Bulk liquid loss control in terminals and depots	A
Bull.	1628	Underground spill cleanup manual	A,L,H
Std.	2000	Venting atmospheric and low-pressure storage tanks	A,L
RP	2001	Fire protection in refineries	A,L,H
RP	2003	Protection against ignitions arising out of static, lightning, and stray currents	A,L,H
Publ.	2009	Safe practices in gas and electric cutting and welding in refineries, gasoline plants, cycling plants, and petrochemical plants	A,L,H
Publ.	2013	Cleaning mobile tanks in flammable or combustible liquid service	A
Publ.	2015	Cleaning petroleum storage tanks	A,L,H
Publ.	2015A	A Guide for controlling the lead hazard associated with tank cleaning and entry	A,L,H
Publ.	2023	Safe storage and handling of petroleum-derived asphalt products and crude oil residues	A

TABLE 4. MAJOR TECHNICAL CODES APPLICABLE TO STORAGE SYSTEMS (Cont'd)

Code No.	Title	Applicable Tank Types
API		
Bull. 2202	Dismantling and disposing of steel from tanks which have contained leaded gasoline	A
Publ. PSD-2207	Preparing tank bottoms for hot work	A,L,H
Std. 2510	Design and construction of LPG installations at marine terminals, natural gas plants, refineries, and tank farms	L,H
Bull. 2519	Use of internal floating covers and covered floating roofs to reduce evaporation loss	A
	Guide for Inspection of Refinery Equipment:	
	- Ch. II - Conditions causing deterioration or failures	A,L,H
	- Ch. III - General preliminary and preparatory work	A,L,H
	- Ch. IV - Inspection tools	A,L,H
	- Ch. V - Preparation of equipment for safe entry and work	A,L,H
	- Ch. VI - Pressure vessels	L,H
	- Ch. XI - Pipes, valves, and fittings	A,L,H
	- Ch. XII - Foundations, structures, and buildings	A,L,H
	- Ch. XIII - Atmospheric and low-pressure storage tanks	A,L
	- Ch. XIV - Electrical systems	A,L,H
	- Ch. XV - Instruments and control equipment	A,L,H
	- Ch. XVI - Pressure relieving device	A,L,H
	- Ch. XVII - Auxilliary and miscellaneous equipment	A,L,H
	- Appendix - Inspection of welding guide for follow-up inspection of interior tank coatings	A,L,H
NFPA		
11	Foam extinguishing systems	A,L,H
11A	High expansion foam systems	A,L,H
11B	Synthetic foam and combined agent systems	A,L,H
12	Carbon dioxide extinguishing systems	A,L,H

TABLE 4. MAJOR TECHNICAL CODES APPLICABLE TO STORAGE SYSTEMS (Cont'd)

Code No.	Title	Applicable Tank Types
NFPA		
12A	Halogenated fire extinguishing agent systems	A,L,H
16	Installation of foam-water sprinkler systems and foam-water spray systems	A,L,H
17	Dry chemical extinguishing systems	A,L,H
30	Code for flammable and combustible liquids	A,L,H
43A	Liquid and solid oxidizing materials	A,L,H
49	Hazardous chemical data	A,L,H
58	Storage and handling of LPG	L,H
59	Storage and handling of LPG at utility gas plants	L,H
68	Explosion venting	A,L,H
69	Explosion preventing systems	A,L,H
70	National electrical code	A,L,H
72A	Installation, maintenance, and use of local protective signaling systems	A,L,H
72B	Installation, maintenance, and use of auxiliary protective signaling systems	A,L,H
72C	Installation, maintenance, and use of remote protective signaling systems	A,L,H
72D	Installation, maintenance, and use of proprietary protective signaling systems	A,L,H
72E	Automatic fire detectors	A,L,H
77	Recommended practice on static electricity	A,L,H
78	Lightning protection code	A,L,H
231	General indoor storage	A
231A	General outdoor storage	A
321	Classification of flammable and combustible liquids	A,L,H
325H	Fire hazard properties of flammable liquids	A,L,H
327	Cleaning small tanks and containers	A,L,H
329	Underground leakage of flammable and combustible liquids	A,L,H
419H	Code for explosive materials	A,L,H
495	Identification of fire hazards of materials	A,L,H
1221	Installation, maintenance, and use of public fire service communications	A,L,H

TABLE 4. MAJOR TECHNICAL CODES APPLICABLE TO STORAGE SYSTEMS (Cont'd)

Code No.	Title	Applicable Tank Types
ASME		
	Boiler and Pressure Vessel Code:	L,H
Section II	- Materials specifications	
Section V	- Nondestructive examination	
Section VIII	- Pressure vessels	
Section X	- FRP pressure vessels	
AWWA		
D108-67	Standard for steel tanks, standpipes, reservoirs, and elevated tanks for water storage	A
D101-53	Standard for inspecting and repairing steel tanks, standpipes, reservoirs, and elevated tanks for water storage	A
D102-64	Standard for painting and repainting steel tanks, standpipes, reservoirs, and elevated tanks for water storage	A
ACI		
	Guide for Protection of Concrete Against Chemical Attack by Means of Coatings and Other Corrosion-Resistant Materials	A,L,H
	Manual of Concrete Practices	A,L,H
344	Design and construction of circular prestressed concrete structures	A,L,H
NACE		
RP-01-69	Control of external corrosion on underground or submerged metallic piping systems	A,L,H
No. 1	Surface preparation for tank linings	A,L,H
No. 2	Surface preparation for some tank linings and heavy maintenance	A,L,H
No. 3	Surface preparation for maintenance	A,L,H
No. 4	Surface preparation for very light maintenance	A,L,H
RP-03-72	Method for lining lease production tanks with coal tar epoxy	A,L,H

TABLE 4. MAJOR TECHNICAL CODES APPLICABLE TO STORAGE SYSTEMS (Cont'd)

Code No.	Title	Applicable Tank Types
SSPC		
5063	White metal blast	A,L,H
10-63	Near-white metal blast	A,L,H
6-63	Commercial blast	A,L,H
7-63	Brush off blast	A,L,H

LEGEND:

Organization:
- API = American Petroleum Institute
- NFPA = National Fire Protection Association
- ASME = American Society of Mechanical Engineers
- AWWA = American Water Works Associaton
- ACI = American Concrete Institute
- NACE = National Association of Corrosion Engineers
- SSPC = Steel Structure Painting Council

Code Number:

A numerical designation assigned to a code, etc., by the promulgating organization.
- Spec. = specification
- RP = recommended practice
- Std. = standard
- Publ. = publication
- Bull. = bulletin

Applicable Tank Types:
- A = Atmospheric
- L = Low Pressure
- H - High Pressure

Adapted from (21).

Standard UL-1316, Glass Fiber Reinforced Plastic Underground Tanks for Petroleum Products (12)--Covers requirements for spherical or horizontal cylindrical, atmospheric-type FRP tanks for the underground storage of petroleum-based flammable and combustible liquids; the requirements do not cover tanks storing alcohol or alcohol-blended fuels. The standard describes UST system design and construction, as well as performance testing for leaks, bending moment, and water load; strengths of lifting fittings; external and internal pressures; earth load; and physical properties of tank materials.

UL of Canada CAN4 S615M83, Standards for Reinforced Plastic Underground Tanks for Petroleum Products (21)--Covers the fabrication and installation of horizontal FRP tanks used for the underground storage of flammable and combustible liquids, such as highly aromatic premium grade gasoline and middle distillate fuels. The standard includes design details of connections, tank capacity, supplemental equipment, metal coatings, lifting lugs, manholes, and internal protection (impact pads under opening). It also covers requirements and tests for internal pressure, concentrated loads, flood loads, subsidence, drop strength, torque and bending strength of tank connections, leakage, immersion, and aging to determine deterioration due to the action of stored materials or surrounding soil conditions.

NACE Standard RP-01-69, Recommended Practice for Control of External Corrosion on Underground or Submerged Metallic Piping Systems (27), and RP-022-85, Recommended Practice for Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems (43)--Encompass criteria for the design, installation, operation, and maintenance of cathodic protection systems; control of interference currents; and corrosion control records. They also include a comprehensive index of coating references and testing standards.

API 1630, Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems (28)--Addresses the theory and practice of cathodic protection, advantages and disadvantages of the two cathodic protection systems, and criteria for determining whether impressed-current cathodic protection has achieved corrosion protection of underground petroleum storage tanks and distribution piping.

API 620, Recommended Rules for Design and Construction of Larger Welded, Low-Pressure Storage Tanks, Seventh Edition (29)--Covers the various aspects of structural design and construction of large, welded, low-pressure storage tanks used for the containment of petroleum products and other materials. Although this standard contains little information on corrosion, it establishes thickness allowances for corrosion.

Steel Tank Institute (STI) Specification for sti-P3 System for External Corrosion Protection of Underground Steel Storage Tanks (30)--Addresses external corrosion control of underground steel tanks, including sacrificial cathodic protection, protective coatings, and electrical isolation of tanks from other underground metallic structures.

ANSI Pressure Piping Code B31.1, Power Piping (31)--Considers allowable stresses in UST piping systems due to internal and external pressures, fluid expansion effects, dynamic effects (impact, wind, earthquake, vibration), weight effects (live, dead, test), thermal expansion and contraction loads, as well as the cyclic behavior of expansion stresses. Provisions are also made for protection against corrosion and erosion.

ANSI Pressure Piping Code B31.3, Chemical and Petroleum Refinery Piping (32)--Considers the loads on UST piping as well as dynamic effects from fluid discharge reaction; thermal loads caused by restraints; loading caused by temperature gradients and by differences in expansion characteristics; effects of support, anchor, and terminal movements; and effects of reduced ductility. It also specifies design criteria for nonmetallic piping.

ANSI Code B31.4 Code for Liquid Petroleum Transportation Piping (33)--Prescribes minimum requirements for design, materials, construction, assembly, inspection, and testing of piping that transports petroleum products. Piping components covered in this code include pipes, flanges, butting, gaskets, valves, relief devices, fittings, hangers, and supports. As this Code does not cover pipes designed for internal pressure less than 15 psig, use of this code for UST systems is limited.

ASME Boiler and Pressure Vessels Code, Section VIII, Divisions 1 and 2 (11)--Covers rules that are applicable for design and construction of pressure vessels and piping systems used for storage of chemicals. The code is usually invoked as a result of requirements specified by owners of the storage facility.

Other applicable standards include the following:

- NFPA-30, Flammable and Combustible Liquids Code (8)
- NFPA-329, Underground Leakage of Flammable and Combustible Liquids (34)
- National Association of Corrosion Engineers (NACE) Technical Practices Committee, TPC Publication 2, Coatings and Linings for Immersion Service (35)
- NACE Coatings and Linings Handbook, 1985 edition (36)
- American Society for Testing on Materials (ASTM) Specification D4021-81, Standard Specification for Glass-Fiber-Reinforced Polyester Underground Petroleum Storage Tanks (37)

STATE AND LOCAL REGULATIONS

States that have already established UST regulations are California (38), Connecticut (39), Florida (40), Maryland (41), and New York (42). Several other states and local governments, e.g., Maine, New Jersey, New

Hampshire, Rhode Island, Dade County, Florida, and Suffolk County, New York are in the process of finalizing similar standards. These regulations incorporate, and may adopt as a requirement, industrial standards and codes developed by trade and professional associations.

DISCUSSION

In the case of high-pressure systems, the ASME Boiler and Pressure Vessel Code is a legally applicable standard for the design of UST systems. However, for low-pressure and atmospheric systems, no such single document or professional group that prepares such documents exists. Instead, hundreds of standards, guidelines, and recommended practices, many having overlapping requirements prepared by several organizations, are presently followed for the design of UST systems. There is a need for a cohesive and definitive set of rules and standards that can be applied universally.

U.S. industries have a successful tradition of preparing and implementing voluntary standards that have improved in public safety and technology. The ASME Boiler and Pressure Vessels Code is a prime example of such a tradition. The success in preventing explosions in high pressure boiler systems as a result of the use of this Code is well documented (43).

Preparation of the ASME Code and other similar industrial voluntary standards in the U.S. are coordinated by one general umbrella organization, viz., the American National Standards Institute (ANSI). This national body provides an organizational framework that brings together various groups that may have an interest in the process, content, and implementation of a particular set of standards. For example, Figure 5 illustrates the various groups involved in the development and implementation of the Boiler and Pressure Vessel Code. The voluntary interaction and participation of groups such as these generally result in standards that are more comprehensive and complete, more acceptable to the user community, and readily enforceable by regulatory agencies. This successful organizational interaction is worthy of consideration to improve standards applicable to UST systems.

