FINAL REPORT

ASSESSMENT OF THE TECHNICAL, ENVIRONMENTAL AND SAFETY ASPECTS OF STORAGE OF HAZARDOUS WASTE IN UNDERGROUND TANKS

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SUMMARY

INTRODUCTION

The objectives of this project were to define current practices for hazardous waste storage in underground tanks; evaluate these practices in relation to spill and damage event data and best engineering judgement; estimate the relative probability and magnitude of waste release from underground tanks; and examine appropriate alternatives for prevention and/or mitigation of releases. The results of activities performed in pursuit of these objectives are summarized below.

UNDERGROUND TANK USE

Based on the results of the U. S. Environmental Protection Agency (EPA) mail survey of 1981 hazardous waste management practices, hazardous wastes are stored in underground tanks which range up to 50,000 gallons in capacity and 35 years in age. The median tank capacity is 3,000 gallons while 90 percent of the tanks have a capacity of 10,400 gallons or less. The median tank age is 8 years and 90 percent of the tanks are less than 25 years old.

A majority of the tanks are constructed of carbon steel, although concrete, stainless steel, fiberglass reinforced plastic (FRP) and other materials are also used. Ignitable wastes are the most commonly stored waste type, followed by corrosive, toxic, E. P. toxic wastes. Underground tanks are used to store other types of hazardous waste significantly relatively infrequently.

Facilities with underground tanks which are used for hazardous waste storage have up to 15 such tanks, with a majority of facilities (55 percent) having only one underground tank. Underground tank capacity ranges up to 95,000 gallons per facility with a median capacity of 10,000 gallons. A majority of these facilities (63 percent) store ignitable waste, with the next most common waste types being toxic (34 percent) and corrosive (28 percent).

DAMAGE CASES AND SPILL EVENT REVIEW

Damage cases and spill events were reviewed as part of the effort to assess the adequacy of current practices for storage of hazardous waste in underground tanks. Available information which was reviewed came primarily from state and local government agencies and trade associations. A majority of this information is derived from petroleum product storage facilities since very limited information is available for hazardous waste storage facilities.

Data from an American Petroleum Institute (API) survey of gasoline storage tanks which were found to be leaking indicate that corrosion is the primary cause of steel tank leaks. The ages of the leaking tanks covered by the survey ranged from 1 to more than 31 years, with 86 percent of the responses for tanks in the 6 to 25 year range. For FRP tanks, breakage or tank separation (i.e., a physical separation of tank wall material) accounted for all of the leaks. For piping, which was also frequently cited as a leak source, corrosion was again reported to be the primary cause of the leakage. Additional conclusions which can be derived from the information are that poor installation can contribute to leaks, primarily through corrosion or loose fittings, and that leaks can occur from tank systems provided with corrosion protection if design, installation or maintenance is inadequate.

Information collected from local government organizations such as the Cape Cod Plannning and Economic Development Commision; Suffolk County, New York; and Prince George's County, Maryland led to conclusions similar to those presented above for the API survey (e.g., corrosion of existing steel tanks is resulting in a significant number of releases). As a result, local ordinances have been or are being developed to more closely monitor the integrity of underground storage tanks. Similar efforts have also occurred at the state level in Michigan and New York.

A survey conducted by the California Regional Water Quality Control Board, San Francisco Bay Region, of facilities storing hazardous materials identified more than 80 facilities which used underground tanks (primarily for product and waste solvent storage) and were judged to have a high potential for leaking hazardous materials. As of May 1983, tank system failures had been found to be the cause of releases to soil and/or ground water at 72 percent of the 57 facilities for which investigations had been completed. Additional leaking tanks are expected to be found as lower priorty groups of tanks are investigated

Prior to the conduct of this survey by the San Francisco Bay Region, 21 facilities were found to have leaking underground hazardous materials storage tanks. In order to incorporate information from these facilities (which pre-date the questionnaire survey) into this report, two case studies were prepared. In combination, leaks from the two facilities resulted in the closing of more than a dozen water supply wells serving about 3,000 people and clean-up costs which were estimated to have reached $20 million by May 1983. In addition, numerous law suits have been filed in an attempt to establish responsibility for the leaks and to require payment of compensatory damages.

RELATIVE RELEASE PROBABILITY AND MAGNITUDE

To provide a basis for comparing the effectiveness of alternative approaches to prevention and/or mitigation of releases from underground tank storage systems, relative release probabilities were estimated for a "typical" underground tank facility. This was accomplished through categorization of release events, development of "typical" tank system characteristics, and estimation of relative release magnitudes and probabilities.

Six types of release events were identified; including: tank overflow, tank leak, tank rupture, ancillary equipment leak, ancillary equipment rupture, fire/explosion and other incidents (e.g., vandalism, earthquakes, etc.). For each type of release, the causes of release were also categorized. The tank and ancillary equipment leak and rupture release event categories were found to share the same release cause categories (design deficiency, installation practices, equipment failure and operational error).

The features of the "typical" tank system used for comparison purposes were defined by the median of the EPA mailed questionnaire survey responses to the extent that data were available. Thus, the "typical" tank system consists of a single 3,000 gallon carbon steel tank which is filled through gravity cast iron piping. The tank has been in service for 8 years and is used to store ignitable waste. The tank was installed in accordance with specifications commonly used at the time of installation in soils which contribute to corrosion (resistivity less than 10,000 ohm-centimeters).

The release magnitude associated with each of these six release event categories depends on the release rate and duration. Release rates are based on assumptions judged to be conservative and release durations are based on assumptions concerning the frequency of testing and tank level measurement. Based on the assumptions made, tank leak is the largest volume release event for the small model facility, followed by tank rupture and ancillary equipment leak. For the medium sized model facility, tank rupture is the largest volume release event, followed by tank leak. Tank and ancillary equipment leak were judged to have the highest relative release probability.

PREVENTION MITIGATION MEASURES

Six measures intended to prevent or mitigate releases from underground tank systems due to tank or ancillary equipment failure were examined, including: secondary containment, tank system testing, environmental monitoring, inventory monitoring, internal inspection and corrosion protection. Each measure is examined in terms of advantages and effectiveness, disadvantages and limitations and equivalent uniform annual costs (EUAC) for two model facility sizes.

Secondary containment is shown to be the most expensive (based on equivalent unifrom annual cost (EUAC)) of the control methods examined for both the small and medium sized model facilities under both new and retrofit conditions. Internal inspection is the second most expensive method, with corrosion protection the least expensive method.

Although secondary containment is the most expensive of the control methods examined, it is clearly the most effective means of preventing both leak and rupture events since it is the only method which reduces both the estimated probability and magnitude of release. Corrosion protection also serves to reduce the estimated release probability, and as shown, it also can control all four release events. Other measures, such as tank system testing and environmental monitoring, serve to mitigate the effects of releases by decreasing the release magnitude but are judged to have relatively little impact on the estimated release probability.

From a release probability perspective, secondary containment is the most cost effective method analyzed (under the conditions assumed). This statement is made since secondary containment for tank and ancillary equipment provides a three order of magnitude greater decrease in release probability than corrosion protection at a cost which is less than two orders of magnitude greater. Secondary containment for both tank and ancillary equipment also provides a 99 percent decrease in the estimated release magnitude. Although the cost associated with this approach is among the highest shown, the cost per unit of release reduction is approximately the same as for tank containment alone. Thus, containment for the entire tank system is indicated to be a better investment in light of the very significant reduction in release probability provided.

Mitigation measures such as tank system testing and environmental monitoring are shown to provide significant reductions in the estimated release magnitude at costs per unit of reduction which are about half those asssociated with secondary containment. However, they provide no reduction in the estimated release probability.

Inspections are also shown to result in reductions in release magnitude without impacting the release probability. While tank inspection can result in the identification of developing problems before a leak or rupture occurs, measurements are taken on a relatively small percentage of the tank surface area. Thus, it was judged that while some reduction in the estimated relative release probability will occur with tank inspection, the reduction will be less than one order of magnitude.

A prevention measure which has no impact on the estimated release magnitude but which results in an estimated release probability reduction of one order of magnitude is corrosion protection. Based on the assumption that corrosion protection is provided by an external coating and sacrificial anode(s), corrosion protection is shown to be the least expensive method of achieving a reduction in estimated release probability.

SECTION 1

INTRODUCTION

Hazardous wastes are stored using a variety of methods including surface impoundments, tanks and containers. Since hazardous waste mismanagement has been shown to have costly and damaging consequences, there is a continuing interest in ensuring that the management practices utilized will protect human health and the environment. Recently, numerous cases of leaking underground storage tanks have been discovered. As a result, a study of underground hazardous waste storage facilities (defined as tanks and appurtenances which are completely buried and are used for storage of hazardous waste for more than 90 days) was initiated.

The objectives of this project were to define current underground tank storage practices and to evaluate them in relation to spill and damage event data and best engineering practice. Once evaluated, this information was used to identify management alternatives. Five management alternatives for mitigation/prevention of waste release were then selected for evaluation, which included examination of applicability, availability, complexity, cost and effectiveness (expressed as the estimated relative probabilities and magnitudes of release).

The results of this investigation are presented in the following four sections. In Section 2, data derived from the EPA Hazardous Waste Tank Questionnaire (OMB no. 2000-0424) are presented and discussed. These data provide a characterization of underground tanks used for hazardous waste storage in terms of: types of wastes typically stored, tank sizes, tank age, materials of construction, methods of leak detection and frequency of use, prevalence of tank linings, type of tank liners as a function of waste type and type of tank liner as a function of waste type and type of tank liner as a function of tank material.

Section 3 presents information regarding release events associated with hazardous materials storage (most frequently petroleum products). The sources of this information were State and Local agencies, trade associations and industry. In addition, two case studies associated with hazardous waste and materials storage are included. The implications of these data with respect to the prevalence of tank systems failures are also discussed.

Section 4 presents an analysis of estimated relative release probabilities and magnitudes associated with a "typical" underground tank storage facility for seven types of release events (i.e., tank leak, ancillary equipment rupture, fire or explosion, etc.). The "typical" facility used for reference is based on the most common current practice as determined from the data presented in Section 2 in conjunction with other relevant sources.

Section 5 is a discussion of five waste release mitigation/prevention measures selected to represent the range of possibilities for reducing the relative probability and magnitude of releases for underground hazardous waste storage tanks. Each measure is discussed with respect to both existing and new tanks. The discussion provides a description of each option and the associated costs, change in probabilities and magnitudes of release and advantages and disadvantages.

SECTION 2

UNDERGROUND TANK USE FOR HAZARDOUS WASTE STORAGE

INTRODUCTION

To put the discussion of hazardous waste storage which appears in the following three sections in perspective and to provide input to the determination of representative facility characteristics, a profile of underground tank used for hazardous waste storage is presented here. The presentation is based on responses to selected portions of a mail survey of the 1981 hazardous waste management practices regulated under Subtitle C of the Resource Conservation and Recovery Act of 1976 (RCRA) conducted for the U.S. Environmental Protection Agency's Office of Solid Waste (EPA OSW) [1]. A description of the design of the survey and how the responses may be used to generalize about all hazardous waste storage tanks is currently being prepared [2].

The discussion presented is based on the questionnaire responses with a focus on percentages of tanks with specific characteristics. Data are also presented at the facility level for selected characteristics such as overall underground tank storage capacity.

TANK USE CHARACTERISTICS

Statistics on selected variables from the mail survey were found to be of interest for this report. One part of the survey asked for a detailed description of all hazardous waste tanks at a facility. Data were obtained concerning the tank descriptions of the underground hazardous waste tanks. Variables selected from the mail survey for inclusion in this report were as follows:

- Capacity and age of underground tanks;
- Interval of time between underground tank inspections;
- Integrity testing of underground tanks;
- Safety equipment on underground tanks;
- Liners of underground tanks;
- Construction material of underground tanks;
- Wastes stored in underground tanks and at facilities with underground tanks;
- Number of underground tanks per facility at facilities with underground tanks; and
- Capacity of underground tanks per facility at facilities with underground tanks.

Following is a summary of the mail survey results concerning underground tanks. The responses include a total of 169 underground tanks, of which none were used for wastewater treatment. Most of the tables and figures are based on data for less than 169 underground tanks. Many of the mail survey responses were reported either as not ascertained, unknown, or with a blank. In addition, some questions on the mail survey relate to only a subset of the 169 tanks.

Table 2-1 lists the cumulative percent of underground tanks by design capacity, volume contained and age. The median design capacity and median "average volume contained" of underground tanks are 3,000 gallons and 1,260 gallons, respectively. The median age that an underground tank has been in use is eight years, with the oldest tank in use for 35 years. Figure 2-1 reveals that the most frequent response to the number of years that an underground tank has been in use is 10 years.

A total of 111 out of 168 underground tanks (66 percent of 168 responses) can be entered for internal inspection. The median interval between internal inspections was reported to be 12 months based on 70 responses. Figure 2-2 also shows that the most frequent response to the average number of months between internal inspections is one year.

Many methods are used to check the integrity of underground tanks. The percentages of underground tanks using different types of integrity testing methods are as follows (based on 118 responses):

Testing Method	Percent Using
Ultrasonic	0
Air	9
Penetrant dye	0
Vacuum box	0
Water/hydrostatic	13
Kent-Moore/Petro-tite	24
Other	37

Various types of safety equipment are employed for underground tanks. The percentages of underground tanks using the different types of safety equipment are as follows:

TABLE 2-1. UNDERGROUND TANKS CHARACTERISTICS

Cumulative Percent	Design Capacity (gallons)	Average Volume Contained (gallons)	Tank Age (years)
10	1,000	140	2
25	1,500	700	4
50	3,000	1,260	8
75	8,000	3,000	14
90	10,400	6,000	24
100	50,000	27,000	35
Total Number of Responses	155	151	165

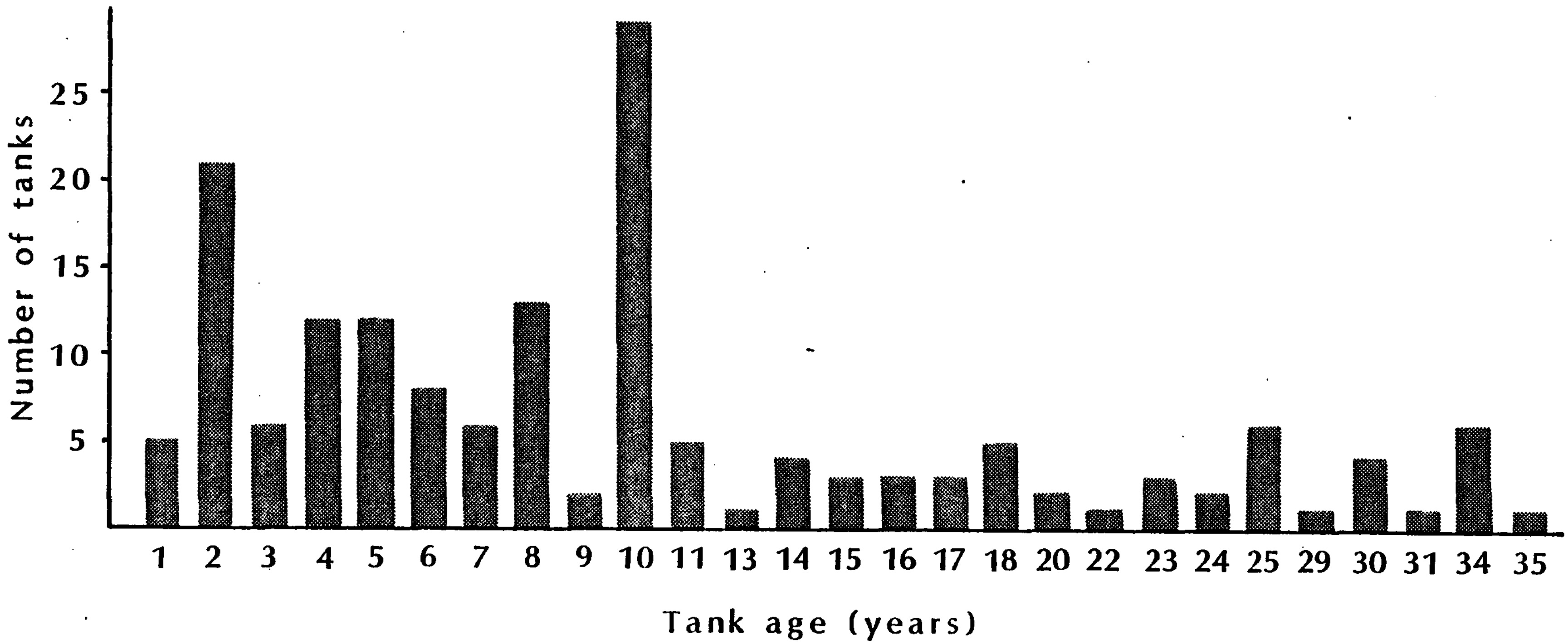

FIGURE 2-1. Frequency distribution of tank age.

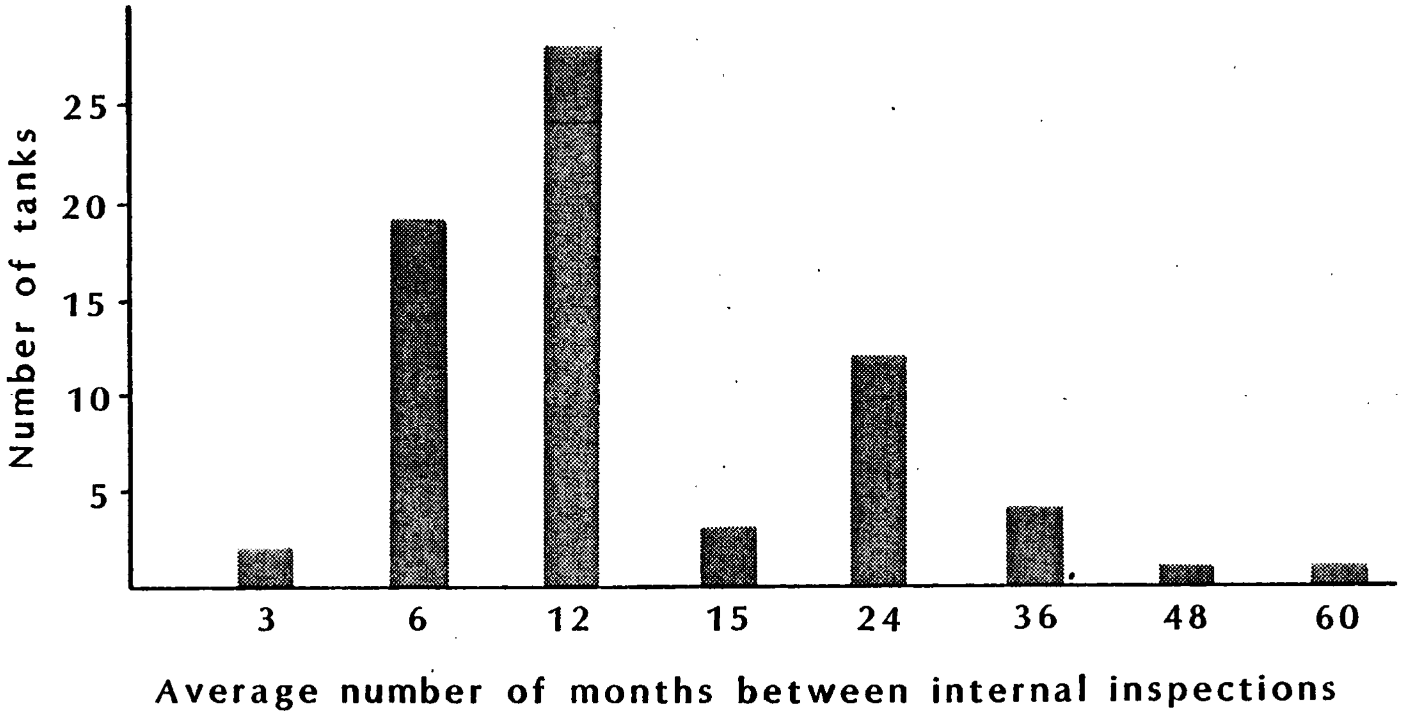

Figure 2-2. Frequency distribution of internal inspections of underground tanks.

Safety Equipment	Percent Using
Lightning arrestors	13
Sparkless motors and wiring	37
Flame arrestors	27
Nitrogen blanketing	2
Other	25

The results of the type of safety equipment used are based on 167 responses.

The vast majority of underground tanks are constructed of carbon steel. The percentages of underground tanks by type of construction material are broken down as follows:

Construction Material	Percent Using
Carbon Steel	60
Stainless Steel	9
Concrete	17
Fiberglass	9
Other	5

The results of the type of tank construction material are based on all the 169 underground tanks reported in the mail survey.

Data were also collected on the use of tank liners. Of the 39 underground tanks reported to have linings, most have plastic liners (54 percent) or a liner made of a material other than rubber, fiberglass, or steel (36 percent). Carbon steel tanks with plastic liners make up the vast majority of lined tanks (43.5 percent of the 39 lined underground tanks). Of the 39 lined underground tanks, most store corrosive wastes (72 percent) or ignitable wastes (54 percent). The majority of lined underground tanks store corrosive wastes in plastic-lined tanks (46 percent). Many of these tanks store ignitable wastes in plastic-lined tanks (28 percent).

Table 2-2 presents statistics on the types of waste stored in underground tanks and the construction materials of the tanks. Based on responses for all 169 underground tanks reported in the mail survey, ignitable waste is the most common (46 percent) waste type. Carbon steel tanks which store ignitable wastes

TABLE 2-2. PERCENT OF UNDERGROUND TANKS BY TYPE OF WASTE STORED AND CONSTRUCTION MATERIAL OF TANK

Waste Stored	Percent of Tanks*	Percent Used By Construction Material of Tanks*				
		Carbon Steel	Stainless Steel	Concrete	Fiberglass	Other
Ignitable	46	34	7	2	3	0
Corrosive	32	17	2	6.5	6.5	1
Reactive	11	1	2	4	3.5	.5
E.P. Toxic	24	5	0	7	7	5
Toxic	28	14	3	6	5	0
Acutely Hazardous	6	6	0	0	0	0
Other	10	10	0	0	0	0

* Percent of all underground tanks (169 tanks) with the specified type of waste stored and construction material of tank indicated; i.e., 46 percent of the tanks (78 tanks) store ignitable waste, of which 34 percent of the tanks (57 tanks) store ignitable waste and are constructed of carbon steel. Total of this column exceeds 100 percent since some tanks store waste which is classified as being in more than one category.

comprise 34 percent of all underground tanks. Acutely hazardous wastes and other types of wastes besides ignitables, corrosives, reactives, E.P. toxics, and toxics are stored only in carbon steel tanks.

Selected cumulative percentages for the number of underground tanks per facility with underground tanks were found to be:

Cumulative Percent	Number of Storage and/or Treatment Tanks per Facility
10	1
25	1
50	1
75	3
90	6
100	15

As indicated, the median number of underground tanks per facility with underground tanks is one since 55.4 percent of the 65 facilities with underground tanks have a single underground tank. Figure 2-3 also indicates that most facilities with underground tanks have one underground tank. Figures 2-4 and 2-5 indicate the distribution of underground storage and treatment tanks respectively. As shown, the data for these two subsets of underground tanks follows the same trend displayed by Figure 2-3. In addition, these data indicate that most underground tanks are storage tanks.

The majority of facilities with underground tanks (63 percent of 65 facilities) store ignitable wastes in underground tanks. The percent of facilities with underground tanks for each type of waste stored in under ground tanks is as follows:

Waste Stored	Percent With Waste
Ignitable	63
Corrosive	28
Reactive	9
E.P. Toxic	18
Toxic	34
Acutely hazardous	3
Other	0

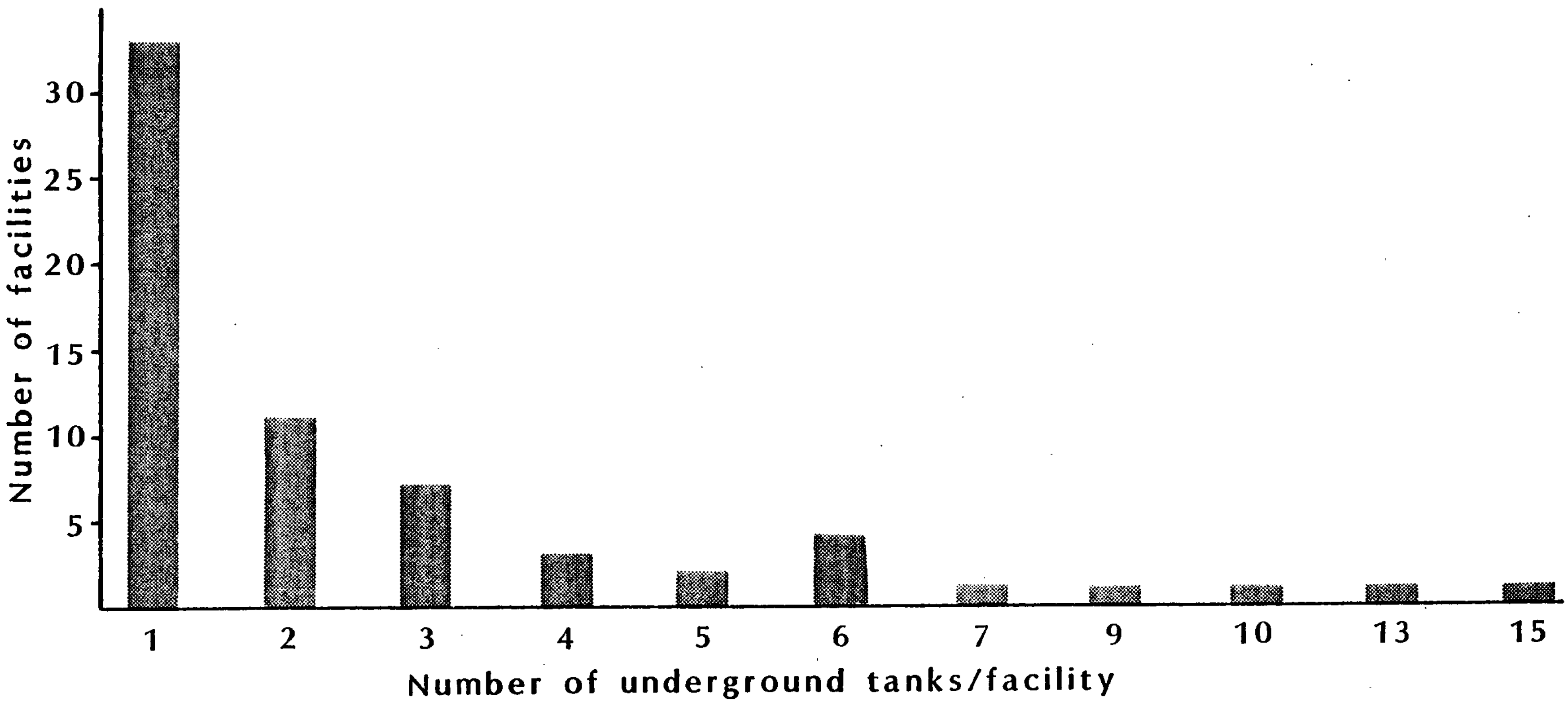

Figure 2-3. Distribution of all underground tanks per facility with underground tanks.

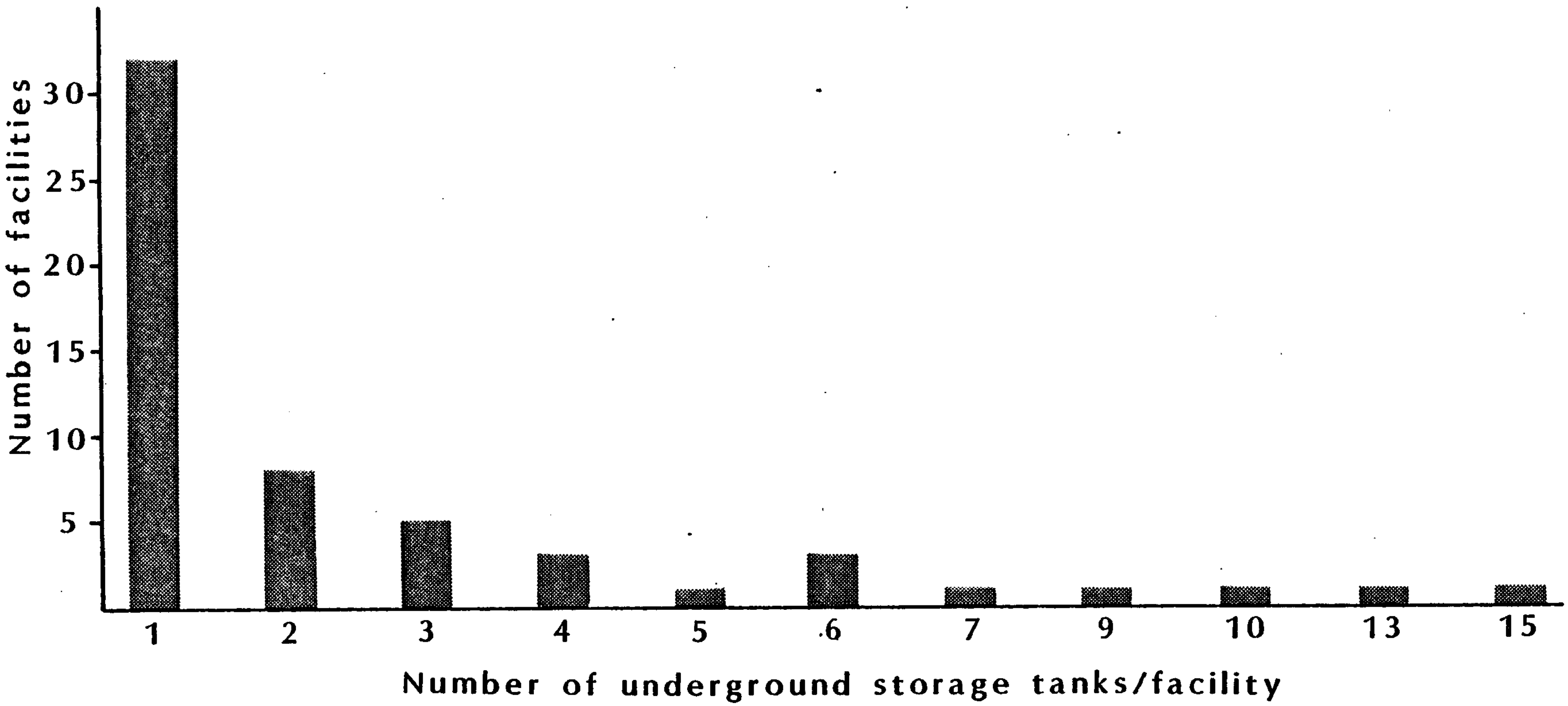

Figure 2-4. Distribution of underground storage tanks per facility with underground tanks.

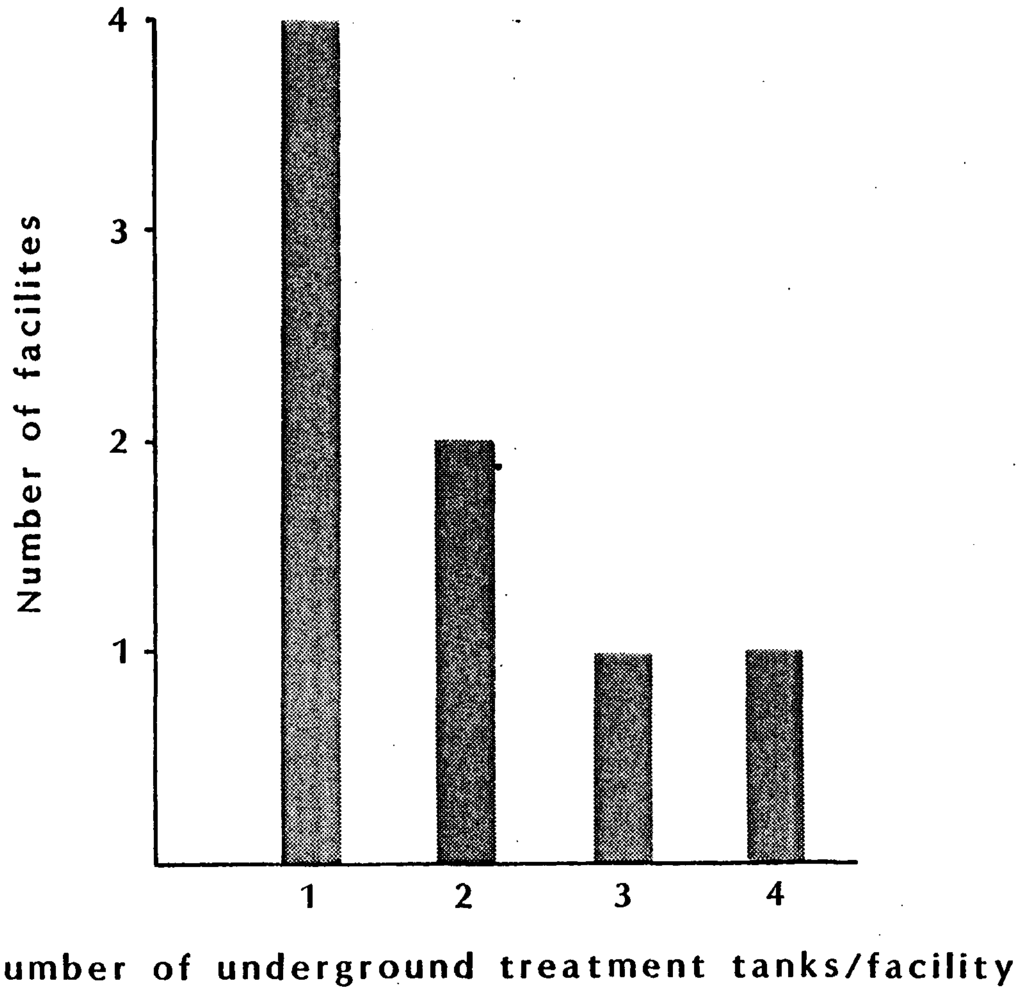

Figure 2-5. Distribution of underground treatment tanks per facility with underground tanks.

The percentages of wastes stored are based on 65 responses for each type of waste.

Selected cumulative percentages of underground tank capacity per facility with underground tanks are listed below:

Cumulative Percent	Capacity of Storage and/or Treatment Tanks per Facility (Gallons)
10	1,000
25	3,300
50	10,000
75	20,000
90	31,200
100	95,000

For all underground tanks, the median total capacity per facility is 10,000 gallons, based on responses for 59 facilities.

In summary, results of the mail survey on underground hazardous waste tanks reveal that a typical (median) underground tank has the following characteristics:

- Design capacity of 3,000 gallons;
- Average volume contained of 1,500 gallons;
- Installed for eight years;
- Checked for integrity by method other than ultrasonic, air, penetrant dye, vacuum box, hydrostatic, or Kent-Moore/Petro-tite methods;
- Constructed of carbon steel;
- Unlined; and
- Stores ignitable wastes.

Most facilities with underground tanks generally have three or less underground tanks which typically store ignitable wastes. The median capacity of underground tanks per facility with underground tanks is 10,000 gallons.

REFERENCES

1. U.S. Environmental Protection Agency. Hazardous Waste Treatment Storage and Disposal Questionnaire-Tank Questionnaire. OMB# 2000-0424. Washington, D.C. December 31, 1982 expiration date.

2. Westat, Inc. Documentation of Mail Survey Questionnaire for U.S. Environmental Protection Agency. Washington, D.C. (in preparation).

SECTION 3

DAMAGE CASE AND SPILL EVENT REVIEW

INTRODUCTION

One objective of this study was to assess the adequacy of current practices for storage of hazardous waste in underground tanks with regard to the protection of human health and the environment. As part of this assessment effort, available data on damage cases and spill events (releases) were reviewed in order to determine the extent to which releases occurred and the causes of these releases. For the purpose of this review effort, "available data" were defined as readily available reports and papers which contained compilations of individual incidents. In addition, organizations with information regarding tank investigation programs and detailed investigation of two specific sites were included.

A listing of the data sources included in this section is presented below:

- American Petroleum Institute "Tank and Piping Leak Survey
- California Water Quality Control Board, San Fransisco Bay Region
- Cape Cod Planning and Economic Development Commission
- Maryland Petroleum Association, "Prince George's County, Maryland, Tank Testing Program
- Michigan Department of National Resources
- New York Department of Environmental Conservation
- Suffolk County, New York

A summary of the overall findings resulting from the review of these sources is also presented at the end of this section.

INFORMATION SOURCES

The relevant source of information evaluated during this effort are individually discussed below. Each review was prepared to provide an overview of the programs or incidents responsible for initiating each study; to present the data compiled during each effort; to point out some of the limitations associated with the data presented; and to present conclusions which can be drawn from the data.

American Petroleum Institute "Tank and Piping Leak Survey"

The American Petroleum Institute (API) "Tank and Piping Leak

Survey" was conducted from the Fall of 1977 to the Summer of 1980 to "identify the location of perforations in leaking tanks to support the effectiveness of tank testing procedures which measure liquid level loss in a tank". [1] As the study progressed API requested additional information such as tank age, cause of leak, leak detection method, piping system information, etc.. in order to better understand the circumstances surrounding tank leaks. This information was collected using a general questionnaire form distributed to the chief engineer (or the appropriate individual(s) who handle reported leaks) at each of the major oil companies (i.e., Exxon, Mobil, Shell, Gulf, ARCO, Chevron, etc...) and to representatives of the Petroleum Equipment Institute (PEI) (Note: Many of PEI's member organizations are involved in supplying or installing replacement tanks.) These questionnaires were then distributed to service station owners (or managers) who had reported leaks from underground storage systems and who volunteered to complete the survey form. Because of this process, only leaking systems were reported (i.e., stations without leaks did not respond to the survey) and survey forms were not completed for every leak occurring during the data collection effort (i.e., since the survey was voluntary not all stations with leaks completed survey forms). In addition, the majority of responses were from service stations owned by the major oil companies.

The data from the survey were compiled by API and are presented below. As noted in Table 3-1, a total of 1953 leaks were reported; 204 of these leaks could not be categorized. Some 64 percent of the categorized leaks were attributed to steel tanks without cathodic protection and 33 percent were attributed to piping. (Note: Piping leak information was not requested on the survey form until a year after the survey was started; by that time, 400-500 questionnaires had already been collected. As a result, more of the reported leaks may be attributable to piping leaks.) The remaining categories only accounted for 3 percent of the reported leaks.

A discussion of the results for each of the three categories of leaks (from steel tanks, fiberglass tanks, and piping) is presented below. Questionnaires were not completed consistently, which resulted in different numbers of responses for the various question; many questions going unanswered; and a need to intepret some of the answers. Although not statistically valid (i.e., the total universe of stations was unknown, the survey was voluntary and as a result not all stations with leaking tanks responded; only data from stations with leaking underground storage systems were surveyed; and the methods used to distribute the survey forms tended to biase the results to represent conditions at facilities owned by the major oil companies) the data shows relative frequencies and trends regarding leaks.

Steel Tank Leaks (see Table 3-2)

- Corrosion was the primary cause of steel tank leaks

TABLE 3-1. PETROLEUM PRODUCT LEAKS BY CATEGORY FROM THE API "TANK AND PIPING LEAK SURVEY". (1977-1980)

	Total	Percentage
Steel Tanks	1,112	63.6
Fiberglass Tanks	28	1.6
Steel Tanks with Sacrificial Anodes	2	0.1
Steel Tanks with Impressed Current Cathodic Protection	19	1.1
Interior Coated Steel	5	0.3
Piping	583	33.3
Subtotal	1,749	100.0
Unspecified Tanks	204	
TOTAL	1,953	

TABLE 3-2. STEEL TANK LEAKS IDENTIFIED DURING THE API "TANK AND PIPING LEAK SURVEY". (1977-1980)

	Total	Percentage
NUMBER OF RESPONSES	1,112	
CAUSE OF LEAK	Total	Percentage
Corrosion Hole	970	92.3
Loose Fitting	9	0.9
Breakage	17	1.6
Other	55	5.2
Subtotal	1,051	100.0
Unanswered	61	
AGE OF TANK		
0-1 Year	2	0.2
2-5 Years	14	1.4
6-10 Years	117	11.8
11-15 Years	262	26.5
16-20 Years	296	30.0
21-25 Years	176	17.8
26-30 Years	80	8.1
31- + Years	41	4.2
Subtotal	988	100.0
Unanswered	124	
HOW LEAK WAS DETECTED		
Inventory Shortage	184	17.5
Water in Tank	584	55.4
Leak Detector	3	0.3
Tank Test	122	11.5
Product in Sewers, Wells, Etc.	45	4.3
Other	116	11.0
Subtotal	1,054	100.0
Unanswered	58	
DID TANK HAVE A FILL TUBE?		
Yes	845	80.5
No	205	19.5
Subtotal	1,050	100.0
Unanswered	62	

TABLE 3-2. (CONTINUED)

WAS LEAK BENEATH FILL TUBE?	Total	Percentage
Yes	180	25.4
No	528	74.6
Subtotal	708	100.0
Unanswered	137	
WAS PART OF TANK IN GROUND WATER?		
Yes	713	68.4
No	329	31.6
Subtotal	1,042	100.0
Unanswered	70	

accounting for 92 percent of the responses. Additional data pointed to external (63 percent of reported cases of leaks due to corrosion) corrosion as the primary type of corrosion.

- Ages of leaking tanks ranged from less than 1 to more than 31 years. Some 98 percent of the responses were for tanks more than 6 years old and 86 percent were for tanks in the 6 to 25 age range.

- Water in the tank was the primary means of leak discovery (this is usually found using a water-finder paste on the bottom of the tank level gauging dip stick), accounting for 55 percent of the finds. This method of detection was followed by inventory shortage and tank testing (primarily Petro-Tite) with 18 percent and 12 percent of the responses, respectively. (Note: 68 percent of the tanks were located in ground water.); and

- Of the 845 tanks reporting to have fill tubes, (i.e., a pipe extending from the surface down into the interior of the tank which is used for filling purposes) 21 percent reportedly had leaks beneath the fill tube. The actual number may have been greater since the question pertaining to this type of leak was not answered for 137 of the tanks with fill tubes.

The results of the survey indicate that corrosion is a major cause of steel tank leaks, with a notable percentage of these leaks at the base of fill tubes. Additional data showed that 22 percent of steel tank leaks reported had some type of "point anode" (i.e., a point from which electric current leaves the surface of the tank, resulting in a destructive alteration or eating away of the metal) at the leak point. These data, along with other information presented, indicate that corrosion is influenced or even enhanced by a number of factors such as:

- The resistivity, pH, moisture content and sulphide content of the soils surrounding the tank;

- The existence of "point anodes" which may result from foreign particles (i.e., cinders, clay etc...) on the tank surface or physical damage of the tank coating such as a scrape which may occur during installation; and

- Tank age. [2]

One of the most common causes considered is tank age, but due to the broad range of ages over which leaks were reported, age appears to be only one of possible variables which influence the occurence of leaks due to corrosion.

- Fiberglass Tank Leaks (see Table 3-3)

  - With only 28 responses, one can conclude that it may be less commonplace for fiberglass tanks to leak. This conclusion is supported by the virtual elimination of the major source of leaks in steel tanks - corrosion. On the other hand, this conclusion may be biased by the smaller number (a total of 28 responses) and the shorter duration of use of fiberglass tanks (approximately 15 years) compared to steel tanks.

  - Breakage or tank separation (i.e., a physical separation of tank wall material) accounted for all leaks. One third of these were caused by dip stick punctures [1];

  - Tank age ranged from less than 1 year to 15 years with 96 percent of the responses falling between 0 and 10 years; and

  - Inventory shortage was the primary means of leak detection followed by water in the tanks.

  Due to the limited number of responses from facilities with fiberglass tanks which leak, few conclusions can be drawn from the data. The principal point to be made is that fiberglass tanks require careful handling during installation and operation (i.e., dip stick level measurements) of the facility.

- Piping Leaks (see Table 3-4)

  - Corrosion was the primary cause of pipe leak, accounting for 64 percent of the responses;

  - Pipe age ranges from less than 1 year to over 31 years with 84 percent of the responses falling between 6 and 20 years.

  - Inventory shortage was the primary means of leak detection, accounting for 45 percent of the responses.

  The results of the survey indicate that with steel or cast iron piping corrosion was a primary cause of release. This is partially influenced by pipe age, but due to the wide range of responses, pipe age is not the only factor that should be considered (i.e., factors such as soil characteristics and installation practices may also influence leak events).

The API "Tank and Piping Leak Survey" served its purpose in identifying the locations of the leaks in tanks. [1] The additional data obtained during the survey, though not consistently collected or statistically based, provides insight into tank and pipe leak occurrences. Additional conclusions can be derived from these data:

TABLE 3-3. FIBERGLASS TANK LEAKS IDENTIFIED DURING THE API "TANK AND PIPE LEAK SURVEY" (1977-1980)

	Total	Percentage
NUMBER OF RESPONSES	28	
CAUSE OF LEAK	Total	Percentage
Breakage	17	60.7
Other (tank separation)	11	39.3
Subtotal	28	100.0
AGE OF TANK		
0-1 Year	8	29.6
2-5 Years	7	26.0
6-10 Years	11	40.7
11-15 Years	1	3.7
Subtotal	27	100.0
Unanswered	1	
HOW LEAK WAS DETECTED		
Inventory Shortage	15	53.6
Water in Tank	9	32.1
Tank Test	1	3.6
Product in Sewers, Wells, etc.	1	3.6
Other	2	7.1
Subtotal	28	100.0

TABLE 3-4. PIPING LEAKS IDENTIFIED DURING THE API "TANK AND PIPE LEAK SURVEY" (1977-1980)

	Total	Percentage
NUMBER OF RESPONSES	583	
CAUSE OF LEAK	Total	Percentage
Corrosion	353	63.9
Loose Fitting	64	11.6
Flex Connector Failure	38	6.9
Breakage	43	7.8
Other	54	9.8
Subtotal	552	100.0
Unanswered	31	
AGE OF LEAKING PIPING		
0-1 Year	10	2.1
2-5 Years	31	6.4
6-10 Years	158	32.8
11-15 Years	159	33.1
16-20 Years	87	18.1
21-25 Years	24	5.0
26-30 Years	11	2.3
31- + Years	1	0.2
Subtotal	481	100.0
Unanswered	102	
HOW LEAK WAS DETECTED		
Inventory Shortage	261	45.2
Water in Tank	19	3.3
Leak Detector	76	13.2
Line Test	82	14.2
Product in Sewers, Wells, etc.	60	10.4
Other	79	13.7
Subtotal	577	100.0
Unanswered	6	

- Poor installation can contribute to leaks either by inducing corrosion or resulting in loose fittings or tank plugs (in many instances, loose fittings were tightened and not reported on survey forms [1]); and

- Corrosion protection systems can fail as indicated by the 21 leaks reported for steel tanks with sacrificial anodes or impressed current cathodic protect. These failures may be result of a number of factors such as inadequate sizing of the sacrificial anode, improper installation, inadequate maintenance, equipment failure or other reasons.

California Water Quality Control Board, San Francisco Bay Region

In September 1980, a case of ground water contamination associated with underground storage of chemicals was discovered at an electronic components manufacturing plant in Santa Clara County. Subsequently, other plants in the region began to examine their hazardous materials storage practices. As a result of these voluntary materials storage surveys, the California Regional Water Quality Control Board, San Francisco Bay Region, became aware of 21 facilities with leaks of hazardous materials (mostly solvents) from underground tanks and sumps by the end of 1981.

In March 1982, the Regional Board initiated a leak detection program. The purpose of the leak detection program was to determine the overall magnitude of hazardous materials leakage (both product and waste) from underground storage and handling facilities in selected parts of the San Francisco Bay area. This leak detection program was divided into three phases:

- Detection - To determine all sources of hazardous materials leaks to usable ground waters;

- Remedial Action - To identify the extent of leak contamination, take remedial action to prevent further migration, and clean up contaminated ground water; and

- Prevention - To develop construction and monitoring standards for underground storage and handling of hazardous materials.

Activities performed by the Regional Board in each of these phases are as follows:

- Detection - The Santa Clara Valley, Niles Cone, and Livermore-Amador Valley ground water basins are important supplies of potable water within the San Francisco Bay region. Figure 3-1 shows the location of the ground water basins of concern. In April 1982, the Regional Board sent a mandatory questionnaire to approximately 1,400 facilities within the three ground water basins.

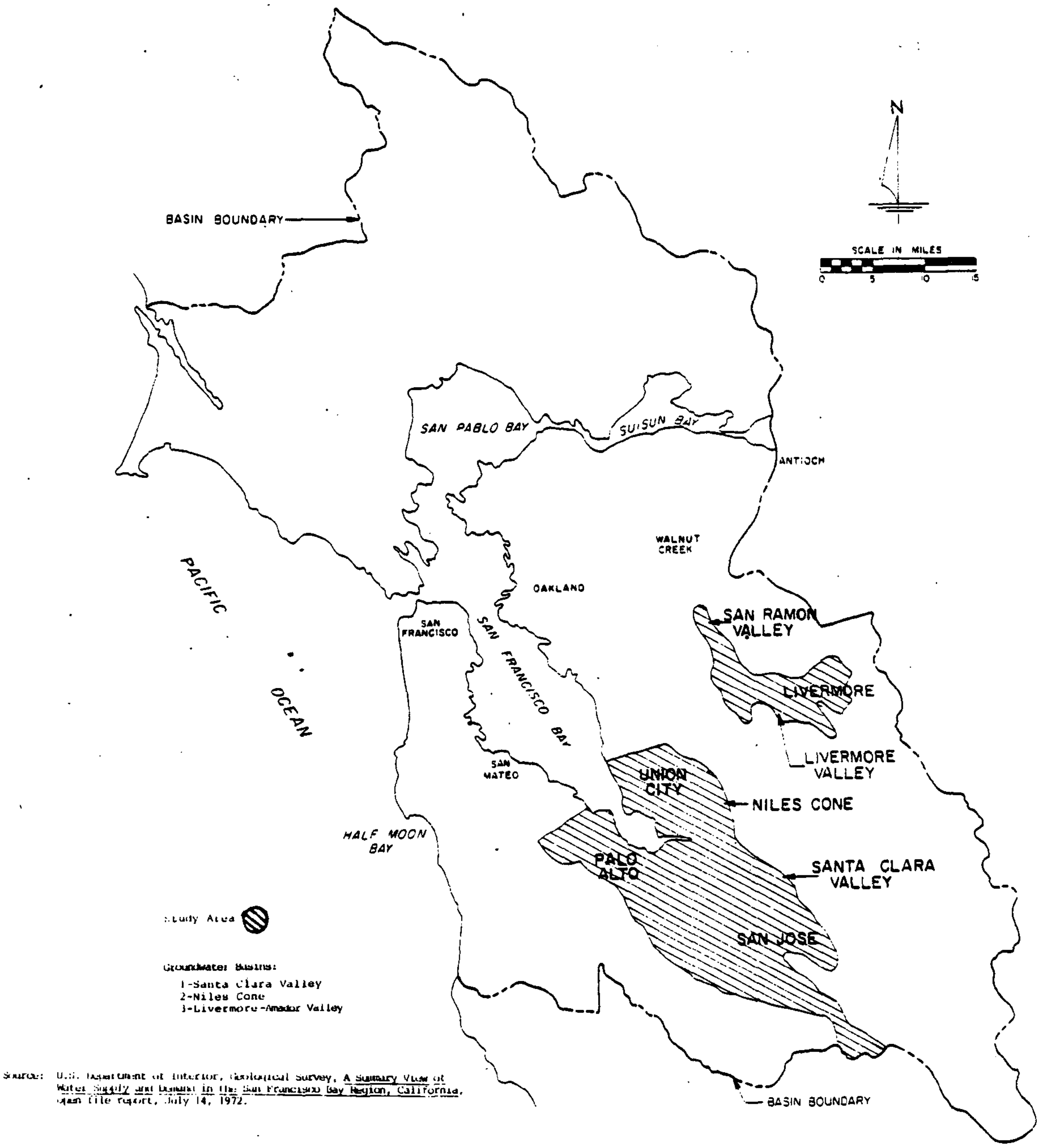

Figure 3-1. Location of ground water basins in the San Francisco Bay area.[4]

cities had enacted major portions of the model ordinance. These eight cities require underground storage facilities, including gasoline stations, to test their tanks for leaks. New or replacement tanks must have concrete vaults or comparable forms of double containment. The Regional Board has also worked to obtain statewide passage of the model ordinance.

The Regional Board is currently nearing completion of Phase I, the Underground Leak Detection Program. A status report summarizing the efforts of the Regional Board from April 1982 to April 1983 is available. [3] Results of corrective actions undertaken at sites with documented subsurface contamination (Phase II) are not yet available. The effectiveness of preventive measures (Phase III) has yet to be determined, since adoption of the model ordinance occurred only recently. Because work on Phases II and III is still in the early stages, results of the program are presented only for Phase I.

As part of the Leak Detection Program, 1,294 out of 1,950 facilities responded to the mandatory questionnaire as of May 1983. Questionnaires for the remaining 656 facilities were either undeliverable (i.e., returned by the Post Office), received by the facility but not completed and returned, due at a later date, or mailed to facilities outside of the study area. A total of 429 facilities indicated that they use or have used underground tanks and/or sumps.

Of these, as mentioned above, 87 facilities with underground tanks and/or sumps were judged to have the highest potential for leaking hazardous materials. As of May 1983, leak monitoring and data interpretation had been completed for 36 of these 87 facilities, with the following results:

No. of facilities	% of 36 Completed	Status
20	56	Contamination due to tank system failure
5	14	Contamination detected; not due to tank system.
11	30	No contamination detected.

Table 3-5 presents a comparison of facility characteristics for the 36 facilities with known monitoring results and the subset of 20 facilities with tank system failures. As shown, the facility characteristics of the sites with tank system failures are comparable to the characteristics of all the sites with known monitoring results. The typical facility has two underground solvent storage tanks and one underground waste solvent tank. Over 80 percent of the tanks are not vaulted and more than one-half are steel. Corrosion protection consists mainly of

Another 550 facilities not included in the original mailing list were later sent questionnaires for a total of 1,950 questionnaires. Based on the responses to the survey, the Regional Board selected 87 facilities judged to have a high potential for leaking hazardous materials, especially solvents, and required these facilities to inititate soil and/or ground water monitoring for underground contamination. The 87 priority facilities are in addition to the 21 ongoing cases discussed above. The Regional Board placed the 87 facilities required to institute subsurface monitoring on either a Priority 1 or Priority 2 list. Priority 1 facilities have or have had either a:

- Non-vaulted buried waste solvent tank(s) without corrosion protection which was placed in operation before January 1, 1975; or

- Concrete sump(s) used for the storage, treatment, separation, or disposal of solvents.

All other facilities which have or have had any product or waste solvent tanks, regardless of installation date or corrosion protection, were included in the Priority 2 list.

- <u>Remedial Action</u> - Currently the Regional Board staff is working with the facilities which reported a detectable level of contamination in the soil and/or ground water. This effort includes the 21 original cases (identified prior to March 1982) and 36 out of the 50 subsurface investigations submitted to the Regional Board as of May 1983. (Fourteen of the 50 facilities were found to have contamination, but the sources were not determined as of May 1983.) The Regional Board is still waiting for results from 37 of the 87 facilities ordered to perform subsurface monitoring.

  Corrective measures undertaken by the industries include:

  - Identification of the lateral and vertical extent of contaminant migration;

  - Actions to preclude further migration of contaminants; and

  - Remedial action to cleanup contaminated ground waters and soils.

- <u>Prevention</u> - The Regional Board staff was actively involved in developing a model ordinance for underground storage and handling of hazardous materials in Santa Clara County. In March 1982, a task force established by the Santa Clara County Fire Chiefs began meeting to develop a model ordinance. Sixteen months later, eight

TABLE 3-5. SAN FRANCISCO BAY REGION QUESTIONNAIRE DATA FOR SELECTED FACILITIES*

Item	36 Facility		20 Facility Subset	
	No. of Tanks	Percent	No. of Tanks	Percent
<u>Unit type</u>				
product storage tank	68	50	48	57
waste storage tank	31	23	22	26
waste treatment tank	17	12	7	8
concrete sump	18	13	8	9
other	3	2	0	0
<u>Vaulted unit</u>				
yes	24	18	12	14
no	113	82	73	86
<u>Unit material</u>				
steel	68	50	49	57
stainless steel	3	2	1	1
concrete	23	17	12	14
fiberglass	9	7	0	0
aluminum	11	8	11	13
other	2	1	2	2
unknown	21	15	11	13
<u>Material contained in unit</u>				
solvents	87	64	59	69
corrosives	2	1	2	2
wastewaters	19	14	6	7
not in use	11	8	9	10.5
unknown	18	13	9	10.5
<u>Unit coating/wrapping</u>				
yes	68	50	53	62
no	34	25	11	13
unknown	35	25	21	25
<u>Unit corrosion protection</u>+				
no	97	71	64	75
sacraficial anodes	1	1	0	0
impressed current	4	3	0	0
unknown	35	25	21	25

TABLE 3-5. (CONTINUED)

Item	36 Facility		20 Facility Subset	
	No. of Tanks	Percent	No. of Tanks	Percent
Corrosion protection maintenance				
yes	3	2	0	0
no	0	0	0	0
unknown	134	98	85	100
Integrity checking of unit**				
yes	57	42	39	46
no	36	26	23	27
unknown	44	32	23	27
Internal inspection of unit				
yes	20	15	12	14
no	117	85	73	86
Ground water monitoring				
no	137	100	85	100
Tank testing				
yes	26	19	24	28
no	111	81	61	72
Inventory monitoring				
yes	24	18	14	16
no	113	82	71	84

* Data for 36 facilities with known monitoring results (as of May 1983) and a subset of 20 facilities with tank system failures. It should be noted that the data presented include all underground tanks reported at the facilities. Information on which tank systems have failed was unavailable.

\+ Other than coating or wrapping.

** Integrity checking of unit indicates that one or more of the following practices was performed prior to receipt of the questionnaire: internal inspection of unit, ground water monitoring, tank testing, inventory control, or another type of integrity checking.

coating and/or wrapping of the tanks. Most facilities report that they do not provide internal inspection of tanks, ground water monitoring, tank testing, or inventory control.

Table 3-6 reports the levels of contamination in the soils and ground water at the 20 sites with tank system failures. The chemicals are grouped by ranges of concentrations as follows:

- Greater than 1,000 parts per billion (ppb);
- Between 500 and 1,000 ppb;
- Between 100 and 500 ppb; and
- Less than 100 ppb.

In most cases the chemicals detected at the 20 sites were various mixtures of a variety of industrial solvents including:

- Acetone;
- Benzene;
- Dichlorobenzene;
- Dichloroethane (DCA);
- Dichloroethylene (DCE);
- Ethylbenzene;
- Freon;
- Isopropyl alcohol (IPA)
- Methyl ethyl ketone (MEK);
- 1,1,1-Trichloroethane (TCA);
- Trichloroethylene (TCE);
- Tetrachloroethylene (PCE);
- Toluene; and
- Xylene.

Although both ground water and soil data were not available for all facilities, these data indicate that both ground water and soil contamination were detected more frequently than either type of contamination alone. At 10 facilities, soil contamination levels exceeded 1,000 ppb for at least one chemical, while 11 facilities had ground water levels over 1,000 ppb. The chemicals detected generally were distributed over a variety of concentration ranges in both media for the 20 sites as a group.

As noted above, questionnaire data on the 21 facilities with leak problems reported prior to initiation of the 3-phased leak control program were not available. In order to incorporate information from these 21 facilities, which pre-date the questionnaire into this report, case studies at two of these facilities were prepared. These case studies, which are presented as Exhibits 3-1 and 3-2, describe the facility characteristics, the environmental setting, the release events and the associated consequences. In combination, leaks from the two facilities resulted in the closing of more than a dozen water supply wells serving about 3,000 people and clean-up costs which are currently estimated at about $20 million and are continuing. Numerous law suits have been filed in an attempt to establish responsibility for the leak and to require payment of compensatory damages.

TABLE 3-6. CONTAMINATION FOUND AT 20 SITES IN SAN FRANCISCO BAY AREA WITH TANK SYSTEM FAILURES*

	SOIL (PPB)				GROUNDWATER (PPB)			
Facility	>1000	500-1000	100-500	<100	>1000	500-1000	100-500	<100
1	Bis-2-ethylhexyl-phthalate	Ethylbenzene	Naphthalene	Benze(a)pyrene	ND+	ND	ND	ND
2	ND	ND	MEK	ND	MEK IPA Cellosolve Cyclohexanone	ND	ND	ND
3	NT#	NT	NT	NT	IPA	ND	ND	ND
4	ND	ND	Cyanide	ND	NT	NT	NT	NT
5	IPA	Dichloromethane	ND	Acetone	ND	ND	ND	ND
6	**				TCA TCE IPA	ND	ND	ND
7	ND	ND	ND	TCA TCE DCE Toluene Methylene Chloride	Benzene Chlorobenzene 1,2-Trans-DCE Ethylbenzene Methylene Chloride Toluene TCE 1,1,2-Trichloro-1,2,2-Tri-flouroethane Methylcyclohexane	TCA	ND	ND
8	Methylene Chloride MEK Acetone	ND	ND	ND	Methylene Chloride MEK Acetone DCE Ethylbenzene Methylene Chloride	ND	ND	ND
9								

TABLE 3-6. (CONTINUED)

	SOIL (PPB)				GROUNDWATER (PPB)			
Facility	>1000	500-1000	100-500	<100	>1000	500-1000	100-500	<100
10	ND	ND	ND	TCA Xylene	Trans-1,2-DCE	1,2-Dichloro-1,2,2-Tri-fluoroethane	1,1,2-Trichloro-fluoroethane TCE	Vinyl Chloride 1,1-DCE
11	ND	ND	ND	ND	MEK	ND	ND	ND
12	MEK Cyclohexanone IPA	ND	ND	ND	MEK Cyclohexanone IPA Acetone Xylene	ND	Toluene Freon	TCA TCE
13	ND	ND	Toluene	ND	Ethylbenzene Xylene TCE Chlorobenzene Toluene	Dichlorobenzene	ND	PCE Benzene DCE DCA Freon
14	Trichlorobenzene Dichlorobenzene	ND	TCE Freon	PCE TCA	ND	TCE Freon	ND	PCE Hexane Acetone Ethyl Benzene Toluene Benzene
15	Phenol Methanol TCA IPA Xylene n-Butyl Acetate	ND	Acetone	Trichloro-fluoroethane Methylene Chloride				
16	Stoddard Solvent	ND	ND	ND				
17	TCE Xylene	Freon	ND	ND	ND	ND	ND	ND
18	ND	ND	ND	ND	Diesel Naptha Xylene Toluene Cellosolve Acetate	MEK	ND	ND

TABLE 3-6. (CONTINUED)

	SOIL (PPB)				GROUNDWATER (PPB)			
Facility	>1000	500-1000	100-500	<100	>1000	500-1000	100-500	<100
19	Dichlorobenzene Freon TCE PCE	DCE	ND	Chloroform TCA	ND	Xylenes	Ethylbenzene TCE	DCE PCE
20	Methylene Chloride Oxybisethanol Heptanone	ND	ND	Xylene Cyclopetnane	Methoxyethanol Methoxypropanol Methylene Chloride Caprolactum Hexanoic Acid Hexanol	Heptanol	Octanol	Acetone Other Heptanols

* See Table 3-5 for additional information on these facilities

+ Not detected

Not tested

** Blank indicates that data were not available as of May 1983

Key to abbreviations:

DCA = Dichloroethane

DCE = Dichloroethylene

IPA = Isopropyl alcohol

MEK = Methyl ethyl ketone

PCE = Perchloroethylene (tetrachloroethylene)

TCA = 1,1,1-Trichloroethane

TCE = Trichloroethylene

In summary, the Regional Board has discovered numerous leaks of solvents from underground storage systems in the San Francisco Bay Region and more are expected to be found. The Regional Board has nearly completed the first phase of its program to identify, correct, and prevent chemical leaks from underground storage systems. As of May 1983, tank system failures had released solvents into the soil and/or ground water at 41 sites (21 sites were identified before the questionnaire was developed and the 20 sites shown in Table 3-5). This represents 72 percent of the 57 facilities with know monitoring results as of May 1983, and nearly 10 percent of the 429 facilities found by the survey to use underground tanks or sumps in the Santa Clara Valley Region.

Remedial measures at these facilities and at other sites where contamination has been detected but not linked with tank system failures are continuing. The Regional Board judged the potential hazards associated with leaks to be high enough to support efforts to develop and enact ordinances at the local level and to assist in the development of legislation statewide to regulate underground tanks storing hazardous materials.

Cape Cod Planning and Economic Development Commission

After completing their 208 Water Quality Management Plan in 1978, the Cape Cod Planning and Economic Development Commission (CCPEDC) developed a number of model ground water protection by-laws and regulations as guidelines for a ground water protection program. Since May, 1980, 14 of the 15 Cape Cod communities have adopted one or more of these ordinances which have resulted in various levels of requirements such as tank registration, tank inspection and zoning restrictions in ground water recharge areas. Since enactment of these ordinances, eight of the more than 159 underground tanks tested were found to be leaking (information on the details of these leak events was unavailable). A telephone conversation with the local health official in Barnstable, Massachusetts revealed that many of the larger oil companies replaced the steel tanks at their service stations as soon as the ordinances were passed. [4]

Maryland Petroleum Association, "Prince George's County, Maryland, Tank Testing Program"

In 1977 The Prince George's County (P.G. County) Government passed legislation requiring tank and piping system testing for tank storage facilities in response to a number of gasoline leak incidents at service stations in the County. Although P.G. County does not maintain statistics on its tank testing program, the Maryland Petroleum Association compiled the results of tests conducted on underground tank systems as of January, 1978.

These data are presented in Table 3-7 and represent the results of Petro-Tite (Kent-Moore) testing of service station tank systems. (Note: Even though piping system testing was included in these tests, no distinction between tank and pipe leaks was made in the available statistics.) It is important to note that only petroleum products and waste oils associated with service stations are stored underground in P.G. County and that all of the tanks tested as of January, 1978 were more than 10 years old. [6]

As shown in Table 3-7, 18 percent of the tank systems tested by the Petro-Tite method were indicated to be leaking. Further investigation of these 108 tanks revealed 61 "verified" leaks (10 percent versus 18 percent of tanks tested). (Note: Information on how leaks were verified could not be obtained.) These data indicate that the tank testing method used (under circumstances of application and verification about which little is known) was, at best, about 50 percent accurate. However, the testing approach used did identify a significant number of leaking tanks which were subsequently removed from service or reconditioned.

Michigan Department of Natural Resources

As a result of a growing number of reports of spills and leaks from underground storage of petroleum fuels and an increasing awareness of the potential for ground water contamination, the Michigan Department of Natural Resources (DNR) undertook an investigation to evaluate the problems associated with the underground storage of petroleum fuels. This evaluation resulted in a report which was released in September 1981, and contained information pertaining to spill and leak events in the State. [7]

Approximately 25,000 underground commercial fuel tanks are in use in the State. These do not include abandoned, private or underground bulk storage tanks. As reported in Michigan's Pollution Emergency Alerting System (PEAS) files, a total of 396 reports of pollution of soils and/or groundwater by petroleum fuels from underground tanks were submitted from 1977 to 1978. A breakdown of these reports showed 30 percent were due to overfilling, 26 percent were leaks from underground tanks, 9 percent were pipe leaks, and 36 percent from unknown sources. Another study completed in 1978 that assessed ground water contamination in Michigan, showed that 21 percent of the 268 known ground water contamination sites "involved petroleum contamination either known or suspected to be from underground tanks". [7]

The data presented above only represents releases reported over a two year period. On-going work by the DNR is finding that more releases are reported from the discovery of gasoline in drinking water wells, subsurface construction sites and buried cable systems than from reports of spills or product loss from tanks. [7] This leads one to believe that the study conducted may have only identified a small portion of the total number of leaking tanks. In addition, it should also be noted that while 30 percent of the reported cases are due to tank leaks and 9 percent of the reports are due to pipe leaks, it is plausible that many of the reported cases from unknown sources are also likely to be due to one of these two events.

TABLE 3-7. PRINCE GEORGE'S COUNTY, MARYLAND TANK TESTING PROGRAM RESULTS FOR UNDERGROUND GASOLINE TANKS AS OF JANUARY 1978.

	Number	Percent
Tank systems tested	604	40*
Tank systems that failed the test	108	18
Number of verified leaking tank systems (56 percent accuracy of test results)	61	10

* All tanks tested as of January 1978, were more than 10 years old. The tested tanks represent approximately 40 percent of all underground commercial gasoline tanks in the County, based on extrapolation from an average of 3.72 tanks per station for 310 (with known numbers of tanks) of the total 406 stations in the County.

Participating: Amoco, BP, Cities, Crown Central, Exxon, Gulf, Mobil, Phillips, Shell, Sun, Texaco and Tenneco

Source: Maryland Petroleum Association. [4]

New York Department of Environmental Conservation

The New York Department of Environmental Conservation (DEC) undertook a two-year bulk storage study program in an effort to reduce petroleum and hazardous liquid leaks and spills into the environment. As part of their program, information was compiled on the number of underground tanks in the State and the incidences of well contamination by gasoline. Additional data pertaining to oil spills reported in 1979 were also included, but no distinction was made between underground and aboveground tank incidences.

The DEC estimates that there are 83,000 functioning underground tanks in the State and that 20 percent of these currently leak. The methods used to derive these estimates are presented in Appendix I. In addition, the State expects that many of the estimated 28,000 underground tanks that have been abandoned over the past 10 years contain materials (primarily gasoline) which, if the tanks are steel, will leak once the tanks corrode. [8]

In a 1979 survey of local health units in New York, 187 wells were reportedly contaminated by gasoline. The information obtained from this survey is presented in Table 3-8. [8]

The work that New York has conducted to date shows that a significant number of wells have been contaminated as a result of leaks from underground storage facilities (primarily petroleum). These figures, which are four years old and do not cover the whole state, combined with the estimated number of current leaks, indicate that more well contamination incidents may have already occurred or will occur in the future.

Suffolk County, New York

In September, 1979, Article 12 of the Suffolk County Sanitary Code was enacted to control ground water contamination resulting from the storage of hazardous materials in underground and aboveground tanks. As a result of the permitting, inspection and testing program subsequently conducted by the Suffolk County Department of Health Services, the information presented in Table 3-9 was obtained for underground tanks. [9]

These data represent the results of the first phase of regulation implementation conducted from 1980 to 1982 for all tanks 20-years old or older. Additional phases of implementation are currently underway which will eventually result in the permitting, inspection and testing of all tanks in the county.

As shown above, of the 4554 underground tanks registered (primarily petroleum product storage tanks) as of December 1982, 1024 privately-owned and 82 county-owned tanks over 20 years old had been tested. The test results showed that approximately 10 percent (98 privately-owned and 15 county-owned tanks) of the 20-years old or older underground storage tanks were leaking. If piping system leaks were included in these statistics the number

TABLE 3-8. SOURCES OF WELL CONTAMINATION BY GASOLINE AS REPORTED IN A SURVEY OF LOCAL HEALTH UNITS IN NEW YORK IN 1978*

Sources of Contamination	Number of Incidences	Percent of Total
Gasoline Stations	94	50
Buried Gasoline Tanks at Sites Other Than Gasoline Stations	16	8
Other**	24	14
Unknown	53	28
TOTAL	187	100

* Data from 13 counties in the state were not included in this survey.

** Includes contamination from other sources such as transfer spills, tank truck accidents, etc...

TABLE 3-9. RESULTS OF SUFFOLK COUNTY, NEW YORK Tank Testing Program as of December 1982.

Privately owned tanks tested*	1,024
Privately owned tanks leaking	98
County owned tanks tested*	92
County owned tanks leaking	15
Percent of total tanks leaking	10
Tanks registered as of December 1982 (includes all tanks all ages)	4,554

* All tanks tested were >20 years old and almost all were steel. Tanks were tested using the Petro-Tite (Kent-Moore) test under the supervision of Suffolk County Department of Health Services Personnel.

(Source: Article 12, Suffolk County Sanitary Code Statistics (December 1982)) of leaking systems would be closer to 30 percent. [10] (Note: Statistics on piping system leaks were not available.) Specific information as to the causes, volumes, durations or impacts of these leaks was not available.

As noted above, the implementation of Article 12 has resulted in the discovery of a number of underground storage system leaks, the majority of which can be attributed to piping system leaks. As a result of the efforts of Suffolk County Department of Health Services, these leaks have been remedied and a number of tanks (911) have been removed or abandoned. However, it can be assumed that additional leaks will be discovered at facilities not yet tested, even though the remaining universe of tanks is less than 20 years old. (This assumption is supported by work conducted by Warren Rogers Associates [2] (see Appendix J) which indicates that tank age is not the principal factor controlling when a tank will begin leaking.)

CONCLUSIONS

The reports, studies and papers presented in this section, though not all-inclusive, document a number of cases of leaks from underground storage facilities as shown. (Note: A majority of these cases are product related (primarily petroleum) due to the historical awareness of the costs associated with product loss.) The following conclusions can be drawn from the information reviewed.

- A large number of leaking underground storage tank systems have been discovered (primarily petroleum product storage) over the past 6 years, and indications are that many more will be discovered in the future as investigations continue and awareness increases. This is supported by the efforts in the San Francisco Bay Region where investigations showed that 72 percent of the facilities tested (with test results available as of May 1983) had one or more leaking tank systems (see Table 3-10).

- Due to the range of percentages of leaking tank systems to tank systems tested (see Table 3-10), it is difficult to draw quantitative conclusions as to the extent of the problem of underground storage.

- Once a leak occurs it may go undetected for years and may result in clean-up costs totalling in the 10's of millions of dollars, as evidenced by the case studies presented in this section.

- The impact from underground storage releases may be effected significantly by the geologic conditions of the area.

TABLE 3-10. SUMMARY OF REPORTED TANK SYSTEM LEAKS

Source	Number Tank System Leaks Reported	Number of Tank Systems Tested	Tank System Leaking Tank System Tested %	Universe of Tank System
API "Tank and Pipe Leak Survey (Petroleum Products)	1,953	Unknown	NA	Unknown
California Regional Water Quality Board, San Francisco Bay Region Statistics[2]	41	57	72	429
Cape Cod Area Statistics (Petroleum Products)	8	159	5	Unknown
Michigan DNR "Underground Gasoline Storage Study"	452	Unknown	NA	25,000
New York DEC Statistics (estimates)	16,000 (estimated)	NA	20 (estimated)	83,000 (estimated)
Prince George's County, Maryland 1977 Statistics (Petroleum Products)	61	604	10	Unknown
Suffolk County, New York Statistics (Petroleum Products)	103	1,116	9	Unknown

1) Tank systems include both tanks and pipe leaks for a facility with one or more underground storage tanks.

2) These values represent the number of facilities with one or more tank systems. The number of tank systems per facility is unknown (these range from 1 to >100 underground tanks per facility) and the number of leaking systems per facility is unknown.

In addition to the figures presented in Table 3-10, Warren Rogers Associates, which has collected data from approximately 10,000 gasoline tank storage sites in the United States and Canada, estimates that there are currently 75,000 leaking gasoline storage tanks in the U.S. [11]

If one assumes that many of the existing underground hazardous waste storage facilities employ similar storage practices (i.e., unprotected steel tanks and piping), an assumption which appears to be confirmed by available data, the potential for similar problems occurring is probably significantly higher than for gasoline unless installation methods and designs are improved. This is based on the assumption that hazardous waste storage facilities store a variety of wastes, some of which may be corrosive or incompatible with tank materials used at the facility. This increases the chances of operator error (e.g., storing waste in the wrong tank or not testing a waste to determine which of the several tanks to store it in) and, as a result, increases the possibility of tank failure.

EXHIBIT 3-1

SITE A STORAGE SYSTEM FAILURE DAMAGE CASE SUMMARY

FACILITY INFORMATION

Site A manufactures electronic components (SIC 367) and uses a variety of solvents or solvent-based chemicals in the manufacturing process including:

- Acetone;
- 1,1-Dichloroethylene (DCE);
- Freon 113; o Hexelmethyldisilane (HMDS);
- Isopropyl alcohol (IPA);
- Methyl alcohol;
- 1,1,1-Trichloroethane (TCA); and
- Xylene

Waste solvents generated by the manufacturing operations are stored in one of three ways, as follows:

- Containers -- A variety of strippers with propriety formulations supplied by outside vendors are used in the manufacturing process. Since the specific chemical formulations of these materials are not known by operating personnel at Site A, waste strippers are seg- regated for storage by using containers to avoid potential compatability problems.

- Small waste tank -- Most mixing of chemicals for use in the production process occurs in one area of the plant. In this area, containers in which chemicals are received are cleaned so that they can be disposed in a sanitary landfill. Waste from the container washing process are stored in a 550 gallon underground tank.

- Large waste tank -- Formerly, waste solvents generated throughout the plant were collected from sink drains with a gravity piping system and stored in a 6,000 gallon underground fiberglass tank. Following failure of this tank, which is the subject of this damage case discussion, waste solvents have been stored in a temporary 1,000 gallon tank.

ENVIRONMENTAL SETTING

Site A is located in a suburban area adjacent to a major city and is surrounded by residential neighborhoods and small farms. Shopping centers, park land, and other industrial facilities are also situated in the immediate vicinity. The site lies in a valley approximately 210 feet above sea level between a ground water recharge area and several water supply wells.

The geology of the broad alluvial valley surrounding Site A is the result of active stream erosion and deposition. Streams flowing out of the highlands and into the valley have deposited large quantities of debris as alluvial fans and outwash plains. The alluvial sediments range in thickness from zero along the hills bordering the valley to 400 feet in the center of the valley. These alluvial fan deposits are very permeable, and the discontinuous clay beds in the area are poor barriers to vertical ground water migration. The large number of high production (over 1,000 gpm) water wells reflects the permeability of the alluvial sediments. Within a one-mile radius of Site A, there are 25 active or potentially active water supply wells.

The alluvial deposits at Site A vary in thickness from 330 to 360 feet and contain four aquifers. The aquifers are designated "A", "B", "C", and "D" with increasing depth from the ground surface, as follows:

Aquifer	Approximate Depth Below Ground Surface (Feet)
"A"	30 - 50
"B"	60 - 100
"C"	150 - 190
"D"	220 - 270

All four aquifers average approximately 40 percent sand and gravel over their total depth. These deposits are separated by silt and silty clay layers ranging from a few feet to 60 feet in thickness. Aquifers "A", "B", and "C" have percentages of silt and clay varying between 3 percent and 19 percent. Aquifer "D" has a slightly higher silt and clay content. Although the silt and clay layers separating the aquifers at the site are discontinuous, they cause ground water to flow primarily in a horizontal direction.

Primary recharge to the aquifers under Site A comes from infiltration ponds along a creek situated approximately 4,000 feet to the east. Ground water elevations indicate a local flow to the west, except when irrigation wells north of Site A cause the flow to be in a more northwesterly direction. A well owned by a local water company that is part of a drinking water supply system for about 700 residents is located approximately 2,000 feet northwest of Site A. Thus, ground water flow from the primary aquifer recharge area passes through Site A toward drinking water sources.

Recharge to the aquifers in the region also occurs by infiltration of irrigation water applied to lawns and agricultural lands and by percolation of percipitation. The estimated direct recharge from irrigation water is small relative to recharge from the percolation ponds. Average annual precipitation for the site area is moderate. (Seasonal rainfall at a nearby weather station averages 14.2 inches (360 millimeters) per year.)

RELEASE FACTS

As a result of construction activities unrelated to Site A, waste solvent storage tanks, solvent contamination of soils and subsequently ground water was discovered. Follow-up investigations identified a 6,000 gallon fiberglass waste solvent storage tank as the source of the solvent contamination. Visual inspection of the tank following excavation revealed that the tank walls had deteriorated to the extent that in some areas only the reinforcing ribs remained. The cause of this tank wall failure has not been determined and is currently under litigation.

The duration and maximum magnitude of the leak has been estimated at 1-1/2 years and 58,000 gallons, respectively, based on a mass balance analysis of solvent purchase and waste removal records. Ideally, a mass balance analysis can be performed by matching the total mass of materials entering a fixed system with the total mass of all materials leaving the system plus any accumulation. However, correlation of solvent purchased with waste solvent removed is difficult under real industrial conditions for several reasons. First, solvent is usually purchased well in advance of the time it is actually used. Second, waste solvent is not removed until the holding tanks or drums accumulate a specified volume. Moreover, some solvent remains either in the original container or on the surfaces of the material cleaned. Thus, mass balance variances of 5 to 10 percent can be expected due to these factors. In addition, approximately 11 percent of all solvent is lost through evaporation.

Table 1 summarizes the results of the mass balance analysis conducted for Site A. As shown, essentially all of the solvent purchased at Site A is accounted for during years 1 to 4-1/2 and year 6. However, an imbalance between "solvents used" and "total out" began in the middle of year 4 and continued until the leak was detected near the end of year 5. During this 1-1/2 year period, the facility can account for the removal of only 43 percent of the solvents used. Thus, the maximum amount of solvent lost appears to equal 57 percent of the total solvent used or approximately 58,000 gallons. The amount of 1,1,1-trichloroethane (TCA) used is included in the table since high concentrations of this solvent were found in the soil and ground water at Site A, as described later in this report.

During the year following the discovery of the leaking tank, Site A had approximately 76 wells drilled on and off their property to determine the areal extent and severity of contamination resulting from the tank leak. In addition to 28 on-site and 40 off-site observation wells, there were 5 on-site and 3 off-site pumping wells installed. The facility also performed sampling at 9 nearby irrigation and drinking water wells. Since ground water flow at Site A moved in a westerly to northwesterly direction, the wells radiated out from the facility in this direction (downgradient) for a distance of approximately 1 mile from the site.

TABLE 1. SOLVENTS USED v. SOLVENTS REMOVED AT SITE A (IN GALLONS)

Year	Months#	Solvents Used* Total Solvents Used	(TCA)##	Solvents Removed** Drums	Bulk	Evaporation+	Total Out++	Solvents Lost %
1	1-12	1,587	62	Ø	Ø	175	175	
2	13-24	9,755	79	2,875	5,040	1,073	8,988	
3	25-36	18,081	327	4,260	8,758	1,989	15,004	
4	37-42	16,952	671	14,814	5,000	1,865	21,680	
SUBTOTAL		46,375	1,139	21,949	18,798	5,102	45,849	1
4	43-48	35,726	386	19,032	1,400	3,930	24,360	
5	49-60	66,720	3,570	9,465	2,904	7,339	19,708	
SUBTOTAL		102,446	3,956	28,497	4,304	11,269	44,068	57
6	61-72	19,068	3,614	6,750	9,425	2,097	18,272	4

* Based on three-month moving average of solvents purchased.
** Based on date solvent accumulated for removal.
\+ Estimated
++ Quantity accounted for by removal or evaporation
\# Consecutive from facility startup.
\## I,I,I-Tri-chloroethane

A variety of well drilling and construction methods were employed at Site A. Borings were drilled by either a continuous flight, hollow stem auger; a mud rotary rig; the reverse circulation drilling method; or the caisson auger technique. Various diameters of steel and PVC casing were used in the wells. Although different types of well casings and other construction methods may affect the accuracy of sampling results, no information was available on how these factors may have affected the analytical results.

Ground water level measurements were taken using a Soil Test M-scope. Most ground water samples were obtained using a submersible bladder, and in a few cases a teflon bailer was used. Analysis of the ground water was performed in accordance with EPA Standards. Soil samples were taken with splitspoon and auger return samplers. Physical testing of the soils included moisture content, dry density, liquid limits, plastic limits, grain size distribution and permeability. Chemical testing of the soils involved several methods. Most soil samples were analyzed by purge and trap/gas chromatography/flame ionization detection (PAT/GC/FID). Some were analyzed by purge and trap/gas chromatography/mass spectrometry (PAT/GC/MS) for quality control or improved quantification.

Results of this ground water and soil chemical testing program revealed a solvent (especially TCA) plume in aquifers "A", "B", and "C" which extended approximately 4,500 feet west-northwest of the site with a maximum width of about 2,000 feet. The highest concentrations of solvents in the soil and in the ground water were obtained from auger caisson borings 32 to 38 feet below the ground surface and from aquifer "A" monitoring wells located within 50 feet of the former waste solvent tank, respectively. Table 2 reports the mean solvent concentrations found at Site A within 50 feet of the tank that failed.

REMEDIAL MEASURES

Remedial measures undertaken at Site A included on-site and off-site work. The on-site remedial effort included removal of soils in the area of the former waste solvent storage tank since these contaminated soils had the potential to act as a continuing source of solvent to the ground water system. In addition, a series of ground water purge wells were installed to hydraulically contain solvents on-site. The off-site remedial plan involved the placement of a four-tiered ground water purge well system to reduce the width and length of the solvent plume. This series of redundant recovery wells was designed to lower the concentration of TCA which had contaminated and resulted in the closure of the drinking water well located 2,000 feet from the faulty tank. The well system also was installed to prevent TCA from reaching another drinking water well situated approximately 6,000 feet in a hydraulically downgradient direction.

TABLE 2. MEAN SOLVENT CONCENTRATIONS FOUND IN THE SOIL AND GROUNDWATER AT SITE A (PPM)*

	Soil (Dry Weight)	Ground Water (Wet Weight)
1,1,1-Trichloroethane (TCA)	1,000	540
Xylenes and ethyl benzene	600	80
Acetone	1,000	25,000
Isopropanol (IPA)	3,000	43,000
Freon 113		.18

* Solvent concentrations found within 50 feet of the tank that failed.

The augered caisson method was considered to be the only cost-effective way to remove the soils surrounding the former leaky tank. Open excavation would have undermined the building footings at Site A and the use of tie-back pilings was considered too risky and costly. The soil removal area extended approximately 50 feet wide by 65 feet long and 52 feet deep. The estimated 3,400 cubic yards of soil removed and transported to a Class I disposal site contained an estimated 38,000 pounds of solvent.

Water pumped from the ground water purge wells located on the periphery of the soil removal area was loaded into tank trucks and hauled to a licensed off-site disposal facility. Pumping the other on-site recovery wells which are downgradient of Site A near the property line lowered the water levels in observation wells beyond the solvent plume. Water from these wells is treated by carbon absorption and discharged to a nearby creek via storm sewers. TCA concentrations at one of these wells decreased from 6.8 ppm to 0.55 ppm after the first three months of pumping. However, the length of time required to reduce the solvent concentrations in the on-site ground water purge system to stable and acceptable levels is unknown.

The offsite drinking water supply well that was closed because of solvent contamination was returned to service as a ground water purge well. Water from this well was treated by a carbon absorption system at Site A and discharged to storm sewers. Treatment of ground water from this well was stopped after one year when TCA concentrations fell sharply and met discharge permit discharge limits. The state has yet to determine what residual level of TCA is acceptable for drinking water. Presently the state's action level for TCA in the ground water is 0.3 ppm.