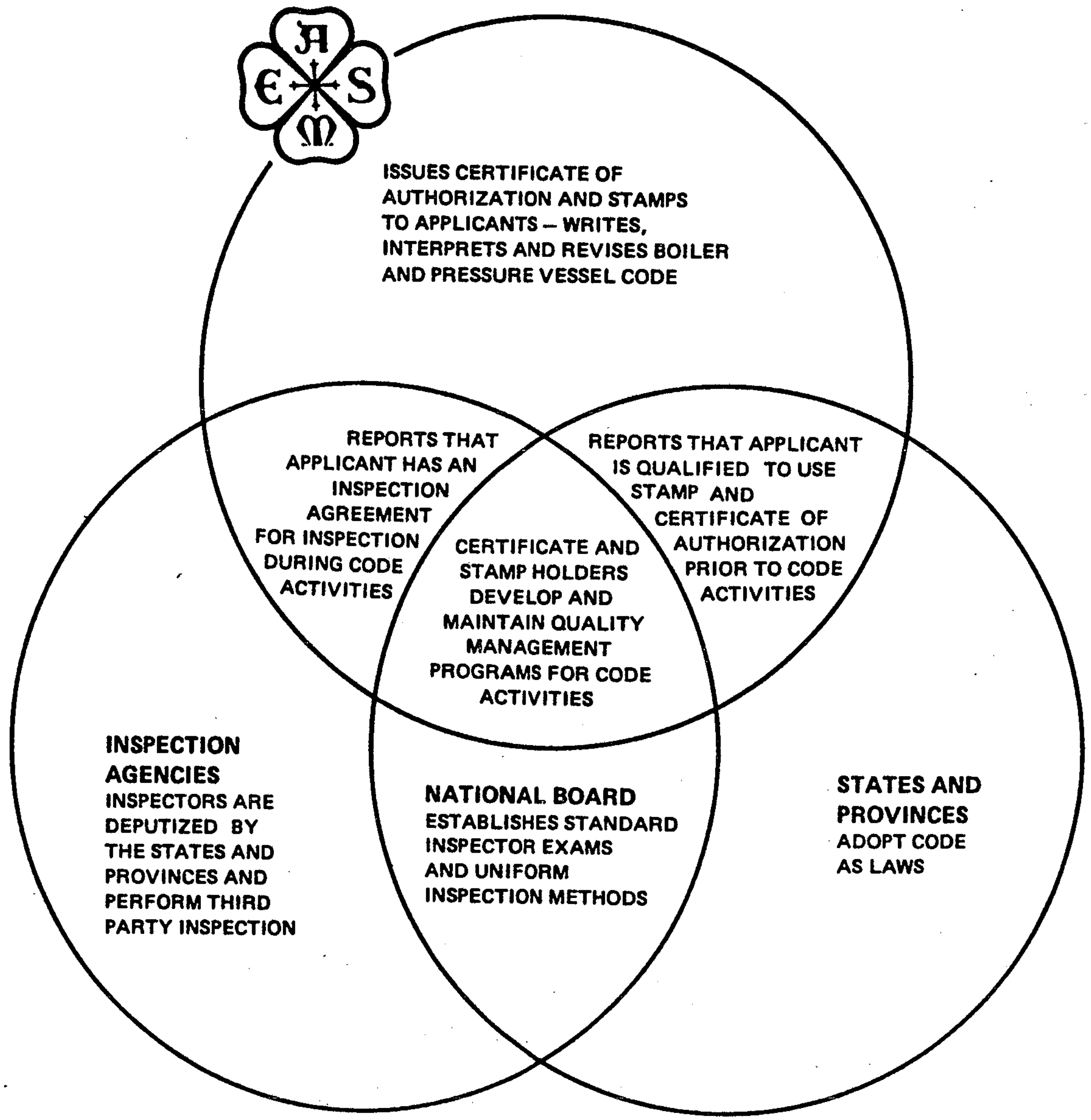


Figure 5. Interaction of various groups in code-making and enforcement. [Reprinted from (43). Used by permission of ASME.]

SECTION 6

INSTALLATION TECHNIQUES

Improper installation of UST systems is a common cause of leakage. Adherence to proper installation and testing procedures that are based on sound engineering principles can reduce such leakages. These procedures should include:

- Investigation of soil conditions and characteristics;
- Selection of materials of construction appropriate for design conditions;
- Selection of proper bedding and backfill material;
- Handling and care of equipment during construction;
- Tightness testing requirements;
- Supervision requirements.

Although state regulations vary, most of them require installation of secondary containers, overfill protection, leak monitoring wells, and alarm systems to signal the presence of leaks.

TANK INSTALLATION

Improper handling of storage tanks before installation and poor installation practices can damage the protective coatings of steel tanks, puncture fiberglass tanks, and result in poor foundations, inadequate anchoring, and improper tank levelling. Damage to coatings can accelerate corrosion. Failure to level a tank properly can create air pockets in the tanks, which leads to inaccurate inventory measurement and masking of leakage.

Chemical properties and electrical characteristics of backfill around an UST can affect the corrosion rates of steel tanks. The coarseness of pea gravel, one of the more commonly used backfills, can damage a coated tank during direct contact. Pea gravel can also permit water to collect, and hasten corrosion.

Most manufacturers (44-48) provide step-by-step procedures for tank installations which must be followed to validate the warranties.

Professional organizations such as the API, and the Petroleum Engineering Institute (PEI) recommend that an owner's best protection against UST system leakage is provided by (10,49):

- Strict compliance with applicable Federal and state regulations;

- Proper planning and design of the UST system;
- Appropriate choice of materials based on site-specific conditions;
- Capable and adequate supervision and inspection during installation;
- Strict adherence to design and installation requirements by installers and contractors;
- Appropriate tests at different stages of installation;
- Proper registration of the UST with the appropriate agency in the state.

Some typical provisions for clearance, depth of excavation, anchoring, backfill requirements, etc. by PEI, API, and New York State are summarized in Table 5. PEI further requires that tank excavations have adequate space for tanks, liners, monitoring wells, cathodic protection, anchoring and other equipment, and for placement and compaction of backfill materials. Definitions of adequate space and acceptable backfill materials differ for steel, FRP, and other tanks.

Most installation practices require that filter fabric be placed between the backfill and adjacent unstable soil, bogs, swamp areas, and landfills to prevent the backfill from migrating (49). FRP tank manufacturers also recommend the use of filter fabric in wet installations. If sand and pea gravel are used to backfill the tank excavation, they should also be separated with filter fabric.

Tanks should be ballasted with the intended product as soon as possible after backfilling (48) to prevent the tank from floating in a high groundwater table. Water ballast may be used as an alternative, but it must be removed before installation of submerged pumping units in the tank. Tanks should not be set directly on a concrete slab or placed on hard or sharp objects that could cause damage to either the tanks or tank coatings.

FRP tank manufacturers and major oil companies recommend two methods of anchoring: concrete anchor pads or prefabricated deadman anchors (46,47,50). Anchor straps should be installed so that the tank and coatings are not damaged. The tanks must be electrically isolated from the anchor straps by placing a section of rubber tire between the tank and anchor strap.

Pressure testing underground storage tanks is recommended at several times during the course of installation: when the tanks are delivered to the site; when they are placed in the excavation pit but before backfilling; and after the installation is completed (48,49).

Multiple tanks storing the same product should be connected through a siphon to permit product equalization in the tanks (48). Such

TABLE 5. RECOMMENDED UST INSTALLATION PRACTICES

	PEI	API 1615	New York State
Minimum horizontal tank clearance	24 in	12 in (steel tank) 18 in (FRP tank)	12 in
Minimum backfill depth	12 in	6 in (steel tanks) 12 in (FRP tanks)	12 in
Minimum backfill material, steel tanks	washed, freeflowing sand, gravel, sand slurry	compacted sand or gravel	compacted pea gravel
Minimum backfill material, FRP tanks	pea gravel, crushed rock, gravel, sand slurry	compacted sand or gravel	compacted pea gravel
Minimum cover depth untrafficked areas	12 in backfill + 12 in earth or 12 in backfill + 4 in reinforced concrete	24 in or 12 in + 4 in reinforced concrete	12 in compacted backfill + 4 in reinforced concrete
Minimum cover depth, trafficked areas	30 in compacted backfill + 6 in asphalt concrete or 18 in compacted backfill + 6 in reinforced concrete	36 in or 18 in compacted backfill + 6 in reinforced concrete or 8 in asphalt concrete	18 in compacted backfill + 6 in reinforced concrete or 18 in compacted backfill + 8 in asphalt concrete (steel tanks) and 30 in compacted backfill + 6 in asphalt concrete (FRP under 20,000 gal)
Maximum static head when fill or vent pipe is filled	10 psig	Not available	Not available

interconnected tanks should be of the same diameter and placed at the same depth in the ground. Siphon action at deliveries greater than 300 gal/min is too slow to maintain the same level in two or more tanks. To fill such interconnected tanks to near capacity, either the delivery rate must be slowed to provide time for liquid leveling, the delivery hose must be moved from one tank to the other, or, more conveniently, manifold fittings and withdrawal piping should be installed.

SECONDARY CONTAINMENT SYSTEM INSTALLATION

The installation of secondary containment systems is often a complex task that can only be performed by qualified contractors.

Flexible Membrane Liners

General guidelines for installation of flexible liners include (18,49,51):

- Installation should be done during dry, moderately warm weather;

- The excavation base and wall should be firm, smooth, and free of sharp rock or debris;

- Factory-trained personnel should perform the thermowelding or adhesive bonding that may be required. If bonding is to be done at the site, prior training of these personnel should include working under typical site conditions. Proof of personnel qualifications should be available at the site;

- A protective layer of puncture-resistant fabric may be required under the liner to prevent damage from paving, rocks, etc.;

- Liners should be pitched toward sumps; the pitch should be tested by pouring harmless test liquids at the high point of the system and measuring when these liquids reach the sumps.

Concrete Vaults

Concrete vaults are mandatory for the underground storage of gasoline and other fuels in some local jurisdictions, e.g., New York City. Concrete vaults must be designed and constructed to insure that joints do not leak or walls do not crack when exposed to a freeze-thaw weather cycle. Standards and codes established by professional associations such as the American Concrete Institute (ACI) should be followed in their design and construction.

Clay Liners and Soil Sealants

The installation of a clay liner involves a series of steps (2,51,52). The excavation should first be drained and stabilized. A bottom layer of clay must be laid and compacted using steel wheel rollers. The thickness of the layer depends upon the soil, its clay content, its density, and local regulations; the minimum acceptable thickness is 6 in (51).

Soil sealant can be made of soil cement or bentonites. Soil cement is a compound mixture of Portland cement, water and in-place soil. Some of the procedures to be followed are:

- The base and wall should be properly finished and well moistened before placing the mix;
- The mix should be plastic enough to consolidate well, but not loose enough to slip on side slopes;
- Liners must be properly cured;
- Bentonite sealants should be wetted to saturation and then compacted.

Double-Walled Tanks

Bed and backfill requirements and installation procedures for single-walled tanks apply to the installation of double-walled tanks as well. Special care should be taken in handling double-walled tanks. Depending on the construction material, weight, and size, double-walled tanks may require special transport and heavy-duty cranes for placement. Once installed, both their inner and outer walls should be tested for tightness.

PIPING AND ACCESSORIES INSTALLATION

Selection, installation, and testing of piping for underground tank systems must be based on appropriate standards and guidelines. Care must be taken to ensure that field attachments are made properly and are protected against corrosion. Such care includes cleaning and preparation of the surfaces to be connected, proper use of thermowelding or mechanical clamps, and application of effective corrosion protection to the bare metal surfaces before backfilling. The following are some recommended practices for the installation of piping systems for USTs storing petroleum products (48):

- Product lines should be run in a single trench between the tank area and the pump island area. Similarly, vent lines between the tank area and the building (or other structure to which the above-ground vent lines are attached) should be placed in a single trench;
- All underground pipe lines (both metallic and nonmetallic) should be laid on a bed of at least 6 in of well-compacted noncorrosive material, such as clean sand or gravel. Bedding and backfill should be of the same material;

- Pipe lines should not cross over underground tanks;
- Vent lines should have a uniform slope of not less than 1/8 in/ft toward the tank;
- Product lines should be at least 12 in below the finished surface;
- Pipe failures can be minimized by installation of swing joints where pipes connect with tanks, or at multiple pipe junctions. Since fiberglass piping is flexible, it does not require swing joints if there is at least 4 ft of straight run at pipe junctions where directional change exceeds 30 degrees;
- FRP pipes are normally joined with adhesive; all joint surfaces must be cleaned before adhesive is applied.