Data from the tiers of other off-site ground water recovery/observation wells indicated a reduction of solvent concentrations within the plume and a reversal of downgradient migration. The one aquifer "A" well located near the second tier of the ground water purge system rarely showed any detectable levels of chemicals. Solvent concentrations in the "B" aquifer decreased by approximately one order of magnitude from the first tier to the third tier of off-site observation wells about 3,000 feet apart where TCA levels dropped to less than 0.005 ppm after one year of pumping. The highest TCA concentration measured in the off-site "B" aquifer decreased from 11 ppm to 0.12 ppm after less than 12 months of pumping. The greatest TCA level in the off-site "C" aquifer was found approximately 3,400 feet from the faulty tank and dropped from 0.23 ppm to 0.15 ppm in less than a month of ground water purging. Concentrations of TCA recorded for aquifer "D" off-site wells never exceeded the permit limit and most were not detectable. Freon and DCE were the only solvents other than TCA detected off-site. The maximum levels of freon and DCE were recorded in aquifer "B" about 1,000 feet from the waste solvent tank at 0.026 ppm and 0.047 ppm, respectively.

As of May 1983, remedial measures involving purge well pumping and treatment of the extracted ground water were continuing. Completion of these activities is dependent on state agency acceptance of aquifer water quality, but may be accomplished by the end of 1983.

RELEASE CONSEQUENCES

As of May 1983, Site A had spent an estimated $12 million over 1-1/2 years on cleanup of the contamination, and costs continue to be incurred. Although pollution levels have been reduced significantly as a result of remedial measures, engineers agree that pumping will probably never completely remove the contaminants from the aquifers.

One drinking water supply well located about 2,000 feet from the leak site, which served 700 residents, was closed because of high TCA concentrations. Several individual water supply wells were also closed, and the leak may also have resulted in minor contamination of another major drinking water source about 6,000 feet from the tank.

The spill also spawned a multimillion-dollar lawsuit by nearby residents who have charged the site with negligent contamination and with being the cause of numerous birth defects in the neighborhood. Site A maintains that no scientific link has been established between its leak and the alleged high number of birth defects in a nearby neighborhood. TCA, the solvent found in the drinking water well at concentrations far exceeding the state's recommended level, is an organic that can cause damage to the central nervous system, the liver and the cardiovascular system if ingested in large doses. In addition, it can cause loss of coordination, eye irritation and dizziness. The National Toxicology Program concluded in a recent draft report that TCA is a liver carcinogen in mice but not in rats.

SUMMARY

Lack of inventory and/or environmental monitoring, tank inspection or tank testing programs at Site A allowed a waste solvent storage tank leak to go undetected for approximately 1-1/2 years. The leaked material contaminated soil and ground water. As a result of the duration and size of the leak and the hydrogeology of the site, transport of the contamination into three aquifers and over an area of about 1/3 square mile occurred.

One drinking water well serving a total of about 700 people, several private wells, and possibly another public drinking water well were closed because of contaminants found in the wells. Cleanup costs have exceeded $12 million and are continuing. These efforts have been effective in reducing levels of ground water contamination. In addition, law suits concerning damages resulting from consumption of contaminated ground water have been filed.

EXHIBIT 3-2
SITE B STORAGE SYSTEM FAILURE DAMAGE CASE SUMMARY

FACILITY INFORMATION

Site B manufactures electronic computing equipment (SIC 3573), semi-conductors and related devices (SIC 3674) and uses numerous underground tanks for the storage and treatment of process chemicals and industrial wastes. Site B has over 100 underground tanks or concrete sumps and about 190,000 feet of underground piping. The tanks are constructed of a variety of materials, including carbon steel, stainless steel, fiberglass, and polypropylene. Information on piping materials in use was unavailable.

Of the 32 existing underground product storage tanks at Site B, 26 (81 percent) are vaulted (i.e., located in a concrete vault). Nearly all of the vaulted product storage tanks are 6,000 or 7,000 gallon capacity, are constructed of stainless steel, and are less than six years old. Chemicals stored in these vaulted tanks include:

- Acetone;
- Ethyl amyl ketone (EAK);
- Freon 113;
- Isophorone;
- Isopropyl alcohol (IPA);
- Kerosene; and
- Nitrogen.

The remaining eight product storage tanks (19 percent) are non-vaulted. The typical non-vaulted tank at Site B has a capacity less than 3,000 gallons, is made of carbon steel, stores gasoline, and was installed more than 10 years ago.

Of the 31 existing underground waste storage tanks at Site B, 28 are vaulted. Most of the vaulted tanks are made of steel, are less than 5 years old, have a capacity of several thousand gallons, and contain waste solvents such as acetone; EAK; freon; IPA; isophorone; 1,1,1-trichloroethane (TCA); 1,1,1-trichloroethylene (TCE); or xylene. The three non-vaulted waste storage tanks are older than the vaulted tanks and have smaller capacities.

Site B has 49 existing treatment tanks or concrete sumps. About one-half of the treatment units are vaulted tanks and one-half are concrete sumps. In addition, there are two nonvaulted treatment tanks. A typical vaulted treatment unit has a 1,000 gallon capacity, is fiberglass, and is less than six years old. The concrete sumps tend to be older than the treatment tanks and range in capacity from 150 to 10,000 gallons.

The facility has removed, abandoned, or relocated about 64 additional tanks or sumps, and more than 3,000 feet of piping.

Some of these units were removed from service as a result of contamination detected near the units. Reasons for discontinuing use of other units are not known. Of the six areas where sources of contamination have been detected at Site B, five have resulted in the removal of underground storage units and the excavation of surrounding soils. These areas include:

- Tank Farm A;
- Tank Farm B;
- Building 14 chemical waste transfer sump;
- Building 25 ink waste tank; and
- Building 100 chromic acid tank.

The three cases of documented ground water contamination at Site B are Tank Farms A and B and the area surrounding Wells A-30 and A-31. Remedial actions at the other three areas appear to have prevented migration of chemicals into the ground water.

Following is a presentation of the known facts concerning tanks removed because of associated contamination. (Note: The excavated tanks and related underground equipment were not all leaking. The corporate practice manual for Site B concerning containment of industrial liquids requires that underground systems with actual or potential leaks be replaced in accordance with the most stringent government regulation, safety and fire protection requirements, or other corporate standards and practices. The Site B corporate practice states that all newly constructed or replaced facilities storing solvents underground shall have secondary containment. The definition of secondary containment is one layer each of chemical/physical resistant coating and liner or two single layers of liner which are applied to or supported by an appropriate structure.)

- At Tank Farm A, 17 non-vaulted solvent tanks and one 2000 gallon non-vaulted waste solvent tank were removed after 11 years of operation. One 24,000 gallon concrete vault containing mixed solvent waste was also removed after five years of use. All units were monitored by level gauges and, except for the concrete tank, were constructed of asphalt-coated carbon steel with capacities between 2,000 and 10,000 gallons, with a median capacity of 2,000 gallons. Solvents stored included acetone, EAK, IPA, isophorone, kerosene, sodium hydroxide, petroleum naptha 365, and 1,1,1-trichloroethane (TCA). The specific cause of the leaking tanks at Tank Farm A is unknown, but possible sources may be attributed to improper disposal of the chemicals or past operational problems. It is unknown how the leaks were discovered.

- At Tank Farm B, nine solvent and six waste solvent underground storage tanks were removed after less than eight years of operation. Six of the tanks were excavated after about three years of use. These six tanks (five product and one waste) each had a capacity of 2,700 gallons and were double-walled with an inner wall of stainless steel and an outer wall of carbon steel. The remaining tanks ranged in size from 1,000 to 5,000 gallons, were constructed of stainless steel or carbon steel with cathodic protection, and were provided with vapor detectors. Chemicals stored included acetone, IPA, freon, methylene, chloride, N-methyl-2-pyrrolidone, and mixed solvents. During excavation of the tanks, a drainline from one of the mixed solvent waste tanks was found to be severely corroded. Just prior to excavation, however, the tank and drainline were tested and revealed no problems.

- At Building 14, the 440 gallon capacity concrete waste transfer sump and its liner were replaced after approximately nine years of operation. Elevated levels of chromium had been found in soil samples taken from outside the building. However, these levels were thought to be due to the mineral content of backfill material brought on-site during construction of Building 14, rather than tank or piping leaks.

- At Building 25, the 4,000 gallon capacity ink waste tank and the surrounding soils were excavated six years after installation. The excavation appears to have stopped inks from migrating to the ground water. Information on the cause of the leak and how it was discovered was unavailable.

- At Building 100, the 1,000 gallon capacity concrete tank with a plastic liner to hold chromic acid waste was abandoned six years after installation and removed four years after abandonment. During removal a total of about 340 cubic yards of material (tank and associated soils) were disposed at a Class I Site. Specifics on why the tank failed and how the leak was discovered were not available.

ENVIRONMENTAL SETTING

Site B is located in a suburban area adjacent to a major city and is surrounded by residential neighborhoods, small farms, a hospital, freeway, and golf course. Other industrial facilities are situated in the immediate vicinity. The site occupies an area of approximately one square mile with more than 30 buildings built in a valley between a ground water recharge basin and numerous wells.

The geology of the broad alluvial valley surrounding Site B resulted from stream erosion and deposition. Streams flowing out of the highlands and into the valley deposited large quantities of debris as alluvial fans and outwash plains. The alluvial sediments range in thickness from zero along the hills bordering the valley to 400 feet in the center of the valley. These deposits are very permeable and the discontinuous clay beds in the area are poor barriers to vertical ground water migration. The high permeability of the alluvial sediments is reflected by a large number of water supply wells. In the area of ground water flow downgradient of and near Site B, there are 18 active and 7 inactive wells.

Site B is underlain by a four aquifer system, designated as aquifers "A", "B", "C", and "D" with increasing depth from the ground surface. Aquifers "B" and "C" appear to be interconnected at numerous random locations and, thus, they do not act as independent permeable formations. The shallow "A" aquifer is generally between 20 and 50 feet below the ground surface. The underlying suite of aquifers begin at about 60 feet and extend to approximately 300 feet below the ground surface.

A generalized description of the subsoil conditions at Site B is as follows:

- Surface to 20 feet - Moist dense brown clayey silt and stiff silty clay;
- 20 feet to 30 feet - Saturated brown sandy silt and silty sand with lenses of silty clay;
- 30 feet to 60 feet - Stiff brown and blue-grey silty clay and clay; and
- 60 feet and deeper - Interbedded sands, silts, clays, and gravels.

A creek which is the primary recharge source for the ground water aquifers is located about 4,000 feet northeast from the center of Site B. Infiltration ponds along the creek are a few miles downstream. Recharge also occurs to a lesser extent by infiltration of irrigation water and through percolation of rainfall which averages 14.2 inches per year. The flow of ground water at Site B is in a west-northwesterly direction.

RELEASE FACTS

As discussed above, six areas of documented contamination have occurred at Site B. Three of these areas have polluted the ground water as far away as 7,000 feet or more. The plume of contaminated ground water emanating from the site has been linked with the contamination of two public drinking water wells located 3,000 feet west and 1 mile northwest of the facility. The water company voluntarily closed the two drinking water sources when trace amounts of TCA and Freon 113 were detected in the wells. Contamination from the site has also been linked with the contamination of 10 private wells. The County environmental health sanitarian recommended that four of the 10 contaminated private wells be closed, including one well serving a mobile home park with 400 residences and three owned by individuals.

The ground water investigation for Site B involves three areas which have been documented as sources of contamination. These areas are termed "Tank Farm A", "Tank Farm B", and "Wells A-30/A-31". At each location the facility has conducted field explorations of the extent of soil and ground water contamination in an effort to determine the most effective remedial strategy. The facility has drilled nearly 250 wells, including more than 200 on-site and about 40 off-site wells, as part of the investigation.

Comparative analyses of well installation and sampling methods were performed at Site B. Most well borings were drilled using a mud rotary rig; some were drilled using a hollow-stem auger. The analyses for organics in the soils and groundwater showed that the drilling procedure did not effect the results. Tests were also performed to examine the difference in results due to collecting samples with a teflon bailer as opposed to a polyethylene, disposable bottle; the sorption potential of PVC; and the use of PVC glue for joining well casings. It was found that the use of polyethylene sample bottles and PVC well casing during normal sampling times did not produce any significant analytical differences. However, the practice of using PVC glue for joining well casings at Site B was stopped after testing indicated the potential for the organics found in PVC glue to adsorb or desorb organic materials.

The analyses of the soils and ground water were performed in accordance with EPA standards. Soil samples were taken with a drill rig equipped with hollow-stem augers and a split-barrel sampler. Ground water sampling in boreholes involved lowering a fresh polyethylene bottle in the bore of the auger and allowing it to fill when submerged. Ground water sampling from wells was performed using a submersible electric pump and PVC pipe. All water samples were taken from the pump discharge line in plastic and glass bottles, except for the volatile organics samples which were taken by lowering a clean polyethylene bottle into the well. Quality control was maintained by taking duplicate and blank samples.

The distribution of Freon 113 and TCA in aquifer "A" two years after the contamination at Site B was detected was largely concentrated in the on-site area. Both chemicals had spread 4,000 feet by 2,500 feet in a west northwest direction and appeared to originate from the same dual sources, Tank Farms A and B, as shown in Figures 1 and 2. The similarity of the two contaminant plumes suggested that the chemicals migrated with the general ground water flow.

The horizontal movement, however, was very slow in aquifer "A", considering that the chemicals had probably been in the

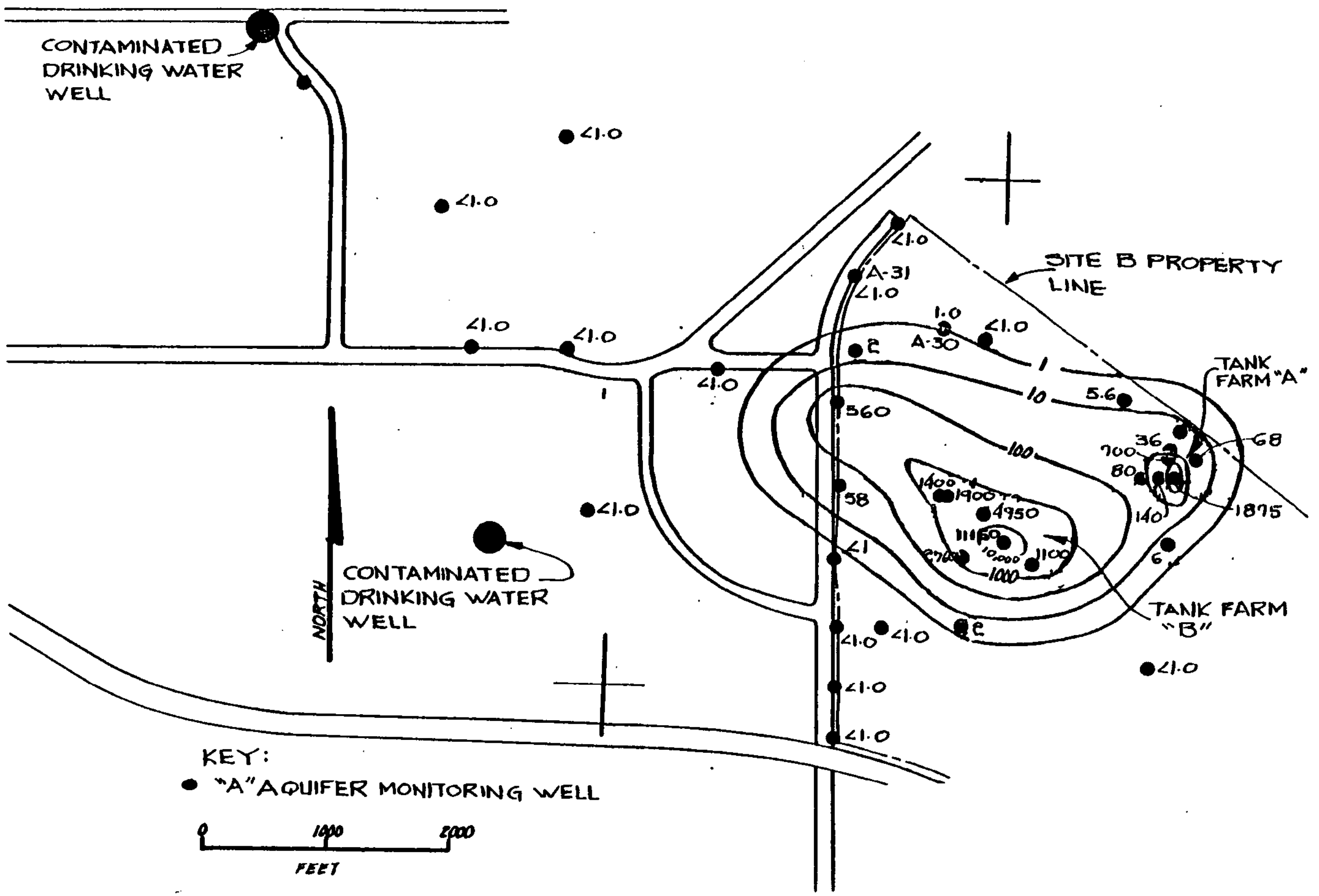

Figure 1. Concentrations of Freon 113 (ppb) in the "A" Aquifer (Average of data for a 2½ month period)

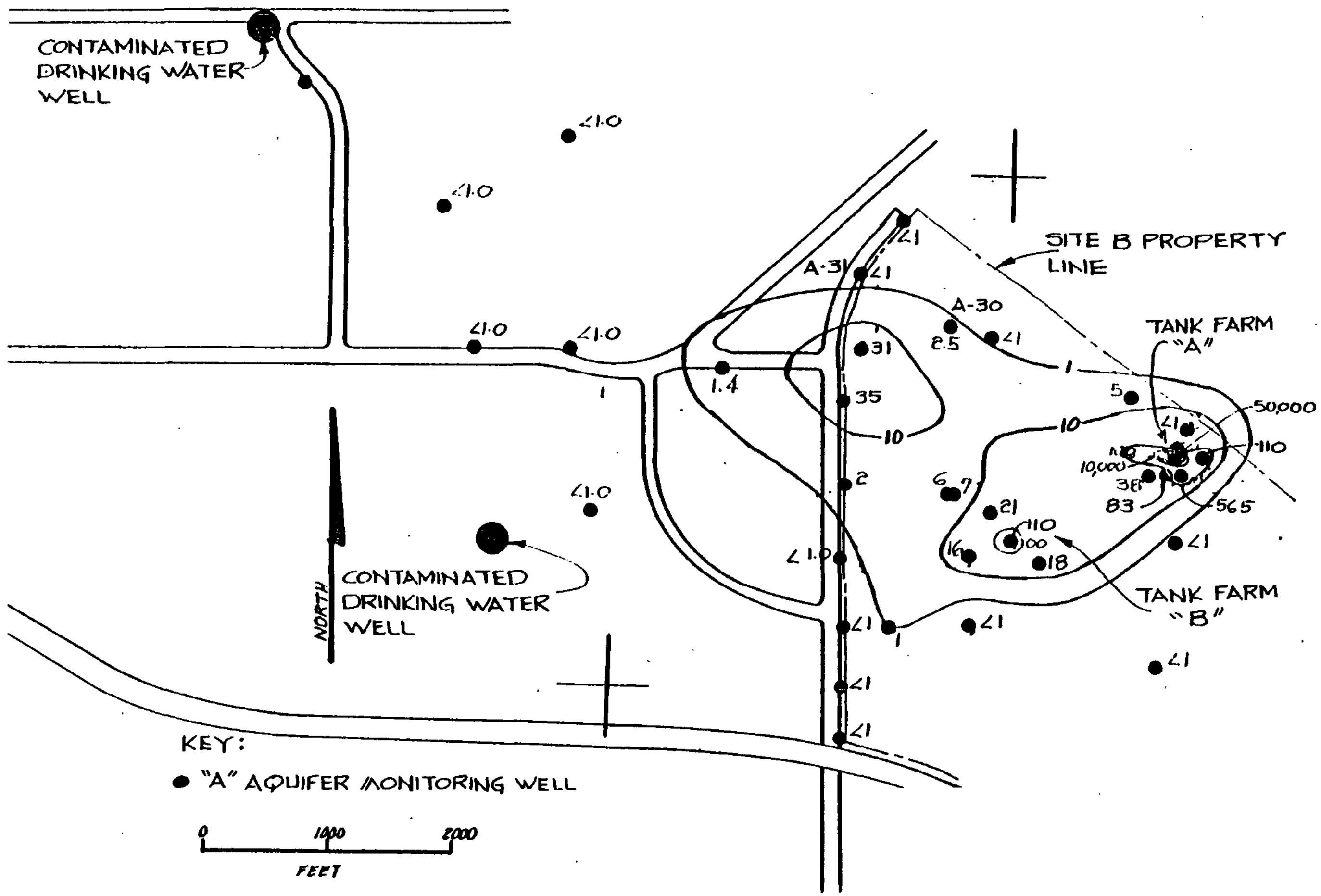

Figure 2. Concentrations of TCA (ppb) in the "A" Aquifer
(Average of data for a 2½ month period)

ground for several years. Since aquifer "A" has limited transmissivity and is only partially saturated, lateral migration of the chemicals was limited. Freon 113 and TCA, being more dense than water, appear to have migrated downward into the underlying aquifers. Once in the hydraulically interconnected aquifers "B" and "C", the contaminants moved horizontally with the ground water due to the high transmissivity and saturation of the formation.

In aquifer "B" the distribution of freon and TCA two years after the detection of contamination at Site B revealed that their plumes extended northwesterly for 7,000 feet or more from the source, as shown in Figures 3 and 4. The alignment of the chemical plume with the contaminated public drinking water well located one mile northwest of the site suggests that pumping of the well influenced ground water flow rate and direction. A spur from the main plume toward another polluted public drinking water well located approximately 3,000 feet west of Site B also suggests that pumping attracted contaminants toward this well. The estimated ambient ground water velocity of five feet per day or 1,800 feet per year implies that a plume extending over 7,000 feet required the chemicals to reside in the aquifer at least four years. Given the length of time that the Tank Farms had occupied the site, a four-year interval is plausible.

At the time the contour maps shown in Figures 1 to 4 were prepared, two years after the contamination was detected and remedial work was started, the maximum concentration of Freon 113 in the "A" aquifer was found near Tank Farm "B" at a level of 11 ppm. Tank Farm "A" revealed the greatest concentrations of TCA in the "A" aquifer at 50 ppm. In aquifer "B", the highest concentration of freon (1.6 ppm) was found less than 1,000 feet downgradient of Tank Farm "B", and the greatest concentration of TCA was about 0.1 ppm found approximately one mile off-site.

High concentrations of another chemical, 1,1,1-trichloroethylene (TCE), were found in the soil and ground water near Wells A-30 and A-31. Possible contamination sources may have been improper disposal of the chemical in the area of the wells or past operational problems at the abandoned Tank Farm A. High levels of TCE appear to have been confined to Wells A-30 and A-31. Nearly all concentrations of TCE reported for aquifers "A" and "B" monitoring wells in the vicinity of Wells A-30 and A-31 were less than 1 ppb, whereas Well A-30 showed as much as 410 ppb in the "A" aquifer.

REMEDIAL MEASURES

Remedial measures undertaken at Site B included localized ground water extraction at the three sources of contamination and soils removal. The on-site cleanup system involved a series of removal wells placed in the "A" and "B" aquifers near the site boundary in a west-northwest orientation. The system also included an extensive array of monitoring wells to evaluate the

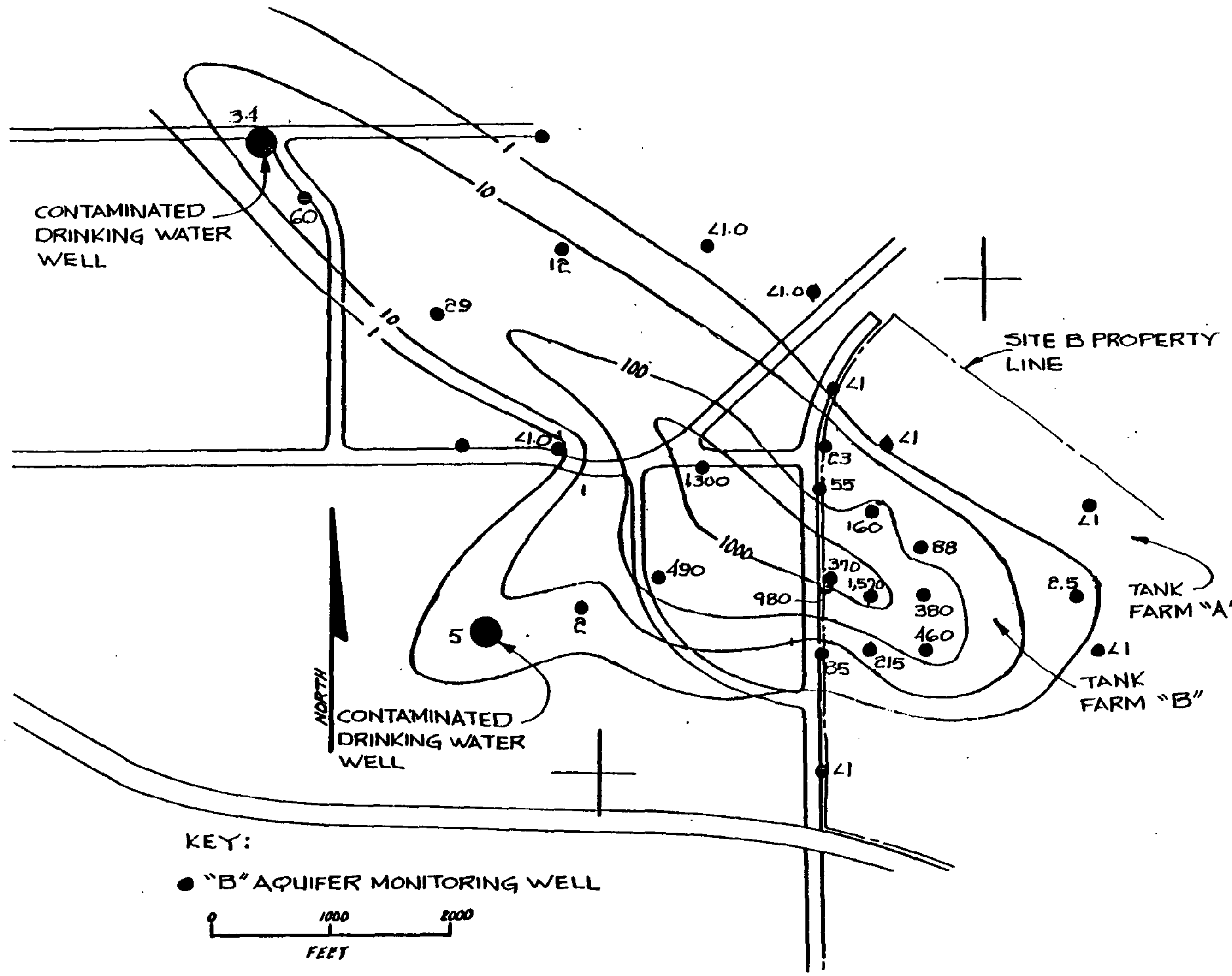

Figure 3. Concentrations of Freon 113 (ppb) in the "B" Aquifer (Average of data for a 2½ month period)

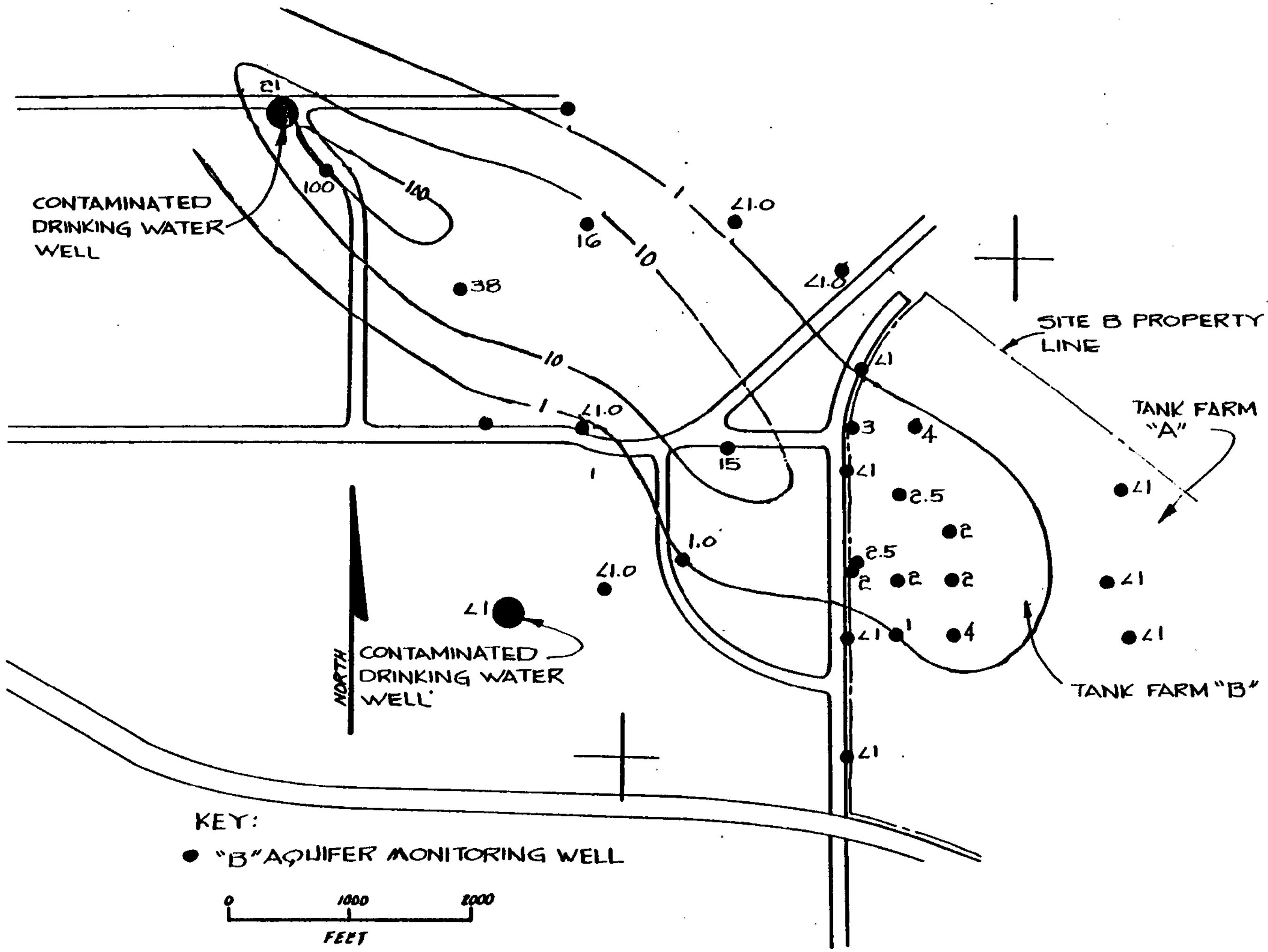

Figure 4. Concentrations of TCA (ppb) in the "B" Aquifer (Average of data for a 2½ month period)

efficiency of the cleanup. The plan for off-site remedial work was not available at the time that this case study was conducted. Remedial measures began in 1980 and are continuing.

Remedial measures in the immediate vicinity of Tank Farm "A" included the removal of 17 solvent tanks, a waste solvent tank, and a waste solvent concrete vault. The specific cause(s) of contamination and the volume of solvent released in this area are unknown. Improper disposal of the chemicals or past operational problems, however, are possible sources of contamination at the abandoned Tank Farm. In other words leaking tanks or piping have not been reported as the cause of the contamination.

The excavated soil (about 7,000 cubic yards) and ground water from the Tank Farm "A" area were disposed of at a Class I disposal facility. A biological oxidation and activated carbon adsorption system was constructed for ground water treatment at the abandoned facility. During excavation, soil and water samples were taken and analyzed by gas chromatography. The highest concentrations found were:

	Soil (ppm)	Ground Water (ppm)
Acetone	5,000	220,000*
EAK		70
IPA	5,000	23,000
Isophorone	150	45
Kerosene	12,000	3,500
Petroleum naptha	25,000	3,300
TCA	3,300	2,200
Xylene	3	290

* Water sample extracted from soil

Remedial actions at Tank Farm "B" were started about one year after the remedial actions were started at Tank Farm A. The cleanup effort included the removal of nine solvent and six waste solvent underground tanks. The cause of contamination appeared to be a severely corroded three-inch drainline from one of the waste solvent tanks. The spilled material surrounding the tank consisted mostly of Freon 113, though acetone, IPA, TCA, and methylene chloride were also detected. Concentrations of the material that was stored in the waste solvent tank were as follows:

Freon 113	93%
TCA	0.9 ppm
Methylene chloride	4.3 ppm
Acetone	1.0 ppm
IPA	280 ppm

The excavated soil and ground water from the Tank Farm "B" area were hauled to a Class I disposal site.

As of this writing cleanup measures for the third area of contamination at Site B, Wells A-3 and A-31 were not known. Soil boring work has been done to identify the possible sources of TCE found in the wells. Remedial efforts are continuing on-site and off-site at Site B, and the date for completion of these activities is unknown.

RELEASE CONSEQUENCES

Site B has not publicly disclosed the cost of remedial measures for cleanup of underground storage system failures. However, it has been estimated that more than $10 million has been spent over three years. Two public drinking water supply wells located about 3,000 feet and one mile from Site B and serving at least 2,000 people were taken out of service because of Freon 113 and TCA contamination. The plume of chemicals from Site B also contaminated 10 private wells. The county health department recommended that four out of the 10 polluted private wells be closed as a result of the most recent data linking TCA to cancer. The public wells were taken out of use even though levels of TCA were 10 times less than the State's recommended limit of .3 ppm. There is no recommended limit for freon.

SUMMARY

Lack of inventory and/or environmental monitoring, tank inspection or tank testing programs at Site B allowed many leaks to go undetected for as long as 11 years before detection. The source of pollution has been determined for only one of the three areas found to have soil and ground water contamination. The duration and size of the leaks and the hydrogeology of the area allowed the released chemicals to enter three aquifers and to travel for a distance of more than a mile.

Two public drinking water supply wells serving at least 2,000 people and 4 out of 10 contaminated private wells have been closed as a result of underground tank system leaks at Site B. Remedial measures are in progress and have been estimated to have cost approximately $10 million through May 1983 (including on-site excavation of tanks, piping and soils). The cleanup efforts have prevented contamination levels from increasing or spreading to a larger area.

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SECTION 4

RELATIVE RELEASE PROBABILITY AND MAGNITUDE

INTRODUCTION

Hazardous waste releases to the environment from underground storage facilities can result from a number of events such as spills during filling or emptying operations, tank overflow or tank and piping system leaks and failures. The purpose of this section is to evaluate the potential for release from underground storage systems both in terms of magnitude and probability. In order to organize the presentation of the methods and results of the release potential assessment, this section was subdivided into five parts as follows:

- A general overview of release events and variables effecting them for all types of underground hazardous waste storage facilities is provided. Release events and variables associated with transfer are excluded.

- A "typical" underground hazardous waste storage facility which will be used to evaluate the relative importance of release events in terms of release probability and magnitude is described.

- The specific release events and variables as well as the relative release magnitudes and probabilities associated with the "typical" underground storage facility are reviewed.

- Brief discussions of additional factors such as environmental setting and waste type which effect release variables and release magnitude, are provided; and

- Data limitations are noted.

Specific underground storage management options and their relative impact on reducing hazardous waste releases as compared to the "typical" facility are discussed in Section 5. The health and environmental concerns, such as environmental pathways and human exposure that arise once the stored material leaves a tank system, are not addressed in this report

RELEASE EVENTS AND VARIABLES

The purpose of this subsection is to provide a "shopping list" of release events and variables which can be used to construct fault-trees for the many different types of underground hazardous waste storage facilities. The release events considered in this analysis include tank overflow, tank leak, tank rupture, ancillary equipment leak, ancillary equipment rupture, fire or explosion and other incidents. The occurrence

of these events and their magnitudes may be influenced by one or a number of different variables which are presented in Figures 4-1 through 4-9.

To show the relationship between the release events and variables resulting in hazardous waste releases to the environment a fault-tree was developed. The basic components of this fault tree were derived from the fault-tree analyses for aboveground facilities conducted by F.G. Bercha and Associates Limited [1, 2], JRB Associates [3] and the information obtained from telephone conversations and documents presented in Appendix G.

The components of the fault-tree presented in Figures 4-1 through 4-9 are connected by either "and" gates or "or" gates which determine the specific relationship between the probabilities of events and/or variables occurring. An "and" gate represents a situation where both of the components must exist or occur for the next step up on the tree to be affected. This situation will result in a multiplication of probabilities of occurrence. For example, in Figures 4-3 and 4-4, the probability of tank leak will be reduced significantly if, when a tank leak occurs, the facility has secondary containment with a leak detection system. Similarly, in Figure 4-8 both an ignition and fuel source (i.e., tank overflow, tank leak, etc.) must be present before a fire or explosion will occur.

An "or" gate represents a situation where the component will occur regardless of the existence or occurrence of the other factors. The "or" gate situation will result in addition of the probabilities of occurrence. This is evident in Figure 4-6 where variables such as corrosion, seal failure and operator error can occur with or without the occurrence of the others.

The events and the variables presented in Figures 4-1 through 4-9 are in most cases directly related to the waste stored and/or the complexity of the storage facility. For example, a fire or explosion will not occur unless an ignitable or reactive waste is stored, and release cannot be influenced by the failure of a corrosion protection system or an overflow prevention system when they do not exist. As a result, the variables presented in these tables may or may not influence the release from specific underground storage facility.

Each of the release events, with the exception of fire or explosion and other incidents, are divided into four general categories: design/installation deficiency, operator error,

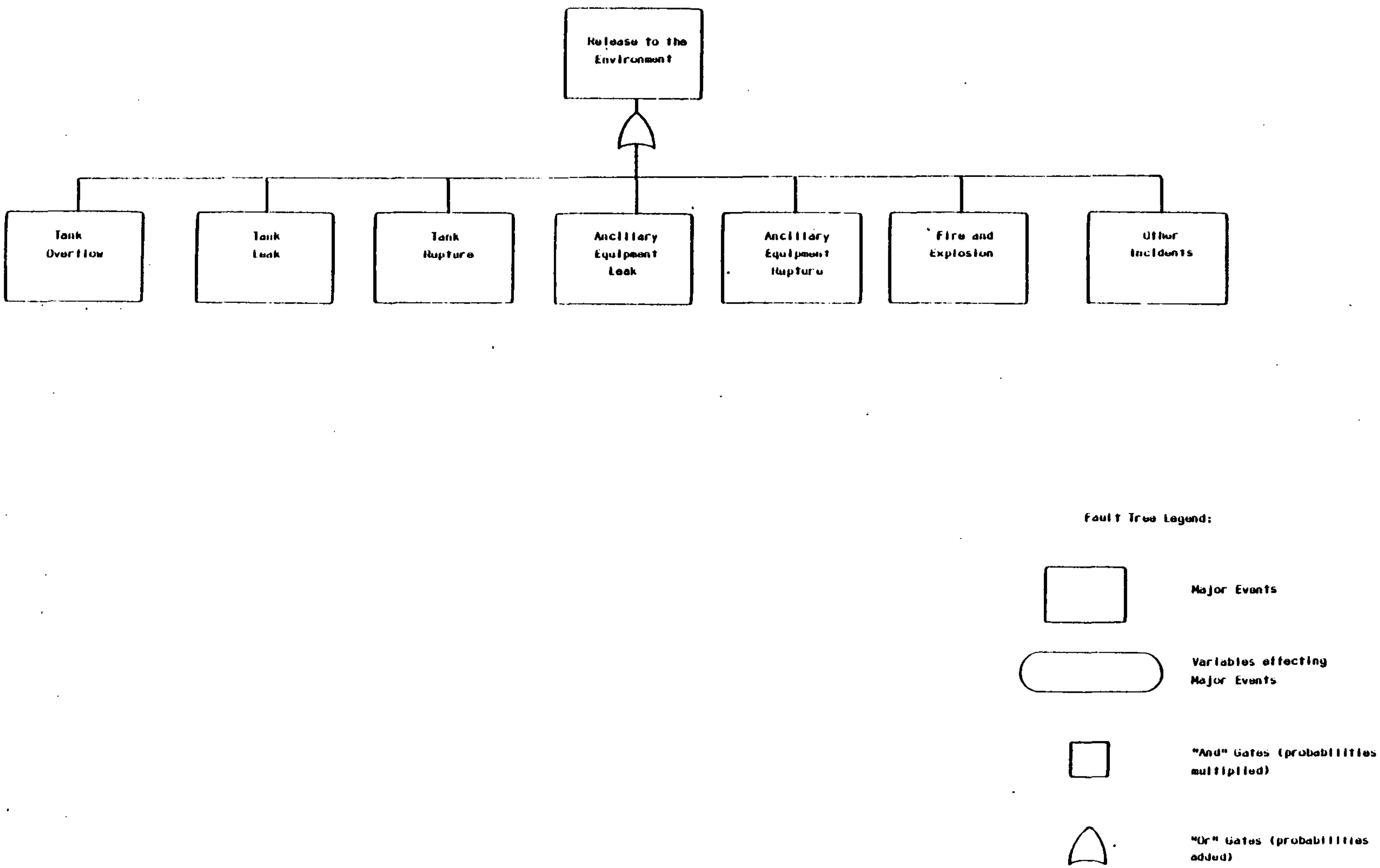


Figure 4-1. Events leading to releases from underground hazardous waste storage facilities.

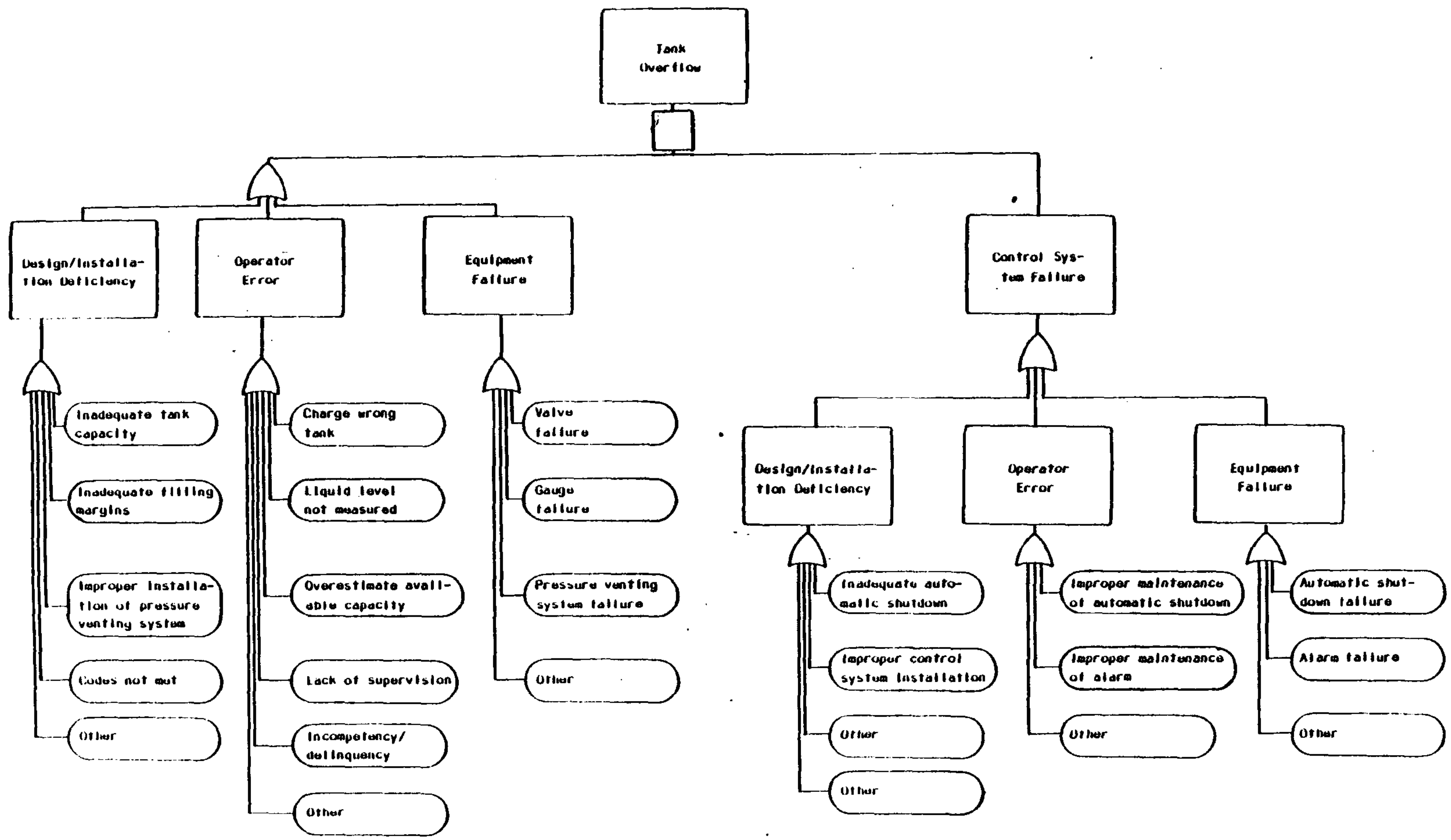


Figure 4-2. Variables effecting tank overflow at an underground hazardous waste storage facility.

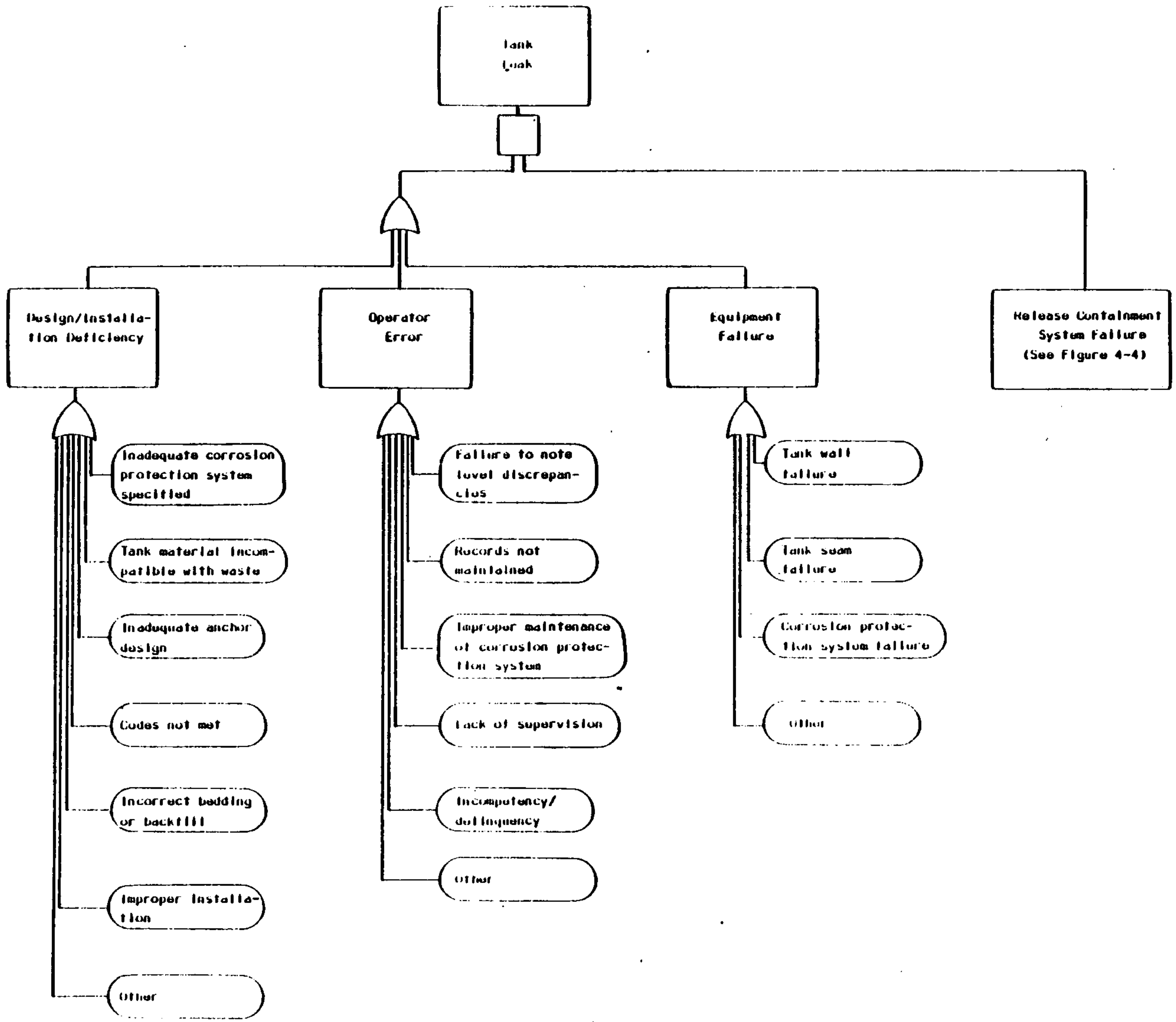


Figure 4-3. Variables effecting tank leaks at an underground hazardous waste storage facility.

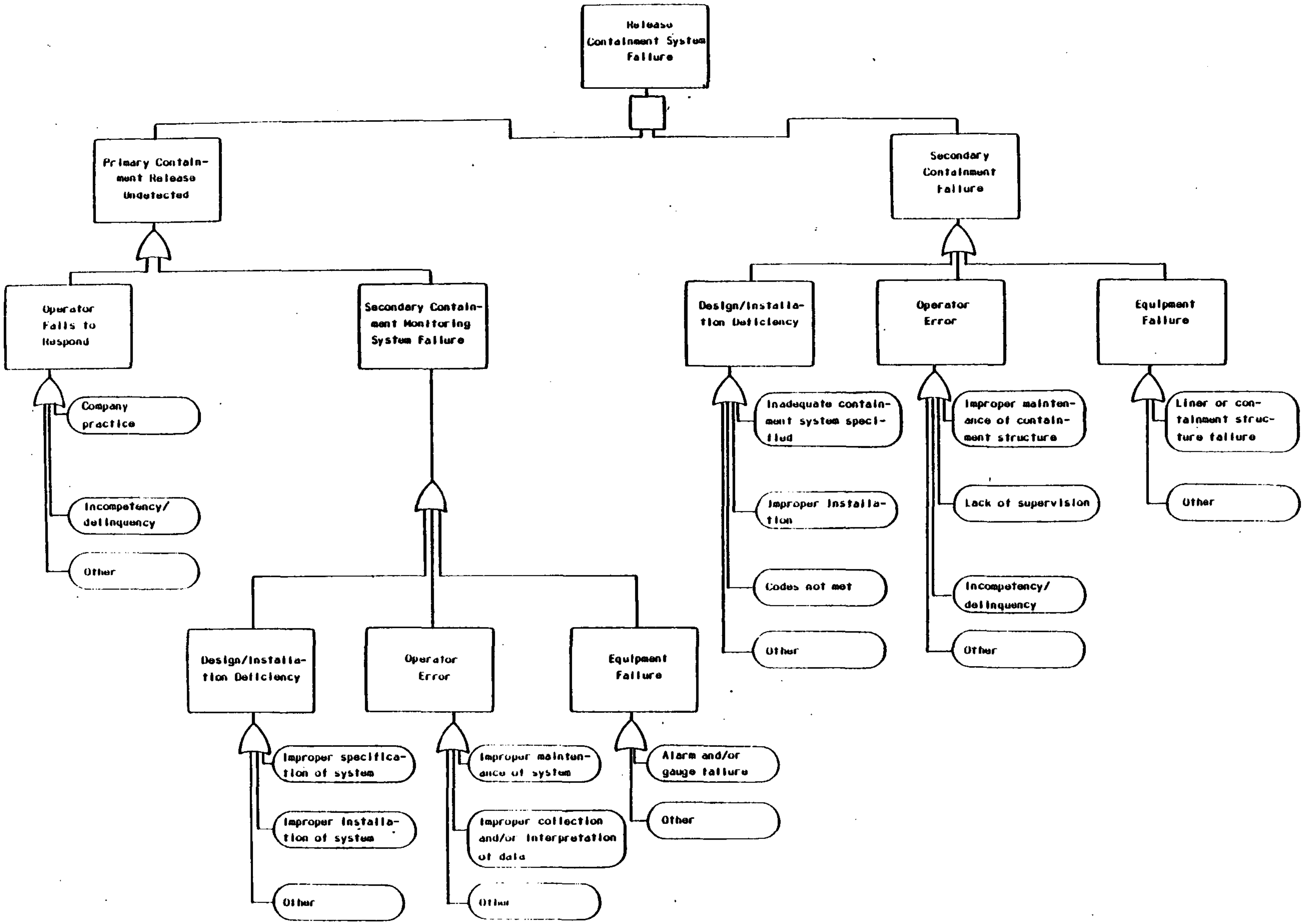


Figure 4-4. Variables effecting containment system failures at an underground hazardous waste storage facility.

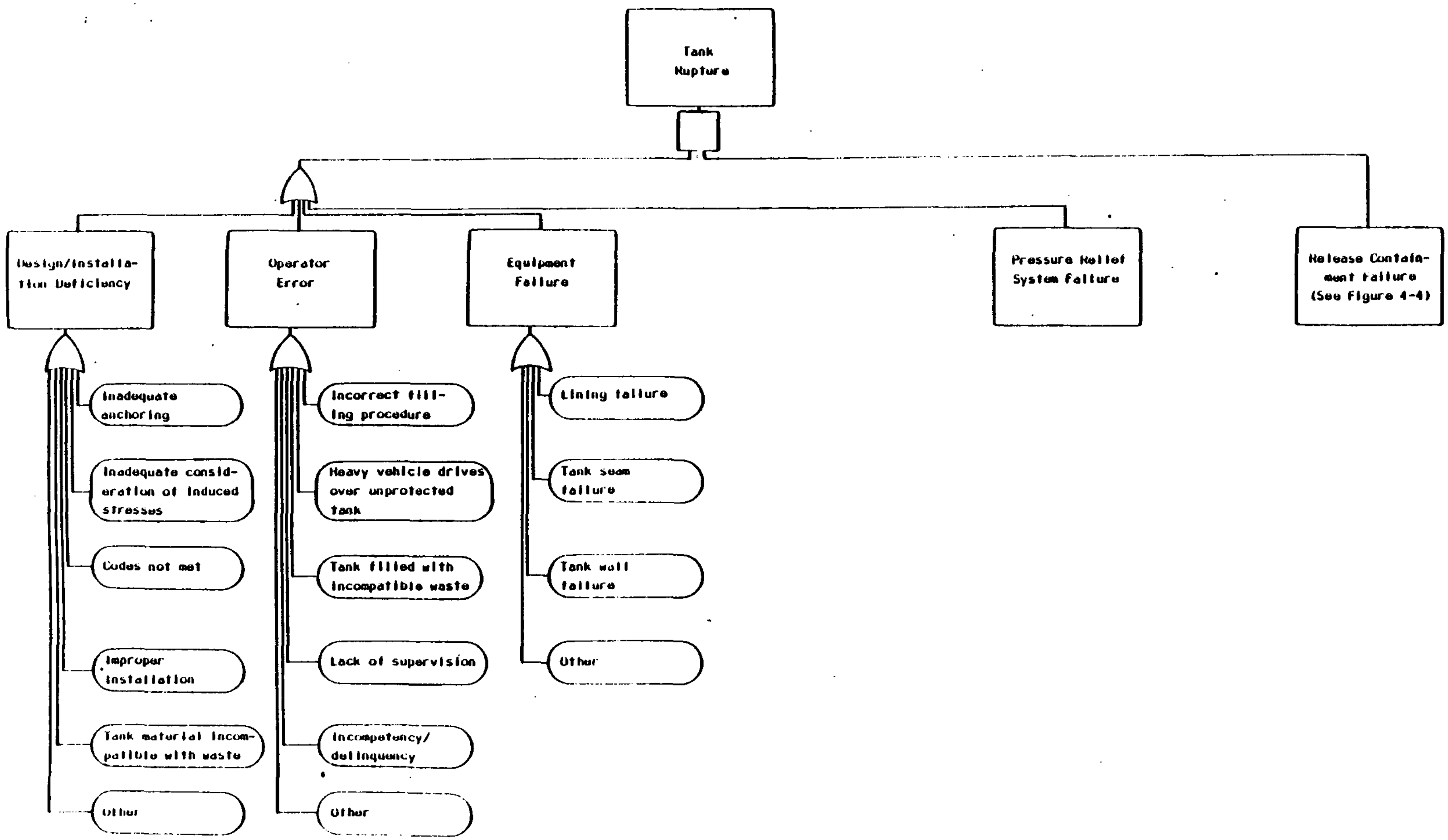


Figure 4-5. Variables effecting tank rupture at an underground hazardous waste storage facility.

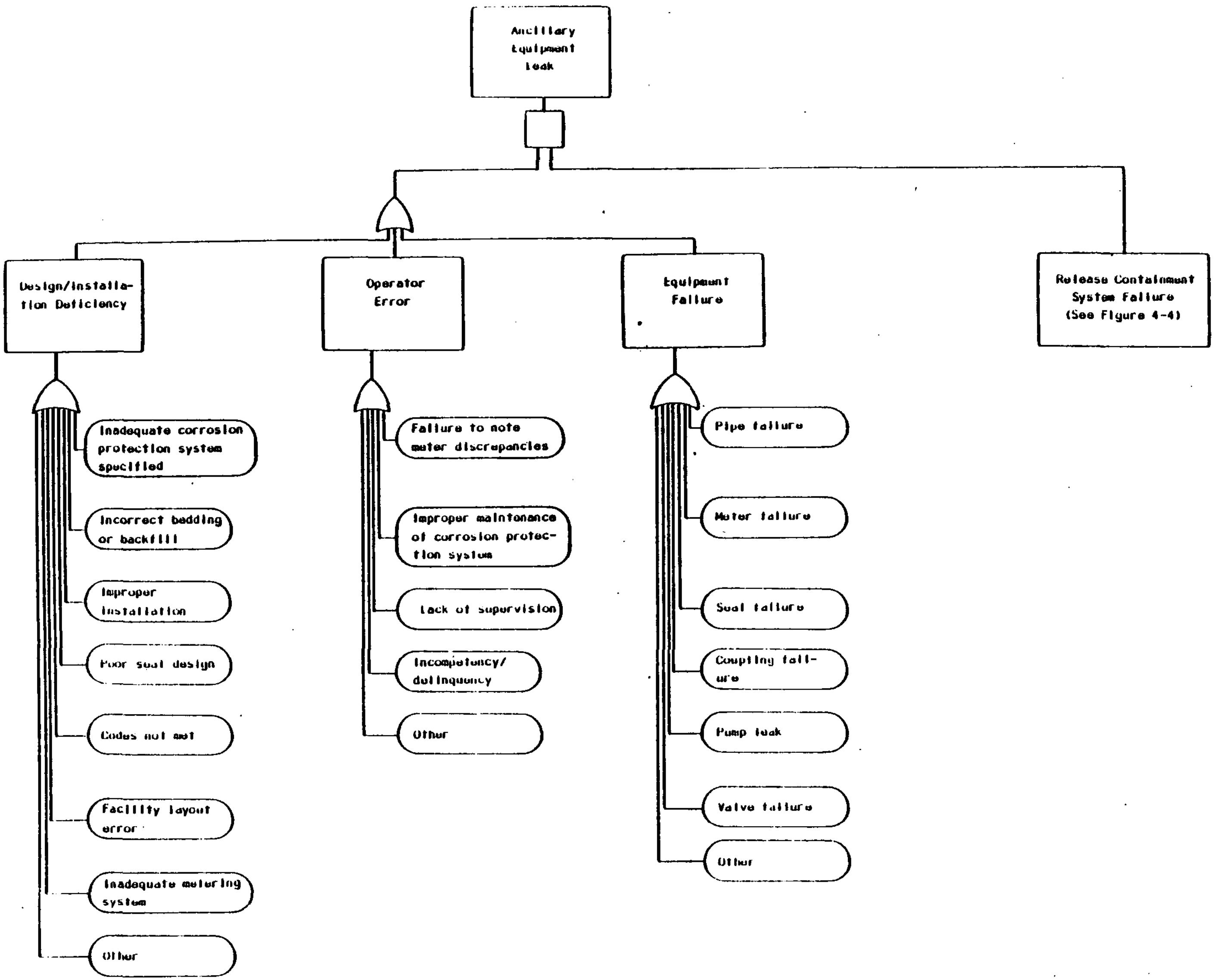


Figure 4-6. Variables effecting ancillary equipment leaks at an underground hazardous waste storage facility.

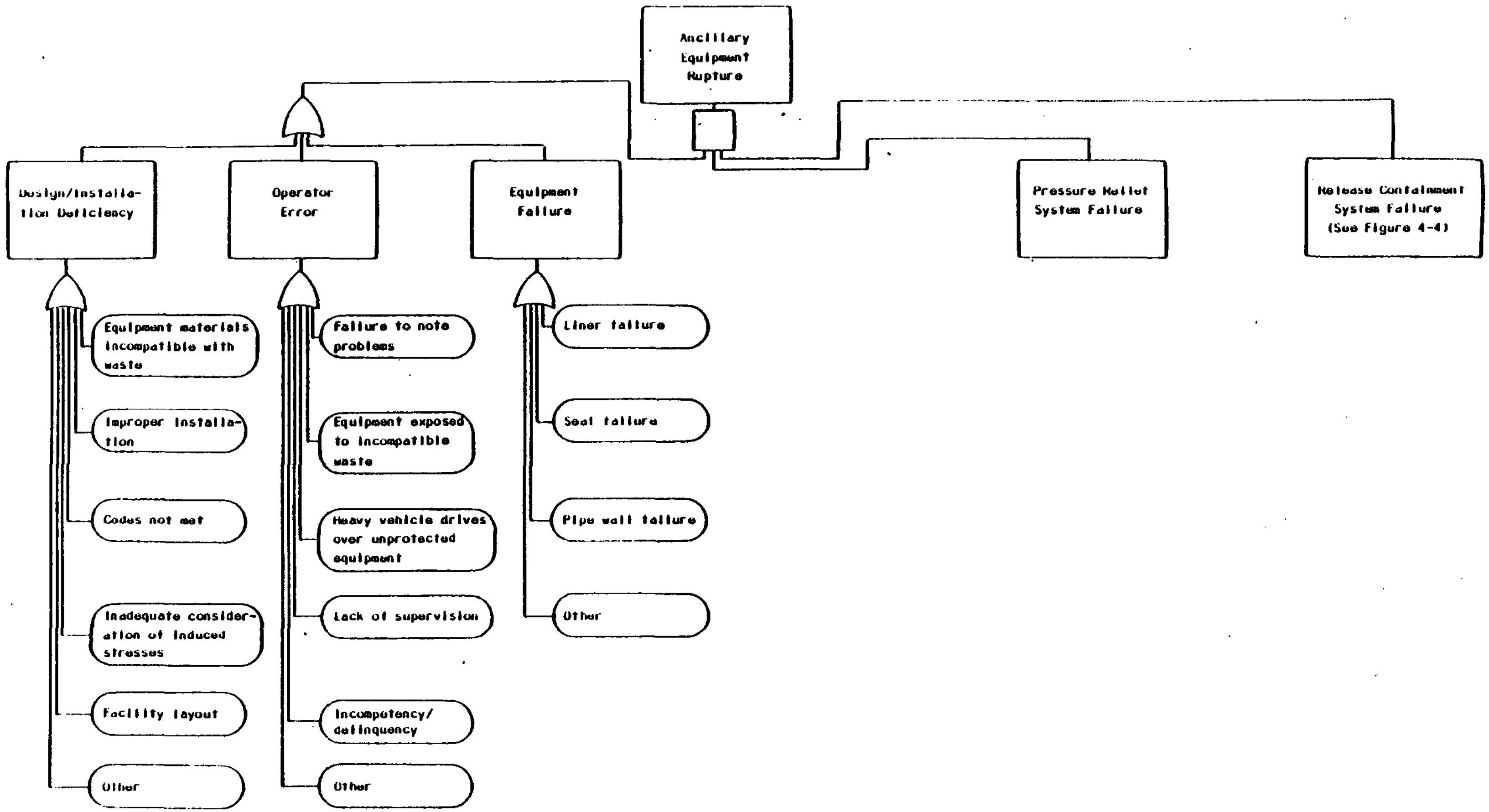


Figure 4-7. Variables effecting ancillary equipment rupture at an underground hazardous waste storage facility.

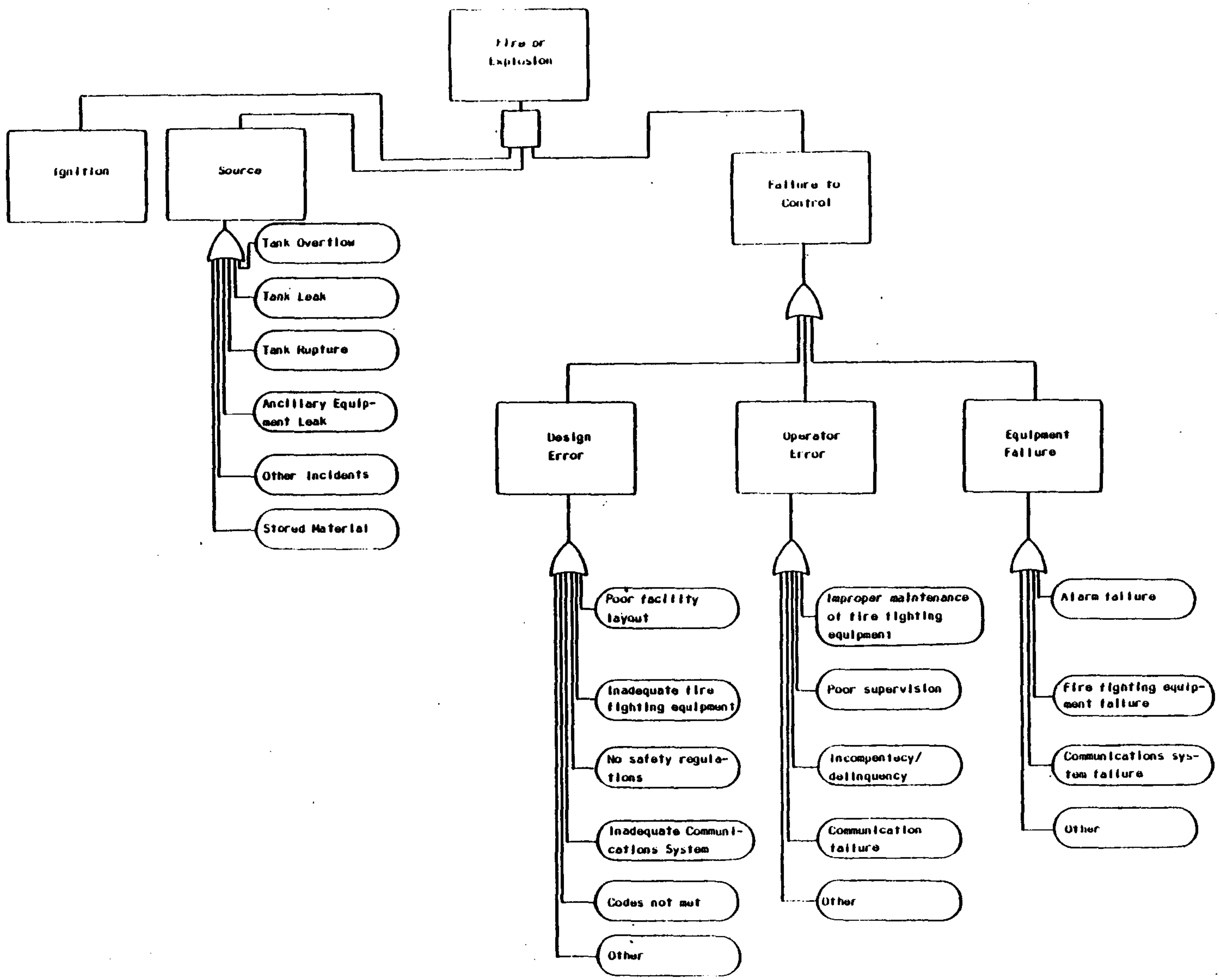


Figure 4-8. Variables effecting fire or explosion at an underground hazardous waste storage facility.

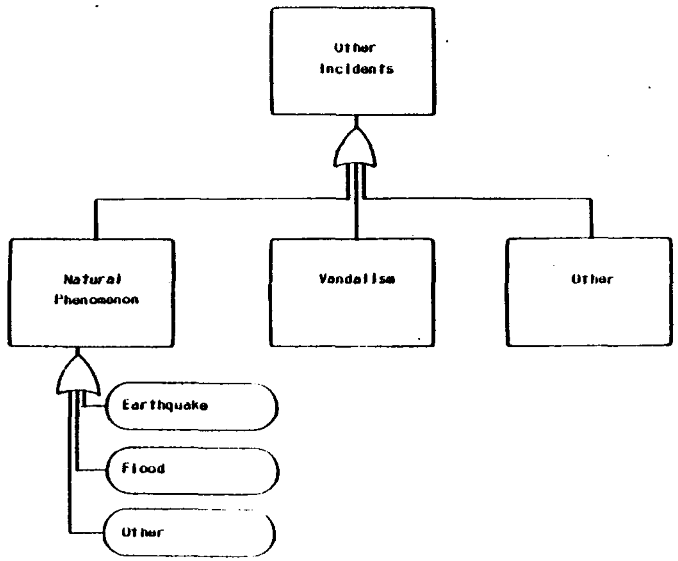


Figure 4-9. Variables effecting other accidents at an underground hazardous waste storage facility.

equipment failure and control system failure. These categories are further divided into the variables which have the greatest influence on release potential and magnitude. Brief descriptions of each of these events and the variables associated with release potential and magnitude are presented below.

Tank Overflow

Tank overflow occurs while filling. As shown in Figure 4-1, this event is influenced by variables such as inadequate design of the overflow control system, overestimation of the available capacity of the tank, failure of the tank level gauge and failure of the automatic shutdown system. The major cause of tank overflow is operator error which depends on factors such as tank filling method, operator competence and whether or not the facility has an automatic shutdown system. In most cases release magnitude is influenced by the operator's ability to identify the problem and the time it subsequently takes to stop the filling operation.

Tank Leak

Tank leak occurs at relatively low rates over an extended period of time (i.e., weeks, months, years). One of the primary causes of leaks in steel tanks is external corrosion which is influenced by installation procedures, soil characteristics (especially soil resistivity and moisture content), tank age and corrosion protection system effectiveness. Since steel tanks are not the only tanks used in underground storage, tank material, installation procedures and leak prevention systems (i.e., secondary containment, corrosion protection systems, etc.) must be addressed when assessing leak potential (see Figures 4-3 and 4-4).

Once a leak occurs, the magnitude of release is dependent upon the size of the leak (i.e., gallons per day) as well as the time it takes for the leak to be detected and stopped. As a result, the existence of a leak detection system or secondary containment, the operators' ability to note level discrepancies in the tank and/or the frequency of tank testing will be the primary factors effecting release magnitude.

Tank Rupture

Tank rupture is defined as the release of large quantities of stored material over a relatively short period of time (i.e., minutes, hours, days). Tank ruptures result from the failure of the tank material due to factors such as failure of the venting system, puncture or cracking of a Fiberglass Reinforced Plastic (FRP) tank, uneven settling from improper installation, and tank material failure resulting from the introduction of incompatible wastes. As shown in Figures 4-4 and 4-5, additional variables also contribute to release potential.

The magnitude of release from tank ruptures is dependent upon the size of the tank, the volume of waste in the tank when the rupture occurs, the existence of a release detection system or secondary containment and the operator's ability to note the loss of stored material. Tank rupture will be identified sooner than tank leaks due to the drastic change in volume of the tank contents or other evidence of system failure.

Ancillary Equipment Leak

Ancillary equipment leaks occur from pipes, pumps, valves, etc. at relatively low rates (i.e., a few gallons per day), over an extended period of time (i.e., weeks, months, years). The major factors, as shown in Figures 4-4 and 4-6, that influence ancillary equipment leaks are external corrosion of steel piping and loose fittings or joints which may result from improper installation or time-induced stresses (i.e., vibration, settling, etc.).

The magnitude of releases are affected by the same factors as tank leaks--the size of the leak (i.e., gallons per day) and detection by the operator. However, due to the lower rate of release, these leaks may go undetected for longer periods of time. As with tank leaks, a leak detection system or secondary containment and/or frequent system testing decreases release magnitudes from ancillary equipment.

Ancillary Equipment Rupture

Ancillary equipment ruptures are defined as the release of large quantities (i.e., greater than 10 percent of the material being transported) of material from pipes, pumps, valves, etc., over a relatively short period of time (i.e., minutes, hours, days). These ruptures are similar to tank rupture in that release usually results from equipment failure due to overpressurization, piping system fracture from induced stresses or improper installation, and piping system failure. (See Figures 4-4 and 4-7).

The magnitude of release from ancillary equipment rupture is dependent upon the volume of waste being transported through the system and the operator's ability to identify the problem. Controls such as secondary containment or release detection systems and tank level monitoring will reduce the magnitude of release.

Fire or Explosion

Fire or explosion is defined as a sudden release of a portion or all of the stored material in a tank as a result of the ignition and/or sudden expansion of a flammable or reactive waste. These events are slightly different from the events described above in that they may occur as the result of an overflow, leak or rupture, or they may arise from conditions within the system such as chemical reactions and thermal expansion (see Figure 4-8).

As mentioned above, these events can result in the release of a portion or all of the stored material depending on the circumstances leading to the events and the control systems available (i.e., foam system, sprinkler systems, etc.).

Other Incidents

Other incidents are defined as events that occur due to natural phenomena, vandalism, etc., which have not been discussed under the other headings. These incidents are dependent on the facility location in the case of variables such as earthquakes and flood, and on the uncontrolled or unpredictable nature of people. Steps such as proper designs and security systems can reduce the probability of their occurrence.

The magnitudes of these release events are variable depending on the extent of the damage incurred. For example, an earthquake may result in either a leak or a rupture depending on the system design.

"TYPICAL" FACILITY

In this subsection, a "typical" underground storage facility is defined to provide a baseline for developing release probabilities and magnitudes. The characteristics of this facility were selected by evaluating current practices to determine the most common features of underground storage facilities. Current practices were defined using data from the "Hazardous Waste Tank Questionnaire" (OMB # : 2000-0424), information collected from equipment manufacturers, trade associations and "standards" organizations (i.e., American Society for Testing and Materials, National Fire Protection Association, etc.), information presented in Section 3 and Appendix G.

Current practices were found to include a wide variety of equipment types (i.e., tanks, ancillary equipment and control systems), facility ages, management/maintenance programs, installation practices and environmental settings. In fact, the features of the alternative management systems discussed in Section 5 are currently used to varying degrees. In this section, a single, "typical" facility (see Figure 4-10) which represents the most common underground storage facility (as defined by the information sources noted above) was evaluated. The characteristics of this facility are presented below. Alternative systems designed to represent a range of options for reducing the probability and magnitude of release as compared to the "typical" facility are discussed in Section 5.

"Typical" Facility Characteristics

Equipment Type--

The "typical" underground storage facility was assumed to consist of:

- One 3,000 gallon carbon steel tank conforming to UL58 with a black asphaltum coating;
- Waste being stored is ignitable;
- Unprotected cast iron piping;
- A trap to prevent vapor migration to the point production facility;
- Steel vent pipes; and
- Gravity piping (so no pumps are included).

Facility Age--

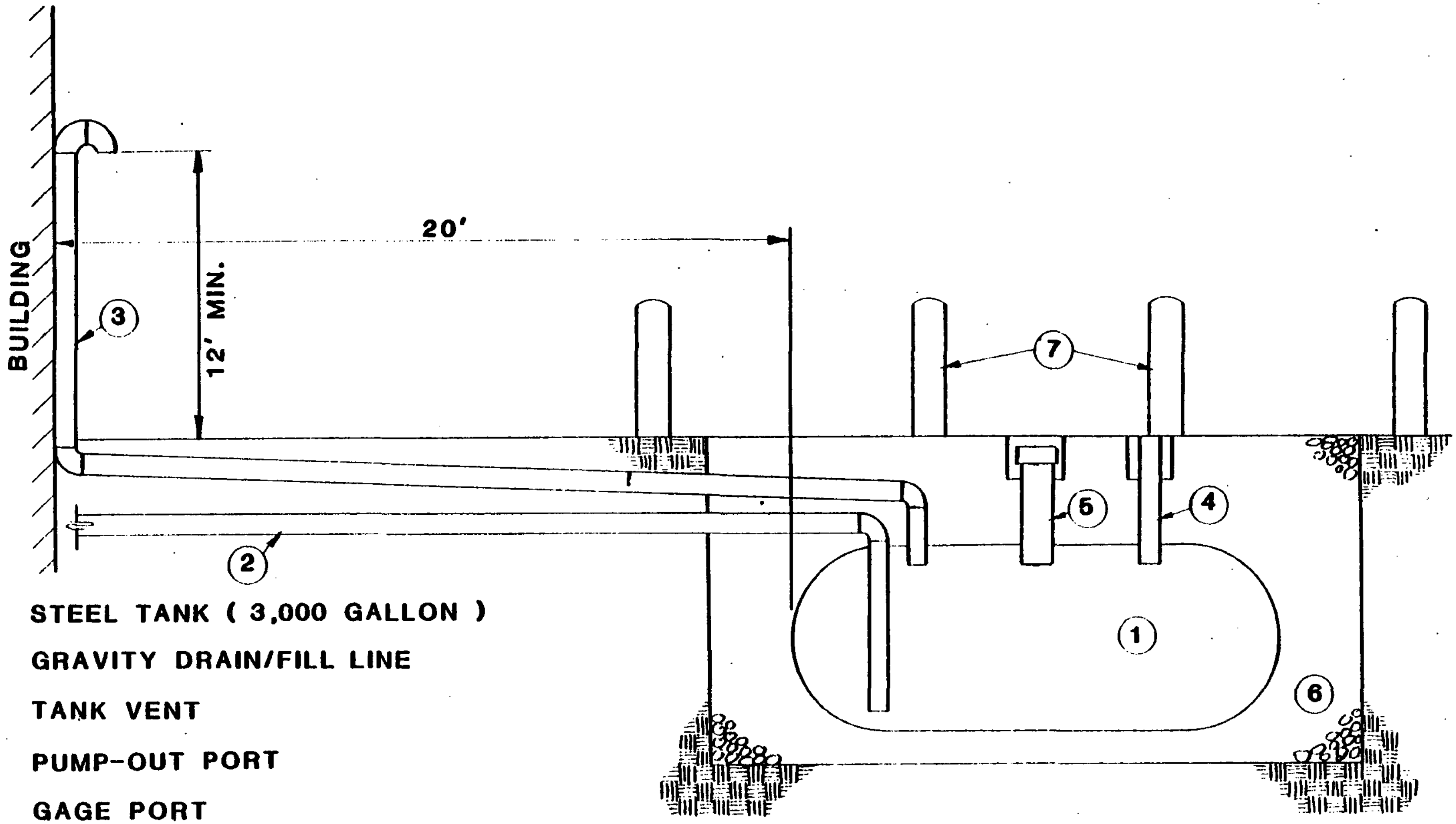
Facility age was assumed to be 8 years.

Management/Maintenance Programs--

Until recently, the concern for management/maintenance programs for underground hazardous waste storage facilities has been minimal. This statement is supported by the large number of releases from underground product storage tanks noted in Section 3 that had gone undetected for relatively long periods of time and by the assumption that the loss of stored product would be of more concern (due to cost considerations) than would waste release. Consequently, the management/maintenance program for the "typical" facility under consideration is assumed to be limited to a simple tank level checking program (i.e., once a week) with waste removal when the tank is three quarters full and tank testing (Petro-tite or equivalent) every 5 years.

Installation Procedures--

Installation of underground tanks is normally in accordance with specifications of the NFPA (NFPA 30) [4] the American Petroleum Institute (API 1615) [5] and/or the tank manufacturer. Installation usually involves excavating an appropriately sized hole and trench for tanks and piping, placing tank and piping in



(1) STEEL TANK (3,000 GALLON)

(2) GRAVITY DRAIN/FILL LINE

(3) TANK VENT

(4) PUMP-OUT PORT

(5) GAGE PORT

(6) NON-CORROSIVE , INERT BACKFILL

(7) TRAFFIC BOLLARDS

Figure 4-10. Diagram of the "typical" Underground Storage Facility.

the excavated areas on sand or gravel bedding, anchoring the tank, if it is located in an area subject to a high groundwater table or flooding, attaching ancillary equipment such as vents, pumps and valves, backfilling with sand or gravel, and installing a concrete pad if the tank is to bear traffic or barriers if traffic is to be prohibited. These procedures were assumed to be used to install the "typical" storage facility with the exception of anchoring since it is assumed that the facility is not subject to high groundwater or flooding.

Environmental Setting--

The environmental setting selected for this analysis consists of poorly drained acidic soils with a resistivity of less than 10,000 OHM-centimeters [4]. (An assumption was made that no corrosion protection system was installed even though NFPA specifies corrosion protection for soils with resistivities at this level. This assumption was made because the results of the API "Leak Survey" showed a large number of tanks without corrosion protection.) In addition, the site is not located in a flood plain and depth to groundwater is at least 20 feet.

"TYPICAL" FACILITY RELEASE MAGNITUDES AND PROBABILITIES

The purpose of this subsection is to present the release events, magnitudes and probabilities associated with the "typical" facility. Initially, the assumptions associated with each event are discussed along with the resulting release magnitudes. This is then followed by a discussion of the relative release probabilities of each event.

To provide a breakdown of the variables effecting the "typical" facility release events, the fault-tree shown in Figures 4-11 through 4-18 was created from the "shopping list" of events and variables presented earlier in Figures 4-1 through 4-9. As shown, parts of the general fault-tree such as the "Release Containment System Failure" shown in Figures 4-3 and 4-4 were not included (see Figure 4-13) since they did not apply to the "typical" facility.

The procedures and assumptions used to develop the release magnitudes and relative probabilities are described below.

Release Magnitudes

Magnitudes of the release events associated with the "typical" facility were estimated by assuming an average volume of waste stored in the tank and the time which might elapse before the release was detected. Release magnitudes for the "typical" facility are discussed below in terms of the events leading to the release, the variables which influence their

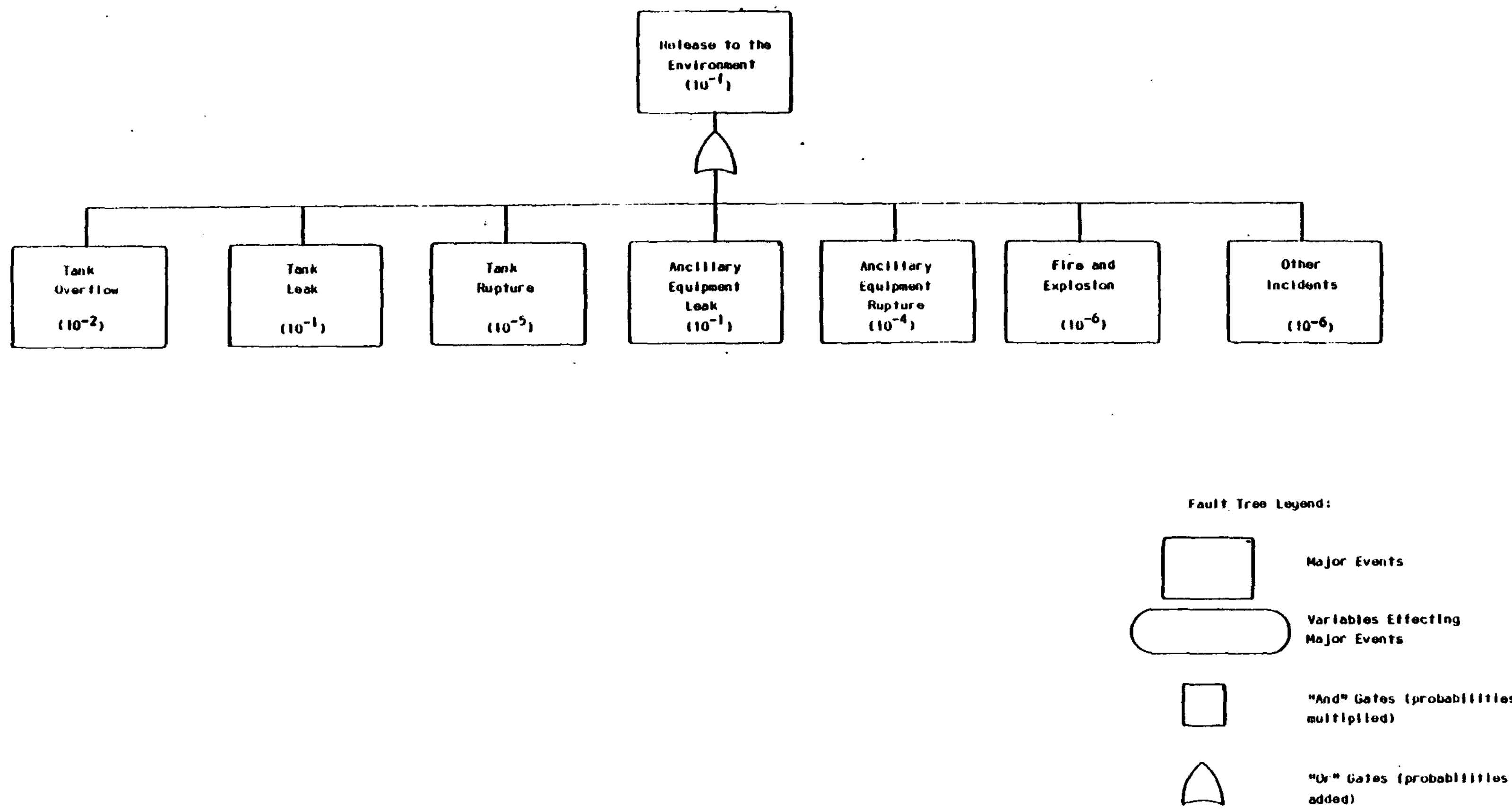


Figure 4-11. Release events and probabilities associated with a "typical" underground hazardous waste storage facility.

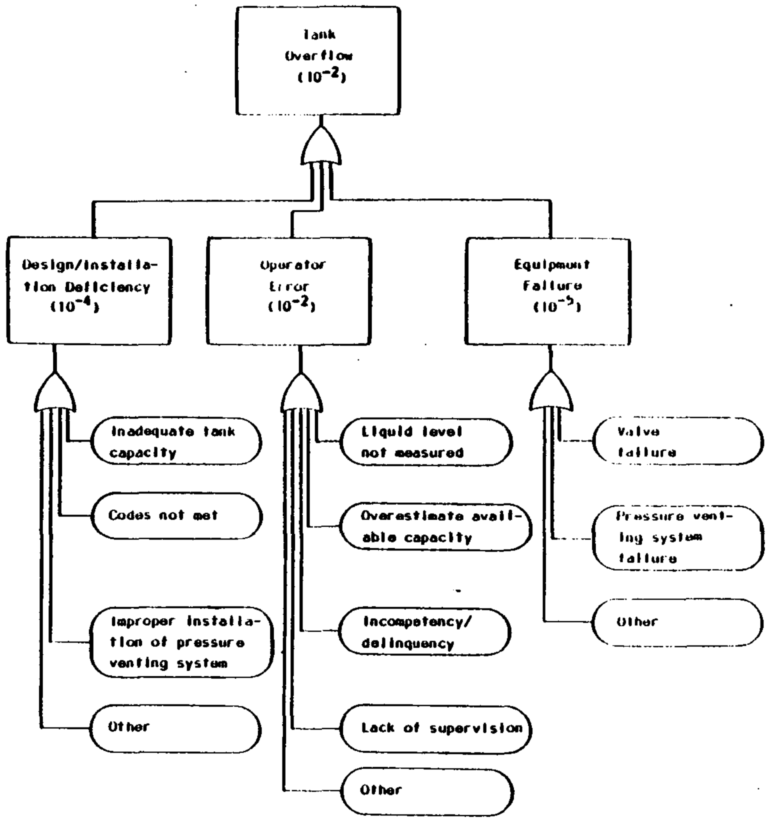


Figure 4-12. Variables and release probabilities associated with tank overflow at a "typical" underground hazardous waste storage facility.

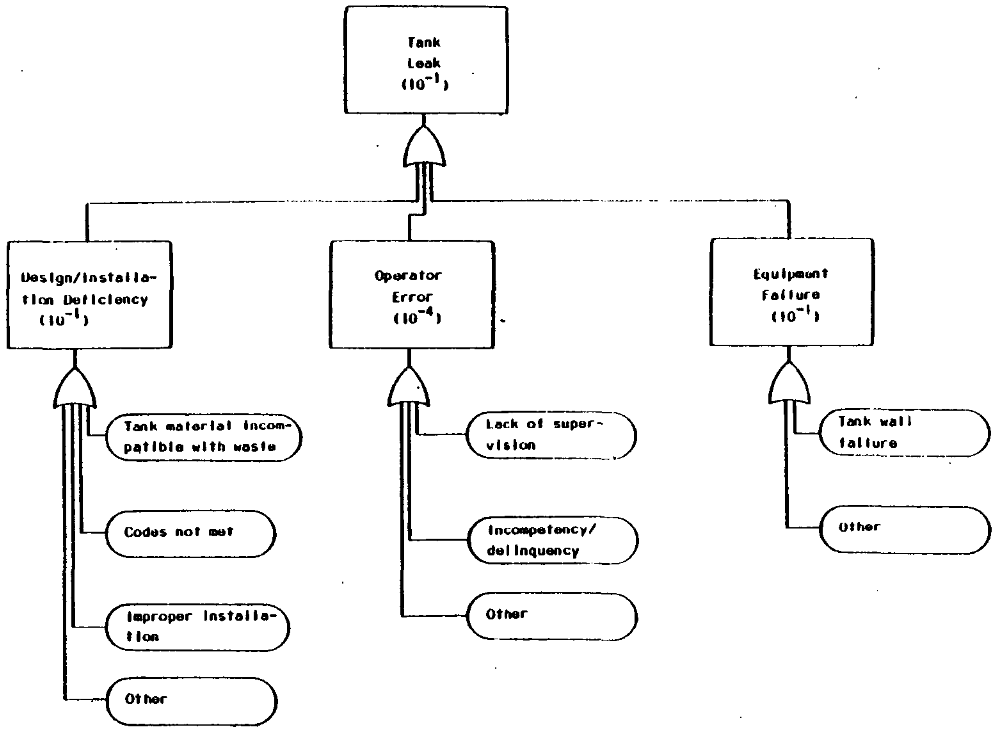


Figure 4-13. Variables and release probabilities associated with tank leaks at a "typical" underground hazardous waste storage facility.

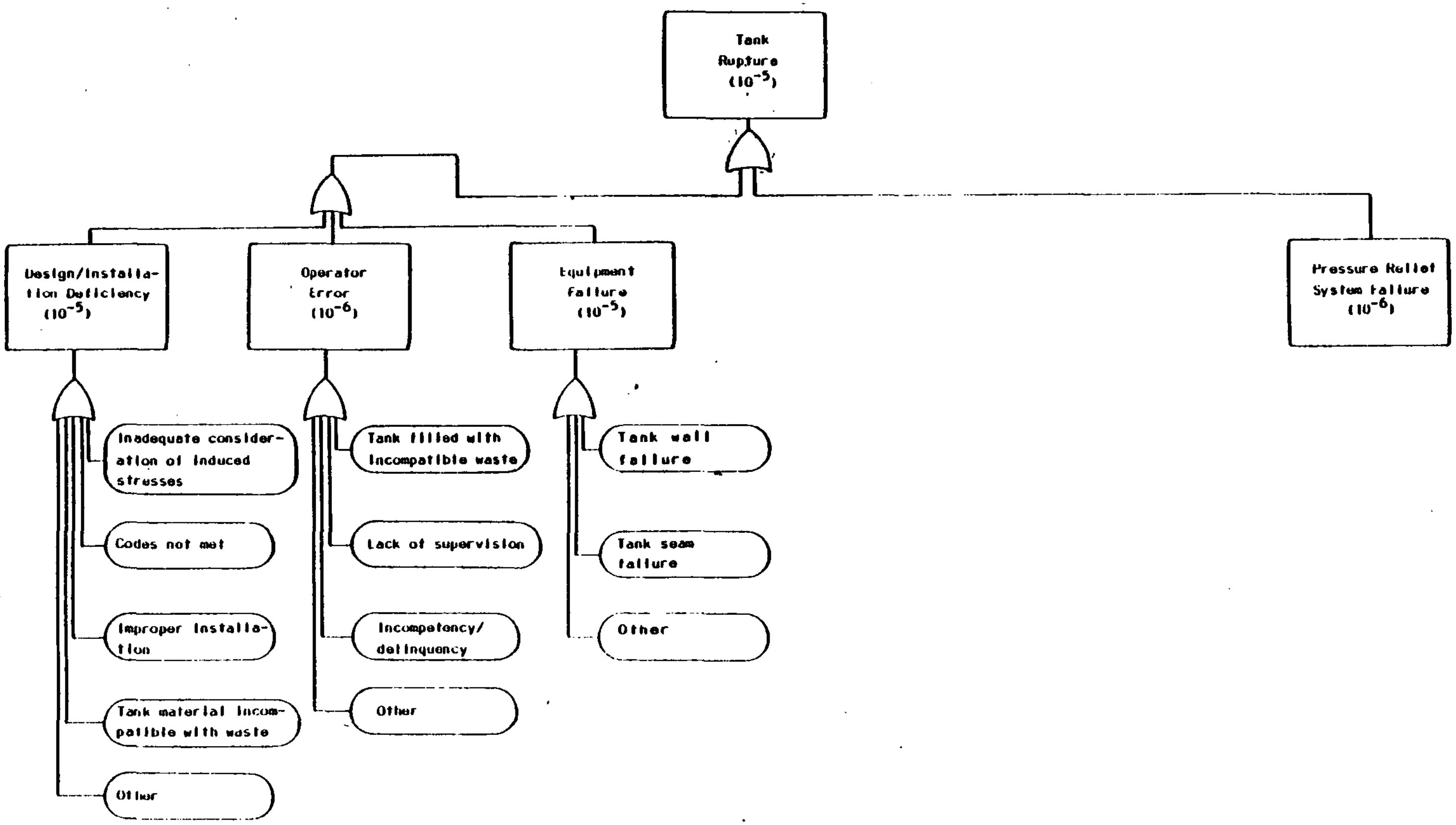


Figure 4-14. Variables and release probabilities associated with tank rupture at a "typical" underground hazardous waste storage facility.

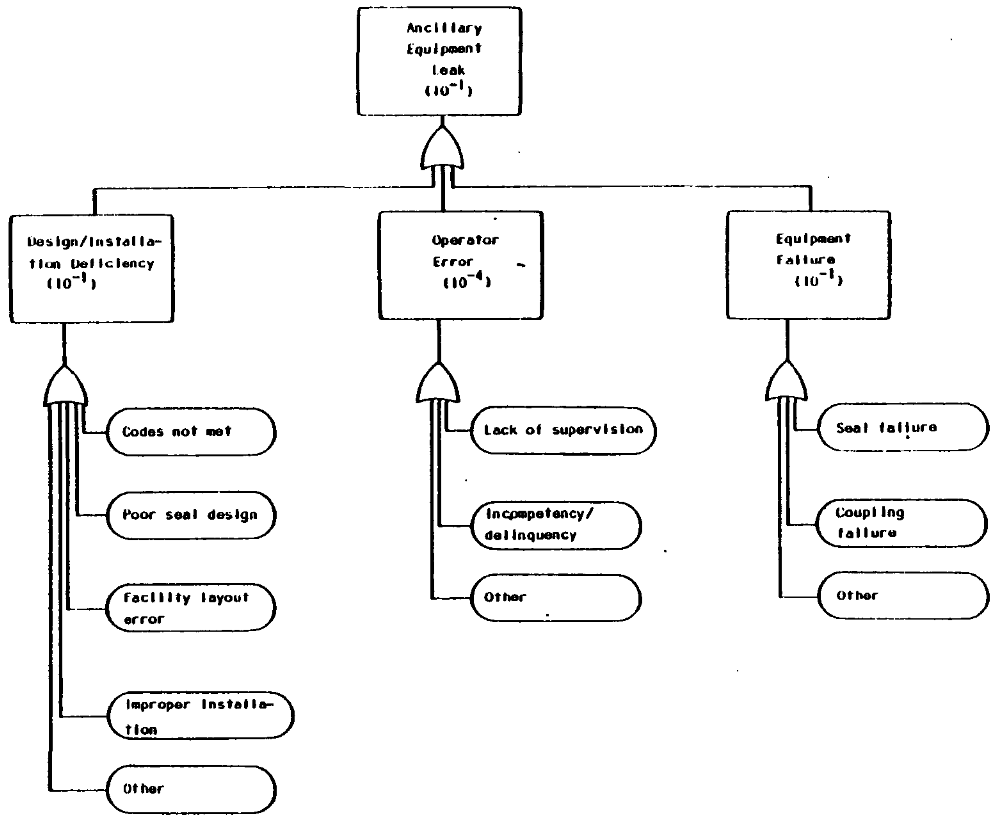


Figure 4-15. Variables and release probabilities associated with ancillary equipment leaks at a "typical" underground hazardous waste storage facility.

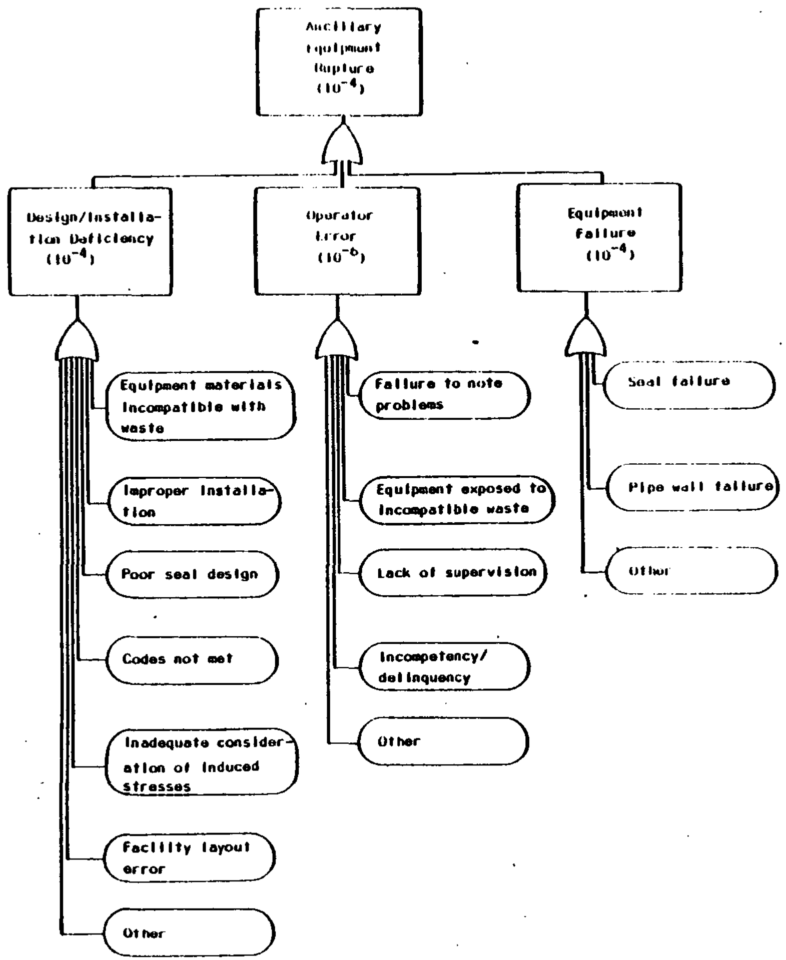


Figure 4-16. Variables and release probabilities associated with ancillary equipment rupture at a "typical" underground hazardous waste storage facility.

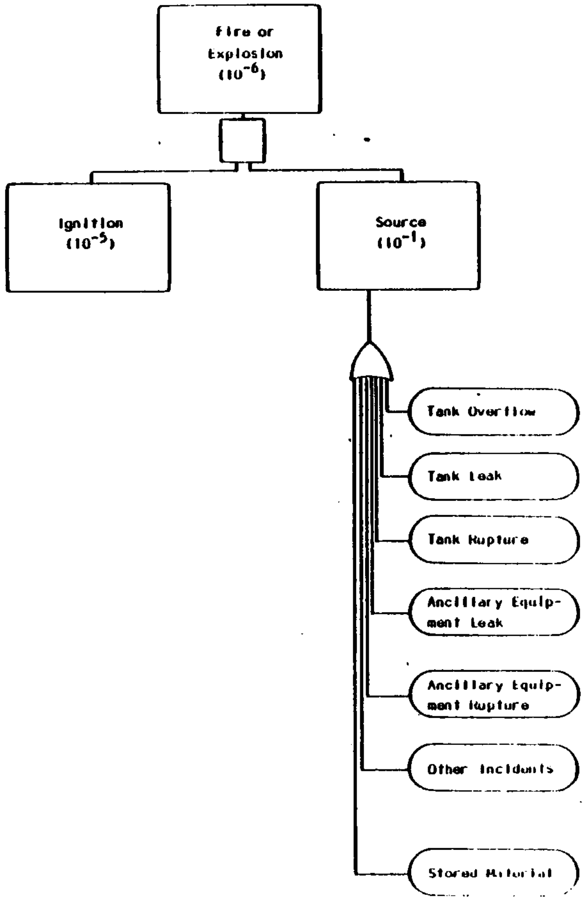


Figure 4-17. Variables and release probabilities associated with fire or explosion on a "typical" underground hazardous waste storage facility.

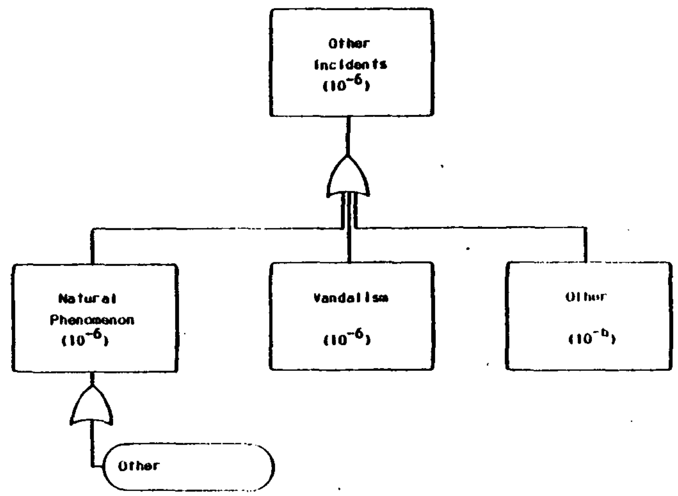


Figure 4-18. Variables and release probabilities associated with other accidents at a "typical" underground waste storage facility.

magnitude and the assumptions made to calculate release magnitudes. The values derived from this exercise are discussed below.

- Tank Overflow: The volume of waste released due to tank overflow is influenced primarily by the operator's failure to have the tank emptied (it is assumed that the tank under consideration is emptied when it reaches 75 percent capacity or every 15 days, whichever comes first), or overestimating the available capacity of the tank. The assumptions made to estimate the "typical" facility release magnitude include:

  - overflow would only occur during filling operations;

  - a single batch load of 150 gallons is drained to the tank daily (assume 75 gallon capacity available in tank at time of filling resulting in overflow of 50 percent (75 gallons) of the batch discharge); and

  - the overflow would be noticed by the facility operator the same day it occurred.

  A release of approximately 75 gallons would occur as a result of this event. [50 percent of batch lost x 150 gallons/batch = 75 gallons].

- Tank Leak: The volume of waste released due to tank leak is dependent on the number, size and location of perforations in the tank wall, the existence of secondary containment and/or leak monitoring systems, and the time it takes the operator to detect the leak. The assumptions made to estimate the "typical" facility release magnitude include:

  - the number and size of tank wall perforations are such that 2 gallons of stored material leak from the tank each day;

  - all of the perforations are in the lower third of the tank;

  - tank testing is conducted once every 5 years and the leak occurred 6 months after the last test (i.e., the leak would go undetected for 4.5 years).

  A release of approximately 3,300 gallons would occur as a result of this event. [1,643 days x 2 gallons/day = 3,285 gallons].

- Tank Rupture: The volume of waste released due to tank rupture is influenced primarily by the location of the opening, the volume of waste in the tank at the time of the event, the existence of secondary containment and/or a relese detection system, and the time it takes the operator to detect the loss of material. The assumptions made to estimate the "typical" facility release magnitude include:

  - the opening is located at the bottom of the tank;

  - the tank contains 1,500 gallons of waste material at the time of rupture;

  - the entire contents 1,(500 gallons) of the tank are lost over a period of a few days; and

  - the rupture is detected after 1 week when the operator makes his weekly tank level reading. (Assume a loss of 150 gallons per day).

  A release of approximately 2,550 gallons would occur as a result of this event. [1,500 gallons (tank content) + (7 days x 150 gallons/day) = 2,550 gallons].

  Ancillary Equipment Leak: The volume of waste released due to ancillary equipment leaks is primarily controlled by the size of the leak, the existence of leak monitoring systems and/or secondary containment and the frequency of tank and pipe testing. The assumptions made to estimate the "typical" facility release magnitude include:

  - the size and location of the leak are such that one percent (1.5 gallons per day) of the daily batch discharge to the tank is released;

  - the facility does not have a leak monitoring system or secondary containment;

  - tank and pipe testing are conducted once every 5 years; and

  - the leak occurred 6 months after the last test (i.e., the leak would go undetected until the next test is performed (4.5 years)).

  A release of approximately 2,470 gallons would occur as a result of this event. [1,643 days x 1.5 gallons/day = 2,465 gallons].

- Ancillary Equipment Rupture: The volume of waste released due to ancillary equipment rupture is primarily controlled by the volume of waste transported through the system, the existence of a leak monitoring system and/or secondary containment and the ability of the operator to detect level discrepancies in the tank. The assumptions made to estimate the "typical" facility release magnitude include:

  - the release is due to a pipe break and 90 percent (135 gallons per day) of the daily batch discharge to the tank is released;

  - the facility does not have a leak monitoring system or secondary containment; and

  - the release would go undetected for 2 weeks. (The leak would be detected as a result of level discrepancies noted during tank level reading.)

  A release of approximately 1,890 gallons would occur as a result of this event. [14 days x 135 gallons/day = 1,880 gallons].

- Fire or Explosion: The volume of waste released due to fire or explosion is primarily controlled by storage facility safety practices and control measures such as spark arrestors on vent pipes, safety training programs for employees and fire suppression systems. The assumptions made to estimate the "typical" facility release magnitude include:

  - the release is the result of a fire followed by an explosion;

  - the storage facility does not have a safety training program, fire suppression system or any other fire or explosion prevention equipment;

  - the tank contains 1,500 gallons at the time of the event; and

  - the entire contents are released as a result of the event.

  Approximately 500 gallons would be lost with a portion being combusted and the balance being released to the environment (i.e., land and air).

- Other Incidents: The volume of waste released due to other incidents is dependent on the type of event. The primary factors which influence this event are facility location (i.e., whether the facility is located in a fault zone, flood plain, etc.) and facility security. The assumptions made to estimate the "typical" facility release magnitude include:

  - the release is a result of arson;
  - the storage facility does not have a fire suppression system;
  - the tank contains 1,500 gallons at the time of the event; and
  - the entire contents of the tank are released as a result of the event.

  Approximately 1,500 gallons would be lost with a portion being combusted and the balance being released to the environment (i.e., land and air).

A summary of the release volumes from these events is presented in Table 4-1.

Relative Release Probabilities

Release probabilities used in this analysis were derived using judgment supported by values from studies done by F.G. Bercha [1] and JRB [3]. The principal reference source for estimating release probabilities was an F.G. Bercha report [1] since these values were relative rather than absolute, and thus were more closely appropriate for the analysis conducted in this section.

These values from F.G. Bercha [1] were then compared to those used in the JRB report to check the relative relationship between fault-tree components. Probability values from the F.G. Bercha study [1] were based primarily on the "Reactor Safety Study" prepared for the U.S. Nuclear Regulatory Commission (NRC) in October 1975 [6], correspondence with equipment manufacturers and facility operators and judgment [3]. As a result, these values represent estimates of bulk plant storage relative release probabilities. Probability values in the JRB report [3] were based on the NRC data mentioned above and additional sources. These values represented actual vs. relative values and were considered inconsistent with the fault-tree developed for this analysis which considers relative rather than absolute probabilities. In both cases, NRC data cannot be considered to

- Tank Rupture: As shown in Figure 4-13, the primary causes of tank rupture are design/installation deficiency (10^{-5}) and/or equipment failure (10^{-5}). The principal variable influencing design/installation deficiency is improper installation which may result in excessive stress due to uneven settling, etc. In the case of equipment failure, the primary cause is tank wall failure which is caused by corrosion. Since the "typical" facility has a carbon steel tank that is not pressurized (i.e., pump fed), there is less likelihood of rupture than for a facility with FRP tank or a pump fed system.

- Ancillary Equipment Leak: As shown in Figure 4-14, the primary causes of ancillary equipment leaks are design/installation deficiency (10^{-1}) and/or equipment failure (10^{-1}). Design/installation deficiency is the most significant factor and occurs primarily due to improper installation procedures such as inadequate tightening and sealing of fittings and inadequate care taken to prevent conditions (i.e., point anodes) which induce corrosion. Equipment failure occurs to a lesser degree, but is still a significant cause of ancillary equipment leaks. The primary causes of equipment failure are corrosion and seal failure.

- Ancillary Equipment Rupture: As shown in Figure 4-15, the primary causes of ancillary equipment rupture are design/installation deficiency (10^{-4}) and/or equipment failure (10^{-4}). The principal variables influencing design/installation deficiency are improper installation and subsequent induced stresses, both of which may result in excessive strain on the system due to differential settlement or vehicular traffic. Equipment failure is somewhat related to design/installation deficiency since pipe wall or equipment failure may result from induced stresses combined with corrosion induced weaknesses. In addition, seal failure may result in equipment failure.

- Fire or Explosion: As shown in Figure 4-16, fire or explosion is directly attributable to the probabilities of the previously discussed events occurring as well as the existence of an ignition source. Since the waste stored at the "typical" facility is ignitable, this event may occur, but its probability will be low since both ignition and material sources must be available for this event to occur. As a result, the probabilities of each must be multiplied to obtain the probability of this event occurring. As presented earlier, the events which will most likely result in providing a source for combustion are tank leaks (10^{-1}) and ancillary equipment leaks (10^{-1}). This, combined with a probability of ignition of 10^{-5}, results in a probability of fire or explosion of 10^{-6}.

- Other Incidents: As shown in Figure 4-17, the primary cause of other incidents is vandalism (10^{-6}) Since the "typical" facility is underground; is located outside of the flood plain; and is not located in a region of high seismic activity, there is little likelihood of this event occurring.

From the information presented above, the most likely events leading to releases of hazardous waste to the environment are tank and ancillary equipment leaks. Release probabilities for each event are controlled by the principal variables mentioned above since, once a release occurs, there are no control systems to prevent the material from entering the environment. Release probabilities estimated for facilities with alternative characteristics including overfill prevention, tank inspection, more frequent testing, etc. are presented in the next section.

Other Factors Influencing Release Probability

The release probabilities and magnitudes discussed above were estimated based on a number of assumptions regarding the characteristics (i.e., management practices, environmental setting, tank material, waste type, etc.) of the "typical" facility. Different facilities, types of waste and environmental settings will cause probabilities and magnitudes to be different. Some of these differences are discussed below.

- Environmental Setting: In this analysis, environmental setting considerations consist of geographic location, soil characteristics and groundwater levels, each of which influence the variables effecting release. These factors are all interrelated, but each plays a slightly different role in this analysis.
  - Geographic location considerations are based primarily on whether or not the facility is located in a fault zone or a flood plain. Since the "typical" facility was assumed not to be located in these types of areas, the probability of release due to natural phenomena in the category of "Other Incidents" is approaching zero. The actual change in relative probability value would vary by site-specific consideration such as the frequency of floods or earthquakes;

  - Soil characteristics, particularly resistivity, are measures of the corrosion potential of steel tank and piping systems. Corrosion is a major consideration in steel tank, ancillary equipment leak and rupture events. If conditions were less conducive to corrosion than those assumed for the "typical" facility, the release probabilities associated with these events might be lower. The actual change in relative probability would depend on specific site conditions and facility configuration.

- Ground water levels are important when considering corrosion potential and installation procedures, both of which may influence tank and ancillary equipment leak and rupture events. Soil moisture content effects corrosion potential. As a result, tanks and ancillary equipment situated in groundwater will be more prone to corrosion (Note: the extent of change in corrosion potential is unknown). Fluctuating groundwater tables may cause a partially filled tank to "float" if it is not properly anchored. This "floating" problem may result in tank and/or ancillary equipment leaks or ruptures. Since the "typical" facility was not influenced by groundwater, the relative probabilities of release in the example, may be lower than in a situation where groundwater is of concern. The actual change in relative probabilities would be site specific.

Tank and Ancillary Equipment Material: Tank and ancillary equipment material is a major consideration when assessing the system's susceptibility to corrosion and structural durability. For example, concrete and steel storage systems are more susceptible to corrosion than FRP storage systems and as a result, have higher probabilities of release associated with events influenced by corrosion. On the other hand, structural durability is of less concern with steel storage systems than with FRP systems. FRP tanks and piping systems have a higher probability of release as a result of puncture and/or fracture due to installation error, puncture due to operator error (i.e., dip stick punctures) [7], and fracture due to induced stresses. The actual change in relative release probabilities varies by site.

- Tank Age: The age of the equipment is one indicator as to how much longer the facility can be expected to be serviceable. However, other factors such as corrosion, puncture due to operator error, and installation deficiencies have a larger effect than age. For example, work by Warren Rogers and Associates [8] has shown that factors such as soil resistivity, pH, sulfide content and moisture content affect corrosion far more than tank age. In a given soil environment a steel tank may last for more than 20 years, whereas in a corrosive soil, the same tank may fail within 2 years. Thus, tank age cannot be the only factor considered when determining release probability.

- Waste Type: Waste type is of concern when selecting compatible material for the underground storage facility and later when considering facility operation. As the number of different wastes handled or the number of tanks at a storage facility increases, the probability that a waste will be accidentally or intentionally emptied into a storage system constructed of an incompatible material increases along with the probability that two chemically incompatible waste types will be mixed. If this situation exists, the relative probabilities of release due to tanks and ancillary equipment rupture and fire or explosion may increase in relationship to those presented for the "typical" facility which handles only one waste type.

DATA LIMITATIONS

As noted previously, a number of assumptions based on a variety of data sources and judgments were used in this section to define current practices and release events and to develop relative release probabilities and magnitudes. Due to their importance, the major assumptions are reiterated below.

- Release events and variables associated with the fault-tree analyses were developed from aboveground bulk plant storage facility studies and information obtained from telephone conversations and documents reviewed for this report.

- Current practices for storing hazardous wastes underground were defined based on information gathered from equipment manufacturers, trade associations and "standards" organizations, in-house knowledge about storage facilities, and literature sources. Information from the tank and general hazardous waste storage questionnaires was originally intended as the primary source of this information, but was unavailable.

- Release probabilities presented in this section are relative values and are not intended to represent actual release probabilities. These values represent judgment

  based on previous studies of bulk petroleum product storage facilities [1] [3] and aboveground hazardous waste storage tanks.

- Release magnitudes were based on judgment using the assumptions presented in this section.

SUMMARY

Examination of information from previous studies of petroleum product storage facilities and contact with equipment manufacturers, trade associations, and "standards" organizations lead to the identification of seven events that cause releases from underground storage tanks, as follows:

- Tank overflow
- Tank leak
- Tank rupture
- Ancillary equipment leak
- Ancillary equipment rupture
- Fire and/or explosion
- Other incidents (e.g., earthquakes, floods, vandalism)

Relative release probabilities and magnitudes are affected significantly by the specific facility features such as tank and ancillary equipment materials, type of waste stored, management practices, method of waste delivery to the storage tank, etc. Thus, a "typical" facility was identified which was believed to represent the most common practice. This facility also serves as a baseline for comparison with alternative practices discussed in Section 5.

Based on the characteristics of this "typical" facility, estimates of relative release probabilities and magnitudes were developed (see Table 4-2). As shown, two of the events with the highest relative probability of occurrence, tank and ancillary equipment leak, also have two of the highest estimated magnitudes of release. The principal assumption affecting the magnitude associated with these events is the duration of the leak (in this case 4.5 years), which is based on a testing frequency of 5 years.

Duration is also a principal factor in determining the magnitudes of release due to tank and ancillary equipment ruptures. These events have a lower relative probability of occurrence, but if they occur and go undetected for longer than the time periods assumed (1 week for tank rupture and 2 weeks for ancillary equipment rupture) their magnitudes could be much higher. For example, if a tank rupture went undetected for 1

TABLE 4-2. RELATIVE RELEASE PROBABILITIES AND MAGNITUDES ASSOCIATED WITH THE "TYPICAL" FACILITY.

Event	Relative Release Probability*	Release Magnitude (Gallons)
Tank Overflow	10^{-2}	75
Tank Leak	10^{-1}	3,300
Tank Rupture	10^{-5}	2,550
Ancillary Equipment Leak	10^{-1}	2,470
Ancillary Equipment Rupture	10^{-4}	1,890
Fire or Explosion	10^{-6}	1,500
Other Incidents	10^{-6}	1,500

* Release probabilities presented in this table are relative versus absolute values and represent the probability of release over the life of the facility.

month and an ancillary equipment rupture went undetected for 2 months, the resulting magnitudes would be approximately 6,000 gallons and 8,100 gallons for tank and ancillary equipment ruptures, respectively.

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5. American Petroleum Institute. Installation of Underground Petroleum Storage Systems. API 1615-1979. Washington, D.C.

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SECTION 5

ANALYSIS OF SELECTED MANAGEMENT ALTERNATIVES

INTRODUCTION

Review of Sections 3 and 4 of this report indicates that current underground storage tank system practices can result in environmental release of hazardous waste. These releases have been described by seven categories of release events, as follows:

- tank leak, defined as release at relatively low rates over an extended period of time (i.e., weeks, months, years);
- tank rupture, defined as release of large quantities (relative to tank volume) of stored material over a relatively short period of time (i.e., minutes, hours, days);
- ancillary equipment leak, defined as release from pipes, pumps, valves, etc. at relatively low rates over an extended period of time;
- ancillary equipment rupture, defined as release of large quantities (relative to the quantity of material handled) of material from pipes, pumps, valves, etc. over a relatively short period of time;
- tank overflow, defined as release associated with over-filling of the storage tank;
- fire/explosion, defined as sudden release of a portion or all of the stored material from a tank system as a result of the ignition and/or sudden expansion of a flammable or reactive waste; and
- other, defined as other miscellaneous events which occur due to natural phenomena, vandalism, etc.

With respect to storage of hazardous waste in underground tanks, 40 CFR Parts 264 and 265 include requirements related to prevention of tank overfilling (264.192 and 265.192), fire/explosion (264.198, 264.199, 265.198 and 265.199) and vandalism (264.14 and 265.14). The impacts of natural phenomena on release from tank storage facilities have been the subject of other investigations [1]. Thus, hazardous waste releases from the first four categories of release events listed above are the subject of this analysis of management alternatives.

Environmental releases resulting from leaks and ruptures of underground tanks and associated ancillary equipment are of particular concern since the occurence of these events often goes undetected for long periods of time (i.e., a year or more). In order to prevent and/or minimize the impact of these release events, it is necessary to understand the causes. Four types of release causes were identified in Section 4 and are used here to facilitate the analysis, as follows:

- design deficiency;
- installation practices;
- equipment failure; and
- operational error.

Design

Although design deficiencies may occur at any stage in the development of a storage tank facility, they are thought to be the least common of the four types of release causes. The specific type of error which occurs will be determined on a case-by-case basis, but generally the errors are caused by the same type of factors which contribute to other types of engineeering errors, and include:

- inaccurate information;
- incomplete information;
- inexperience (on the part of the engineer, equipment manufacturer and/or facility operator); and
- errors in judgement.

Solutions to deficiencies associated with facility design obviously involve correcting these deficiencies (i.e., through improved availability and accuracy of baseline design information, etc.). Thus, improvements can be expected if the effort is made. However, errors will still occur even with improved practices, although with a lower frequency.

Installation

Installation practices are indicated to be an important source of problems at existing facilities, with the type of problem often depending on the the tank system materials. For all types of tank systems, improper joining of piping and appurtenances are a significant source of leaks. For steel systems, the primary concern is the increased rate of corrosion (expecially non-uniform corrosion) caused by events such as:

- damage to a cathodic protection system (i.e., sacraficial anode or impressed current equipment attached to the tank);

- lack of homogeneous and inert backfill material;
- damage to protective coatings; and
- attachment of mud clods to the tank or similar contributors to point corrosion.

Other concerns associated with steel tank installation include inadequate fill compaction leading to differential settling and damage to piping connections and improper anchoring. For FRP systems, problems are generally related to puncture or breakage of the tank due to foreign objects in the excavation or fill material; damage due to floating of inadequately anchored tanks; and breakage of the tank or piping due to differential settlement. For concrete systems, concerns include stress cracks and cracks resulting from settlement, both of which may lead to leakage. Minimizing these problems generally involves conformance with manufacturers recommendations, applicable codes and standards and guidance available from organization such as ASTM, API, UL, etc.

Equipment

Equipment failure has also been indicated to be an important cause of release, although equipment failures are also frequently linked to the three other types of release event causes. The equipment failures which occur are of many different types. Probably the most significant from a release perspective are related to corrosion and/or failure of ancillary equipment.

Corrosion-induced failures cover the range of types of corrosion (i.e., uniform, erosion, stray current, pitting, galvanic; etc.) and may be aggravated by improper installation, incompatible waste and/or design deficiencies. Ancillary equipment failures may involve pump diaphragms and packing, valve seals, piping connections, etc. and be caused by excessive pressures, design deficiencies, improper installation, incompatable materials and many other factors. Thus, equipment failures are minimized primarily by utilizing improved practices associated with equipment selection, installation and operation.

Operation

Operation is the fourth type of release event cause identified above and is an important factor in some types of release events. Operational errors may result from a variety of factors including lack of training, lack of maintenance, lack of security, human shortcomings (i.e., carelessness) or a lack of contingency planning and preparedness. Such operational errors may result in direct releases or may trigger other causes of release, as in the case of an accidental addition of an incompatible waste into a tank which results in equipment failure due to accelerated corrosion or explosion. As reflected by current regulations, improved practices can lead to decreases in release from operational causes. For example, 40 CFR Part 264.194 requires daily inspection of overfill control equipment to insure proper operation. In spite of such measures, however, operational releases are likely to remain an important, although reduced, source of release.

For the four release event causes common to the four release events categories discussed here, reductions in the frequency and size of waste releases can be accomplished through application of improved knowledge and practices. However, these causes cannot be completely eliminated. Thus, additional measures can be taken to reduce the frequency and size of tank system releases.

In this section of the report, five types of measures designed to provide for reduced levels of environmental release from underground tanks are discussed, as follows (see Section 2 for a discussion of how these measures were selected for consideration):

- secondary containment;
- corrosion protection;
- system testing;
- system monitoring (inventory and/or environmental); and
- inspection.

In order to provide a basis for comparison of these five types of approaches to reducing tank system releases, model facilities were developed. A discussion of the two model facility sizes used, including the relative importance of the four categories of release events at these facilities, is also provided.

MODEL FACILITIES

In order to provide a common point of reference for comparison of the various management alternatives, two sizes of model facilities were selected to represent small and medium sized facilities. The specific sizes of the model facilities selected were based on data from three sources. One source of data used was the preliminary data from the U.S. EPA Hazardous Waste Tank Questionnaire (OMB No. 2000-0424) [2]. A second data source was the San Francisco Bay Region of the California Regional Water Quality Control Board [3], and a third source was a profile of hazardous waste tank and container storage facilities which relied primarily on the Hazardous Waste Data Management System (HWDMS) for input data [4].

From these data sources, facility sizes of one 1,000 gallon tank and two 5,000 gallon tanks were selected to represent small and medium sized facilities respectively. Data from the Hazardous Waste Tank Questionnaire indicate that the median facility has an underground hazardous waste storage tank capacity of 10,000 gallons provided by three or less tanks, and that 14 percent of the underground hazardous waste tanks have a capacity of 1,000 gallons or less.

The physical and operational characteristics of the facilities assumed in the subsequent analysis of prevention and mitigation options are the same as those of the "typical" facility presented in Sections 4 unless otherwise noted. Particularly noteworthy characteristics are as follows:

- equipment and operation;
  - carbon steel tanks conforming to UL 58;
  - stored waste is ignitable;
  - waste enters tanks through gravity feed piping;
  - waste supply piping is underground and 20 feet in length;
  - tank vent piping runs parallel with the supply piping to the building and then up the side of the building;
  - waste is transferred to the small tank in 50 gallon batches once each week;
  - waste is transferred to each tank at the medium facility in 150 gallon batches twice each week;
  - tank level measured daily;
- installation was conducted in accordance with appropriate specifications available at the time of installation;
- located in poorly drained acidic soils with a resistivity considered to be conducive to corrosion; and
- tank age is 8 years.

The specific features of these facilities are assumed to be the same as for the "typical" facility discussed in Section 4 (see Section 4 for details) with the exceptions noted in this Section. In addition, hazardous waste storage facility characteristics associated with compliance with 40 CFR Part 264 Subparts B through G and J are assumed.

Subpart B addresses waste analysis, security, general inspection requirements and personnel training. As applied to underground storage facilities, waste analysis requirements include chemical and physical analysis of the waste prior to storage, repeat analysis as necessary to insure that it is accurate and up-to-date and a waste analysis plan. Facilities receiving waste from off-site sources must specify the procedures to be used to insure that the characteristics of waste received match the accompanying manifest.

For underground tank storage facilities, compliance with the security requirements could take several forms depending on site specific conditions. For example, facilities that also perform treatment and/or disposal functions would presumably integrate compliance with security requirements for all of their hazardous waste functions. In most instances, compliance would likely involve surveillance and/or fencing with gates to control access.

The general inspection requirements of Subpart B require that a facility must conduct (and record) inspections with a frequency sufficient to identify problems in time to correct them before harm to human health or the environment occurs. The type of inspection which is feasible for underground tanks and associated equipment varies with the installed configuration. For the model facilities, it was assumed that the piping is not accessible for inspection while the tank is accessible for inspection. For tanks which were not provided with manways at the time of construction, a manway may be retrofitted (see below for more details). The type and frequency of tank inspection are discussed below.

Preparedness and Prevention (Subpart C) and Contingency Plan and Emergency Procedures (Subpart D) require that design, construction, maintenance and operation minimize the possibility of unplanned waste releases. In addition, specific equipment (especially for fire control) and procedures (especially for ingitable or reactive wastes) are required unless specifically waived by the Regional Administrator.

Supart E defines requirements for the manifest system, recordkeeping and reporting which apply to hazardous waste storage facilities. Subpart G defines closure and post-closure requirements, which are also mentioned in Subpart J. Subpart J, which specifically addresses hazardous waste storage tanks (excepting underground tanks which cannot be entered for internal inspection) requires sufficient shell strength to prevent collapse or rupture (see also Appendix D) and that tank materials (or liners) are compatible with the waste stored (see also Appendix A).

In addition, requirements which expand on those in other Subparts regarding inspection, closure, reactive/ignitable waste and incompatible waste are also included in Subpart J. Requirements for internal inspection of tanks which can be entered for inspection are specifically excluded from the model facility since they are discussed below as one of the five approaches for preventing and/or mitigating releases.

Review of the release probabilities presented in Section 4 for tank and ancillary equipment leak and rupture release events indicates that compliance with these regulatory requirements does not change the release probabilities of these events (see Tables 4-13 through 4-16). This occurs primarily due to the assumption that the model facilities are also existing (rather than new) facilities and to the exclusion of compliance with the internal inspection requirement for the model facilities (since inspection is discussed below as one of five mitigation/prevention measures).

The model facility release magnitudes, on the other hand, are not the same as for the "typical" facility discussed in Section 4 due to changes in tanks size and operating assumptions. The values derived for the model facilities are as follows:

Event	Volume of Waste Released (gallons) per Event (gallons) by Facility Size	
	Small	Medium*
Tank Leak	1600	1600
Tank Rupture	500	2500
Ancillary Equipment Leak	120	700
Ancillary Equipment Rupture	90	540

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* Values are rounded to two significant figures.

The volume of waste released due to tank and ancillary equipment leak and rupture depend on the duration and rate of the event. Since empirical data for use in deriving estimated release rates are extremely limited, the values above are based primarily on assumptions. The key assumptions are presented below.

- Tank Leak: The volume of waste released due to tank leak depends primarily on the number, size and locations of perforations in the tank wall with respect to the liquid level in the tank, the type of waste stored and the time it takes the operator to detect the leak. The assumptions used with respect to leak rate and duration are:

  - the leak rate averages 1 gallon per day, with the initial rate lower and the final rate higher than the average. Thus, the leak rate at the time of detection is slightly above the rate which is detectable with most tank testing procedures and is the same as the rate assumed for the "typical" facility. The assumed leak rate (which is thought to be conservative) is based on judgement since empirical data were unavailable; and

  - tank system testing is conducted once every 5 years and the leak occurred 6 months after the last test (i.e., the leak would go undetected for 4.5 years. This assumed testing frequency is based on judgement since no empirical data were available. the range of testing frequencies actually used is thought to be large, with some facilities testing as often as every six months and others not at all.

- Tank Rupture: The volume of waste released due to tank rupture is determined primarily by location of the opening, the volume of waste in the tank at the time of the event and the time it takes the operator to detect the loss. The assumptions used with respect to these variables are:

  - the rupture occurs in the bottom of the tank;

  - the tank contains 50 percent of capacity when the rupture occurs and the tank contents are released over a period of 1 to 2 days; and

  - the rupture is detected after one day when the operator makes a daily tank level reading.

- Ancillary Equipment Leak: The volume of waste released due to ancillary equipment leak is determined primarily by the size of the leak, waste transfer characteristics and the time it takes for the operator to detect the leak. Assumptions used with respect to these variables are:

  - one percent of each batch discharge to the tank is leaked; and

  - tank system testing is conducted once every 5 years and the leak occured 6 months after the last test (i.e., the leak would go undetected for 4.5 years.

- Ancillary Equipment Rupture: The volume of waste released due to ancillary equpment rupture is primarily controlled by the waste transfer characteristics and the time it takes for the operator to detect the leak. The assumptions used for these variables are:

  - the release is due to a pipe break and 90 percent of each waste transfer is released; and

  - the release would go undetected for 2 weeks, at which time the operator would notice that the tank level had increased only nominally.

LEAK AND RUPTURE RELEASE MITIGATION/PREVENTION

Five types of prevention/mitigation measures are discussed here. For each approach, the following are provided:

- a brief description;

- a general discussion of the types of release causes and events which the measure mitigates/prevents;

- identification of the specific choices available for implementation;

- presentation of selected implementation options, including costs, advantages and disadvantages; and

- a brief summary.

In addition, summary tabulations of release probabilities, costs and effectiveness are included.

Secondary Containment

Secondary containment as discussed here includes both the provision of a containment structure in addition to the tank and interstitial leak detection equipment for identifying the failure of either the primary or secondary containment structure. It can be applied to both tanks and ancillary equipment to prevent environmental release of the stored waste in the event of a leak or rupture, and has the following features:

- provides a second line of defense against tank and ancillary equipment design deficiencies;

- removes concern for problems associated with undetected leakage due to installation errors, except for damage to the monitoring system which may occur during installation; and

- provides protection against equipment failures, except for failure of the monitoring equipment.

For both existing and new facilities, containment can be provided a number of different ways. For tanks, the secondary containment options include double-walled tanks, concrete vaults, and liners of various types, such as clay or synthetic membranes. For piping, containment options include covered trenches (i.e., a concrete utility trench), double-walled piping and tunnels. Depending on the type of containment used for the tank and piping, interstitial (between the primary and secondary containment units) monitoring can be accomplished using vacuum, pressure, sensors or visual inspection.

Selection of one of the above methods for use at a storage facility will depend on a variety of factors, such as number, size and location of tanks; waste type; and environmental setting, including soil and groundwater characteristics. These factors vary such that most if not all of the secondary containment methods identified above will see some use. Thus, most are discussed below. Clay liners are not discussed due to the substantial variations in cost as a function of clay availability and the similarity of applicability to synthetic liners. Tunnels for piping are also not discussed due to the substantially higher cost than the other options.

Double-walled tanks are available in steel, stainless steel, fiberglass or combinations of these materials, although fiberglass tanks are not available in sizes larger than 4,000 gallons. As discussed above, use of steel tanks for the model facilities is assumed since this is thought to be the material most commonly used (see Section 2). Alternatives are also available for the extent of secondary containment (i.e., complete containment, double walls only on the bottom half of the tank, etc.) and the type of monitoring system used (i.e., measurement of vacuum or resistivity to detect water and/or waste in the interstitial space).

The advantages, disadvantages and costs associated with the use of double-walled tanks for both existing and new facilities are presented in Table 5-1. As shown, the primary disadvantage is the lack of availability in some materials and sizes and the primary advantages are greater ease of cleanup if primary containment does fail, and lower cost.

The initial costs for existing facilities assume cleaning and removal of the existing tank, replacement (in the same excavation) with a double wall tank and reuse of the existing ancillary equipment. The initial costs for new facilities represent the difference between the cost of the facility with a double wall tank and the cost with a single wall tank. Annual costs for both existing and new facilities are based on the assumption that the interstitial monitors must be checked each operating day to comply with 40 CFR 264.194. This daily checking of the monitoring equipment is estimated to require 5 minutes per day, 260 days per year at a cost of $16 per hour. Thus, the annual cost is $350 per year.

The costs and advantages and disadvantages associated with the concrete vault approach to secondary containment for underground tanks are also shown in Table 5-1. The primary advantage of the concrete vault approach to secondary containment is that the containment structure will not need replacement in the event of tank failure. The principal disadvantages are the generally higher cost than for double wall tanks; the increased risk of fire or exposion in the event of release of ignitable or reactive waste from the tank (as compared to a directly buried tank); and the requirement of some local codes that the vault be backfilled if the tank contains ignitable waste.

Since concrete is porous and susceptible to cracking, it is assumed that the containment structure is lined with an epoxy or similar material which is compatable with the waste to be contained. In addition, it is assumed that the exterior of the vault is water proofed to help prevent water from entering the secondary containment area. Use of a liner material on the concrete vault adds relatively little cost to the system and will also facilitate clean-up (if waste is released from the tank) and closure (since concrete will not be contaminated).

TABLE 5-1. SECONDARY CONTAINMENT*

Model Facility Type	Method**	Disadvantages/limitations	Advantages	Incremental Cost ($)* Initial	Annual	EUAC**
Existing-small	Concrete vault for tank(s) with continuous monitoring	- Some local codes require backfilling if tank contains ignitables. This prevents periodic visual inspection and complicates clean-up if a release occurs. Maintenance of sensors for monitoring is also more difficult of the tank exterior and secondary containment. - May require lining, depending primarily on waste type. - Cracking may impare integrity	- Available - Containment will rarely need replacement following a tank release - If not backfilled, clean-up should should be relatively fast and inexpensive. - Provides for containment and detention of tank releases and monitoring of containment integrity.	16,000	350	1,400
	Synthetic liner for tank excavation	- Clean-up of releases relatively expensive as compared to other methods of secondary containment. - Liner incompatible with some wastes.	- Expensive to install relative to other secondary containment methods. - Provides for containment and detention of tank releases and monitoring of containment integrity. - Available	38,000	350	2,900
	Double walled tanks	- Not available in all materials and tank sizes.	- Least expensive clean-up following tank release. - Provides for containment and detention of tank releases and monitoring of containment integrity.	16,000	350	1,400
	Concrete trench for ancillary equipment containment	- May require lining, depending on waste type. - Some local codes may require backfill. See concrete vault for tanks above.	- Available - Provides for containment and detention of ancillary equipment and monitoring of containment integrity.	6,000	350	750

TABLE 5-1 (Continued)

Model Facility Type	Method++	Disadvantages/limitations	Advantages	Incremental Cost ($)+ Initial	Annual	EUAC**
	Double walled piping	- Replacement relatively expensive unless pipe walls are independent. - Does not control releases from pumps valves, and other ancillary equipment.	- Available - Provides for containment and detention of pipe releases and monitoring of containment integrity. - May be more practical than trenches for retrofit installation in many situations.	1,500	350	450
Existing - medium	Tank concrete vault	Same as above	Same as above	44,000	350	3,300
	Synthetic liner for tank excavation	"	"	67,000	350	4,900
	Double walled tank	"	"	46,000	350	3,400
	Piping trench	"	"	6,000	350	750
	Double walled piping	"	"	2,500	350	520
New - small	Tank concrete vault	"	"	9,200	350	970
	Synthetic liner for tank excavation	"	"	33,000	350	2,600
	Double walled tank	"	"	9,200	350	970
	Piping trench	"	"	6,000	350	750
	Double walled piping	"	"	1,300	350	440
New - medium	Tank concrete vault	"	"	18,000	350	1,600
	Synthetic liner for tank excavation	"	"	50,000	350	3,700
	Double walled tank	"	"	31,000	350	2,400
	Piping trench	"	"	6,000	350	750
	Double walled piping	"	"	2,100	350	490

+Increase in cost from the baseline facility. Costs for tanks assume piping is left unchanged and pipe costs assume tanks are left unchanged. If secondary containment of tanks and concrete trench for piping are combined, the initial cost will be $2,600 less and the annual cost will be $250 less than the sum of the two costs presented here since one monitoring system control unit can be eliminated. If tank secondary containment is provided by a vault and a concrete trench is used for piping, an additional $2,500 initial cost savings will result from elimination of the piping trench sump.
++All methods presented assume continuous monitoring.
*See accompanying text for additional information on assumptions used in developing this table. Costs are rounded to two significant figures.
**Equivalent Uniform Annual Cost.

It is also assumed that the vault is provided with a manway to permit inspection of the vault liner material, the tank and the sensors which are assumed to be used to continuously monitor for leakage in the secondary containment area. The initial costs for exisiting facilities also assume removal of the existing tank, construction of a concrete vault in the same excavation, reuse of the exisiting tank in the vault and reuse of the ancillary equipment. The initial costs for a new facility represent the incremental cost for inclusion of the concrete vault and associated monitoring equipment. Annual costs for both existing and new facilities assume daily checking of the monitoring equipment at a cost of $350 per year. In addition, one inspection per year of the vault lining, tank exterior and monitoring sensor at a cost of $24 (one and one-half hours at $16 per hour) is assumed. Thus, annual costs are $374.

Use of a synthetic liner below the tank is the third method of tank secondary containment presented in Table 5-1. As shown, it is a more expensive method of containment than either of the other two methods discussed under the assumptions used here. The key construction assumptions effecting cost are the slope at which the liner is installed on the sides of the tank excavation and the number of tanks placed within a single liner. For the costs presented in Table 5-1, it was assumed that a slope of 2 to 1 (2 feet horizontal to 1 foot vertical) was used. Installation on steeper slopes may be possible, but such applications are not warranteed by the liner manufacturers. Use of a 1 to 1 slope, however, would result in initial costs which are less than instead of greater than those for the other two containment methods.

For the medium sized model facility, the wastes contained in the two tanks are assumed to be sufficiently compatable to permit both tanks to be installed within one liner. If separate liners are required, the costs would be significantly higher.

The initial costs presented for an existing facility also assume removal of the existing tank, additonal excavation, liner installation, and reuse of the existing tank and ancillary equipment. The initial costs for new facilities represent the incremental cost for inclusion of the liner and associated monitoring equipment (resistivity sensor and control unit). The annual costs for both exisiting and new facilities assume daily checking of the monitoring equipment at a cost of $350 per year.

Use of a concrete utility trench with resistivity sensors to detect leakage of either the ancillary equipment or the trench itself is one of two methods of ancillary equipment secondary containment presented in Table 5-1. This method has several advantages, including the ability to use a containment structure for ancillary equipment associated with several tanks, to replace failed ancillary equipment without replacing the containment structure and to integrate leak sensing with tank secondary containment. The principal disadvantage is that some local codes may require backfilling for ignitable wastes.

The initial costs for exisiting facilities assume installation of a pre-cast concrete trench with new piping and abandonment of exisiting piping in place. The initial costs for a new facility represent the cost for inclusion of the trench and associated leak monitoring equipment (resistivity sensor and control unit). If the concrete utility trench approach to secondary containment for ancillary equipment is used in conjunction with tank secondary containment (which is assumed to include sensors for containment monitoring), the initial costs for small and medium sized existing and new facilities will be reduced by $2,200.

The annual costs for both existing and new facilities assume daily checking of the monitoring equipment at a cost of $350 per year. If this approach to piping containment is used in conjunction with tank containment, the annual cost can be assumed to be eliminated since their will be no separate monitoring devices to read and record.

Use of double walled piping is the second ancillary equipment containment method presented in Table 5-1. As shown, it has the advantage of being easier and less expensive to install than a concrete trench in many situations. The principal disadvantage is the lack of economies of scale which are possible with a concrete trench both in terms of containment and leak detection monitoring.

The initial costs for existing facilities assume installation of double wall piping with pressurization of the interstitial space and abandonment of the existing piping in place. The initial costs for a new facility represent the differential between the installed costs of single and double wall piping. The annual costs for both existing and new facilities assume daily checking of a pressure gauge at a cost of $350 per year.

All of the above methods of tank and ancillary equipment secondary containment have the advantage of significantly reducing the magnitude and probably of release from both leak and rupture events. Magnitudes are reduced because event duration is reduced due to the use of continuous monitoring equipment, as follows:

Event	Reduction in Waste Released per Event by Model Facility Size*			
	Small		Medium	
	gal.	percent	gal.	percent
Tank Leak	1595	99+	1595	99+
Tank Rupture	495	99	2495	99+
Ancillary Equipment Leak	115	96	695	99
Ancillary Equipment Rupture	85	94	535	99

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* Values are based on the following assumptions:

- for events to result in release, the primary and secondary containment structures and the leak monitoring system must fail simultaneously. It is assumed that failure of the secondary containment system takes the form of a small leak (1 gallon per day) in the event of primary containment failure.

- event duration is five days for both rupture and leak events since it is assumed that the leak will be discovered and the tank drained within this period due to the daily inspection of the secondary containment monitoring equipment (the leak detection system is not discovered to be malfunctioning for three days and it takes two days to complete pump out of the tank and secondary containment area.

Use of secondary containment (including continuous monitoring equipment) for both tanks and ancillary equipment is estimated to <u>reduce the probability of release due to leak or rupture by four orders of magnitude.</u> Such a large reduction results from the numerous "and" gates in the fault tree for the system. Specifically, a release can occur only if the primary containment fails <u>and</u> the monitoring equipment fails or the operator fails to respond to an indication of a leak <u>and</u> the secondary containment structure fails over the same time period. Thus, they provide a high level of protection against design deficiency, installation error, operator error and equipment failure causes of waste release.

Use of either tank or ancillary equipment containment alone fails to provide a reduction in the probability of release from the facility as a whole since significant events remain uncontrolled. Some reductions in estimated release magnitude also occur, but they are generally small.

<u>Tank System Testing</u>

Tank system testing as discussed here includes testing of both tanks and piping systems to identify the presence, and in some cases, the rate and/or locations, of leaks. (Other methods which provide for testing of tanks only are also discussed in Appendix H.) Thus, tank system testing serves to reduce the magnitude of tank and ancillary equipment release by reducing the duration of an undetected leak or rupture. Some leak test methods only test for tank leaks, but are not considered here since they offer no particular advantages and have the obvious disadvantage of failing to detect piping leaks.

As shown in Table 5-2, a variety of methods exist for tank system testing. (Note: Table 5-2 is not all-inclusive.) Additional detail on these and other methods is provided in Appendix

TABLE 5-2 TANK SYSTEM TESTING SUMMARY*

Model Facility Type	Method	Disadvantages/limitations	Advantages	Incremental Cost ($)+		
				Initial	Annual	EUAC**
Existing - small	Sunmark Leak Lokator	- Applicability dependent on waste type. - Cannot detect very small (less than 0.03 gallons/hour) leaks. - Availability limited, but improving. - Tank needs to be full to give most reliable results.	- Tests both tanks and pipes. - Reported to be accurate to 0.003 gallons/hour. - Detects leaks throughout tank depth. - Compensates for temperature changes. - Relatively short set-up and testing time. - All testing coordinated by one company, which improves personnel training and testing reliability.	---	1,500	1,500
	VacuTect	- Sophisticated equipment requires specially trained personnel. - Leak rate not measured. - Applicability may be limited by waste type.	- Tank deficiencies and waste temperature do not affect results. - Short test time. - Tests both tanks and pipes. - Full tank not required. - Generally available.	---	500	500
	Smith & Denison (helium)	- Tank system must be empty for testing. - Leakage rate not measured. - Pressurized testing. - Requires specially trained personnel.	- Tests tank and pipes. - Applicability not dependent on waste type. - Not affected by temperature changes or tank deformation. - Relatively short test duration. - Generally available.	---	500	500

*See accompanying text for additional information on assumptions used in developing this table. Costs are rounded to two significant figures.

TABLE 5-2 (CONTINUED)

Model Facility Type	Method	Disadvantages/limitations	Advantages	Incremental Cost ($)+ Initial	Annual	EUAC**
	Petro-Tite	- Full tank and extra waste required. - Relatively long test duration. - Cannot detect very small (less than 0.05 gallons per hour) leaks. - Applicability dependent on waste type.	- Generally available. - Tests both tanks and pipes. - Reported to be accurate to 0.05 gallons per hour. - Temperature effects and tank deformations accounted for. - Detects leaks throughout tank depth.	---	500	500
Existing - medium	Sunmark Leak Lokator	Same as above	Same as above	---	1,500	1,500
	Vacutest	"	"	---	800	800
	Smith & Denison	"	"	---	800	800
	Petro-Tite	"	"	---	800	800
New - small	All 4 methods	"	"	Same as existing small		
New - medium	"	"	"	Same as existing medium		

+ Increase in cost from the baseline facility. Costs for tanks assume piping is left unchanged and pipe costs assume tanks are left unchanged. If secondary containment of tanks and piping are combined, the cost will be $3,000 less than the sum of the two costs presented here since one monitoring system control unit can be eliminated.
** Equivalent Uniform Annual Cost.

H. For all of the methods, there are three principal concerns associated with selection of a testing method: 1) compatibility of the testing equipment with the waste, 2) the minimum detectable size of a leak, and 3) the availability of equipment and trained personnel.

A potential disadvantage of all of the methods listed is that there is limited experience with testing tanks used to store hazardous waste. For tests which require equipment contact with the waste, waste characteristics are likely to limit the applicability of the testing procedure in some circumstances.

The minimum detectable leak size also varies with the method used, but is generally in the range of 0.03 to 0.05 gallons per hour for the more sensitive methods. For some methods, such as the Smith and Denison helium testing method, leak rate is not measured. For other methods, such as hydrostatic testing, the minimum detectable leak is notably larger. In general, the sensitivity of tank testing methods is at best aproximately one gallon per day.

The Sunmark Leak Lokator is reported to have been used to test commercial, non-petroleum, underground tanks and piping systems for leaks [5]. However, the availability of this method at a reasonable cost in some areas may be a problem. The Petro-Tite leak test method has been used primarily on underground gasoline storage tanks. It appears that the test method could be used to test tanks containing hazardous wastes as long as the stored product was compatible with the testing equipment and extra product was available to raise the liquid level above the top of the tank. The requirement of additional product may limit the extent to which this testing method can be used to test hazardous waste underground storage tanks for leaks. Availability of the other two methods shown in Table 5-2 is more limited.

As shown in Table 5-2, the costs associated with testing tank and piping systems vary with testing method, but are the same for existing and new facilities. However, costs for each method may vary significantly with location. Due to this variation and the other factors discussed above, selection of a testing method will generally not be made based on a comparison of the costs presented here.

For whichever method is used, the benefit derived will be a reduction in the magnitude of release due to earlier detection. The magnitude of this reduction will depend primarily on when the leak occurs in relation to system testing and the leak rate. For comparison purposes, estimated reductions in release magnitudes based on an annual testing frequency for the model facilities are as follows:

Event	Reduction in Waste Released per Event by Model Facility Size*			
	Small		Medium	
	gal.	percent	gal.	percent
Tank Leak	1420	89	1420	89
Tank Rupture	0	0	0	0
Ancillary Equipment Leak	110	91	78	89
Ancillary Equipment Rupture	0	0	0	0

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* Values are based on the following assumptions:

- the leak begins at the mid-point of the testing cycle. Thus, the leak duration for all facilities is 26 weeks, and leak magnitudes using tank testing are as follows:
  - 180 gallons (26 weeks x 7 days/week x 1 gallon/day) is the tank leak magnitude for both small and medium facilities;
  - 13 gallons (26 weeks x 50 gallons/week x 1%) is the ancillary equipment leak magnitude for small facilities; and
  - 78 gallons (26 weeks x 300 gallons/week x 1%) is the ancillary equipment leak magnitude for medium facilities.

Since developing leaks are not detected, no reduction in release probability is achieved.

Environmental Monitoring

Another method of reducing release magnitudes without affecting release probabililities (i.e., detecting releases after they have occured) involves the monitoring of the environment adjacent to a hazardous waste storage tank. Such monitoring could be conducted in the saturated zone and/or unsaturated zone using observation wells and any of three methods of detection, including: 1) thermal conductivity or electrical resistivity sensors, 2) gas detectors; or 3) sample collection and analysis. Regardless of the specific method used, the objective of such monitoring would be early detection of tank leakage, thereby minimizing release volume.

Soil and ground water monitoring of existing hazardous waste storage tanks has been used for leak detection in various situations. Perhaps the most concentrated use of this approach has been the program initiated by the California Regional Water Quality Control Board, San Francisco Region, to detect potential leakage from underground tanks. As part of this program, soil sampling and ground water well installation (where depth to ground water was less than 30 feet) have been conducted at approximately 100 locations since March, 1982, and monitoring at additional sites is anticipated.

The applicability of environmental monitoring for monitoring release from underground tanks containing hazardous waste is dependent on waste type and site conditions. Dependence on waste type is due to the fact that leak detection after the fact may not be acceptable for some types of waste (e.g., acutely toxic). In addition, waste type affects the selection of a specific environmental monitoring approach. For example, only volatile wastes can readily be monitored using gas detectors. Dependence on site conditions is due to soil and ground water characteristics discussed in detail below.

Site specific conditions and waste type also determine the practicality of a specific monitoring approach. As a result, four alternative approaches to environmental monitoring are discussed:

- ground water sampling and analysis;
- ground water wells with continous monitoring sensors;
- volatile gas monitoring with stationary probes; and
- soil water sampling and analysis.

In areas where the saturated zone is relatively close to the surface (i.e. 20-30 feet) ground water wells might be used. In order to document that contamination, if detected, is originating from the equipment (e.g., tank or piping) being monitored, both up-gradient and down-gradient wells are assumed.

The frequency of ground water sampling and analysis has a significant impact on the cost of implementing this management alternative. Since the overall objective of the monitoring program is to detect leakage as quickly as practicable, the sample collection/analysis interval should be no greater than the estimated time of migration from the equipment to the well. This time of migration wil depend primarily on: 1) the distance between the monitoring well and the equipment, and 2) the rate of transport in the saturated and unsaturated zones.

The rate of transport is extremely variable due to the dependence on a wide range of parameters including:

- soil porosity;
- soil permeability;
- waste mass density (which is a function of temperature);
- waste viscosity;
- waste saturated hydraulic conductivity; and
- size/rate of leak.

Thus, a desirable monitoring frequency based on the rate of waste transport and the distance between the equipment and the monitoring well could vary over a range of from minutes to many years. For example, soil transport calculations for benzene which assume a volumetric loading of 0.4 cubic meters/square meter indicates a 20 meter penetration in about 25 minutes from a surface spill at 20* C (ambient) over coarse sand and a 1 meter penetration in about 3 years from the same spill over clay till [6]. For the purposes of this analysis, a range of monitoring frequency of 4 times per year is assumed.

Assumptions used in estimating the costs associated with ground water sampling and analysis (see Table 5-3) at existing facilities are as follows:

- 1 up-gradient and 2 down-gradient wells for both small and medium facilities;
- well depth of 20 feet;
- 4 inch well diameter with drilling and casing cost of $16/foot;
- sampling equipment cost of $200; and
- drill rig mobilization cost of $300.
- sampling costs $50 per well per quarter;
- sample analysis costs $100 per sample; and
- samples from down-gradient wells are composited prior to analysis, so that 2 samples are analyzed each quarter.

Costs associated with new facilities are based on these same assumptions, with the exception that down-gradient wells will be replaced with casing installed in the backfill below the tank such that samples can be collected to monitor for leakage. The installed cost of this casing is $15/foot and it is assumed that 30 feet of casing are required for each tank.

Based on these assumptions, the advantages, disadvantages and costs associated with the use of the ground water sampling and analysis approach to environmental monitoring for both existing and new facilities are presented in Table 5-3. As shown, the primary disadvantage is the failure of this approach to provide for continuous monitoring, while the primary advantage is the relatively low initial cost.

An alternative to collection and analysis of samples from wells is the use of monitoring sensors which measure electrical resistivity or thermal conductivity to detect leaks. As shown in Table 5-3, a significant advantage of this approach is that it provides for continuous monitoring at a relatively low EUAC and

TABLE 5-3. ENVIRONMENTAL MONITORING SUMMARY*

Model Facility Type	Method	Disadvantages/limitations	Advantages	Incremental Cost ($)+		
				Initial	Annual	EUAC**
Existing - small	Ground water sampling (quarterly)	- Source of any detected contamination may be difficult to identify. - Duration of leak which can go undetected depends on soil permeability, waste type, well placement, sampling frequency, etc. - Does not provide for continuous monitoring.	- Can detect both tank and ancillary equipment leaks. - Lower initial cost than other monitoring methods. - Available. - Soils can also be sampled during well installation.	1,500	950	1,100
	Ground water wells with conductivity or resistivity sensors.	- Source of any detected contamination may be difficult to identify. - Duration of leak which can go undetected depends on soil permeability, waste type, well placement, etc.	- Can detect both tank and ancillary equipment leaks. - Available - Provides for continuous monitoring. - Soils can also be sampled during well installation.	5,000	350	690
	Volatile gas monitoring with stationary probes.	- Applicability limited to volatile materials with appropriate sensors available. - Duration of a leak which can go undetected depends on soil permeability, well placement, waste type, etc. - Source of any detected contamination may be difficult to identify.	- Can detect both tank and ancillary equipment leaks and applicability is independent of ground water depth. - Provides for continuous monitoring. - Soils can also be sampled during probe installation. - Available.	3,700	650	900
	Soil water sampling and analysis.	- May not be applicable to same wastes. - Duration of a leak which can go undetected depends on soil permeability, lysimeter placement, waste type, etc.	- Can detect both tank and ancillary equipment leaks. - Available. - Soils can also be sampled during installation.	1,400	950	1,000

*See accompanying text for additional information on assumptions used in developing this table. Costs are rounded to two significant figures.

TABLE 5-3 (CONTINUED)

Model Facility Type	Method	Disadvantages/Limitations	Advantages	Incremental Cost ($)* Initial	Annual	EUAC**
		- Does not provide for continuous monitoring. - Source of any detected contamination.				
Existing - medium	Ground water sampling	Same as above.	Same as above.	1,500	950	1,100
	Ground water wells with sensors.	"	"	5,000	350	690
	Gas wells with sensors.	"	"	3,700	650	900
	Soil water sampling	"	"	1,700	1,000	1,100
New - small	Ground water sampling	"	"	1,270	900	990
	Ground water wells with sensors.	"	"	3,500	350	590
	Gas wells with sensors.	"	"	1,000	350	420
	Soil water sampling.	"	"	1,030	900	970
New - medium	Ground water sampling	"	"	1,700	950	1,100
	Ground water wells with sensors.	"	"	4,700	350	670
	Gas wells with sensors.	"	"	2,100	700	840
	Soil water sampling.	"	"	1,200	950	1,000

* Increase in cost from the baseline facility.
** Equivalent Uniform Annual Cost.

is equally applicable to both new and existing installations. A potential disadvantage is that experience with use of sensors in observation wells for monitoring tank leakage is limited. In addition, the sensitivity of sensors is less than that for the sampling and analysis approach.

The costs shown are based on the same assumptions listed above for the sampling and analysis approach, with the following changes:

- the $200 initial cost for sampling equipment is deleted;
- the installed cost for sensor equipment at existing facilities is $3700;
- the installed costs for sensor equipment at small and medium new facilities are $2600 and $3150 respectively; and
- annual costs are associated with daily readings of the sensor control unit, which require 5 minutes per day, 260 days per year at a cost of $16 per hour.

A large percentage of the initial cost is associated with the sensor control unit which can be used to monitor multiple sonsors. Thus, there are significant economies of scale for this method.

For underground tanks which contain volatile wastes, monitoring for waste vapors is a third method of environmental monitoring. As with monitoring of ground water wells, vapor monitoring can be accomplished through continuous measurement or sample collection and analysis. For continuous monitoring, a detection device is mounted in an observation well, while for the sampling/analysis approach, samples are periodically taken from the well for laboratory analysis. Only the continuous approach to to vapor monitoring is discussed in detail due to the leak detection advantages of continuous monitoring and the similar costs associated with the two approaches.

The advantages, disadvantages and costs associated with the use of continuous vapor monitoring are shown in Table 5-3. As shown, the primary advantage of this approach it that applicability is independent of ground water depth, but the primary disadvantage is that applicability is limited to volatile wastes. The vapor monitoring approach has the second highest initial cost but the second lowest EUAC, based on the following assumptions:

- both existing facility sizes require 3 monitoring sensors, with initial costs as follows;
  - mobilization cost of $300;
  - sensor depth of 10 feet;
  - installed cost of 2 inch casing of $14/foot;

- installed cost of sensors at $980 each;

- a new small facility requires one sensor installed below the tank with an installed cost of $1040 complete;
- a new medium facility requires one sensor under each tank, with a total installed cost of $2080 for the facility;
- annual costs for existing facilities and a new medium facility include daily reading of the monitoring devices which requires 10 minutes/day, 260 days/year at a cost of $16/hour; and
- annual costs for a new small facility include daily reading of the monitoring device which requires 5 minutes/day, 260 days/year at a cost of $16/hour.

The fourth approach to monitoring for leak detection involves the use of suction lysimeters to collect samples for analysis from unsaturated soils. Suction lysimeters or comparable devices have been used to collect water samples from unsaturated soils for a wide variety of applications. Applicability for monitoring hazardous waste tanks will depend on a variety of factors such as waste type, soil conditions and climate. Where lysimeters can be used, soil conditions and tank configuration and size determine the number and location of samplers required.

The advantages, disadvantages and costs associated with the use of lysimeters are shown in Table 5-3. As shown, the primary advantages of this approach are that the cost is relatively low and it can be used to monitor for leakage of non-volatile wastes in areas where the saturated zone is relatively deep. The primary disadvantage is that sample collection and analysis from lysimeters does not provide for continuous monitoring. In addition, lysimeters tend to be more susceptable to clogging than wells.

The estimated costs for monitoring with lysimeters shown in Table 5-3 indicate that this approach has the lowest initial cost, but the second highest EUAC based on the following assumptions:

- an existing small facility requires 3 lysimeters (including one background) with an initial cost as follows;
  - mobilization cost of $300;
  - installed lysimeter depth of 10 feet;
  - drilling cost of $12/foot;
  - installation cost of $300;
  - pump, lysimeter and sampling equipment costs of $480;

- an existing medium facility requires 4 lysimeters (including one background) with an initial cost which is $290 above that of the existing small facility;

- a new small facility requires 2 lysimeters (one below the tank and one background) with costs as follows;

  - mobilization cost of $300;

  - installation of background lysimeter at 10 depth with a drilling cost of $12/foot;

  - installation of 2 lysimeters (with one in fill material below the tank) at a cost of $170 each (including the lysimeter);

  - pump and sampling equipment costs of $270;

- a new medium facility requires 3 lysimeters (one background and one under each tank) at a cost of $170 more than the new small facility; and

- annual costs include sample collection costs of $50/lysimeter and $800 in analysis costs (one background and one composite from tank monitoring lysimeters taken quarterly, yielding 8 samples per year, with analysis costs of $100 each).

All four of the methods of environmental monitoring discussed above can reduce the estimated magnitude of release from underground tanks by reducing the duration that a leak or rupture goes undetected. The extent to which magnitudes are reduced is extremely dependent on: 1) appropriate selection and placement of the monitoring devices: 2) the rate of waste migration from the tank system to the monitor; and 3) waste type (solubility, viscosity, etc.). The estimated reductions in release magnitude shown below are based on arbitrary assumptions concerning release duration and are included only to permit comparison of this option with the other prevention/mitigation measures discussed: (The event durations assumed are thought to be reasonable and sufficient to allow for meaningful comparison with other options.)

Event	Reduction in Waste Released per Event by Model Facility Size* for continuous monitoring			
	Small		Medium	
	gal.	percent	gal.	percent
Tank Leak	1586	99	1586	99
Tank Rupture	0	0	0	0
Ancillary Equipment Leak	119	99	694	99
Ancillary Equipment Rupture	0	0	0	0

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* These values are based on the assumption that it takes two weeks for waste released from the tank system to appear at the monitoring sensors. Thus, ruptures are discovered as a result of the daily tank level monitoring conducted at the facility and not as a result of environmental monitoring. The migration time can expected to be somewhat less for new installations, but well within the confidence interval of the these estimates.

Event	Reduction in Waste Released per Event by Model Facility Size* for intermittent monitoring			
	Small		Medium	
	gal.	percent	gal.	percent
Tank Leak	1558	97	1558	97
Tank Rupture	0	0	0	0
Ancillary Equipment Leak	117	98	682	97
Ancillary Equipment Rupture	0	0	0	0

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* These values are based on the assumption that it takes two weeks for waste released from the tank system to appear at the monitoring well or lysimeter and that the leak occurs at the midpoint of the monitoring cycle. Thus, ruptures are discovered as a result of the daily tank level monitoring conducted at the facility and not as a result of environmental monitoring.

As discussed above, applicability of the four methods varies with waste type and environmental setting. Thus, selection of a particular method will generally be based on site-specific factors and will not include consideration of relative effectiveness (in terms of the release probabilities shown above) of the methods. Since leak detection is after the fact for all of the monitoring approaches, there is no effect on estimated release probabilities.

Inventory Monitoring

Another method of monitoring for tank system leakage involves monitoring of waste quantities. Delivery of hazardous waste to the storage tanks at the model facilities is assumed to be accomplished through a gravity piping system since this appraoch is generally less costly and more reliable than pressure delivery and is frequently possible with underground tanks. Methods available for gauging of gravity flow pipes include liquid level sensors or Venturi meters. Use of the liquid level measurement technique requires computation of flow using pipe slope and roughness coefficients, and would be inexact in the relatively small diameter pipe used in underground tank systems. Use of a venturi meter requires that the pipe be full (since it only measures velocity), and this condition is not typical. Thus, gauging of the liquid level in the tank over a time period without withdrawals or additions of waste (e.g., a weekend) is the most probable method of inventory monitoring.

The advantages, disadvantages and costs associated with three methods of inventory monitoring are shown in Table 5-4. For storage of product (i.e., gasoline) in underground tanks, the traditional method of level measurement is the dipstick. Use of this method for hazardous waste storage tanks has a number of disadvantages, including:

- lower accuracy than automated methods;
- more labor intensive than automated methods;
- may not be performed as scheduled (i.e., due to inclement weather);
- presents the potential for release of the waste stored via material retained on the dipstick when it is removed from the tank;
- water seepage into a tank in the event of a leak or rupture mau prevent leak detection; and
- presents the potential for increased worker exposure to the waste.

The principal advantage associated with this approach is the lack of an initial cost, although the EUAC is higher than for some other methods.

A wide variety of methods exist for level monitoring as indicated by the some 22 different types of level gauging equipment discussed in a recent state-of-the-art survey [7]. These range from simple float type level indicators which are read at the fill port to electronic level sensors with remote indicator and recorder at a control panel. Selection of a specific monitoring system for an underground hazardous waste storage tank by a design engineer would include consideration of cost, accuracy, reliability, simplicity, time requirements and possible complications associated with use (e.g., increased potential for fire associated with bubbler tube measurement of ignitable waste).

To represent a range of the equipment which may be used at a facility, both direct and remote read-out level sensing equipment are included in Table 5-4. As shown, the remote read-out approach has the disadvantage of a higher initial cost, but has the advantages of a lower EUAC and is less susceptible to operator errors.

TABLE 5-4 INVENTORY MONITORING SUMMARY*

Model Facility Type	Method	Disadvantages/limitations	Advantages	Incremental Cost ($)*		
				Initial	Annual	EUAC**
Existing - small	Dip stick	- Relatively low accuracy. - May not be performed as scheduled. - More labor intensive than automated methods. - Potential for worker exposure to waste. - Potential for release of the stored waste via material retained on the dipstick where it is removed. - Sensitivity depends on length of time between measurements and accurate records of previous measurements.	- Very low initial cost. - Available. - Detection of large releases.	---	700	700
	Level sensor (pneumatic-read at tank location).	- Applicability of specific equipment affected by waste type. - Readings may not be made (i.e., inclement weather). - More labor intensive than remote readout systems. - Cannot detect small leaks.	- More accurate than dipstick. - Detection of large releases. - Available.	850	490	550
	Level sensor (electronic-remote records and readout).	- Applicability of specific equipment affected by waste type. - Cannot detect small leaks. - Relatively high initial cost as compared with the other two methods. - Cannot detect small leaks	- More accurate than dipstick. - Detention of large releases. - Effectiveness relatively independent of operator. - Low recurring costs. - Available.	2,200	350	500

*See accompanying text for additional information on assumptions used in developing this table. Costs are rounded to two significant figures.

TABLE 5-4 (CONTINUED)

Model Facility Type	Method	Disadvantages/limitations	Advantages	Incremental Cost ($)+ Initial	Annual	EUAC**
Existing - medium	Dipstick	Same as above	Same as above	---	1,000	1,100
	Level sensor (at tank)	"	"	1,700	700	810
	Level sensor (remote)	"	"	4,300	350	640
New - small	Dipstick	"	"	---	700	700
	Level sensor (at tank)	"	"	850	490	550
	Level sensor (remote)	"	"	2,100	350	490
New - medium	Dipstick	"	"	---	1,100	1,100
	Level sensor (at tank)	"	"	1,700	700	810
	Level sensor (remote)	"	"	4,100	350	630

+Increase in cost from the baseline facility.
** Equivalent Uniform Annual Cost.

In general, inventory monitoring can help to reduce release magnitudes but has no effect on release probability since releases are detected after they occur. However, the ability of inventory monitoring to reduce release magnitude is limited by the size of the minimum detectable leak, which is controlled by a variety of factors, including:

- the temperature of the tank and waste contained. The significance of this factor is determined by the coefficient of expansion of the waste and the degree of temperature fluctuation;
- the extent to which waste material is lost through vaporization, which is affected by the waste temperature and vapor pressure;
- the accuracy of the level measuring technique used, which is determined by the specific device used, the volume of the tank and the level of waste in the tank; and
- the effects of water inflow (in the event of a leak or rupture) on tank level reading.

Based on these factors and experience with gasoline stations [8], leaks of less than approximately 15 gallons/day cannot be reliably detected with inventory monitoring. Thus, inventory monitoring is helpful in reducing the magnitude of rupture events but does not reduce the magnitude of leak events for the model facilities, as follows:

Event	Reduction in Waste Released per Event by Model Facility Size* for continuous monitoring			
	Small		Medium	
	gal.	percent	gal.	percent
Tank Leak	0	0	0	0
Tank Rupture	50	10	150	6
Ancillary Equipment Leak	0	0	0	0
Ancillary Equipment Rupture	45	50	405	75

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* These values are based on the assumptions that leak rates are below the detection limit of the inventory monitoring equipment. In addition, it is assumed that tank rupture is discovered within one day, but that the tank contents have been lost by this time (so that a single batch transfer is the only release reduction). The ancillary equipment rupture values were estimated assuming that the rupture is discovered after one transfer, and that 90 percent of the transfer was released.

Internal Inspection

Inspection of tanks can be used to detect actual leaks, or to locate potential leak locations resulting from corrosion or other damage to the tank, liner or coating material. Since the hazardous waste storage tanks considered in this project are completely buried in the ground, inspection of the tanks can only be accomplished from inside the tank, and then only if the tank has a manway. Since internal inspection is limited to tanks, this mitigation/prevention measure does not help to control ancillary equipment release events.

Before a tank can be inspected, any waste contained must be pumped into containers, another on-site tank or a tank truck; the tank atmosphere decontaminated to allow personnel entry with the minimum of danger to health and safety; and the tank cleaned. Decontamination of the tank atmosphere may not always be required prior to cleaning, but is assumed to be a typical part of the tank inspection process. This is assumed to normally be accomplished by creating an inert atmonphere in the tank using dry ice [9].

Cleaning of the tank can be accomplished via a variety of methods, including sand blasting, hydro-blasting, steam cleaning and/or chemical cleaning. Selection of a cleaning method is somewhat dependent on the tank contents, condition and material of construction. Data on the relative prevalence of these methods for cleaning underground tanks are not available.

Sand blasting has the advantage that contractors capable of providing the service can be assumed to be readily available. However, it has the disadvantage of creating dust within the tank which makes monitoring of the cleaning process more difficult. Hydro-blasting is similar to sand blasting except the abrasives used in the cleaning process are suspended in water. The principal advantage of this approach is that the progress of the cleaning process is more easily monitored (visually) than with sand blasting. Steam cleaning has characteristics similar to hydroblasting, and the choice between the two would primarily be determined by the type of waste in the tank to be cleaned. Chemical cleaning has the disadvantage of generally being slower and more costly than the other cleaning options and normally is used only as a last resort in tank cleaning in preparation for inspection [9].

Following cleaning, the inspection process is assumed to proceed with a visual inspection and subsequent use of ultrasonic equipment. Visual inspection only was considered, but this approach to inspection was considered to be unacceptable since it can identify only relatively large defects on the inside of the tank and cannot detect potential problem areas on the outside of the tank.

For aboveground tanks, a ball peen hammer is normally used to aid in the inspectionn process and is considered to give a reliable indication of where thinning of the shell has occurred. On underground tanks, variations in backfill characteristices such as moisture content, compaction and material make this approach less reliable. The rationale for selection of ultrasonic equipment (rather than other available techniques such as radiography) to improve the effectiveness of inspection for detection/prevention of tank leaks is present in Appendix D. While the visual inspection of the tank interior will help to locate some potential problem areas (e.g., spot corrosion, etc.), it obviously will not detect potential problems which exist on the exterior of the tank shell. Thus, it is assumed that the entire tank will be tested ultrasonically from the inside.

As with the other alternatives discussed, costs will vary depending on the specific implementation. For inspection with ultrasonic equipment, significant cost variables include: distance between the tank facility and the location of the inspection contractor (if a contractor is used); cleaning materials disposal cost; and method of tank cleaning.

The advantages, disadvantages and costs associated with internal tank inspection are presented in Table 5-5. As shown, the primary advantage of internal inspection is that some (but not all) developing problems may be identified. The primary disadvantage is that thickness measurements are made on a relatvely small percentage of the tank surface. Thus, localized problems (such as small perforations resulting from point corrosion) may go undetected. Other disadvantages are that ancillary equipment releases are not effected and that the tank must be taken our to service to permit inspection. The costs shown for inspection are based on the following assumptions:

- there will be no initial costs since inspection will be performed by a contractor. This assumption is made based on the relatively high cost of the equipment involved as compared to contractor rates and the assumed inspection frequency (annual). Additional information related to this and other assumptions is provided in Appendix D;

- the inspection contractor charges for travel time (one-half hour each way is assumed) between his location and the tank facility;

- the operator "empties" the tank prior to the arrival of the tank cleaning crew using his normal methods and the cost of this activity is not part of the inspection cost;

- cleaning a 1,000 gallon tank requires a 2-man crew for 4 hours and cleaning of two 5,000 gallon tanks requires a 2-man crew for 8 hours (including travel time) at a rate of $120/hour for hydroblast cleaning, including materials and breathing apparatus [9];

TABLE 5-5. INSPECTION SUMMARY*

Model Facility Type	Method	Disadvantages/limitations	Advantages	Incremental Cost ($)+ Initial	Annual	EUAC**
Existing - small	Visual (internal) and ultrasonic.	- Tank must be enterable for inspection. - Training and experience required for proper inspection makes use of a contracted service desirable. - Not applicable to ancillary equipment. - Both existing and developing problems may go undetected due to the point measurement nature of the equipment.	- Since tank wall thickness is measured, developing as well as existing leaks can be identified. - No initial cost. - Tank cleaning and inspection contractors are readily available.	---	730	730
Existing - medium	Same as above	Same as above	Same as above	---	2,300	2,300
New - small	"	"	"	---	730	730
New - medium	"	"	"	---	2,300	2,300

*See accompanying text for additional information on assumptions used in developing this table. Costs are rounded to two significant figures.
+ Increase in cost from the baseline facility.
* Equivalent Uniform Annual Cost.

- cleaning materials are removed from the tank facility by the cleaning contractor and disposal of these materials is included in the cleaning rate charge;

- an ultrasonic survey of the tank interior with subsequent additional measurements made in potential problem areas identified in the survey or thorough visual inspection is assumed. The survey of the tank interior is assumed to be performed at a rate of 60 square feet per hour (one measurement per square foot) while a detailed inspection rate of 3 square feet per hour was assumed. Detailed inspection is assumed to be performed on 10 percent of the tank. The cost for ultrasonic testing is $25/hour.

- the 1,000 gallon tank has a diameter of 4 feet and length of 10.6 feet and the 5,000 gallon tanks are each 7 feet in diameter and 17.4 feet long.