Galvanized steel piping can be used where size, complexity, and design characteristics preclude the use of fiberglass material (50). Fill pipes and other vertical risers under dispensers or vapor equipment are usually made of galvanized steel pipes with standard galvanized malleable iron fittings. Joints with steel piping should be made with an approved gasoline pipe compound or Teflon tape.

Steel tanks with cathodic protection require nonmetallic tank bushings in tank openings at all points of connection between product and vent piping to the tank, with separate protection provided for steel piping (48). When remote pumps are used, an insulated fitting should be installed in the electrical conduit at the pump. After piping has been tested, all exposed threads of galvanized pipes should be coated with a coal-tar product or tape film. This prevents the formation of an electrolytic cell between the galvanized fitting and the threaded area.

General guidelines for testing of piping systems before backfilling are as follows (48):

- The piping must first be isolated from the tanks, pumps, and dispensers. The piping should then be subjected to an air test of 1.5 times the working pressure, but not less than 50 psig. The pressure should be maintained for a minimum of 60 minutes;
- Leaks can be detected by applying soap suds to all joints while the piping is under pressure.

Shell Oil specification (50) recommends a low-pressure, 5 psig, leak test before the 50 psig test. It also specifies a 30 min hold time for the higher pressure.

Another major oil company specification calls for pipes to be tested before the trenches are backfilled. Piping lines are isolated from tanks, and then pressure-tested (50 psi) from the tank connection to the base of the pump/dispenser. Pressure should be maintained for at least 15 min.

All cathodic protection components should be inspected and tested. A negative voltage of at least 0.85 volt (as measured by a copper-copper sulfate reference half cell) is deemed to be adequate (49). During this test, anodes and reference cells must be backfilled with the same material used for tanks and piping and soaked in water to accelerate conductivity. Electrical continuity between the tank and associated piping should also be tested. No continuity should be detected, where dielectric bushings and unions are installed, indicating that they have been effectively isolated.

DISCUSSION

Since most state regulatory codes and new Federal acts regard the owner as having primary responsibility for UST system compliance, owners can take the following steps after installation to protect themselves from potential allegations of poor design, workmanship, and operational practices (80):

- Maintain a file of pre-operational test results at least for one year;
- Prepare and file "as-built" drawings or photographs of underground piping, monitoring, and other system components. The documents may be in the form of a "marked-up" set of installation drawings; photographs showing the location of piping, conduit, and other significant system components; or both;
- Maintain a record of installation instructions, test procedures, and preventive maintenance schedules, including tank charts indicating gallonage at various depths;
- Train personnel in the operation of the system, inventory control procedures, and operation of leak-detection and monitoring systems;
- Establish a program of preventive maintenance and periodic testing procedures.

Installation procedures and guidelines provided by various agencies and institutions address most steps that are necessary to prevent impairment of UST systems containing gasoline. If the procedures and guidelines are followed, leaks caused by improper installation would be reduced to a great extent. However, at present, there is no way to determine whether these procedures are understood or in fact followed in the field. Procedures that apply to storage systems for other products are also not readily available. Training and, if necessary, certification of installers, and development of installation procedure for a wider range of applications are needed.

SECTION 7

OPERATING PRACTICES AND GUIDELINES

Operating procedures and guidelines for UST systems that store gasoline have been developed by manufacturers and professional and trade organizations. These procedures are designed to prevent release of products during filling and transfer operations, and to enable prompt recognition of underground leaks that result from impairment of tanks, pipes, or accessories. The procedures include: overfill prevention, transfer spill prevention, vapor recovery, and leak detection and monitoring.

OVERFILL PREVENTION

An ideal overfill prevention system should include (2,53,54): a level-sensing device with an alarm to alert the operator of impending overfill, and an automatic product shutoff when the tank is full.

Level-Sensing Devices

Available level-sensing devices operate on the basis of one or more of the following principles:

- Buoyancy
- Hydrostatics
- Capacitance
- Thermal conductivity
- Optics
- Ultrasound

Detailed descriptions of these devices are available in product literature (55-65). Devices that operate on the principles of buoyancy, hydrostatics, capacitance, and thermal conductivity depend on fluid flow rates, pressure, and temperature. Those that operate by reflected light (optics) or sound waves (ultrasound) are generally not affected by fluid temperature and pressure variables. All these sensing devices can be equipped with an audible or visual high-level alarm. These devices are found to measure liquid levels with an accuracy wthin 1/16 in to 1/2 in.

Retrofitting existing USTs with level-sensing devices with high-level alarms would require considerable site excavation and retrofitting.

Automatic Shutoff

Automatic shutoff systems stop product delivery at a level that permits drainage of the transfer hose without overfilling the tank. Flow can be partially shut off by an inexpensive float vent valve installed in the tank vent line that severely restricts product flow when 95% of tank capacity is attained. A ball in the float vent valve closes the vent line when the tank is 95% full and blocks the venting of air and vapor. This blockage causes the flow rate to decrease from a typical 400-450 gal/min to 3-5 gal/min. The reduced flow rate allows the delivery operator to shut off the delivery, avoiding spillage. A completely automatic shutoff system is not commercially available in this country (91). However, such systems are claimed to be available in Europe. One primary reason for the wider use of these systems in Europe is believed to be the standardized designs of tanks and delivery trucks. The wide variability in tank and truck design make such systems less used in this country.

Regulations

Many states have regulations that call for overfill protection. For example, California regulations (38) require that all underground storage tanks be equipped with an overflow protection system that includes the following provisions:

- o A spill catchment basin that surrounds the fill pipe and prevents the inflow of regulated substances into the subsurface;
- o A level-sensing device that continuously monitors and indicates the liquid level in the UST;
- o An audible or visual alarm system triggered by a liquid-level sensor to alert the operator of an impending overfill condition;
- o An automatic shutoff device that stops the flow of delivered product when a UST is full.

New York regulations (42) require product delivery operators to determine if a tank has the capacity to receive additional petroleum. Florida requires overfill protection in the form of an impervious manhole that acts as a containment in case of overfill (40). Maryland relies on strict operating procedures to prevent overfill (41).

TRANSFER SPILL PREVENTION

Proper operating practices that should be followed to prevent transfer spills are well documented (34). These practices require:

- o Tight connections between the hose and fill pipe;
- o Periodic inspection of all transfer hoses;
- o Inspection of tank ullage before product delivery to ensure sufficient capacity;
- o Proper identification of stored products and container capacities;
- o Proper training of all operators who perform loading or unloading operations.

VAPOR RECOVERY SYSTEMS

Gasoline vapors and volatile organic compound (VOC) emissions from UST systems may violate ambient air quality standards. These releases occur during UST filling and vehicle refueling. Vapors are also emitted from truck tanks as gasoline displaces the gasoline-enriched air in the tank. These vapors can be controlled by venting through charcoal filters in the truck tank itself or back into the UST.

Two types of vapor recovery systems exist: Stage I vapor recovery and Stage II vapor recovery. In a Stage I vapor recovery system at a gasoline station, shown in Figure 6, vapors are vented to the top of the tank truck during product transfer either from individual vent lines connected to each tank, or from a single vent outlet valve in an interconnected tank system. In Stage II vapor recovery systems, vapors from the gas dispensing outlet nozzles are diverted back into tanks through vapor return pipe lines. A Stage II recovery system is used where product mixture cannot be tolerated.

LEAK DETECTION

Leak detection is an integral part of the regulatory requirements for prevention of leaks. Methods and strategies for leak detection include: inventory control, in-tank continuous leak monitoring, nonvolumetric methods, leak effects monitoring, and tank integrity testing. Several states and local jurisdictions have come up with specific requirements for leak detection.

Inventory Control

Advocates of inventory control claim that it is the simplest and most economical method for detecting leaks. It is generally believed, however, that the technique has not worked well because recommended procedures are not always followed by practitioners.

An inventory accounting system that contains the following provisions is believed to be very effective (66):

- A record of all sales and quantity of product otherwised dispensed;

- Daily reconciliation between sales, use, receipts, and inventory on hand.

The inventory accounting system also includes procedures to be followed when products are received:

- Gauging all tanks and checking them for water before and after delivery;

- Reinstalling all fill and gauge caps;

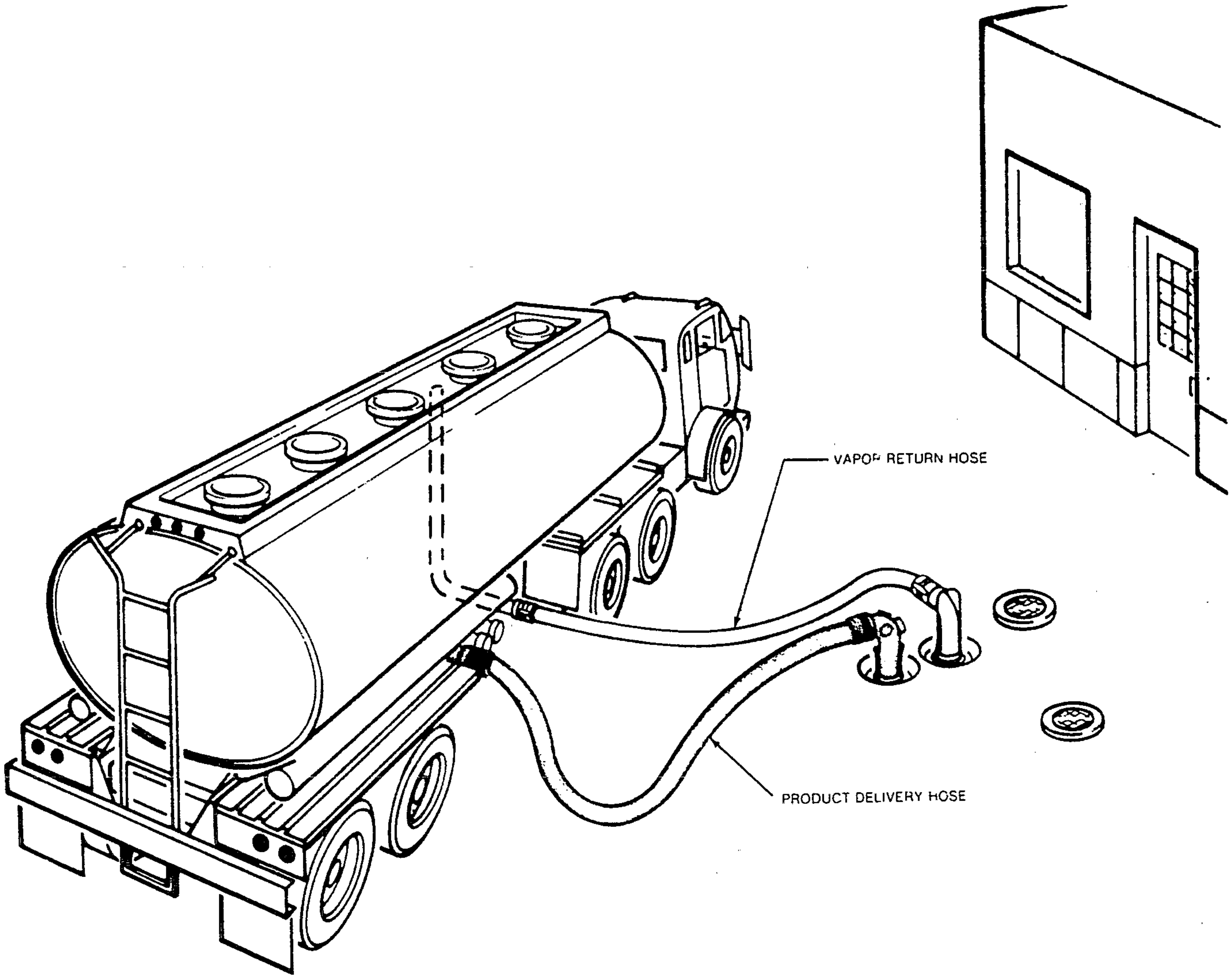


Figure 6. Stage I vapor recovery. (Reprinted from OPW-Dover Corporation. Catalog SVR, February 1984. Used by permission of OPW-Dover Corporation.)

- Calculating the amount of product received with proper accounting for water level in the tank and comparing this with the amount shown on the invoice.

Many of the manual procedures described above are unnecessary if an in-tank automatic inventory system is used. These systems continuously monitor the contents of tanks, record all deliveries, compare them with metered deliveries, alert operators to product loss or leakage, and shut off flow if the tank becomes too full.