The effectiveness of internal tank inspection in mitigating tank releases depends primarily on the frequency of inspection since this controls the release duration. For purposes of comparison, annual inspection has been assumed, which results in the following reductions in release magnitude:

Event	Reduction in Waste Released per Event by Model Facility Size*			
	Small		Medium	
	gal.	percent	gal.	percent
Tank Leak	1420	89	1420	89
Tank Rupture	0	0	0	0
Ancillary Equipment Leak	0	0	0	0
Ancillary Equipment Rupture	0	0	0	0

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* These values are based on the assumptions that tank leak begins in the middle of the inspection cycle. Thus, the leak goes undetected for 180 days and release occurs at a rate of 1 gallon per day.

Tank inspection may impact release probabilities for two reasons. First, the methods available for inspection of underground tanks are such that existing small leaks may go undetected. This may occur if the leaks are not revealed by visual inspection and the problem is sufficiently localized that it goes undetected in the ultrasonic survey of the tank. On the other hand, some developing leaks may be detected before they occur, thereby tending to reduce the release probability. Within the context of the order of magnitude estimates of release probabilities developed, the effect of the these two factors are judged to balance each other such that internal inspection <u>does not effect release probability</u>.

Corrosion Protection

Corrosion protection may be provided for a variety of tank system materials in a variety of ways. Regardless of the material being protected or the approach used, the objective of corrosion protection is to protect the tank system materials from corrosion during their intended service life. As such, corrosion protection helps to control tank and ancillary leak and ruptures by protecting against the most frequent cause of tank and pipe equipment failure. In addition, it helps to minimize increased corrosion which may be caused during installation.

Discussion of the mechanisms of corrosion and alternative approaches to corrosion protection are provided in Appendix A and are the subject of a large body of literature. As discussed here, corrosion protection applies to protection of steel tank system equipment only, although it is recognized that corrosion protection is occasionally required for other construction materials as well. A wide variety approaches to corrosion protection are possible, including anodic protection, cathodic protection, linings, coatings, compressive strength induction, etc. For underground tank systems, the three methods which are most commonly used and which are discussed here are external coatings, internal linings and cathodic protection (either impressed current or sacrificial anodes).

External coatings may be used alone or in conjunction with cathodic protection (normally sacrificial anode(s)) to protect underground steel tanks and piping from corrosion. A wide variety of coating materials are commonly used for corrosion protection, including both generic and trademarked materials. Selection of a material will depend on site-specific installation conditions and the equipment supplier (since not every coating material will be available from a given supplier).

Since coatings may be damaged during shipping and installation, thereby creating point corrosion problems, coatings are most effective when used in conjunction with a sacrificial anode. In fact, sacraficial anodes are normally used only on coated tanks since the coating significantly reduce the size of the anode required to provide protection throughout the normal tank system design life (20 years). Additional discussion of sacraficial anodes is provided below.

The advantages, disadvantages and costs associated with use of external coatings for corrosion protection are presented in Table 5-6. As shown, coatings are not judged to be applicable to existing tanks, primarily since the cost of retrofit application makes purchase of a new tank preferable. Use of coatings on new steel tank systems is common, at least in part due to National Fire Protection Association Codes 30 and 31 which include (as of 1981) a responsibility for cathodic protection or corrosion resistant materials. The costs shown are based on factory installation of a coal-tar epoxy coating (e.g., Koppers 300M or equal).

TABLE 5-6 CORROSION PROTECTION SUMMARY*

Model Facility Type	Method	Disadvantages/limitations	Advantages	Incremental Cost ($)*		
				Initial	Annual	EUAC**
Existing - small	External coatings.	- Generally not applicable for retrofit of existing tanks.	-----	---	---	---
	Internal lining for tanks.	- Lining flaws more of a problem than for factory applied linings on new tanks. - Tank must be enterable. Small tank dimensions may make lining installation expensive and/or impractical.	- Available - May prolong the service life of a tank which has developed minor leaks. - May be used to alter tank and waste compatability.	2,000	---	130
	Cathodic protection - impressed current.	- Requires partial excavation of system for installation.	- Less expensive than replacement. - Available. - Applicable to both tanks and piping.	5,000	60	400
	Cathodic protection - sacrificial anodes	- Requires partial excavation of system for installation. - Applicability limited to tanks which were coated prior to installation.	- Less expensive than replacement - Available. - Applicable to both tanks and piping.	1,200	---	80
Existing - medium	External coatings.	Same as above	Same as above.	---	---	---
	Internal linings.	"	"	6,300	---	460
	Cathodic protection - impressed current	"	"	5,000	120	460
	Cathodic protection - sacrificial anodes	"	"	3,400	---	230

*See accompanying text for additional information on assumptions used in developing this table. Costs are rounded to two significant figures.

TABLE 5-6 (CONTINUED)

Model Facility Type	Method	Disadvantages/limitations	Advantages	Incremental Cost ($)+		
				Initial	Annual	EUAC**
New - small	External coatings.	- Drainage during installation may reduce tank life below that of a bare tank due to erection of point anode(s) where accelerated corrosion may occur.	- Available - Generally low cost. - No maintenance required.	400	---	30
	Internal linings.	- Requires that tank be constructed with a manway. - Cost highly dependent on lining material. - Generally not applicable to piping.	- Available - May be used to modify tank and waste compatibility.	1,200	---	80
	Cathodic protection - impressed current.	- On-going power consumption - More expensive than sacrificial anodes for small single tank facilities.	- Available. - Applicable to both tanks and pipes.	5,000	60	400
	Cathodic protection - sacrificial anodes	- Anode size depends on site-specific conditions and design life.	- Available. - Very little maintenance required. - Applicable to both tanks and piping.	450	---	30
New - medium	External coating.	Same as above.	Same as above.	1,400	---	90
	Internal lining	"	"	4,800	---	320
	Cathodic protection-impressed current	"	"	5,000	120	460
	Cathodic protection-sacrificial anodes	"	"	1,800	---	140

+Increase in cost from the baseline facility.
** Equivalent Uniform Annual Cost.

Linings in tanks and piping may be used to protect them from the corrosive effects of the material contained. The advantages, disadvantages and costs associated with tank lining for both existing and new facilities are presented in Table 5-6. As shown, the primary limitations are that application to existing tanks requires access into the tank and that problems with quality control may be greater than for factory installed linings on new tanks. On the other hand, linings have the advantages that they may be used to extend the service life of a tank or allow a change in the material stored.

The costs shown in Table 5-6 were derived based on the following assumptions:

- an existing small facility requires 4 hours to clean at a cost of $120/ hour prior to lining (158 square feet) with an epoxy resin which costs $9.50/square foot;

- an existing medium facility requires 8 hours to clean at a cost of $120/hour prior to lining (918 square feet total) with an epoxy resin which costs $6.50/square foot;

- lining a new tank costs 20 percent less than lining an existing tank; and

- tank interiors are prepared in accordance with the Steel Structures Painting Council Specification No. 6 Commercial Blast Cleaning.

Cathodic protection can be provided through the use of impressed current or sacrificial anodes (see Appendix A for more detail). As shown in Table 5-6, sacrificial anodes have the disadvantage of having applicability limited for existing tanks to tanks which were coated prior to installation. The primary advantage of both approaches is that they can effectively protect against both internal and external corrosion, excepting corrosion caused by incompatable waste materials.

As shown, impressed current is substantially more expensive for use at the model facilities than is the sacraficial anode method of cathodic protection, and both provide the same type of protection. As a result, impressed current will normally be used only at large facilities with a large number of tanks and/or extensive piping networks to protect. Costs shown in Table 5-6 for cathodic protection are based on the following assumptions:

- a typical minimum cost for an impressed current corrosion protection system is $5000;

- installation of sacraficial anodes at existing facilities requires;

  - removal of existing pavement
  - excavation to the top of the tank

- installation of anodes
  - 2 at 9 pounds each for the small facility
  - 2 at 24 pounds each for the medium facility

- backfill and compaction
- replace pavement
- haul away old pavement

- for new facilities, the costs are based on factory installation of a coating and sacraficial anodes (size and number identical to existing facilities) to provide sti-P3 (TM) type of protection. It should be noted that tanks porvided with both coatings and sacrificial anodes for corrosion protection are readily available.

All of the methods of corrosion protection discussed are judged to reduce the chance of a leak occurring. Use of either impressed current or a coating in combination with sacraficial anodes is estimated to <u>reduce the probability of release by one order of magnitude</u>. Use of coatings or linings alone will result in some reduction in release probability which is estimated to be less than one order of magnitude. Once a leak occurs, however, corrosion protection is not thought to have a significant impact on the leak rate, and therefore does not reduce the estimated release magnitude associated with tank system leak or rupture.

CONCLUSIONS

The advantages, disadvantages and equivalent uniform annual costs (EUAC) associated with each of the six release mitigation/prevention measures discussed above are summarized in Table 5-7. The costs shown are incremental costs, and as a result costs for new facilities are significantly lower than for existing facilities for methods which involve significant construction costs (e.g. secondary containment).

As shown, secondary containment is the most expensive (based on EUAC) of the control methods examined for both the small and medium sized model facility under both new and retrofit conditions. Internal inspection is the second most expensive method, with corrosion protection the least expensive method. The benefit of the greater expense associated with secondary containment is that this method, unlike all of the others discussed, reduces both the probability and magnitude of release events.

The effects of the release prevention/mitigation measures discussed above on the estimated probability of tank leak, tank rupture, ancillary equipment leak and ancillary equipment rupture release events are summarized in Table 5-8. As shown, secondary containment is clearly the most effect means of preventing both leak and rupture events. Corrosion protection also serves to reduce the estimated release probability, and as shown, it also can control all four release events. Other measures, such as tank system testing and environmental monitoring, serve to

TABLE 5-7. "SOLUTION" COMPARISON SUMMARY*

Type of "Solution"	Disadvantages/limitations	Advantages	Effectiveness	EUAC ($) by Facility Type** Existing small	Existing medium	New small	New medium
Secondary containment for tanks	- Double walled tanks have limited availability in materials other than steel (including stainless).+ - Concrete vaults may not be applicable to ignitable waste due to local code requirements. - Clean-up of a release to a synthetic liner secondary containment area will be more difficult and expensive than for other methods, but will still be less expensive than clean-up of an environmental release.	- Cleanup of releases to secondary containment area easier and less costly than environmental clean-ups, and especially easy for double walled tanks. - Concrete vaults applicable to all types of tank materials. - Provides for containment and detection of tank releases prior to environmental release. - Provides for detection of secondary containment failure independent of primary containment failure.	- Very effective in preventing environmental release from tanks.	1,400	3,400	970	2,400
Secondary containment for ancillary equipment.	- Concrete trenches may not be applicable to ignitable waste due to local code requirements.	- Concrete trenches can be integrated with concrete tank vaults to provide continued capacity in excess of tank volume. - Provides for containment and detection of ancillary equipment (esp. pipe) releases prior to environmental release. - Clean-up of release to secondary containment area easier and less costly than environmental clean-up.	- Very effective in preventing environmental releases from piping and other ancillary equipment.	1,600	3,800	1,100	2,000
Tank system testing	- Limited track record for waste tank system testing. - Applicability of some tests depend on waste type. - Will not help to prevent leaks; rather, it will help to minimize volume through earlier detection. - Does not provide continuous monitoring.	- Provides for detection of tank and piping leaks. Size of detectable leak varies with test, but is generally in the range of 0.03 to 0.05 gallons per hour.	- Generally effective for tank and pipe leak detection, although small leaks may go undetected and errors in performing a test may cause enormous results. Also dependent on testing frequency (assumed here to be annual).	500	800	500	800

TABLE 5-7 (Continued)

Type of "Solution"	Disadvantages/limitations	Advantages	Effectiveness	EUAC ($) by Facility Type** Existing small			
				Existing		New	
				small	medium	small	medium
Environmental monitoring	- Specific method applicable depends on site conditions and waste type. - Duration which a leak may go undetected depends on soil permeability, well/sensor location, waste characteristics, etc. - Source of any detailed contamination may be difficult to identify.	- Can provide continuous monitoring for tank system leaks. - Soils may also be sampled during installation. Especially applicable to existing facilities.	- Generally effective for detecting releases. However, the duration of leakage prior to detection depends on site specific conditions.	690	690	590	590
Inventory monitoring	- Difficult to implement when tanks are filled by trickle gravity flow.	- Will detect ruptures or large leaks. Speed of detection depends on frequency of measurement, which may be continuous or intermittent.	- Generally effective in detecting ruptures or large leaks.	500	640	490	630
Internal inspection	- Tank must be taken out of service, generally for at least one to two days. - Does not address possible ancillary equipment problems.	- Can detect developing problems before leaks occur. - Tank cleaning precedes inspection, so the use of the tank can be changed relatively easily following inspection.	- Can help to prevent leaks, but reliability is not known; can also indicate existing leaks, but is thought to be less reliable than tank system testing.	730	2,300	730	2,300
Corrosion protection	- External coatings required. Damage during installation may increase corrosion rate. - Monitoring of performance generally requires use of one or more of the other "solutions" discussed.	- Protects against both tank and piping leaks resulting from corrosion. - Little or no maintenance required.	- Generally effective in preventing tank and pipe (primarily steel) releases due to corrosion failure, but does not provide a mechanism for readily checking the system performance.	80	220	30	140

+FRP tanks are also available in sizes up to 4,000 gallons.
* See accompanying text for additional information on assumptions used in developing this table. Costs are rounded to two significant figures.
** Equivalent Uniform Annual Costs which represent least cost methods presented in Tables 5-1 through 5-6. Note that these least costs methods may not be applicable in some situations.

TABLE 5-8. MODEL FACILITY RELEASE PROBABILITIES*

Solution	Method	Order of Magnitude Change in Estimated Release Probability by Event†			
		Tank Leak	Tank Rapture	Ancillary Equipment Leak	Ancillary Equipment Rupture
Tank secondary containment	Concrete vault for tanks w/continuous monitoring	-4	-4	0	0
	Synthetic liner for tank excavation	-4	-4	0	0
	Double walled tanks	-4	-4	0	0
Ancillary equipment secondary containment	Concrete trench for pipes	0	0	-4	-4
	Double walled piping	0	0	-4	-4
Tank system testing**	Any method identified in Table 5-2	0	0	0	0
Environmental monitoring **	Any method identified in Table 5-3	0	0	0	0
Inventory monitoring**	Any method identified in in Table 5-4	0	0	0	0
Inspection	Visual inspection with ultrasonic testing	0	0	0	0
Corrosion protection	Cathodic protection	-1	-1	-1	-1

* See accompanying text for additional information on assumptions used in developing this table. Costs are rounded to 2 significant figures.
† For example, a value of -4 indicates a reduction in the estimated probability of release 10^{-4}.
** Will only identify leaks after they have occurred

mitigate the effects of releases by decreasing the release magnitude and have no impact on the estimated release probability.

From a release probability perspective, secondary containment is the most cost effective method analyzed. This statement is made since secondary containment for tank and ancillary equipment provides a three order of magnitude greater decrease in release probability than corrosion protection at a cost which is less than two orders of magnitude greater.

It should be noted that the specific costs and release probabilities which led to the above conclusion are based on a variety of assumptions presented earlier in this Section. Assumptions regarding facility layout, materials of construction, method of secondary containment, etc., all affect the cost of the release mitigation/prevention measures discussed. These and other assumptions also affect the estimated release probabilities shown in Table 5-8. However, secondary containment remains the most cost effective method over a wide range of conditions.

The effects of the release prevention/mitigation measures on the model facilities as a whole (instead of the effects on individual release events) are presented in Tables 5-9 and 5-10 for existing and new facilities respectively. Effects on both estimated release probabilities and magnitudes as well as equivalent uniform annual costs (EUIC) associated with each measure are also presented. As shown, secondary containment for both tank and ancillary equipment provides a 99 percent decrease in the estimated release magnitude. Although the cost associated with this approach is among the highest shown, the cost per unit of release reduction is approximately the same as for tank containment alone. Thus, containment for the entire tank system is indicated to be a better investment in light of the very significant reduction in release probability provided.

Mitigation measures such as tank system testing and environmental monitoring are shown to provide significant reductions in release magnitude at costs per unit of reduction which are about half those asssociated with secondary containment. However, they provide no reduction in the estimated release probability.

Inspections are also shown to result in reductions in release magnitude without impacting the release probability. While tank inspection can result in the identification of developing problems before a leak or rupture occurs, measurements are taken on a relatively small percentage of the tank surface area. Thus, it was judged that while some reduction in the estimated relative release probability will occur with tank inspection, the reduction will be less than one order of magnitude.

A prevention measure which has no impact on the estimated release magnitude but which results in an estimated release probability reduction of one order of magnitude is corrosion

TABLE 5-9. INCREMENTAL COST AND EFFECTIVENESS SUMMARY - EXISTING FACILITIES*

Solution	Method	Reduction in Estimated Release Probability and Volume and Solution Cost by Model Facility Type**							
		Small				Medium			
		Release Probability	Release Volume (gallons)	Release Volume (percent)	Incremental EUAC ($)	Release Probability	Release Volume (gallons)	Release Volume (percent)	Incremental EUAC ($)
Tank system secondary containment	-Concrete vault for tank & concrete trench for piping with leak detection sensors and alarm	10^{-4}	1595	99	1600	10^{-4}	3190	99	3500
	-Double walled tank and piping w/leak detection & alarm	10^{-4}	1595	99	1600	10^{-4}	3190	99	3700
	-Synthetic liner containment for tank w/leak detection sensors & alarm	0	1480	93	2900	0	1800	56	4900
	-Concrete vault for tank w/leak detection sensors and alarm	0	1480	93	1400	0	1800	56	3300
	-Double walled tank w/ leak detection and alarm	0	1480	93	1400	0	1800	56	3400
Tank system testing	-Most methods in Table 5-2	0	1420	89	500	0	2840	89	800
Environmental Monitoring	-Ground water wells w/ sensors & alarms	0	1481	93	690	0	1812	57	690
Inventory Monitoring	-Level sensors w/remote recorder, readout and alarm	0	0	0	500	0	0	0	640
Inspection	-Internal visual and ultrasonic inspection	0	1420	89	730	0	1800	56	2300
Corrosion Protection	-Cathodic Protection	10^{-1}	0	0	80	10^{-1}	0	0	230

* See accompanying text for additional information on assumptions used in developing this table. Costs are rounded to 2 significant figures.

** Estimated release volumes are presented to the gallon to help document how they were derived. Accuracy is, at best, 2 significant figures. Reduction volumes for the medium facility are double those presented in the text in order to represent the reduction on per facility basis rather than a per event basis.

TABLE 5-10. INCREMENTAL COST AND EFFECTIVENESS SUMMARY - NEW FACILITIES*

Solution	Method	Reduction in Estimated Release Probability and Volume and Solution Cost by Model Facility Type**							
		Small				Medium			
		Release Probability	Release Volume (gallons)	Release Volume (percent)	Incremental EUAC ($)	Release Probability	Release Volume (gallons)	Release Volume (percent)	Incremental EUAC ($)
Tank system secondary containment	-Concrete vault for tank & concrete trench for piping with leak detection sensors and alarm	10^{-4}	1595	99	1100	10^{-4}	3190	99	1800
	-Double walled tank and piping w/leak detection & alarm	10^{-4}	1595	99	1200	10^{-4}	3190	99	2600
	-Synthetic liner containment for tank w/leak detection sensors & alarm	0	1480	93	2600	0	1800	56	3700
	-Concrete vault for tank w/leak detection sensors and alarm	0	1480	93	970	0	1800	56	1600
	-Double walled tank w/ leak detection and alarm	0	1480	93	970	0	1800	56	2400
Tank system testing	-Most methods in Table 5-2	0	1420	89	500	0	2840	89	800
Environmental Monitoring	-Ground water wells w/ sensors & alarms	0	1481	93	590	0	1812	57	670
Inventory Monitoring	-Level sensors w/remote recorder, readout and alarm	0	0	0	490	0	0	0	630
Inspection	-Internal visual and ultrasonic inspection	0	1420	89	730	0	1800	56	2300
Corrosion Protection	-Cathodic Protection	10^{-1}	0	0	30	10^{-1}	0	0	140

* See accompanying text for additional information on assumptions used in developing this table. Costs are rounded to 2 significant figures.

** Estimated release volumes are presented to the gallon to help document how they were derived. Accuracy is, at best, 2 significant figures. Reduction volumes for the medium facility are double those presented in the text in order to represent the reduction on per facility basis rather than a per event basis.

protection. For the costs presented in Tables 5-9 and 5-10, corrosion protection was assumed to be provided by an external coating and sacraficial anodes. Based on this assumption, corrosion protection is the least expensive method of achieving a reduction in estimated release probability.

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APPENDIX A

Excerpts from "Technology for the Storage of Hazardous Wastes, A State-of-the-Art Review", New York State Department of Environmental Conservation, January 1983

INTRODUCTION

As part of their Bulk Storage Program, the New York State Department of Environmental Conservation (DEC) prepared a State-of-the-Art Review Manual applicable to underground and above-ground storage system. Companion documents prepared as part of this program included the "Manual on Criteria and Guidance for Storing Hazardous Substances", the "Model Local Ordinance for Storage of Hazardous Substances", and the "Siting Manual".

The State-of-the-Art Review Manual compiles much of the latest information on the equipment available for storing and handling hazardous liquids. Included are data on tanks, hoses, overfill prevention devices, piping, valve, and pumps. Important information is also provided on the field practices and equipment available for leak detection and spill cleanup. It is a well-prepared overview. Accordingly, the portion describing underground storage systems and related background information are included as an appendix to this report.

This material discusses the technology and practices for storage of petroleum and other hazardous liquids which could be accidentally released into the environment. It should be noted that hazardous liquids vary widely in their characteristics and in the manner in which they should be stored.

This manual should serve only as a guide. Each chemical and each environmental setting requires its own specific storage design. It is the responsibility of the owner of the storage facility to seek the assistance of a professional engineer who has the skills to design a storage system which can be used safely and which provides the necessary measures for utility and environmental protection.

The mention of trade names or commercial products in this manual does not constitute endorsement or recommendation for use by the DEC, U.S. Environmental Protection Agency, or SCS Engineers.

The following chapters from the State-of-the-Art Review Manual are included:

- Title Page, Acknowledgements, Table of Contents and Introduction. This material shows what is included in the entire manual.

- Part I, Chapter 1: Leaks and Spills of Hazardous Liquids. Included in this chapter is a discussion regarding the generally recognized mechanisms of corrosion. It should be noted that the primary measure of corrosivity is the soil resistivity, as evidenced by design standards and a field test program conducted by the National Bureau of Standards. [1]

- Part I, Chapter 2: Hazardous Substances.

- Part II, Underground Storage Systems, Chapters 1 to 5 and 7: The design standards which are most commonly followed for bare steel tanks are Underwriters Laboratories (UL) 58 and National Fire Protection Association (NFPA) 30. American Petroleum Institute (API) Publication 1615, which is generally recognized for installation of underground petroleum storage systems, is also applicable for systems used to store hazardous wastes. API Publication 1602 is being phased out as a standard for udnerground gasoline tanks and API Publication 1611 is primarily a guide for sizing and laying out tankage for service stations. The primary design and installation standards applicable for hazardous waste storage systems are briefly described in Appendix C of this report.

- Appendix B, Compatibility Chart for Fluids, Seals, and Metals is included as an example for metal tanks, and should not be interpreted as a complete presentation.

[1] E. Escalante, "Soils and Underground Corrosion", Chemical Stability and Corrosion Division, National Bureau of Standards, Washington, D.C.

TECHNOLOGY FOR THE STORAGE OF HAZARDOUS LIQUIDS

A State-Of-The-Art Review

NEW YORK STATE

DEPARTMENT OF ENVIRONMENTAL CONSERVATION
DIVISION OF WATER
BUREAU OF WATER RESOURCES

ALBANY, NEW YORK

JANUARY 1983

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INTRODUCTION

A. PURPOSE

Within the past five to ten years there have been major advances in the technology and practices of storing and handling hazardous liquids. New tank designs and tank materials have been applied to solve problems of corrosion and to prevent leaks. Mechanical and electronic flow control and level detection devices have been invented to prevent transfer spills and monitor storage volumes. Laser technology, capable of measuring the loss of product stored in a tank with a resolution of 0.000001 inches, has been used experimentally to test for tank leaks. Secondary containment designs have been developed and applied by many sectors of the industry.

It is the purpose of this report to evaluate these and other aboveground and underground storage practices. It is a report on the state-of-the-art for the following:

- Tanks for storing hazardous liquids.
- Secondary containment systems.
- Piping and safety valves.
- Overfill prevention systems and practices.
- Inspection, testing and monitoring.
- Closure and abandonment practices.

Hopefully, this report will provide timely information for the industry and government officials faced with problems on the storage of hazardous liquids and will encourage the use of the best technology and practices for preventing spills and leaks.

B. REPORT OVERVIEW

This report is divided into three parts. Part I represents an overview of the general concerns associated with the underground or aboveground storage of hazardous liquids. This part of the report includes discussion of:

- The properties and characteristics of various hazardous liquids.
- The compatability of various tank and piping system materials with certain hazardous liquids.
- The types of leaks and problems which can occur in bulk storage facilities.
- The cause of corrosion.
- Other technical factors that must be considered prior to the storing of hazardous liquids.

Part II of this report addresses the state-of-the-art for underground storage systems. Part III addresses these same items for aboveground storage systems.

Some of the material discussed applies to both aboveground and underground systems, therefore, cross referencing is employed throughout this report. More detailed references, such as those prepared by the American Petroleum Institute, the National Fire Protection Association, and other institutions, are identified in the text. The reader is specifically directed to these references for futher information on the technology and measures for spill and leak prevention.

Because of the large quantity of gasoline and other petroleum products handled and stored in the state and the extensive information on the storage of these materials available from the American Petroleum Institute and other organizations, much of the detailed material presented in this manual is drawn from the experience of the petroleum industry. Although the basic principles illustrated are applicable to the storage of all hazardous liquids, some of the specific details presented may not be directly applicable in all situations. There are many ways by which environmentally acceptable storage facilities can be achieved. The manual is intended to serve as a source of background information and guidance to aid government officials, designers and users of bulk liquid storage systems in understanding the many different considerations and features which may impinge upon design and installation of such systems. It is not intended as a standard or as a substitute for sound engineering practice as applied to the design and installation of bulk storage systems for specific materials at specific locations.

Part I
STORAGE OF HAZARDOUS SUBSTANCES

INTRODUCTION

The purpose of Part I of this report is to present background information describing the characteristics of hazardous substances, the types and causes of leaks and spills, and the behavior of these leaks and spills in the environment. Chapter 1 of this part of the report addresses the types and causes of leaks from both aboveground and underground storage systems, the sources of leaks and spills and methods available to control them. This chapter also includes a description of the behavior of hazardous substances when they are spilled on or in the ground.

Chapter 2 of this part of the report presents data on the types of hazardous materials of concern and their properties. This chapter refers to general listings of hazardous substances, and provides detailed information regarding such items as type of hazard, specific gravity, boiling point, melting point, solubility in water, etc. for a select group of these substances. This chapter also provides information regarding the compatibility of various types of hazardous substances with the metals or other materials which may be used to construct storage system components (tanks, pipes, fittings, etc.).

Part I
CHAPTER 1: LEAKS AND SPILLS OF HAZARDOUS LIQUIDS

A. BEHAVIOR OF HAZARDOUS LIQUIDS IN THE ENVIRONMENT

1. Background [1,2,3,4]

Spills (including leaks) of hazardous liquids can have substantial environmental, public health and social impacts. Such spills can result in the contamination of soils, surface water and groundwater supplies and air, all of which can directly affect crops, wildlife, plants and ultimately humans. Many hazardous liquids are conservative substances (i.e., they do not biodegrade or decompose), therefore, once the substance has been spilled it will remain a hazard unless it can be removed to below the level of harmful concentration.

A hazardous substance which finds its way into the environment may be a serious threat to the health of people who come in contact with it. It may contaminate water supplies, crops and food supplies, fisheries or wildlife habitat. The non-environmental impacts which result from spills of hazardous liquids can also be far-reaching. These impacts can include the following:

- The dislocation of people.
- The loss of valuable product.
- The loss of property resulting from contamination, fire, explosions, etc.
- The economic and social costs of spill cleanup [1].

Storage tank leakage problems are more readily controlled and resolved with aboveground structures because the leaks are more likely to be visible. Below ground systems present potentially more serious problems of contamination because of the likelihood of undetected leakage, but minimize the possibility of fires and explosions when flammable and reactive chemicals are to be stored. The threat of potential groundwater pollution must be balanced against other safety considerations. In some parts of New York State, groundwater is the only source of fresh water, and areas such as Long Island have already witnessed a large number of groundwater pollution incidents. A prime example occurred in East Meadow, Long Island where a service station leaked 50,000 gallons of gasoline from a below ground storage tank and the hazardous fumes seeped into the basements of more than a score of the surrounding homes. The gasoline distributor purchased the homes and they are still uninhabitable [1].

A contributing factor in the increasing number of documented incidents like this is the large number of active and abandoned underground storage tanks. New York State has more than 100,000 aboveground and buried bulk storage tanks containing a variety of chemicals (cleaning solvents, pesticides, industrial process chemicals, etc.). However, most contain petroleum, primarily gasoline. For these alone, the New york State Gasoline Retailers Association estimates that at least 68,000 are underground at gasoline service stations. Roughly 24,000 of these tanks are at abandoned service stations that went out of business during the recent period of gasoline shortages. Although in disuse, many are suspected of containing a residual gasoline supply. In addition to the gasoline retailers, thousands of storage tanks across the State are used at motor depots, contracting yards, farms, schools, industrial sites and at some private homes [2].

Many tanks were installed in the early 1950's when growth in the chemical industry and highway transportation was booming. These tanks are now 20-30 years old – at or beyond their life expectancy. Other contributing causes to the problem include improper material selection during the design stage and, just as important, improper installation practices. The percent of failure is not known but it is estimated that 10 to 20 percent are leaking [2].

The effects of underground leakage and spills can be both short-and long-term. the short-term effects from gasoline spills, for example, as well as other hydrocarbon type materials, are potentially devastating because of their volatile nature. Seepage of liquids and fumes, into underground structures can result in gas and vapor accumulation and consequent explosion and health hazards. In the long-term, contaminated underground water supplies (aquifers) are practically impossible to reclaim once they have been contaminated. To understand the potential hazard posed by spills and leaks of hazardous liquids, one must develop some understanding of the behavior of such spills and leaks.

2. Spill Behavior

Spills and leaks of volatile hazardous liquids may pose potential air quality and explosion problems. The level of potential hazard is dependent upon several factors including the volatility of the spilled substance and vapor dispersion characteristics in the vicinity of the spill or leak. Surface waters may also be contaminated by spills and leaks traveling across or within soils posing a potential threat to aquatic life and human health.

However, of primary concern in New York State is the potential effect that spills or leaks may have upon soils, surface water and groundwater [1]. Hazardous liquids spilled or leaked into soil typically tend to flow downward, with some lateral spreading due to gravitational forces, as illustrated in Figure 1.1-1. The rate of movement in the soil will depend on product properties such as solubility, miscibility, viscosity, soil permeability and compaction, and the rate or volume of the leak or spill. For example, given the same soil properties, lighter liquids, such as gasoline, will penetrate the soil rapidly, while heavier, more viscous liquids will move more slowly. Alternately, if the soil has a low permeability, as is characteristic of clays, the product may have little or no penetration. However, if the soil is very porous, the product will penetrate it quickly.

Absorption by Soil [3,4]. As spilled liquids pass downward through soils, individual soil particles will be coated with a thin film of that liquid. In addition, surface tension will act to hold small amounts of that liquid in the voids between soil particles, as shown in figure 1.1-2. These actions combine to result in the absorption of the liquid into the soil. Once absorbed, extraction of the liquid is virtually impossible.

A spilled or leaked liquid will move downward in the soil until:

- It is absorbed by the soil.
- It encounters an impermeable bed or layer.
- It reaches the water table.
- It seeps from groundwater to surface water.

Movement at an Impermeable Layer [3,4]. The downward movement of a spilled liquid through soil is affected by variations in permeability of the soil layers through which it passes. If the flowing liquid encounters an impermeable layer of soil it will spread laterally until either it becomes immobile or it comes to the surface at the outcrop of the impermeable layer. Should the latter phenomenon occur, a second cycle of soil contamination could begin (Figure 1.1-3).

Note that Figures 1.1-3 through 1.1-6 illustrate the movement of product which is lighter than water and immiscible. A spilled chemical with a specific gravity greater than 1.0 will tend to sink to the bottom of the aquifer while one with a high solubility will tend to mix with the groundwater.

Downward movement of spilled material may also be complicated by the presence of thin lenses of material with low permeability (Figure 1.1-4). If such lenses are present, the fluid path could be substantially altered.

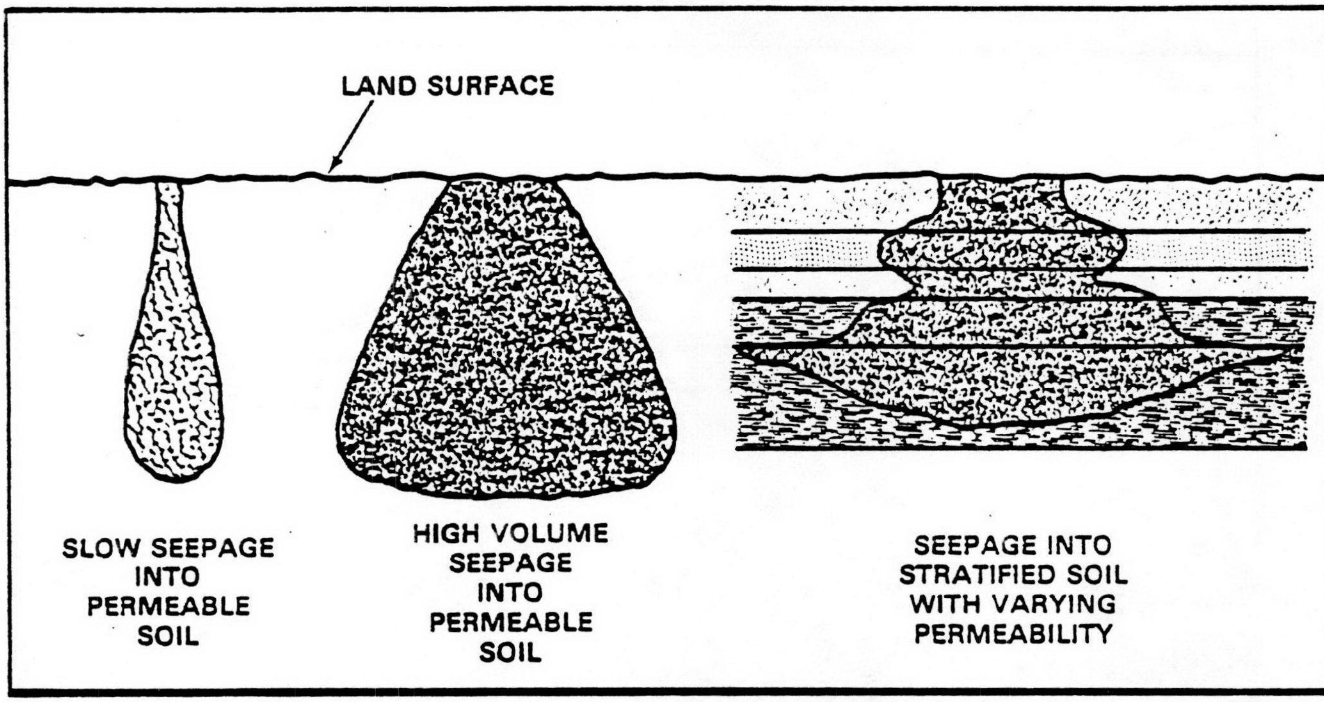
Movement Into Groundwater [3]. The following excerpt from API Publication 1628 describes the intrusion of spilled liquids into groundwater:

> "The contact of spilled product with the water table usually is the most troublesome result of an on-land spill. This condition greatly increases the risk of polluting a water supply, and may increase the chance of movement to some underground structure, such as a basement, sewer or conduit. The degree of risk depends on the nature of the groundwater system and the way it is utilized.
>
> Figure 1.15 illustrates a pattern of oil descent to a water table. A sudden, large-volume spill will depress the water table and spread in all directions in a layer above the water table. As the layer becomes thinner, it will begin to move in the direction of groundwater flow (Figure 1.1-6).
>
> A slower leak will descend in a narrow cone and spread in the direction of water movement. Lateral spreading will usually be slower than the flow rate of the groundwater."[3]

More detail discussions of this type can be found in API Publication 1628 [3], and NFPA 329 [4].

Figure 1.1-1

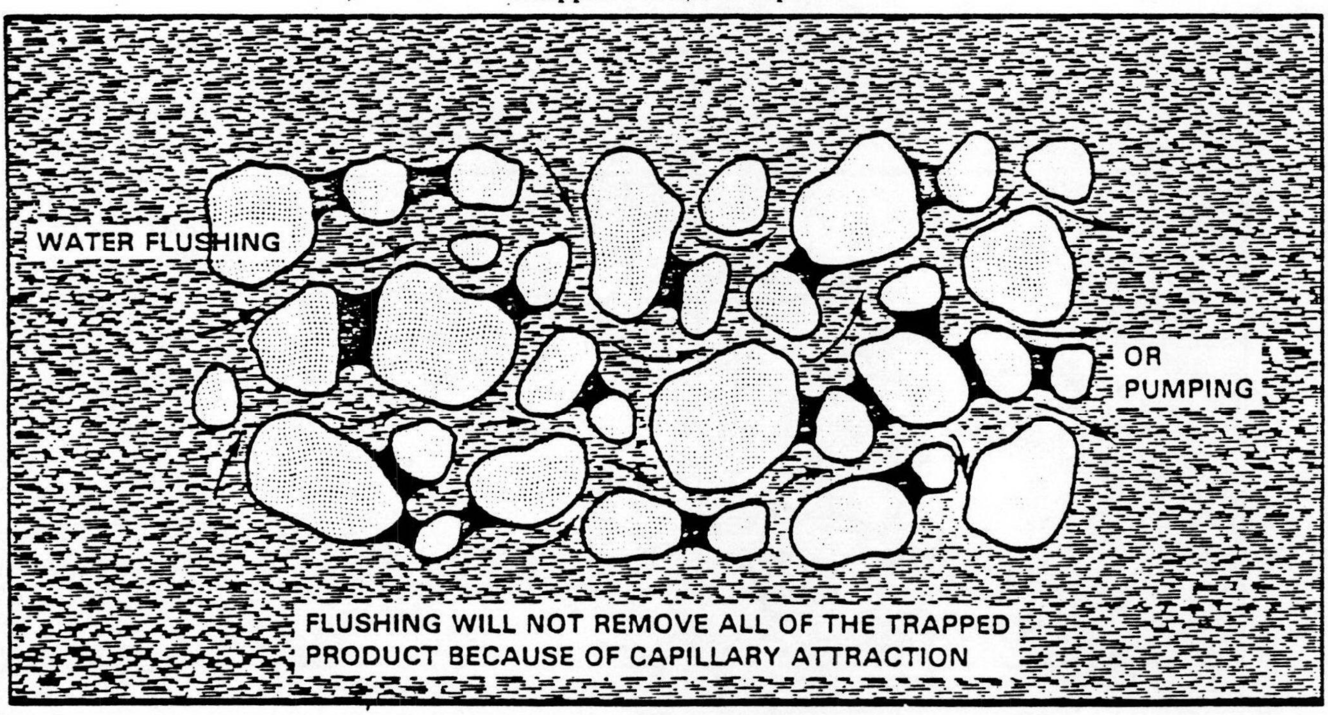
Product Seepage



Source: API Publication 1628, *Underground Spill Cleanup Manual*, 1980.

Figure 1.1-2

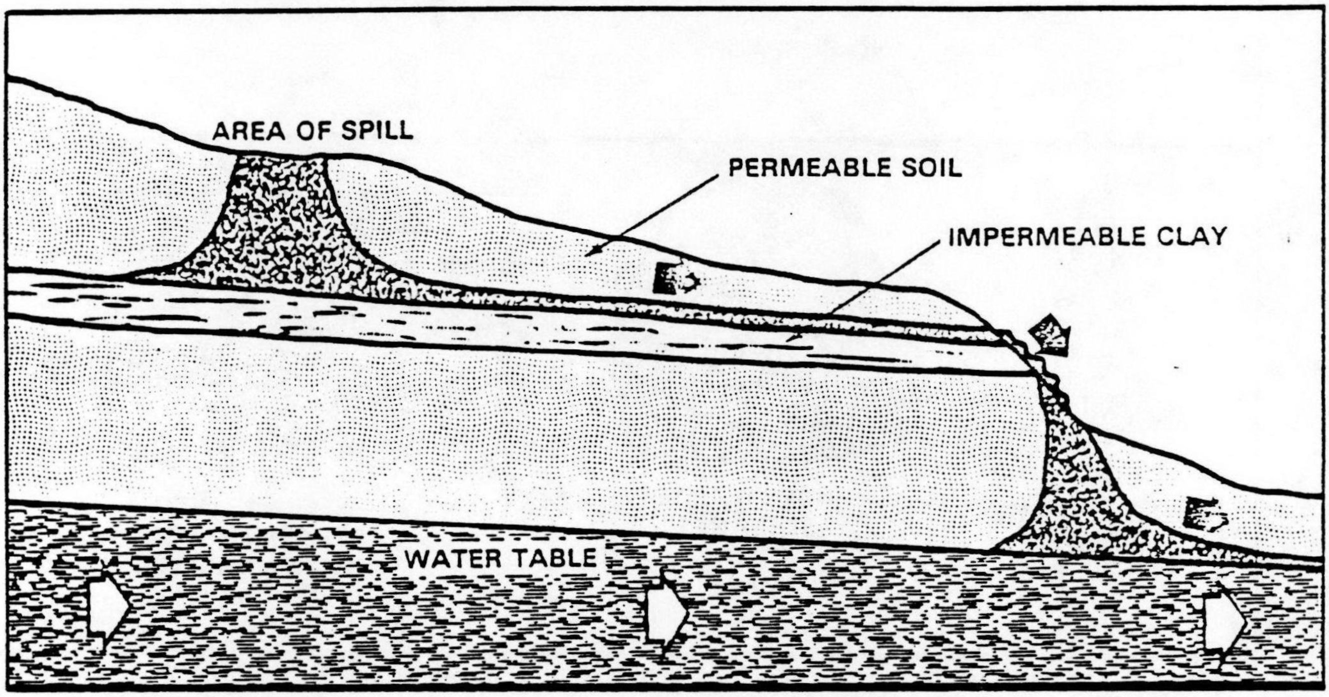
Trapped Product Droplets



Source: API Publication 1628, *Underground Spill Cleanup Manual*, 1980.

Figure 1.1-3

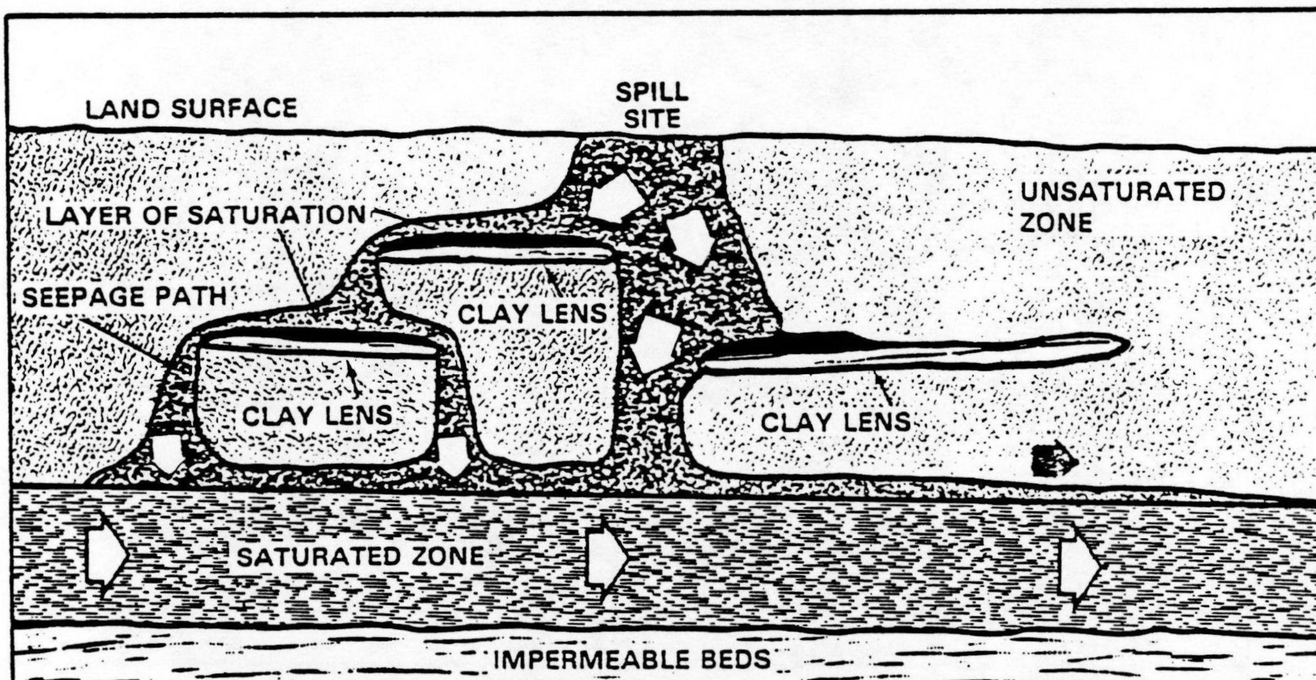
Possible Migration of Product to Outcrop Followed by Second Cycle Contamination



Source: API Publication 1628, *Underground Spill Cleanup Manual*, 1980.

Figure 1.1-4

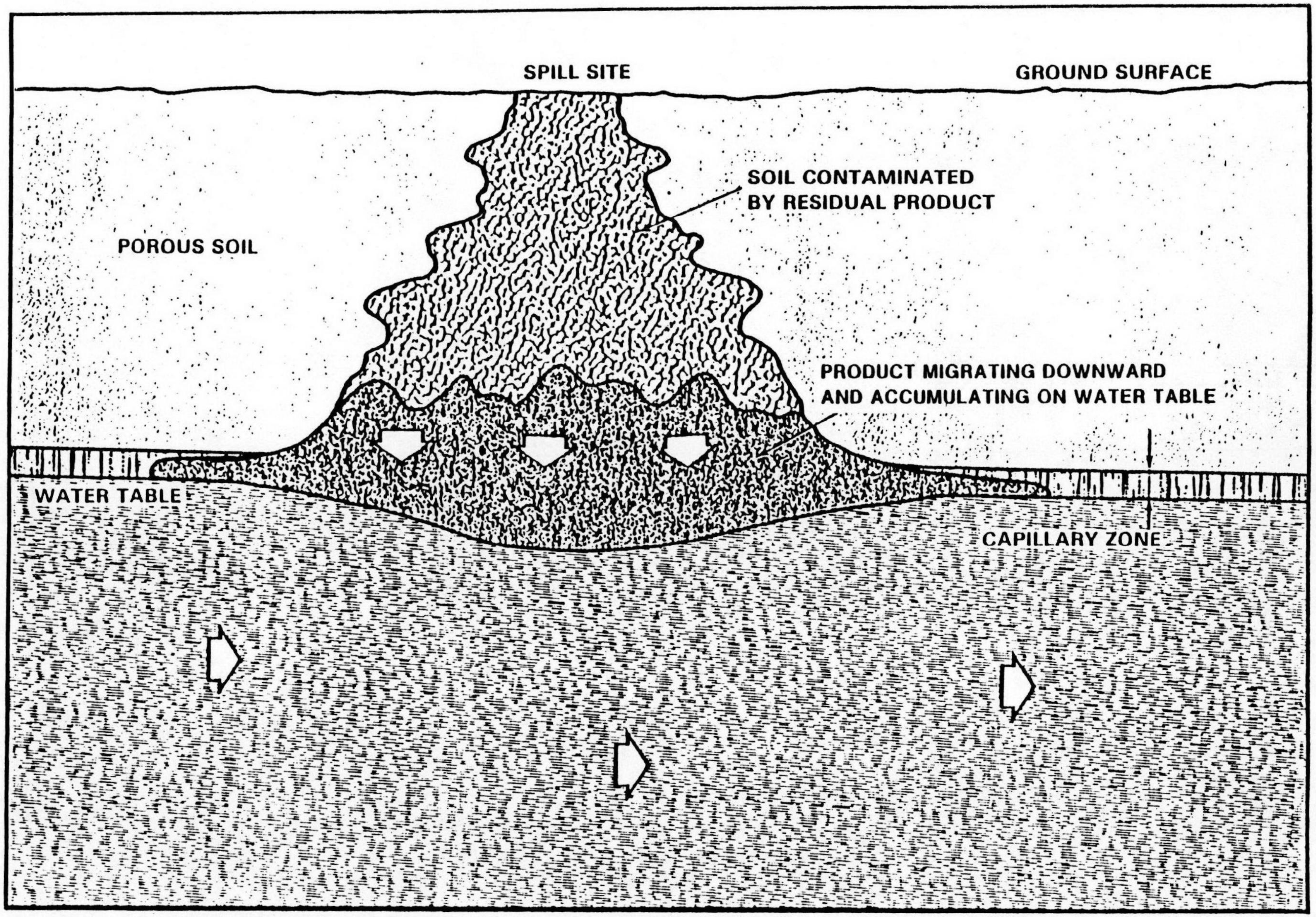
Effect of Clay Lens in Soil



Source: API Publication 1628, *Underground Spill Cleanup Manual*, 1980.

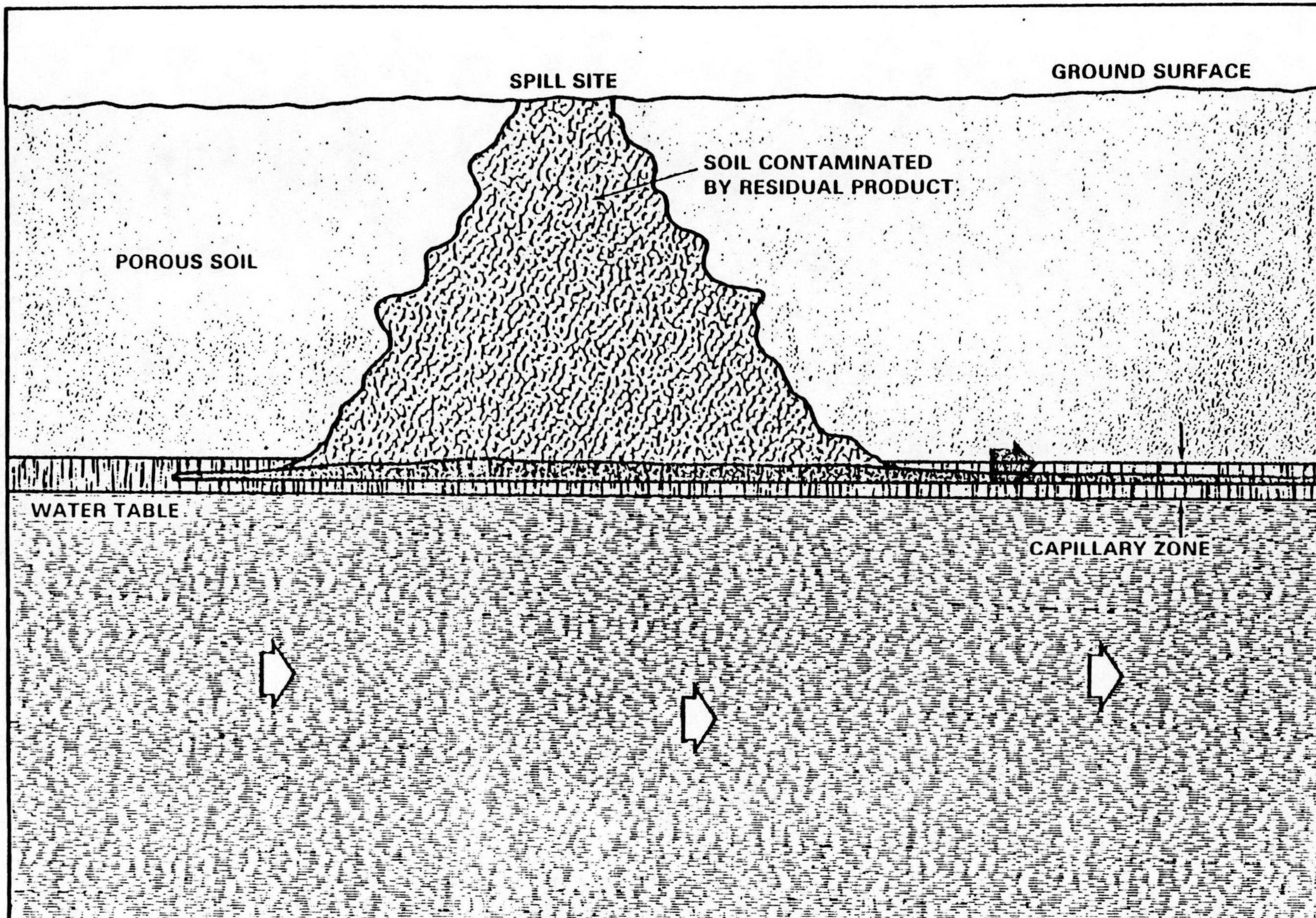
Figure 1.1-5

Typical Behavior in Porous Soil
Following a Sudden, High Volume Spill



Source: API Publication 1628, *Underground Spill Cleanup Manual*, 1980.

Figure 1.1-6
Behavior of Product After Spill Has Stabilized



Source: API Publication 1628, *Underground Spill Cleanup Manual*, 1980.

Movement from Groundwater to Surface Water. Contaminated groundwater may enter surface water through springs or by direct influent seepage into a creek, lake or river. It may now become visible or be detected by odor. The presence of the contaminant may also be apparent if there is a fish kill. It will cause immediate concern if the surface water is used for drinking water or for primary contact recreation (bathing).

3. The Importance of Spill Prevention

The first line of defense against the potential environmental and public health impacts of hazardous liquids spills and leaks is the implementation of good spill/leak prevention practices. Such prevention practices are always more cost-effective and environmentally effective than attempts to clean up a spill or leak after it has occurred. For this reason, the importance of adopting and rigidly following a spill/leak prevention and detection program cannot be overemphasized.

The practices which can be employed for spill and leak prevention are discussed in detail throughout the remainder of this document.

B. TYPES AND CAUSES OF SPILLS AND LEAKS [1,5,6,7]

1. General

Spills and leaks of hazardous liquids at bulk storage facilities, either above or below grade, may emanate from any of several sources and may be precipitated by one or more of several causes. The types of spills which may occur include: (1) large spills such as those that result from tank or pipe rupture; (2) slow leaks or drips such as those that result from slow deterioration (e.g. corrosion) of a storage system component; and (3) small spills such as those that result from fluid transfer mishaps (e.g. overfills) or other storage yard spills. Spills or leaks can also occur as a general result of poor housekeeping practices, or as a result of vandalism or acts of malicious intent. Spills or leaks can occur anywhere in the bulk storage facility where liquids are handled or stored if proper care is not taken. Examples of leak locations from bulk storage and handling facilities are presented in Table 1.1-1.

An adequate spill/leak prevention and detection program has a number of key elements, including the following:

- Tank (material) selection guidelines.
- Tank installation guidelines.
- Piping system (material) selection and installation guidelines.
- Steps for corrosion and tank failure prevention.
- An overfill prevention system and overfill protection guidelines.
- Standardized practices for periodic inspection and preventive maintenance.
- A leak detection system with periodic monitoring.
- Procedures for inventory control.
- Spill containment facilities.
- Emergency response procedures.
- Guidelines and procedures for the closure and abandonment of storage systems.
- Transfer facility design requirements.

Table 1.1-1

Types of leaks from Bulk Storage and Handling Facilities

Bulk Storage Facilities - Tank Farms and Tankage

1. Leaks and overfilling of tanks
2. Rupture of tanks
3. Leaks in pipe, valves and fittings
4. Leaks in containment dikes
5. Inadequate dike volume to hold contents of leaking tanks
6. Product flow from dike area through open dike valve
7. Leaks from pump seals and maintenance
8. Level instrument failure allowing tank overfilling
9. Piping damage by collision with mobile equipment
10. Spills from water drawoff from storage tanks
11. Spills from tank bottom cleanout and sludge disposal
12. Improper disposal of samples
13. Overflow of wastewater treatment systems by rainfall flooding
14. Poor maintenance of pipe, valves and fittings
15. Plugging of drainage system by debris
16. Wastewater treatment systems with insufficent capacity to remove product
17. Inadequate secondary containment devices
18. Spills from line flushing
19. Spills from pipe and tankage changes
20. Possible sabotage
21. Improper installation

Bulk Handling Facilities - Terminals, Pipelines

1. Spills from quick-connect coupling operation
2. Overfilling tank trucks, tank cars, barges, tankers, etc.
3. Lack of curbs, drains and spill collection system
4. Improper operation of product/water separators

Table 1.1-1 continued

5. Leaks from loading arms, especially joints and gaskets
6. Leaks from underground storage tanks
7. Improper disposal of sludge from product filters
8. Insufficent sump capacity (should be equal to volume of largest compartment of tank truck of rail car)
9. Leaks from damaged loading connections
10. Operators incorrectly setting loading meters and tanks overfilling
11. Level instrument and subsequent sump pump failure on oil sumps
12. Leaks from heating coils in heavy fuel tanks
13. Possible sabotage
14. Improper installation

Adapted from reference 5.

These causes of storage system leaks and spills and state-of-the-art methods of controlling them are addressed briefly in the discussions of aboveground and underground storage systems that follow this section. A guide to the more detailed discussions of these items throughout Parts II and III of this document is presented in Table 1.1-2.

2. Aboveground Storage Systems [1,5,8,9]

The deterioration of the components of aboveground storage systems can occur for any one of several reasons. The most common reason for component deterioration, particularly the deterioration of metal components, is corrosion [1], which is addressed in detail later in this section. Other reasons include the following:

- Mechanical failure, such as failure of valves, gaskets or pumps.
- Cracks in tanks, piping or fixtures which could result from faulty welding, unrelieved stress concentrations around fittings, insufficient reinforcement around openings, settlement or earth movement, vibration, or poorly designed repairs [8].

Methods of controlling the deterioration of storage system equipment include: (1) the use of better system designs; (2) the incorporation of a good preventive maintenance program; and (3) proper training of employees.

Leaks and spills due to overflow, overfilling and other liquid transfer operations are another important category of product loss from storage systems. These can be controlled through the use of overflow protection devices and level sensing devices in storage tanks; the use of secondary containment, curbing, pumps, etc.; and the incorporation of adequate housekeeping and operational procedures.

One of the most important causes of leaks is the improper installation of storage tanks and related equipment. Many leaks can be traced to problems such as:

Table 1.1-2

Guide to Discussion of Causes and Mitigative Measures for Spill and Leaks from Hazardous Liquid Storage Systems

Cause of Leak Spill	Equipment Affected	Section of Report
Equipment deterioration		
Corrosion	All components	Part I. Chapter 2.
	Underground tanks	Part II. Chapter 1.
	Underground piping	Part II. Chapter 2
	Aboveground tanks	Part III. Chapter 1
	Aboveground piping	Part III. Chapter 2
Mechanical Failure and cracks	Underground Tanks	Part II. Chapter 1
	Underground piping	Part II. Chapter 3
	Aboveground tanks	Part III. Chapter 1
	Aboveground piping	Part III. Chapter 2
Transfer spills and leaks	Underground tanks, piping and spill containment systems	Part II. Chapters 3 and 4
	Aboveground tanks, piping and spill containment systems	Part III. Chapters 3 and 4
Improper installation of system components	Underground tanks	Part II. Chapter 1
	Underground piping	Part II. Chapter 2
	Aboveground piping	Part III. Chapter 2
Poor Housekeeping	Underground storage systems	PartII. Chapters 5 and 6
	Aboveground storage systems	Part III. Chapter 5
Improper Temporary or permanent closure	Underground storage systems	Part II. Chapter 7
	Aboveground storage systems	Part III. Chapter7

- Damage to tank coatings.
- Outright structural damage to the tank and other equipment during transportation and installation.
- The more subtle damage associated with the improper installation of beddings and foundations for tanks and piping systems.
- The improper connection of system components, such as the improper installation of valves, flanges or other fittings.
- Overpressurization caused by overfilling or improper venting of tanks.

Problems such as these can be avoided through careful adherence to the design and installation requirements of storage system components.

Sloppy housekeeping also results in spills and leaks. Such accidents can be avoided through the implementation of good housekeeping practicies. A clean and orderly work area reduces the possibility of accidental spills caused by mishandling of equipment and should reduce safety hazards to plant personnel. Examples of good housekeeping include neat and orderly storage of chemicals; prompt removal of small spillage; regular garbage and rubbish pickup and disposal; maintenance of dry and clean floors by use of brooms, vacuum cleaners, or cleaning machines; and provisions for storage of containers or drums to keep them from protruding into open walkways or pathways.

A good security system is helpful in preventing hazardous chemical spills or leaks due to vandalism, theft, sabotage or other improper and illegal use of storage plant facilities. The elements of such a system could include the following:

- Routine patrols of the plant by security personnel.
- Fencing.
- Good lighting.
- Vehicular traffic control.
- Controlled access to the plant.
- Locked entrances.
- Locks on drain valves and pumps for chemical storage tanks.
- Television monitoring.

3. Below Ground Storage Systems [1,5,10]

Underground storage systems are susceptible to leaks and spills from the same types of causes as aboveground storage systems, and, in general, the same methods of spill and leak control are applicable. In the case of thse systems however, data indicates that corrosion and poor installation are by far the most common causes of storage system leaks and spills [1,10]. For example, the American Petroleum Institute (API) conducted a survey of 1,717 underground tanks and piping systems that were known to be leaking. The data was collected via questionnaire from 1977 through 1980. A categorization of the reported leaks is displayed in Table 1.1-3. Since no data base exists in this study concerning the number or age of the various types of tanks in the ground at the time of this survey or the average ages of each type of tank, the use of the study for comparing types of tanks is meaningless. Much valuable data is contained in the study but any attempt to compare tank types would be a misuse of the data.

The life expectancy of any given tank is difficult to predict. Experience has shown that underground steel tanks have a finite life, but this life is variable between 5 and 45 years depending on the thickness of the steel, installation practices, soil resistivity, pH, soil moisture level, the presence of sulfides, the type of backfill material used, and the tank size. The average life expectancy of these tanks is about 15 years, but age by itself is a poor indicator of tank integrity.

The causes of leaks in steel tanks, as determined by the API Leak Survey, are shown in Table 1.1-4. Overall, roughly 91 percent of the leaks in steel tanks were caused by corrosion. Other causes included loose fittings and physical breakage. Of the 28 leaking fiberglass tanks included in the survey, 9 had dip stick punctures, 4 had breakage from improper handling, 1 had a backhoe puncture, and 14 had experienced physical breakage or separation due to other causes. For piping systems, corrosion was also the most common cause of leaks as shown in Table 1.1-5.

Table 1.1-3

Leaks by Source Categories

Source	Number	Percent of total
Unprotected Steel Tanks	913	62
Steel tanks with Impressed Current	13	0.9
Steel tanks with Sacrificial Anodes	0	0.0
Interior Coated Steel Tanks	7	0.5
Fiberglass tanks	28	1.9
Steel piping	454	30.8
Fiberglass piping	50	3.4
Steel piping with Impressed Current	7	0.5
Sub-Total	1472	100
Unspecified Tanks	216	
Unspecified Piping	29	
Total	1717	

Source Reference 10.

Table 1.1-4

Causes of Leaks in Steel Tanks

Cause	Total	Percent of Total
Corrosion	775	90.7
Loose Fittings	10	1.2
Physical Breakage	14	1.6
Other	55	6.4
Sub-Total	854	99.9
Unknown or unanswered	59	

Table 1.1-5

Causes of Piping Leaks

Cause	Number	Percent of Total
Corrosion	343	66.6
Flex Connector Failure	31	6
Physical Breakage	34	6.6
Loose Fittings	57	11.1
Other	50	9.7
Sub-Total	515	100
Unknown or Unanswered	25	

Note: These tables emphasize the importance of corrosion as a cause of storage system leaks.

Source: Reference 10.

Underground tanks which are connected together with siphoning pipes present unique problems. Leak testing becomes difficult, if not impossible, to accomplish. the ususal reason for siphoning between tanks is to add capacity to a system. When a small tank does not provide enough gallonage for increased business (usually after several years), a second tank is installed and is connected to the first with a siphon. The new tank and the new piping become targets for electrolytic corrosion from the old tank.

C. CORROSION [8,11,12,13,14,15,16,17,18,19,20]

The corrosion of tanks and piping systems is a complex phenomenon that may take one or more of several forms. Corrosion results from interactions betweeen the tanks and piping and their surroundings, both internal and external.

The deterioration of plastics and other non-metallic materials, which are susceptible to softening, cracking, swelling, etc., is essentially chemical in nature [11]. Non-metallic materials may deteriorate rapidly when exposed to corrosive elements. The corrosion of non-metallic storage system components can be controlled and essentially eliminated through proper selection and careful handling of tank and piping materials.

In metallic materials, corrosion is a chemical or electrochemical process. Corrosion control in these materials is therefore more complicated. The remainder of the discussion in this chapter focuses on the causes of internal and external corrosion of metals, the factors which influence this corrosion, and the steps which can be taken to protect against this form of deterioration.

1. Corrosion Mechanisms

As stated above, the corrosion of metals is primarily an electrical process; it may take the form of either galvanic or electrolytic corrosion. As shown in Figure 1.1-7, electrolytic corrosion is a result of direct current from outside sources entering and then leaving a particular metal structure by way of the electrolyte (surrounding material, such as soil for underground structures or water for submerged structures). The structure is usually unaffected or is provided with some degree of protection at the point the current enters (the cathodic area). Corrosion occurs where the current leaves the structure (the anodic area). In underground structures, this type of corrosion is often referred to as stray current corrosion, and is a result of current entering the ground from sources of DC current such as street railways or DC machinery.

The mechanisms of galvanic corrosion are illustrated in Figure 1.1-8. Galvanic corrosion is a self-generated activity resulting from differences in electrical potential that develop when metal is placed in an electrolyte. These differences in electrical potential can result from the direct coupling of dissimilar metals, or they can result from variations in conditions which exist upon the surface of a single metal. The variations could include:

- Variations resulting from non-homogeneity of the metal.
- Differences which exist within the electrolytes.

When two dissimilar metals' are connected electrically and immersed in an electrolyte, as shown in Figure 1.1-8, current will be generated and galvanic corrosion will occur in one of the metals. Current from the corroding metal will flow into the electrolyte, over to the non-corroding metal, and then back through the connection between the two metals. The corroding metal (the one from which current leaves to enter the electrolyte) is known as the anode; the metal which receives current is known as the cathode. Table 1.1-6 shows the anodic-cathodic (galvanic) series of various metals.

Alternately, as stated previously, the same metal can develop differences in potential, and, as a result, portions of the surface of that metal become anodic with respect to the remainder of the surface. As shown in figure 1.1-8, corrosion will occur at these anodic locations.

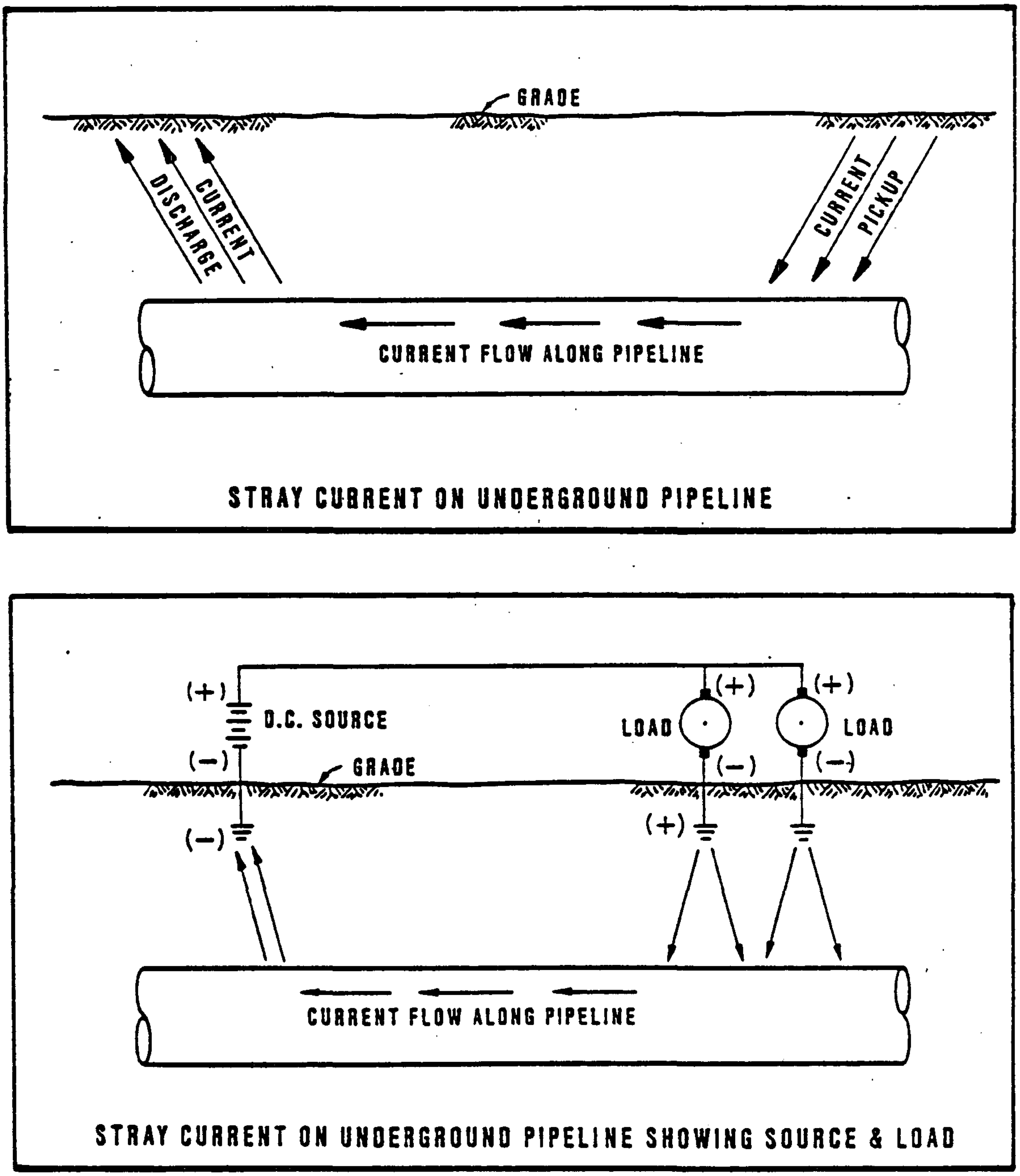
Electrolytic and galvanic corrosion are similar in that corrosion always occurs at the anodes. The essential difference between the two is that in electrolytic corrosion it is the external current which generates the corrosion, whereas in galvanic corrosion it is the corrosion activity which generates the current.

2. Forms of Corrosion [8,11]

The deterioration of tank or piping material may appear as either general or localized corrosion. General corrosion appears as a relatively uniform loss of surface material if viewed without magnification. Localized corrosion results in a non-uniform loss of material from the corroded structure. Types of localized corrosion are described briefly in Table 1.1-7.

Figure 1.1-7

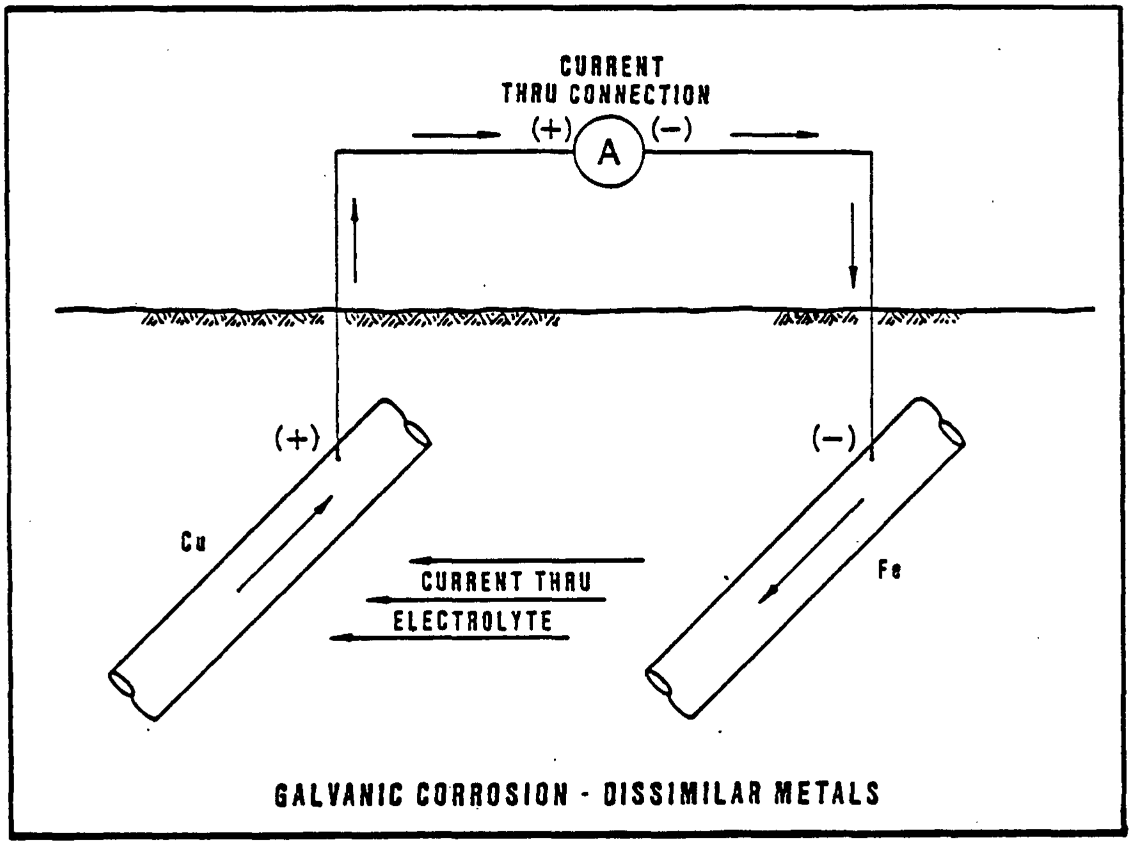
Electrolytic Corrosion

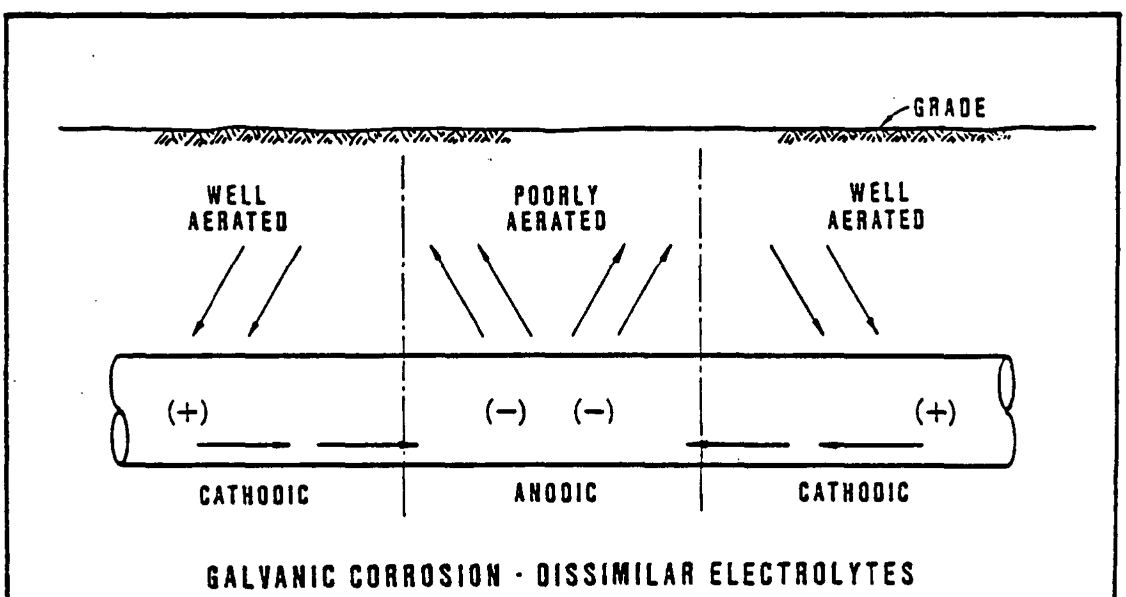


Source: Harco Corporation

Figure 1.1-8

Galvanic Corrosion





Source: Harco Corporation

Table 1.1-6

The Galvanic Series of Metals and Alloys

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)

Note: In general, when dissimilar metals are used in contact with each other in an electrically conductive enviroment, combinations of metals should be chosen that are as close as possible in the galvanic series. The coupling of two metals which are far apart in the series will result in more rapid deterioration of the more active metal. However, this table should be used only as a general guide since exceptions to this series may be encountered.

Adapted from reference 11.

3. Factors Influencing Corrosion [8,11]

There are innumerable factors that can influence the presence and rates of internal and external corrosion in both aboveground and underground storage tanks and piping systems. The more prominent of these factors include solution acidity, temperature, moisture levels, oxygen levels, soil resistivity, and bacterial action. The following discussion explains the importance of these and other factors. The more important of these factors are highlighted in figures 1.1-9 and 1.1-10.

Electrolyte Acidity. The acidity of the electrolyte (solution, soil, etc.) with which the material is in contact could have a substantial affect on the rate of corrosion. Acidic (low pH) electrolytes are, as a general rule, more corrosive than neutral (pH 7) or alkaline (high pH) electrolytes in the case of ordinary iron and steel. However, for the amphoteric metals, such as aluminum and zinc, highly alkaline electrolytes may be more corrosive than acidic electrolytes. The effects of electrolytic acidity are highlighted in Figure 1.1-9.

Presence of Oxidizing Agents. The presence of oxidizing agents, of which oxygen is the most prominent, may accelerate the corrosion of one type of material and retard corrosion in another type.

Table 1.1-7

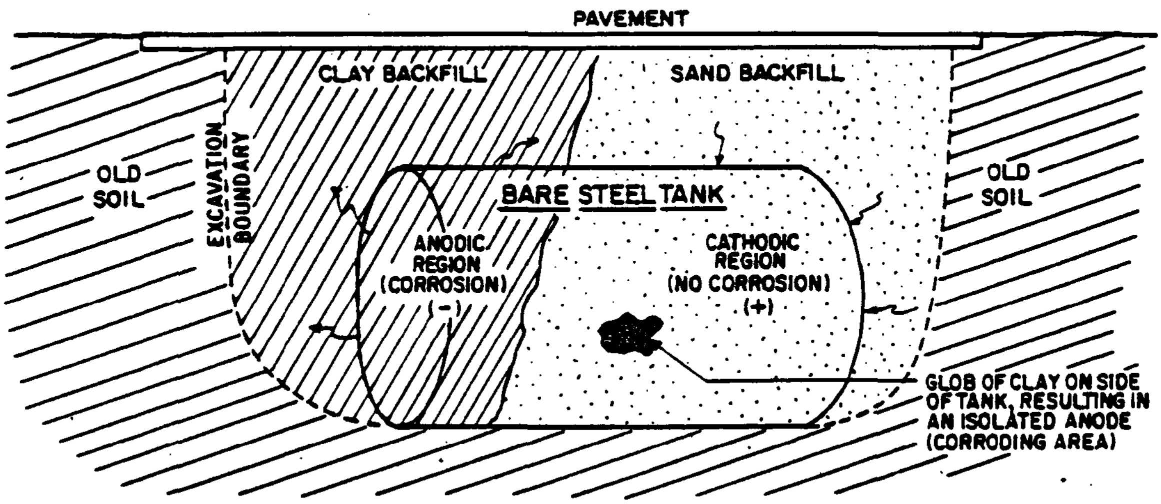
Common Forms of Localized Corrosion

Type	Description
Pitting Corrosion	Formation of shallow depressions or deep pits (cavities of small diameter).
Stress Corrosion Cracking	Corrosion accelerated by residual stresses resulting from fabrication operations or unequal heating and cooling of structure.
Contact or Crevice Corrosion	Occurs at the point of contact or crevice between a metal and non-metal or two metals.
Intergranular Corrosion	Selective corrosion at the grain boundaries (microscopic) of a metal or alloy.

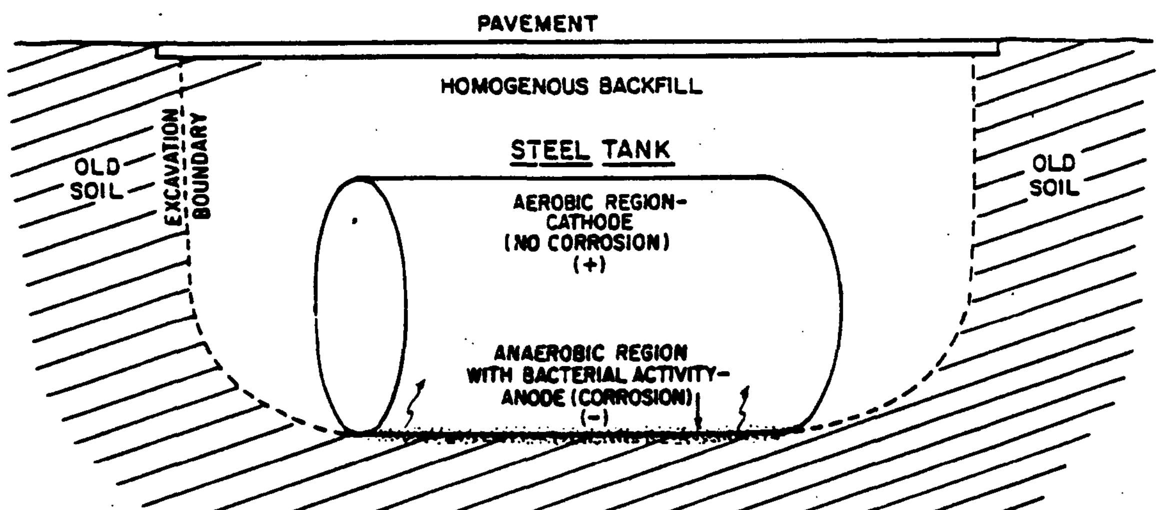
Figure 1.1-9

Some Corrosion Mechanisms at an Underground Steel Tank

Small differences in electric (ionic) potential can cause serious corrosion of underground steel tanks and pipes. Such differences can be created when there is a presence of dissimilar soils or bacterial activity, as shown in the figures below. The curled arrows (⁓→) show the flow direction of electrical current in these figures.



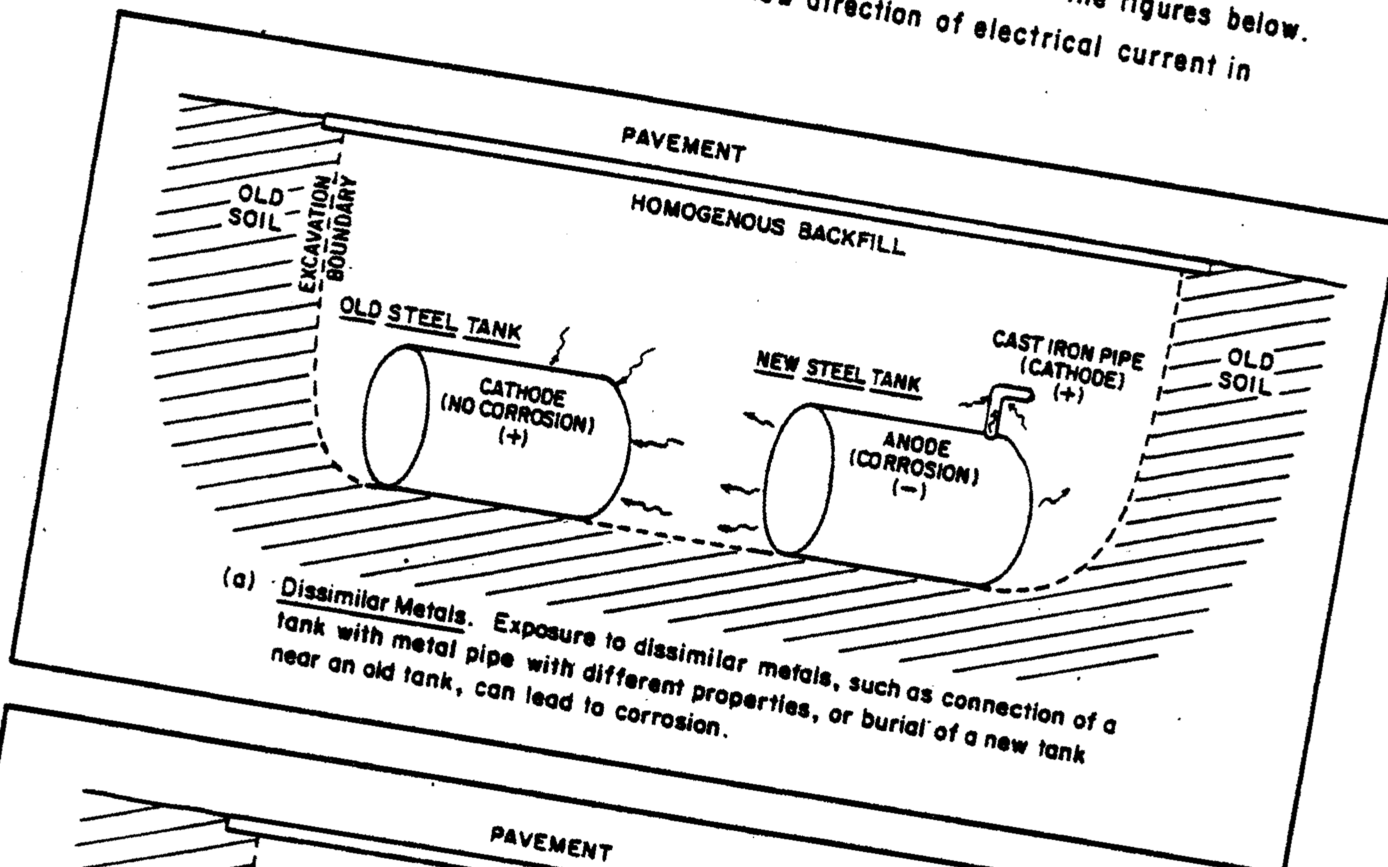
(a) Dissimilar Soils. Variations in soil type or soil properties such as acidity or restivity can lead to corrosion in an underground steel structure.



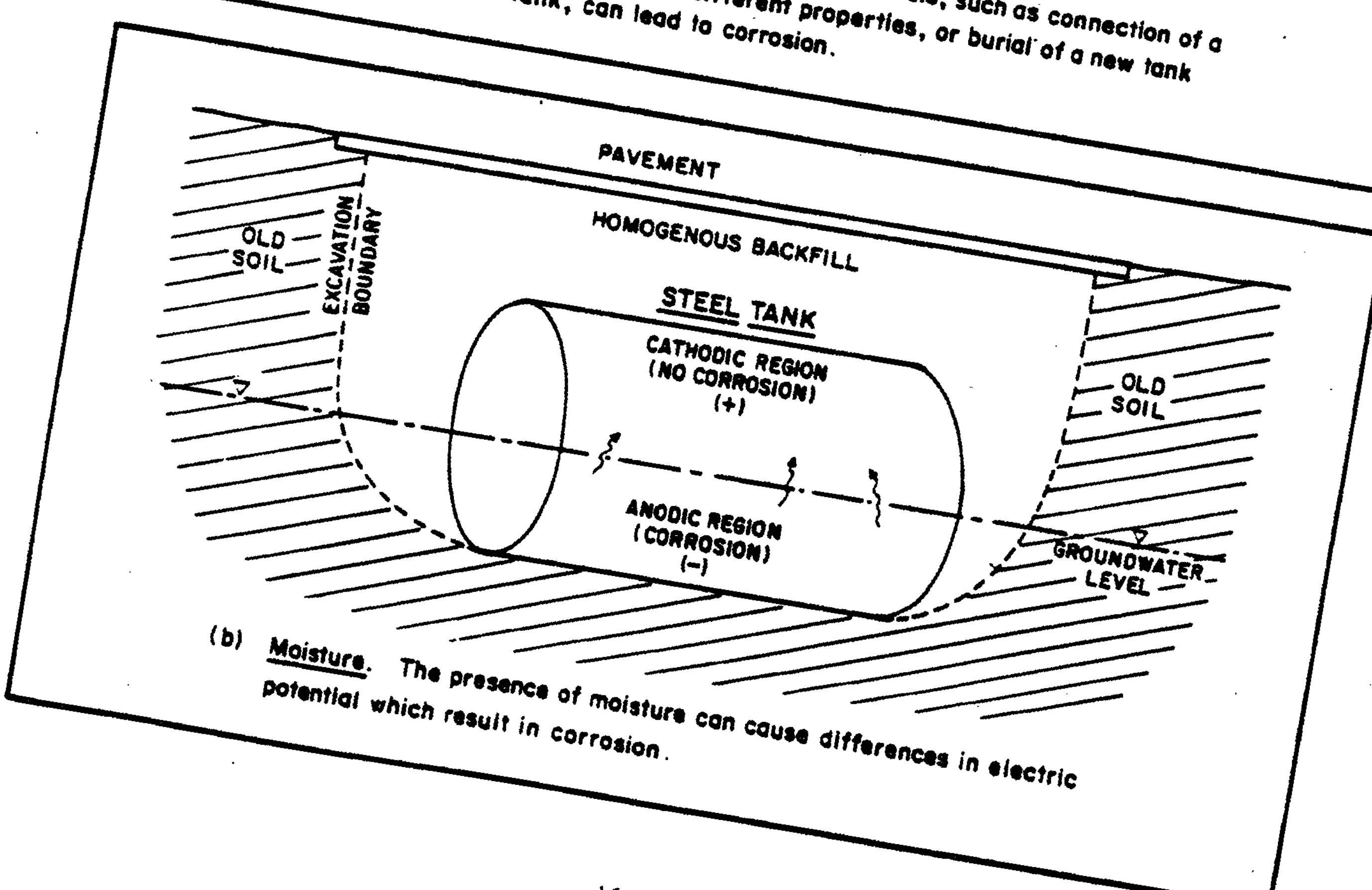
(b) Bacterial Activity. The metabolic activity of certain microorganisms can create corrosive environments around an underground structure.

Figure 1.1-10
More Corrosion Mechanisms at an Underground Steel Tank

Other items which can promote corrosion at underground steel tanks include the presence of dissimilar metals or moisture, as shown in the figures below. The curled arrows (~→) show the flow direction of electrical current in these figures.



(a) Dissimilar Metals. Exposure to dissimilar metals, such as connection of a tank with metal pipe with different properties, or burial of a new tank near an old tank, can lead to corrosion.



(b) Moisture. The presence of moisture can cause differences in electric potential which result in corrosion.

Temperature. The rate of corrosion tends to increase with rising temperature. Temperature also has a secondary effect through its influence on the solubility of air (oxygen), which is the most common oxidizing agent influencing corrosion.

Surface Films. Once corrosion has started, its progress is often controlled by the nature of the film that forms on the corroding metal. Some corrosion products may be insolubale and completely impervious to the corroding solution and, therefore, completely protective; or they may be very permeable and thus allow localized or general corrosion to proceed unhindered. In addition, discontinuous or non-uniform films may induce localized corrosion in particular areas.

Bacterial Action. The metabolic activity of certain microorganisms can either directly or indirectly affect the corrosion of metals. Such activity can:

- Produce a corrosive environment.
- Create electrolytic concentration cells, leading to crevice corrosion.
- Alter the resistance of surface films.
- Alter the environment composition.
- Influence the rate of anodic or cathodic reaction.

An example of microorganisms that directly influence corrosion rates are the sulfate-reducing bacteria found in many soils. These bacteria use hydrogen to reduce sulfate contained in the soil. The corrosion of metals results in the formation of hydrogen on the metals surface. If this hydrogen is not removed corrosion is inhibited. Sulfate-reducing bacteria can consume this hydrogen, thus speeding up the rate of corrosion. In addition, the reduction of sulfate results in the formation of hydrogen sulfide, which, in turn, causes further corrosion. This effect is shown in Figure 1.1-9.

Soil Resistivity. Soil resistivity is a measure of the resistance of soil to the flow of electric current, and is a very important factor in determining the potential rate of corrosion of underground pipes and tanks. The lower the resistivity of the soil, the greater the probability of corrosion. Soil resistivity is dependent upon several factors, including soil moisture content. In general, soil resistivity is low where soils are moist and groundwaters contain high levels of dissolved solids. The relationship between soil resistivity and corrosivity is demonstrated in Table 1.1-8.

Moisture Level. The presence of water can also promote corrosion of metals. The presence of moisture in soils acts to reduce soil resistivity thereby increasing the probability of corrosion (see Figure 1.1-10). Water accumulation inside tanks is also a major cause of internal corrosion. Water is often present in tanks due to condensation, precipitation from tank contents, and because water is often used as a ballast for underground tanks.

Soil Variations. Corrosion of underground tanks and pipes can be influenced by variations in soil conditions along the surfaces of those tanks and pipes. Variations in soil type, soil resistivity, moisture content, etc., can promote galvanic activity in the buried metal, thus accelerating the rate of corrosion.

Table 1.1-8

Soil Corrosivity vs. Soil Resistivity

The USDA Soil Conservation Service has categorized soil corrosivity levels as follows:

Class of Soil Corrosivity	Type of Soil	Resistivity (ohm-cm)
Very High	Poorly Drained Clay	Below 1,000
High	Poorly Drained Clay	1,000 to 2,000
Medium	Poorly Drained Clay	2,000 to 5,000
Low	Poorly Drained Clay	5,000 to 10,000
Very Low	Well Drained Gravel	Above 10,000

Environmental Elements. Corrosion can also be influenced by the presence of atmospheric pollutants, both externally and internally. For example, sulfur dioxide can form sulfuric acid in the presence of air and moisture and can thus promote corrosion of certain metals.

Adjacent Underground Metal Structures. Corrosion of underground tanks and piping can also result when new structures are installed near existing tanks or other underground metal structures or when new piping is installed. Since the older structures have rusted to some extent, they can become cathodic to the newer tanks or pipes. The system becomes an electrical cell. The older tank acts as a cathode. The newer metal (tanks or pipes) becomes an anode and the moist soil or fill which separates them becomes an electrolyte. A current flows through the system, carrying oxide, chloride, sulfide, etc., ions to the new metal surfaces and carrying metal ions away from the new surfaces. If the surface area of the old structure, as for instance a large tank, is much greater than the new structure (a replaced length of pipe), the replacement of the new surface with corrosion products (rust) will proceed at a relatively fast rate. This effect is illustrated in Figure 1.1-10.

Stray Electrical Currents. Stray underground currents from nearby electrical facilities using DC current, such as electrified railway or transit systems, factories, shops or nearby cathodic protection rectifiers can induce electrolytic corrosion in underground tanks and pipes. This effect has been shown in Figure 1.1-7.

Internal corrosion of underground tanks is also often found directly under the fill pipe. This is frequently caused by repeated impact of the measuring dip stick. If the stick does not have a soft tip, the impact breaks down any protective film which may have developed on the tank surface. The result is selective corrosion.

4. Corrosion Protection [8,11,20]

There are a number of methods available to protect against corrosion. These include the use of soluble inhibitors, protective coatings, cathodic protection and the use of corrosion resistant materials of construction. No method or material is a universal containment; the containing material or system must be "fitted" to the product being contained.

Soluble Corrosion Inhibitors. Soluble inhibitors are substances which can be added to the contents of a storage system to inhibit internal corrosion. The choice of a particular chemical for use as an inhibitor is largely dependent on the composition of the storage system and its contents. Typical examples of inhibitors that are used to minimize the corrosion of iron and steel in aqueous solutions are the chromates, phosphates and silicates. These substances act to increase anodic polarization and are therefore called anodic inhibitors. Substances which control cathodic polarization, such as certain organic sulfides or amine materials are effective in minimizing the corrosion of iron and steel in acid solutions. These substances are called cathodic inhibitors.

Paints, Coating and Linings. Paints and coatings are widely used as protective measures against corrosion, particularly corrosion due to exposure to atmospheric elements. In these instances the paint helps to exclude water and oxygen from the metal surface, thus minimizing corrosion. Inhibitive pigments, such as red lead or chromates, can be used in paints to protect metals against corrosion. These pigments can act to inhibit corrosion through several mechanisms:

- The pigment may neutralize acids.
- The pigment may promote the formation of protective ferric oxide films at the iron surface.
- Red lead breaks down sulfur dioxide, which is a very corrosive constituent of ambient air in urban and/or industrial areas.

Linings applied to the walls of tanks and piping can also serve to protect these structures from contact with their environment, thereby inhibiting corrosion. Examples of common lining materials are rubber, epoxies and silicones. A more detailed discussion of coating and lining properties, and their resistance to chemical and electrochemical attack, is included in Part II of this document. It should, however, be noted that no tank or pipe coating is impervious, no matter how carefully it is applied. Flaws will eventually develop and accelerated corrosion will occur at these breaks in the coatings. Consequently, tanks or pipes that are coated, without other forms of protection frequently fail faster than bare structures. Thus, most present-day installation codes require coating in concert with another form of corrosion prevention, such as cathodic protection.

Cathodic Protection. Cathodic protection is a widely used and highly recommended method of protection for tanks and pipes. It is particularly effective in underground applications. The method works by reversing the electrochemical action of corrosion. Instead of allowing electrons to flow away from the structure (thereby permitting corrosion to occur) an electron flow toward the structure is induced, thereby protecting the structure.

Cathodic protection can be applied to either bare metal or coated metal, but is more effective and less expensive on coated structures. On bare tanks, cathodic protection may be only 90 percent effective, due primarily to the existence of active pits into which the protective current cannot penetrate [19]. There are two basic types of cathodic protection. These are the sacrificial anode (or galvanic) cathodic protection method and the impressed current (or electromotive force) method.

The galvanic cathodic protection method employs a sacrificial anode, such as magnesium or zinc, in electrical contact with the metal structure to be protected. These may be anodes buried in the ground for the protection of underground tanks, or attached to the surface of materials in electrolytic solutions (i.e., the tank or pipe). The current required is generated by corrosion of the sacrificial anode material. A typical galvanic cathodic protection system for underground tanks and piping is illustrated in Figure 1.1-11.

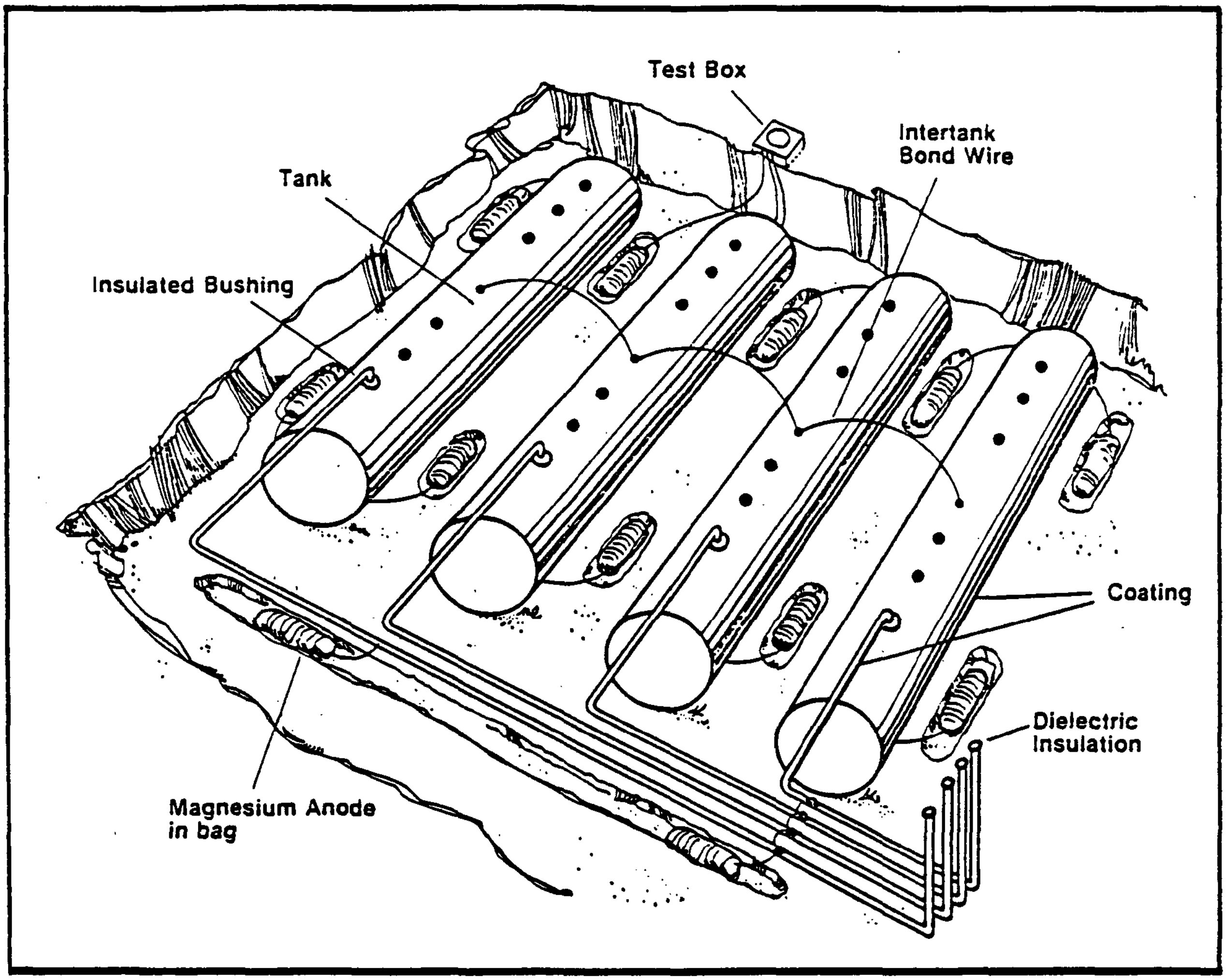
The impressed current cathodic protection method employs direct current provided by an external source. This current is passed through the system by the use of non-sacrificial anodes such as carbon, non-corrodible alloys, or platinum. These anodes are buried in the ground (in case of underground structures) or otherwise suspended in the electrolyte and connected to the external power supply. An impressed current system for underground tanks and piping is illustrated in Figure 1.1-12.

Note that the National Association of Corrosion Engineers' recommended practice NACE RP-01-69 recommends a –0.85 volt potential, tank to soil, as measured by a $Cu\text{-}CuSO_4$ half cell reference. This will ensure continued cathodic protection.

Electrical Isolation. Electrical isolation is another method of corrosion prevention. As the name implies, it involves the use of non-conductive dielectric fittings, bushings, connections, etc. to electrically isolate metal components in a storage system; this minimizes the potential for the generation of electrical currents between dissimilar metals. Electrical isolation is often employed in concert with other corrosion prevention methods, such as sacrificial anode cathodic protection, to further decrease the likelihood of corrosion.

Figure 1.1-11

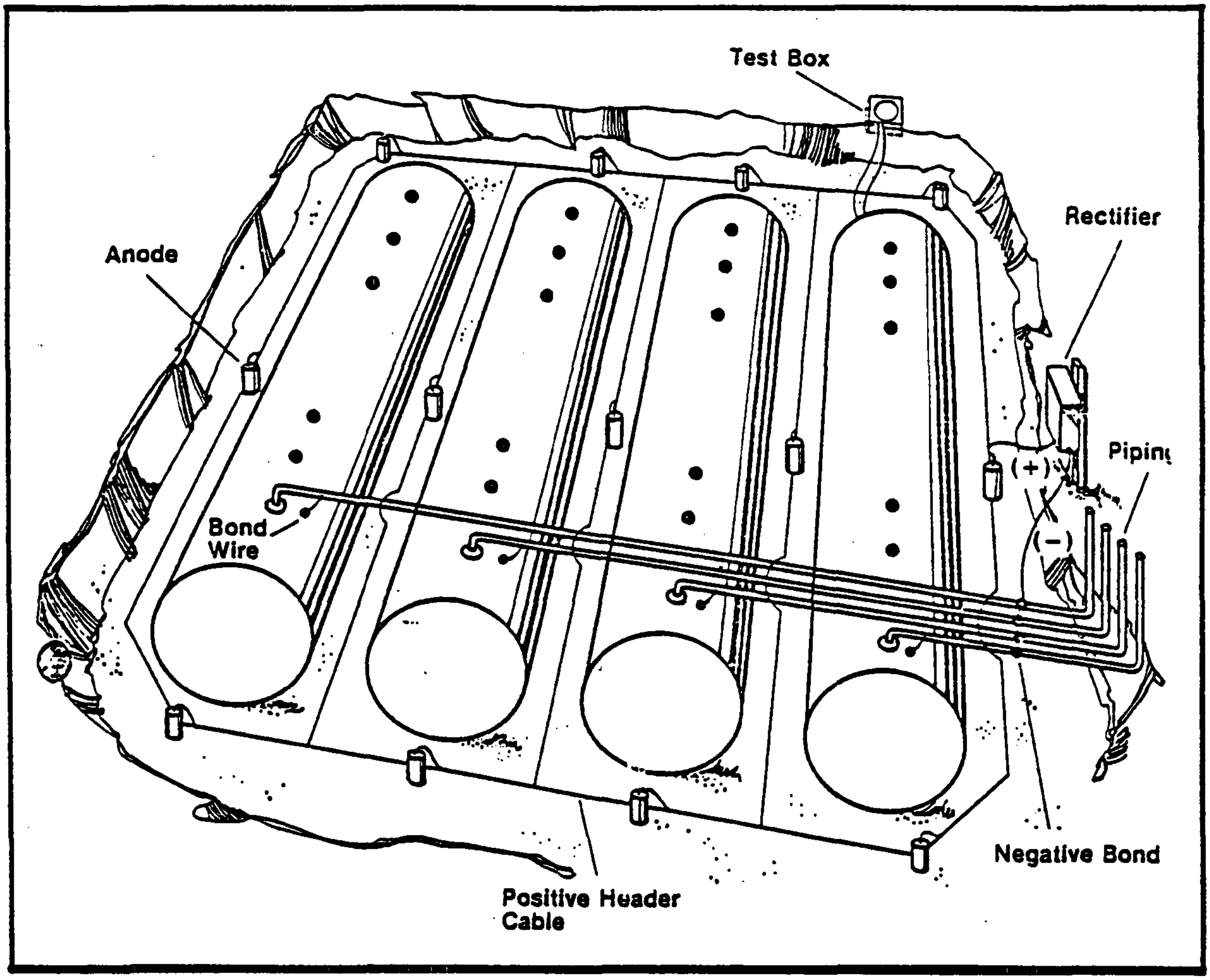
Magnesium Anode Cathodic Protection
Typical Configuration



Source: *Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping;* The Hinchman Company, Detroit, MI.

Figure 1.1-12

Impressed Current Cathodic Protection
Typical Configuration



Source: *Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping;* The Hinchman Company, Detroit, MI.

Corrosion Allowance. Often corrosion is anticipated, and items are constructed with enough metal to allow for corrosion to proceed to a point without interfering with the normal function of that item. An example of such a corrosion allowance is a tank whose design thickness is such that appreciable corrosion can be tolerated before a leak or tank failure will occur.

Corrosion-Resistant Materials of Construction. Corrosion can also be controlled through the use of corrosion-resistant materials of construction. Examples of such items include special alloys, fiberglass reinforced plastic, and fiberglass reinforced plastic coatings. Special alloys are most often used when difficult-to-contain fluids are to be handled. Stainless steel is an example of such a material. Stainless steel is a family of alloys. The corrosion resistant properties of the specific material chosen for the containment vessel should be appropriate for the material being contained.

From the perspective of corrosion resistance, fiberglass reinforced plastic (FRP) tanks are an effective means of storing many fluids in underground storage systems, most notably petroleum products. These tanks are not subject to corrosion and are strong enough to withstand most soild and other loading stresses when they are properly installed. The importance of proper installation of FRP tanks is discussed in further detail in Part II. The FRP piping is also applicable in these types of situations.

Fiberglass reinforced plastic coatings are also available and generally consist of thick (on the order of ⅛ inch) coatings applied to steel tanks. The concerns expressed above and elsewhere in this document regarding the use of coatings apply to these types of coatings as well.

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Part I
CHAPTER 2: HAZARDOUS SUBSTANCES

A. LISTINGS OF HAZARDOUS SUBSTANCES

The term hazardous liquids includes a broad range of chemicals and chemical types. They may be designated as hazardous because they are flammable, combustible, corrosive, toxic or explosive (reactive). By their nature, they are of great concern to society, and to those governmental agencies which are responsible for public health, environmental protection, transportation, occupational safety, and fire and emergency response.

Several agencies have prepared lists of hazardous substances and have included these lists in regulations to control use, transporation and disposal of these materials. The listings of materials regulated by the U.S. Environmental Protection Agency (EPA) and the U.S. Departments of Labor and Transportation are described in Table 1.2-1. These listings can be obtained from the Federal Register or the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

There are also several published reports which provide information on the physical and chemical properties of and safe handling practices for various hazardous materials. Some of the more widely used reports are described in Table 1.2-2. A more comprehensive list of references is provided at the end of this chapter.

B. PROPERTIES OF HAZARDOUS SUBSTANCES

1. Chemical Properties

Appendix A of this document includes a series of tables that identifies the chemical and physical characteristics of various solids, liquids and gases that are classified as toxic or hazardous substances. These tables identify substances which are poisonous to humans, flammable, corrosive, reactive and highly toxic to aquatic life. Other properties that are identified are the biodegradeability of liquids and solids, the amenability of liquids and solids to biological waste treatment, the volatility of liquids and the solubility of solids.

Table 1.2-1

Listings of Regulated Hazardous Substances

Hazardous Materials Listing
(49 CFR 172.101) — The labeling, packaging and transportation of these material are regulated by the U.S. Department of Transportation.

Toxic and Hazardous Substances Listing
(29 CFR 1910 Subpart Z) — Occupational exposure of these substances are controlled by the U.S. Department of Labor.

Listing of Hazardous Waste
(40 CFR 261) — The disposal of chemical wastes on this listing are regulated by the Environmental Protection Agency under the Resource Conservation and Recovery Act (RCRA).

Designation of Hazardous Substances
(40 CFR 116)—Chemicals which are hazardous to the environment are identified by the Environmental Protection Agency on this listing.

Available from: Federal Register or
U.S. Goverment Printing Office
Washington, D.C. 20402

A listing of the physical and chemical properties of twenty-nine commonly used hazardous substances in New York State is given in Table 1.2-3. This table represents common chemicals that are stored in bulk. Usage of these chemicals is from 1 million to 450 million pounds per year (not counting petroleum). The properties which are identified in this table include the following:

- The physical state at 20°C.
- The melting and boiling points.
- The specific gravity at 20°C or other specified temperatures.
- The solubility in water.
- The vapor pressure.
- The associated hazard (flammable, corrosive or toxic).
- The reactivity with common storage tank materials.

Knowledge of these various physical and chemical properties is important in determining the proper mode of storage of these substances. For example:

- The melting and boiling points of substances is useful in determining the appropriate range of storage temperatures.
- The solubility of the substance is helpful in determining whether the substance should be allowed to come in contact with water.

Table 1.2-2

Reports Describing Hazardous Materials

U.S. Dept. of Transportation Hazardous Materials Emergency Response Guidebook [1]:

- numerical and alphabetical indices of hazardous materials
- descriptions of health hazards and fire or explosion potential
- procedure to be followed in the event of fire, spill, leak or personnel exposure.
- isolation and evacuation distances for selected hazardous materials

U.S. Department of Transportation
Washington, D.C. 20590

National Fire Protection Assn. Publication NFPA 49: Hazardous Chemicals Data [2]:

- degree of health hazard
- potential for reactivity
- flammability
- physical descriptions
- fire explosion hazard
- particular life hazards
- personal protection requirments during handling
- fire fighting phases

National Fire Protection Association
Batterymarch Park
Quincy, MA. 02269

U.S. EPA Hazardous Materials Spill Monitoring and Safety Handbook and Chemical Hazard Guide Parts A and B [3]:

Part A

- Safety consideration
- first aid procedures
- protective equipment
- priority listing of hazardous material

Part B

- hazard priority number
- hazards
- safety measures
- synonyms

National Technical Information Service
Springfield, VA. 22161
or
U.S. Environmental Protection Agency
Office of Research and development
Environmental Monitoring amd Support Laboratory
Las Vegas, NV. 89114

The Chemical Hazards Response Information System (CHRIS) Manuals [4]:

- Medical data (exposure hazard)
- flammability data (fire hazard)
- pollution data
- biological data
- physical properties
- chemical properties
- preventative and precautionarey initial
- response information

United States Coast Guard
U.S. Dept. of Transportaion
Washington, D.C. 20590

- The vapor pressure of the liquid substances is necessary to determine appropriate storage pressures (pressures at which significant vapor formation can be limited).
- The hazard associated with a particular substance is important in determining handling and storage protocols.
- How the substances react with various materials of construction is important in determining the mode of storage and the materials used in storage.

2. Relationships Between Temperature, Pressure and Volume Within a Storage Tank

In the handling and storage of hazardous liquids, it is important to note that most liquids expand and contract with changes in temperature. Variations in the temperature of the stored liquid can lead to changes in the volume of the stored liquid. In addition, variations in pressure can lead to changes in the volume of the storage tank itself. These volume variations become extremely important when one is attempting to detect small leaks from storage tanks.

The temperature of a liquid stored in a tank either above or below ground can vary throughout the year. The reasons for such variations include the following:

- The seasonal variations in ambient temperature.
- Changes in the weather (e.g., hot, sunny days vs. cold, rainy nights).
- Changes in pressure (compression) of the liquid.

An annual temperature profile for an underground tank is displayed in Figure 1.2-1. Although this profile was observed in an underground gasoline tank, it is typical of the types of variation that can be expected of most liquids which are stored underground.

Liquid temperatures can also vary throughout the storage tank itself. The reasons for such variation include the following:

- Variation in the surface temperature of aboveground tanks due to weather or exposure to the sun.
- Stratification of temperature in the ground surrounding an underground storage tank.
- The introduction of new liquid into a tank that has a different temperature than the liquid already stored in the tank [5.6].

Table 1.2-3

Physical and Chemical Properties of the Twenty-Nine Most Commonly Used Hazardous Substances in New York State

Substance	Physical State at 20°C	Melting Point C°	Boiling Point C°	Specific Gravity	Solubility[2] (mg/l) in H_2O	Vapor Pressure[3] (mm of Hq)	Hazard[4]	Petroleum Tank	Chemical Tank	Carbon Steel
1. Petroleum					Insoluble	NA	E, F	OK	—	OK
-Gasoline	Liquid	NA	60-199	0.132	NA	NA	E, F	OK	—	OK
-No. 2 Fuel Oil	Liquid	NA	NA	NA	515	28	E, F	—	OK	OK
2. Toluene	Liquid	-95	110.4	0.866 20/4	$2,860^{20}$	5	E	—	OK	8
3. Tetrachloro-	Liquid	-44	146.5	1.58 25/4						
ethane					1,000	74^{25}	E, F	—	—	7, 8
4. Methyl Chloride	Gas	-97	-23.7	0.918 20/4						
5. Trichloro-	Liquid	-73	87.1	1.45560 25/4	1,000	100^{32}	C	—	—	8
ethylene										
6. Tetrachloro-	Liquid	-23.25	121.20	1.6230 20/4	150	15.8^{22}	—	—	OK	8
ethylene										
7. Methylene	Liquid	-96.7	39.8	1.32	13,200-20,000	362.4	F	—	—	8
Chloride (Di-										
chloromethane)										
8. Phenols	Solid	43°	182	1.071 25/4	82,000	0.20^{25}	C, E	—	—	7, 8
9. Cresols	Liquid	10.9-35.5	191-203	1.048 20/4	25,000	1^{18}	C	—	—	8
10. Xylene	Liquid	25.4-75	203-225	NA	NA	NA	NA	—	OK	NA
	or Solid				60	$2,600^{25}$	C, E	—	OK	NA
11. Vinyl Chloride	Gas	-160	-13.4	0.908 25/25	$1,780^{30}$	95.2	E, F	—	—	OK
12. Benzene	Liquid	5.51	80.093-	0.8794	Very Slightly	5.5	E, F	—	OK	OK
			80.094		Insoluble	1^{22}	C, E	—	—	8
13. Styrene	Liquid	-31	146	0.9074 20 4	NA	5^{25}	NA	—	—	OK
14. Chlorotoluene	Liquid	-43	179	1.1026 18 4						
15. P-Chlorobenzo-	Liquid	-36	139.3	1.353 15.5 15.5	NA	NA	NA	—	—	NA
trifluoride					448^{30}	$10^{22.2}$	F	—	—	7, 8
16. Octyl Phenol	Solid	NA	280-283	0.941 24 4						
17. Chlorinated	Liquid	-45	131.7	1.113 15.5 15.5	480-4,400	96		—	OK	OK
Benzenes					7,840	192	—	—	—	8

Table 1.2-3 continued

18. Trichlorethane	Liquid	4-39	74	1.31	NA	NA	F[5]	—	OK	NA
19. Chloroform	Liquid	-63.5	61.26	1.49845^{15}	$60.000^{15} 1^{32,4}$	C		—	—	OK
20. Sevin	Solid	142	NA	1,232 20 20	Insoluble	$10^{54,8}$	C	—	OK	OK
21. Hydroquinone	Solid	170.5	286.2	1,358 20 4						
22. P-Dichlorobenzene	Solid	53	173.4	1.4581 20.5 4	Insoluble	$10^{13,2}$	E, F	—	—	OK
					60,000	$1^{34,8}$	C	—	—	OK
23. Pyridine	Liquid	-42	115.3	0.982 20 4	Infinitely	$1^{108,8}$	C	OK	—	OK
24. Aniline	Liquid	-6.2	184.4	1.20 20 4	36.000^{18}					
25. Diethylphthalate	Liquid	-40.5	296-302	1.110-1.21 20 20	35.000	71.2	E, F	—	—	OK
26. 2-Butanone (Methyl Ethyl Ketone)	Liquid	-86	79.6	0.805 20, 4						
					Insoluble	$200^{13,5}$	E	OK	—	NA
					800	100^{23}	—	—	OK	8
27. Freon 113	Liquid	-35	47.6	1,576 20/4						
28. Carbon Tetrachloride	Liquid	-22.6	76.8	1,597	30	0.87^{25}	C, E	OK	—	OK
29. Naphthalene	Solid	80.1	217.9	1,162 20/4						

Notes:

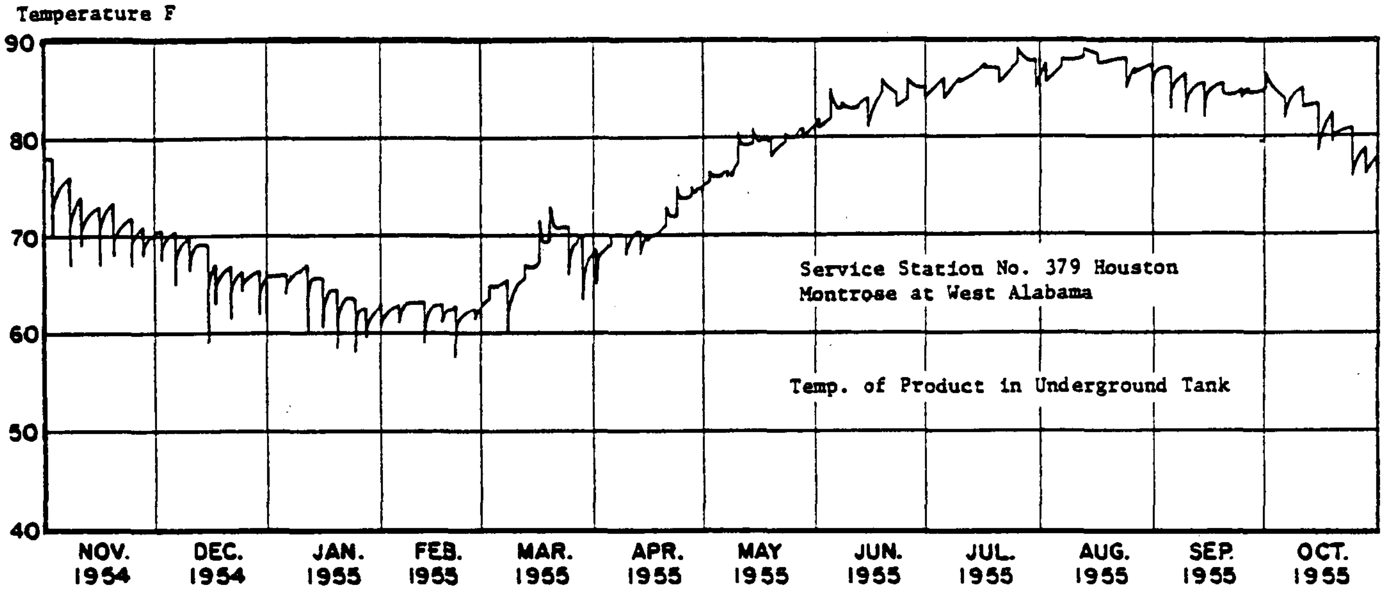
1. Specific gravity at 20° C or as otherwise stated. Where stated, numerator is temperature of substance, denominator temperature of water.
2. Solubility at 25° C or as otherwise stated.
3. Vapor pressure at 20° C or as otherwise stated.
4. All listed substances are toxic to humans at some concentrations.
   E = Explosive
   F = Flammable (flashpoint of less than 80° F)
   C = Combustable (flashpoint of 80° F or higher)
5. Compound itself is not flammable but it is usually dissolved in a combustible liquid.
6. Not recommended.
7. Corrosive at high temperatures.
8. Corrosive at high concentrations.
9. Chemical compatibility may vary from what is shown in this table if special resins or other materials are used for tank construction. Check with the manufacturer for lab analyses of chemical compatibility and for other assurances that the tank you are using is warranteed for the chemical being stored.

NA = Not available

Sources: References 4, 11, 12, 15, 19, 20, 22

Figure 1.2-1

Typical Annual Tank Temperature Variation
For an Underground Gasoline Tank



This graph shows temperature recordings for an entire year by combining the results of 52 weekly graphs. The vertical lines, either down or up show the immediate effect of the delivery on the tank temperature and the curving lines show the gradual return to underground temperatures.

The graph also shows a seasonal change of 30°F in underground temperatures occurring in south Texas. Much greater differences between summer and winter would exist in New York State.

Source: Reference 21.

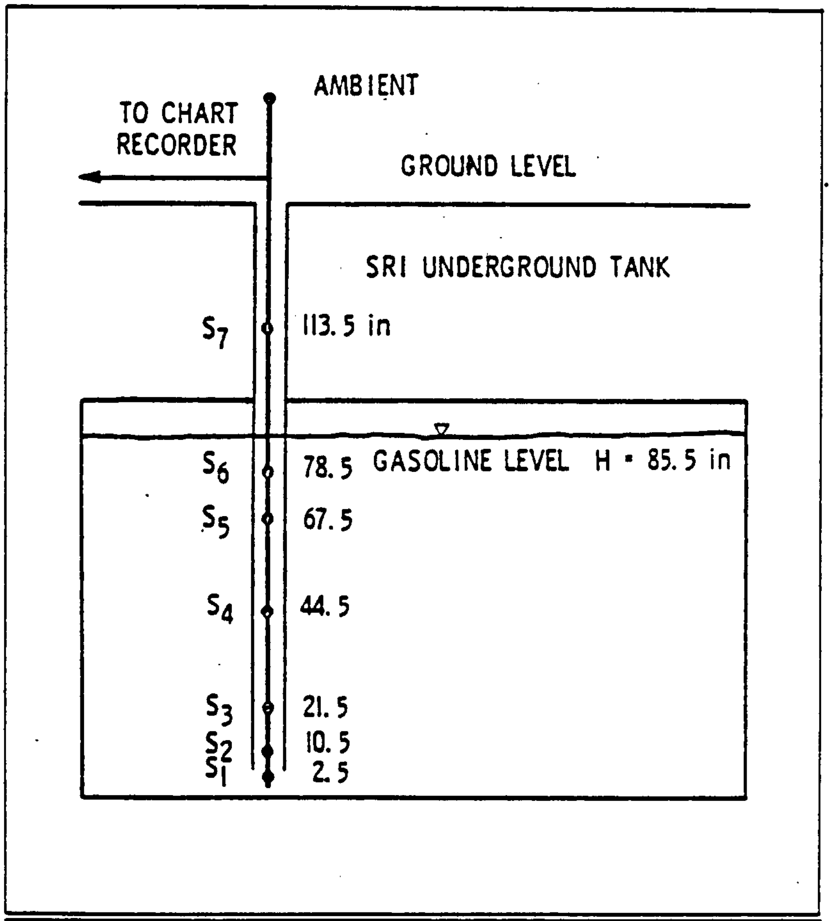
Figures 1.2-2, 1.2-3 and 1.2-4, taken from a Stanford Research Institute study on detection of small leaks, illustrate temperature variations throughout an underground gasoline tank [5]. Figure 1.2-2 shows the location of temperature sensors in the tank. Tank temperatures at these various sensor levels, as a function of time for a 24-hour period after tank filling, are displayed in Figure 1.2-3. As shown in this figure the tank temperature at each level differs and all these temperatures vary with time. The mean temperature variation, as a function of depth for this same tank over four different 24-hour periods, is illustrated in Figure 1.2-4. Again, as shown for each of the 24-hour periods, the liquid temperature can vary substantially throughout the tank.

Because liquids expand or contract as their temperature is raised or lowered, seasonal, day-to-day and tank-wide variations in temperature heavily affect the detection of small leaks. For example, in an 8-foot diameter, 8,000-gallon storage tank half-full of gasoline, a 1.2 gallon per day (0.05 gallon per hour) leak would cause only a 500 micro inch (0.0005 inches) height change in the gasoline level. A mean gasoline temperature change of only 0.012°C (0.022°F) would also result in a 500 micro inch height change of the gasoline level. Thus a 1.2 gallon per day leak could be hidden by a 0.012°C rise in mean liquid temperature [5].

Internal tank pressure can also affect tank volume by leading to increases or decreases in the size of the tank. For example, the total forces exerted on the ends of tanks (assuming flat ends) of different diameters by different pressures are exhibited in Table 1.2-4. This table shows that a 3 pound per square inch (psi) pressure exerted on a tank's contents results in a force of over 10 tons on the ends of an 8-foot diameter tank [6]. This is sufficient force to cause the tank ends to bulge outward some small fraction of an inch, thus increasing the volume of a tank.

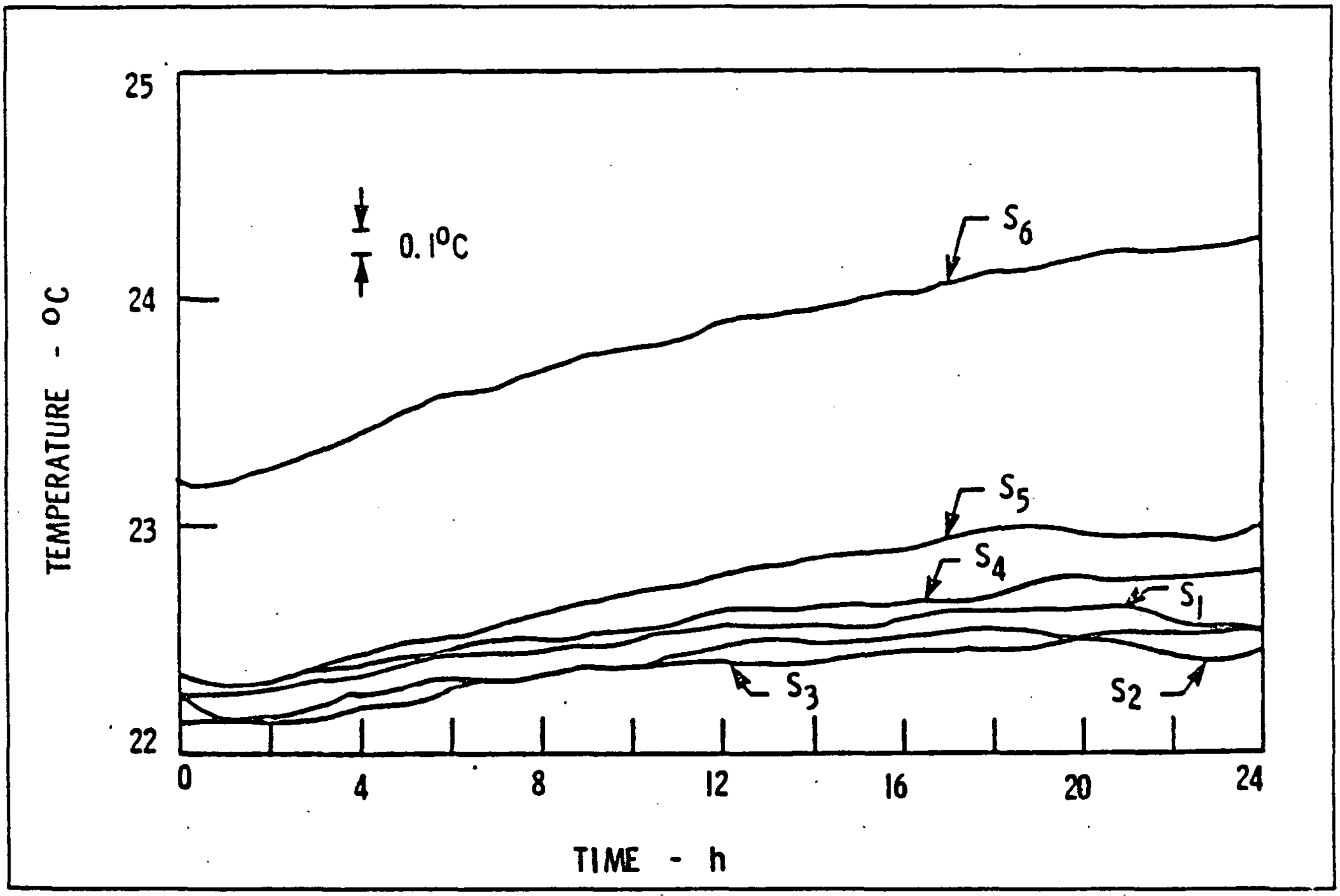
Figure 1.2-2

Location of Temperature Sensors In The SRI Tank



Source: Stanford Research Institute, "Measurement of Small Leaks in Underground Gasoline Storage Tanks Using Laser Interferometry," sponsored by the American Petroleum Institute, 1979.

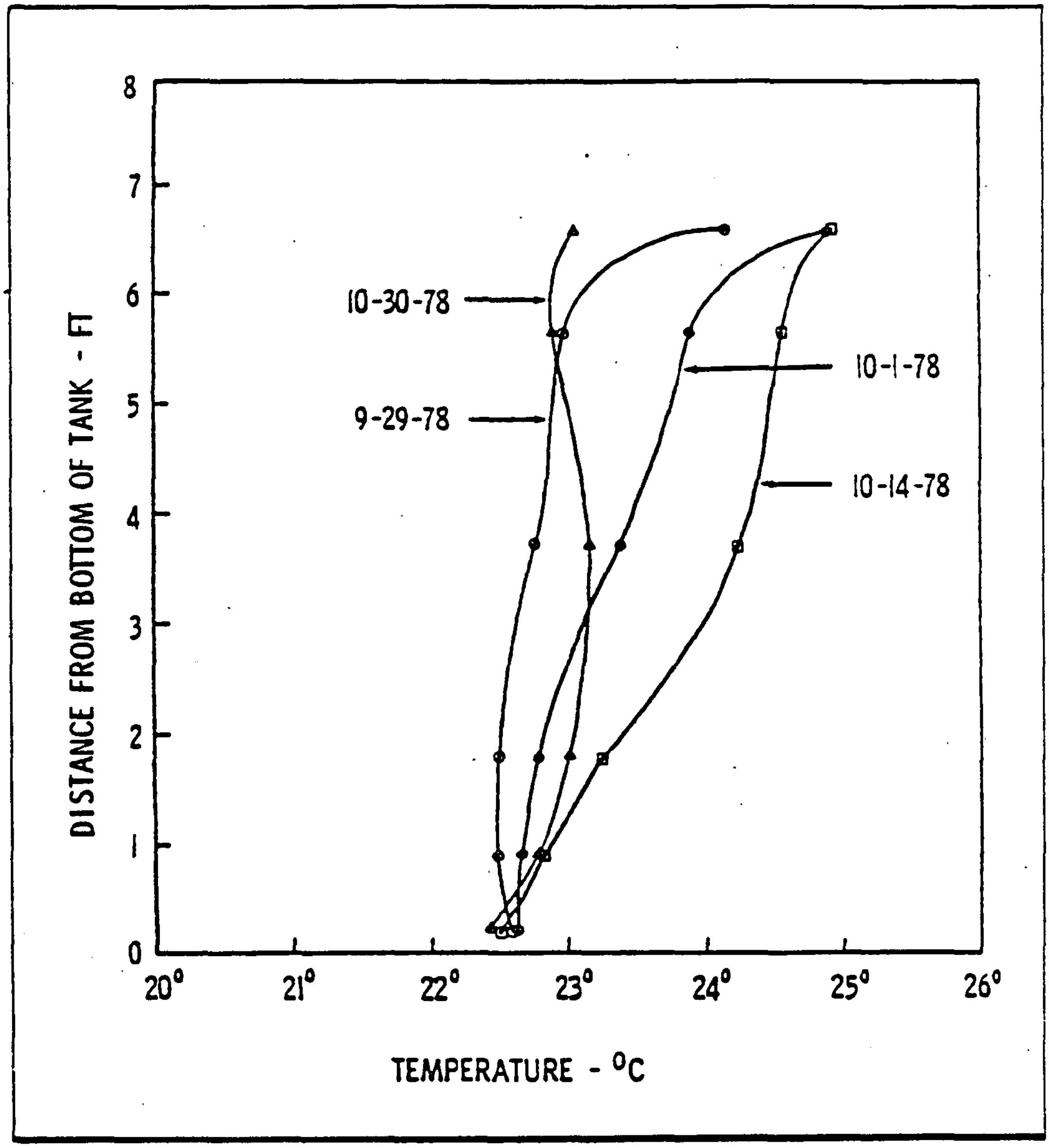
Figure 1.2-3
Tank Temperature at Various Heights
As a Function of Time for a 24-Hour Period
After Tank Fill-up



Source: Stanford Research Institute, "Measurement of Small Leaks in Underground Gasoline Storage Tanks Using Laser Interferometry," sponsored by the American Petroleum Institute, 1979.

Figure 1.2-4

Mean Temperature Distribution as a Function Of Depth for Four Different 24-Hour Periods



Source: Stanford Research Institute, "Measurement of Small Leaks in Underground Gasoline Storage Tanks Using Laser Interferometry," sponsored by the American Petroleum Institute, 1979.

Table 1.2-4

Total Force on Tank Ends Due to Internal Pressure

Tank Diameter (inches)	Total Force in Tons 1 psi	2 psi	3 psi	4 psi	5 psi
48	0.9	1.8	2.7	3.6	4.5
64	1.6	3.2	4.8	6.4	8.0
72	2.0	4.0	6.0	8.0	10.0
84	2.8	5.6	8.4	11.2	14.0
96	3.6	7.2	10.8	14.4	18.0

Source: Reference 6

The extent of tank bulging under pressure is dependent upon several factors, including tank diameter, tank age, the softness or wetness of the surrounding soil (for underground tanks), and past filling practice [6]. However, an 8-foot diameter tank could bulge enough to increase tank volume by 13 gallons or more [6].

These pressure effects become very important when one is attempting to detect small leaks using a method such as standpipe testing which places a pressure on the tank contents. For example, filling a 4-foot long standpipe on an 8-foot diameter gasoline tank buried three feet below grade puts an average pressure of 3.69 psi on the center of the tank [6]. This is sufficient to put more than 10 tons of force on the ends of the tank, and will lead to an increase in tank volume and a corresponding loss of volume in the standpipe. Thus, the detection of small leaks using a standpipe testing method becomes difficult.

C. STORAGE AND HANDLING PROTOCOLS

1. Storage and Handling Systems

Both aboveground and underground bulk storage systems should be composed of five basic components. These are:

- The product storage system (storage tanks).
- The product transfer (piping) system.
- An overfill prevention system.
- A spill containment and collection system.
- A leak detection system.

The basic methods and design considerations associated with these five components are summarized in Table 1.2-5 as a prelude to Parts II and III of this report. The advantages and disadvantages of the various materials of construction employed for product storage and transfer systems are summarized in Table 1.2-6.

2. Aboveground vs. Underground Storage

The choice of aboveground or underground tanks as an appropriate means of storage for a particular hazardous substance is dependent upon several factors, including the following:

- Type and amount of liquid to be stored.
- The availability of space (real estate) for storage.
- The level of product and tank accessibility required.
- The type of soil in the area.
- Groundwater levels in the area.
- Fire hazard considerations.

A comparison of the advanatages and disadvantages of aboveground and underground storage systems is presented in Table 1.2-7.

The reader should note that the storage of liquefied or compressed gases, such as liquefied natural gas, requires adherence to special design criteria as described in the following publications:

- API Standard 2510—The Design and Construction of Liquefied Petroleum Gas Installations at Marine Pipeline Terminals, Natural Gasoline Plants, Refineries and Tank Farms [7].
- NFPA Standard 58—Standard for the Storage and Handling of Liquefied Petroleum Gas [8].
- NFPA Standard 59—Standard for the Storage and Handling of Liquefied Petroleum Gas at Utility Gas Plants [9].

In addition, the American Society of Mechanical Engineers (ASME) has written the *A.S.M.E. Boiler and Pressure Vessel Code* [10], which contains rules for the design, fabrication and inspection of boilers and pressure vessels. This code consists of eleven sections as follows:

I	Power Boilers
II	Material Specifications
III	Nuclear Power Plant Components
IV	Heating Boilers
V	Nondestructive Examination
VI	Recommended Rules for Care and Operation of Heating Boilers
VII	Recommended Rules for Care of Power Boilers
VIII	Pressure Vessels, Division 1
	Pressure Vessels, Division 2, Alternative Rules
IX	Welding Qualifications
X	Fibergalss-Reinforced Plastic Pressure Vessels

Table 1.2-5

Storage System Components — Methods, Materials, and Design Considerations

Product Storage	Product Transfer Piping & Accessories	Overfill Protection	Spill Containment	Leak Detection
-aboveground tanks -underground tanks -single-walled tanks -tank linings and coatings -tank wrappings -design considerations corrosion resistance chemical compatibility structural strength pressure relief foundation requirements safety factors -tank materials selection carbon steel stainless steel fiberglass-reinforced plastic (FRP) fiberglass/steel bonded tanks -coating and lining materials selection alkyds epoxies phenolics -wrappings vinyl polyethylene	-surface/subsurface piping -hoses -loading racks -design considerations corrosion resistance chemical compatibility structural strength pipe supports safety factors -materials selection carbon steel stainless steel fiberglass-reinforced plastic (FRP) polyvinyl chloride (PVC) polypropylene -check valves -emergency shutoff valves -coupling mates to prevent mixing of incompatible chemicals	-level control devices floats displacers gas bubblers hydrostatic head devices capacitance devices thermal conductivity devices ultrasonic devices optical devices nucleonic devices -automatic shutoff controls and flow diversion -high level alarms -liquid level gages -check valves -operating practices for overfill protection -dry disconnection hose valves -catchment basins	-impervious perimeter dikes, berms cutoff walls curbs aprons/slabs drainage ditches troughs -liners synthetic membranes asphalt, contrete -in-situ absorbing/neutralizing media for spill containment -spill collection systems -secondary containment tanks (double-walled tanks) -clay liners	-inventory control -visual inspection -interstitial monitoring of double walled tanks -soil/ground-water monitoring -tightness tests -structural tests

Table 1.2-6

General Properties of Materials Used for Storage Tanks and Piping

Structural Materials	Advantages	Disadvantages	Relative Cost
Carbon Steel	Compatible with petroleum products but not compatible with corrosive chemicals, such as mineral and oxidizing acids, without coatings. High structural strength.	Subject to attack by corrosive soils and corrosive chemicals such as mineral and oxidizing acids.	Low
Stainless steel	Material has better corrosion resistance than carbon steel and higher structural strength. There are more than 70 standard types of stainless steel and many special alloys.	Lower grade steels (i.e., martensitic steels) are not suitable for reducing acids such as HCl.	Medium to high, depending on grade of steel.
Fiberglass-reinforced plastic (FRP)	Compatible with petroleum and several chemical products.	Lacks the structural strength and impact resistance of steel tanks. Not compatible with some organic solvents.	Comparable to coated steel.
Polyvinyl chloride (PVC)	Excellent chemical resistance to acids, alkalis, and gasoline.	Plastics have low structural strength and are less resistant to mechanical abuse than steels. They are generally not suited for the storage or handling of organic solvents such as benzene, carbon tetrachloride and acetone.	Low
Concrete	Generally good resistance to chemical attack when exposed to dilute organic acids. Epoxy coatings are often applied to concrete to provide chemical resistance and decrease permeability.	Concrete is subject to cracking and spalling with changes in temperature such as during freeze/thaw cycles. Generally poor resistance to chemical attack.	High
Aluminum	Excellent resistance to atmospheric conditions and compatible with mineral and organic acids.	Pure aluminum has relatively low structural strength and as such is generally not used in the fabrication of tanks and pipes. Aluminum alloys are available but they are costly.	High
FRP/steel bonded tanks	Material has the combined advantage of the corrosion resistance of fiberglass and the structural strength of steel.	The main disadvantage of these tanks is their cost.	Medium
Linings and Coatings			
Alkyds	Alkyd-phenolics and alkyd-silicones have good weather-ability and good to excellent resistance to gasoline, non-halogenated organic solvents and alchohols. They may be applied to both the interior and exterior of tanks and pipes.	Not compatible with mineral acids, alkalis, chlorinated solvents, and organic acids.	Low

Table 1.2-6 continued

Epoxies	These materials include epoxy-amines, epoxy-esters and epoxy-phenolics. These materials have excellent weatherability and excellent chemical resistance to gasoline, non-halogenated organic solvents, alkalis and mineral acids. Epoxies may be applied to both interior and exterior of tanks and pipes.	Generally good to poor resistance to orgranic acids depending on the acid.	Low
Glass	Used for internal coatings. Very good chemical resistance.	High cost. Very fragile.	High
Phenolics	Excellent durability and excellent resistance to gasoline, non-halogenated organic solvents, and alcohols. Phenolic coatings may be applied to both interior and exterior of tanks and pipes.	Phenolic coatings generally exhibbit poor resistance to alkalis, mineral acids, chlorinated solvents, and organic acids.	Low
Wrappings			
Vinyl	Good resistance to gasoline, non-halogenated solvents, alkalis and mineral acids. Vinyl coatings are usually applied as loose wrappings around tanks and pipes.	Not compatible with chlorinated solvents, and exhibits excellent to poor resistance to organic acids depending on the acid. Wrappings are usually not as effective as coatings because water often penetrates the space between the wrapping material and the tank.	Low
Polyethylene	Very good resistance to oxidizing acids, and some organic acids and alkalis. Polyethylene is usually applied as a loose wrapping around tanks and pipe.	Not compatible with gasoline and organic solvents. Wrappings are usually not as effective as coatings because water often penetrates the space between the wrapping material and the tank.	Low

Source: Reference 3.

Table 1.2-7

General Comparison of Aboveground and Underground Storage

Type of Storage	Advantages	Disadvantages
Aboveground	Accessible for equipment inspection and surveillance (leak detection).	Generally not aesthetically pleasing because equipment is visible.
	Allows for storage of much greater volumes in a single tank.	Requires large spill containment volume.
	Tanks accessible for cleanout and maintenance.	Subject to damage in flood area.
		Greater potential for vapor loss in atmospheric tanks due to temperature fluctuations because tank is exposed.
		Equipment is exposed to weathering.
		Greater exposure to fire.
Underground	Equipment out of sight; generally aesthetically pleasing; more efficient use of limited yard space.	Not accessible for inspection, surveillance, or easy maintenance.
	Accidental damage to equipment due to vehicular traffic (running into equipment) or similar causes is avoided.	One must be concerned with soil induced corrosion.
	Less subject to fire hazards and vandalism.	Potential for undetected leak and resultant groundwater contamination is much greater.
	Can be used at existing facilities located in flood plains if properly designed. (New facilities, whether aboveground or underground, may not be located in a flood plain under NYS regulation).	

Table 1.2-8

Capatibility Chart:
Chemicals vs. Structural Materials

Construction Material	Generally Incompatible with:
Steel	Mineral acids; nitric, hydrochloric, dilute sulfuric acids
Aluminum	Alkalies; potassium hydroxide, sodium hydroxide, mineral acids
Magnesium	Mineral acids
Lead	Acetic acid, nitric acid
Copper	Nitric acid, ammonia
Zinc	Hydrochloric acid, nitric acid
Tin	Organic acids, alkalies
Titanium	Sulfuric acid, hydrochloric acid
Fiberglass Reinforced plastics	Some organic solvents
Lining Materials	**Generally Incompatible with:**
Alkyds	Strong mineral acids, strong alkalies, alcohols, ketones, esters, aromatic hydrocarbons
Vinyls (poly-vinyl-chloride-PVC)	Ketones, esters, aromatic hydrocarbons
Chlorinated Rubbers	Organic solvents
Epoxy: (amine-cured, polyamide cured, or esters)	Oxidizing acids (nitric acid), ketones
Coal Tar Epoxy	Strong organic solvents
Latex	Oxidizing acids, ketones, esters
Polyesters	Oxidizing acids, strong alkalies, mineral acids, ketones, aromatic hydrocarbons
Silicones	Strong mineral acids, strong alkalies, alcohols, ketones, aromatic hydrocarbons

3. Chemical Compatibility

A primary concern in the handling and storage of hazardous liquids is the compatibility of these liquids with the storage system components. If, for example, a liquid is stored in a tank composed of a material which is incompatible with that liquid, accelerated and possibly very rapid deterioration of the tank could occur. This could result in a major leak or spill incident.

General information regarding the compatibility of various hazardous liquids with different materials of construction and lining materials is provided in Table 1.2-8. As shown in this table, steel is generally compatible with hydrocarbons, but is incompatible with most acids. In using Table 1.2-8 as a reference, the reader should note that when FRP is used as a material of construction, resins that are compatible with the material to be stored must be used. Other sources of information on material compatibility are listed in Table 1.2-9.

The compatibility of hazardous liquids with other types of liquids is also of concern. Liquids may come in contact with one another if, for example, a tank storing liquid A is not thoroughly cleaned before it is used to store liquid B. If these liquids were incompatible, a violent reaction could ensue with potentially destructive effects.

Table 1.2-9

References on Material and Chemical Compatibility

Chemical Engineering Handbook, Perry and Chilton [11]

Corrosion Data Survey, National Association of Corrosion Engineers [12]

"Beat Corrosion With a Rubber Hose," Gallagher, Chemical Engineering, September 8, 1980 [13]

"Guide for Protection of Concrete Against Chemical Attack by Means of Coatings and Other Corrosion-Resistant Materials," American Concrete Institute Committee 515 [14]

The Merck Index, Merck and Company [15]

A Method of Determining the Compatibility of Hazardous Wastes, U.S. EPA-600/1-80-076, April, 1980 [16]

The Chemical Hazards Response Information System, Chemical Data Handbook, U.S. Coast Guard, U.S. Department of Transportation [17]

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2. National Fire Protection Association, *Hazardous Chemicals Data*, NFPA 49, Batterymarch Park, Quincy, MA 02269, 1975.

3. U.S. Environmental Protection Agency, *Hazardous Materials Spill Monitoring and Safety Handbook and Chemical Hazard Guide, Parts A and B*, EPA-600/4-79-008a/b, PB295853 and PB295854, Office of Research and Development, U.S. Environmental Protection Agency, P.O. Box 15027, Las Vegas, Nevada 89114, January, 1979.

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9. National Fire Protection Association, *Standard for the Storage and Handling of Liquefied Petroleum Gas at Utility Gas Plants*, NFPA 59, Batterymarch Park, Quincy, MA 02269.

10. American Society of Mechanical Engineers, *A.S.M.E. Boiler and Pressure Vessel Code*, American Society of Mechanical Engineers, 345 East 47 Street, New York, NY 10017.

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23. National Association of Corrosion Engineers, Recommended Practice RP-01-69, "Control of External Corrosion on Underground or Submerged Metallic Piping Systems," 2400 West Loop South, Houston, TX 77027.

Additional Information on Hazardous Chemicals

The following sources may be consulted for additional information:

A Comprehensive Treatise on Inorganic and Theoretical Chemistry, J.W. Mellor, John M. Wiley and Sons, Inc.

Accident Prevention Manual for Industrial Operations, National Safety Council.

American Insurance Association (Chemical Hazards Bulletins, Research Reports, Special Interest Bulletins).

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Chemical and Engineering Dictionary, Chemical Publishing Company.

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Dangerous Properties of Industrial Materials, N. Irving Sax, Reinhold Publishing Corp.

Encyclopedia of Chemical Technology, Kirk and Othmer, Interscience Publishing Company.

Fire Officer's Guide to Dangerous Chemicals, Charles W. Bahme, NFPA.

Guide to Safety in the Chemical Laboratory, Manufacturing Chemists' Association.

Handbook of Chemistry, N.A. Lange, McGraw-Hill Book Company, Inc.

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U.S. Department of Transportation, Regulations for Transportation of Explosives and Other Dangerous Articles.

Part II
UNDERGROUND STORAGE SYSTEMS

INTRODUCTION

Part II of this report describes the components and concerns associated with underground storage facilites for hazardous liquids.

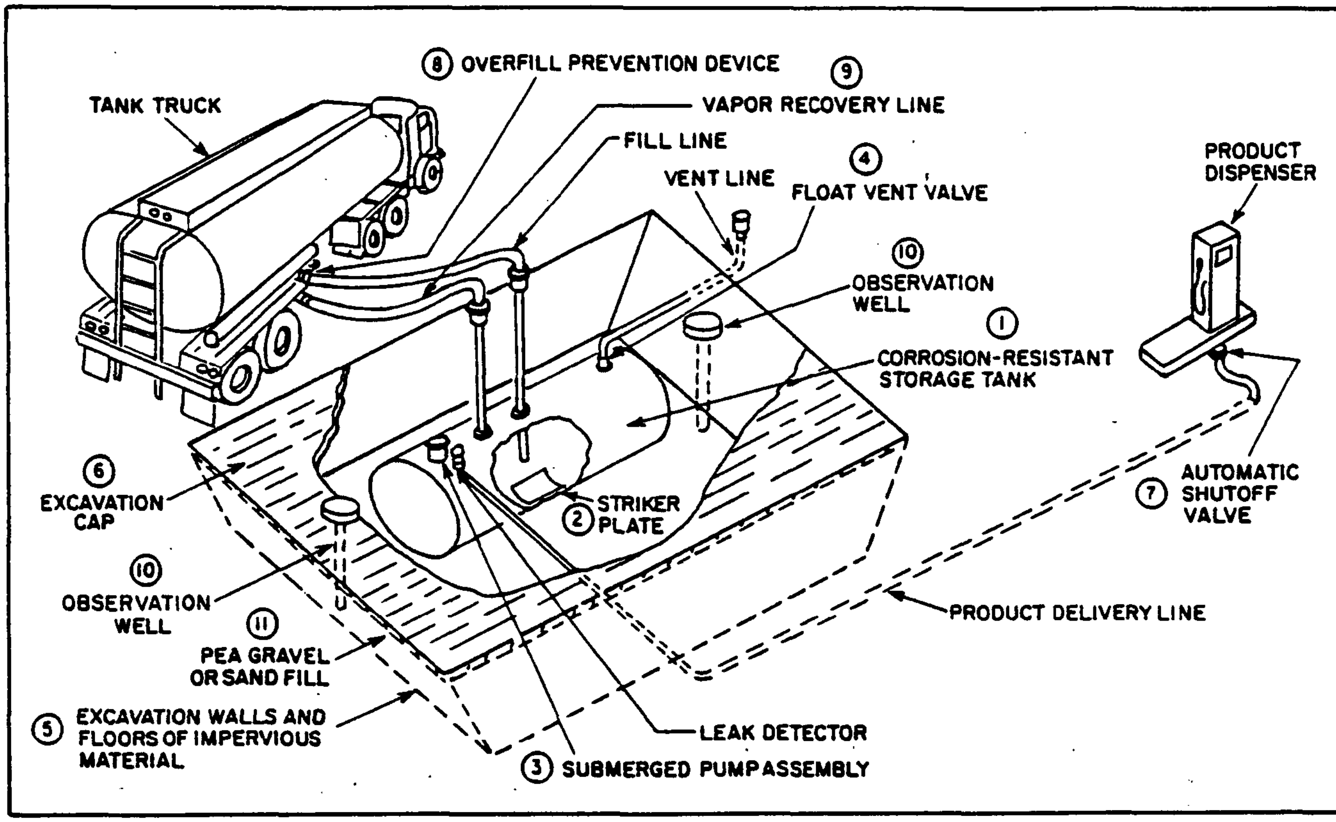
The basic principles shown in figure 2-1 are applicable to all underground storage systems. However, because chemicals are highly variable in the characteristics and the risks they present, underground storage may not always be an appropriate storage practice, or it may be appropriate for the design engineer to consider other practices not illustrated in this generalized drawing.

The items covered in detail in the following chapters include (1) the types of storage tanks available; (2) piping and pumping system components and their performance; (3) underground spill containment systems; (4) the types of overfill prevention systems and their performance; (5) leak monitoring and surveillance; (6) the testing and inspection of underground storage systems; and (7) the closure and abandonment of underground storage facilities.

A schematic diagram showing the key components of an underground storage system is presented in Figure 2-1.

Figure 2.1

Elements of an Underground Storage Tank Installation



Well designed underground storage systems usually contain the following:

1) corrosion resistant tank; 2) striker plate under tank fill line; 3) submerged pump with leak detector on product delivery line: 4) float vent valve in tank vent line; 5) excavation walls and floor of impervious material; 6) asphalt or concrete excavation cap; 7) automatic shutoff valve on delivery line at pump island; 8) overfill prevention device at fill line on tank truck; 9) vapor recovery in tank truck during filling operation; 10) observation wells located inside excavation boundaries; 11) pea gravel or sand fill for excavation.

These are all important aspects of a good underground storage system.

Part II

CHAPTER 1: UNDERGROUND STORAGE TANKS

A. INTRODUCTION

Several types of underground storage tanks or storage systems are available for use in today's market. These include the following:

- Bare steel tanks.
- Steel tanks with coatings.
- Cathodically protected steel tanks (galvanic protection).
- Cathodically protected steel tanks (impressed current protection).
- Fiberglass reinforced plastic (FRP) tanks.
- FRP/steel bonded tanks.
- Double containment systems, such as
  - Double-walled tanks,
  - Vaulted tank storage system, and
  - Impermeable liners.
- Relined tanks.
- Tanks which combine several design features such as cathodically protected double walled steel tanks or double walled steel tanks with a fiberglass bonded outer shell are available on custom order from many manufacturers.

Summaries of the characteristics and limitations of these various types of tanks and storage systems are presented in Table 2.1-1.

B. TANK LAYOUT

Idealized layouts for underground storage facilities are illustrated in Figures 2.1-1 and 2.1-2. The diagram of Figure 2.1-1 depicts a tank equipped with a suction pump while the illustration in Figure 2.1-2 is that of a tank equipped with a submerged pump. The discussion in chapter 2 explains these pumping systems in more detail.

It is highly desirable for the owner to prepare and keep at the storage site, a plot plan which shows the layout of the facility. The plot plan should show age of tanks, material of construction, depth and location of pipe galleries, chemical stored in tank and phone number and address of person to contact in case of an emergency.

The tank connections shown in Figures 2.1-1 and 2.1-2 include the following:

- A fill and gauge tube.
- A vent line, with a float vent valve installed at the vent line tank connection for overfill prevention.
- A manhole fitted over the fill and gauge tube to permit easy access to the tube.

In addition, Figure 2.1-2 shows a manhole over the pump manifold assembly to permit access for maintenance, and a leak detector mounted on the pump manifold, which detects leaks in the product supply line. Leak detectors are required by NFPA 30.

The utility and economics of providing a storage tank with a manhole are subject to debate. They add approximately $500 to the cost of a tank. A tank can be cut open and entered for inspection for about $700 and effectively resealed. However, all tanks may not require inspection in a normal life and only a small fraction may require re-entry.

Manholes have the advantage of allowing internal inspection of emptied tanks and are especially useful on fiberglass tanks where access for measuring diameter deflections is important. However, Manhole gaskets can leak, resulting in stormwater entry and can give a false reading during a leak test. Air pockets formed in the manhole area can interfere with leak testing, though this condition can be corrected with a properly placed bleeder valve.

All tanks, and especially FRP tanks, should be provided with a striker plate under the fill line. The striker plate is a heavy metal plate attached to the bottom of the tank which absorbs the shock of the dip stick when it is dropped into a tank to measure liquid level. It is becoming common practice to have striker plates under all tank openings.

Table 2.1-1

Characteristics of Underground Storage Tanks

Type	Description	Applications*	Types of Soil Suitable	Major Causes of Leaks	Relative Costs	Remarks (advantages and disadvantages)
Bare steel	Carbon steel	Compatible with fuels and a number of other chemical products. Not compatible with corrosive liquids such as acids.	Not compatible with corrosive soil.	Corrosion	Low	Fifty percent of the bare bare steel tanks leak after 15 years. Life expectancy is dependent on soil corrosivity and method of installation.
Coated/lined steel	Carbon steel with exterior coating and/ or interior lining.	Generally compatible with corrosive chemicals such as alkalis and organic and inorganic acids if internal lining is applied.	Generally compatible with corrosive soil if external coating is applied.	Corrosion due to defects in coating or lining.	Low	Coating/ lining must be properly applied and free of defects (holidays). the effecttiveness of the coating/ lining will vary with the type of coating. Internal lining can increase life span of tanks.
Pre-engineered cathodically protected steel tanks-galvanic protection (e.g. Sti-P3 and B-10 tanks)	Steel tank with pre-engineered corrosion protection consisting of sacrificial anodes, protective coating and electrical isolation.	Compatible with gasoline, diesel fuel, kerosene, bunker oil and a number of other chemical products.	Can withstand corrosion in soils with resistivities greater than 2000 ohm-cm [26].	Internal corrosion	Medium	Life expectancy of these tanks is difficult to predict but the record for the fifteen years that the tank has been available is impressive.
Cathodically protected steel tanks-impressed current	Steel tanks to which a constant supply of electric current is applied.	Petroleum products and a number of other chemical products.	Will withstand highly corrosive soil if properly designed.	Internal corrosion	Medium	Good life expectancy if the cathodic protection is properly maintained.
Vaulted tank	Tanks are installed in concrete valults to provide seccondary containment of leaks. Vaults sometimes have interior coatings and external polyethylene wrapper to prevent permeation through concrete.	Frequently used for secondary containment of highly hazardous chemicals.	Generally resistant to soil corrosion.	Low risk of leaks	High	Poorly designed concrete vaults are susceptible to cracking and chemical attack by salts and acids. Porosity of concrete is a problem.

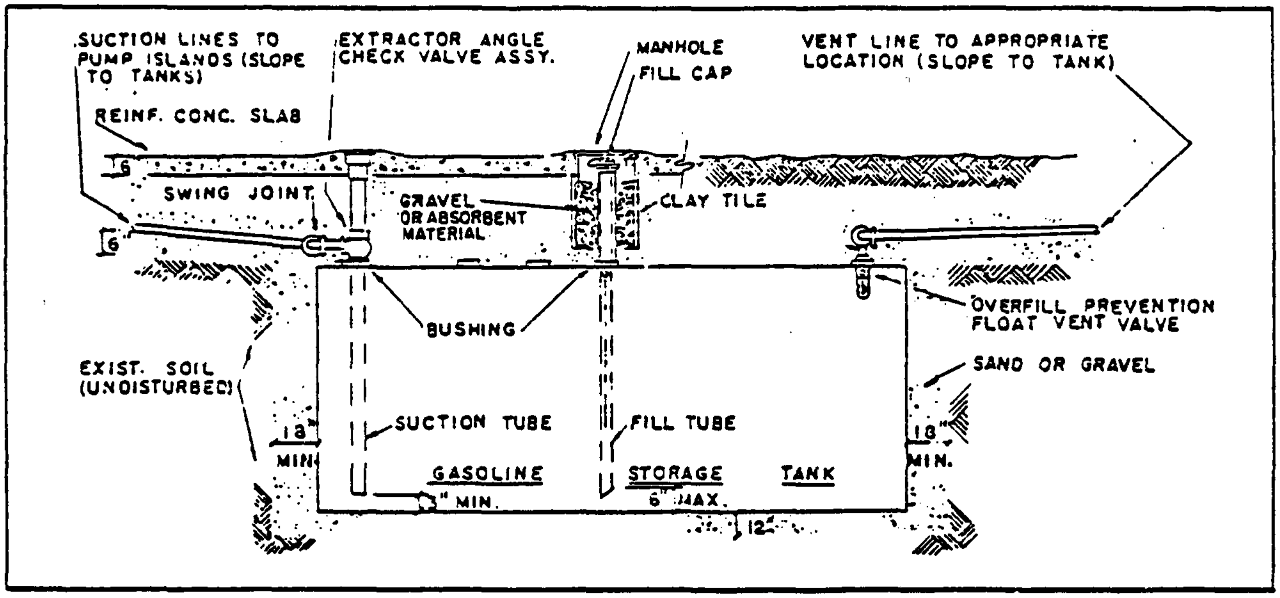
Table 2.1-1 continued

Impermeable liners	Involves the use of an impermeable liner as secondary containment in the tank excavation. Examples include membrane, clay, and bentonite liner.	See Part II, Chapter 4	See Part II, Chapter 4	Low risk of leaks	Medium	Care must be taken to insure that lining material is compatible with stored material. Should include a leak detection system within the confines of the liner containment area.
Relined tanks	Existing steel tank relined with corrosion resistant material.	Petroleum products and corrosive chemicals. Used to extend the lifespan of underground tanks.	Bare steel tanks with interior liners will continue to corrode in corrosive soil.	Defects in lining	Low	Condition of the tank is a key consideration. It is important that the relining material be compatible with the material to be stored and that workmanship be according to the API standards.
Fiberglass reinforced plastic (FRP)	Plastic resins reinforced with glass fiber.	Petroleum and a number of other chemical products.	Suitable in highly corrosive soils.	Tank rupture	Medium	FRP tanks cannot withstand loads as does steel and may easily be damaged if dropped, mishandled or subjected to excessive loads because of improper installation.
FRP/steel	Outer FRP layer fused to an inner layer of steel by a polyester resin bond.	Petroleum products and a number of other chemical products.	Resistance to soil corrosion is comparable to that of fiberglass tanks.	Low risk of leaks, but tank is susceptible to internal corrosion.	Medium	Combines strength of steel with corrosion resistance of fiberglass.
Double-walled	Tank within a tank with a vacuum or pressurized space between the inner and outer walls. Currently manufactured doubled-walled tanks are composed of either steel (with coating and galvanic cathodic protection on outer wall) or FRP.	Applications are dependent upon the materials of construction. See descriptions of FRP and coated, galvanically protected steel tanks above.	Suitable in highly corrosive soils, depending on the materials of construction.	Low risk of leaks	High	Some models only available in capacities up to to 4000 gallons. These tanks usually include a built-in leak detection system located between the inner and outer walls.

* Refer to Table I.2-8 and Appendix A for more inforamtion on chemical compatibility.

Figure 2.1-1

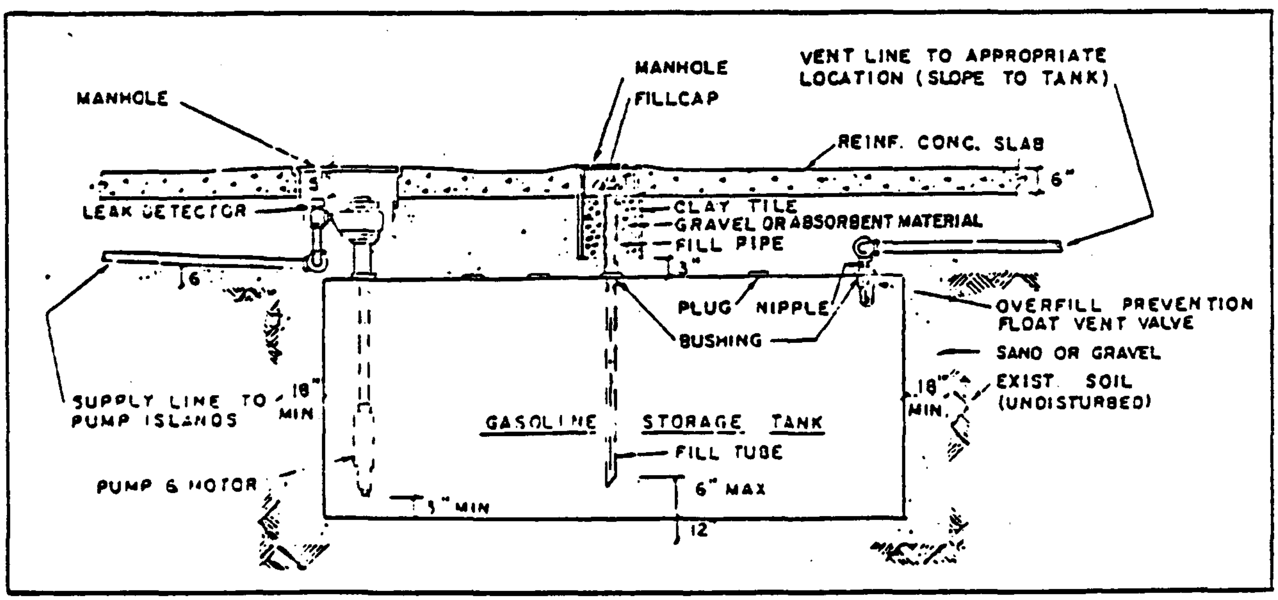
Tank Piping Details – Suction System



Source: API Publication 1615, *Installation of Underground Petroleum Storage Systems*, 1979.

Figure 2.1-2

Tank Piping Details – Submerged System



Source: API Publication 1615, *Installation of Underground Petroleum Storage Systems*, 1979.

C. TYPES OF UNDERGROUND STORAGE TANKS

1. Bare Steel Tanks

Bare steel tanks constructed of mild carbon steel may be used in non-corrosive soil environments to store non-corrosive materials, such as gasoline and other petroleum derivative products. The compatibility of steel with various petroleum and chemical products is discussed in Part I and Appendix B. The degree of environmental protection provided by bare steel tanks is minimal and consequently their use has declined in recent years.

Please note that many bare steel tanks have a thin surface coating to protect against rust. This is essentially a cosmetic coating, and should not be confused with more substantial corrosion protection coatings.

Design Standards. The capacities, dimensions and construction details for bare steel tanks generally follow established standards. These include the following:

Underwriter Laboratories (UL) Inc.:

UL 58 – *Steel Underground Tanks for Flammable and combustible Liquids* [6].

National Fire Protection Association (NFPA):

NFPA 30 – *flammable and combustible Liquids Code* [19].

American Petroleum Institute (API):

API Publication 1602 – *Recommended Standard for Underground Gasoline Tanks* [21].

API Publication 1611 – *Service Station Tankage Guide* [20].

API Publication 1615 – *Installation of Underground Petroleum Storage Systems* [1].

American Society of Mechanical Engineers:

ASME/Pressure Vessel Code, Section VIII/[14].

Of these standards, the Underwriters Laboratories standards are the most detailed in that they specify many of the tank design details. These include steel thickness, tank head design, bracing requirements for multi-compartment tanks, the sizes of vent connections, and tank marking and testing requirements.

The American Society of Mechanical Engineers Pressure Vessel Code may be used for storage tanks intended for industrial service.

The thicknesses of horizontal, atmospheric-type steel tanks of various capacities as recommended in UL 58 are shown in Table 2.1-2. This standard also recommends that the length of the tank be no more than six times its diameter [6]. As a source of reference, the capacity per foot of length for tanks having diameters of 24 to 144 inches is given in Table 2.1-3.

Installation of Underground Steel Tanks. Sources of information and recommendations of installation practices for underground storage tanks include API Publication 1615 [1], NFPA 30 [19] and the New York State Department of Environmental Conservation (NYSDEC) manual covering standards of practice for bulk storage of hazardous liquids [30]. Most manufacturers supply step-by-step procedures for tank installation and require that these steps be followed to validate the guarantees and warrantees.

The installation recommendations given in the API publication identify tank clearance, depth of excavation, and anchoring and backfilling requirements. Examples of the recommendations given in API Publication 1615 include the following:

- At least 6 inches and preferably 12 inches of well-compacted sand or gravel placed underneath the tank.
- A minimum tank clearance of 12 inches in all horizontal directions.
- In areas not subject to traffic, the cover depth should be a minimum of 24 inches, or not less than 12 inches plus a reinforced concrete slab not less than 4 inches in thickness.
- Where tanks are subject to traffic, cover depths should be a minimum of 36 inches, or not less than 18 inches of well-tamped material plus at least 6 inches of reinforced concrete or 8 inches of asphaltic concrete.

It should be noted that the burial depth of a tank is dependent upon several factors, including local regulations, the type of finished surface to be applied, soil conditions, topography, and suction pumping lift requirement [1].

The recommendations of NFPA 30 concur with those of API Publication 1615, with the addition that steel underground tanks shall be set on firm foundations and surrounded with at least 6 inches of noncorrosive inert material, such as clean sand or gravel, well-tamped in place [19].

The backfill for steel tanks is typically a clean, noncorrosive, porous material such as clean washed sand or gravel. Backfilling operations are very important to the life of the installation. It is important that the backfill be well compacted to avoid undue stresses on the tank. Application and compaction of the backfill in layers is often specified to chieve optimum compaction (eliminate voids in the backfill).

Table 2.1-2

Thickness of Steel Tanks

Capacity		Maximum* Diameter		Manufacturers Standard or Galvanized Sheet	Nominal Thickness			
					Uncoated		Galvanized	
U. S. Gallons	dm^3	Inches	m	Gage No.	Inches	mm	Inches	mm
Up to 285	Up to 1078	42	1.07	14	0.075	1.91	0.079	2.01
286 to 560	1082 to 2120	48	1.22	12	0.105	2.67	0.108	2.74
561 to 1100	2124 to 4164	64	1.63	10	0.135	3.43	0.138	3.51
1101 to 4000	4168 to 15142	84	2.13	7	0.179	4.55		
4001 to 12,000	15145 to 45425	126	3.20	1/4 inch	0.250	6.35		
12,001 to 20,000	45429 to 75708	144	3.66	5/16 inch	0.312	7.92		
20,001 to 50,000	75712 to 189270	144	3.66	3/8 inch	0.375	9.53		

* Length of tank shall be not greater than 6 times the diameter

Source: This material is based on and taken, with permission, from Underwriters Laboratories Inc. Standard for Safety for Steel Underground Tanks for Flammable and Combustible Liquids, UL 58, Copyright 1976 (by Underwriters Laboratories Inc.), copies of which may be purchased from Underwriters Laboratories, Inc., Publication Stock, 333 Pfingsten Road, Northbrook, Illinois 60062.

Note: UL shall not be responsible to anyone for the use of or reliance upon a UL Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon a UL Standard.

Table 2.1-3
Gallon Capacity per Foot of Length

Diameter in Inches	U.S. Gallons 1-foot Length	Diameter in Inches	U.S. Gallons 1-foot Length	Diameter in Inches	U.S. Gallons 1-foot Length
24	23.50	65	172.38	105	449.82
25	25.50	66	177.72	106	458.30
26	27.58	67	183.15	107	467.70
27	29.74	68	188.66	108	475.89
28	31.99	69	194.25	109	485.00
29	34.31	70	199.92	110	493.70
30	36.72	71	205.67	111	502.70
31	39.21	72	211.51	112	511.90
32	41.78	73	217.42	113	521.40
33	44.43	74	223.42	114	530.24
34	47.16	75	229.50	115	540.00
35	49.98	76	235.56	116	549.50
36	52.88	77	241.90	117	558.51
37	55.86	78	248.23	118	568.00
38	58.92	79	254.63	119	577.80
39	62.06	80	261.12	120	587.52
40	65.28	81	267.69	121	597.70
41	68.58	82	274.34	122	607.27
42	71.97	83	281.07	123	617.26
43	75.44	84	287.88	124	627.00
44	78.99	85	294.78	125	638.20
45	82.62	86	301.76	126	647.74
46	86.33	87	308.81	127	658.60
47	90.13	88	315.95	128	668.47
48	94.00	89	323.18	129	678.95
49	97.96	90	330.48	130	690.30
50	102.00	91	337.86	131	700.17
51	106.12	92	345.33	132	710.90
52	110.32	93	352.88	133	721.71
53	114.61	94	360.51	134	732.60
54	118.97	95	368.22	135	743.58
55	123.42	96	376.01	136	754.64
56	127.95	97	383.89	137	765.78
57	132.56	98	391.84	138	776.99
58	137.25	99	399.88	139	788.30
59	142.02	100	408.00	140	799.68
60	146.88	101	416.00	141	811.14
61	151.82	102	424.48	142	822.69
62	156.83	103	433.10	143	834.32
63	161.93	104	441.80	144	846.03
64	167.12				

Source: This material is based on and taken, with permission, from Underwriters Laboratories Inc. Standard for Safety for Steel Underground Tanks for Flammable and combustible Liquids, UL 58, copyright 1976 (by Underwriters Laboratories Inc.), copies of which may be purchased from Underwriters Laboratories, Inc., Publication Stock, 333 Pfingsten Road, Northbrook, Illinois 60062.
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It is also recommended in API Publication 1615 that tanks be ballasted with the product as soon as possible after backfilling. Water ballast may be used as an alternative, but it is necessary to defer installation of submerged pumping units in the tank until after the water ballast is removed. If ballasting is necessary in order to prevent tank flotation (from a high water table or from rain), the product to be stored should be used as a first choice [1].