Employees must be trained to look for evidence of leaks from both the inventory control records and abnormal operation of pumping equipment. Some of the more obvious signs of leaks are:

- Product level change in a tank during periods when product is not dispensed. While this usually indicates a leaking tank, it might also indicate unaccounted withdrawal, theft, or extreme temperature change;
- An increase of water in the tank. Leakage of water into an impaired tank is possible if surrounding ground is saturated. However, an increase in water may also be due to a leaking gauge or fill cap; both should be examined and, if necessary, made watertight before concluding that the tank is leaking;
- Increasing differences between the amount of product received and dispensed. These may also indicate a meter calibration problem, or theft;
- Large differences appearing consistently between amounts invoiced and the tank gauges after deliveries. These may indicate a leak in the remote fill line, which should be tested;
- A hesitation in delivery from a standard dispensing pump. This may indicate a leak in the suction piping or foot valve, or, in warm weather, vapor lock. Inventory control records may indicate whether the cause is mechanical or whether product is actually being lost;
- Meter spin without product delivery in a remote pumping system. This may indicate a pipe leak;
- Gasoline odor in underground spaces adjacent to the station, which may indicate leaks in either the tank or piping.

In-tank Continuous Leak Detection

Volumetric leak detection methods are the most vigorously pursued in-tank continuous leak detection technologies by the UST industry. A leak is quantified by measuring the changes in product level in the tank. Each product level is then converted, with a knowledge of the containment geometry, to a corresponding liquid volume. The changes in volume are then analyzed by various algorithms, and a determination of leak rate is made. Currently, some 15 leak detection devices are available in the market that claim to have the accuracy and precision that would be acceptable to state and federal regulatory agencies. However, these performance claims have not been fully validated, and these devices have not yet been universally applied by the UST community. A test program initiated by the EPA in Edison, New Jersey, is presently underway to establish the performance characteristics of these and other volumetric leak detection devices (67).

Nonvolumetric Leak Detection Method

Nonvolumetric methods measure changes in a variable other than tank product level. The most common approach is to monitor the presence of a tracer gas (e.g., helium) or an acoustic signal in the tank. Changes in these signal variables are evaluated, and after appropriate analysis, a declaration of the tank integrity is made. Determination of a specific leak rate based upon nonvolumetric observations, however, is difficult, since a quantitative correlation between the measured variable and the size of a leak is difficult to establish. Other deficiencies of the method are:

- Potential for product contamination if tracer gas is not inert;
- Enhancement of small leaks and risk of explosion if tank has to be pressurized;
- Long testing time.

Nonvolumetric methods can be used to detect leaks in double-walled tanks and pipes by applying the method to both the interior of tanks and pipes and the interstitial space between the double walls.

Detailed descriptions of available nonvolumetric leak detection methods are given in (68).

Leak Effects Monitoring

Leak effects monitoring determines the presence of leaks by examining the surrounding tank environment for evidence of product. Numerous methods based on various types of instrumentation are available for performing leak tests. These methods, while determining the presence of a leak, do not provide a quantitative estimate of the leak rate. This limitation is similar to that encountered with nonvolumetric methods.

State Regulations

In compliance with federal mandates, many states have introduced leak detection requirements in their UST regulations. A summary of such requirements in California, Connecticut, and Florida, are given in Tables 6-8 (69). For example, the state of California allows local agencies to

TABLE 6. ACCEPTABLE LEAK DETECTION REQUIREMENTS AND ALTERNATIVES FOR EXISTING TANKS UNDER CALIFORNIA REGULATIONS

	Required Tests and Their Schedules					
Acceptable alternative	Tank integrity testing	Vadoze zone monitoring	Ground-water monitoring	Soils sampling	Inventory reconciliation using automatic metering devices	Pipeline leak devices
1	Monthly	-------	-------	--------	---------	--------
2	------	Daily or continuous	Semi-annually	One-time	---------	--------
3	Annually	Daily	-------	One-time	---------	--------
4	------	-------	Weekly	One-time	---------	--------
5	Annually	-------	-------	--------	Daily	Continuous

TABLE 7. REQUIRED TANK INTEGRITY* TESTING SCHEDULE IN CONNECTICUT

Material of construction	Required tank integrity testing: 3 to 6 months after installation	21 to 24 months after installation	12 to 9 months prior to end of life expectancy**
FRP	Yes	Yes	Yes
Cathodically protected steel	No	Yes	Yes

*Alternative methods and schedules for leak detection at existing tanks may be used only with prior written approval of the commissioner.

**Life Expectancy is determined by the warranty time provided by the tank supplier.

TABLE 8. FLORIDA LEAK DETECTION REQUIREMENTS FOR EXISTING TANKS

Year tank installed	Year visual/odor* monitoring wells must be installed
Prior to 1970	1986
1970 to 1975	1987
1976 to 1980	1988
1981 to Sept. 1, 1984	1989

*Florida requires groundwater monitoring wells but does not normally require laboratory analysis of samples.

adopt and impose any one of the eight monitoring alternatives, five of which are shown in Table 6, for detection of leaks in existing tanks. The requirements of the three remaining alternatives are similar to alternative number 5 listed in the table. Several other states also have introduced leak detection requirements, generally less elaborate than those in California, in their UST system regulations. Tables 7 and 8 list the requirements in Connecticut and Florida, respectively.

DISCUSSION

Efforts to improve operating practices should focus upon three areas: methods, equipment, and people. The methods that are currently in vogue for overfill and transfer spill prevention, leak detection, and monitoring, etc. are largely developed by manufacturers of equipment and by industry organizations. Adequacy of these methods has not been fully evaluated and established. For example, in the inventory control method, which is widely used by gasoline station owners for potential leak detection, compensation for product temperature variation and product evaporation, accuracy and resolution of dip-stick measurements and dispenser meters, etc., are not accurate enough to indicate leaks until an appreciable fraction of the stored volume has leaked out. Similarly, in nonvolumetric leak detection methods, there are presently no procedures that can be used to correlate leak indicator readings to leak rate. Methodologies to enhance the utility of these methods are needed.

In the area of equipment, two deficiencies are noted. First is the need to standardize UST system accessories and delivery and transfer equipment. The second area is the improvement of volumetric leak detection devices. Performance characteristics of available leak detection devices must be known. In addition, leak detection devices for large-volume tanks and for tanks that store chemicals other than gasoline need to be developed.

Operator training is the third area that requires attention. It has been noted (3), that nearly 50 percent of almost 2500 reported leaks from various states resulted from structural failures caused by vehicle impact, ruptures caused by excessive pressure during tank tightness tests, ruptures due to improper excavation, etc. These failures could be reduced by training operators. An ideal training program should include:

- indoctrination on the hazards of underground leaks;
- lessons on the proper use of tools and equipment;
- lessons on trouble-shooting and problem resolution;
- basic principles of safety and emergency procedures.

Training programs should include periodic refresher courses and training updates.

SECTION 8

CORRECTIVE ACTIONS

Corrective actions are taken to prevent or inhibit UST system failure processes, to revamp and restore those UST components that can be repaired, and to properly dispose of components and systems that are irreparably damaged or that are targeted to be taken out of service. Inspection, maintenance, and repair retrofitting, and closure comprise corrective actions.

INSPECTION

Proper inspection of tanks and other UST system components is carried out before, during, and after the system is installed and operated. The purpose is to ascertain the structural defects of the UST system components, either existing or impending, and to suggest possible remedies to correct the defects. Inspection of tanks and components that are already in place, however, is difficult, if not impossible, unless provisions have been made for inspection ports, manways, and other means of access.

A quality inspection program should include methods for identifying excessive corrosion, erosion of interior parts due to abrasion by particles suspended in moving fluids, structural fatigue or cracking, deterioration of liners and accessories, and weakened or cracked welds and joints (70). To ensure quality of the inspection program, formal checklists should be prepared and used, and records of inspection maintained. Frequency of inspection is usually recommended by the manufacturers.

Structural Integrity Test Methods

Methods to test the structural integrity of tanks and other UST components include (21,71):

- Radiographic inspection;
- Ultrasonic inspection;
- Magnetic particle inspection;
- Liquid (dye) penetrant inspection;
- Hydrostatic tests;
- Eddy current inspection;
- High voltage spark method.

These methods have been used, in varying degrees of success, in other industries, e.g., boiler and pressure vessels industry. The types of defects measured, applications, advantages, and limitations of these methods are summarized in Table 9. A brief description of these methods follow.

Radiographic Inspection

Radiography is used to detect surface cracks, internal cracks, voids, and defects in weldments. The technique is based on the differential absorption of radiation--either shortwave electromagnetic radiation or particulate radiation--directed toward the part that is inspected. Variations in density, differences in thickness, internal flaws, inclusions, defects, etc. that may be present in the part result in the absorbance of different amounts of radiation. The unabsorbed radiation passing through the part is recorded on a sheet or film or is viewed on a fluorescent screen. After development, the film presents a two-dimensional "shadow picture" of the object, which is analyzed to determine the location, size and shape of flaws. X-rays and gamma rays are widely used in radiography. Neutron radiography uses a stream of neutrons rather than electromagnetic radiation, but the result is the same (72).

Ultrasonic Inspection

Ultrasonic inspection uses high-frequency sound waves to detect flaws. The sound waves travel through the material and experience a loss of energy (attenuation) depending upon the internal structure of the part. The reflected beam is analyzed to determine the location and size of flaws.

Magnetic Particle Inspection

Magnetic particle inspection is used to locate surface and subsurface flaws in ferromagnetic materials. When a tank is magnetized, magnetic discontinuities perpendicular to the magnetic field form a leakage field at and above its surface. This field is detected by applying finely divided ferromagnetic particles over the tank surface. These particles are magnetically held by the leakage field to provide an indication of the location, size, and shape of the flaws.

Liquid (Dye) Penetrant Inspection

Surface cracks can be detected by applying liquid penetrants, which seep into any opening by capillary action, to the surface. The process is well suited for detecting all types of surface cracks, porosity, shrinkage, laminations, and other similar discontinuities. It is used extensively to inspect wrought and cast products made of both ferrous and nonferrous metals, powder metallurgy parts, ceramics, plastics, and glass.

Hydrostatic Tests

Hydrostatic tests are performed by pressurizing the tank or piping to a pressure higher than the design pressure. While under pressure, the

Table 9. Structural Integrity Test Methods

Method	Measures or Detects	Applications	Advantages	Limitations
Radiography	Internal defects and variations; porosity; inclusions; cracks; lack of fusion; geometry variations; corrosion thinning; density variations thickness, gap and position; misassembly; misalignment	Castings; electrical assemblies; weldments; small, thin, complex wrought products; nonmetallics; composites	Permanent film records; high sensitivity to density changes; geometry variations do not affect direction of X-ray beam	High initial costs; orientations of linear defects in part may not be favorable; radiation hazard; Depth of defect not indicated; sensitivity decreases with increase in scattered radiation
Ultrasonic	Internal defects and variations; cracks, lack of fusion, porosity, inclusions, delaminations, lack of bond, texturing; thickness	Wrought metals; welds; brazed joints; adhesive-bonded joints; nonmetallics	Most sensitive to cracks; test results known immediately; automating and permanent record capability; portable; high penetration capability	Small, thin, complex parts may be difficult to check; reference standards required; trained operators for manual inspection requried; special probes required
Magnetic particle	Surface and slightly subsurface defects; cracks, seams, porosity, inclusions; permeability variations; extremely sensitive for locating small tight cracks	Ferromagnetic materials; bar, forgings, weldments, extrusions, etc.	Advantage over penetrant is that it indicates subsurface defects, particularly inclusions; relatively fast and low cost; may be portable	alignment of magnetic field is critical; demagnetization of parts required after tests; parts must be cleaned before and after inspection; masking by surface coatings
Liquid dye penetrants	Defects open to surface of parts; (cracks, porosity, seams, laps, etc.); through-wall leaks	All parts wth nonabsorbing surfaces forgings, weldments, castings, etc.	Low cost; portable; indications may be further examined visually; results easily interpreted	Surface films, such as coatings, scale, and smeared metal may prevent detection of defects; parts must be cleaned before and after inspection; defect must be open to surface; bleed-out from porous surfaces can mask indications of defects
Hydrostatic Tests	Through-wall leaks; cracked walls and joints; lose fittings; overall structural integrity	Pressure boundaries of tanks, pipes, and valve casings	Provides an overall integrity of the containment system	Requires special safety provisions; applied pressure may weaken containment boundaries by accentuating dormant defects or cracks; requires special equipment and trained staff
Eddy current	Surface and subsurface cracks and seams; alloy content; heat treatment variations; wall thickness, coating thickness; crack depth; conductivity; Permeability	Tubing; "Spot checks" on all types of surfaces; proximity gage; metal detector; metal sorting; measure conductivity	No special operator skills required; high speed, low cost automation possible for symmetrical parts; permanent record capability for symmetrical parts; no couplant or probe contact required	applicable only for conductive materials; shallow depth of penetration (can apply for thin walls only); masked or false indications caused by sensitivity to variations such as geometrical discontinuity; reference standards required
High voltage spark method	Integrity of coatings or linings	Detects holidays in coatings of thickness 15 mils	Portable; easy to operate	Possible damage if dielectric strength exceeded

tank is inspected for leaks. A decrease in pressure indicates that the tank may be leaking.