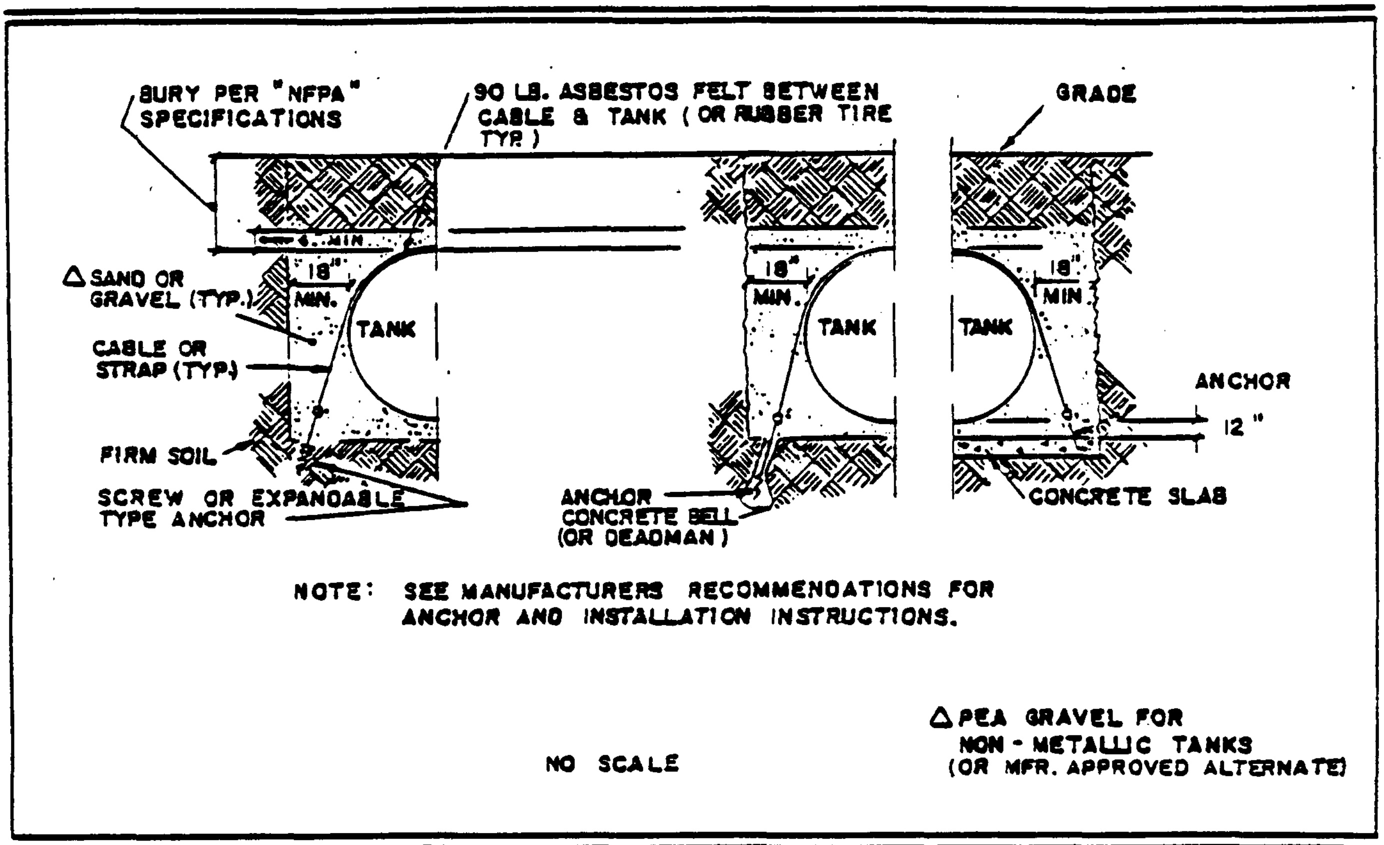
When a high water table is present, anchoring should be used to prevent tank flotation. A concrete slab is often used to anchor underground tanks as shown in Figure 2.1-3. When such a concrete slab is used, tanks should be separated from the slab by no less than 12 inches of compacted sand. Tanks should not be set directly on the concrete nor placed on hard or sharp material that could cause deformation or damage to the tank or tank coatings. Anchor straps should be installed so as not to damage the tank or tank coating. Material such as asbestos felt or pieces of rubber tire should be placed between the tank and the anchor straps to provide electrical isolation [1].

For complete information on the installation of underground steel tanks, the reader is directed to the NYSDEC standards of practice document, NFPA 30, API Publication 1615 and other sources, such as Occupational Safety and Health Administration regulations (29 CFR, Part 1910, Section 1910.106) [29] and specific manufacturer recommendations.

Characteristics of Carbon Steel. Carbon steel is the most common, most versatile and least costly metal used in industry. It is two-thirds the weight of lead and three times heavier than aluminum [14]. Carbon steel may be annealed (i.e. heated and then cooled) to make it stronger and more flexible, and galvanized (coated with zinc) to improve its corrosion resistance. The mechanical properties of carbon steel are strongly influenced by the carbon content.

Over the years, various types of carbon steel have been developed, for example, structural and pressure vessel steels. There are only minor metallurgical differences between these types of steel; the important differences are in the quality of the steel (resulting from adherence to tighter specifications).

Figure 2.1-3
Anchoring of Tanks Installed in High Groundwater Tables



Source: Reference 2

There are a number of standards and specifications for carbon steel in various forms, such as in the form of bars, pipe and plate. The American Society for Testing and Materials (ASTM) publishes specifications on many materials of construction including carbon steels. For detailed specifications and chemical analyses, references should be made to these ASTM standards. The American Iron and Steel Institute also issues specifications on a variety of carbon and alloy steels. The American Society of Mechanical Engineers, the American National Standards Institute, and the American Petroleum Institute are also active in the area [14]. For more information on these steel specifications and how they may be obtained, please refer to the list of steel specification references at the end of this chapter.

2. Coated Steel Tanks

Organic coatings may be applied to both the interior and exterior of underground steel tanks. Interior coatings are often called tank linings. In the case of shop-assembled tanks, coatings and linings are generally applied at the factory. The recommendations of the tank manufacturer should be followed when a coating is required since improper selection can lead to early failure and product contamination. When installing the tank, care must be exercised in order to avoid damage to the coating. The properties, compatabilities and costs of common organic coatings are given in Appendix C. Refer to Section D of this chapter for additional information on application of coatings and linings.

3. Cathodically Protected Steel Tanks — Galvanic Protection

As described in Part I, Chapter 1, Section C of this report, cathodic protection is used to reduce or eliminate corrosion of a metallic structure which is in contact with corrosive soil. This is accomplished by applying an electric current to the structure which is greater in strength and opposite in direction to the current that is causing corrosion.

The galvanic cathodic protection method employs sacrificial anodes, composed of materials such as magnesium or zinc, in electrical contact with the metal structure to be protected. These anodes are attached to the surface of the protected material (tank or pipe) in the soil or other electrolytic solution, and the required current is generated by corrosion of the sacrificial anode. A typical configuration for galvanic protection is shown in Figure 2.1-4.

The design of an adequate galvanic protection system requires making a measurement of the soil resistivity. If the amount of electric current required to protect the tank has been determined, the soil resistivity must be known in order to determine the type and size of anode(s) required to protect the tank. The life expectancy of the storage system is also important in determining the number and type of anodes required [22].

Magnesium anodes are the most common type of sacrificial anode, although zinc anodes may be used in soils with resistivities less than 1000 ohm-cm. Magnesium, because of its higher driving voltage, can be used quite effectively in soils with resistivities up to 5000 ohm-cm, and on well coated structures can often be used up to 10,000 ohm-cm or more [10, 12, 27].

In general, because of the low driving voltages of sacrificial anodes (1.1-1.6 volts) and the low electric currents generated (usually less than 100 milli-amperes per anode), it is desirable from both an economic and an engineering standpoint that galvanically protected tanks be coated. Bare tanks require a greater electric current, and hence a larger number of sacrifical anodes than coated tanks.

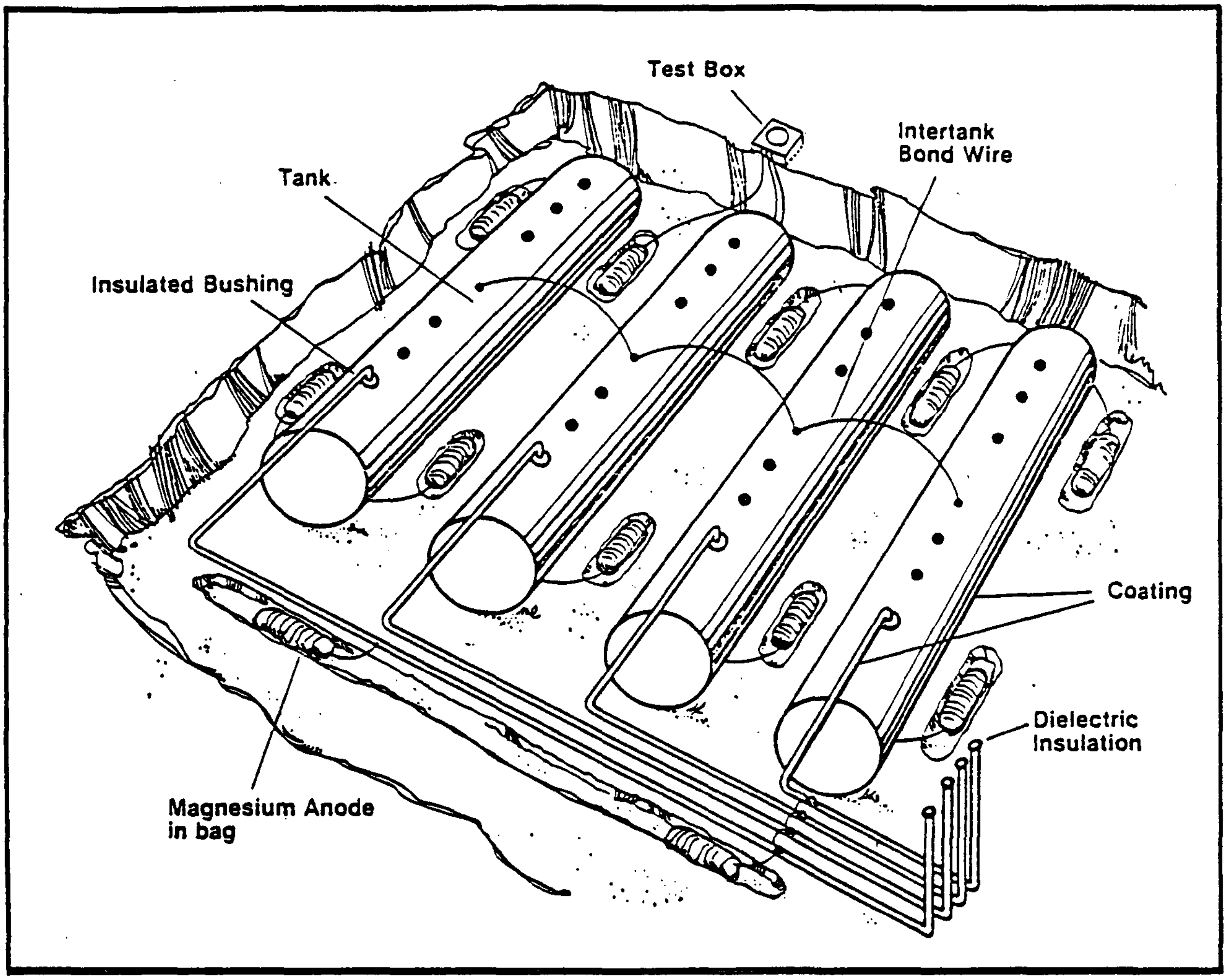
Periodic testing of cathodic protection is essential if the system is to function properly and provide long-term protection. The current from the anodes may fail because of anode deterioration or broken lead wires. Changes in underground conditions (e.g., installation of a water pipe) or coating deterioration can also change protective current requirements. Measurements of tank-to-soil potentials and anode output should be made at least once a year to ensure proper operation of the system [10].

In addition, care must be exercised during the installation of galvanic protection systems to ensure electrical continuity of the system. This means providing bonding wires between tanks when several tanks are installed and across flexible pipe joints, if such joints are used. Screwed piping should not be relied upon to provide electrical continuity.

Examples of pre-engineered, galvanically protected steel tanks include the Sti-P3 tank and the BT-10 tank. Both are standard steel tanks provided with three levels of corrosion protection: cathodic protection, a protective coating and electrical isolation. High-potential magnesium anodes are permanently attached to the heads of each tank to provide a flow of protective current. In the case of Sti-P3 tanks, the anodes are packaged in a special moisture-holding material which improves conductivity and current flow from the anodes. The second protective component in these systems is a coal-tar epoxy or urethane coating. Electrical isolation is the third component of these systems; this protects the tanks against stray currents that could otherwise reach them via piping connections. In those areas where internal corrosion may be a problem, optional construction may include striker plates, internal welding or internal zinc strips which serve as sacrificial anodes. If the product to be stored is not compatible with steel, then an internal lining of compatible material may be applied.

Figure 2.1-4

Magnesium Anode Cathodic Protection
Typical Configuration



Source: *Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping*, The Hinchman Company, Detroit, MI.

4. Cathodically Protected Steel Tanks (Impressed Currents)

The impressed current cathodic protection method employs direct current provided by an external source. This current is passed through the system by the use of non-sacrifical anodes composed of materials such as carbon, non-corrodible alloys, or platinum. These anodes are buried in the ground (in the case of underground structures) or otherwise suspended in the electrolyte and connected to the positive terminal of the external power supply. The tanks and other structures to be protected (e.g., pipes) are connected to the negative side of that power supply [27]. An impressed current system for underground tanks and piping is illustrated in Figure 2.1-5.

Impressed current cathodic protection systems are used extensively at service stations. These types of cathodic protection systems are particularly applicable for storage situations in highly corrosive soils. Because of the large power supply (electric current) provided by these systems, they can be used to protect bare as well as coated tanks [10].

A major advantage of impressed current is that short circuits can be overcome more easily than with sacrifical anode systems [10]. This facilitates installation, particularly when electrical continuity must be insured between two or more tanks. Major disadvantages of these systems are their high power consumption and the greater possibility of electrical interference on foreign structures [10].

As is the case with sacrificial anode systems, periodic testing of the cathodic protection is necessary to ensure proper protection. Current may fail because of rectifier malfunction or interruption of power. The system should be tested regularly in accordance with manufacturer's recommendations and adjusted as needed. At least once a year, tank-to-soil potential measurements should be made to check the adequacy of protection and determine if any rectifier adjustments are needed [10].

5. Fiberglass-Reinforced Plastic

Fiberglass-reinforced plastic (FRP) tanks are widely used for underground storage of flammable and combustible liquids. They are constructed of a plastic resin which provides chemical resistance, and a fiberglass material that gives the tank its structural strength. Insuring compatibility of the tank with the stored product is an important consideration since numerous resins and glass materials can be used in the fabrication of FRP tanks. Most fiberglass tanks are designed specifically for petroleum and its derivatives. However, fiberglass tanks suitable for storage of other chemicals have been developed. The tank manufacturer should be consulted on the selection of a resin which will be compatible with the product to be contained (see Table 1.2-3).

Two techniques are used to fabricate FRP tanks. One technique utilizes a centrifugal casting machine which allows the tank to be made in one continuous piece. The chopped fiberglass is sprayed on the interior of a revolving mold which forms the ribs, shell and hemispheres in one continuous piece. Two identical pieces can be fabricated by this technique and joined together in the middle to form the tank. The other fabrication technique consists of building the tank in alternating layers of resin and fiberglass. This type of FRP tank is usually more costly but is also stronger than the molded tank [13, 15, 29].

Design Standards. As with steel tanks, various standards have been developed by Underwriters Laboratories and the American Society of Testing and Materials for the design and construction of FRP storage tanks. For more information on accessing these standards, please refer to the tank design reference list at the end of this chapter.

In addition to the UL and ASTM standards, FRP tanks to be used in underground applications must adhere to requirements in the following National Fire Protection Association standards:

- NFPA 30: *Flammable and Combustible Liquids Code* [19].
- NFPA 31: *Standards for Installation of Oil Burning Equipment* [28].

Installation Requirements. The installation recommendations for FRP tanks, as listed in API Publication 1615, differ somewhat from those recommendations for steel tanks. Examples of the recommendations made in that publication for the underground installation of FRP tanks include the following:

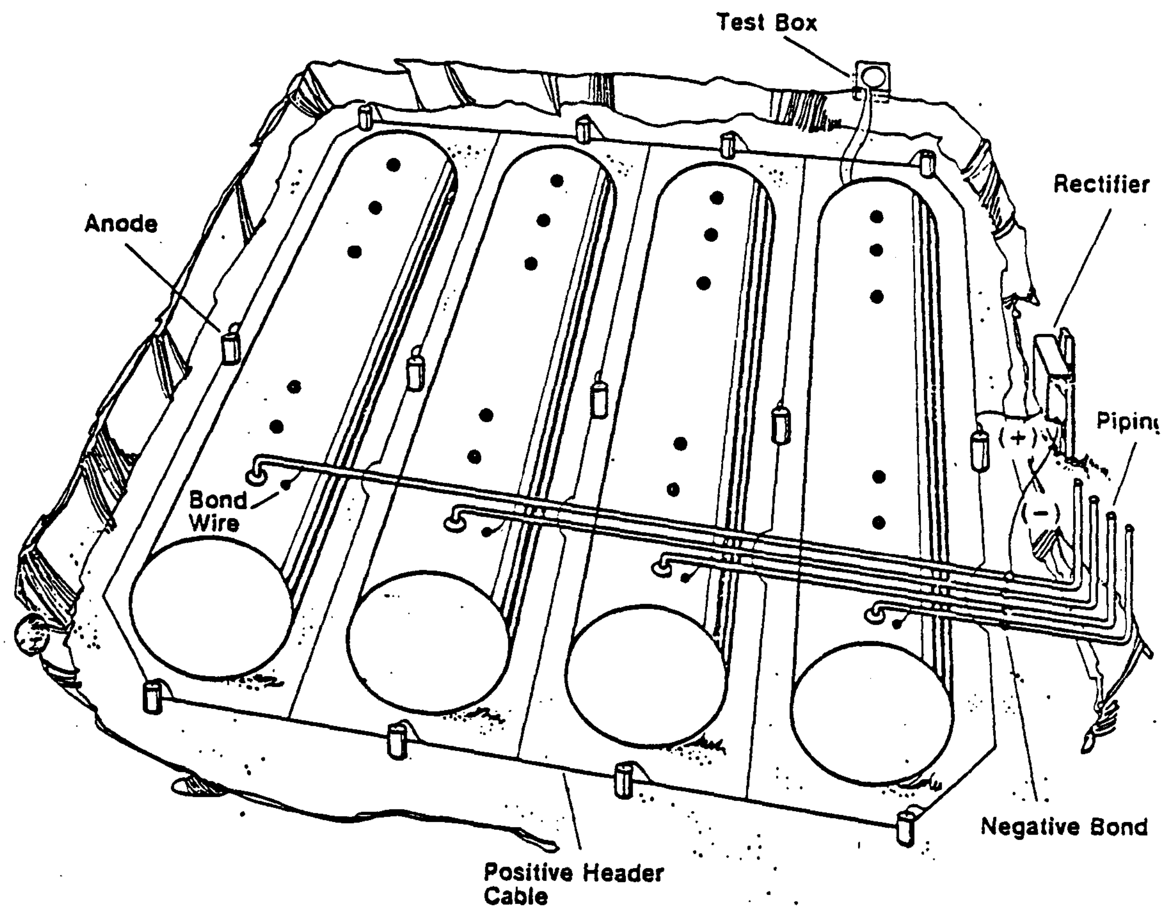
- The tank excavation should provide a minimum clearance in all horizontal directions of 18 inches.
- The excavation should be deep enough to provide at least 12 inches of backfill below the tank.
- A uniformly distributed backfill, which conforms to the tank manufacturer's specifications, must be used. Proper backfilling is essential to the performance of these tanks [1].

As is the case with steel tanks, proper anchoring and ballasting are important aspects of an FRP tank installation in an area of high ground water. Strict adherence to manufacturers installation recommendations and those of API Publication 1615 is important to insure the integrity of the storage facility.

Extreme care must be exercised in the installation of FRP tanks because they lack the structural strength to withstand the high stresses which may be induced during a difficult or improper installation [8]. For more complete information of FRP tank installation, refer to API Publication 1615, NFPA 30, the NYSDEC standards of practive document [30], and the literature of specific FRP tank manufacturers.

Figure 2.1-5

Impressed Current Cathodic Protection
Typical Configuration



Source: *Suggested Ways to Meet Corrosion Protection Codes for Underground Tanks and Piping*. The Hinchman Company, Detroit, MI.

6.FRP/Steel Bonded Tanks

FRP/steel tanks combine the corrosion resistance of fiberglass-reinforced plastic and the strength of steel. They are constructed of an outer layer of FRP fused to an inner layer of carbon steel via a polyester resin bond. FRP/steel tanks are protected against soil corrosion, but remain subject to internal decay from corrosive chemicals [7].

The steel inner structure on an FRP/steel tank provides structural support and serves to keep stresses evenly spread. FRP/steel tanks may be installed in accordance with NFPA 30 and API Publication 1615 guidelines (see sections on bare steel and FRP tanks). Saddles or "chock blocks", which interfere with the proper distribution of the load, should not be used, however. In addition, anchoring, as described in the discussion of steel tanks, should be used to prevent tank flotation from a high water table.

As is true with steel tanks, FRP/steel tanks are compatible with petroleum products, such as gasoline and diesel fuel, and other non-corrosive liquids.

7. Tanks of Other Materials

This group includes tanks made of such materials as stainless steel, aluminum and plastic. Although these materials have a higher resistance to corrosion than carbon steel, their use is overshadowed by that of steel, coated steel and FRP. Plastic tanks, including such materials as polyvinyl chloride (PVC) and polypropylene, are not widely used in underground installations because of their low structural strength, which makes them unable to withstand large structural loads. Aluminum tanks are not widely used because they also lack structural strength, and stainless steel tanks are not widely used because of their higher cost.

8. Double Containment Systems

Several methods of double containment for underground tanks are in use. These include the following.

- Double-walled tanks.
- Concrete vaults.
- Impermeable liners.

Double-walled tanks [4,23]. These tanks are essentially a tank within a tank (jacket) with a vacuum or pressurized space between the inner wall and outer wall. Leaks due to internal or external corrosion can be detected by loss of pressure or vacuum. Product or water detecting probes may also be inserted into interstitial space. Common materials of construction include coated steel and fiberglass. An inner liner may also be specified specified for steel tanks. Because double-walled tanks provide both two wall protection and monitoring of the interstitial (annular) space, they are well suited for storing highly toxic chemicals or for storing materials in sensitive environmental areas.

A double-walled fiberglass tank that is widely used in Europe is illustrated in Figure 2.1-6. This tank is constructed with inner and outer fiberglass shells supported by a concrete bearing wall in between. A built-in leak detection system monitors a vacuum drawn between the inner and outer shells. Products that may be stored in this tank include gasoline, diesel fuel, acid and caustic solutions, and other hazardous substances [4].

Another type of double-walled tank, manufactured in Canada, is fabricated of steel and includes a vacuum leak detection system between the inner and outer walls. This pre-engineered tank system also includes an external epoxy coating and sacrificial anodes to provide corrosion protection. This tank system is shown in Figure 2.1-7 [23].

More and more firms are producing double walled tanks, some with two walls of steel and an outer layer of bonded fiberglass, some with a complete outer shell of steel and epoxy coating, and others with just a double bottom to provide protection where corrosion is usually most severe. The high degree of environmental protection provided means that their usage will be more common in the near future.

Concrete vaults. Concrete vaults (also knows as concrete tanks) are generally used as secondary enclosures intended to contain any spills from the primary storage tank. Concrete vaults tend to crack with freezing and thawing, and are also susceptible to chemical attack by salts and acids. Coatings are often applied to the inside of concrete vaults to enhance their resistance to chemical attack (see Coating Compatibility Chart Appendix B).

Impermeable liners: Impermeable liners may also be used for secondary containment of underground spills. Examples of such liners include the following:

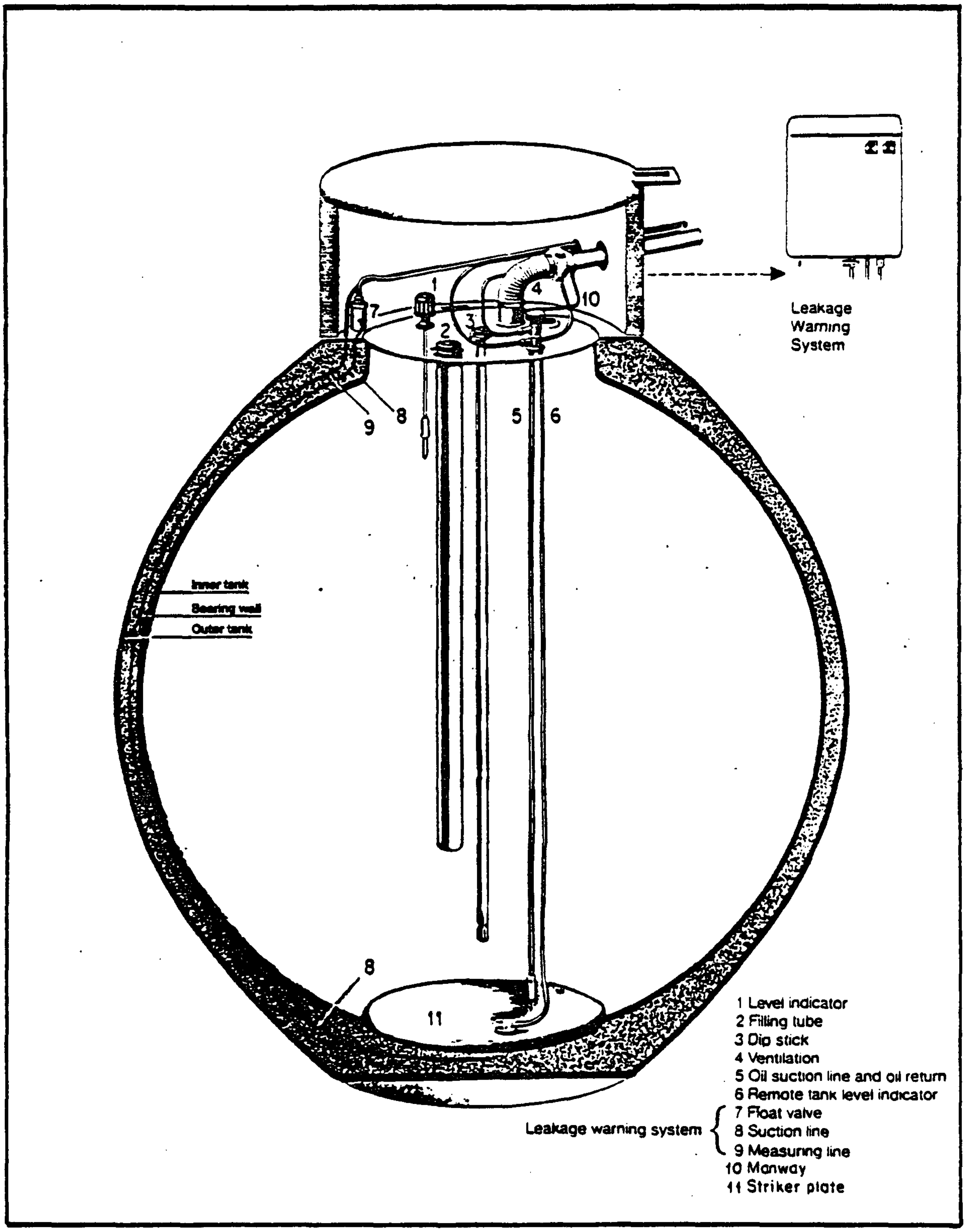
- Membrane liners.
- Clay liners.
- Bentonite (or similar material) liners.

In instances where impermeable liners of these types are used, care must be taken to insure that the lining material is compatible with the material being stored.

Impermeable liner systems should also include a leak detection system located within the confines of the enclosure formed by the liner. These types of systems are discussed in detail in Chapter 3 of this part of the report.

Figure 2.1-6

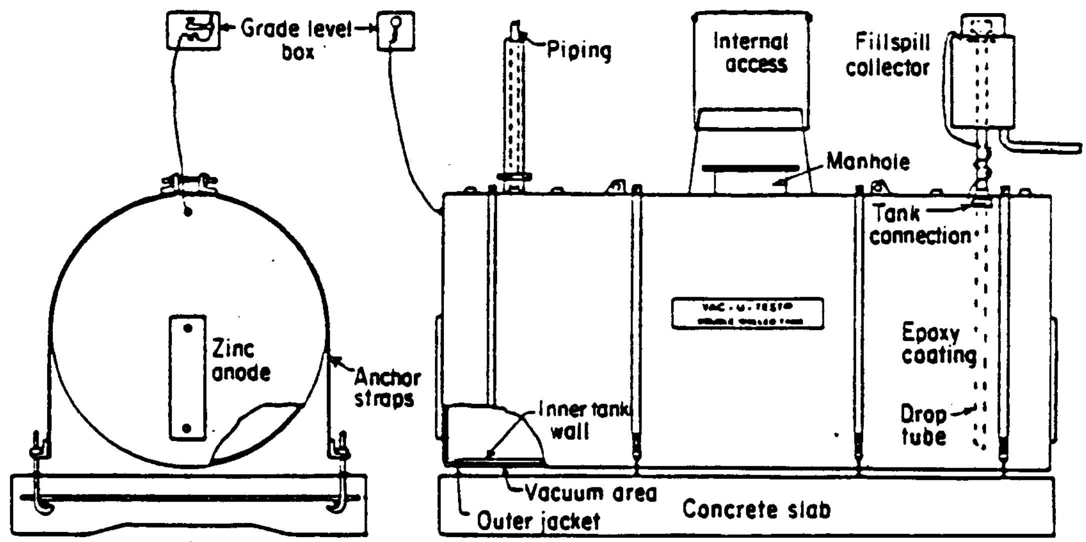
Fiberglass-Reinforced Plastic Double-Walled Tank With Built-In Leak Detection



Source: Betco Associates

Figure 2.1-7

Double Wall Steel Tank with Epoxy Coating and Sacrifical Zinc Anode



Model No.	Capacity Litres	Inside Diameter	Inside Length
1352	5 000	1 600	2 500
1353	10 000	2 000	3 185
1354	15 000	2 500	3 060
1355	25 000	2 500	5 100
1356	35 000	2 500	7 130
1357	50 000	2 500	10 200
1358	50 000	3 600	4 920
1359	75 000	3 000	7 080
1360	100 000	3 600	9 830
1361	125 000	3 600	12 290
1362	150 000	3 600	14 740

Source: Reference 23

9. Relined Tanks

In-place underground steel tanks may be relined internally provided the tank is not badly corroded. This is a widely used practice for extending the useful life of steel petroleum storage tanks. If consideration is being given to the relining of a tank which stores a non-petroleum product, the design engineer should secure assurances that the lining material is compatible with the product to be stored and check government regulations to see whether this practice is acceptable.

Interior relining is possible without unearthing the tank by entering it through a manhole. If the tank is not equipped with a manhole, one must be installed prior to relining the tank [18]. Before entering the tank, however, it must be completely emptied and freed of toxic or flammable vapors. Refer to the discussions in Part II, Chapter 7 and Part III, Chapter 7 for information on the emptying and degassing of tanks. Prior to relining, the existing lining must be completely removed and the tank must be properly prepared. Holes must be plugged and the surface must be sandblasted to etch a pattern for good bonding. Refer to the sections on the selection and application of coatings and linings for specific procedures and considerations. The combination of external cathodic protection with internal lining provides a reasonably low cost safeguard system for existing steel tanks and is useful as a repair technique for a leaking steel tank in generally good condition. The relining work should be done only by qualified specialists.

The following inset describes suitability factors for steel tank relining.

Tank Relining

A steel tank is not normally suitable for interior lining and should be removed or abandoned if it has one of the following:

- A split greater than 3 inches.
- A single hole greater than 1 inch diameter.
- More than 10 small perforations (none larger than ¼ inch diameter).

D. TANK COATINGS AND LININGS

Coatings are those corrosion- and chemical-resistant materials which are sprayed, brushed, or rolled onto the metal surface of a storage tank. Coatings serve one of two main purposes: (1) they protect the metal from attack by a corrosive liquid or environment, and (2) they protect the product from contamination by corrosion products. Coatings may also be applied to concrete vaults. When applied to the interior of a tank, coatings are often referred to as tank linings. Several factors affect the effectiveness and durability of tank linings and coatings. These include the following:

- Proper selection of the coating.
- Preparation of the tank surface.
- Proper application of the coating to the required thickness.
- Proper treatment (curing) of the coating.
- Testing and inspection of the applied coating.

Selection of coating. To insure the compatibility of the lining or coating, it is often necessary to consult with its manufacturer. As a reference tool, the properties of some commonly used linings and coatings are given in Appendix B.

Preparation of the Tank Surface. Steel, and for that matter any surface being coated, should be cleaned of all dirt, grease, moisture and loose powdery contaminants that might interfere with coating adhesion. The best method of steel surface preparation for most coating application scenarios consists of sandblasting all surfaces to be coated to SSPC-SP6 commercial blast. Sandblasting to commercial 6 produces a clean surface with a good profile for adhesion. This combination generally provides for maximum effectiveness of the chemical and physical forces of adhesion between the coating and the metal surface [16,17].

Surface preparation specifications may differ depending upon the type of application to be made, particularly in the case of retrofits and field oriented operations. Various specifications from the Steel Structures Painting Council are listed and described in Table 2.1-4 [16,32].

Coating Application. The following excerpt describes conventional coating and lining technology:

> "The coating system can be applied a number of ways including brushing, rollering and spraying. While brushing, and to a lesser degree rollering, have the advantage of working a coating into a rough or irregular surface, spraying is by far the most common application method.
>
> With conventional air spraying, air is used to atomize and propel the paint onto the surface being coated. The equipment is cheaper than airless equipment. The principal advantages of air spraying are the ability to partially trigger the gun to provide an air blow-down prior to paint application, and a finer atomization resulting in a smoother finish.

Airless spraying utilizes high pressure to hydraulically push paint through a small orifice. Upon going from high to low pressure the paint atomizes in a manner similar to water from a garden hose. The advantages of airless spraying are leading to its ever increasing use in industrial coating work. These include a thicker film with less chance of air entrapment, greater mobility for the painter because there is no air line, less turbulence in the spray pattern, and less chance of contamination with moisture and oils from improperly cleaned field compression equipment." [16]

Newer coating and lining application techniques include electrostatic spraying, powder coating, force drying and electron beam curing. Their advantages and disadvantages are summarized in Table 2.1-5.

Personnel safety is an important consideration in coating and lining application. In most instances, respirators should be worn as a minimum during application operations.

Table 2.1-4

Surface Peparation Specifications

Specification and subject		Purpose
SSPC-SP 1,	Solvent Cleaning	Removal of oil, grease, dirt, soil, salts, and contaminants by cleaning with solvent, vapor, alkali, emulsion or steam.
SSPC-SP 2,	Hand Tool Cleaning	Removal of loose rust, loose mill scale, and loose paint to degree specified, by hand chipping, scraping, sanding and wire brushing.
SSPC-SP 3,	Power Tool Cleaning	Removal of loose rust, loose mill scale, and loose paint to degree specified, by power tool chipping, descaling, sanding, wire brushing and grinding.
SSPC-SP 4,	Flame Cleaning of New Steel	Dehydrating and removal of rust, loose mill scale, and some tight mill scale by use of flame, followed by wire brushing.
SSPC-SP 5,	White Metal Blast Cleaning	Removal of all visible rust, mill scale, paint and foreign matter by blast cleaning by wheel or nozzle (dry or wet) using sand, grit or shot. (For very corrosive atmosphere where high cost of cleaning is warranted.)
SSPC-SP 10,	Near-White Blast Cleaning	Blast cleaning nearly to White Metal cleanliness, until at least 95% of each element of surface area is free of all visible residues. (For high humidity, chemical atmosphere, marine or other corrosive environment.)
SSPC-SP 6,	Commercial Blast Cleaning	Blast cleaning until at least two-thirds of each element of surface area is free of all visible residues. (For rather severe conditions of exposure.)
SSPC-SP 7,	Brush-Off Blast Cleaning	Blast cleaning of all except tightly adhering residues of mill scale, rust and coatings, exposing numerous evenly distributed flecks of underlying metal.
SSPC-SP 8,	Pickling	Complete removal of rust and mill scale by acid pickling, duplex pickling or electrolytic pickling. May passify surface.

Source: Excerpted by special permissin for *Chemical Engineering*, December 4, 1972, Copyright (c) 1972, by McGraw-Hill, Inc., New York, N.Y. 10020.

Proper Treatment of the Coating. Proper treatment (curing) of the coating surface is an important step in the coating application procedure. There are numerous coatings available to protect steel and other metals with curing requirements varying from baking at temperatures on the order of 400°F to force drying at temperatures slightly above ambient. The proper curing or drying procedure for the various coating materials is specified in manufacturers' application instructions [17].

Testing and Inspection of the Applied Lining or Coating. After the coating is installed, it is the general practice to inspect its thickness and integrity. There are a variety of field instruments used to measure coating thickness and porosity after the coating has been applied and cured. These include dry gauges, such as the magnetic and semi-destructive scratch gauges, and the wet gauge known as the comb type gauge. Low voltage pinhole detectors (spark tests) may also be used to detect small imperfections in the coating. Other instruments that may 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 [16].

Table 2.1-5

Latest Coating Techniques

Electrostatic Spraying—An electric charge is applied to the paint by the spray gun. The charged paint particles are attracted toward the grounded object being coated, depositing at points of maximum electrostatic attraction (thin areas). Can be combined with air and airless spray methods.

Advantages: *Minimizes overspray, has "wrap-around" effect, edges and protruding irregularities receive heavier coatings.*

Disadvantages: Requires electric source, electrostatic attraction diminishes as paint thickness increases; water base paints, or those using highly polar solvents or containing metallic pigments may be too conductive to be applied by electrostatic spray. The object being coated must be grounded and electrically conductive.

Powder Coating—Coating resins in powder form that are applied by electrostatic spray, fluidized bed or other methods. The coated object is heated, melting and sintering the powder to form a continuous coating.

Advantages: Insoluble resins can be applied such as polyethylene, polypropylene, nylon and fluorocarbons, as well as other thermoplastic resins. Either thick or thin coatings can be applied in one application. The object can be handled immediately upon cooling.

Disadvantages: Powdered materials present health and explosion hazard unless proper precautions are taken; expensive.

Force Drying—Heating of coated object after application to accelerate drying or rate of coating cure. Ventilation system prevents solvent escape into atmosphere. Dry time to topcoat or handle shortened. However, expensive to install and operate.

Electron Beam Curing—Recent innovation in which electrons are accelerated through a vacuum and directed toward *object coated by conventional means with a coating capable* of being crosslinked. The electron beam excites the reacting molecules, completing crosslinking and cure within seconds.

Advantages: Rapid handling and cure times, less solvents in paint.

Disadvantages: Cost; only a few coatings can be crosslinked at present (polyesters and acrylics); coatings in excess of seven mils cannot be cured.

Source: Excerpted by special permissin for *Chemical Engineering*, December 4, 1972, Copyright (c) 1972, by McGraw-Hill, Inc., New York, N.Y. 10020.

E. WRAPPINGS

Another method of corrosion protection involves the application of polyethylene as a loose wrapper around the tank. Wrappers act as exterior coatings which minimize the possibility of contact between the metal and the soil. Wrappers have the advantage that they are an inexpensive method of corrosion protection; however, the initial savings must be weighed against long-term economics and effectiveness. Wrappers are difficult to install properly and are frequently ineffective; they may actually trap moisture on the tank surface and thus lead to accelerated corrosion [10].

The life expectancy and performance of a wrapper depends upon several factors, including the following:

- Its incompatibility with the surrounding soil.
- Its incompatiblity with the liquid stored if the wrapper is exposed to that liquid.
- The wrapper thickness.
- The care taken to avoid tearing during its installation.

Some oil companies have reported extended tank lives attributable to polyethylene wrappers, but to date there is insufficient long-term experience to formulate a solid judgement regarding their effectiveness [10].

Information on Specifications for Tank Materials and Construction

Carbon Steel

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

American Society of Mechanical Engineers
345 East 47th Street
New York, NY 10017

American National Standards Institute
1430 Broadway
New York, NY 10018
Information on standards and specifications of the Canadian Standards Association and the International Organization for Standardization may also be obtained from ANSI.

American Petroleum Institute
2101 L Street, N.W.
Washington, D.C. 20037

American Iron and Steel Institute
1000 Sixteenth Street, N.W.
Washington, D.C.

American Welding Society
2501 N.W. Seventh Street
Miami, FL 33125

National Association of Corrosion Engineers
1440 South Creek
Houston, TX 77084

Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062

National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

Steel Tank Institute
666 Dundee Road
Northbrook, Illinois 60062

Fiberglass-Reinforced Plastic

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062

National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

Tank Relining – Surface Preparation

Steel Structures Painting Council
4400 5th Avenue
Pittsburgh, PA 15213

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Part II
CHAPTER 2: UNDERGROUND PIPING SYSTEM

A. INTRODUCTION

The components of a piping system for an underground storage facility, as shown in Figure 2.2-1, include pipe, valves, pumps, and their associated connecting joints and fittings. These components represent a major potential source of leaks from underground storage facilities. Such leaks may occur due to: (1) corrosion; (2) physical breakage; or (3) loose connections attributable to wear or improper installation.

This chapter addresses the causes and methods of preventing product leaks in the piping system of an underground storage facility. The discussion focuses on the types of piping, pumps, connecting joints and fittings which are unique to underground (buried) service. Piping systems described here are typical of those found in the petroleum industry. Those components which are usually located aboveground or in accessible locations, such as valves and large pumps, are discussed in Part III of this report.

B. CAUSES AND METHODS OF PREVENTING LEAKS

The major causes of leaks from the piping system are deterioration of piping system components and improper installation of these components. The deterioration of piping system components can occur for any one of several reasons: the most common of these, particularly in the case of metal components or parts, is corrosion, which has been discussed in detail in Part I. Other reasons included the following:

- Mechanical failure (physical breakage or rupture), such as the failure of valves or valve seals, pumps, or the gaskets in fittings.
- Cracks in piping or connecting joints. These could result from settlement or earth movement, vibration, or unrelieved stress concentrations.

Many leaks have also been traced to improper handling and installations practices, such as the following:

- The improper connection of system components.
- The improper installation of bedding and foundations for underground piping.
- Structural damage to piping, pumps, etc. during transportation and installation.
- Corrosion when impressed current cathodic protection is improperly bonded to the system.

Underground piping leaks can be prevented through the following:

- Proper design (selection of materials, component sizing, etc.)
- Proper installation.
- Proper testing.
- Timely replacement.

1. Proper Design

The design and selection of appropriate components for a particular piping system depends upon the intended use of those components. The items that must be considered include those listed in Table 2.2-1. In short, piping system concerns in underground applications focus on: (1) physical strength of the components; (2) ability to handle the required volumes (flow rates); and (3) ability to withstand such phenomena as internal and external corrosion, thermal loadings due to freezer-thaw cycles, and the physical loads caused by surges of liquid flow.

2. Piping System Installation

Faulty installation of pipe and pipe fittings is a major cause of leaks and spills at liquid storage facilities. The following is a list of important considerations during underground pipe installation:

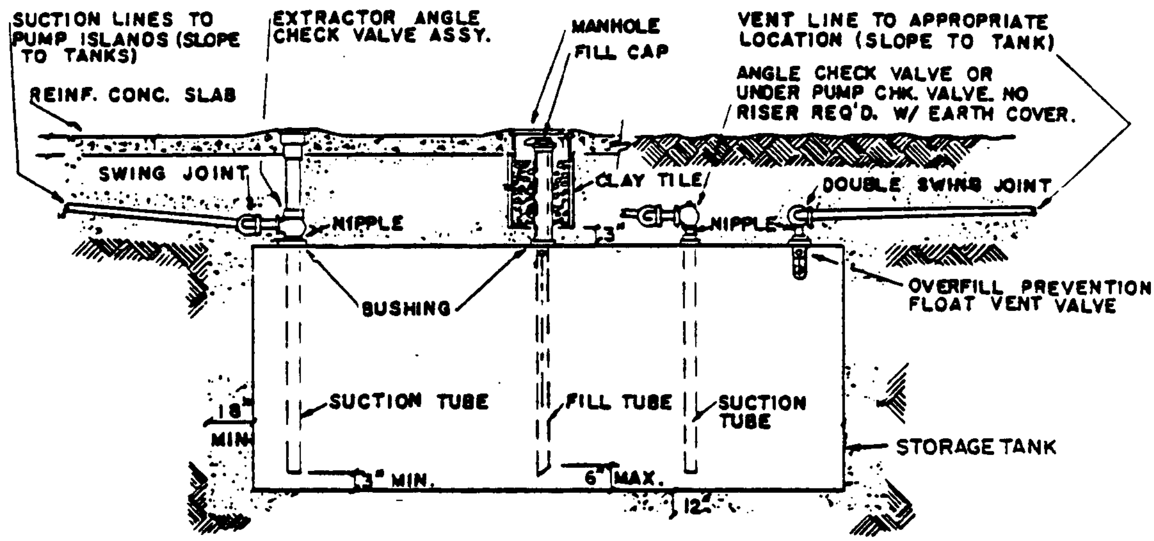
Table 2.2-1

Important Criteria in the Design of Piping System Components

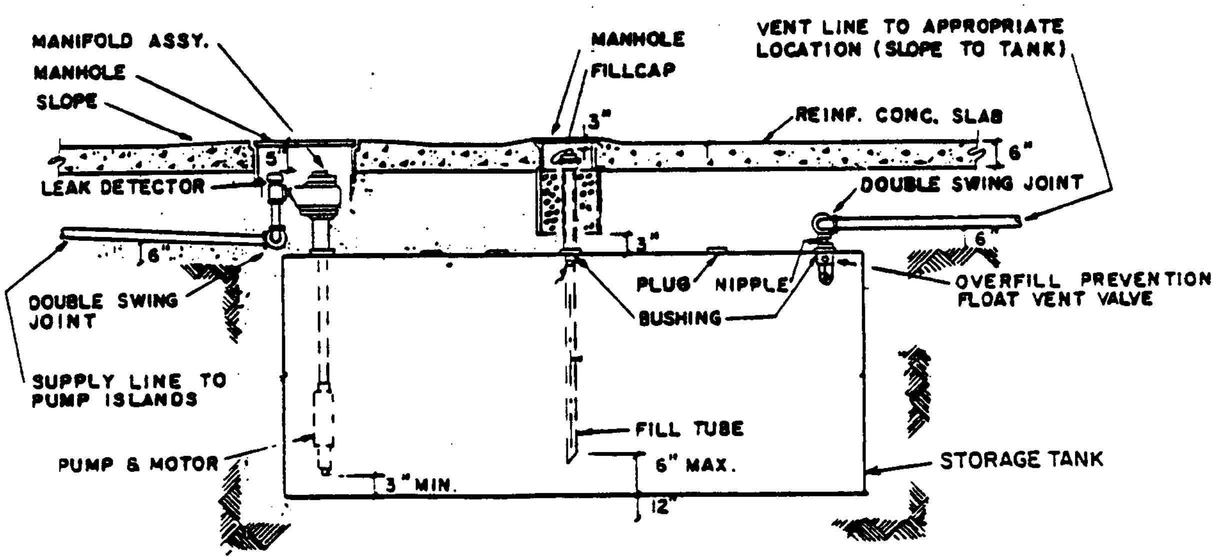
- The type of service (transporting liquid, vapor or slurry).
- The (corrosive) characteristics of the material to be transported, and the ability of piping system components to withstand that corrosion.
- The volume of material to be transported.
- The extent to which surges in flow are expected or likely.
- The characteristics of the soil or other atmosphere to which the piping system components are exposed.

Figure 2.2-1

Piping Systems for Underground Storage



SYSTEM WITH SUCTION PUMPING



SYSTEM WITH SUBMERGED PUMP

Source: API Publication 1615, *Installation of Underground Petroleum Storage Systems*, 1979.

- Product lines should be run in a single trench between the tank area and their destination. The same is true for underground vent lines. This will facilitate access to the piping system for repairs or replacement of components.
- Before any underground lines are laid, the trench or ditch for underground piping should receive a minimum 6 inch-deep bed of well-compacted noncorrosive (i.e., provides less corrosive environment than most native soils) material, such as clean, washed sand or gravel. All trenches should be wide enough to permit at least 6 inches of such protection around all underground lines. This applies to both metallic and nonmetallic underground piping. Bedding and the covering backfill should be of the same material. Providing bedding and covering in this manner serves two purposes: (1) it provides proper structural support for the pipe; and (2) it provides a less corrosive environment for metallic piping system components than most native soils.
- Piping should be arranged so that lines do not cross over underground tanks. This will minimize the possible creation of electrical connections between pipes and tanks which could accelerate corrosion. Pipe connections to tanks should be through insulated bushings.
- Underground product lines should have a minimum cover of 12 inches for adequate protection from the loads of surface traffic.
- Careful attention must be paid to the tightness of all joints and pipe fittings. Tightness should be tested (e.g. all joints and piping should be soap tested) before covering the pipe.
- The possible breakage of underground piping, or the loosening of pipe fittings resulting in product leaks, can be minimized through the use of swing joints. Swing joints, which are described later in this chapter, provide for movement at pipe connections without putting stress on the pipe. These types of joints should be installed in lines at the points where piping connects with underground tanks and where the piping ends at pump islands and vent risers. Fiberglass piping, which is inherently flexible, does not require swing joints if at least 4 feet of straight run is provided between any directional change exceeding 30 degrees.
- The actual location of pipe should be noted on as-built drawings, especially if there is a change from facility design drawings. Photographs of underground piping are also desirable as part of the permanent record of piping locations. Pipe location records of these types minimize the likelihood of pipe breakage accidents during future excavation at the storage facility.
- Product lines and vent lines should have a uniform slope toward the tank of not less than ⅛ inch per foot. This facilitates pipe drainage and avoids sags or traps in the line in which liquid can collect. Sloping is very important in insuring tight check valve and proper leak detection operation.

More information and direction on pipe installation practices can be found in API Publication 1615 [2].

3. Periodic Testing

Periodic testing of underground piping system components is also an important aspect of any leak/spill prevention program. Inasmuch as leaks in piping systems can occur in inaccessible (buried) pipe lengths and joints because of corrosion, thermal stresses and mechanical stresses, periodic testing is an important means of incuring safety and reliability.

Underground piping systems may be tested using the Kent-Moore Test as well as other types of tests. These testing techniques and their accuracy are described in Chapter 6 of this part of the report.

The required frequency of piping system testing will vary depending upon the severity of service, available historical data, and local regulatory requirements:

- Testing will be more frequent when high rates of internal or external corrosion are expected due to the nature of the stored products or the soil in which the piping system is buried.
- If the performance history of underground tanks or piping in the area indicate the likelihood of rapid deterioration of buried components, testing will be more frequent.
- The frequency of testing of underground tanks and piping may be mandated by law. OSHA regulations require submerged transfer pump piping tests at five year intervals.

4. Timely Replacement

Equally important in an adequate leak prevention program is the repair and/or replacement of deteriorated or damaged pipe prior to the occurrence of a leak or spill. Piping should always be of sufficient thickness and integrity to withstand normal working pressures due to fluid flow as well as the stresses caused by mechanical loading, hydraulic surge pressures, thermal expansion and contraction, and other conditions which can impose stresses on piping. When the pipe wall thickness or structural integrity of the pipe joints, connections, etc. approach a point at which these stresses cannot be withstood, that piping should be replaced.

Underground metallic piping at a storage facility should be replaced when metallic underground storage tanks are replaced to avoid accelerated corrosion in the new tanks; such accelerated corrosion could result from a reaction between the older pipe and the newer tank (see discussion of corrosion in Part I).

C. TYPES OF PIPING

There are a wide variety of types of piping commercially available. Those that are extensively used for underground applications include the following:

- Carbon steel.
- Stainless steel.
- Plastic.
- Fiberglass-reinforced plastic.
- Galvanized steel.
- Other composites, such as rubber-, plastic-, or epoxy-lined steel.

These types are typically used in sizes ranging from 1 to 4 inches in diameter, although larger pipe may be used in certain applications, such as at large bulk storage facilities. Data describing the chemical compatibility, and the advantages and disadvantages of the types of pipe listed above are summarized in Table 2.2-2.

In handling very hazardous or toxic liquids there are double walled pipes available. One type consists of an outer wall enclosing several pipes of smaller diameter. This whole ensemble is contained by a bulkhead at the end of each segment. The interstitial space of the outer wall is slightly pressurized with nitrogen. The inner pipes are filled with nitrogen at a higher pressure. With this configuration, pipe runs can be checked for leakage. A drop in pressure indicates leakage in the outer wall. A rise in pressure shows a leak in one of the inner pipes. See figure 2.2-2.

D. FITTINGS

Fittings are the connecting links of the piping system. This includes pieces of pipe that perform the following functions:

- Join two pieces of pipe, as do couplings and unions.
- change pipe direction, such as is the case with elbows and tees.
- Change pipe diameter, as do reducers.
- Terminate a pipeline, such as is the case with plugs and caps.
- Join two streams to form a third, as is the case with tees, wyes and crosses.
- Allow for pipeline directional flexibility, as do swing joints (or swivel joints) and expansion joints.

As stated earlier, fittings are frequent locations of piping system failure due to improper installation, mechanical stress, or wear. To insure proper operation, these components should be installed carefully and tested periodically.

E. EXPANSION JOINTS AND SWING JOINTS

Expansion joints and swing joints are used to add directional flexibility to pipelines, thereby preventing the building up of potentially destructive stresses. As shown in Figure 2.2-3, expansion joints typically consist of a flexible bellows jointed to pipe at each end. These types of joints can be designed for axial movement, lateral movement, or a combination of axial and lateral movement (see Figure 2.2-4). The most common types of expansion joints are rubber reinforced with steel rings and flexible corrugated metal bellows.

Expansion joints are used in piping systems for the following purposes:

- Prevent stresses. Piping systems expand and contract with temperature changes; an expansion joint compensates for this movement.
- Eliminate vibration and noise. Pumps, compressors, engines and pressure surges in pipe lines create vibration and objectionable noises.
- Compensate for misalignment. Piping and mechanical equipment often move out of normal alignment during operation due to wear, load stresses or settling of buildings and foundations.
- Reduce flange breakage. Undue stress caused by misalignment, vibration, expansion or contraction will break metal connecting flanges.

Note that there is a potential for leaks from expansion joints because the repeated flexing of the joint will eventually cause the joint to fail. To prevent this occurrence, the joint should be periodically tested (piping system tests) and, where accessible, inspected. They should not be used unless they are inspectable.

Swing joints or swivel joints are employed to provide rotational flexibility to a pipeline. As shown in Fig. 2.2-5, they may be designed to provide one, two, or three planes of rotation. These types of joints are used primarily to prevent torsional stresses in pipelines, thereby reducing the likelihood of flange or pipeline failure. Swivel joints, however, must be protected so that no dirt can enter the area of the bearing or bearing race.

F. UNDERGROUND PUMPS

The types of pumps used at underground storage facilities are typically submersible pumps or suction pumps. Suction pumps are located at grade, either directly above the storage tank or, as is the case in some dispensing operations, at some distance from the storage tank. Suction pumps may be either centrifugal, rotary or reciprocating pumps. The differences between these types of pumps and the concerns associated with their operation are addressed in Part III, Chapter 2, and in references such as the *Chemical Engineers' Handbook* [3].

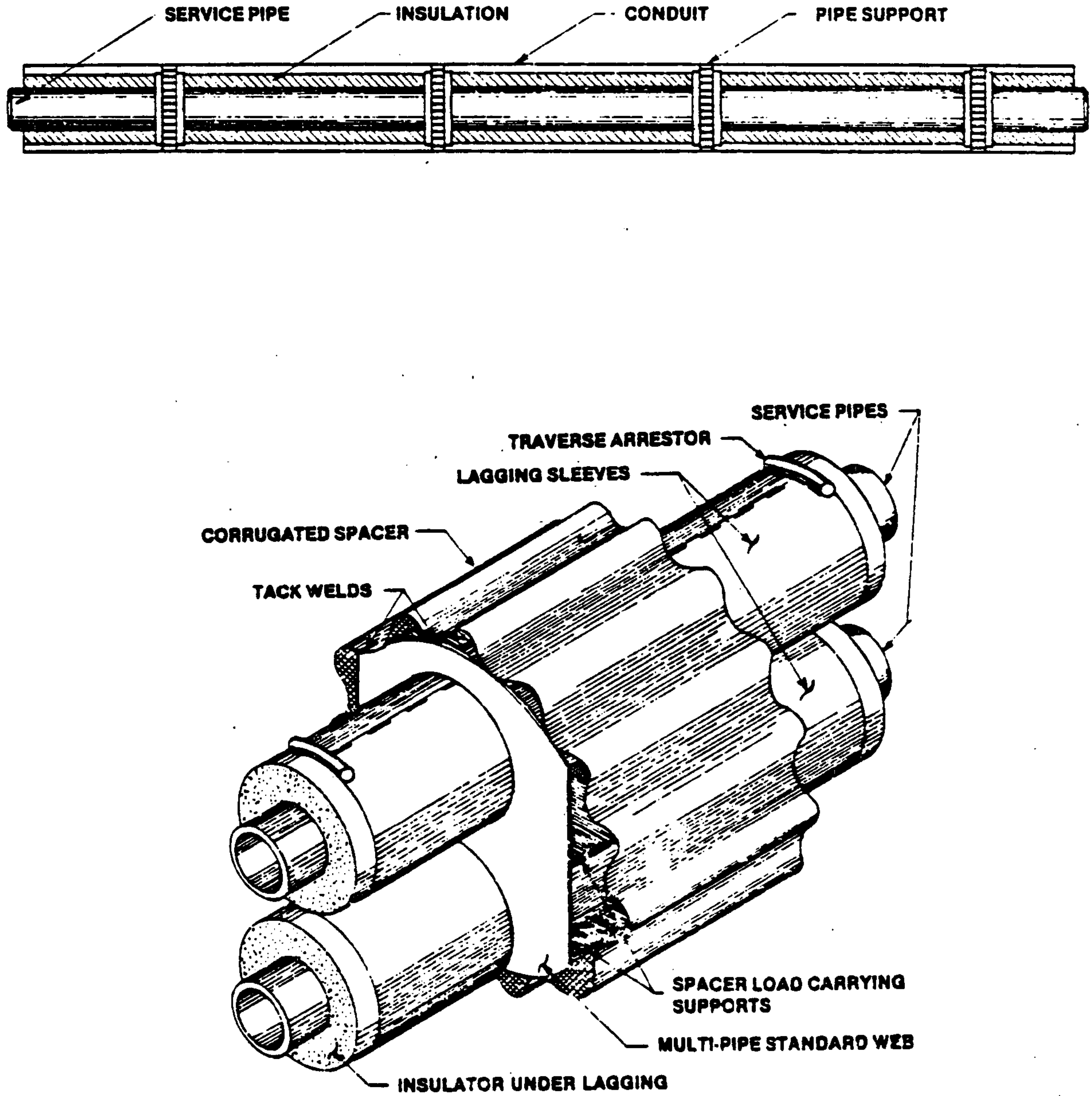
Table 2.2-2

Characteristics of Piping Materials for Underground Service

Type of Pipe	Chemical Compatibility	Remarks
Carbon steel	Compatible with petroleum products but not compatible with corrosive chemicals such as acids without coatings.	Susceptible to corrosion if not coated. galvanized or cathodically protected. Relatively inexpensive. Galvanized steel is used extensively at service stations and other petroleum industry applications.
Stainless steel	Compatible with petroleun and corrosive chemicals, such as acids, depending on grade.	Used when product purity is of great concern. High relative costs. Primarily used for corrosion protection when coatings will not suffice (e.g. at high operating temperatures).
Cast iron	Resists corrosive attack by natural or neutral waters and neutral soils as well as atmospheric corrosion. Resistant to concentrated acids (nitric, sulfuric and phosphoric as well as alkaline and caustic solutions. Dilute acids and acid-salt solutions will attack this material.	Low relative cost. Provides more metal for less cost than steel piping systems. Brittle - has poor resistance to impact or shock. More widely used for non-hazardous service (e.g., water) than for hazardous chemicals service. Widely used for low pressure service where corrosion causes extensive loss of metal.
Plastic tube and pipe	Various plastics can be chosen for their resistance to specific chemicals. For example: Polyethylene pipe and tubing have excellent resistance to salts, sodium and ammonium hydroxides, and sulfuric, nitric and hydrochloric acids. Polyvinyl chloride pipe and tubing have excellent resistance at room temperatures to salts, alcohol, gasoline, ammonium hydroxide, and sulfuric, acetic, nitric, and hydrochloric acids; may be damaged by ketones, aromatics and some chlorinated hydrocarbons. Polypropylene pipe and tubing having excellent resistance to most common organic and mineral acids and their salts, strong and weak alkalies, and many organic chemicals.	Free from internal and external corrosion. Do not cause galvanic corrosion when coupled to metallic material. Allowable stresses and temperature limits are low. Low structrual strength when compared to steel. Plastics are suitable for underground service when UL-approved for the product being carried by the pipe.
Plastic lined piping	Same as plastic tube and pipe above.	Combines the chemical resistance of the various plastics and the tensile and structural strength of steel.
Fiberglass and fiberglass-reinforced pipe	Compatible with a wide range of petroleum and chemical products. See chemical compatibility chart in Part II, Chapter I.	Less structural strength than steel. High resistance to external and internal corrosion. Suitable for underground piping when UL approved for the product being carried.

Figure 2.2-2

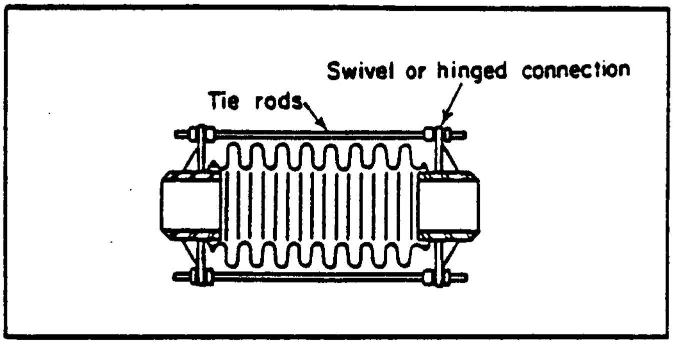
Double Walled Pipe



Source: Perma-Pipe, division of Midwesco, Inc.

Figure 2.2-3

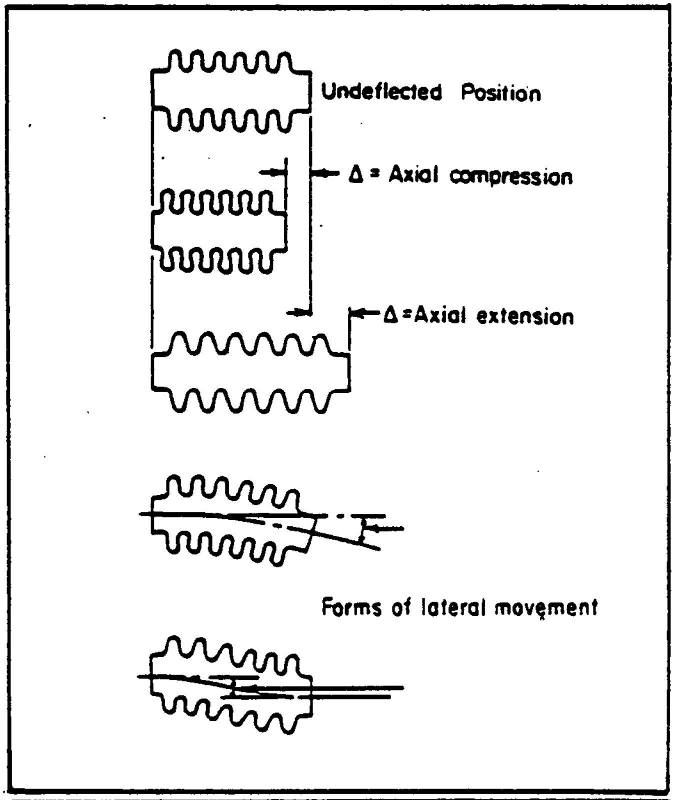
Diagram of a Universal-Type Expansion Joint



Source: From *Chemical Engineers' Handbook*, Perry, R.H. and Chilton, C.H., Copyright (c) 1973, McGraw-Hill, Inc. Used by special permissionof McGraw-Hill Book Company.

Figure 2.2-4

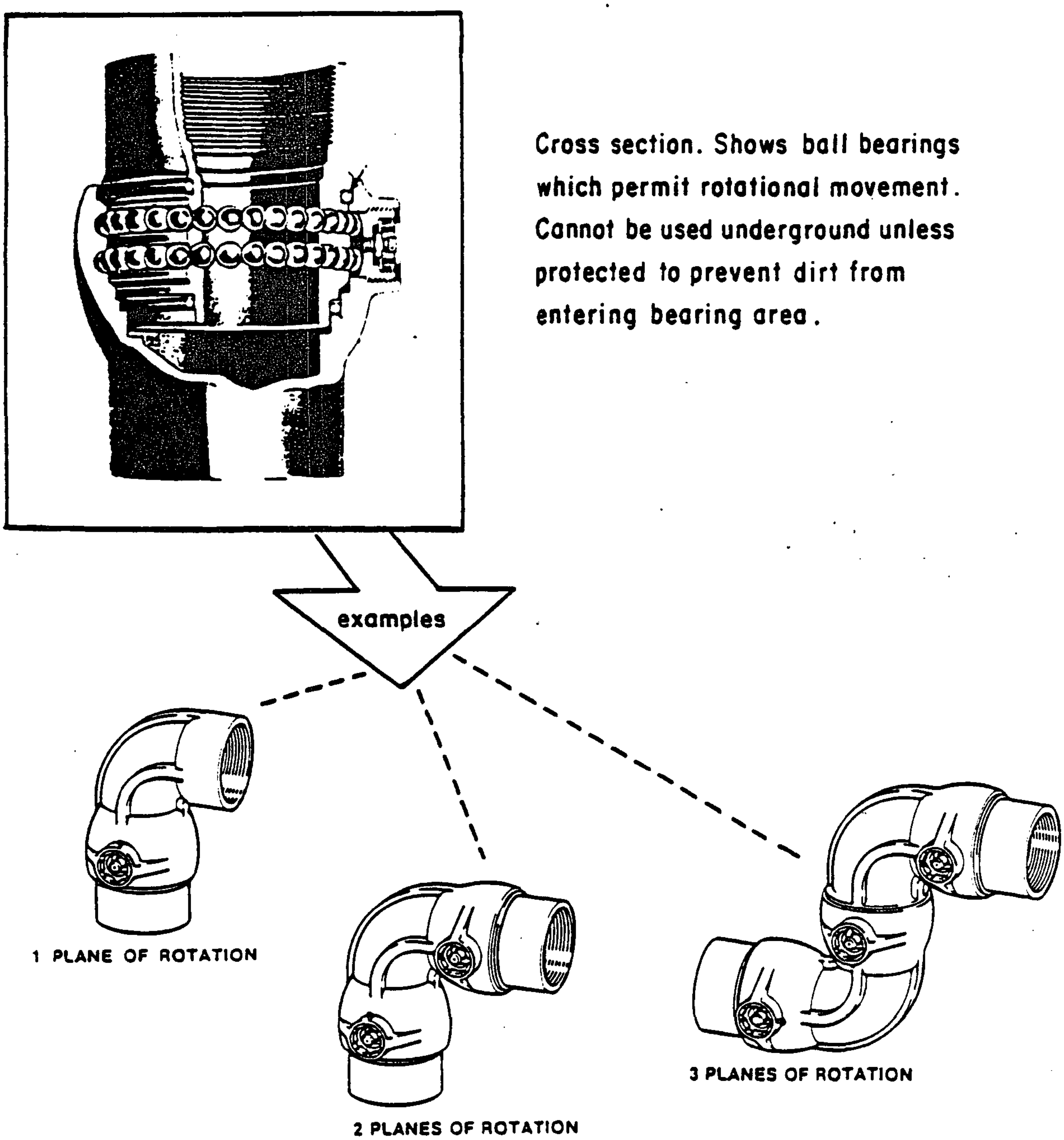
Action of the Bellows of an Expansion Joint



Source: From *Chemical Engineers' Handbook*, Perry, R.H. and Chilton, C.H., Copyright (c) 1973, McGraw-Hill, Inc. Used by special permissionof McGraw-Hill Book Company.

Figure 2.2-5

Swing or Swivel Joints



Source: *OPW Division/Dover Corp.*

The submersible pump (submerged transfer pump) system works on the principle of positive pressure to push the liquid from a low point to a high point. Unless there is a leak line detector in the system or the leak is large, loss of product will not be detected until considerable volume has been lost. A suction pump system works because of a vacuum at the high end which draws liquid from the low end. A large leak in the system would result in lack of suction and an immediate indication of trouble. A small leak would result in drainage of the pipe overnight and a lack of prime in the morning which would cause the system to be inoperative. A check valve under the product dispenser might hold enough product to reprime the pump but such a system should be discouraged because it would mask a line leak.

Submersible pumps are mounted inside the tank; they are centrifugal pumps closely coupled with an electric motor that can operate when submerged. These types of pumps may be commonly used in situations such as gasoline service stations.

When suction pumps are used, leaks in the pump delivery line that result in significant losses of product can be detected through a loss of pump suction, resulting in inefficient or poorer pump operation. When such a situation is encountered, operations should be halted until the source can be identified and corrective action taken.

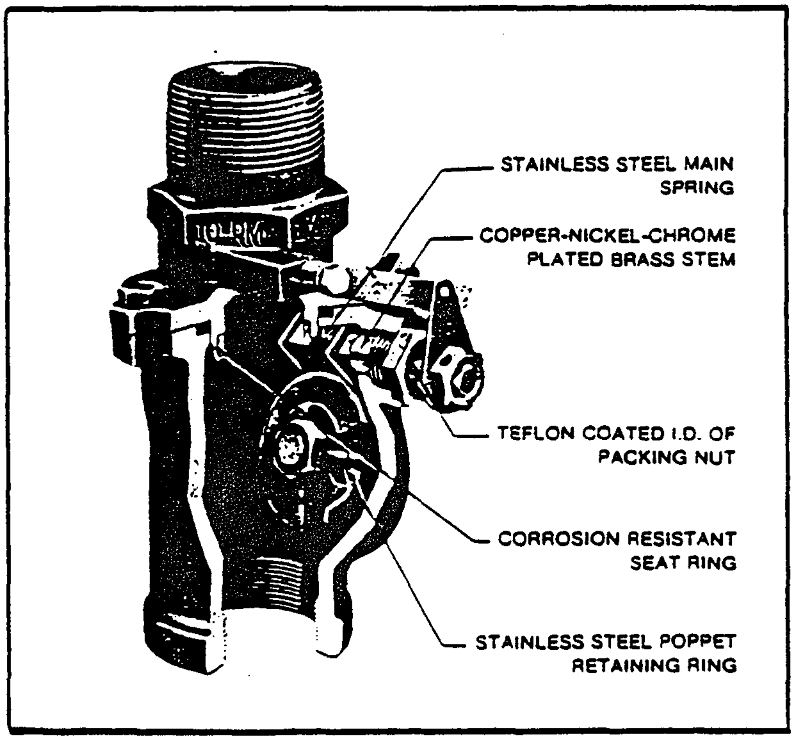
In the case of submerged pumping systems, leaks in the product delivery line can be detected through the use of product delivery line leak detectors. These devices are mounted immediately above the tank on the pump delivery line as shown in Figure 2.2-1; they are designed to detect losses of pressure in the product delivery that do not correspond to decreases in the discharge pressure of the submerged pump. Such a loss of pressure in the product delivery line indicates a loss of liquid in that line before it reaches the discharge point of the pipeline.

Another device recommended (actually required by NFPA 329) for use in submerged pumping systems or remote pumping systems, is a remote pump shut-off valve. In service stations these valves are located at the base of the dispensers. Should the dispenser be overturned, due to bumping or impact, the valve automatically closes, preventing extensive product spillage. These valves also contain a fusible link which closes the valve upon exposure to excessive heat or fire. A cross-section of a remote pump shut-off valve is shown in Figure 2.2-6.

Systems are also available that automatically shut off pipe flow in case of a drop in pressure or a difference of input compared to outflow.

Figure 2.2-6

Typical Remote Pump Shut-Off Valve



Source: *OPW Division/Dover Corp.*

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Part II
CHAPTER 3: UNDERGROUND SPILL CONTAINMENT SYSTEMS

A. INTRODUCTION

1. Background

Underground spills or leaks can range in severity from a minor leak at a pipe joint or tank wall to a catastrophic tank rupture that spills the entire tank contents into the ground. The largest spills come from sizeable leaks that go undetected for years. Regardless of the severity of the incident, the resulting impacts in terms of soil and groundwater contamination are highly undesirable and should be avoided. The steps which can be taken to prevent long-term and widespread contamination of the soil and ground water include the following:

- Leak prevention and early detection practices such as good housekeeping, inventory control, and monitoring of the immediate storage area.
- Containment of the storage area.
- Removal of contaminated soil or groundwater before extensive spreading of the contaminant.

Good housekeeping is an important aspect of any leak prevention program. Many incidents occur due to carelessness and sloppy housekeeping, practices which should not be tolerated. Good housekeeping practices were addressed in Part I of this report.

Early warning leak detection practices such as inventory monitoring and tank excavation monitoring form the first line of defense against extensive soil and groundwater damage due to leaks. These techniques are discussed in detail in Chapter 5 of this part of the report.

Undergound spill or leak containment systems represent the second line of defense agaist propagation of soil or groundwater contamination. They can also act to enhance the effectiveness of early warning leak monitoring systems by confining the leak or spill until detection is possible.

The removal of contaminated soil and groundwater represent the last line of defense against widespread contamination. Practices such as extensive soil excavation for disposal, or the use of recovery wells to remove contaminated groundwater fall into this category and are drastic and relatively expensive steps. In addition, actions of this type are not always completely successful. For example, it may be impossible to remove all of a contaminant from a groundwater if it has spread extensively or become thoroughly mixed in the groundwater table. Recovery wells are discussed briefly in Part II, Chapter 5 of this report.

2. Containment Technology

The control technology used to contain underground spills and leaks consists of establishing a barrier around the storage tank so that any leaked liquid does not have a free path to escape from the storage area. The barrier materials used for containment include the following:

- Liners with low soil permeability (clay).
- Synthetic membrane liners.
- Soil sealants, such as soil cement or bentonites.
- Concrete vaults.
- Double-walled tanks.

It is important to include a liquid removal and monitoring system as part of secondary containment. The containment floor should be sloped to a sump from which a sample can be taken for analysis to determine if product is leaking from the tank. If the secondary containment does not have an impervious cover, accumulated rainwater which percolates to the liner should be removed by siphoning, pumping or via an underground drainage system. In fact some water will probably collect above the containment liner even with an impervious cover. Such water should be considered as contaminated and should receive proper treatment after being drained off.

Selection of the proper containment material for a particular application depends upon several factors, including:

- The type of material being stored.
- Local environmental conditions.
- Legislative requirements.

Type of Material Being Stored. Consideration of compatibility with the liquid being stored is important: the liner material must be able to maintain its integrity and impermeability when exposed to the stored product.

Local Environmental Conditions. The sensitivity of the environment in the vicinity of the storage facility can largely affect the level of environmental protection and hence the type of containment liner required. For example, in areas where the storage facility is located near or above an aquifer, greater care may be required in the selection and installation of the containment liner.

Legislative Requirements. In addition, local governments may be highly prescriptive and specific in terms of the type of containment barrier required. Such legislation requirements are often based upon local environmental conditions.

Containment systems will be effective only as long as they remain intact. Disruption of clay liners or soil sealants by tree roots, or the ripping of synthetic liners during handling are examples of incidents that can lead to ineffective leak or spill containment.

Table 2.3-1 presents a summary comparison of the various types of underground containment systems. Further details are provided in the remainder of this chapter.

B. CLAY LINERS

1. Chemical and Physical Properties [5,8,10]

Due to their general availability in many areas, clays are often considered the first altemtive for storage tank containment liners. Clays are relatively inexpensive liner materials that can be extremely effective for tank storage. These materials can also be effectively used as liners for pipe trenches.

Clays are complex minerals that have a wide range of compositions and properties. They are subject to changes in composition due to several factors, including the following:

- Weathering when exposed to air.
- Leaching of components when exposed to groundwater or other solutions.
- Ion exchange, or the replacement of ions in the clay with other ions of similar charge, when exposed to substances such as water containing acids, alkalis, or dissolved salts.
- Destabilization when exposed to some organic solvents.

Other factors that influence the performance of clay liners include: (1) compatibility with the stored product; (2) the thickness of the clay liner; (3) the shrink-swell potential of the clay; (4) the plasticity of the clay; and (5) the moisture content, density, and degree of compaction of the clay. The selection of a clay material for a particular liner application should be based upon tests for suitability by a soils engineer or a soils chemist.

2. Design and Installation Requirements [5,8]

Before installing a clay liner, it is necessary to first drain and stabilize the excavation. A bottom layer is then laid in place and compacted using a device such as a steel wheel roller. This bottom layer should be at least 6 inches deep; depths of 2 to 4 feet are not uncommon. When this bottom layer is more than 6 inches thick, it is usually the practice to apply it in stages to ensure proper compaction. The required degree of compaction depends upon the composition of the soil itself, its clay content, density, and moisture content. Once the bottom layer has been properly installed, the tank should then be installed in accordance with New York State standards and guidelines, and the excavation backfilled with more clay material to provide containment all around the tank. The installation of clay liners can be a complex operation requiring a trained contractor to ensure high levels of quality control.

C. SYNTHETIC MEMBRANE LINERS

1. Chemical and Physical Properties [5,8]

Synthetic membrane liners are polymeric materials, manufactured in sheet form, that can be spread over the tank excavation walls or floor to contain a leak or spill. As a class, these types of liners have several advantages and disadvantages. The advantages of synthetic membrane liners include the following:

- They can contain a wide variety of liquids with minimum loss through seepage.
- They have high resistance to bacterial deterioration.
- They have high resistance to chemical attack.
- They are relatively economical to install and maintain.
- They are readily installed for many applications.

In general, the disadvantages of synthetic membrane liners include the following:

- They are vulnerable to attack from ozone and ultraviolet light (sunlight) when compared to other types of liners.
- They have limited ability to withstand heavy loads.
- They are susceptible to laceration, abrasion, and puncture.
- They are prone to cracking at low temperatures, and stretching and distortion at very high temperatures.

The synthetic polymeric membranes that are most commonly used to contain chemical and petroleum products are polyvinyl chloride (PVC), polyethylene, chlorinated polyethylene (CPE), chlorosulphonated polyethylene (CSPE or hypalon), oil-resistant polyvinyl chloride (ORPVC), ethylene proylene diene monomer (EPDM), butyl rubber and neoprene. In addition, DuPont has developed a proprietary elasticized polyolefin called 3110. Table 2.3-2 presents a general summation of the advantages and disadvantages of thse synthetic materials, and Table 2.3-3 presents a summary of the compatibility of these substances with various types of hazardous materials. For more information on the chemical compatibility of synthetic membrane liners, please refer to references 5 and 8.

Table 2.3-1

Comparison of Underground Spill Containment Systems

Type of System	Advantages	Disadvantages	Relative Cost
Clay Liners	The least expensive liner if clay is available close to the site.	Subject to drying and cracking and thus must be protected with soil cover.	Low
	Use of clay is a well established practice and standard testing procedures are available.	Subject to leaching of components when exposed to groundwater or other solutions.	
		Subject to ion exchange when exposed to water containing acids, alkalis, or dissolved salts.	
		Subject to destabilization when exposed to some organic solvents.	
Polymeric Liners	Well established solution to problem of containing petroleum products.	Require subgrade preparation and sterilization to reduce risk of puncture.	Moderate to High
	Particularly good for temporary storage.	Must be protected from damage, particularly due to vehicular traffic.	
	High resistance to bacterial deterioration.	Must be protected from sunlight and ozone.	
		May be attacked by hydrocarbon solvents particularly those with high aromatic content.	
		Good oil resistance and good low temperature properties do not normally go hand in hand.	
Soil Cement	Good durability.	Subject to degradation due to frost heaving of subgrade.	Moderate
	Resistance to aging and weathering	In place soil usually used; permeability varies with the type of soil.	
Bentonite	Low permeability.	Untreated bentonite may deteriorate when exposed to contaminant.	Moderate
	Does not deteriorate with age.	Requires protective soil cover, typically 18 inches.	
	Self sealing.	Subject to destabilization when exposed to some organic solvent.	
Concrete Vaults	Good strength and durability.	Requires surface coating to insure impermeability.	High
		Subject to cracking when exposed to freeze/thaw cycles.	
Double Walled Tanks	Constructed of material (FPR or coated steel) which is resistant to the stored product and to external corrosion.	Some models only available in tank sizes up to 4,000 gallons.	High
	Includes leak detection system in tank design.		

2. Design and Installation Requirements [5,8]

In most instances, installation of the liner is as important to the overall success of the application as material selection. Liner installation is a relatively complicated task that should be performed by a qualified contractor, paying attention to important details such as the following:

- The base of the excavation should be compacted to prevent settling under the liner and tank after they are in use.
- The slope of the excavation should be stable to avoid collapse after the liner has been installed.
- The base and sidewall areas that will contact the membrance should be finely finished. All rocks, rubble and debris which could puncture the lining should be removed. Sand layers should be placed above and below the membrane to further prevent punctures and to facilitate underdrainage. Soil sterilization with a herbicide may be considered in instances where vegetation may propagate, but the herbicide should not be applied indiscriminately.
- The liner should be carefully placed and seamed (bonded) in accordance with manufaturers' specifications. Table 2.3-4 summarizes the important considerations of synthetic liner installation.

Membrane liners are typically used in areas of high groundwater, although they can be employed in other instances. When the material to be stored is lighter than water, the liner is always installed around the sides of the excavation perimeter extending down beneath the groundwater level. For these types of chemicals, the groundwater acts as the bottom containment for any leak or spill. When the liquid to be stored is heavier than water, the liner is always installed under the tank along the excavation base as well as along the sidewalls to prevent the liquid from migrating outside the excavation area. With the liner under the tank, the bottom liner cover area should be drained before closure. An observation well to a low point of the membrane could be used to confirm liner integrity. The excavation should have an impervious cover to prevent flooding of the lined area. Figures 2.3-1 and 2.3-2 illustrate these types of applications.

Membrane liners can also be used as wrappers around underground storage tanks. Polyethylene wrappers have been used in such a manner to enclose steel tanks. Some success in tank leak prevention has been reported using such a technique. However, corrosion can occur under the wrapper if groundwater enters the space between the tank and wrapper through a tear or other imperfection. In addition, such a wrapper is not adequate for use with cathodic protection for steel tanks [9]. Further discussion of this tank protection technique has been included in Part II, Chapter 1.

Table 2.3-4

Considerations During Liner Placement

Use a qualified installation contractor having experience with membrane liner installation, preferably the generic type of liner being installed.

Plan and implement a quality control program which will help insure that the liner meets specification and the job is installed per specifications. Inspection should be documented for review and recordkeeping.

Installation should be done during dry, moderately warm weather if possible.

The excavation base and wall should be firm, smooth, and free of sharp rocks or debris.

D. SOIL SEALANTS

The types of soil sealants more commonly used for lining storage tank containment areas are soil cement and bentonites (clay materials). These types of sealants are discussed in detail below.

1. Soil Cement [5,8]

Chemical and Physical Characteristics. Soil cement is a compacted mixture of Portland cement, water, and selected in-place soils. The result is a low strength Portland cement concrete with greater stability than natural soils. The permeability of this mixture varies with the type of soil used, a more granular soil produces a more permeable soil cement.

Any soil can be treated with cement. However, there are some exceptions where cement should not be used:

- Highly organic soil retards cement hydration because of absorption of calcium ions.
- Clean well-graded gravels and crushed rock are sometimes unsuitable because of shrinkage problem.
- Clays can be unsuitable because of the difficulty of incorporating a fine cement powder into a wet, plastic clay and because property changes are not significantly affected.
- Saline soils are unsuitable, but this can be overcome by increasing the cement content.

The aging and weathering characteristics of soil cements are good, especially when exposed to wet-dry and freeze-thaw cycles. Some degradation has been noted when this substance is exposed to highly acidic

Table 2.3-2

Comparison of Various Synthetic Polymeric Membranes

Liner Type	Advantages	Disadvantages	Relative Cost
Polyvinyl Chloride (PVC)	Good resistance to ozone and ultraviolet ligh when properly stabilized	Poor hydrocarbon resistance.	Low
	Good resistance to puncture.	May deteriorate in presence of certain chemicals and in contact with heat.	
	High tensile strength.		
Oil Resistant PVC	Improved resistance to aromatic hydrocarbon relative to standard grades of PVC.	Poor low temperature handling properties.	Moderate to High
Polyethylene[1]	Great resistance to bacteriological deterioration.	Poor puncture resistance.	Low
	Good tensile strength.	Poor tear strength.	
	Few restrictions on chemical exposure.	Susceptible to weathering and stress cracking.	
	Good low temperature characteristics.		
Chlorinated Polyethylene (CPE)	Excellent weatherability.	Limited range of tolerance for chemicals, oils and acids.	Moderate
	Good tensile and elongation strength.	Low recovery when subject to tensile stress.	
	Good resistance to ultraviolet lignt and ozone.		
	Excellent crack and impact resistance at low temperatures.		
	Moderate to good hydrocarbon resistance.		
Chlorosulfonated Polyethylene (CSPE or hypalon)	Good puncture resistance.	Low tensile strength.	Moderate
	Good resistance to microbiological attack.	Poor resistance to aromatic hydrocarbons.	
	Excellent resistance to low temperature cracking.		
	Excellent weather resistance.		
	Good resistance to ozone and ultraviolet light.		
	Flexible and resilient.		
Ethylene Propylene Diene Monomer	Good weathering characteristics.	Poor resistance to aromatic hydrocarbons.	Moderate
	Good temperature flexibility.	Low peel and shear strength.	
	Good heat resistance.		
	Resistant to mildew, mold, and fungus.		
	Excellent resistance to water vapor transmission.		
Butyl Rubber	Excellent resistance to water.	Poor resistance to hydrocarbons particularly petroleum solvents, aromatics, and halogenated solvents.	Moderate to high
	Excellent resistance to ultraviolet light and ozone.		
	High tolerance for temperature extremes.	Poor sealability.	
	Good tensile and shear strength.		
	Good resistance to puncture.		
	Ages well in general, but some compounds will crack on ozone exposure.		