Eddy Current Inspection

Eddy currents are electrical currents induced within a conductor when it moves through a nonuniform magnetic field. A test coil carrying electrical current placed around the specimen creates the magnetic field. Structural defects or variations within this specimen creates a nonuniform magnetic field, and a corresponding eddy current is measured.

Eddy current inspection can be used to detect cracks, voids, and inclusions. It can also be used to measure the thickness of a nonconductive coating on a conductive metal, or the thickness of a nonmagnetic metal coating on a magnetic metal.

High Voltage Spark Method

This method, also known as a holiday-detection method, is used to test the integrity of coatings and linings. The method is based on a voltage applied to the coating. The electrical resistance will be different wherever a discontinuity (or "holiday") exists. The high-voltage (spark) holiday detector is used for coatings with a thickness of 15 mils or more. The low-voltage holiday detector is used for coatings with a thickness of 20 mils or less.

Life Prediction

Inspection of underground tanks and other UST components by visual, sonar, or other nondestructive examination, is not always possible because of the practical and technical limitations of such methods; nor do such methods always give a reliable assessment of the physical state and integrity of underground tanks and other components. Predictive methods based on theoretical or empirical models, therefore, become a useful tool in leak prevention strategies. Such models can be used to complement and supplement information gathered from physical inspections. Two predictive models that have been proposed and used by the Petroleum Association for Conservation of the Canadian Environment (PACE) are: the Soil Aggressiveness Value (SAV) method (73) and Roger's Regression Analysis (74).

Soil Aggressiveness Value (SAV) Method--

The SAV method is based on the premise that the age at which an underground storage tank fails (leaks) is directly related to the soil condition it is exposed to. The soil condition is assigned a numerical value, viz., soil aggressiveness value (SAV). SAV is an aggregate number determined on the basis of the points assigned to the following soil properties at the site:

- o Average values of soil resistivity, soil pH and soil moisture;
- o Differential values, i.e., the ranges of resistivity and pH;

o Presence of sulfides (which promote bacterial action on the surface of the tank).

Table 10 gives the points assigned to each of the above properties.

A relationship between SAV for the soil at a particular site and the probable tank age at failure was established by PACE using actual age-at-failure data and corresponding soil SAV data. This relationship, illustrated in Figure 7, can be used as a decision tool for tank testing, replacement, or retrofitting with additional protection. The use of this graph is explained below.

Suppose an existing tank 25 years old is at a site with SAV = 10. This ordered pair of SAV and age falls in region 1 of Figure 7, marked by the boundary curve D. The most prudent decision is to immediately replace the tank, because the actual tank failure data showed that 60 percent of tanks that failed had an SAV/Age combination falling in region 1. If the ordered pair of SAV and age of another tank falls in region 2, the decision would be to replace or retrofit the tank with additional protection based upon tests and inspection of the tank. The curve S that marks the lower boundary of region 2 is drawn such that an assertion can be made with a 95 percent confidence that failure data point for any tank, most likely, will fall in regions 1 and 2 combined. Region 3 represents a condition in which a tank is likely to fail at an age less than what is normally considered an average useful life, viz., 17 years. Economics dictate that additional tank protection should be provided to reduce the failure probability and increase tank life to 17 years or more as desired by the tank owner. Finally, region 4 represents a benign region where the tank life is likely to be more than 17 years and thus no corrective action is warranted. Based on the actual failure data, PACE (73) defined the regions 1, 2, 3, and 4 as follows:

Region	Recommended Action
1. $I \geq 180$	Replace tank
2. $69 \leq I < 180$	Test, and replace or retrofit
3. $I < 69$ and $SAV \geq 4$	Retrofit
4. $I < 69$ and $SAV < 4$	Benign, no corrective action warranted

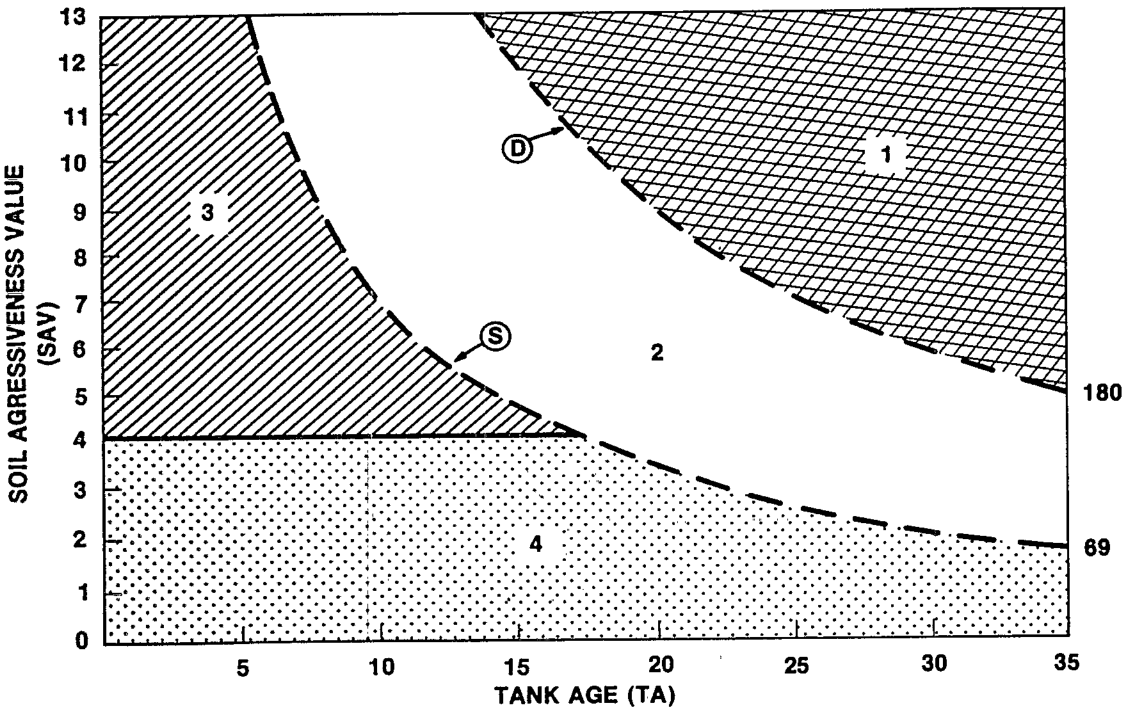
where I = SAV x Age

The SAV method described above is conceptually attractive and has some similarity to the well-established fatigue life prediction method used by the manufacturing industry for design against fatigue failures. In the fatigue design, the number of cycles to failure--a measure of the "age"--is plotted against applied stress (Figure 8). A test data line is drawn, line A in the figure, that gives the best fit of the data. (Note that line A is the one-to-one equivalent to curve S in the SAV/Age graph.) A factor of safety of 20 on number cycles and 2 on applied stress is used to obtain line B which is used for safe fatigue design.

TABLE 10. BASIS FOR THE EVALUATION OF UNDERGROUND ENVIRONMENTS (SAV SYSTEMS)

I. BASIC CHARACTERISTICS		POINTS
Soil Resistivity	less than 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
	greater than 25,000	0
Soil pH	less than 3	8
	3 - 5	6
	5 - 6.5	4
	6.5 - 7.5	2
	7.5 - 9	1
	greater than 9	0
Soil Moisture		
	Saturated	3
	Damp	2
	Dry	0
II. DIFFERENTIAL CHARACTERISTICS		
Resistivity (ratio of extremes)	greater than 1:10	3
	greater than 1: 5	2
	greater than 1: 3	1
	less than 1: 3	0
Soil pH (difference in pH value)	3	2
	1.5 - 3	1
	0 - 1.5	0
III. SULFIDES		
	Positive	4
	Negative	0

Based on (41).



Region 1 Replace
2 Test, and replace or retrofit
3 Retrofit
4 Benign, no corrective action warranted

Figure 7. Tank evaluation graph. (Adapted from (73).)

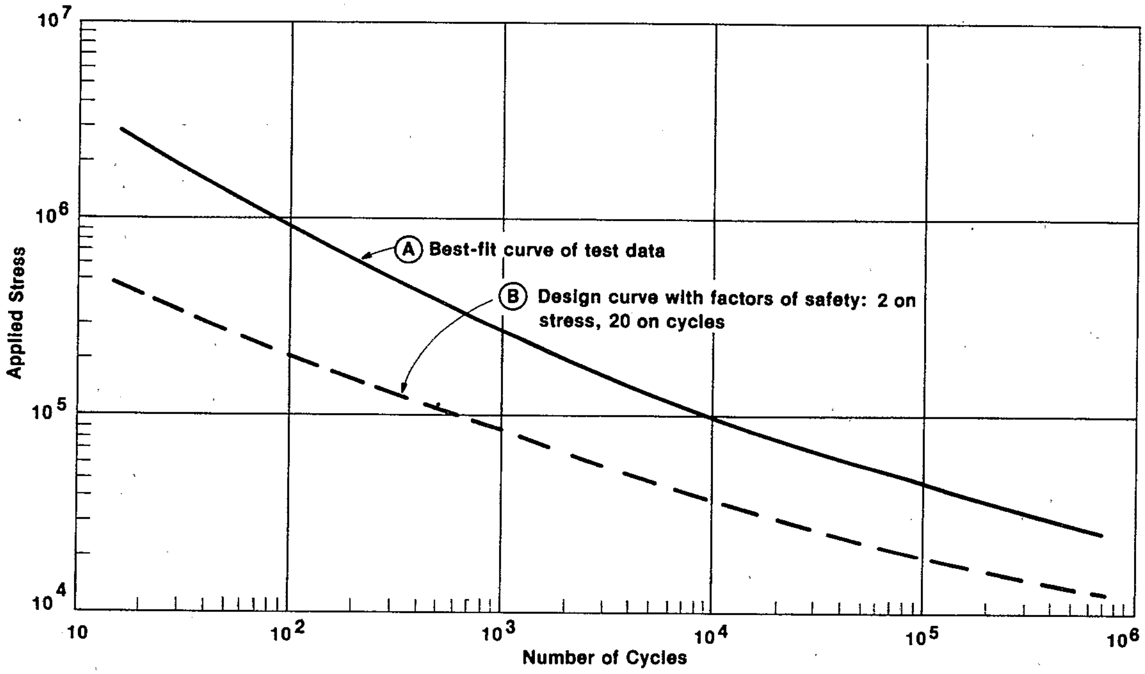


Figure 8. Construction of design fatigue curve.

The SAV method proposed by PACE differs from that described above for fatigue design in one fundamental way. The SAV method allows the UST system to continue to operate, albeit with tests and additional protection, above the most probable failure curve S (in region 2), whereas the time-honored approach for design against fatigue imposes a factor of safety that brings the design stress and applied number of cycles far below the failure regime, i.e., below curve B. This fundamental difference in the approach used for the SAV method needs to be evaluated before it can be recommended for use in UST system design.

Roger's Regression Analysis--

As the name suggests, this is an empirical method based on statistical analysis of the age-to-leak data correlated to measureable characteristics of the tank environment (74). The correlation equation for mean age-to-leak is given by

$$L = 5.75\, R^{.05}\ T^{-.017}\ \exp\,(.12^{P} - .42\, M - .26S)$$

where L = mean-age-to-leak, years
R = soil resistivity, ohm-cm
T = tank size, Imperial gallons
P = soil pH
M = a factor related to moisture content in the soil; 1 = saturated, 0.5 = damp, and 0 = dry
S = a factor related to sulfides content in the soil; 1 = strongly present, 0.5 = trace, and 0 = no sulfides

It is claimed that approximately 75 percent of the total variability in the dependent variable L is explained, with a high degree of statistical significance, by the full set of independent variables included in the model. Roger's equation, exercised with four sets of values for independent variables, results in a mean age-to-leak range of 13.5-16 years, with an average of 14.9 years. This is certainly close to reported mean ages-to-leak of 17-19 years.

Some limitations of the method, however, should be noted. Regression equations, by their very mathematical construction can only be used to explain the data within the range of the independent variables that have been considered, and not outside of their range. Thus, caution should be exercised in the use of the method. A second issue is that the method does not allow the changes in the values of the independent variables that are likely to occur during the life of the UST system, e.g., changes in soil resistivity and moisture content, during the life of the tank system. The third consideration is that the method assumes that tank failure occurs only as a consequence of the external soil properties without any influence of internal conditions.

Even with the limitations noted above, life prediction methods are useful tools to establish test, maintenance, and repair schedules and programs. However, additional work is required to improve the accuracy and range of applicability of such methods. The UST system failure data base must be improved, both in its content and sample size, to develop better statistical models that incorporate a wider range of factors that contribute to failures.

MAINTENANCE AND REPAIR

Maintenance and repair are routine tasks required to keep an UST system in working order. Equipment manufacturers usually recommend maintenance tasks and their required frequencies. Maintenance helps increase mean time between failures and the operating life of UST components and systems.

Repairs must be carried out once impairment of tanks or other components of UST systems are detected. Generally, repairs can be carried out only by qualified professionals responsible for maintaining the equipment.

There are presently no standard maintenance or repair practices or programs available that tank owners can follow and implement. However, many states are now introducing regulations that mandate proper inspection and maintenance repair programs. Implementation of such state requirements would require a pool of qualified and trained inspectors, testers, and maintenance personnel. Personnel must be trained to recognize impending failures and failure warnings, and to respond with appropriate corrective actions. Input from designers, manufacturers, installers, and suppliers is required to develop training manuals with procedures and practices that can be easily implemented by the owners and operators of UST systems.

The need for certification or licensing of inspectors, testers, and maintenance personnel must also be evaluated. The issues to be resolved are:

1. What is an acceptable level of competancy required for these tasks?

2. Is certification or licensing necessarily the most effective way to impart this competency and to develop a competent labor pool?

3. Should the certifcation or licensing, if determined to be valid, be at the national, state, or local level?

4. What are the organizational, economic, and institutional issues that must be resolved for a certification or licensing program to work effectively?

RETROFITTING

Retrofitting extends the useful life of an existing UST system. The decision to retrofit depends upon the nature and degree of the system or component impairment, physical condition of the site and its surroundings, and the anticipated performance improvements that result from retrofitting. Two retrofitting ideas that merit consideration are tank relining, and retrofitting unprotected steel tanks and piping systems with cathodic protection.

Relining of Tanks

The relining of the interior of a tank is an acceptable retrofitting method provided: (1) the tank has never before been so restored; and (2) the metal thickness of the tank is adequate to ensure the structural integrity of the tank. The steps involved in relining include opening the tanks, preparing and inspecting the tank interior, selecting a lining material, applying the lining, pretesting before closing, and tank closing and final tightness testing (75).

Opening of Tanks

Appropriate safety procedures, including tank isolation, product removal, removal of flammable vapors (gas freeing), and testing of flammable vapor concentrations, should be implemented before opening and entering a tank. If there is no manhole in the tank, an opening with minimum dimensions of 18 in x 18 in should be cut through the top of the tank. Cutting through welded seams should be avoided.

Preparation of Tank Interior

The sludge accumulations on the bottom of the tank must be removed and the interior surface of the tank prepared for inspection. If the wall is badly deteriorated, the tank cannot be lined and returned to service. The following defects are considered as limiting conditions:

- An open seam or split longer than 3 in;
- A perforation larger than 1-1/2 in, or a perforation larger than 2-1/2 in below an opening;
- Five or more perforations, none larger than 1/2 in in any 1 ft^2 area;
- 20 or more perforations none larger than 1/2 in in a 500 ft^2 area.
- A crack or fissure within 6 in of any seam weld.

To enable visual inspection of the defects, the interior surface is abrasively cleaned to render it free of scale, rust, or foreign matter. Perforations and seams are hammered with a brass ballpeen to obtain structurally sound edges.

The tank surface must be cleaned of all dirt, grease, moisture, scale, rust, and foreign matter. Abrasive blasting should be performed as per SSPC specifications for white metal blast cleaning. The State of New York recommends sandblasting to SSPC-SP6 commercial blasting (2). Surface preparation specifications vary depending upon the type of application. Before sandblasting, all perforations should be plugged with boiler plugs or hydraulic cement.

Selection of Lining Material

Lining materials and adhesives should be compatible with the tank material and stored products. Table 4 in Section 5 listed the compatibility of 18 lining materials with six chemical products commonly stored in UST systems. Advantages and limitations of seven lining materials are listed in Table 11. While lining material suppliers are believed to know the type and properties of adhesives used, and specific combinations of liners, adhesives, and tank materials, such information does not appear to be readily available in the open literature.

Application of Lining

Lining material can be applied by brushing, rolling, or spraying (76). Brushing and, to a lesser degree, rolling, have the advantage of working a coating into a rough or irregular surface. Spraying, however, is by far the most common application method. The latter includes conventional air spraying, high pressure hydraulic airless spraying, and electrostatic spraying.

After the coating is cured, it is inspected for thickness and integrity. Dry gauges, such as magnetic and semidestructive scratch gauges, and a wet gauge known as the comb-type gauge (2) are used to measure coating thickness and porosity. Other instruments that can be used include surface temperature thermometers, sling psychrometers for calculating dewpoint and its relation to the surface being coated, surface profile comparators for blast-cleaned steel surfaces, and moisture meters for concrete and masonry surfaces.

Tank Closing

If an opening has been cut into the tank, guidelines to closing it are as follows (2):

- A 1/4 in thick steel cover plate, rolled to the contour of the tank, should be made to overlap the hole at least two inches on each side (e.g., plate should measure at least 26 in by 26 in if manhole as cut 22 in by 22 in);

- The cover should be used as a template to locate 3/4 in diameter holes not exceeding 5-in centers, 1 in from the edge of the cover;

- The cover plate should be sandblasted to white metal on both sides and the entire inside surface coated with coating material to act as a gasket;

TABLE 11. ADVANTAGES AND LIMITATIONS OF COMMON LINING MATERIALS

Lining Material	Advantages	Limitations
Vinyls	Insoluble in oils and grease Resistant to water and salt Fire resistant Good abrasion resistance Low toxicity Tough and flexible	Will not adhere to base steel Pinholes in dried film more prevalent
Chlorinated Rubbers	Excellent resistance to water Resistant to alkalis, acids Good abrasion resistance Excellent adhesion to concrete and steel	Degraded by heat (60°C) Difficult to spray
Epoxy, Coal	Excellent resistance to salt and fresh water Good acid and alkali resistance Relatively low cost	Embrittles in cold weather Will not cure below 10°C
Alkyls	Excellent primers for rusted and pitted steel Good resistance to weathering Relatively low cost	Not suitable for alkaline surfaces
Polyesters	Excellent resistance to acids and organic solvents Good abrasion and abuse resistance	Hard and inflexible Swells and softens by strong alkalis
Silicone	Can resist temperatures up to 760°C Can be combined with other coatings to improve properties	Only moderate chemical fume resistance
Zinc rich	Resistant to weathering and mild chemical fumes Resistant to abrasion and temperatures up to 370°C Eliminates pitting corrosion	Difficult to apply Requires clean steel surfaces Must be top coated

- o Before the coating on the cover cures, the cover should be fastened to the tank with at least 1/2-in diameter bolts. The bolt shafts should be placed through the holes from the inside of the tank and held in place by spring clips, then fastened with local washers and nuts;

- o After being bolted to the tank, the cover plate and surrounding tank surface should be properly sandblasted, coated with material, and allowed to cure before backfilling the hole.

After closing the tank and before backfilling, tightness testing is recommended.

Retrofitting with Cathodic Protection

Retrofitting of UST systems with cathodic protection is another way to extend the useful life of old installations. However, the design and layout of the UST system may prevent this option. For example, if tanks are buried very close together, there may not be enough space to position the anode between them. In such a situation, unless major changes in the layout of the tanks are made, retrofitting with cathodic protection will not be effective. Recommended practices for retrofitting by cathodic protection issued by NACE suggests that suitability of this option has to be evaluated on a case by case basis.

TANK SYSTEM CLOSURE

Proper closure of underground storage tank facilities is necessary to prevent the environmental hazard posed by abandoned leaking USTs.

There are few state regulations that address tank system closure. For example, Florida regulations (40) require owners to dispose of the tank as per API (77), within 90 days of discovery. California requires that property deeds include notification of abandoned tanking (38).

Underground tanks can be taken out of service by one of three methods (8):

- o Temporary closure, in which the tank and piping system are emptied and sealed;

- o Abandonment in place, in which the tank and piping system are emptied, filled with inert material, and sealed;

- o Removal, in which the tank and piping system are emptied and removed from the ground.

Temporary Closure

Underground tanks may be considered temporarily out of service if they are in good condition and idle, but will be returned to service within a defined period of time (depending on state and local regulations) or will be abandoned in place or removed within 90 days.

For this procedure all stored product should be removed from the tank and piping system unless the stored liquid is flammable, in which case a sufficient quantity (approximately 4 in) of product should be left in the tank to ensure a saturated vapor space. This is done as a safety procedure to keep the vapor space above the upper explosive limit. All fill, gauge pipe, and draw-off lines are then capped, however, keeping the vent lines open. All power to the system must then be turned off and the area secured against tampering.

Permanent Closure

Tanks can be closed permanently by abandonment in place or by removal. The decision to choose either of these options depends on the tank's age, condition, salvage value, and reuse potential. Other factors that determine the option for permanent closure, include (77):

- o Tank location and proximity to other structures and tanks;
- o Cost of available labor and equipment;
- o Proximity of disposal site;
- o Use of the site after closure.

Abandonment in place--

The procedure for abandonment should include the following steps:

- o Remove all product;
- o Remove fill tube and disconnect fill gauge and all product lines;
- o Plug all pipes and lines except the vent line;
- o Punch a large hole in top of tank and fill tank with inert material such as sand, gravel, or concrete;
- o Keep records of tank location, date of abandonment, and method use.

Removal--

Removal is the permanent closure procedure. The recommended steps are as follows (77):

- o Drain and flush the fluid in the pipes into the tank;

- Remove all liquid and flammable/explosive vapors from the tank;
- Test for flammable/explosive vapors;
- Disconnect and cap all plumbing and controls that are not to be used further;
- Temporarily plug all tanks openings;
- Remove tank from ground;
- Plug or cap all holes except for a 1/8-in hole for venting;
- Transport the tank from site.

API provides guidelines for both storing and selling used tanks for reuse or as scrap (77). These are summarized below:

- Store used tanks in secure areas to which the public has no access;
- Store gas-free tanks with all openings plugged, with one plug havng a 1/8-in vent hole to allow the tank interior to remain clean and to prevent the tank from being subjected to extreme pressure differentials due to temperature changes;
- Record the tank's former content, gas-freeing technique, and date;
- Handle tanks that contain flammable liquids carefully, even if gas-free.

Tanks that contained flammable or hazardous liquid should have warnings on both the tank and the bill of sale stating that the tank should not be used for storing drinking water or food.

DISCUSSION

The methods and procedures described in the proceeding paragraphs if applied rigorously can substantially improve the useful life of UST systems, reduce unexpected and costly failures, and reduce the potential for fines and damages resulting from noncompliance of applicable regulations or losses resulting from lawsuits.

It is not clear, however, how much of these procedures are adopted and applied by practitioners in UST system operation. The need exists to disseminate effective methods to the practitioners, and to train them in their application.

Retrofitting of existing tank systems with cathodic protection is one area that warrants special attention. Attempts made in this study to evaluate the degree of application and effectiveness of retrofitting UST systems with cathodic protection have resulted only in fragmentary information. The general consensus among those experts, manufacturers and potential users of the system who were consulted in this study appears to be that retrofitting is effective if it is properly designed, installed, inspected, and maintained according to the guidelines set forth in NACE Standard RP-02-5 and API Publications 1615 and 1632. However, no definitive data exist as to the extent of the actual use of the retrofitting concept and the degree of success in extending the life of UST system as a result of such use. A need to generate this information exists.

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APPENDIX A

CORROSION PREVENTION

CORROSION PROCESSES

Engineering alloys have an inherent tendency to revert to their more stable oxide forms when exposed to the environment. This reversion process induces corrosion which may be defined as the process of metal deterioration that occurs as a consequence of chemical or electrochemical reactions with the surrounding environment. Corrosion can occur in both external and internal surfaces of UST system components.