Table 2.3-2 continued

Neoprene	Excellent aging and weathering characteristics. Overall good resistance to hydrocarbons, but shows some swell when exposed to aromatics and other cyclic hydrocarbons. Flexible and elastic over a wide range of temperatures.	Not heat or solvent sealable.	High
Elasticized Polyolefin (DuPont 3110)	Resistant to ultraviolet light; does not require earth cover. Good resistance to weathering and aging. Good resistance to ozone attack and soil microorganisms. Good resistance to hydrocarbons and will accomodate a broad range of solvents.	Relatively untested. Vunerable at low temperatures.	Moderate

NOTE 1 - Refers to low density polythylene. High density polyethylene is much less susceptible to puncture, tears, weathering and stress cracking.

Table 2.3-3

Chemical Compatibility of Membrane Liners with Hazardous Materials

Lining Material	Strong Acids	Strong Bases	Petroleum Products	Halogenated Solvents	Aromatic Solvents
Polyvinyl chloride (PVC)[1]	R	R	NR	NR	NR
Chlorinated Polyethylene (CPE)	R	R	NR	NR	NR
Chlorosulfonated Polyethylene (CSPE or Hypalon)	R	R	NR	NR	NR
Ethylene Propylene Diene Monomer (EPOM)	R	R	NR	NR	NR
Neoprene	R	R	R	NR	NR
Butyl Rubber	R	R	NR	NR	NR
Oil Resistant Polyvinyl Chloride (ORPVC)[1]	R	NR	R	NR	NR
Polyethylene	R	R	R	R	R

NOTES: 1. Not recommended if liner is exposed to the atmosphere due to extreme susceptibility to ultraviolet light and/or ozone

R = recommended

NR = not recommended

Source: References 1,2 and 4.

environments, but soil cements can resist moderate amounts of alkali, organic matter, and inorganic salts. One of the main deficiencies of soil cement as a liner material is its tendency to crack and shrink on drying. Severe cracking and detrioration may also result if the cement content of the mixture is too high.

Design and Installation. The details for construction, excavation base and wall preparation, and placing and curing of soil cement liners can be obtained from documents such as reference 5, 8 and 9, and from consulting engineers in this field. Some of the considerations and procedures are highlighted in Table 2.3-5.

Table 2.3-5

Highlights of Soil Cement Design and Installation

- Preparation of the base and walls is extremely important. The base and wall should be properly finished, and well moistened before placing the concrete to prevent the liner from drying too quickly.
- Concrete mixes should be plastic enough to consolidate well, but not stiff enough to slip on side slopes.
- Proper curing of the liner is important.

2. Bentonites [8,10]

Chemical and Physical Characteristics. Bentonites are naturally occurring inorganic swelling clays which are typically chemically treated, and are marketed under various trade names. Mixtures of soil and chemically treated bentonites may be used to line excavations for underground tanks and contain spills. When the bentonite is mixed with a sandy soil and saturated with water, the granular bentonite particles in the soil swell to fill the voids with a tough leather – like mastic, thereby forming an impermeable barrier. Bentonite can swell up to 15 times its dry bulk volume when used in such a manner. Untreated bentonites are generally not as effective when used as soil sealants and are more susceptible to degradation, particularly if the water used to wet the material during installation contains a high concentration of dissolved salts (i.e., hard water), acids, or alkalis. Bentonites are also subject to destabilization when exposed to some organic solvents.

Design and Installation Requirements. Before installing a bentonite liner, it is necessary to first drain and stabilize the excavation. The mixture of soil and bentonite is then used to line the bottom of the excavation. The mixture is typically wetted to saturation, and compacted using a wobble wheel or steel wheel roller [8]. The tank is then installed in accordance with New York State standards and guidelines and/or the manufacturer's recommendations, and the excavation is backfilled with more clay/soil mixture. When preparing the mixture, the manufacturer's recommendations should be

Figure 2.3-1

Synthetic Liner Installation for Storage of Lighter-Than-Water Liquids in Area of High Groundwater

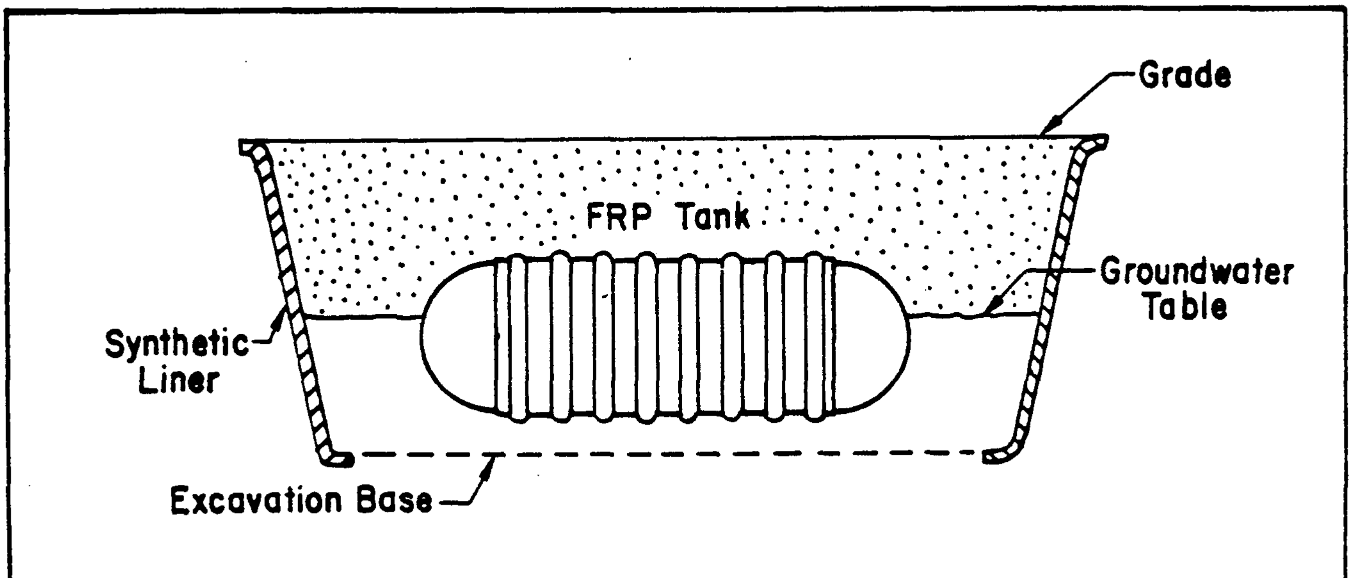
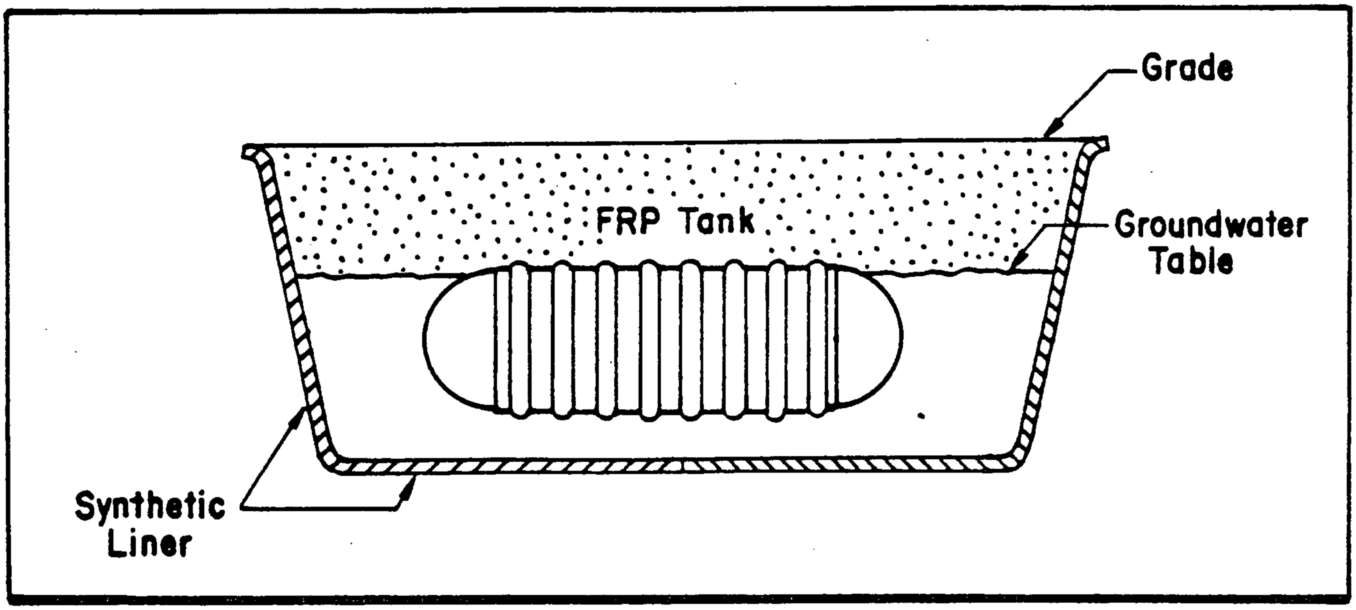


Figure 2.3-2

Synthetic Liner Installation for Storage of Heavier-Than-Water Liquids in Area of High Groundwater



followed as to the percent of the clay and soil, the amount and quality of water used for wetting, and the degree of compaction required. The mixture varies, but usually consists of one part bentonite and three parts clean uncontaminated soil.

E. CONCRETE VAULTS

Concrete vaults are secondary enclosures consisting of concrete walls and a concrete bottom slab upon which the tank is fastened. The vault system may include a cover.

The vaults may contain one, or more than a dozen tanks. Some vaults have an open interior so that tanks can be physically inspected while others are filled with a bedding of sand which provides structural support for the tanks. When the vaults are of open design, the interior tanks are supported structurally on cradles. Unusally the vault contains a sloped floor and a sump installed with a monitoring probe and a product recovery pump.

Concrete by itself is not an effective liquid barrier. Leaks through concrete occur in the vapor phase. Concrete will pass vapors of many chemicals after only a few days of exposure.

Coatings to make concrete impermeable are effective but there is no universal concrete coating for all chemicals, weather, and moisture conditions. Coatings will peel, crack or wear (in traffic areas) over time. In areas of wear, successive layers of coatings are color-coded, to show wear patterns.

A common practice is to put a vapor barrier around the outside of the vault. Concrete vaults must be carefully designed and constructed; otherwise joints may leak or the walls and floor may crack when exposed to freeze-thaw cycles for extended periods or if settling of the tanks occurs. Concrete vaults are mandatory in New York City for the underground storage of gasoline and other fuels.

F. DOUBLE-WALLED TANKS

Spill containment may also be provided with double-walled tanks. These tanks are essentially a tank within a tank and are described in Part II, Chapter 1 of this report.

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Part II

CHAPTER 4: TRANSFER SPILL AND OVERFILL PREVENTION SYSTEMS FOR UNDERGROUND STORAGE TANKS

A. INTRODUCTION

Spills can occur at underground storage tank facilities because of tank overfilling and drainage from product transfer hoses. For example:

- It is common practice to unload products from vehicles into underground storage tanks without automatic means to prevent overfilling tanks. Without such protection, underground tanks can be overfilled with product which will rise through the vent lines until it attains a level equal to the product level inside the tank truck being unloaded.
- It is common practice to use quick disconnection couplings on the ends of discharge hoses rather than dry-break couplings which are heavier and more difficult to maneuver. With quick disconnect couplings, product remaining in the discharge hose is frequently spilled near the tank area. Beside the obvious dangers which can result from sloppy practices, the daily small spills seeping into the ground near the tank areas can accumulate into sizeable and hazardous volumes over a period of time.

To avoid situations such as these, it is good practice to equip underground tanks with overfill prevention systems and to equip transfer hoses with an automatic shut-off device which prevents backflow when the hose is disconnected. Adherence to good operating practices is also a prerequisite.

An ideal underground tank overfill prevention system would include the following basic elements: (1) a level sensing device that monitors and indicates the liquid level in the tank; (2) an alarm to alert the operator of an impending overfill condition; and (3) an automatic shut-off device that stops the flow of product when the tank is full.

Spills from transfer hoses can be prevented by using couplings equipped with spring loaded shut-off valves which stop flow automatically when the hose is disconnected and by using dry-disconnect couplings. Emergency shut-off valves may also be used to stop product flow, such as in the case of fire.

Devices for overfill and spill prevention add to the system cost, however. Underground tanks are not normally equipped with overfill prevention devices. Truck fleets generally are not equipped with dry disconnect couplings and there is some argument as to the reliability of such equipment on trucks.

The following text summarizes overfill and transfer spill prevention methods for underground storage systems.

It should be emphasized that the methods described are far more prevalent with aboveground systems (where a spill or overfill would be highly visible) than with underground systems. The evolving awareness of hazardous conditions that result from loss of product from an underground system and the financial accountability for site cleanup are changing the picture. The day of the deliveryman relying on a calibrated stick to determine available capacity in a buried tank may be passing.

B. OVERFILL PREVENTION SYSTEMS FOR UNDERGROUND STORAGE TANKS

1. Elements of an Overfill Prevention System.

Overfill protection is accomplished by measuring and controlling the level of liquid in a tank. A partial system may include only a gauge which indicates liquid height in the tank. A sophisticated system could include automatic flow control system and a backing audible high level alarm to warn the operator of emergency conditions.

The elements of a complete overfill prevention system are highlighted in table 2.4-1. These include the following:

- Sensors, which detect the level of liquid in the tank and indicate the liquid level through gauges or other types of indicators.
- High level alarms, which are activated to warn the operator of an impending overfill condition.
- Automatic shut-off devices of systems which prevent overfilling from occuring.

Table 2.4-1

Elements of a Good Overfill Prevention System

- Level sensing device.
- Level indicating device.
- High level alarm.
- Automatic shut-off control system.
- Interlocking of the unloading process and the overfill prevention system so that loading cannot take place if the overfill prevention system is inoperative.
- Bypass prevention so that the overfill prevention system cannot be overridden by the operator.

It may be desirable to interlock the unloading process with the overfill prevention system so that loading cannot take place unless the overfill prevention system is operative. A bypass prevention feature should also be included so that the overfill prevention system cannot be overridden by the operator.

Level Sensing Devices and Indicators. There are a variety of level sensing devices that have been marketed for detecting liquid levels in bulk storage tanks. These devices generally sense liquid characteristics, such as capacitance or thermal conductivity, or operate on such common principles as buoyancy, differential pressure, and hydrostatic head. Devices which operate based on these common priniciples are generally independent of product flow rate, pressure and temperature [13].

Indicators for underground tanks are typically remotely mounted (e.g., in a control room), although above-the-tank gauges may be employed in some cases. The devices are typically gauges, although more sophisticated electronic devices may be used in some overfill prevention systems.

High Level Alarms. Overfill alarms may be visual or audible instruments which are remotely mounted. Audible alarms may be the preferred type of alarm because they do not require visual monitoring. However, when several tanks are being monitored in the same control room, individual warning lights are generally provided for each tank. Ideally, an audible alarm would also be included in such systems to alert the operator that one of the tanks is overfilling.

Automatic Shut-off Controls. Automatic shut-off control systems interface with level sensing devices to: (1) prevent tank overfilling by shutting off the tank loading pump at a preset high level; (2) prevent damage to the tank unloading pump by shutting it off at low level; (3) operate various flow valves to control product flow. These control systems receive a signal from the level sensing device which is transmitted electrically or pneumatically to the control system. Pneumatic devices require a regulated supply of clean and dry instrument air, generally at 20 pounds per square inch (psi). Electric (or electronic) devices generally require 115V line voltage. Table 2.4-2 shows the characteristics of pneumatic and electronic controls.

2. Specific Level Sensing Devices.

The types of level sensing devices available for liquid level detecting in bulk storage tanks can be classified as follows:

- Float-actuated devices
- Displaced devices
- Hydrostatic head sensors
- Capacitance sensors
- Ultrasonic devices
- Optical devices
- Thermal conductivity sensors

Floated activated, capacitance, ultrasonic, optical, and thermal conductivity sensors can be readily used in underground tanks. Their applications are summarized in Table 2.4-3 and discussed below. The other types of sensors are used in aboveground storage systems , and are discussed in Part II, Chapter 4 of this report.

Float-Actuated Devices. Float-actuated devices are characterized by a buoyant member which floats at the surface of the liquid. Float-actuated devices may be classified on the basis of the method used to couple the float motion to the indicating system. Examples of classifications include tape float guages and float vent valves.

A simple tape float gauge designed for use in underground gasoline tanks is shown in Figure 2.4-1. The device provides a local (above the tank) readout of both gasoline and water levels while prohibiting vapor loss.

Float vent valves are simple, inexpensive devices that are used to prevent overfilling of underground fuel tanks. These devices, which are shown in Figure 2.4-2, are installed in the tank's vent line. The float closes the vent line when high liquid level is attained, thus blocking the escape of air. This action causes the pressures inside the storage tank to equalize with the discharge head in the tank truck, thereby interrupting the flow of liquid.

Table 2.4-2

Characteristics of Pneumatic and Electronic Controls

Feature	Pneumatic	Electronic
Transmission distance	Limited to few hundred feet	Practically unlimited
Standard transmission signal	3-15 psi practically universal	Varies with manufacturer
Compatibility between instruments supplied by different manufacturers	No difficulty	Nonstandard signals require special consideration and may not be compatible
Control valve compatibility	Controller output operates control valve operator	Pneumatic operators with electropneumatic converters or electrohydraulic or electric motor operator required
Compatibility with digital computer or data logger	Pneumatic-to-electric converters required for all inputs	Easily arranged with minimum added equipment
Reliability	Superior if energized with clean dry air	Excellent under usual environmental conditions
Reaction to very low (freezing) temperatures	Inferior unless air supply is completely dry	Superior
Reaction to electrical interference (pickup)	No reaction possible	No reaction with the system if properly installed
Operation in hazardous locations (explosive atmosphere)	Completely safe	Intrinsically safe equipment availble equipment must be removed for most maintenance
Reaction to sudden failure of energy supply	Superior-capacity of system provides safety margin-backup inexpensive	Inferior-electrical failure may disrupt plant-backup expensive
Ease and cost of installation	Inferior	Superior
System compatibility	Fair-requires considerable auxilary equipment	Good-conditioning and auxilary equipment more compatible to systems approach
Instrument costs	Lower if installation costs are not considered	Higher-becomes competitive when total including installation is considered
Ease and cost of maintenance	Fair; procedures more readily mastered by people with minimim of training	Good-depends upon capability of personnel
Dynamic response	Slower but adequate for most situations	Excellent-frequently valve becomes limiting factor
Operation in corrosive atmosphere	Superior-air supply becomes a purge for most instruments	Inferior, unless special consideration is given and suitable steps taken
Performance of overall control systems	Excellent, if transmission distances are reasonable	Excellent-no restriction on transmission distance
Politics (the unmentioned factor that frequently pops up)	Generally regarded as acceptable but not the latest thing	Often regarded as the latest and most modern approach

Source: Reference 2

Table 2.4-3

Level Detection Devices for Underground Storage Tanks

Type	Monitor Liquid Level	Level Indication	Alarm and Shutoff Response [1]
Float Actuated Devices			
Tape float gauges	Yes	Gauge	Interfaces with electronic or pneumatic controls.
Float vent valves	No	None	Automatic Shut-off.
Capacitance devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.
Thermal conductivity devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.
Ultrasonic devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.
Optical devices	Yes	Gauge	Audible alarm and automatic shutoff electronic controls.

The device also includes a pressure build-up relief bleed hole. Once flow from the tank truck has ceased due to pressure equalization, the storage tank fill line can be disconnected. Then, as vapor escapes through the float vent valve bleed hole, the liquid remaining in the fill line can drain into the tank. If dry disconnection couples are used, the liquid will be held in the transfer line until this draining can occur, thus preventing any spillage of product.

This device was developed as part of the Vapor Recovery Stage I system. Its purpose is to prevent product spillover into the vapor manifold, which might result in lead contamination of an unleaded gasoline grade. Its use as overfill protection has merit, but it is not used for that purpose generally.

The float vent valve must be installed in an "extractable tee" connection which permits removal of the float valve for tank testing. The Kent-Moore (Heath Petro-Tite Tank Tightness) Test cannot be run with the valve in place.

Float-actuated devices are made of a variety of materials, including aluminum, stainless steel and coated steel, depending upon the application [10]. They may be used in conjunction with pneumatic or electronic devices to operate valves, pumps, remote alarms or automatic shut-off systems.

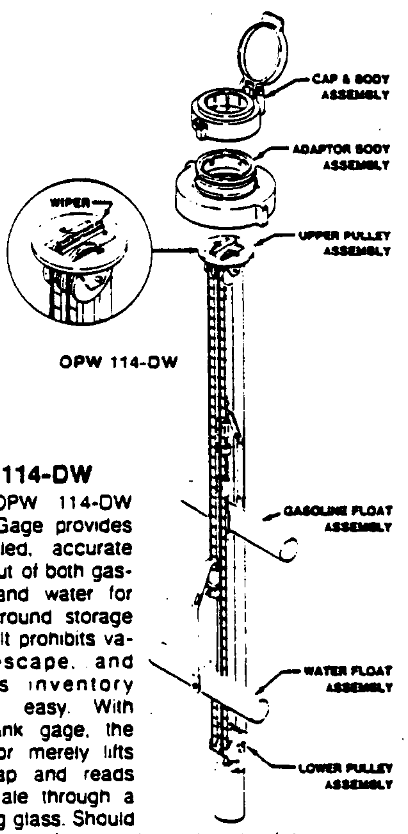
Capacitance Sensors [7]. Devices that operate based on the electrical conductivity of fluids may be used to monitor liquid level. A typical device consists of a rod electrode positioned vertically in a vessel, the other electrode usually being the metallic tank wall. The electrical capacitance between the electrodes is a measure of the height of the interface along the rod electrode. The rod is usually electrically insulated from the liquid in the tank by a coating of plastic.

Capacitance devices are suitable for use with a wide range of liquids, including the following: petroleum products, such as gasoline, diesel fuel, jet fuel and no. 6 fuel oil; acids; alkalis; solvents; and other hazardous liquids. They may be used in conjunction with electronic controls to operate pumps, valves, alarms or other external control systems.

Thermal Conductivity Sensor [18,19]. Devices which operate on the principle of thermal conductivity of fluids may be used to monitor liquid level. A typical device consists of two temperature-sensitive probes connected in a Wheatstone bridge (a type of electrical circuit configuration). When the probes are in air or gas, a maximum temperature differential exists between the active and reference sensors, which results in a great imbalance in the bridge circuit and a correspondingly high bridge voltage. When the probes are submerged in

Figure 2.4-1

Tape Float Gauge for Underground Storage Tank



OPW 114-DW

The OPW 114-DW Tank Gage provides a sealed, accurate read-out of both gasoline and water for underground storage tanks. It prohibits vapor escape, and makes inventory control easy. With this tank gage, the operator merely lifts the cap and reads the scale through a viewing glass. Should condensate form on the underside of the glass, a turn of the cap wipes it clean.

These tank gages are for use in 4" riser pipes, and are pre-assembled at the factory. One man can install the 114-DW tank gage by using the furnished instruction sheet as a guide.

Materials
Body: hard coat aluminum
Cap: hard coat aluminum
Gaskets: buna-N
Pulley: Acetal
Tape: steel with epoxy paint

OPW 114-SW

Similar to OPW 114-DW above, except it indicates product level only.

Source: OPW Division/Dover Corp.

a liquid, the temperature between the sensors is equalized and the bridge is brought more nearly into balance. The probes may be installed through the side wall of a tank or pipe, or assembled together on a self-supporting mounting and suspended through a top connection on the tank.

Thermal conductivity devices may be used to control level with great accuracy. They may be used with any liquid regardless of viscosity or density. They may also be used with immiscible liquids and slurries and in conjunction with electronic controls to operate pumps, valves, alarms or other external control systems.

Ultrasonic Sensors [16,17]. Devices which operate on the principle of sonic-wave propagation in fluids also may be used to monitor liquid level. These devices use a piezoelectric transmitter and receiver, separated by a short gap. When the gap is filled with liquid, ultrasonic energy is transmitted across the gap to a receiving element thereby indicating the liquid level. These devices may be used in conjuction with electronic controls to operate pumps, valves, alarms or other external control systems.

Another sonic technique used for level measurement is a sonar device. A pulsed sound wave, generated by a transmitting element, is reflected from the interface between the liquid and the vapor-gas mixture and returned to the receiver element. The level is measured in terms of the time required for the sound pulse to travel from the transmitter to the vapor/liquid interface and return.

Optical Sensor [9]. Devices which operate on the principle of light beam refraction in fluids may be used to monitor liquid level. An optical liquid level monitoring system consists of a sensor and an electronic control device. A specific electronic signal is generated and aimed at the tank mounted sensors. The sensors convert the electronic signal to a light pulse. This light pulse is transmitted into the tank by fiber optics, through a prism and out again via fiber optics. The light pulse is then converted to a specific electronic signal to indicate the liquid level. A distinct advantage of this type of system is that it is self-checking. Any interruption will sound the alarm, so if equipment is damaged or malfunctions the operator is alerted.

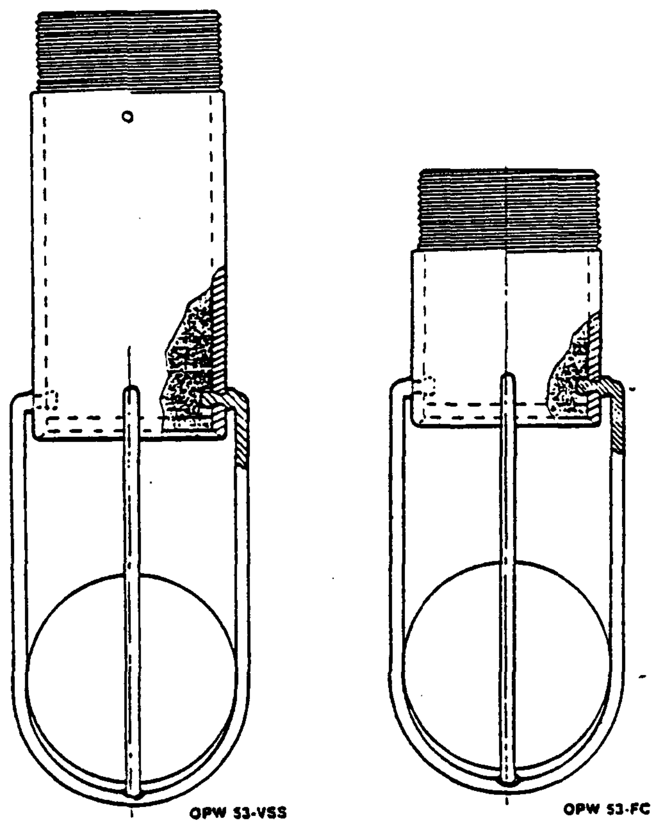
Figures 2.43 and 2.44 show typical applications of the optical liquid level sensing system for a tank truck and a bulk storage tank respectively. The sensor detects the level of liquid in the tank and sends a signal to the controller device (i.e. control monitor) which in turn activates the shut-off valve or the level alarm.

C. TRANSFER SPILL PREVENTION SYSTEMS

Spill prevention during transfer operations can be accomplished by using couplings equipped with spring loaded valves which automatically block flow when the hoses are disconnected. These include quick-disconnect couplings equipped with ball valves and dry-disconnect couplings. Emergency shut-off valves may also be provided in the product transfer line to stop flow in case of fire. Applications of these spill prevention devices are summarized in Table 2.4-4 and discussed below.

Figure 2.4-2

Float Vent Valves Used For Overfill Prevention



Source: OPW Division/Dover Corp.

1. Check Valves

Check valves are commonly used in the discharge piping of a pump or the fill line of a tank to prevent reversal of flow. Check valves are available in three basic designs: (1) swing check valves; (2) lift check valves; and tilting-disk check valves. They are available in a wide wariety of sizes and materials of construction to suit most applications. A more complete description of these devices can be found in Part II, Chapter 2 of this report.

2. Couplings

The use of tight couplings is essential to prevent spills when transferring hazardous products from one storage tank to another. Many types of couplings are available and their selection depends on temperature, pressure and the chemical properties of the material conveyed. The higher the temperature and/or pressure, the more securely the coupling must be attached. Also, the material being conveyed must not damage the coupling. The factor which determines the amount of pressure a coupling will withstand is generally the strength of the hose-coupling connection. If correctly applied (and at moderate working temperatures) bolt clamps will handle low pressure, bands will take low to medium pressures, and interlocking clamps and swaged or crimped ferrules will handle high pressures.

As mentioned earlier in this chapter, quick-disconnect couplings are commonly used because they are generally lighter and easier to handle than other types of couplings. However, precautions must be taken to prevent spill or loss of the product remaining in the transfer lines when these types of couplings are used. Quick-disconnect couplings equipped with ball valves and dry-disconnect couplings are used to minimize spills when the hoses are disconnected. Dry-disconnect couplings are the best type of coupling available in terms of product spill control. They are equipped with a spring loaded valve which is normally closed until the coupling is attached and the valve is manually opened with a lever. Figure 2.4-5 demonstrates the difference between the types of couplings.

Another good product transfer practice is the selective use of couplings and adapters to preclude the mixing of incompatible liquids. By carefully selecting couplings and adapters that are only compatible with each other, one can prevent undesired mixing of products.

Imbiber beads are useful for soaking up small spills, for example in the fill box. These beads absorb hydrocarbons and swell to many times their original size, but do **not** absorb water.

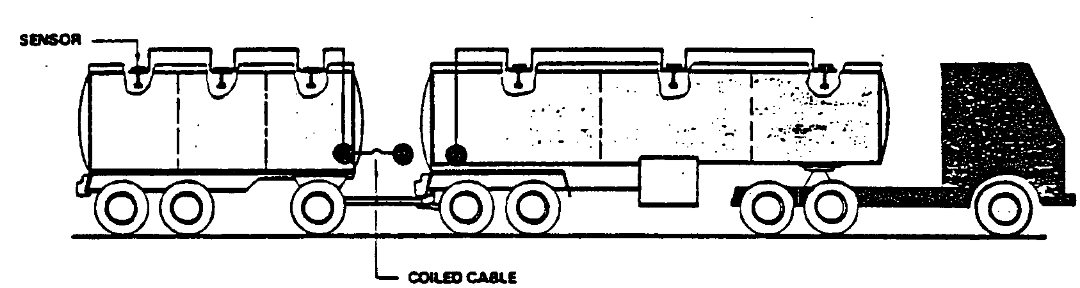
D. OPERATING PRACTICES FOR OVERFILL PROTECTION

Certain operating practices specified in Publication 385 of the National Fire Protection Association may be used to prevent overfilling of tanks [14]. Practices that are applicable to the transfer of any hazardous liquid include the following:

- Loading and unloading of tank vehicles shall be done in approved locations.
- The driver, operator, or attendant of any tank vehicle shall not remain in the vehicle and shall not leave the vehicle unattended during the loading or unloading process. The delivery hose, when attached to a tank vehicle, shall be considered to be a part of the tank vehicle. Some companies prefer to have their own trained personnel conduct all unloading operations so as to minimize the potential for human error. Whoever does the unloading must be cognizant of the potential problems and

Figure 2.4-3

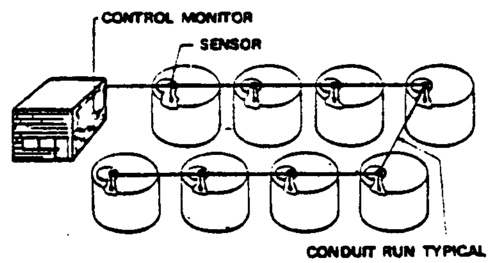
Optical Liquid Level Sensing System For Tank Truck



Source: OPW Division/Dover Corp.

Figure 2.4-4

Optical Liquid Level Sensing System For Bulk Storage System



Source: OPW Division/Dover Corp.

Table 2.4-4

Tranfer Spill Prevention Systems

System	Function	Spill Control	Applications
Ordinary quick-disconnect coupling	Product transfer	None	Tank vehicles and storage tanks.
Quick-disconnect coupling equipped with ball valve	Product transfer	Built-in valve reduces spills from disconnect hoses.	Tank vehicles and storage tanks.
Dry-disconnect coupling	Product transfer	No spills from disconnected hoses.	Tank vehicles and storage tanks.
Emergency shut-off valves	Flow control	A fusible metal link melts and closes the valve in case of fire or impact.	For use any place that, in the event of fire, it is important to stop flow.

dangers (overfilling, leaks, vapor or liquid explosions, fire, etc.), and must remain alert at all times. Human error is a major cause of transfer spill incidents, and in most instances spills could be avoided through proper personnel training and alert observation of all operations.

- When transferring Class I (flammable) liquids, motors of tank vehicles or motors of auxiliary or portable pumps shall be shut off during making and breaking hose connections. If loading or unloading is done without requiring the use of the motor of the tank vehicle, the motor shall be shut-off throughout the transfer operation of the liquid. These precautions should be taken to minimize the possibility of fire or explosion.
- No cargo tank (or compartment) containing volatile, flammable or combustible liquid may be fully loaded. Sufficient space (outage) must be provided to prevent leakage due to thermal expansion of the liquid transported. One percent is the minimum outage required.

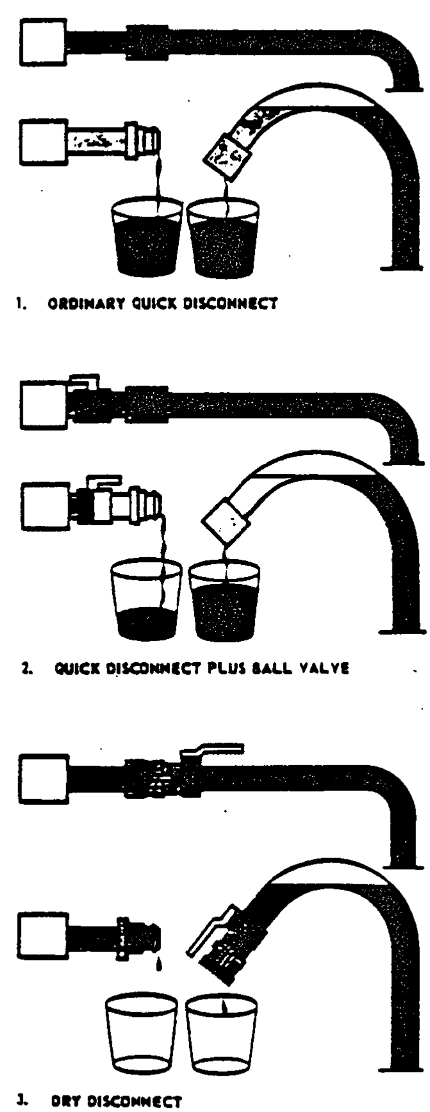
Please refer to NFPA-385 for more information on loading and unloading practices [14].

Other precautions which may be taken to prevent overfills and spills include the following:

- The use of labels, markings or color codes on hoses and special couplings that can be used only for transferring product to prevent accidental mixing of incompatible materials.
- Periodic inspection of hoses for leaks.
- Ensuring that the operator of any loading/unloading operation is properly trained and is aware of all potential problems. As stated earlier, a high percentage of transfer spills are caused by human error.

Figure 2.4-5

Types of Couplings



Source: OPW Division/Dover Corp.

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Part II

CHAPTER 5: LEAK AND SPILL MONITORING FOR UNDERGROUND STORAGE

A. INTRODUCTION

Before any extensive discussion begins, a distinction must be made between system monitoring and system testing. Monitoring means either:

a) **Early warning leak detection systems** that provide continuous surveillance for leaks and spills.

b) **Area-wide surveillance methods** that may be used to investigate or pinpoint the source of a spill or leak.

Testing refers to special equipment and methods that are not part of normal operations. System testing is used to determine whether a tank or pipe system is leaking at a particular time. (Chap. II-6 discusses testing at length). Table 2.5-1 compares the various leak monitoring systems.

B. EARLY WARNING LEAK DETECTION SYSTEMS

Early warning leak detection systems typically provide continuous surveillance for the presence of a leak or spill. The types of early warning monitoring systems most widely used are the following:

- Inventory monitoring (also called inventory contol).
- Interstitial monitors in double-walled tanks.
- Systems that monitor the storage tank excavation. These types of systems include observation wells, U-tubes, and wire grids. The types of leak sensors used include:
  - thermal conductivity sensors;
  - electric resistance sensors; and
  - gas detectors.

1. Inventory Control

Early detection of leaks may be achieved by proper product accounting (i.e., recordkeeping), regular inspections of the visible parts of the product handling system, and prompt recognition of the conditions that indicate leaks in underground tanks and piping. Inventory monitoring is a technique that is widely applicable to any stored or transported product.

Evidence of leakage from buried tanks and pipelines can be gathered from inventory control records and from abnormal operation of pumping equipment. The following are some of the more obvious symptoms of such leaks:

- Loss of product in a tank during periods when product is not dispensed usually indicates a leaking tank, but might also indicate faulty accounting or metering of the product, theft, or extreme temperature change.
- An unaccountable increase in water in an underground tank may be caused by a leak in the tank if the ground surrounding it is saturated. Under such circumstances, water may leak into the tank instead of product leaking out. The increase in water may also be caused by a leaking gauge or fill cap, and these should be examined and made watertight, if necessary, before concluding that the tank is at fault.
- Increasing differences between the amount of product received and dispensed may indicate a meter calibration problem, theft, or a leak in tanks or piping.
- Where fill boxes are located remotely from the tanks, large differences appearing consistently between the amounts invoiced and the tank gauges after deliveries may indicate a leak in the remote fill line. In such event, the line should be tested.
- A hesitation in the delivery from a standard dispensing pump may indicate a leak in the suction piping, although such hesitation may also be caused by a leaking foot valve or, in warm weather, by vaporlock. Should this occur, the inventory control records may indicate whether the cause is mechanical or whether product is actually being lost.
- In a remote pumping system, meter spin without product delivery may indicate a leaking pipe.
- Gasoline odor in spaces below ground adjacent to the tank may be evidence of underground leaks, whether in the tank or piping. However, such odors may also be evidence of underground leaks, whether in the tank or piping. However, such odors may also be evidence of product spills during product delivery and tank filling.

Should the operator observe any of the foregoing symptoms, he should immediately notify those responsible for maintaining the equipment. He should not attempt to correct the condition himself, as the operation may involve some hazard and may require special equipment. Furthermore, in some locations, only specially licensed mechanics can work on storage equipment.

Table 2.5-1

Comparison of Various Leak Monitoring Techniques

Approach	Description	Applications	Substances Detected	Relative Cost	Advantages/Disadvantages
Inventory Control	A system based on product recordkeeping, regular inspections, and recognition of the conditions which indicate leaks.	Any storage tanks and buried pipelines.	Any product stored or transported.	Low	The technique is widely applicable to any product stored or transported in pipelines. However, it requires good bookkeeping, and will not detect small leaks.
Thermal Conductivity Sensors	Uses a probe that detects the presence of stored product by measuring thermal conductivity.	Can monitor groundwater or normally dry areas.	Any liquid.	Medium	Primary advantage is early detection which makes it possible for leaks and spills to be corrected before large volumes of material are discharged. Typically requires ¼ inch of product on groundwater to guarantee detection of product/water interface in wet (groundwater) applications [16].
Electric Resistivity Sensors	Consists of one or a series of sensor cables that deteriorate in the presence of the stored product, thereby indicating a leak.	Can monitor groundwater or normally dry areas.	Any liquid.	Medium	Primary advantage is the early detection of spills. Once a leak or spill is detected, the sensors must be replaced. Can detect small as well as large leaks.
Gas Detectors	Used to monitor the presence of hazardous gases in vapors in the soil.	Areas of highly permeable, dry soil, such as excavation backfill or other permeable soils, above groundwater table.	Highly volatile liquids, such as gasoline.	Medium	Once the contaminant is present and detected, gas detectors are no longer of use until contamination has been cleaned up.
Sampling	Grabbing soil or water samples from area for analysis.	Universal; primarily used to collect groundwater samples, as would be the case with tanks stored in high groundwater area.	Any substance	High	Highly accurate intermittent evaluation tool. However, does not provide continuous monitoring.
Interstitial Monitoring in Double-Walled Tanks	Monitors pressure level or vacuum in space between walls of a double-walled tank.	Double-walled tanks.	Pressure sensors monitor tank integrity and are applicable with any stored liquid. Fluid sensors monitor presence of any liquid in a normally dry area, and are also applicable with any stored liquid.	High	Accurate technique which is applicable with any double-walled tanks.

Table 2.5-1 continued

Groundwater Monitoring Wells (wet wells)	Wet wells are used to detect and determine the extent of contamination in groundwater tables.	Area-wide or local monitoring for groundwater contamination from underground storage tanks and pipelines. May be used for periodic sampling or may employ one of the sensors described above to detect leaks or spills.	Any hazardous liquids which can be detected by on-site instruments or laboratory analysis.	Medium to High	The type, number and location of wet wells depends upon the site's hydrogeology, the direction of groundwater flow and the type of spill containment and spill collection systems used.
Vapor (sniff) Wells	Vapor wells are used to detect and monitor the presence of hazardous gases and vapors in the soil.	Area-wide or local monitoring of the soil surrounding underground storage tanks and pipelines.	Many different combustible and non-combustible gases and vapors.	Low	The type, number and location of vapor wells depends upon the extent of the spill, the volatility of the product, and the soil characteristics. Vapor wells are subject to contamination from surface spills and cannot be used at contaminated sites.
Dyes and Tracers	Substances with a characteristic color or other characteristics (e.g., radioactive tracers) that can be used to trace the origin of a spill.	Area-wide monitoring of underground tanks and buried pipelines.	Dye itself is detected visually or with the use of instruments.	Low Medium	Dye or tracer could be low in cost, but the time required to perform a study could be great. Also may require the drilling of observation wells to trace the dye or other material. Radioactive tracers require a license and approval from the Nuclear Regulatory Commission or the U.S. Department of Labor. Therefore, they are generally discouraged.

There are a number of factors that limit the accuracy of inventory control as a leak detection method. These include the following:

- Product thermal expansion. Fluctuations in temperature can lead to expansion, contraction, evaporation and/or condensation of the stored product, thereby affecting inventory monitoring results. The relationship between temperature and storage volume is addressed in Part I of this report.
- Errors associated with faulty reading of dip stick measurements.
- Errors associated with resolution in meter readings. All meters have an associated level of error, typically on the order of 0.5% of the level of resolution of the meter.

Given these limitations in accuracy, even a carefully conductd inventory monitoring program can only detect leaks that are an appreciable fraction (typically 0.75%) of the stored volume. It should be emphasized that inventory control, conscientiously followed, is the first defense against leaks. Measuring the liquid level, (and the water level with a water finding paste) twice a day and comparing these levels with product deliveries and sales will indicate trends of product loss or water gain in a short time. Major oil companies require inventory records. Any unreported losses become the responsibility of the operator and reports of consistent product losses are followed by testing the suspected tank for leaks .

2. Interstitial Monitoring in Double-Walled Tanks

An early warning monitoring technique characteristic of double-walled tanks involves monitoring the space betwen the inner and outer walls of the tank, using either fluid sensors or pressure sensors. Pressure sensors would be used to monitor tanks that either have a vacuum drawn in the space between walls, or have that space pressurized. Failure of either the inner or outer wall is detected by loss of vacuum or pressure. Fluid sensors, on the other hand, would be located between the tank walls to detect the presence of a liquid due to failure of the inner wall (detecting stored product) or the outer wall (detecting water). (These systems may be applied at atmospheric pressures to vaulted tanks.)

3. Tank Excavation Monitoring Sensors

Tank excavation monitoring systems are aimed at detecting a spill or leak before the contamination spreads beyond the tank excavation or its immediate surroundings. The leak or spill sensing mechanisms that may be used in tank excavation monitoring systems include thermal conductivity sensors, electrical resistivity sensors, gas detectors and sample analysis.

Thermal Conductivity Sensors [1.2]. Thermal conductivity sensors detect changes in the thermal conductivity of their surrounding environment to determine if a leak or spill has occurred. These types of sensors can be used in wet or dry applications (i.e. areas of either low or high groundwater), and are particularly applicable for the detection of hydrocarbons such as gasoline, gasohol, fuel oils, alcohols, and trichloroethylene.

A system using a thermal conductivity sensor typically consists of an electronic control device that is connected by cable to a thermal conductivity probe. The probe is fitted with a sensor that determines if the monitored area is dry, wet with water, or wet with some other substance. The control device may be located up to 1,000 feet from the probe and can continuously indicate the site condition through indicator lights. A non-water liquid presence may also be indicated by an audible alarm, and recorded using a chart recorder. A relay contact that can activate external alarms, recovery pumps or other automatic controls can also be provided.

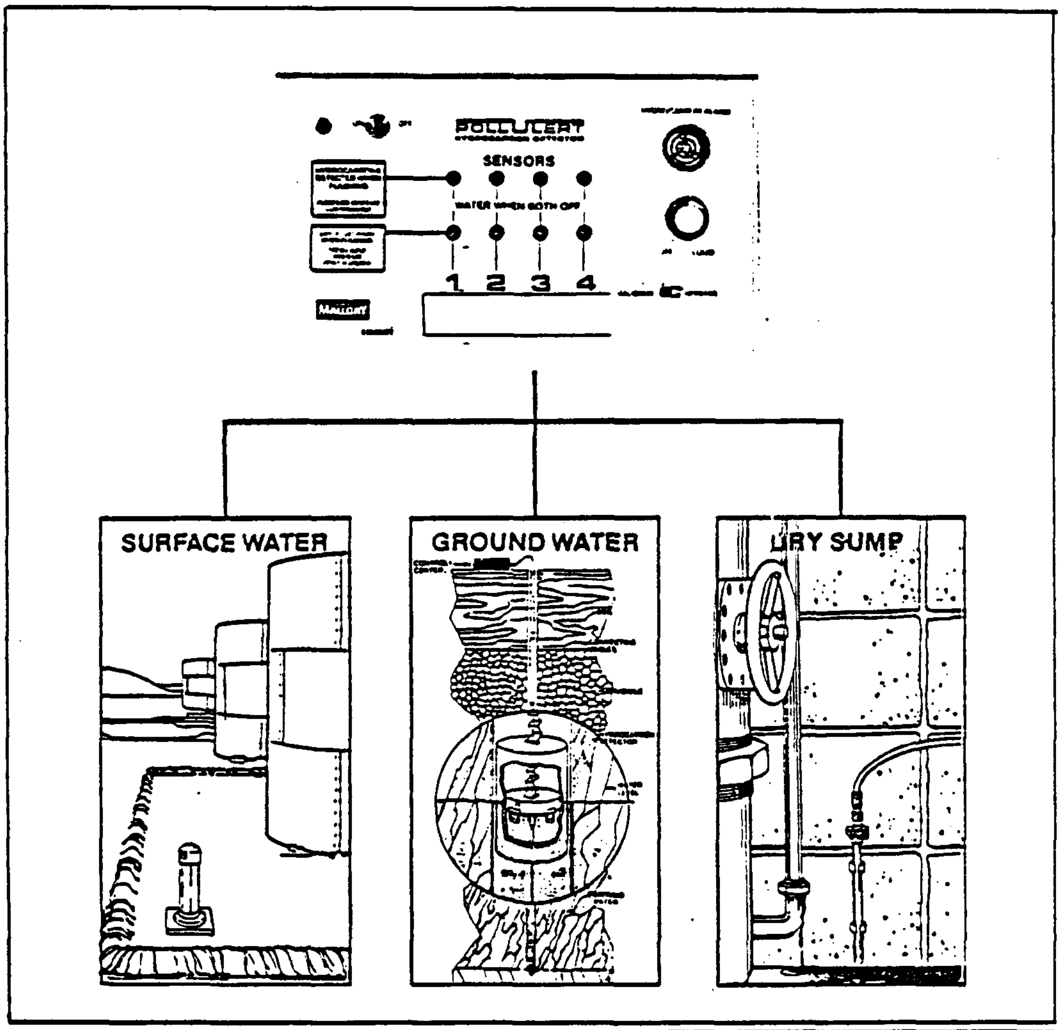
Figure 2.5-1 shows examples of thermal conductivity sensors installed in a diked area, a dry well or sump, and a wet well (in the groundwater table). When used to monitor a groundwater table, one sensor located in a monitoring well will only indicate the presence of contamination but not the extent of it. By using several sensors located at various levels the thickness of the contaminant layer may be ascertained.

Electrical Resistivity Sensors [3]. Systems employing this leak detection technique rely on the change in resistance in a wire due to exposure to the stored product to indicate the presence of leak or spill. The key to systems of this type is the use of wires or wire coatings that are highly susceptible to degradation when exposed to stored product. For example, bare steel wires may be used in acid storage areas or bare aluminum wires may be used in areas storing caustics. Correspondently, if the stored liquid is not corrosive to metals, the wires must be coated with a degradable material, such as rubber coatings in areas storing aromatic solvents. The wires in turn are connected to an electrical sensing device that passes a current through them to evaluate their electrical properties. Any degradation of the wire or its coating will result in a significant change in the circuit resistivity, thus indicating the existance of a product leak or spill.

Electrical resistivity sensors are applicable for either dry or wet (in groundwater) applications. Ambient temperature and soil moisture should have minimal effects on sensors of this type, particularly in applications involving coated wires. The drawbacks of these types of leak detection devices include the following:

Figure 2.5-1

Typical Applications of a Leak Monitoring System Based on Thermal Conductivity



Source: Reference 1

- Once a leak has been detected, the sensing wire must be replaced.
- They cannot be used in a previously contaminated well or soil unless the contamination has been removed. Otherwise they will rapidly deteriorate and require replacement.

The control units associated with electrical resistivity sensors can be designed to interface with audible alarms, visual alarms (e.g., indicator lights), control equipment such as pumps or valves, and computer controls. Occasional checks of systems of this type would be required to insure that the power supply and all controls are in working order.

Gas Detectors [4]. Gas detectors are available to detect a large number of combustible and non-combustible gases and vapors. These types of devices are generally applicable in areas of permeable soil or backfill, where gases and vapors are likely to migrate easily. Gas detectors are particularly applicable in instances where the stored product is highly volatile and the storage area (excavation) is relatively dry (free of groundwater).

There are a wide variety of both portable and permanent gas detection devices available that may be operated in conjunction with audible or visual alarm systems.

Sample Collection. Sample collection typically involves collecting samples from a well in the excavation area. Sample collection is an accurate but expensive method of leak detection that is particularly applicable in areas of high groundwater where direct groundwater contamination is of concern. Sample analysis can be performed using any of several techniques such as mass spectrometry and gas chromatography; therefore sample collection can be used to detect any stored product. However, sample collection is an intermittent as opposed to a continuous monitoring technique; sample cannot be collected 24 hours a day, 365 days a year. Therefore, sample collection may not be as desirable a monitoring technique as those described above.

4. Tank Excavation Monitoring Systems

There are several types of leak monitoring systems which may be employed using the leak sensors or detection techniques described above to detect leaks in or around underground tank storage areas. These system types include the following:

- Wire grids.
- Observation wells.
- U-tubes.

Table 2.5-2 summarizes the applicability of the types of leak sensors of detection techniques described above to these types of leak monitoring systems.

Wire Grids. This type of leak detection system employs electrical resistivity sensors in a wire grid located either within or just outside the containment region (e.g. just inside or outside the containment area synthetic liner). The wire grid is connected to a mini-computer that continuously monitors the electrical properties of each wire in the grid. If a leak occurs, the mini-computer can determine which wires in the grid have had their electrical properties altered, thereby identifying the location and extent of the leak. A drawback of this type of system is that is is susceptible to disabling by a spill. The insulation around the grid wire is dissolved, thereby registering a change in resistivity.

Observation Wells. Observation wells are most commonly used in areas of high groundwater, where the underground tank is likely to be anchored in the groundwater during normal operation. They may employ any of the types of leak sensors described above to provide continuous leak surveillance. An example of an observation well installation is shown in Figure 2.5-2.

Observation wells typically consist of a 4 inch diameter (schedule 40) PVC pipe driven into the tank excavation. The wells are constructed with a well screen long enough to provide a length of 5 feet or more above the water table, or to the well cap, and extending a minimum of 5 feet into the groundwater or 2 feet below the tank bottom, whichever is greater. Well screens typically have a slot size of 0.02 inches, and are extended to grade and covered with a water proof cap which is capable of being sealed.

U-tubes. A U-tube typically consists of a 4 inch diameter (schedule 40) PVC pipe installed as shown in Figure 2.5-3. The horizontal segment of the pipe is half-slotted (typical slot size - 0.06 inches), wrapped with a mesh cloth to prevent backfill infiltration, and sloped (pitched) toward the sump with a slope on the order of ¼ inch per foot. At the higher end of the pipe there is a 90 degree sweep to a vertical pipe that is extended to grade. At the other (lower) end of the hori-

Table 2.5-2

Applicability of Types of Leak Sensors in Tank Excavation Areas

Sensor Type	Sruveillance Method		
	Observation Wells	U-tubes	Wire Grids
Thermal Conductivity	X	X	
Electrical Resistivity	X	X	X
Gas Detectors	X	X	
Sample Collection and Analysis	X	X	

zontal pipe there is a tee connection with a vertical pipe; this vertical section is extended to grade, and extended 2 feet below the tee to act as a collection sump. All vertical pipe sections are unperforated, and the bottom of the sump is sealed so as to be leak proof. All openings to grade are provided watertight caps capable of being sealed.

The U-tube is a relatively new design that has not been extensively tested in the field. It appears to offer an economical method for monitoring and recovery of leaks and spills at underground installations. When the U-tube is installed without an underlying impervious liner it functions on the assumption that a leak will trickle downward along the exterior surface of the tank and drip off the very bottom directly into the U-tube. When installed with an underlying impervious liner, the U-tube will collect all liquids moving downward through the soil in the vicinity of the tank including rainwater. This provides positive assurance of collecting a leak from a tank but presents a problem with removal of rainwater which floods out the system.

U-tube monitoring systems, as shown in Figure 2.5-3, are most effective in areas of low groundwater, where it is unlikely that the tank will be exposed to groundwater during normal operation. However, U-tube installations can be used in conjunction with observation wells in areas where the groundwater table level is known to fluctuate to a level above the bottom of the storage excavation.

U-tubes may employ any of the leak detection devices discussed above to provide continuous surveillance of the storage installation.

C. AREA-WIDE SURVEILLANCE METHODS

Area-wide surveillance methods include the use of monitoring wells and the use of dyes or tracers. These methods are relied upon to investigate or pinpoint the source of a known leak or spill.

1. Dyes and Tracers

Dyes and tracers may be used as investiative tools to track down a source of groundwater contamination. The technique consists of injecting a strong dye or tracing material into a storage tank suspected of being the source of the contamination and monitoring the point where the contamination was first discovered for the appearance of the dye or tracer. A variety of dyes and tracers are available and include organic and fluorescent dyes, metallic tracers, ultraviolet tracers, and radioactive tracers. The use of dyes and tracers is governed by the prohibitions and limitations of the New York State DEC Ground Water Effluent Standards (Title 6, Official Compilation of Codes, Rules and Regulations, Part 703).

Rhodamine B is a fluorescent dye generally recomended for time-of-travel and dispersion measurements. Fluorescein and Rhodamine dyes are also typically used for groundwater applications. Pontacyl Pink is a good tracer dye, but is usually more costly than the others. In addition, detection of this dye requires a fluorometer [8].

Techniques that utilize radioactive tracers as detection elements may also be used to pinpoint the source of an underground spill. These techniques consist of injecting a small amount of a radioactive material such as tritium into the underground storage tank or pipeline and using a detection device to track its movement through the soil or groundwater [13]. However, there are a number of problems associated with the use of radioactive tracers including the following:

- A license or approval from the U.S. Department of Labor or the Nuclear Regulatory Commission will be required before such materials can be used.
- There are portential ecological and health hazards associated with the use of radioactive materials in this manner. Whatever materials are injected into a leaking tank will enter and remain in the environment, possibly generating a problem more serious than contamination of the environment with the stored product.

Monitoring techniques using dyes and tracers are often unsuccessful for several reasons:

- If only vapor is found at the discovery point, the dye or tracer may be useless [6].
- The dye or tracer may be absorbed by the soil or bleached by chemicals in the soil before it reaches the point of discovery [6].
- If underground flow is very slow, the site will have to be monitored for a long time to detect any leaked dye or tracer [6].
- The dye or tracer may contaminate underground water supplies [6]
- The dye or tracer may contaminate the product [6].

2. Monitoring Wells

Monitoring wells are typically employed as areal surveillance tools; they are used to investigate the movement of either a liquid or a gas in the ground.

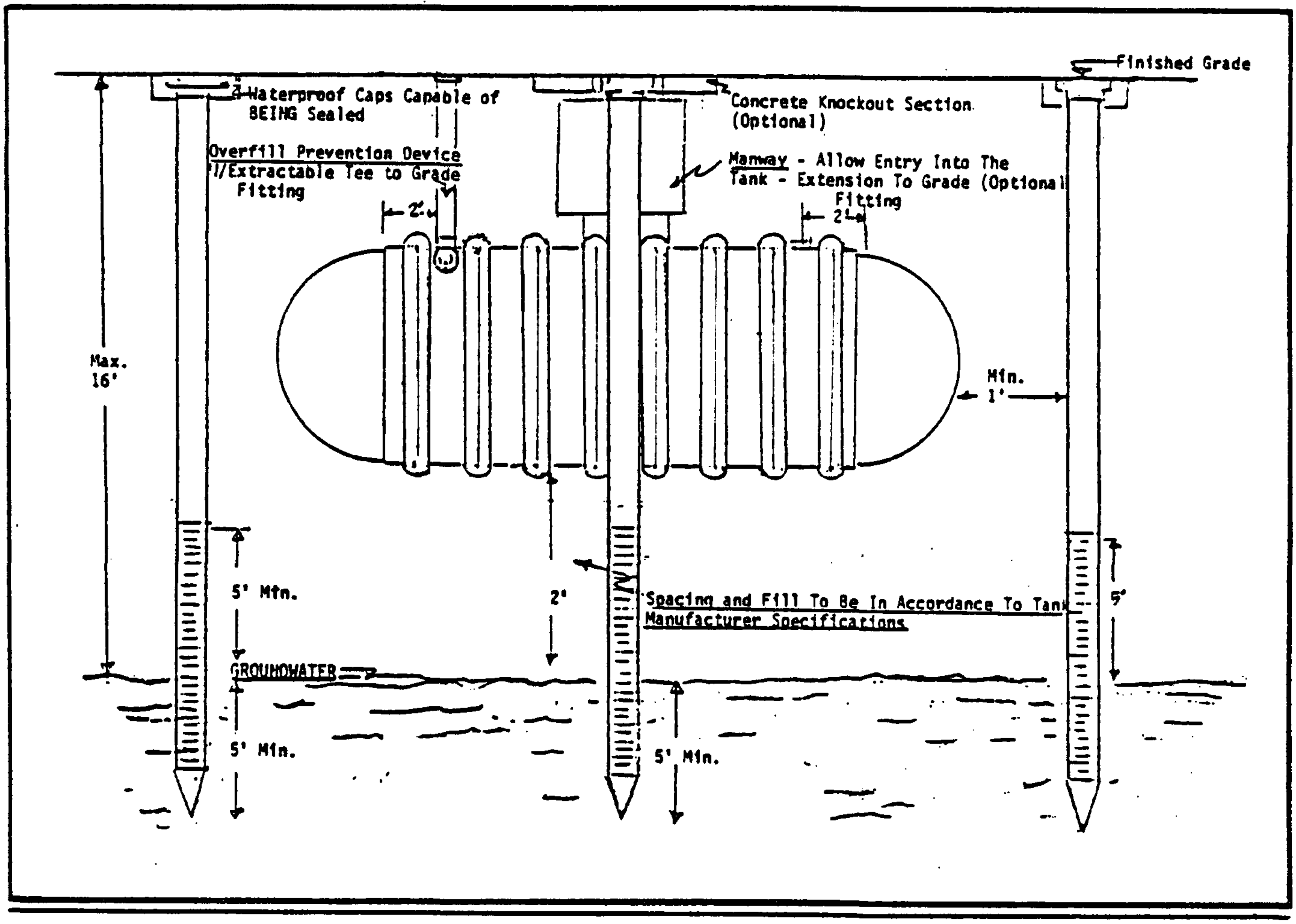
There are two basic types or categories of monitoring tht can be conducted using monitoring wells. These are:

- Detective monitoring, which establishes the presence or absence of contaminants and the need for further monitoring.
- Interpretative monitoring, which determines the extent of contamination.

Detective monitoring can be conducted using contaminant sensing devices such as those described earlier in this chapter. Interpretative monitoring, on the other hand, typically requires a sample collection and analysis.

Figure 2.5-2

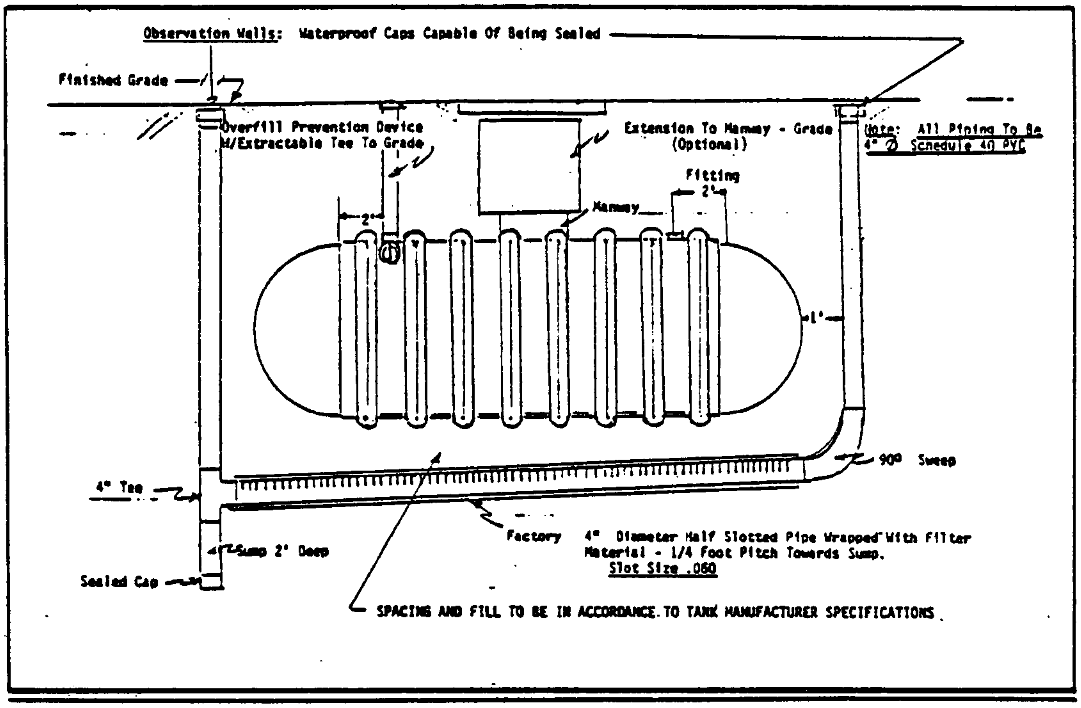
Examples of Observation Wells. Each Well Consists of 4" Perforated PVC Pipe, Driven at Least 2 Feet Below the Bottom of the Tank and at Least 5 Feet into the Groundwater



Source: Adapted from Reference 15

Figure 2.5-3

Example of a U-Tube Installation



Source: Adapted from Reference 15

In the effective administration of a monitoring program using wells, it is important to have some understanding and appreciation of hydrogeology and its limiting influences on areal surveillance. Monitoring the movement of a contaminant in the soil or groundwater is completely different from monitoring a surface water or an air pollution plume; the main differences are the unpredictability and the difficulty and expense of obtaining representative data.

A listing of the type of data necessary to develop an adequate monitoring well program is given in Table 2.5-3. These data lead to the key item in deciding the location and depth of any monitoring wells that must be driven: a determination of the location and flow pattern of the groundwater and the contaminant.

The limitations of monitoring well techniques include the following:

- A monitoring well is used to sample a very small part (a point) of the soil or groundwater, thereby limiting its representativeness to the quality of the soil or groundwater in the immediate vicinity of the well.
- The extraction of samples from wells may be difficult due to the tightness of the geological formation or the depth to the groundwater.
- Determination of the groundwater flow rate and direction are prerequisites to determining the placement of groundwater monitoring wells. Drilling and measurements of the groundwater surface may be necessary.
- Groundwater flow rates are extremely slow (typically varying from one foot per day to much less), resulting in a correspondingly slow change in water quality at a particular well. This phenomenon could require data collection over long periods of time (months or years).

The attempt has been made here to emphasize the fact that the design and construction of a monitoring well program can be a complicated undertaking. For more detailed information see references 10, 11 and 12.

Vapor Wells. Vapor wells or sniff wells may be used to detect or monitor the presence of hazardous gases or vapors in unsaturated soil. That is, these types of wells may be used in permeable soils in the region above the groundwater table where vapors or gases are more likely to migrate.

Vapor wells typically employ gas detectors on permanent probes or portable gas sampling devices to monitor for gaseous contaminants. These types of devices will detect a large number of combustible and non-combustible gases and vapors. It should be noted that many contaminants have odors that can be manually detected, even at low concentrations. Gasoline, for example, can be detected by smell at concentrations as low as 0.1 mg/l (of water).

Vapor wells are an advantageous means of detecting volatile soil contaminants before they are dissolved into the groundwater. However, their primary use is in indicating the presence of a contaminant. Once contamination has been detected, the vapors will remain present until cleanup; another monitoring technique (e.g. sample collection) will be required for further monitoring until that cleanup occurs.

A typical vapor well installation is shown in Figure 2.5-4.

Table 2.5-3

Types of Site Data Needed to Design an Appropriate Groundwater Monitoring Program

Geologic:

- surface geology (topography and type/depth of overburden)
- lithology of aquifer
- type of geology formation (local stratigraphy and structure)

Hydrogeologic:

- depth to water table
- water-table contours
- thickness of aquifer(s)
- relative hydraulic heads, if more than one aquifer
- annual precipitation
- aquifer permeability and porosity

Geochemical:

- Background water quality
- chemistry of geologic formation
- presence of other sources of chemical or biological contamination.

Source: Reference 10

Groundwater Monitoring Wells. Groundwater monitoring wells, or wet wells, may be used to detect or define the movement of a spilled or leaked substance in a groundwater table.

These types of wells are typically constructed of a PVC well casing that is screened or perforated in the region that is being sampled. The material used to fill the well borehole must be permeable to allow water to flow into the screened area of the casing. The well may be monitored using instruments such as the sensors described above, or samples may be collected manually for laboratory analysis.

There are various types of groundwater monitoring wells that may be used to detect and define groundwater contamination. These include the following:

- A well screened or open over a single vertical interval.
- A well cluster.
- A single well with multiple sample points.

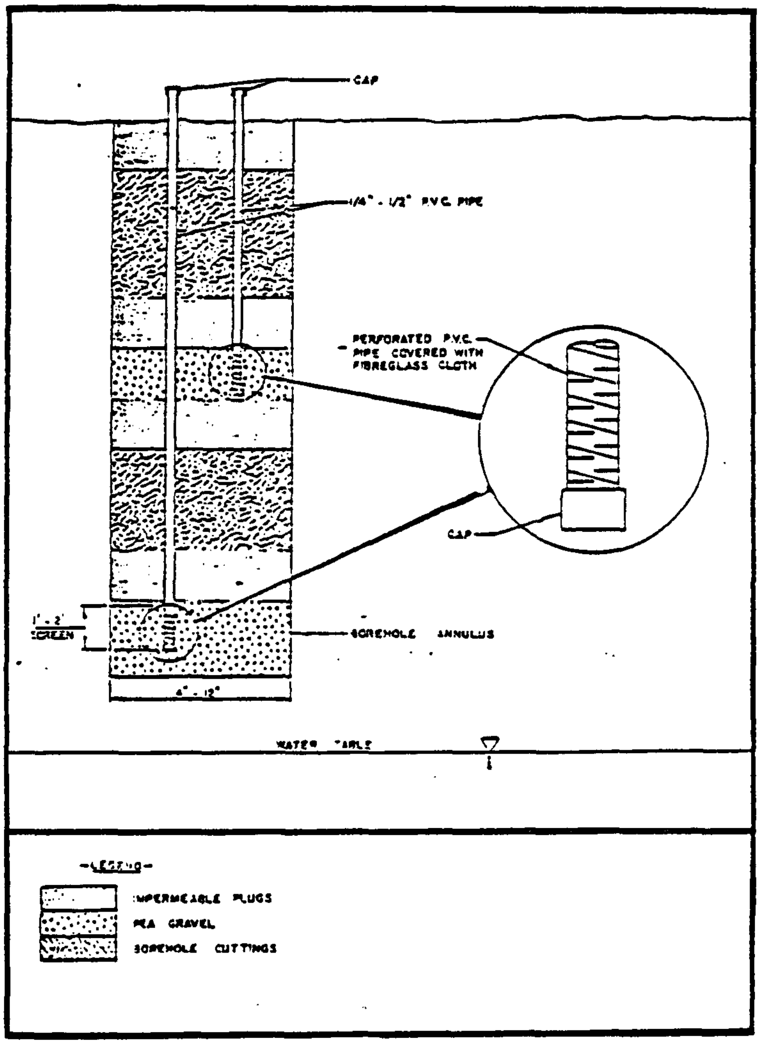
These advantages and disadvantages of these configurations are summarized in Table 2.5-4 and described below.

Wells Screened Over a Single Interval. An example of a well screened over a single verticle interval is shown in Figure 2.5-5. This type of monitoring well configuration is routinely used to monitor groundwater contamination. However, a single well screened in such a manner is not effective in providing information on the vertical distribution of a contaminant.

Well Clusters. Investigators have used well clusters to define the vertical distribution of a contaminant in the groundwater. As shown in Figure 2.5-6, each cluster consists of a group of closely-spaced wells completed at different depths. From these wells, water samples that are representative of different levels in the groundwater table can be collected. Thus, careful placement of well clusters will allow delineation of both vertical and areal contaminant distribution. However, regardless of the selected depths of the wells in each cluster, there will remain unsampled regions through which contaminant may pass undetected.

Figure 2.5-4

Typical Wells for Continuous Gas or Vapor Monitoring



Source: Reference 4

Table 2.5-4

Types of Groundwater Monitoring Wells

Type of Well	Advantages	Disadvantages
Well Screened or Open Over a Single Vertical Interval	Can provide composite groundwater samples if screen covers saturated thickness of groundwater table.	No information is given on the vertical spread of the contaminant.
		Improper completion depth can cause error in determining the spread of contamination.
		Screening over much of the aquifer thickness can contribute to vertical movement of contaminant.
		The contaminant may become diluted in the composite sample, resulting in lower-than-actual concentrations.
Well Clusters	Excellent vertical sampling made possible if sufficient number of wells are constructed.	If only a few wells are installed, large vertical sections of the aquifer are not sampled. Artificial constraint on data by completion depths.
	"Tried and true" methodology, accepted and used in most contamination studies where vertical sampling is required.	Small diameter wells can be used only for monitoring. They cannot be used in abatement schemes.
	Low cost if only a few wells per cluster are involved and if the drilling contractor has equipment suitable for installation of small-diameter wells (1-4 inches in diameter).	In small-diameter wells, development and sample collection become tedious and difficult if water is below suction lift.
Single Well-Multiple Sample Points (Nested Well)	Excellent information gained on vertical distribution of the contaminant.	Relatively expensive.
	If necessary, well diameter is large enough for use with pumping equip-equipment.	Proper well construction and sampling procedures are critical to successful application.
	Sampling depths are limited only by the size and lift of the pump.	It is possible to skip large sections of the groundwater table and thereby miss the contamination plume.
	Rapid installation possible.	

Source: Reference 10.

Single Well – Multiple Sample Points. Another method used to provide sampling at multiple levels in the groundwater table is to use multiple sampling points in the same well. This type of monitoring well is called a nested well. An example of such a well is shown in Figure 2.5-7. This technique requires great care in construction of the well and isolation of the various sampling depths.

Another method has been recently developed by the Suffolk County, N.Y. Health Dept. It involves the use of a hollow stem auger to drill a sampling well which is first pumped and sampled at the deepest desired level. The screen is then withdrawn to the next sampling level, pumped and sampled again. The process is repeated until the top of the water table is reached. The well screen is usually set there. [17]

D. RECOVERY WELLS

Recovery wells may be used to recover oil or any other hazardous liquid that has been spilled and is floating on the groundwater table. Such wells are located so as to take advantage of natural gradients or induced gradients in the groundwater table in drawing out the contaminated water. Through judicious placement and operation of recovery equipment, the spill can be concentrated in one of a few recovery sites.

The factors that must be considered when establishing a recovery well program include:

- The required pumping rate to recover product from the groundwater.
- The establishment of a well network that insures adequate coverage of the spill.
- The prevention of soil contamination during recovery operations.
- Existing environmental and public health standards which will be used to determine when spill recovery operations have been completed satisfactorily.
- The required depth of the recovery well.
- The geologic formation.
- The required well diameter.

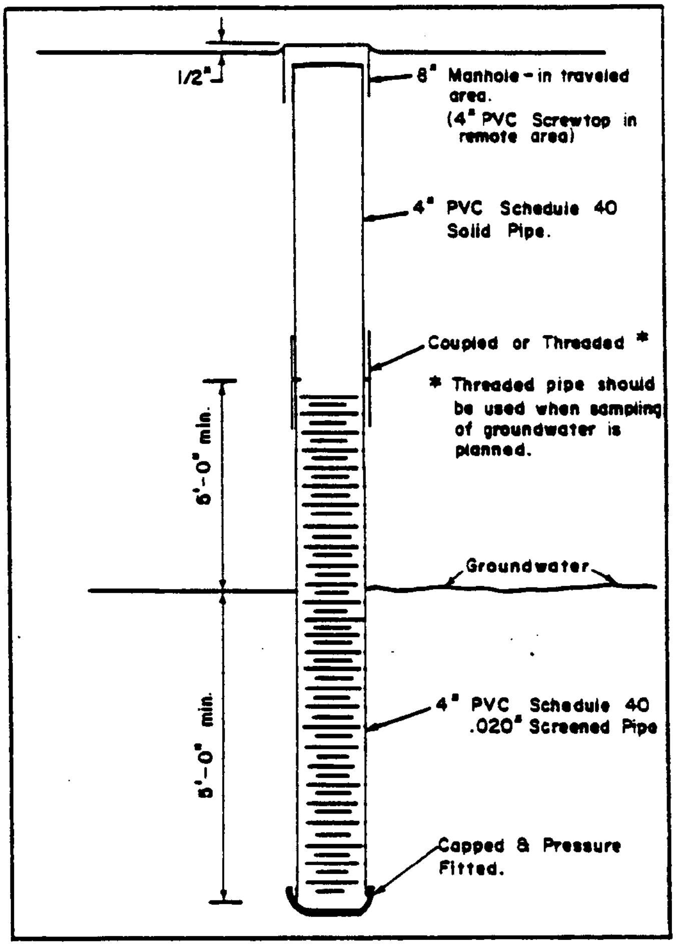
The information required to adequately address these factors is generally obtained through separate pumping tests and through consultation with a hydrogeologist [7]. Typical single pump and two-pump recovery systems are shown in Figures 2.5-8 and 2.59 respectively.

E. EXAMPLES

A partial list of manufacturers of leak detection systems and devices is presented in Table 2.5-5.

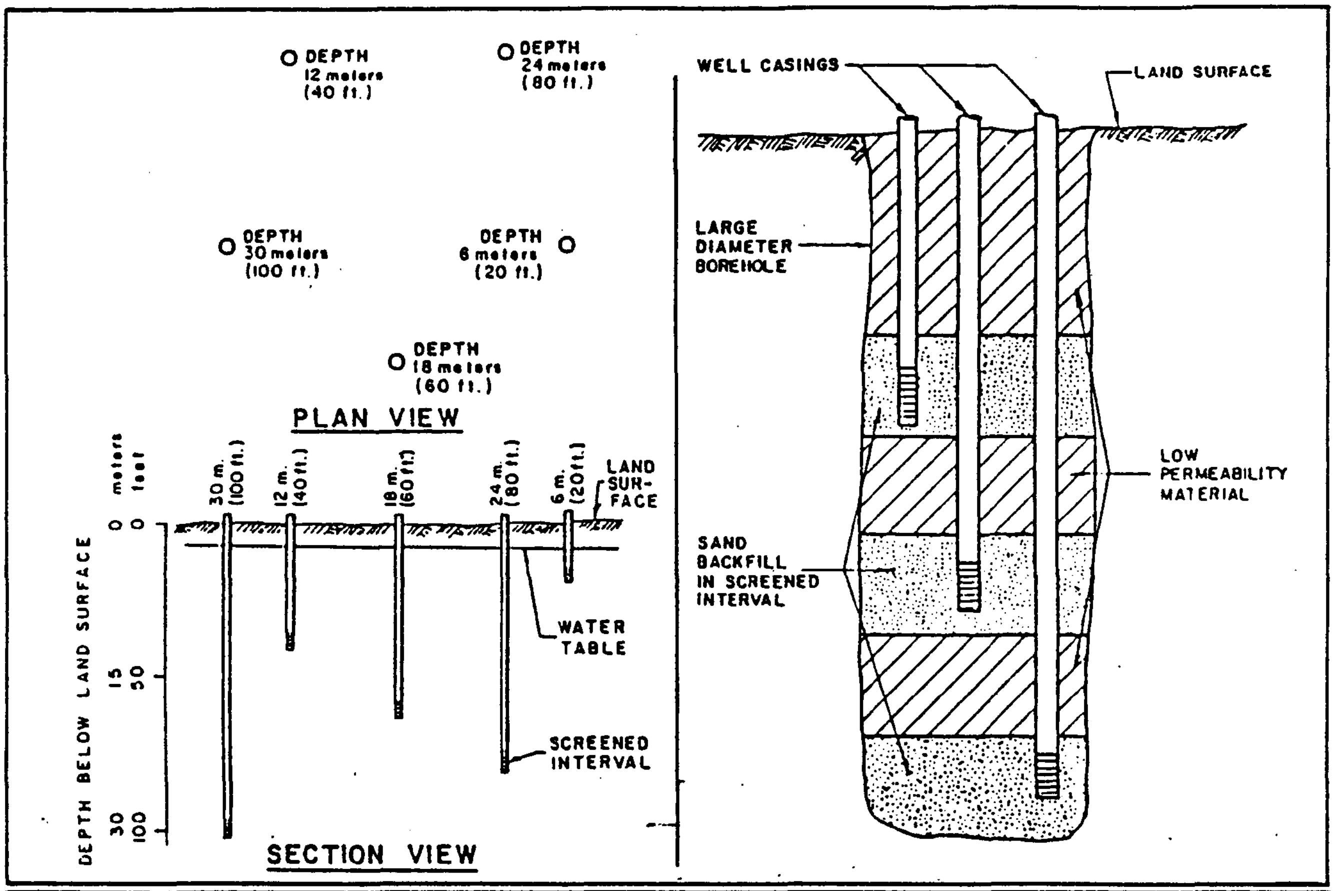
Figure 2.5-5

Typical Single Monitoring Wet Well



Source: Lawrence Peterec, P.E., New York State Department of Transportation, Oil Spill Prevention and Control Division.

Figure 2.5-6
Typical Wet Well Cluster



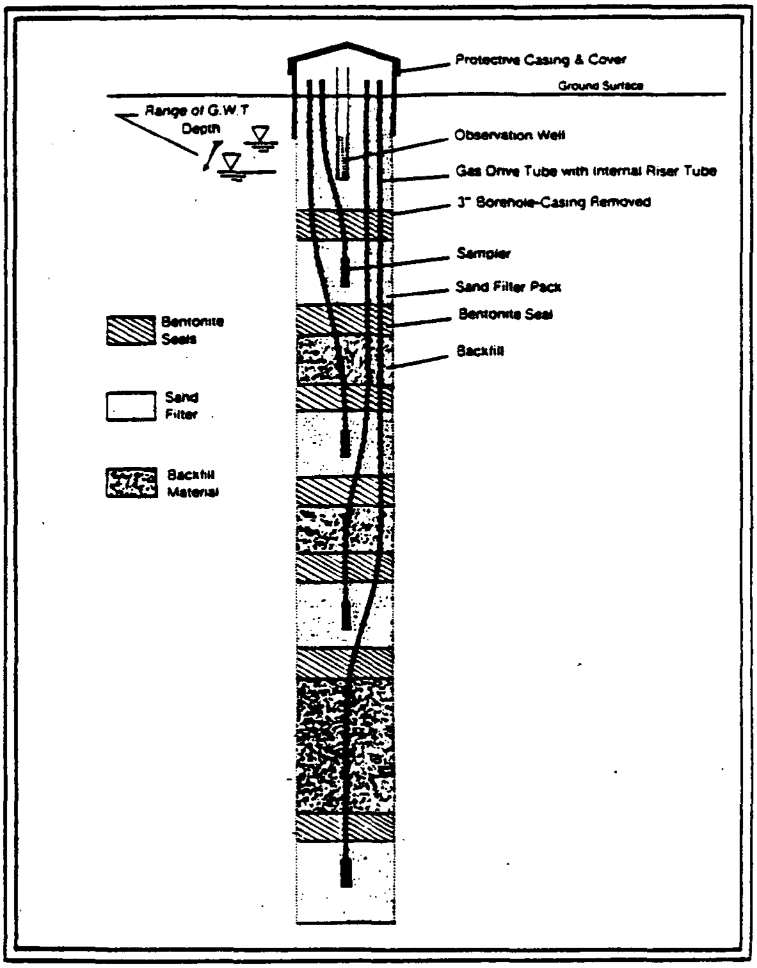
Source: Reference 10.

Table 2.5-5

Leak Detection System Manufacturers

Pollulert System	Pollullert System Mallory Components Group P.O. Box 706 Indianapolis, IN. 46206 (317) 261-1130
Leak-X Gas and Liquid Monitoring Systems	Leak-X Corporation 560 Sylvan Avenue Englewood Cliff, N.J. 07632 (201) 569-8989 (212) 822-6767
McTighe Hydrocarbon Detector	McTighe Industries, Inc. P.O. Box 370 Huntington, N.Y. 11743 (516) 549-0050

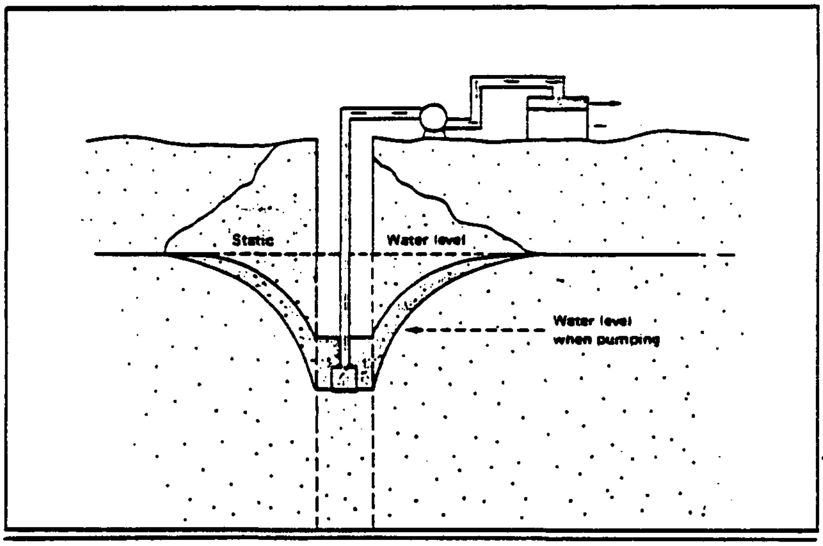
Figure 2.5-7
Schematic of a Typical Nested Monitoring Well System



Source: Reference 15.

Figure 2.5-8

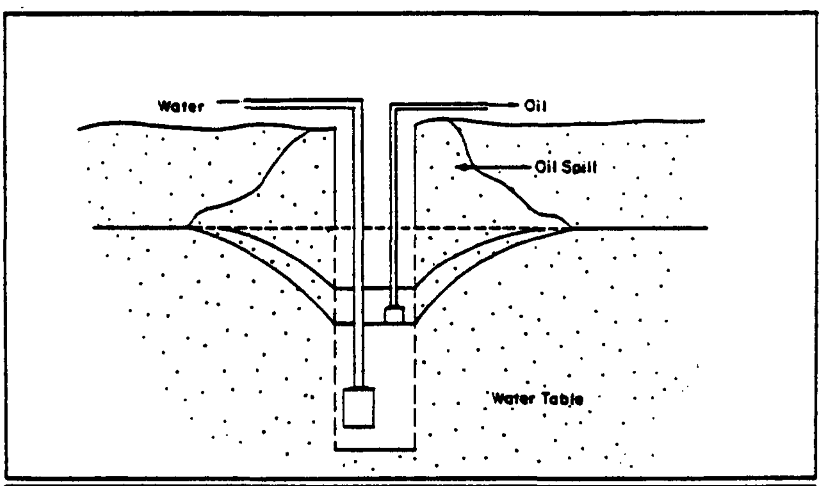
Typical Single-Pump Recovery System



Source: Reference 7.

Figure 2.5-9

Typical Two-Pump Recovery System



Source: Reference 7.

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Part II

CHAPTER 7: TEMPORARY CLOSURE, ABANDONMENT AND REMOVAL OF UNDERGROUND TANKS

A. INTRODUCTION

The use of proper procedures for the temporary or permanent closure of underground storage tanks is important for several reasons:

- Product that is left in the bottom of the tank (e.g. below the withdrawal line) will eventually leak out, leading to potential environmental contamination and health hazard problems.
- Empty tanks left in place underground may be used for illegal storage or disposal of hazardous wastes.
- Improperly closed tanks may be accidently filled with a material that is incompatible with the previously stored material.
- Accidental intrusion into the abandoned tank site may occur. A classic example of such is children playing near an abandoned gasoline storage tank, where a casually discarded lit cigarette or match can lead to catastrophe.
- A tank may be reused in a sensitive application, such as for food product storage, without being properly cleaned and decontaminated.
- Tanks left empty may eventually collapse.
- An empty, forgotten tank could pose a long term threat, such as explosion, if site is excavated.

The options available for the temporary or permanent closure of an underground storage system are:

- Temporary closure: the tank and piping system are emptied and sealed so as to be "temporarily out of service".
- Abandonment in place: the tank and piping system are emptied and sealed and the tank is filled with an inert material.
- Removal for reuse or disposal: the tank and piping system are removed from the ground after being emptied.