Most of the destructive effects of the corrosion process in steel USTs and piping are the result of electrochemical reactions. Such reactions take place on metal surface areas with differing electrical potentials (anodes and cathodes) that are electrically connected with an electrolyte. Anodes and cathodes exist on the surface of almost all engineering alloys because of inherent chemical or structural nonhomogeneity, surface discontinuities, inclusions, heterogeneities, and surface contamination incurred during fabrication, handling, and installation.

The corrosion can be either general or localized, with localized corrosion being far more destructive because of its intensification of electrolytic cell activity.

General Corrosion (1-6)

When a metallic surface is wetted by moisture or water an electrical potential is created between anodic (+) and cathodic (-) sites located a short distance from each other on the surface. The moisture or water, which contains equal concentrations of positively charged hydrogen ions (H^+) and negatively charged hydroxyl ions (OH^-), permits the transfer of ions between the anodic and cathodic sites, in a manner similar to an electrolytic cell, resulting in corrosion of the anodic cell. As the ion transfer process proceeds, oxidation occurs at the anodes, and hydrogen gas, which inhibits the corrosion process, accumulates at the cathodes. However, the hydrogen combines with the oxygen to form water, and the electrochemical reactions and microcorrosion processes at the individual anodic cells are continued. When a large number of such microcorrosion cells form on the metal surface, uniform metal loss or general corrosion occurs.

The severity of corrosion depends upon the magnitude of the electrical potential differences, which are greatly influenced by the chemical, structural, and surface characteristics of the metal surface and water or moisture content, chemical composition, conductivity, pH, and temperature of the soil.

Localized Corrosion (1-5)

Localized corrosion includes pitting, crevice corrosion, bimetallic galvanic corrosion, and stray-current corrosion. These occur in a manner similar to general corrosion but result in more site-specific destruction of metal.

Pitting--

Pitting occurs in minute locations on metal surfaces where protective oxide films or coatings have broken down. This breakdown is followed by the formation of electrolytic cells, the anodes being the minute areas of exposed metal and the cathodes, the larger surrounding area of the protected metal. The electrical potential difference induces a flow of current resulting in rapid corrosion of the anodes. Pitting processes are accelerated in the presence of chloride ions, particularly when combined with such depolarizers as oxygen or oxidizing salts, e.g., ferrous chloride. Once an electrical potential has been established, the solution within the pit usually becomes increasingly acidic and corrosive, even though the surrounding material may be neutral or alkaline.

Concentration cells or crevice corrosion--

Crevice corrosion is often associated with conditions where moist, stagnant fluid areas are in contact with the tank's metal surfaces. The bottom of a tank pit is an ideal site for crevice corrosion. The most important factors in initiating crevice corrosion processes are variations in oxygen and metal ion content, pH, and temperature of the electrically conductive environment (electrolyte) in contact with the tank.

Bimetallic/galvanic corrosion--

The coupling of two dissimilar metals placed in an electrolyte results in bimetallic or galvanic corrosion. The magnitude of the corrosion current depends upon the differences in electrical potential of the dissimilar metals.

In the galvanic series of various metals and alloys (Table A1) metals at the top of the list are more reactive (anodic) and have a greater tendency to corrode than those at the bottom of the list (7). Coupling of metals far removed from each other in this series will result in accelerated corrosion of the anodic metal based on the increased electrical potential or reactivity differential of the metals. For example, a pipe, made of the more reactive (anodic) mild steel, connected to a valve made of the less reactive (cathodic) bronze results in an electrical potential difference that allows an electrochemical reaction and corrosion to occur on the steel pipe. Therefore, when dissimilar metals are placed in contact with each other, they should be as close as possible in the galvanic series. Such galvanic corrosion is greatly accelerated if the area of the cathode is larger than that of the reactive anode.

TABLE A1. THE GALVANIC SERIES OF METALS AND ALLOYS (7)

Corroded End (Anodic, or Least Noble)
Magnesium
Zinc
Galvanized steel or galvanized wrought iron
Aluminum
Cadmium
Mild Steel
Wrought iron
Cast iron
13 percent Chromium stainless
18-8 stainless type 304
Lead
Tin
Naval brass
Nickel (active)
Inconel (active)
Yellow brass
Aluminum Bronze
Red brass
Copper
Silicon bronze
Nickel (passive)
18-8-3 stainless type 316
Silver
Graphite
Gold
Platinum
Protected end (Cathodic or Most Noble)

Stray-current corrosion (1)--

Stray-current corrosion occurs in buried metallic objects when direct current generated from outside sources (e.g., machinery, electrified railways, or transit systems) travels through the electrolyte, e.g., soil, and enters and leaves the object, e.g., USTs and piping. The area where the current leaves suffers corrosion.

Other localized corrosion mechanisms include intergranular corrosion, which occurs between the grains of metals and alloys due to electrical potential differences set up at the different grain boundaries, and stress-corrosion cracking, which occurs when stress is applied to a metal causing electrical potential differences at the grain boundaries. These two types of corrosion are less common in carbon steel structures. However, welded austenitic stainless steel components are particularly susceptible to these corrosion processes when subjected to a chloride-ion-bearing environment.

FACTORS THAT AFFECT EXTERNAL CORROSION IN USTS (7,10,12)

Soil Resistivity

Of all the factors affecting corrosion in USTs, soil resistivity is probably the most important. Soil resistivity (ohm-cm), a measure of the resistance of soil to the flow of electric current, determines the potential rate of corrosion of underground tanks and piping. It is a function of moisture content and the ionized salts present in the soil, as well as of temperature. The lower the resistivity of the soil, the greater the probability of corrosion. The general relationship between corrosivity, resistivity and soil characteristics is shown in Table A2.

Soil Type and Variation

Variations in soil type and composition promote corrosion of USTs and piping. Factors include moisture content, acidity, bacterial content, and the presence of adjacent structures.

Moisture Level--

High moisture content in soil decreases soil resistivity and provides an electrically conductive environment for both general and localized corrosion.

Acidity--

High acidity of the electrically conductive environment increases the conductivity and therefore the ion transfer and corrosion rate of carbon steel UST systems. Higher acidity values (pH 4) are particularly corrosive, while basic values (pH 9.5) are relatively noncorrosive to steel.

TABLE A2. SOIL CORROSIVITY VS. SOIL RESISTIVITY (10)

Corrosivity	Soil Characteristics	Resistivity (Ohm-cm)
Very Low	Well drained gravel	10,000 & higher
Low	Well drained sand & gravel	5,000 - 10,000
Medium	Poorly drained sand & gravel	2,000 - 5,000
High	Poorly drained fine sand and silt	1,000 - 2,000
Very high	Poorly drained clay	Less than 1,000

Bacterial Action--

The metabolic activity of certain microorganisms can alter the resistance of metal surface films and create electrolytic concentration cells leading to crevice corrosion. Bacteria found in many soils consume the hydrogen generated in steel corrosion processes. Hydrogen also combines with sulfates in the soil to form hydrogen sulfides. The reduction of hydrogen on the corroded metal surfaces accelerates corrosion.

Adjacent Underground Metal Structures (2)--

Corrosion of underground tanks and piping may occur when new structures/piping are installed near existing USTs or piping. Older structures usually contain protective layers of corrosion products (rust), which represent oxidized metallic ions, making them cathodic to newer tanks or replacement piping. The system behave as an electrical cell -- with the older tank acting as the cathode, the newer structure as the anode, and the moist soil between them as the electrolyte. Current flowing through the system carries metal ions away from the newer structure. If the surface area of the old structure is much larger than that of the new structure, the latter will corrode even more rapidly.

INTERNAL CORROSION FACTORS

Incompatibility of materials of construction with the stored products resulting from either improper design or product contamination is the primary cause of internal corrosion. UST systems at service stations are commonly made of carbon steel because of its compatibility with gasoline.

Product contamination can occur due to several reasons (12). Consider a gasoline station, for example: gasoline is a hygroscopic product. Small amounts of water as well as oxygen are usually introduced during use and fill operations. Condensation can also add water to the system. In addition, the introduction of other contaminants (dirt and scale) and bacteria lead to the formation of precipitates and sludge, which settle on bottom surfaces in crevice areas and provide the environments that are conducive to localized corrosion.

Mechanical factors also affect the rate of corrosion of tank interiors. These factors include:

- Slope of the tank;
- Continual striking of the tank bottom by the measuring dipstick;
- Frequency of filling and emptying the tank;
- Length of the drop-tube fill connection;
- Dents and irregularities caused by installation.

Since water, which is corrosive to steel, has a higher density than gasoline, it sinks to the tank bottom. If the tank is sloped, water will accumulate in the sloped area as well as along the bottom and thus contribute to internal corrosion. Severe internal corrosion can also occur at welded joints of laps, butts, and offsets, where dissimilar metals are in contact with each other, and immediately below any submerged drop tube or dipping point. Internal corrosion is also often found directly under the fill pipe, since this area is repeatedly struck by the measuring dipstick. Such impact breaks down any protective film that may have developed, and accelerates pitting in the area.

CORROSION PREVENTION

Corrosion prevention is critical for decreasing failure rates of UST systems. UST systems preengineered with both external and internal corrosion protection are marketed by several companies. Generally, external corrosion processes are considered less predictable than internal corrosion. Therefore, more attention has been paid by the industry to prevent external corrosion.

External Corrosion Protection

The corrosion of external surfaces of steel tanks can be controlled by a number of methods, some of which are used in combination to provide the necessary protection. Such corrosion control systems are often preengineered and installed during fabrication. Some of the more common control methods are:

- o Protective coatings
- o Cathodic protection
- o Electrical isolation/cladding

Protective coatings--

Coatings isolate the external surfaces of tanks and piping from the environment. To be effective, coatings must have the following characteristics (43):

- o High dielectric resistance;
- o Resistance to moisture and penetration;
- o Good adhesion to metallic surface;
- o Resistance to mechanical damage during handling, storage, and installation;
- o Resistance to cathodic bonding;
- o Ease of repair;
- o Retention of physical properties with time.

The most common coatings applied by the tank manufacturer are epoxy- and urethane-based coatings. These coatings are designed to withstand environmental and abrasive conditions and are usually 15 to 20 mil thick when dry and cured.

Coal-tar epoxy, a widely used coating, cures by the chemical action of a resin and a catalyst. This coating is durable, requires no primer, resists gasoline, has excellent adhesion properties, resists gouging and scratching, and may be applied cold by spray or brush. However, this type of coating is also costly and requires excellent surface preparation and immediate application after mixing.

For optimum corrosion protection from any protective coating product, manufacturers' recommendations for curing time/temperature, required thicknesses, application, and surface preparation methods should be followed. Steel surfaces are best prepared by sandblasting according to Steel Structures Painting Council (SSPC) specifications for commercial blasting (15). Sandblasting to this specification produces a clean surface with a good metal profile for adhesion.

After application, the thickness of the coating is determined by using nondestructive magnetic film thickness testers. The coatings are also electrically tested for the presence of pinholes and other defects, which are remedied before shipment. Extra care must be taken in handling and shipping coated tanks to avoid damage to the coatings.

Despite all efforts to ensure total integrity of the coatings, some pinholes or ruptures in the coatings may go undetected by inspection. The presence of these holidays is extremely dangerous as any defective area becomes an anodic focal point for intensive electrolytic cell corrosion.

Cathodic protection--

One of the most widely used techniques for external corrosion control is cathodic protection, a technique that makes the entire tank surface the cathode of an electrochemical cell. Corrosion processes are not eliminated, but are transferred from the metal surface to an external anode. Two types of cathodic protection systems are: sacrificial or galvanic anode systems and impressed-current systems.

The following factors should be considered when designing cathodic protection for UST systems.

- Soil resistivity;
- Present and future current requirements;
- Life of the cathodic protection system in relationship to the intended life of the tank system;
- Presence of stray currents;
- Condition of the tank systems to be protected (new or old, coated or uncoated);
- Reliability of cathodic protection system components.

The following information should be obtained before designing cathodic protection system (32):

- Site plan and layout;
- Construction dates;
- Neighboring buried metallic structures, including location, ownership, and corrosion control;

- o Pipes, fittings, and other appurtenances;
- o Pumps and power supply;
- o Protective coatings;
- o Possible sources of electrical interference;
- o Special environmental conditions;
- o Accessibility of structure;
- o Feasibility of electrical isolation from adjacent structures;
- o Electrical continuity of the system.

The most important guideline on cathodic protection systems is NACE Standard RP-02-85, "Control of External Corrosion in Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems" (14). This document, along with other standards cited therein, provide guidelines for the design, installation, maintenance, and monitoring of cathodic protection. An adequate cathodic protection system is one that is designed, installed, and maintained by competent corrosion engineers using these guidelines.

<u>Sacrificial or galvanic anode method</u>--The sacrificial or galvanic anode method utilizes a metal anode that is significantly more reactive (higher on the galvanic list) than the tank material being protected. For steel tanks, magnesium or zinc anodes are commonly employed. The anodes are electrically connected to the UST; a galvanic corrosion cell develops; and the active metal anode sacrificially corrodes, while the UST becomes cathodic and is protected. The galvanic cell induces a current flow from the sacrificial or galvanic anode to the cathodic UST; the current then returns to the sacrificial anode through a metallic conductor (Figure A1). Once this galvanic corrosion cell has been established, it minimizes the potential for general or localized external corrosion processes to proceed by preventing the competing electrochemical reaction to occur.

The low driving voltages and low current outputs (usually less than 0.10 amp/anode) of sacrificial anodes generally limit them to protecting well-coated structures. New installations involving coated tanks or distribution piping are particularly amenable to sacrificial cathodic protection.

New USTs with attached sacrificial anode cathodic protection systems are available from tank manufacturers. These "preengineered" tanks are designed specifically to meet standards of industrial groups such as the Steel Tank Institute or tank companies. Preengineered cathodic protection systems for new tanks are developed to satisfy requirements for most soil situations. In some instances, such as in locations with low soil resistivity, the life of these systems may not be as long as expected.

Tanks with preengineered cathodic protection systems must be carefully handled during transportation and installation to protect against coating damage or rupture of anode packages. Anode wires, test leads, tank coatings, and tank isolation bushings should be inspected for obvious damage before final installation. A regular monitoring program is necessary after installation to determine that corrosion protection is being maintained.

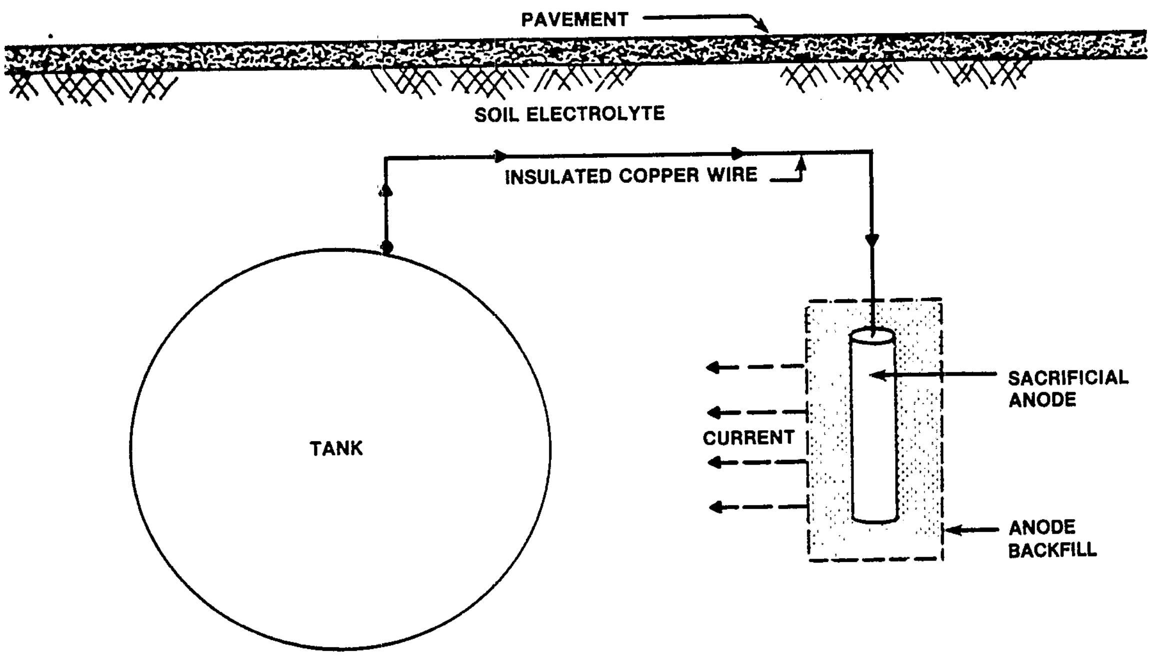

Figure A1. Sacrificial anode cathodic protection.

Where sacrificial anodes have been installed, their proper operation should be confirmed by a qualified person within six and twelve months of installation, and one year thereafter. If these tests confirm proper operation, subsequent inspection intervals can be extended to five years. However, if underground work is performed at the protected site, cathodic protection should be remonitored six to twelve weeks after work completion and one year thereafter before again extending the inspection interval.

There are several advantages to sacrificial anode cathodic protection systems, including:

- No requirement for an external power supply;
- Relatively easy installation;
- Low operating costs;
- Minimal maintenance costs after installation;
- Rare interference problems (stray currents) on foreign structures.

Disadvantages of sacrificial anode cathodic protection systems are:

- Limited driving potential preventing protection of large structures;
- Subject to soil resistivity limitations.

Impressed-current method--The impressed-current method utilizes an anode made of relatively inert electrically conductive materials that are subjected to a direct current from a rectifier powered by an AC power source. The system works on exactly the same principle as a sacrificial anode system, except for this external power source. Impressed-current cathodic protection is often the most economical way to control corrosion of existing buried steel petroleum storage tanks and distribution piping systems. Figure A2 illustrates the impressed-current cathodic protection system.

Because the electric current flow is induced by an external power source, impressed-current anodes are typically made of relatively inert electrically conductive materials. This ensures efficient flow of current and minimal corrosion of the anode. Materials commonly used include graphite, high-silicon cast iron, platinized niobium, tantalum, or titanium. Anodes can be located in remote ground beds, in deep wells, or distributed closely around the structure. Wherever possible, anodes should be installed in carbonaceous backfill, which provides good electrical contact and reduces the total circuit resistance by lowering anode-to-soil resistance.

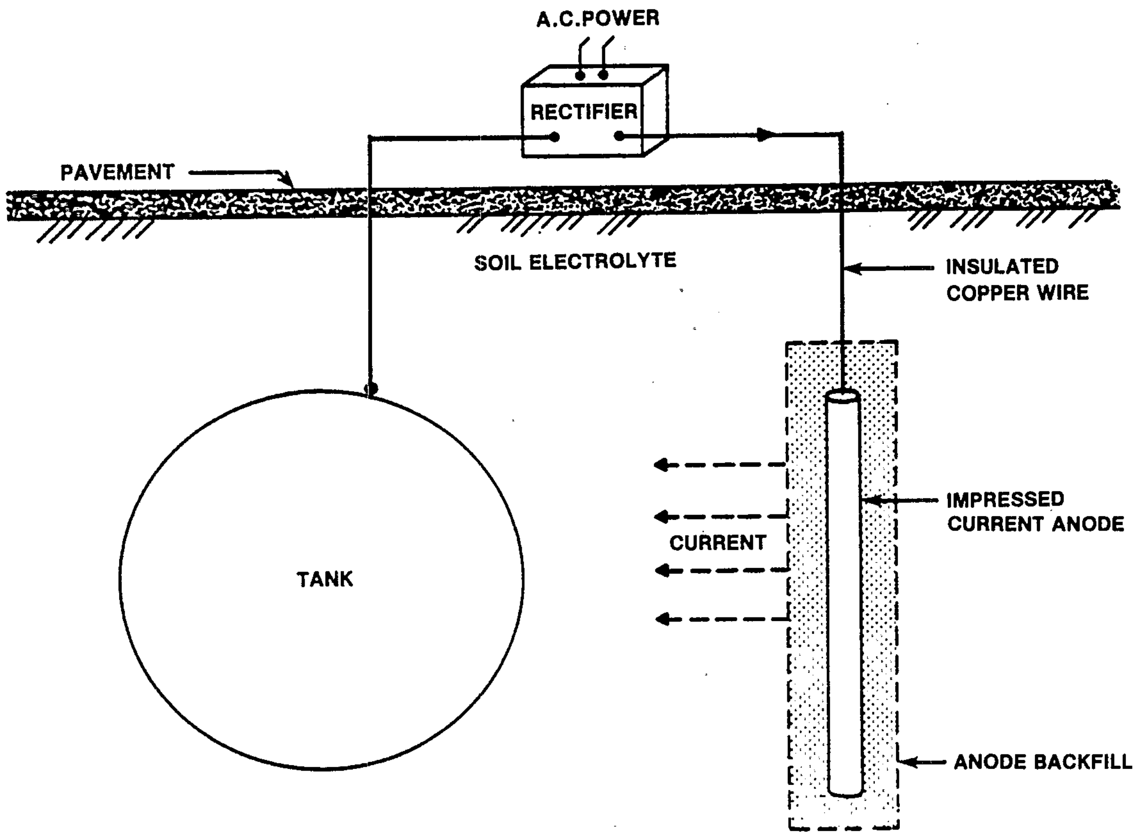

Figure A2. Impressed current cathodic protection.

Proper installation of the impressed-current system is critical to the performance of the system. The negative lead of the rectifier must be attached to the UST. All connections and wire splices should be waterproofed and covered with electrical insulating material. Backfill should be free of sharp stones so as to prevent damage to wire insulation. A permanent soil-access manhole should be provided so that the cathodic protection system can be monitored and tested. Anchor straps, if used, should be installed so that the tank coating is not damaged. After installation of the impressed-current protection system, voltage on the UST system must be measured with a reference electrode on the soil surface as close as possible to the UST.

Monthly checks of rectifiers are necessary to verify that they are operating properly. Structure-to-soil and structure-to-structure potentials of an impressed-current system must also be tested routinely to ensure continued satisfactory operation.

Some advantages of impressed-current cathodic protection system are:

- o Electrical potential limited only by power supply;
- o High current output capable of protecting other underground steel structures at a low operating cost;
- o Flexible current output control;
- o Applicability to almost any soil resistivity;
- o Ability to protect large, bare-steel structures.

The following disadvantages should, however, be noted:

- o Possibility of electrical interference (stray currents) with other structures;
- o Potential for switching off the current and eliminating protection if not equipped with a fail-safe device;
- o Requirement of monitoring and maintenance on a regular schedule.

Electrical isolation/cladding--

Electrical isolation improves corrosion prevention provided by cathodic protection method. This method involves installing devices to isolate metal components in an UST system. Nonconductive dielectric fittings, bushings, unions, etc. are usually used as isolating devices. Use of an electricity-resistive envelope also isolates the tank system.

Electrical isolation devices are rated for temperature, dielectric strength, and compatibility with the stored product. The tank system must be installed so that these devices remain physically separated from all foreign underground metallic structures. Isolating devices may also require protection from voltage surges caused by lightning or alternating current from overhead high-tension wires. Guidelines for protection from such damage have been developed.

Another method for electrical isolation of steel tanks is an external cladding of fiber-reinforced plastic material, which acts as an insulator and eliminates electrolytic activity.

Internal Corrosion Protection

The corrosion control measures commonly used to protect the internal surfaces of steel tanks include:

- Coatings/linings
- Galvanic protection (sacrificial anodes)
- Striker plates below fill lines
- Avoidance of dissimilar metal weld joints
- Use of double-welded butt joints

To be effective, internal coatings/linings must be chemically compatible with products.

Galvanic protection may also be provided internally by the installation of zinc strips in a manner similar to magnesium anodes applied externally. These anodes are usually installed near the bottom of the tank, where corrosion occurs due to the accumulation of water and other corrosive contaminants.

Striker or wear plates provide valuable protection against dipsticks puncturing protective oxide films and blast erosion occurring under the fill tube. Wear plates should be installed under each opening. Striker plates in steel tanks are normally flat, 1/4 in thick and 12 in square. The plates should be sandblasted to ensure that they are anodic to the tanks.

Coupling of dissimilar metals, which leads to galvanic corrosion, is for the most part controlled by the tank manufacturer. However, dissimilar metals can be accidentally introduced during installation or when in service. Such a situation must be carefully avoided. Initial installation instructions and operation and maintenance procedures should clearly specify the metallurgical requirements necessary to prevent galvanic corrosion.

The joints of a steel tank may be butt welded or lap welded. However, double-welded butt joints are less susceptible to corrosion and are preferred. They are stronger than lap joints, which may be susceptible to the concentration-cell or crevice-attack corrosion mechanisms described earlier.

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