The concerns associated with these closure options are presented in the box below. The steps involved in each of the closure options are summarized in Table 2.7-1 and discussed in the remainder of this chapter.

B. TEMPORARY CLOSURE

Underground storage tanks may be considered temporarily closed or "temporarily out of service" if: (1) they are idle and in sound condition, and will be returned to service; (2) they are awaiting abandonment in place; or (3) they are awaiting removal from the ground. These are typically tanks that are intended to be returned to service within two years or are scheduled for abandonment or removal within 90 days.

Temporary closure practices include procedures to:

- Remove product from the tank.
- Cap the lines leading into the tank.
- Secure the tank against tampering.

The product removal requirements can be met in several ways. The best practice in most instances is to pump out the residual product and fill the tank with water containing a corrosion inhibitor. This practice minimizes the possibility of a leak developing while the tank lies dormant. In addition, such a practice is necessary in instances where ballasting is required to keep the tank in place due to a high groundwater table. It should be noted, however, that when the tank is reactivated for service a problem exists with the proper disposal of a large volume of contaminated water. This can be transported away from the location by a licensed hauler only and must be disposed of in a manner which takes into consideration applicable regulations governing air and water pollution abatement.

In situations where water fill is not used and the stored product was non-flammable, all product should be removed from the tank. In the case of flammable liquids, a sufficient quantity (approximately 4 inches) of product should be left in the tank to ensure a saturated vapor space. This saturated vapor space is needed to reduce the possibility of vapor explosions.

Concerns Associated With the Closure of Underground Storage Systems

- Monitoring the physical integrity of tanks during temporary or permanent closure procedures.
- Ensuring that product spills do not occur.
- Ensuring that the possibility of explosions of product vapors or fires are minimized or eliminated.
- Ensuring that illegal or accidental access to the tank is not possible.
- Ensuring to the extent possible that projected future uses of the site and surrounding environs are not adversely affected.

Specific information on residual volume amounts to ensure saturated vapor space should be available from the liquid manufacturer.

Table 2.7-1

Closure, Abandonment and Removal of Underground Tanks

Closure Practice	Reason for Practice and Circumstances of Application	Typical Procedures	Relative Costs
Temporary Closure ("temporarily out of service")	For sound tanks intended to be returned to service within two years or scheduled for abandonment or removal within 90 days.	Remove product from tank. The best approach is to remove all product and fill the tank with water and a corrosion inhibitor. In lieu of this: (1) remove all non-flammable product; or (2) remove flammable product, leaving sufficient quantity (approx. 4 inches) to assure saturated vapor space in tank; or (3) empty tank and fill with a CO_2 atmosphere.	Relatively low costs.
	Provides for safeguards against tampering or accidental use until ultimate fate of tank is determined.	Use concrete cast in place to cap all fill and draw-off lines, and cut off power to tank pumps.	
		Leave any vent lines open.	
Abandonment in Place	Permanent closure technique which avoids cost of tank removal.	Remove all liquid possible from tank and piping systems.	Relative costs range from low to high.
	Application dependent upon tank age and salvage values and projected use of site after closure.	Remove or disconnect and plug all fill, gauge and product lines and cap.	
		Purge remaining product by filling tank with water.	
		Tank may be opened and filled with an inert solid like sand, or be pumped full with a grout mixture.	
Tank Removal	For tanks intended for junking or reuse.	Remove all liquid from tank and piping system.	Relatively high costs.
	May be required by local regulation or because of the projected future use of the site.	Remove all tank connections and temporarily plug all openings.	
		Purge tank of flammable vapors. The sequence should be repeated until vapors are no longer evident.	
		Remove tank from ground. Safeguard against tampering (Vapors must be periodically monitored until final disposition. Vapor may be released from sludge and scale and again reach explosive level).	

In instances where the future use of the tank is to be different from or incompatible with the cement use, product removal practices also include procedures to wash down and rinse the tank.

All fill lines, gauge lines and product lines leading to the tank should be capped during the temporary closure to prevent casual or accidental use. For example, a concrete cap can be poured over the fill line; this cap can later be tapped out with a hammer. In addition, all power servicing pumps that are conducted to or mounted in the tank should be turned off to prevent casual or accidental use. However, vent lines sould be left open in the case of flammable liquids to prevent the accumulation and pressurization (due to high temperatures) of explosive vapors.

In general, the temporarily closed tank should be secured against tampering. The use of locked caps or concrete caps on all plugged lines, and the isolation of the tank area through the use of locked fence are examples of precautions which should be taken.

C. PERMANENT CLOSURE

The determination of whether to abandon a tank in place or remove it for reuse or disposal is dependent upon several factors, such as the age and condition of the tank, its salvage value, and its potential for reuse. Governmental regulations may require tank removal. Other factors that are important include the following:

- Tank Location. The depth to which the tank is buried and the type of soil in which it is buried will affect the ease, and hence, the cost, of tank removal. The potential for damage to concrete or asphalt traffic surfaces and nearby utilities should also be considered.
- Projected Use of the Site After Closure. If site plans call for development that involves excavation or regrading to the level of the tank, it is very likely that the tank will have to be removed.
- The Cost and Availability of Labor and Equipment. Tank removal will require the use of heavy equipment and experienced labor. If the cost of this labor and equipment are prohibitive, abandonment in place may be the preferred option.
- The Proximity of Disposal Site. The proximity of the disposal site can also greatly affect the cost of tank removal. Tank transportation costs could be prohibitive, making abandonment in place the preferred option.
- Regulatory Requirements. Local laws or ordinances may require removal of the tank as part of any permanent closure procedures.

1. Abandonment in Place

Practices for abandonment in place, or on-site closure of underground tanks must include procedures for:

- Removing all product.
- Disconnecting all plumbing and controls.
- Filling the tank with an inert solid such as sand, gravel or concrete. This is important to prevent subsidence of the ground above the tank if and when the tank corrodes or otherwide deteriorates.
- Capping all fill lines, product lines, vent lines, etc. to prevent future entry into the tank.

More detailed information on on-site closure of underground tanks is available in NFPA 30 [1] and API Publication 1604 [2].

2. Removal of Tanks

Practices for removal of tanks must include procedures for:

- Removing all liquid product.
- Disconnecting and capping all plumbing and controls.
- Temporarily plugging all tank openings except for a 1/8 inch hole for venting.
- Removing the tank from the ground.
- Freeing the tank of all flammable or toxic vapors.
- Transporting the tank from the site.

If the tank is to be disposed of, a sufficient number of holes should be made in it to render it unfit for further use. The reason for making holes in the tank is to discourage possible future use of it as a container for some edible products that would be contaminated by residual deposits of the material that was previously stored in the tank. Sources of more information on the disposal of storage tanks include NFPA 30 [1] and API Publication 1604 [2].

If the tank is to be reused, care should be taken to assure that the tank is properly cleaned and that the future use of the tank is compatible with the past use. For example, a tank that stored gasoline should not be used to store a product destined for human or animal consumption or a product that reacts adversely with gasoline. References for the proper cleaning and reuse of underground tanks include NFPA 327 [6] and API Publication 2015 [4].

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Appendix B
COMPATIBILITY CHART FOR FLUIDS, SEALS, AND METALS

Appendix B:

CHEMICAL–MATERIALS COMPATIBILITY

The following chart presents compatibility data for several common materials of construction, including: steel, stainless steel, and aluminum. Other excellent sources of information include the following:

1. Hamner, Norman, E., *Corrosion Data Survey*, Fifth Edition
   includes: A comprehensive compilation of corrosion data for metals and non-metals.
   available from: National Association of Corrosion Engineers
   1440 South Creek
   Houston, Texas 77084
   (713)492-0535

2. Gallagher, Raymond, "Beat Corrosion With A Rubber Hose"
   published in: *Chemical Engineering*, Sept. 8, 1980, pages 105-118,
   includes: Comprehensive information on the compatibility of various hose materials with a wide range of chemicals.
   available from: McGraw-Hill Book Company
   1221 Avenue of the Americas
   New York, N.Y. 10020
   (212)997-1221
   or
   Mr. Raymond Gallagher
   The Gates Rubber Company
   999 South Broadway
   Denver, Colorado 80217
   (303)744-4041

3. Perry, R.H., Chilton, C.H., *Chemical Engineers' Handbook*
   includes: A series of tables presenting corrosion resistance (chemical compatibility) data for several ferrous and non-ferrous metals, plastics, and natural and synthetic rubbers.
   available from: McGraw-Hill Book Company
   1221 Avenue of the Americas
   New York, N.Y. 10020
   (212)997-1221

COMPATABILITY CHART FOR FLUIDS, SEALS AND METALS

Resistance of Metals & Gasket Materials to Various Compounds

CODE: G = Good; F = Fair; P = Poor

FLUID	METAL: ALUMINUM	METAL: BRONZE	METAL: IRON	METAL: STEEL	METAL: ST. STEEL	SEAL MATERIAL: BUNA	SEAL MATERIAL: BUTYL	SEAL MATERIAL: NEOPRENE	SEAL MATERIAL: TEFLON	SEAL MATERIAL: VITON
Acetaldehyde	G	P	G	G	G	P	G	P	G	
Acetate Solvents - Crude	G	F	F	F	G	P	P	G	G	
Acetate Solvents - Pure	G	G	G	G	G	P		G	G	
Acetic Acid - Pure	G	G	P	P	G	F	F	F	G	
Acetic Anhydride	G	P	F	P	G	G	G	G	G	
Acetic - Glacial	G	G	P	P	G	G	G	G	G	P
Acetone	G	G	G	G	G	P	G	F	G	P
Acetyl Acetone	G	G	G	G	G	P	P	P	G	
Acetyl Chloride	F	F	F	G	G				G	
Acrylonitrile	G	G	G	G	G	P	F	G	G	
Aliphatic Hydrocarbons	G	G	G	G	G	G	P	G	G	G
Aluminum Chloride	F	F	P	P	F	G	G	G	G	
Aluminum Nitrate	G		P	P	G	G	G	G	G	
Aluminum Sulphate	G	F	P	P	G	G	G	G	G	
Ammonium Hydroxide	F	P	G	G	G	G	G	G	G	
Ammonium Liquors	F	P	G	G	G				G	
Ammonium Nitrate	G	P	G	G	G	G	G	G	G	
Ammonia, Anhydrous	G	P	G	G	G	G	G	G	G	
Ammonia, Aqua	F	P	G	G	G	F	G		G	
Amyl Alcohol	G	G	G	G	G	G	G	G	G	G
Anthracene	G	G	G	G	G				G	
Aromatic Hydrocarbons	G	G	G	G	G	G	F	F	G	G
Asphalt	G	G	G	G	G	F	P	F	G	
Aviation Gasoline	G	G	G	G	G	G		G	G	G
Beer - Beer Wort	G	G	F	F	G	P	G	G	G	G
Benzene - Benzol	G	G	G	G	G	P	F	P	G	F
Benzyl Alcohol	G	G	P	P	G	P	G	G	G	G
Benzyl Chloride	P	P	P	P	G	P	G	P	G	
Brines		G					G		G	
Butadiene	G	G	G	G	G	G			G	G
Butane	G	G	G	G	G	G	P	G	G	G
Butyl Acetate	G	G	G	G	G	P	F	F	G	
Butyl Alcohol - Butanol	G	G	G	G	G	G	G	G	G	G
Butyl Ether	G	G			G	F		P	G	
Butylene	G	G	G	G	G	G			G	G
Calcium Hydroxide	F	G	G	G	G	G	G	G	G	G
Calcium Nitrate	F	G	G	G	G	G		G	G	G
Carbitol Solvent	G	G				G	G	G	G	G
Carbolic Acid - Phenol	G	G	P	P	G	P	P	P	G	
Carbon Disulphide	G	F	G	G	G	P	P		G	G
Carbon Tetrachloride	F	G	F	G	G	F	P	F	G	
Carbonic Acid	G	P	P	P	G	F	G	G	G	
Castor Oil	G	G	F	F	G	G	G	G	G	G
China Wood Oil - (Tung Oil)	G	G	F	F	G	G		G	G	G
Chloroacetone	P	G		G				G	G	
Chloroethane		G			G	P		P	G	
Chloroform	G	G	G	G	G	P	P	P	G	
Chlorobenzene	G	G	G	G	G	P	P	P	G	
Chlorine - Dry	F	F	G	G	G	F	F	F	G	
Chlorine Gas	F	G	G	G	G				G	
Chloromethane	G	G	F	F	G	P		P	G	
Citric Acid	G	F	P	P	G	G	F	G	G	G
Corn Oils	G	G	G	G	G	G	G	F	G	G
Cotton Seed Oil	G	G	G	G	G	G	G	G	G	G
Creosol	G	G	G	G	G	P	P	G	G	
Creosote, Crude	G	F	G	G	G	G	P	F	G	G
Cresylic Acid	G	G	G	G	G	G	P	P	G	G
Cumene	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			G	G	
Cutting Oils	G	G	G	G	G	G			G	G

FLUID	METAL: ALUMINUM	METAL: BRONZE	METAL: IRON	METAL: STEEL	METAL: ST. STEEL	SEAL MATERIAL: BUNA	SEAL MATERIAL: BUTYL	SEAL MATERIAL: NEOPRENE	SEAL MATERIAL: TEFLON	SEAL MATERIAL: VITON
Cyclohexane	G	G	G	G	G	G	P	G	G	G
Cyclohexanol	G	G	G	G	G	G		G	G	G
Cyclohexanone	G	G	P	G	G	P	F	P	G	
Detergent Oils			G	G	G	G		G	G	G
Diacetone Alcohol	G	G	G	G	G	P	G	F	G	
Dichlorobenzene	G	G	P	P	G	P	P	P	G	G
Dichloro Ethane	G	G		G	G	F			G	
Dichloro Ethylene	G	G	G	G	G	P	P	P	G	
Diesel Oil	G	G	G	G	G	G			G	G
Diethyl Ether	G	G	G	G	G	F		G	G	
Diethyl Phthalate		G	G	G	G	P		P	G	
Diethylene Glycol	G	G	G	G	G	G		G	G	G
Ethyl Acetate	G	G	G	G	G	P	F	F	G	
Ethyl Alcohol	G	G	G	G	G	G	G	G	G	G
Ethyl Benzene	G	G	F	F	G	P	P	P	G	
Ethyl Benzoate	G	G	G	G	G	G	P	P	G	G
Ethyl Chloride	G	G	G	G	G	G	G	G	G	G
Ethyl Ether	G	G	G	G	G	F	F	F	G	
Ethylene Chloride	G	G	P	G	G				G	
Ethylene Glycol	G	G	G	G	G	G	G	G	G	G
Ethylene Oxide	G	F	G	G	G	F		P	G	
Fatty Acids	G	F	P	P	G	G	F	F	G	G
Foods	G				G				G	
Formaldehyde	G	G	F	F	G	G	G	G	G	G
Formic Acid	G	F	P	P	G	P	G	P	G	
Freon, Dry	G	G	G	G	G	G	F	P	G	G
Fuel Oil	G	G	G	G	G	G	P	G	G	G
Gas, Natural - Manufactured	G	G	G	G	G	G	P	P	G	G
Gasolene, Sour	G	F	F	F	G	G	P	G	G	G
Gasolene, Motor	G	G	G	G	G	G	P	G	G	G
Gasolene, Aromatic	G	G	G	G	G	F	P	P	G	
Gasolene, Aviation	G	G	G	G	G	F	P	P	G	G
Glycerine - Clycerol	G	G	G	G	G	G	G	G	G	G
Grease	G	G	G	G	G	G	F	G	G	G
Heptane	G	G	G	G	G	G		G	G	G
Hexane	G	G	G	G	G	G	P	G	G	G
Hexanol - Hexyl Alcohol	G	G	G	G	G	G		G	G	G
Hi-Boiling Naptha		G			G				G	G
Hi-Flash Naptha		G			G				G	G
Hydraulic Oil		G			G	G	G	F	G	G
Hydrochloric Acid, 150°	P	P	P	P	P	G	G	G	G	G
Hydrogen Peroxide	G	P	P	P	G	G	G	G	G	G
Hydrogen Sulphide, Wet	G	F	G	G	G	F	G	F	G	
Isoctane	G	G	G	G	G	G	P	G	G	G
Isopentane		G			G	G			G	G
Isopropyl Acetate	G	G	G	G	G	P	G	P	G	
Isopropyl Alcohol	G	G	F	G	G	F	G	F	G	G
Isopropyl Ether	G	G	G	G	G	G	P	F	G	G
Jet Fuel - JP 4 JP-5	G	G	G	G	G	G	P	F	G	G
Kerosene	G	G	G	G	G	G	P	G	G	G
Lacquer Solvent	G	F	F	F	G	P	P	P	G	
Lactic Acid	G	F	P	P	G	F	F	F	G	

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COMPATABILITY CHART FOR FLUIDS, SEALS AND METALS

FLUID	METAL					SEAL MATERIAL				
	ALUMINUM	BRONZE	IRON	STEEL	ST. STEEL	BUNA	BUTYL	NEOPRENE	TEFLON	VITON
Lard - Lard Oil	G	G	G		G	G	F	G	G	G
Linseed Oil	G	G	G	G	G	G	G	G	G	G
Lube Oil	G	G	G	G	G	G	P	G	G	G
Methyl Alcohol - Methanol	G	G	G	G	G	G	G	G	G	G
Methyl Amyl Alcohol	G	G			G	F		P	G	
Methyl Amyl Acetate	G	G			G	P		P	G	
Methyl Acetate	G	G	G	G	G	P		P	G	
Methyl Chloride	P	P	P	P	G	F	F	P	G	
Methyl Ether	G	G			G	F		P	G	
Methyl Ethyl Keytone	G	G	G	G	G	P	F	P	G	P
Methyl Isobutyl Keytone	G	G	G	G	G	P	F	P	G	P
Methyl Propyl Keytone	G	G	G	G	G	P		P	G	P
Methylene Chloride	P	G	G	G	G	P		P	G	
Milk	G	P	P	P	G	G	G	G	G	G
Mineral Oils	G	G	G	G	G	G	F	F	G	G
Molasses	G	G	G	G	G	G		G	G	G
Naptha	G	G	G	G	G	G	P	P	G	G
Napthalene	G	G	G	G	G	P	P	P	G	
Naptha Solvents	G	G	G	G	G	G	P	P	G	G
Natural Gas	G	G	G	G	G	G	P	G	G	G
Nitric Acid - (Conc)	P	P	P	P	G	P	P	P	G	
Nitric Acid, Crude	P	P	P	P	G	P	P	P	G	
Nitric Acid, Diluted	P	P	P	P	G	P	G	P	G	
Nitrobenzene	G	G	G	G	G	P	G	P	G	
Nitroethane	G	G	G	G	G	P	G	P	G	
Nitromethane	G	G	G	G	G	P	G	P	G	
Nitropropane	G	G	G	G	G	P	G	F	G	
Nitrogen Fertilizers	G		G	G	G	G		G	G	G
Octyl Alcohol	G	G			G	F		G	G	G
Olive Oil	G	G			G			G	G	G
Oleic Acid	G	F	F	F	G	F	G	G	G	
Organic Phosphates	G	F	F	F	G	P	G	P	G	
Palm Oil	G	G	F	F	G			G	G	
Paraffin Oil	G		G	G	G			G	G	
Peanut Oil	G	G	F	F	G			G	G	
Pentane	G	G	G	G	G	G		G	G	G
Perchlorethylene	G	G	G	G	G				G	
Petroleum Ether	G	G	G	G	G	G	F	P	G	G
Petroleum Naptha	G	G	G	G	G	G		P	G	G
Petroleum Oils	G	G	G	G	G	G	P	G	G	G
Petroleum Spirits	G	G	G	G	G	G		P	G	G
Phenol	G	F	F	F	G	P	G	F	G	
Phosphoric Acid, Crude	P	P	F	F	G	F	G	F	G	
Phosphoric Acid, Pure 45%	P	P	P	P	G	F	G	F	G	
Pine Oil	G	G			G	F	P	F	G	
Potassium Hydroxide	P	P	F	G	G	F	G	G	G	
Propylene	G	G	G	G	G	P	P	P	G	
Propane	G	G	G	G	G	G	P	G	G	G
Propionic Acid	G	G	P	P	G	F	F	F	G	
Propyl Alcohol - Propanol	G	G	G	G	G	G	G	G	G	G
Propylene Glycol	G	G		G	G	G	G		G	G
Propylene Oxide	G	G	G	G	G				G	

FLUID	METAL					SEAL MATERIAL				
	ALUMINUM	BRONZE	IRON	STEEL	ST. STEEL	BUNA	BUTYL	NEOPRENE	TEFLON	VITON
Rapeseed Oil	G	G			G			G	G	
Sewage	G		G		G	G	F	F	G	G
Skydrol		G			G	G			G	G
Sodium Bicarbonate	G	G	F	F	G	G	G	G	G	G
Sodium Bisulphite	F	F	P	P	G	G	G	G	G	G
Sodium Carbonate	F	F	G	G	G	G	G	G	G	G
Sodium Chloride	F	F	G	G	G	G	G	G	G	G
Sodium Cyanide	P	P	G	G	G	G	G	G	G	G
Sodium Hydroxide	P	P	G	G	G	F	G	F	G	
Sodium Hypochlorite	P	P	P	P	G	F	F	F	G	
Sodium Metaphosphate	P	P	P	P	G	G	G	F	G	G
Sodium Nitrate	G	F	G	G	G	G	G	F	G	G
Sodium Perborate	G	F	F	G	G	G	G	G	G	G
Sodium Peroxide	G	F	F	F	G	F	G	F	G	
Sodium Phosphate, Mono-Basic	G	F	F	F	G	G	G	G	G	G
Sodium Phosphate, Di-Basic	F	F	F	F	G	G	G	G	G	G
Sodium Phosphate, Tri-Basic	P	P	G	G	G	G	G	G	G	G
Sodium Silicate	P	F	G	G	G	G	G	G	G	G
Sodium Sulphate	G	G	G	G	G	G	G	G	G	G
Sodium Sulphide	P	P	G	G	G	G	G	G	G	G
Sodium Thiosulphate	G	F	F	F	G	G	G	G	G	G
Soya Bean Oil	G	G	F	F	G	G	G	G	G	G
Stoddard Solvent	G	G	G	G	G	G	P	F	G	G
Styrene	G	G	G	G	G	P	P	P	G	
Sugar	G	G			G		G	G	G	
Sulphur, Dry	G	P	G	G	G	F	F	F	G	
Sulphur, Chloride	P	P	F	F	F	F	P	F	G	
Sulphuric Acid - 10% Cold	P	P	P	P	G	G	G	G	G	G
Sulphuric Acid - 10% Hot	P	P	P	P	F	G	G	G	G	G
Sulphuric Acid - 10-75% Cold	P	P	P	P	F	F	G	F	G	
Sulphuric Acid - 10-75% Hot	P	P	P	P	F	F	G	F	G	
Sulphuric Acid - 75-95% Cold	P	P	G	G	G	F	G	F	G	
Sulphuric Acid Fuming	P	P	G	G	F	P	P	P	G	
Sulphuric Acid Fuming Hot	P	P	G	G	F	P	P	P	G	
Synthetic Lubricants		G			G	F	P	F	G	G
Tar	G	G	G	G	G	G	P	G	G	G
Tetraethyl Lead		G			G				G	
Toluene - Toluol	G	G	G	G	G	G	P	G	G	G
Trichlorethylene	G	G	G	G	G	P	P	P	G	
Tung Oil	G	G	F	F	G	G	G	G	G	G
Turbine Oil					G	G		G	G	G
Turpentine	G	F	F	F	G	G	P	F	G	G
Varnish	G	G	F	F	G	G	P	G	G	G
Varsol	G	G	G	G	G				G	
Vegetable Oils	G	G	G	G	G	G	G	G	G	G
Water, Fresh	G	F	G	G	G	G	G	G	G	G
Water, Sea	F	F	F	F	G			G	G	
Xylene - Xylol	G	G	G	G	G	P	P	P	G	

APPENDIX B

"Corrosion Guide" for Fiberglass Reinforced Plastic Tanks, from Raven Industries Inc., Sioux Falls, South Dakota

RAVEN CORROSION GUIDE

The long useful life of Raven tanks in customer service illustrates the chemical resistance of these tanks. Where new applications are found, the specific chemical resistance requirements should be determined. The following table represents a composite of testing of the resin suppliers, our own chemical testing, and field experience.

Since minor variations in chemical mixture or service conditions can make major changes in the chemical resistance of a plastic part, **this table is supplied as a guide** for your selection and testing and **does not imply a guarantee** of the chemical resistance of any product.

NOTE: The resistance of any material to chemical attack is a function of several elements---the specific chemical, the chemical concentration, the temperature, and the time of contact. When the temperature, chemical concentration, or time of contact can be reduced, the service life of the tank will increase. The life of the tank will be affected when using aggressive chemicals that indicate lower service temperatures.

LEGEND: NR: Not Recommended
NT: Not Tested

Maximum Service Temperature in Degrees F.

Material	% Concentration	Fiberglass Laminate Std.	Fiberglass Laminate Prem.	Polyethylene	Fittings PVC	Fittings Nylon	Grommets & O-Rings Nitrile	Grommets & O-Rings Viton	Grommets & O-Rings EPDM
Acetic acid	10	170	210	140	140	NR	140	104	212
Acetic acid	25	150	210	140	140	NR	100	75	212
Acetic acid	50	NR	180	140	140	NR	NR	NR	212
Acetic acid	75	NR	180	70	140	NR	NR	NR	140
Acetone	100	NR	NR	NR	NR	125	NR	NR	212
Aluminum chloride	All	170	210	140	140	NR	212	212	212
Aluminum chlorohydroxide	50	170	80	NT	NT	NT	NT	NT	NT
Aluminum potassium sulfate	All	170	210	140	140	NR	212	212	212
Aluminum sulfate	All	170	210	140	140	NT	212	212	212
Ammonium bicarbonate	10	NR	150	NT	140	NT	212	212	212
Ammonium bicarbonate	50	NR	150	NT	140	NT	212	212	212
Ammonium carbonate	50	NR	100	140	140	75	212	212	212
Ammonium chloride	All	170	210	140	140	NR	212	212	212
Ammonium hydroxide	5	NR	150	140	140	75	212	104	212
Ammonium hydroxide	10	NR	150	140	140	75	212	104	212
Ammonium hydroxide	20	NR	150	140	140	75	140	104	140
Ammonium hydroxide	29	NR	100	140	140	75	104	75	140
Ammonium nitrate	Up to 50 %	170	210	140	140	NT	140	212	140
Ammonium persulfate	Up to 25 %	140	150	140	140	NT	NT	NT	68
Ammonium sulfate	20	170	210	140	140	NT	212	212	212
Amyl alcohol	All	170	100	140	72	NT	140	140	212
Aniline sulfate	All	NR	210	70	NR	NT	NR	75	NT
Antimony trichloride	All	170	210	140	140	NR	68	68	212
Barium carbonate	All	170	210	140	140	NT	140	140	NT
Barium chloride	All	170	210	140	140	NR	140	140	140
Barium hydroxide	10	NR	150	140	140	NT	140	140	140
Barium sulfide	All	80	180	140	140	NT	140	140	140
Benzaldehyde	100	NT	NR	NR	NR	NT	NR	NR	68
Benzene	100	80	NR	NR	NR	75	NR	68	68
Benzene sulfonic acid	0-75	NR	210	NR	NT	NT	NT	NT	68
Benzoic acid	All	170	210	140	140	NR	212	212	NT
Benzyl alcohol	All	NR	100	NT	NR-	NT	NR	NR	68
Boric acid	All	170	210	140	140	75	140	140	140
Bromine	Gas or Vapor	NR	NR	NR	140	NR	NR	68	NR
Butyl alcohol	All	NR	100	140	140	NT	140	140	140
Butyric acid	25	170	120	NT	72	NR	68	68	140
Butyric acid	50	80	210	NT	NR	NR	68	NR	140
Calcium chlorate	All	170	210	140	140	NT	140	140	NT
Calcium chloride	All	170	210	140	140	NR	212	212	212
Calcium hydroxide	25	170	210	140	140	NT	140	NT	140
Calcium hypochlorite	All	80	210	140	140	NT	68	140	140
Calcium sulfate	All	170	210	140	140	NT	212	212	NT
Carbon dioxide	All	170	210	140	140	NT	212	212	212
Carbon disulfide	100	NR	80	NR	NT	NT	NR	68	NT
Carbon monoxide	All	170	210	140	140	NT	140	140	NT
Carbon tetrachloride	100	80	80	NR	NR	125	NR	140	NR
Chlorine, wet	100	80	210	NR	NR	NR	NR	68	68
Chlorine water	Saturated	80	180	70	140	NR	NR	68	68
Chlorobenzene	100	NR	80	NR	NR	NT	NR	68	NT
Chloroform	100	NR	NR	NR	NR	NT	NR	NR	NR
Chromic acid	5	80	150	140	140	NR	NR	140	68
Chromic acid	10	NR	150	140	140	NR	NR	140	68
Chromic acid	20	NR	150	140	NR	NR	NR	140	NR
Chromic acid	30	NR	NR	70	NR	NR	NR	140	NR

THIS TABLE IS SUPPLIED AS A GUIDE AND DOES NOT IMPLY A GUARANTEE

LEGEND: NR: Not Recommended
NT: Not Tested

Maximum Service Temperature in Degrees F.

Material	% Concentration	Fiberglass Laminate		Polyethylene	Fittings		Grommets & O-Rings		
		Std.	Prem.		PVC	Nylon	Nitrile	Viton	EPDM
Citric acid	All	170	210	140	140	NR	140	140	210
Copper chloride	All	170	210	140	140	NR	140	140	140
Copper cyanide	All	170	210	140	140	NT	140	140	NT
Copper sulfate	All	170	210	140	140	NR	212	212	212
Crude oil, sweet and sour	100	170	210	NR	140	75	212	212	NR
Dichlorobenzene	100	NR	NR	NR	NR	NT	NR	68	NT
Electrosol	5	NT	150	70	NT	NT	NT	NT	NT
Ethyl alcohol	All	80	100	140	140	125	68	68	68
Ethyl ether	100	NR	NR	NR	NR	75	68	NR	NT
Ethylene chloride	100	NR	NR	NR	NR	NT	68	NR	140
Ethylene dichloride	100	NR	NR	NR	NR	NT	NT	NT	140
Ferric chloride	All	170	210	140	140	NR	212	212	212
Ferric nitrate	All	170	210	140	140	NT	NT	NT	NT
Ferric sulfate	All	170	210	140	140	NR	NT	NT	212
Ferrous chloride	All	170	210	140	140	NR	NT	NT	212
Ferrous nitrate	All	170	210	140	140	NT	NT	NT	NT
Ferrous sulfate	All	170	210	140	140	NR	NT	NT	212
Fluoboric acid	All	80	210	140	140	NT	NT	NT	NT
Fluosilicic acid	25	NR	100	140	140	NR	68	NT	140
Formic acid	All	NR	100	140	140	NR	NR	104	140
Gasoline	100	170	100	NR	140	75	140	140	NR
Glycerin (Glycerol)	100	170	210	140	140	75	140	140	140
Heptane	100	170	210	NR	140	NT	140	140	NR
Hydrobromic acid	25	30	180	140	140	NT	NR	140	212
Hydrobromic acid	50	80	150	140	140	NT	NR	140	140
Hydrochloric (muriatic) acid	10	170	210	140	140	NR	NR	140	212
Hydrochloric acid	20	NT	210	140	140	NR	NR	140	212
Hydrochloric acid	37	NR	210	140	140	NR	NR	68	140
Hydrocyanic acid	10	80	150	140	140	NT	NT	NT	NT
Hydrofluoric acid	10	NR	150*	70	140	NR	NR	140	NR
Hydrofluoric acid	20	NR	100*	70	72	NR	NR	104	NR
Hydrogen peroxide	30	NR	150	140	140	NR	NR	68	140
Hypochlorous acid	10	80	210	140	140	NT	NT	NT	NT
Hypochlorous acid	20	80	150	140	140	NT	NT	NT	NT
Hypochlorous acid	50	NR	150	140	140	NT	NT	NT	NT
Kerosene	100	170	100	NR	140	75	140	140	NR
Lactic acid	All	170	210	140	140	75	212	212	68
Lead acetate	All	170	210	140	140	NT	140	212	NT
Linseed oil	100	170	210	NR	140	NT	140	212	140
Magnesium carbonate	All	170	150	140	140	NT	140	140	NT
Magnesium chloride	All	170	210	140	140	75	212	212	212
Magnesium sulfate	All	170	210	140	140	75	212	212	212
Maleic acid	All	140	210	70	140	NR	212	212	NT
Mercuric chloride	All	170	210	140	140	75	140	140	140
Mercurous chloride	All	170	210	140	140	75	140	140	NT
Methyl alcohol	All	NR	100	140	140	NR	68	68	68
Methylethyl ketone	100	NR	NR	NR	NR	125	NR	NR	68
Methylene chloride	100	NR	NR	NR	NR	NT	NR	68	NR
Naphtha	100	170	210	NR	140	NT	NT	NT	NR
Naphthalene	100	170	210	NR	NR	NT	68	68	NR
Nickel chloride	All	170	210	140	140	NT	140	140	140
Nickel nitrate	All	170	210	140	140	NT	140	140	NT
Nickel sulfate	All	170	210	140	140	NT	140	140	140
Nitric acid	5	150	150	140	140	NR	NR	140	140
Nitric acid	20	NR	150	140	140	NR	NR	140	140
Nitrobenzene	100	NR	NR	NR	NR	NT	NR	NR	NR
Oleic acid	All	170	210	NR	140	NT	140	140	140
Oleum (fuming sulfuric acid)	All	NR	NR	NR	NR	NR	NR	68	NR
Oxalic	All	170	210	140	140	NR	140	212	140
Perchloric acid	10	NR	150	140	140	NR	NR	140	NT
Perchloric acid	30	NR	100	70	72	NR	NR	68	NT
Phosphoric acid	10	170	210	140	140	NR	140	140	140
Phosphoric acid	25	170	210	140	140	NR	140	140	140
Phosphoric acid	50	170	210	140	140	NR	140	140	140
Phosphoric acid	85	170	210	140	140	NR	68	140	68

*Synthetic veil required

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LEGEND: **NR**: Not Recommended
NT: Not Tested

Maximum Service Temperature in Degrees F.

Material	% Concentration	Fiberglass Laminate Std.	Fiberglass Laminate Prem.	Polyethylene	Fittings PVC	Fittings Nylon	Grommets & O-Rings Nitrile	Grommets & O-Rings Viton	Grommets & O-Rings EPDM
Photographic solutions	All	170	210	140	140	NT	80	104	NT
Phthalic acid	All	170	210	NT	NT	NT	140	140	NT
Picric (alcoholic) acid	10	80	210	NR	140	NT	68	68	68
Potassium bicarbonate	10	150	180	140	140	75	140	140	140
Potassium carbonate	10	NR	150	140	140	75	140	140	140
Potassium carbonate	25	NR	100	140	140	75	140	140	140
Potassium carbonate	50	NR	80	140	140	75	140	140	140
Potassium chloride	All	170	210	140	140	75	212	212	212
Potassium dichromate	All	170	210	140	140	NT	NR	68	140
Potassium ferricyanide	All	170	210	140	140	75	140	212	NT
Potassium hydroxide	10	NR	150	140	140	75	68	NT	212
Potassium hydroxide	25	NR	150	140	140	NR	68	NT	140
Potassium nitrate	All	170	210	140	140	NT	140	140	NT
Potassium permanganate	All	80	210	140	72	NR	NR	104	NT
Potassium persulfate	All	80	210	NT	140	NT	NR	212	NT
Potassium sulfate	All	170	210	140	140	75	140	140	140
Selenious acid	All	NT	210	70	72	NT	NT	NT	NT
Silver nitrate	All	170	210	140	140	NT	176	176	212
Sodium acetate	All	170	210	140	140	NR	NT	NT	NT
Sodium bicarbonate	10	150	180	140	140	75	140	140	140
Sodium bisulfate	All	170	210	140	140	75	NR	140	140
Sodium carbonate	10	NR	150	140	140	NR	140	140	140
Sodium carbonate	25	NR	150	140	140	75	140	140	140
Sodium carbonate	32	NR	150	140	140	75	140	140	140
Sodium chlorate	50	NR	210	140	140	NT	NR	212	140
Sodium chloride	All	170	210	140	140	75	212	212	212
Sodium cyanide	All	170	210	140	140	NT	140	NT	140
Sodium ferricyanide	All	170	210	140	140	NT	NT	NT	NT
Sodium hydroxide	5	NR	210*	140	140	75	140	104	212
Sodium hydroxide	10	NR	180*	140	140	75	140	104	212
Sodium hydroxide	25	NR	210*	140	140	NT	140	104	212
Sodium hydroxide	50	NR	210*	140	140	NT	NR	NR	140
Sodium hypochlorite	5¼	NR	150**	140	140	NT	NR	68	140
Sodium hypochlorite	10	NR	180**	140	140	NT	NR	68	68
Sodium hypochlorite	15	NR	180**	140	140	NT	NR	68	68
Sodium nitrate	All	170	210	140	140	75	140	140	140
Sodium nitrite	All	170	210	NT	140	NT	NR	140	NT
Sodium silicate	All	NR	210	NT	NT	NT	140	140	140
Sodium sulfate	All	170	210	140	140	75	140	140	140
Sodium sulfide	All	80	210	140	140	75	140	212	140
Sodium sulfite	All	80	210	140	140	NT	140	NT	140
Stannic chloride	All	170	210	140	140	NR	212	NT	140
Stannous chloride	All	170	210	140	140	NR	NT	NT	NT
Stearic acid	All	170	210	140	140	75	140	140	68
Sulfonated detergents	100	80	150	NR	NT	75	NT	NT	NT
Sulfuric acid	25	160	210	140	140	NR	104	140	104
Sulfuric acid	50	80	210	140	140	NR	NR	68	NR
Sulfuric acid	70	NR	170	70	140	NR	NR	68	NR
Tannic acid	All	170	210	140	140	NT	68	140	68
Tartaric acid	All	170	210	140	140	NT	68	NT	140
Tetrachloroethylene	100	NR	80	NT	NR	NT	NR	NR	NR
Trichloroacetic acid	50	80	210	NT	NT	NT	140	NR	NT
Trisodium phosphate	All	NR	210	140	140	75	NT	NT	NT
Toluene	100	80	80	NR	NR	75	68	NR	NR
Urea-ammonium nitrate fertilizer mixture	100	100	100	70	140	75	140	140	NT
Water (Distilled)	All	170	210	140	140	212	212	212	212
Water (Demineralized)	All	140	210	140	140	212	212	212	212
Water (Deionized)	All	140	210	140	140	212	212	212	212
Xylene	100	80	80	NR	NR	NT	68	NR	NR
Zinc chloride	All	170	210	140	140	NR	140	212	212
Zinc sulfate	All	170	210	140	140	NT	212	212	212
8-8-8 Fertilizer	100	120	100	70	140	75	104	104	104

THIS TABLE IS SUPPLIED AS A GUIDE AND DOES NOT IMPLY A GUARANTEE.

* Synthetic veil required.
** Due to variable service life, factory should be contacted for recommendations.

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APPENDIX C

Summary of Design Standards for Underground Storage Tanks Prepared by SCS Engineers

UL 58

Title: "Steel Underground Tanks for Flammable and Combustible Liquids"

Scope: UL 58 requirements cover horizontal cylindrical, atmospheric type, welded steel tanks, intended for installation and use in accordance with NFPA No. 30, the Flammable and Combustible Liquids Code, and NFPA No. 31, Standard for the Installation of Oil-Burning Equipment. These tanks are fabricated, inspected, and tested for leaks before shipment from the factory. Capacities, dimensions, and metal thicknesses are specified in tables in the Standard. The stell shall be new, commercial quality, uncoated or galvanized, and of good welding quality.

NFPA 30-1981

Title: "Flammable and Combustible Liquids Code"

Scope: The code applies to all flammable and combustible liquids except those that are solid at 100 F or above. The code contains separate chapters on tank storage; piping, valves, and fittings; container and portable tank storage; industrial plants; bulk plants; service stations; processing plants; and refineries, chemical plants, and distilleries. Rules for storage tanks concern aspects of tank materials, linings, fabrication, design standards, installation, site requirements, venting, and control of spillage.

Note that NFPA 30 is not a design standard for tanks, but prescribes which design standards may be used, and provides certain requirements or recommendations on the aspects noted above.

API Publication 1615

Title: Instatllation of Underground Petroleum Storage System

Scope: This bulletin covers the installation of underground gasoline, diesel fuel and waste oil systems and is primarily applicable at retail and commercial facilities. Emphasis is on the correct selection of the tank material and size, location of the tank and ancillary piping and equipment, correct installation procedures, and testing both during and after installation to detect leaks.

The material in their bulletin is applicable to hazardous waste storage systems.

ASME Section VIII Division I

Title: "Rules for Construction of Pressure Vessels"

Scope: The rules in this Division of Section VIII cover minimum construction requirements for the design, fabrication, inspection and certification of pressure vessels other than those covered in other Sections and other exceptions. Subsection A covers the general requirements applicable to all pressure vessels. Subsection B covers the specific requirements that are applicable to the various methods of fabrication: welding, riveting, forging, and brazing. Subsection C covers specific requirements applicable to several classes of materials: carbon and low-alloy steels, non-ferrous metals, high-alloy steels, non-ferrous metals, cast iron, clad and lined materials, cast nodular iron, and ferritic steels. The rules have been formulated on the basis of design principles and construction practices applicable to vessels designed for pressures up to 3000 psi. For pressures above 3000 psi, deviations from and additions to these rules are necessary to meet the requirements of design principles and construction practices for these higher pressures. The design temperature shall not be less than the mean metal temperature (through the thickness) expected under operating conditions; in no case shall the surface temperature exceed the maximum temperature listed in the stress tables for materials nor exceed temperature limitations specified elsewhere in Division I or Section VIII.

Corrosion is covered by ASME Section VIII, Division I, Appendix E, "Suggested Good Practice Regarding Corrosion Allowance", and by ASME Appendix F, "Suggested Good Practice Regarding Linings". In the former, paragraph UA-156 states that "when the rate of corrosion is already predictable, additional wall thickness...shall be provided, which shall be at least equal to the expected corrosion loss during the desired life of the vessel". Paragraph UA-157 states that when the corrosion effects are indeterminate prior to design of the vessel, or when corrosion is incidental, localized, and/or variable in rate and extent, the designer must exercise his best judgment in establishing a reasonable maximum excess shell thickness. Paragraph UA-159 suggests that, when a vessel goes into corrosive service without previous service experience, service inspections be made at frequent intervals until the nature and rate of corrosion in service can be definitely established.

ASTM D4021-81

Title: "Standard Specification for Glass-Fiber-Reinforced Polyester Underground Petroleum Storage Tanks"

Scope: Specification covers fiberglass-reinforced horizontal, cylindrical, and spherical-type underground tanks for atmospheric pressure storage of petroleum-based fuels and oils. The specification covers the materials, the manufacture, workmanship, external load requirements, internal pressure, fitting-moment load and torque load ratings, leakage, internal impact resistance, chemical resistance, quality control, and test methods.

UL 1316

Title: "Proposed First Edition of the Standard for Glass - Fiber-Reinforced Plastic Underground Storage Tanks" (January, 1982 draft)

Scope: These requirements cover spherical or horizontal cylindrical, atmospheric-type tanks of fiberglass-reinforced plastic (FRP) that are intended for the underground storage of petroleum-based flammable and combustible liquids. These tanks are completely assembled and tested for leakage before shipment, and intended for installation and use in accordance with the Standard Installation of Oil-Burning Equipment, NFPA No. 31, and the Flammable and Combustible Liquids Code, NFPA No. 30. The standard allows for the incorporation of manholes; therefore, 40 CFR 264.191(1), which states "The regulations of this Subpart (Subpart J - Tanks) do not apply to facilities that treat or store hazardous wastes in covered underground tanks that cannot be entered for inspection", will remove from consideration those tanks fabricated without manholes.

ACI 318-77

Title: ACI Standard, Building Code Requirements for Reinforced Concrete

Scope: This is the basic standard for the proper design and construction of buildings of reinforced concrete. It covers (1) standards for tests and materials, (2) concrete quality, (3) mixing and placing concrete, (4) formwork, embedded pipes, and construction joints, (5) details of reinforcement, (6) analysis and design, and (7) structural systems. The code provides minimum requirements for design and construction of reinforced concrete structural elements of any structure erected under requirements of general building codes, but does not specifically cover tanks. The code states that for special structures, including tanks, provisions of this code shall govern where applicable.

ACI 350 R-77 (formerly ACI 74-26)

Title: Concrete Sanitary Engineering Structures

Scope: As indicated by "R" in the ACI designation, this is for a committee report, and as such contains recommendations for structural design, materials, and construction of concrete tanks, reservoirs, and other structures commonly used in water and waste treatment works where dense, impermeable concrete with high resistance to chemical attack is required. Special emphasis is placed on designs which minimize cracking and accomodate vibrating equipment and other special loads. Chapter 5 - Protection Against Chemicals - states that concrete made with the proper type of cement, which has been properly proportioned, mixed, placed, and cured, will be dense, strong, watertight, and resistant to most chemical deterioration or corrosion. However, in industrial waste treatment plants, where the pH of acid waste may go as low as 1.0, the types of protection generally used are chemical-resistant mortar, acid-proof brick or tile, thick bituminous coatings, epoxies, and heavy sheets or liners of rubber or plastic.

APPENDIX D

Memoranda from SCS Engineers to Bill Kline Regarding Tank Shell Thickness

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July 22, 1983
File No. 28001-03

MEMO

TO: Mr. William Kline, Environmental Protection Agency

FROM: SCS Engineers

SUBJECT: Tank Shell Thickness as Regards Permit Issuance

A. Shell Thickness Measurement

1. Nondestructive Techniques

a. Calipers

The simplest method of making a thickness determination is to use calipers. Obviously this technique is limited to areas of the shell that are within reach of an opening so that the calipers can be inserted through the opening and measurement taken from both inside and outside the shell.(1,2)

b. Ultrasonic Inspection

Ultrasonic instruments can be used to measure tank shell thickness as well as to determine the location, size and nature of defects. They can be used while the tank is in operation as only the outside of the tank needs to be contacted. They can be used on steel, FRP and concrete tanks. Two types of ultrasonic instruments, the resonance and the pulse type, are commonly used for tank thickness measurement. The pulse type instrument utilizes electric pulses and transforms them into pulses of ultrasonic waves. The waves travel through the metal until they reach a reflecting surface. The waves then are reflected back, converted into electric pulses, and show up on a time-baseline of an oscilloscope. The instrument is calibrated by using a material of known thickness; therefore, the time interval between the pulses corresponds to a certain thickness. There are two types of resonance ultrasonic instruments. In one of these, an electric oscillator transmits electric energy of constant ultrasonic frequency to a crystal (transducer) which, in turn, converts this energy into mechanical pressure waves that travel through the material being measured in the direction of its thickness. The pressure waves travel at a constant velocity and are reflected at the opposite surface back to the crystal. Because velocity through a given material is constant, the time required for a wave to circumnavigate is a function of the distance traversed, in this case, equal to twice the thickness. Therefore, by measuring the time interval, the thickness can be determined. In the other type of resonance device, a crystal (piezoelectric transducer) is applied to the surface of the wall to be measured, and an electronic circuit causes it to vibrate over a range of frequencies. When the vibrating frequency of the crystal matches the natural frequency of the vibration of the material being measured, a signal is fed through the circuits of the instrument and interpreted electronically as an indicated thickness. This indication is fed through an oscilloscope and emerges as a series of vertical lines across the face of the tube. These lines indicate thickness on a transparent plastic scale mounted directly on the face (front) of the oscilloscope tube. Ultrasonic instruments can provide digital readouts, can provide a permanent record of measurements, and are accurate to within one percent of the thickness of the tank shell being measured. Ultrasonic instruments are the most applicable for shell thickness measurement. (1,2,3)

A brief synopsis of the cost of ultrasonic inspection is appropriate at this point. Should a consideration be to buy ultrasonic inspection equipment the price ranges from $1,500 to $2,600 and provides an accuracy of plus or minus 0.005 inches or better, depending on the price of the equipment. This type of equipment provides a digital readout and will give thickness readings of a specific point on the tank surface. Numerous models are available in the marketplace from different manufacturers. The most exotic ultrasonic inspection instrument costs in the vicinity of $10,000 and provides a continuous readout accurate to plus or minus 0.001 inches with a digital readout. Readings can be made using a sweeping motion of the probe as opposed to a point reading provided by the equipment discussed above, and therefore will provide thickness readings along a line or of an area. For an additional $5,000 approximate cost a strip chart recorder can be purchased which will record all of the readings taken in a continuous manner by this continuous readout probe. Should the option chosen be to hire a professional testing firm that uses ultrasonic inspection equipment, the prices are somewhat more reasonable. The current standard hourly rate for ultrasonic inspection is $25.00 per hour plus mileage with a $100 minimum per job.

This rate will provide the user with point thickness measurement and normally the methods involved will cover a two to four square foot per hour area which allows you to calculate how much it would cost to do an inspection of any given size tank by calculating the square area involved. Should the customer request the strip chart recorder be utilized as well as the digital readout that comes with all equipment, the hourly rate rises to $35 per hour and the job minimum rises to $140. The customer then receives a chart of area thicknesses and can locate areas of local corrosion and pitting with these. Coverage using the strip chart recorder is somewhat slower than the two to four square foot per hour coverage noted above. Should the customer require a formal report signed by a professional engineer, the rate rises to $60 per hour. It becomes obvious that unless the customer intends to make a multitude of thickness measurements over a short period of time, the purchase of ultrasonic inspection equipment is financially disadvantageous. It appears to be much more appropriate to hire a professional testing firm for each inspection requirement and pay the hourly rate. (4,5,6,7,8)

c. Radiographic Inspection

Radiography may be used to determine shell thickness, as well as to detect flaws, such as cracks and voids, and can be used on steel, fiberglass reinforced plastic, and concrete. However, access to both sides of the tank shell is required. The ray source must be on one side and the film on the other. The rays commonly used in tank shell thickness measurement are the X-ray and the gamma ray. The X-ray is produced in a CRT tube within an X-ray machine; the gamma ray is produced from a radioactive material (source) contained in a small capsule. The two rays are similar. Each has unique advantages in penetrating power and ease of mobility. Recently, a gamma ray system has been devised that is portable and, therefore, much easier to use than the older type fixed X-ray and gamma ray producing equipments. The rays pass through the tank shell and are photographed on film. Then the film is compared with film taken of the same material of known thickness to determine the thickness of the tank shell in question. Radiography is better suited to weld inspection and flaw detection than to thickness measurement. (1,2,3)

Briefly the cost data pertaining to radiographic inspection equipment is that to buy such equipment would cost approximately $2,700 at a minimum. The equipment is expensive to use due to the expensive film and the processing of that film and because the gamma ray source will only last for 90 days and then must be replaced. In addition, further expense is incurred because radiographic technicians must be hired to operate the equipment. Should the customer desire to hire a professional testing firm that uses radiographic inspection equipment, the cost currently in the marketplace is $40 per picture and the process is quite slow and cumbersome. Apparently ultrasonic inspection techniques are far superior in both cost and accuracy to radiographic techniques.(4,5,8)

2. Destructive Techniques

The one destructive technique that is utilized in measurement of tank shell thickness is known as the hook gauge. The technique involves drilling a hole through the empty tank and inserting the hook gauge through the hole to measure thickness in the shell at that location. The hole is then repaired by tapping threads into the hole and inserting a plug in accordance with the code under which the tank was built.(1,2)

B. Minimum Shell Thickness Calculations

Shell thickness calculations are quite different, depending on the type of material. The discussion below is subdivided by type of material: steel, fiberglass reinforced plastic (FRP), and concrete.

1. Carbon Steel and Stainless Steel

Any discussion of steel tank shell thickness must involve two specific points. The first portion of the tank shell thickness is determined by calculating the stress that will be exerted on the steel shell and is a structural thickness. The remainder of the tank shell thickness is an allowance to offset the effects of corrosion. The summation of these two thicknesses, the structural thickness and the corrosion allowance, as it is known, provides one with the total shell thickness minimums.(1,3,9)

a. Structural Shell Thickness

All of the codes and standards that deal with steel tank design and construction discuss structural shell thickness.

The standards published by the American Petroleum Institute, specifically API 620 and API 650, discuss in some detail the calculation of structural shell thickness and provide formulas for that calculation. (See Attachments A and B) Additionally, two other standards published by the American Petroleum Institute, API 12B and API 12D, provide minimum structural thickness for not only the shell but for the roof and deck plates in tabular form. These two standards do not provide formulas for thickness calculation. The standards published by Underwriters Laboratories, specifically UL 58 for underground tanks and UL 142 for above ground tanks, provide the structural thickness in tabular form, but do not provide formulas for its calculation. In all cases, minimum shell thicknesses are provided, regardless of what the structural shell thickness formula dictates. In most cases the minimum shell thickness for steel tanks is 3/16 in. with the exception of UL 58 and UL 142, which provide for shell thicknesses of less than 3/16 in. for smaller tanks.(10,11, 12,13,14,15)

b. Corrosion Allowance

The codes deal with corrosion allowance in a variety of ways, but, due to an inability to set forth formulas for determination of corrosion allowance, the codes normally leave the corrosion allowance thickness up to the purchaser. For example, API 650 states: "The purchaser shall specify, when necessary, the corrosion allowance to be provided for each shell course, the bottom, the roof, and the structurals, giving consideration to the total effect of liquid stored, the vapor above the liquid, and the atmospheric environment." Corrosion is effected by many variables. It is apparent that those responsible for writing codes for design of steel tanks are unable to set forth definitive guidance concering corrosion allowance. The structural thickness is determined to the nearest 0.001 in., and then a corrosion allowance to be determined by the purchaser is added to that structural thickness to obtain the overall desired minimum thickness of the tank shell.

Corrosion of steel is affected by a multitude of variables, as mentioned above. Some of these variables are: the compatibility of the liquid being stored with the tank material, the temperature of the liquid being stored, the pressure inside the tank, the amount of movement of the fluid within the tank, bacterial action that may occur within or outside the tank, soil resistivity in reference to tanks that are either underground or partially below the surface, moisture level either in the soil or in the air in reference to exterior corrosion, variations in the soil which set up an electrical current and can cause electrolytic corrosion, and finally environmental elements such as atmospheric pollutants. Corrosion and corrosion allowance will be discussed further in the last major portion of this memorandum.(1,9,10,11,16,19)

2. Fiberglass Reinforced Plastic (FRP)

FRP is a corrosion resistent, laminated material used in tank construction. The term corrosion allowance does not apply when discussing FRP because the failure of FRP due to the corrosivity of either the fluids being contained or of the atmosphere and/or soil outside the tank does not normally occur by material being corroded away from the shell thickness. Failure occurs when FRP loses its rigidity due to reaction with a chemical or chemicals either within or outside the tank. So there is no discussion of corrosion allowance when addressing FRP, and thickness determination is based on structural integrity. The specification which guides the design and construction of FRP tanks is the American Society of Testing and Materials (ASTM) Standard D3299-81 "Filament-Wound Glass-Fiber Reinforced Polyester Chemical-Resistent Tanks". (See Attachment C) FRP tanks constructed in accordance with this specification are built in layers, as set forth below: (18,19)

a. Inner Surface

The inner surface, or surface exposed to the liquid inside the tank, is a reinforced layer 10 to 20 mils minimum thickness. The reinforcement materials are chemically resistent glass surface mat, and are present to give form to the layer rather than add to the overall structural integrity of the tank.

b. Interior Layer

The interior layer is reinforced with noncontinuous glass strands applied in a minimum of two plies of chopped strand mat or alternately in a minimum of two passes by the spray-up process. Glass content is specified as 20 to 30 weight percent. Before filament winding is applied, the interior layer is allowed to gel completely so the corrosion barrier will not be squeezed down to a thin layer of glass content over 30 percent. The combined thickness of the inner surface and the interior layer is not less than 100 mils.

c. Exterior Layer - Filament Wound

Subsequent reinforcement is continuous strand roving in accordance with minimum thickness requirements as set forth in ASTM D3299-81. The thickness of the filament wound portion of the tank shell may be varied with tank height (tapered wall construction), providing minimum thickness requirements are met at any height level. If additional longitudinal strength is required, the use of other reinforcement such as woven fabric, chopped strand mat, or chopped strands, may be interspersed in a winding to provide additional strength. Glass content of filament winding will be 50 to 80 weight percent. The minimum thickness of the summation of the inner surface, the interior layer, and the exterior layer - filament wound is 180 mils.

d. Exterior Layer - Contact Molded

The exterior layer or body of the laminate is of chemically resistent construction suitable for the service intended and provides additional strength as necessary to meet the tensile and flexural requirements. Where separate layers such as mat, cloth, or woven roving are used, all layers are lapped a minimum of 1 in. Laps are staggered as much as possible. If woven roving or cloth is used, a layer of chopped strand glass is placed as alternate layers. The exterior surface is relatively smooth with no exposed fibers or sharp projections.

e. Outer Surface

For added resistence to chemical exposure (spillage), an exterior surface of chopped glass or surfacing mat, or both, made from either glass or organic fibers may be employed, as agreed upon between manufacturer and purchaser. This layer is used only if contact between the stored liquid and external surface of the tank is considered likely.

f. General

As can be seen from the above descriptions of the layers of an FRP tank, the minimum thickness requirements are quite specific. The main subject of concern with FRP tanks is the compatibility of the tank material with the liquid to be stored, as well as with the soil and atmosphere. Corrosion allowance is not the issue; resistance to loss of structural strength of FRP caused by chemical reaction is the issue.

3. Concrete

Tanks constructed of concrete utilize codes just as do the materials discussed above. The two codes most commonly used are American Concrete Institute (ACI) Specification 67-40 entitled Design and Construction of Circular Prestressed Concrete Structures (See Attachment D), and ACI 74-26 entitled Concrete Sanitary Engineering Structures (Copy provided when received). These specifications provide formulas for determining the minimum shell thickness required in concrete tanks and also provide minimum dimensional limits for the tank shell thickness, as set forth below. If the tank is constructed of a shot crete - steel diaphragm type construction, the minimum shell thickness is 3 1/2 in. If the construction is cast-in-place concrete without vertical prestress, the minimum shell thickness is 8 in. For cast-in-place concrete tanks with vertical prestress, the minimum shell thickness is 6 in. The minimums sited above are from ACI 67-40, for prestressed tanks. Similar minimum thicknesses are provided in ACI 74-26. Minimums are provided for the overhead dome and the floor of the tank as well. As with FRP tanks, there is no added thickness provided to offset corrosion. The problem is dealt with not by adding thickness to the tank shell, but by providing additives to the concrete or lining or coating the concrete to prevent chemical reaction with the stored liquid, or to prevent reaction with the atmosphere or with the surrounding soil. Therefore, the thicknesses provided from the formulas in the ACI specifications are for structural integrity (or ease of construction), and do not have a corrosion allowance as did the thickness of steel discussed above. (20,21,22)

C. Visual Inspection versus Actual Shell Thickness Measurement

1. General

The question of when visual inspection is sufficient and when actual shell thickness measurement utilizing one of the techniques discussed above is required, is a difficult one.

The variables that influence the answer to this question are numerous. Those variables that have the greatest impact are discussed below.

2. <u>Variables</u>

a. Leak Impact(1)

The impact that a leak will have on the surrounding environment must be considered when evaluating visual versus actual shell thickness measurement. Several relevant questions are:

- Will a liquid leak cause a serious threat to the health of people who come in contact with it?
- Will a leak contaminate water supplies, crops and food supplies, fisheries or wild life habitat?
- Will a leak cause dislocation of people?
- Will a leak cause loss of property resulting from contamination, fire, explosions, etc?
- What are the economic and social costs of leak clean up?

b. Corrosion(1,9,16,19,22,23) (See Attachments E & F)

The mechanism of corrosion is the primary concern when discussing shell thickness in regard to both steel and concrete tanks. Corrosion can take many forms. A common form of corrosion with steel tanks is electrolytic corrosion. This form of corrosion is the result of a direct current from outside sources entering and then leaving a particular metal structure by way of the electrolyte (surrounding material, such as soil for underground structures or water for submerged structures). A similar type of corrosion known as galvanic corrosion is a self generated activity resulting from differences in electrical potential that develop when metal is placed in an electrolyte. These differences in electrical potential can result from the direct coupling of dissimilar metals, or they can result from variations and conditions which exist upon the surface of a single metal. Electrolytic and galvanic corrosion are similar in that corrosion occurs at the anodes. The primary difference between the two is that in electrolytic corrosion the external current generates the corrosion, whereas in galvanic corrosion the corrosion activity itself generates the current.

Many factors influence corrosion rates in metals. The acidity of the electrolyte (solution, soil) with which the material is in contact can have a substantial effect on the rate of corrosion. The presence of oxidizing agents, of which oxygen is the most prominent, may accelerate the corrosion of one type of material and retard corrosion in another. The rate of corrosion tends to increase with rising temperature. Once corrosion has started, its progress is often controlled by the nature of the film that forms on the corroding metal. Some corrosion products may be insoluble and completely protective; or they may be very permeable and thus allow localized or general corrosion to proceed unhindered. The metabolic activity of certain microorganisms can either directly or indirectly affect the corrosion of metals. The soil resistivity is the largest single factor controlling the rate of corrosion caused by either the soil in which the tank is buried or the soil on which the tank is sited. The lower the resistivity of the soil, the greater the probability of corrosion. The presence of water can also promote corrosion of metals. The presence of moisture in soil acts to reduce soil resistivity, thereby increasing the probability of corrosion. Water accumulating inside tanks is also a major cause of internal corrosion. Corrosion of underground tanks and pipes can be influenced by variations in soil conditions along the surfaces of those tanks and pipes. Variations in soil type, soil resistivity, and moisture content can promote galvanic activity in the buried metal, thus accelerating the rate of corrosion.

Corrosion can also be influenced by the presence of atmospheri(pollutants, both externally and internally. For example, sulfur dioxide can form sulfuric acid in the presence of air and moisture and can thus promote corrosion of certain metals.

Concrete tanks also suffer from corrosion; sulfate attack causes concrete to break down. Sulfate reacts with hydrates, the resultant compounds expand and rupture the concrete. The severity of the attack depends on the concentration of the solution. If the concrete is exposed on one side only, rather than on both sides, the rate of corrosion will increase If the concrete is alternately saturated and then allowed to dry, the corrosion rate caused by sulfate attack will increase

Concrete is attacked by sea water. This form of corrosion is more severe on reinforced concrete. The absorption of salt from the sea water sets up anodic and cathodic areas within the concrete, causing electrolytic action to take place. Corrosion products then accumulate on the reinforcing steel, and this accumulation causes the concrete surrounding the steel to rupture. Portland cement is highly susceptible to acid attack. Acid dissolves cement, leaving aggregate exposed.

Surface treatments have been successful in the prevention or retardation of the corrosion of concrete. Coal tar pitch, rubber or bituminous paints, epoxy resins, and magnesium silico fluoride are some of the surface treatments that have been used successfully in preventing concrete corrosion or repairing tanks that have exhibited some corrosion.

c. Compatibility(1,9,16,18,19,22)

A major concern in any tank is the compatibility of the liquid being stored with the material of construction. There are many questions that arise when discussing compatability.

- What is the vapor pressure of the liquid?
- What are the melting and boiling points of the liquid?
- Is the liquid flammable, corrosive, toxic or reactive?
- What will be the allowable pressure inside the tank?

The main question, of course, is whether the stored liquid will attack the material of the tank. This compatability question is present for not only steel and concrete tanks but for FRP tanks as well. With steel and concrete, the liquid normally will corrode or erode the tank wall. With an FRP tank, a stored liquid that is not compatable with the components of the laminated shell will cause a loss of structural integrity which will sometimes be accompanied by an actual swelling of the shell thickness rather than a thinning of the shell thickness as takes place during a corrosive reaction.

d. Shell Protection(1,2,9,10)

One of the variables that controls how often a tank is inspected and whether visual inspection or sophisticated shell thickness measurement is required involves the question of whether the tank shell is protected in any way. In steel tanks, cathodic protection is used to prevent or retard electrolytic corrosion. In addition, the tank can be electrically isolated from its surroundings. Tanks constructed of many different materials beneft from the protection afforded by various paints, coatings and linings. This protection may be used internally and/or externally.

e. Siting(1)

In deciding between visual inspection and tank shell thickness measurement, the siting of the tank or tanks must be considered. Underground tanks cannot be as thoroughly inspected visually as can above ground tanks. Thus, corrosion and other defects cannot be located as easily. This may warrant more frequent, actual shell thickness measurement.

f. Historical Data(1)

For a used tank, quite often historical data will provide an indication of how susceptible the tank is to corrosion or erosion from either the liquid being stored or the atmosphere and/or soil outside the tank. If the corrosion rate indicated by the data shows that the corrosion allowance is still in tact, actual thickness measurement may not be required at present. For a new tank, historical data from like tanks storing similar or the same liquids can be used to help make the determination.

3. Conclusion

The question of when visual inspection is sufficient and when operators or owners should be required to make actual shell thickness measurements is affected by many variables, as can be seen from the above discussion. The successful operation of any tank farm is in large measure dependent upon a schedule of inspections followed by both preventive and corrective maintenance predicated on what has been found during those inspections. Where a visual inspection is possible, this will always be the first step in shell thickness determination. The purpose of the visual inspection is to seek out any signs of attack on the tank shell from either the inside due to the liquid being stored or from the outside by either the atmosphere or the soil. It should be pointed out that although we have been talking about shell thickness as the critical measurement, the measurement of the bottom of the tank for its thickness is just as critical. The visual inspection should be very thorough and should be looking for localized corrosion, pitting, areas where rust is prevalent, blistering, discoloration, stress cracks and any other indications that a change is taking place in the material of the tank shell. Previous visual inspections which indicated possible defects should be used as a basis for increasing the frequency of inspection. The permit writer must consider the following factors in deciding whether shell thickness measurement by instrument is required:

- The impact of the leak on the surrounding environment
- The presence of factors which lead to corrosion or give increased probability of corrosion
- The liquid being stored is not compatable with the tank shell material and no lining or coating is provided
- The shell has not been protected using protection or cathodic or anodic inhibitors or electrical isolation
- The tank has not been designed in accordance with any accepted code or standard
- The cost of performing actual shell thickness measurement using ultrasonic techniques.

If there is doubt in the permit writers mind concerning the sufficiency of visual inspection, actual shell thickness measurement using ultrasonic techniques should be considered.

Several scenarios are presented here as examples of appropriate actions to be taken by the permit writer. In the first case, a permit application is received by the permit writer for three ten thousand gallon above ground FRP tanks. The tanks have been built in accordance with ASTM specifications D-3299-81, and the liquid to be stored appears to fit within the guidelines provided by that specification. A substantial leak of the liquid from the tank would be very likely to infiltrate the groundwater table and probably the surface water nearby if allowed to run freely. An acceptable system of dikes and curbs as secondary containment have been provided. An inspection schedule has not been presented by the applicant, but the permit writer and the applicant have worked out a satisfactory inspection and maintenance schedule. In this particular case, the permit writer has no basis for requiring actual shell thickness measurement as long as the inspection schedule sets forth conditions under which actual shell thickness measurement would be required in the future.

The second permit application received by the permit writer involves a twenty thousand gallon, underground, carbon steel, storage tank. The applicant has presented somewhat sketchy historical data which indicates that the tank has been inspected over its 12 year life, but that no such inspection has been conducted during the last 5 years. The tank does have a man way permitting internal inspection and is lined with epoxy but there is no information concerning the age or condition of the epoxy liner. The tank was originally designed in accordance with the fifth edition of Underwriters Laboratory Standard for Safety No. 58. In this particular case, the permit writer does not have sufficient information concerning the thickness of the tank shell or the condition and thickness of the epoxy liner. He should require actual tank thickness measurement using ultrasonic techniques prior to the issuance of a permit.

The two examples presented above give some indication of the variables encountered by the permit writer. The decision to require actual shell thickness measurement is one that must be made based on the best information available. The two examples are fairly clear cut, but the permit writer will not always be able to make his judgement as easily. Each application must be evaluated on its own merits.

JD Wright

J. D. Wright, P.E.
SCS ENGINEERS

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ATTACHMENTS

A. Excerpt from American Petroleum Institute Standard 620 - Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks-concerning shell thickness design.

B. Excerpt from American Petroleum Institute Standard 650 - Welded Steel Tanks for Oil Storage - concerning shell thickness design.

C. American Society for Testing and Materials Standard Specification D-3299-81 - Filament-Wound Glass-Fiber Reinforced Polyester Chemical-Resistant Tanks

D. American Concrete Institute Title Number 67-40 Design and Construction of Circular Prestressed Concrete Structures

E. National Association of Corrosion Engineers, Basic Corrosion Course, Chapter 8 - Localized Corrosion by H.P. Godard

F. Excerpt from American Society for Metals Handbook. 8th Edition, Vol. 1, "Properties and Selection" - concerning carbon steel and stainless steel corrosion.

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File No. 28001.03
November 25, 1983

MEMORANDUM

TO: Bill Kline
FROM: John Wright

SUBJECT: Addendum to SCS Memorandum dated July 22, 1983 Entitled "Tank Shell Thickness as Regards Permit Issuance"

A. Shell Thickness Measurement

1. Nondestructive Techniques

a. Hammering Technique

Hammering, or the physical inspection of a tank using a hammer, deserves some discussion because it is the technique normally used to do a routine inspection of a tank prior to using a more sophisticated technique. The inspection of a tank should always involve a visual inspection prior to proceeding to one of the other techniques. A normal follow-on to a visual inspection would be to inspect the tank using a hammer. The hammer will not tell the inspector what the thickness of the tank shell is at any location, but will indicate if the thickness has changed indicating a defect. Other subtle differences that a trained inspector will look and listen for that may indicate a defect are vibration, denting, and movement. The key to the usefulness of this technique is that the operator of the hammer must be skilled in the art and know what to listen for and what he is feeling. The only way that he can become skilled is through actual experience.

The accuracy of sounding with the hammer is dependent upon the operator's ability to distinguish minute differences in sound together withdifferences in the rebound of the hammer. He must then have the ability to translate these differences in sound and rebound into changes in thickness of the shell and/or changes in the structural integrity of the shell. Once this technique has located a change in thickness or a difference in structural integrity, another more accurate technique such as ultrasonics or radiography should be used to make a determination of thickness and strength.

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Care should be exercised when using this technique on tanks that are in service, so that a failure or rupture is not caused by the hammer itself. Certain equipment should not be subjected to the hammering technique to include enameled, ceramic or glass-lined tanks; equipment in caustic service because stress corrosion cracks may result; brittle materials such as cast iron, high alloy steels, brass or bronze; and other locations where hammering might result in damage to the tank and its appurtenances.

B. Failure of Fiberglass Reinforced Plastic (FRP) Tanks

The failure of the shell of an FRP tank occurs quite differently than the failure of a steel tank shell. To protect a steel tank from the effects of corrosion, the tank is lined with a corrosion resistant liner (inside protection) or cover (outside protection) or the thickness of the shell is increased with what is called a corrosion allowance and corrosion is allowed to proceed at a known rate. In the case of FRP tanks, the primary concerned is still the compatibility of the liquid being stored with the interior surface of the tank and the compatibility of the outer surface of the tank with the material around the tank. However, the effects of incompatibility do not appear as a loss of thickness of the shell as it does with a steel tank. FRP tends to lose its structural integrity and may even swell. This swelling is caused by a reaction between the components of the tank shell and either the liquid in the tank or the soil and/or groundwater outside the tank. Another possible indication that a problem exists with an FRP tank shell is a change in the color of the FRP. This may also be an indication that a reaction is taking place.

The methods used to combat the incompatibility problem with FRP tanks are relatively simple. The resins chosen for use in a given tank must be compatible with both the liquid to be stored and the material on the outside of the tank (backfill and/ or groundwater). Added thickness of the tank shell is not particularly effective from a compatibility standpoint although it may provide some additional structural strength to the tank. Resins are available thatare resistant to almost any chemical or combination thereof.

C. Failure of Conrete tanks

The minimum shell thickness of the concrete walls of a tank are determined by the structural requirements of the tank, not by any corrosion considerations. The phenomenon of corrosion is addressed by using additives to the concrete mix or by using linings or coatings to protect the concrete from the effects of corrosion. As with FRP, the effects of corrosion on concrete normally make themselves know by a softening of the concrete, spalling of the surface of the concrete or by a change in the color. All of these are indicative that a reaction of some sort has taken place between the concrete and either the chemical being stored or the backfill or atmosphere. Sulfate attack is one of the more common types of problems found with concrete shells. One of several possible sulfates reacts with a hydration product and the result is an increase in volume. If the volume increase takes place before the concrete sets, it is not critical. But if the concrete has already set, the volume increase can cause explosive forces that can cause the concrete to self-destruct. This form of attack may be countered by using a high-quality cement paste made with a sulfate-resistant cement. There is also evidence that suggests that the substitution of from 15 to 30 percent of an active pozzolanic material for the cement will help.

The effects of seawater on concrete tanks was adequately discussed in the original memorandum, but the problems resulting from the alternate freezing and thawing of concrete were not. Normal concrete contains 1 to 2 percent air entrapped in the mix. If these air voids become filled with water and the water is then frozen, the water expands when it freezes and forms ice resulting in hydraulic pressures which can disrupt the concrete and cause spalling or breaking apart of the surface. Freeze-thaw problems can be minimized by increasing the percentage of air entrapped in the concrete mix by using an air-entraining add mixture, thus producing a concrete with from 4 to 8 percent air entrapped in the mix. Freeze-thaw resistance of concrete is also enhanced by using a high-quality portland cement that limits the amount of water in proportion to cement used in the concrete mix. Finally, durable aggregates are absolutely necessary.

APPENDIX E

Chapter 8, "Inspections", from "Permit Writers Guidance Manual for Hazardous Waste Tanks", Draft Prepared by Battelle-Columbus Division for Region II, U.S. Environmental Protection Agency, July 1983

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on

PERMIT WRITERS' GUIDANCE MANUAL FOR HAZARDOUS WASTE TANKS

to

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION II

from

BATTELLE
Columbus Division
505 King Avenue
Columbus, Ohio 43201

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PREFACE

This Working Draft of the "Permit Writers' Guidance Manual for Hazardous Waste Tanks" was developed to provide guidance to the permit reviewer in evaluating the design of hazardous waste tanks, piping, controls, and ancillaries (containment measures, vents, etc.). The manual is aimed at presenting supporting material where possible within the manual or, alternatively, offering summaries or indications of content and coverage of the extensive technical material contained in existing standards, codes, handbooks, etc.

Because of the wide spectrum of tank characteristics and applications anticipated to be encountered by the permit reviewer, the content of this document contains a diversity of subject matter. Some of the content was selected for coverage on the basis of comments from Regional Offices contacted as the first step in the preparation of this manual. The format and arrangement of the draft manual have been selected with the aim of allowing for addition of supplementary material by the individual user and possibly the incorporation of uniform changes and additions at some future time.

Similarly, each section contains a detailed listing of content intended as an aid in assessing material as different requirements arise.

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CHAPTER CONTENTS

8.0 INSPECTIONS

A tank and its auxiliary equipment must be properly inspected on a routine basis to ensure that the tank system is in good working order primarily to prevent uncontrolled discharges of hazardous wastes to the environment. Inspections may result in the conclusion that the tank should be derated or no longer used for service if the tank is not economically repairable. The regulations do not require secondary containment for tanks and, therefore, any leak or other failure is an extremely hazardous situation to be avoided. Regular inspections using effective procedures are the only mechanism available to forecast the possibility of tank failure.

The permit writer is responsible for specifying the minimum allowable shell thickness and the frequency of inspections. According to regulation 40 CFR 264.194(b), the applicant is required to develop a procedure to assess the condition of its tanks. The permit writer should be concerned that the procedure proposed by the applicant will detect any defect in the tank before the defect's depth can violate the minimum shell thickness. The maintenance of a minimum shell thickness for a tank may be viewed as being similar to the requirement for secondary containment.

In general, this chapter 8.0 is written with metal tanks in mind. Fiberglass-reinforced plastic tanks are somewhat different in that they often fail by different mechanisms of deterioration than metal tanks. Section 4.2 "Fiberglass-Reinforced Plastic Tanks" presents further information about plastic tanks, including a discussion about minimum shell thickness equivalent (Section 4.2.3) and frequency of inspection (Section 4.2.4).

Stress corrosion around weld seams, corrosion at the liquid-vapor interface, oxidative corrosion due to the presence of oxygen (from the air) in the vapor space of vented atmospheric tanks, caustic embrittlement, and hydrogen blistering are all types of corrosion which may occur in a non-uniform way on the surface of the metal. However, careful visual inspection for these types of corrosion will usually be adequate to detect the possibility of defects which would require more detailed examination. However, pitting is another form of corrosion that in some cases may not be readily detected through visual inpsection. Furthermore, the nature of corrosion by pitting is such that once the pit has been formed, the rate of corrosion may be accelerated.

Pitting may occur where the liquid is locally stagnant, and a concentration gradient of electrolyte may develope that, in turn, develops a small electrolytic cell, causing localized corrosion in the form of a pit. Tank bottoms, weld seams and dead pockets are the tank locations in which pitting often occurs. Liquid streams containing chlorides are notorious for the possibility of pit corrosion, as are liquid streams containing sludges which may settle.to the tank bottom and, thus, form a dead pocket. Pitting has been observed directly below openings on tanks storing crude petroleum due to rainwater settling to the bottom and forming electrolytic solutions from the salts contained in the petroleum. In some cases, the pits formed in the metal may not appear to be pits upon causual inspection because they have become filled with corrosion products and sludge.

Thus, the permit writer should

- Require that the applicant provide information on the expected corrosion rate of the liquid on the tank material and the likelihood of pitting and other forms of non-uniform corrosion.
- Insist that the applicant provide information supporting the conclusion that inspections will be performed by qualified personnel using procedures that would detect both uniform and non-uniform corrosion of all types.

All permit writers unfamiliar with tank inspection procedures should read the American Petroleum Institute Guide for Inspection of Refinery Equipment, Chapter XIII,"Atmospheric and Low-Pressure Storage Tanks". Particular attention should be given to sections 1302 through 1306.03.

A list of tools required for tank inspections is presented in Section 1304 of the API Inspection Guide as Tables 1 and 2. (Also see section 8.5 of this manual.) Relatively detailed explanations on how many of the common tools are used in inspection are presented in the text.

It should be noted that in the API Guide relatively heavy reliance is made initially on visual techniques of tank inspection to detect evidence of non-uniform corrosion; however, upon detection of potential defects, more sophisticated methods are used to verify and determine the extent of the defect. For example, pits may be measured by depth gage; thicknesses determined by calipers or, in some cases, drilling a hole, which is then measured by hook gage and plugged; cracks measured by penetrant dye or magnetic particle techniques and leaks verified by a vacuum-box tester with soapy water. In some cases test specimens may be removed from some portion of the tank (frequently the bottom) for detailed examination. Some of the methods mentioned above are destructive in nature. Ultrasonic thickness detectors are commonly used to measure for changes in thickness due to uniform corrosion and to detect other flaws. Ultrasonic inspection has the advantage that measurements may be made from the exterior of the tank.

8.1 Evaluation of Inspection Plan

The inspection plan proposed in a permit application should clearly describe all the procedures required to comply with the regulations in 40 CFR 264.194. In brief outline format the required inspections are:

(1) Overfilling control equipment, once per day
(2) Data on tank operating conditions, once per day
(3) Level in uncovered tanks, once per day
(4) Above-ground (external) portions of the tank to detect corrosion and leaks, once per week
(5) Area around tank to detect signs of leaks, once per week
(6) Detailed external and internal assessment of tank condition adequate to detect cracks, corrosion, erosion, or wall thinning that may lead to leaks or inadequate strength according to a predetermined schedule.

The daily inspection of (1) overfilling control equipment is covered in greater detail in Section 8.4.3.

The daily inspection of (2) data on tank operating conditions such as pressures, temperatures, and liquid levels that should be recorded on operator's log sheets or on charts from recording instruments, should be part of the normal operating procedure. Operators and foremen, should be trained about the range of values that are acceptable practice and to notify supervision when such values have been violated. Further discussion of this latter type of inspection is not presented here.

The daily inspection of the (3) level of wastes in uncovered tanks to assure adequate freeboard to prevent overtopping due to winds or precipitation is reasonably self-explanatory. Of course, specific standards should be established to guide operators on the maximum levels that can be allowed without problems. It would be prudent for the applicant to initially set very conservative maximum levels and then base any changes on observations made on windy days. The minimum freeboard that should be allowed is a function of many variables, including maximum wind velocity, nearby topography and buildings, windscreens, wind direction, tank diameter, liquid viscosity, and maximum 24-hour (or longer) rainfall. This inspection is to be made visually and not by reliance on instruments and other indirect means of data acquisition. Further discussion on this inspection is not presented herein.

The weekly inspection of (5) the area around tanks to detect signs of leaks such as wet spots, dried residues, dead vegetation, or discolored spots does not require further explanation.

The remainder of this section presents information to guide the permit writer on the inspection of

(1) Over-filling control equipment, daily

(4) Above-ground (external) tank inspection for leaks and corrosion, weekly

(5) Detailed external and internal assessment of tank condition

8.2 Weekly Above-Ground External Tank Inspection

Regulation 264.194(a)(4) requires inspection of "the construction materials of the above-ground portions of the tank, at least weekly, to detect corrosion or erosion and leaking of fixtures and seams". The intent of this regulation should be viewed more as an attempt to detect leaks or the potential for imminent leaks, and less as a detailed assessment of the condition of the tanks. Items to be assessed during this inspection include:

- Erosion around and cracks in the foundation and pads
- Corrosion, leaks, or distortion around nozzles and piping connected to the tank
- Evidence of deterioration of protective coatings by the appearance of corrosion, discoloration, blisters or other film lifting.
- Evidence of corrosion of tank tops or roofs
- Proper functioning of roof seals (if any) and roof drains (if any)
- Corrosion, discoloration, leaks, cracks, bulges, and buckles of seams and plates of the tank wall and bottom (if accessible).

If the external portions of the tank are covered with insulation, then careful inspection of the insulation for leaks or evidence of leaks such as discoloration would be the appropriate procedure.

Until potential defects are observed, this inspection is strictly a visual inspection. However, upon detection of a defect, more sophisticated inspection procedures would be appropriate. Of course, if a leak is detected, further leakage should be stopped and the tank promptly repaired or replaced.

8.3 Detailed Assessment of Tank Condition, (as scheduled)

The detailed assessment of tank condition proceeds in two stages, the external inspection and the internal inspection, as follow:

8.3.1 External Inspection

Many elements of the external tank inspection may be made while the tank is in service; for example, ultrasonic examination of the average shell thickness. (However, the measurement of average shell thickness is listed as part of the internal inspection procedure in this document.) A detailed description of the external tank inspection procedure is presented as section 1304.02 of the API Guide of Inspection of Refinery Equipment, Chapter XIII, "Atmospheric and Low-Pressure Storage Tanks" and is not repeated herein. However, a checklist of the items to be investigated and what to look for has been presented as Table 8-1 based on the API Guide. Some external inspection procedures should not be performed until the tank has been shut down and emptied.

8.3.2 Internal Inspection

The internal inspection described by the applicant should take place in at least two major phases--emptying the tank and the inspection. According to 40 CFR 264.184(b), the applicant must establish procedures for emptying the tank to allow entry and inspection of the interior. Although the intent of this regulation is not made explicit, the permit writer should be concerned with safety of personnel, avoidance of spills to the environment, and other hazardous conditions. A checklist of items with which to be concerned is presented in Table 8.2. The checklist includes consideration of lined and fiberglass-reinforced plastic (FRP) tanks. (Further information about FRP tanks is presented in Section 4.2.3.)

8.4 Inspection of Auxiliary Equipment

Common auxiliary equipment and system components attached to tanks used for hazardous waste include pipes, valves, and fittings; pumps and compressors; and instruments, control equipment, and electrical systems. Inspection of these are discussed in the following sections.

TABLE 8-1. CHECKLIST OF TANK EXTERNAL-INSPECTION POINTS

A. Tank In Service

(1) Ladders, Stairways, Platforms and Walkways
- worn or broken parts and treads
- corroding parts
- cracked or spalled concrete pedestals
- low spots where water can collect
- loose rivets and bolts

(2) Foundations
- erosion
- uneven settlement
- cracks and spalling in concrete pads, base rings,and piers
- deterioration of water seal between tank bottom and the foundation
- distortion of anchor bolts

(3) Pipe Connections
- external corrosion
- cracks and distortion

(4) Electrical Grounds
- corrosion where enters ground
- resistance

(5) Protective Coatings
- rust spots, blisters, and film lifting

(6) Tank Walls
- corrosion (underground and under insulation in particular)
- discoloration of paint surface
- cracks at nozzle connections, in welded seams, and at the metal ligament between rivets
- cracks, buckles, and bulges
- tightness of bolts or rivets, if applicable

(7) Tank Roofs
- malfunctioning of seals
- blockage or breakage of water drains on roofs
- corrosion

TABLE 8.1. (Continued)

(8) Overfilling Control
- malfunction of controls
- insufficient freeboard

B. Tank Out of Service

(1) Tank Bottoms (only if appropriate)
- tunneling method

(2) Pipe Connections
- hammering
- at point of entrance at soil line

(3) Tank roofs, pontoons, double decks, seals, and purlins
- hammering
- visual
- leaks

(4) Valves and Valve Seats
- visual

(5) Auxiliaries
- vents for plugging, breather valves for seating
- liquid-level controls for cracks and corrosion
- pressure gages for plugging and accuracy.

TABLE 8-2. CHECKLIST FOR TANK INTERNAL INSPECTION (TANK OUT OF SERVICE)

A. Tank Emptying and Preparation For Inspection

- avoidance of spills
- avoidance of hazardous conditions (reaction, ignition, or toxic exposure)
- use of appropriate materials of construction for any temporary storage containers (or tanks) and connecting systems
- cleaning and ventilation procedure
- complete disconnection or blanking off of all connecting piping
- air quality check
- adequate lighting
- personal safety equipment as appropriate (clothing and respiratory)
- Standby equipment and services readily available

B. Interior Inspection of Solid Steel Tanks

(1) Roof and Structural Supports (visual first for safety)
- no hazard of falling objects
- corrosion

(2) Roof and Structural Supports (more rigorous)
- loss of metal thickness
- cracks, leaks at welds
- cracks at nozzle connections
- malfunction of floating roof seals
- water drain system deterioration
- hammering

(3) Tank Shell
- cracks at seams
- corrosion of vapor space and liquid-level line
- cracking of plate joints
- cracking of nozzle connection joints
- loss of metal thickness

TABLE 8-2. (CONTINUED)

(4) Tank Bottom
- hammer testing
- corrosion pits
- sprung or cracked seams
- rivets for tightness and corrosion
- depressions in the bottom areas around or under roof supports and pipe supports
- bottom thickness
- unevenness of the bottom
- sample coupons, if appropriate

C. Interior Inspection of Lined Steel Tanks

NOTE: Some of the procedures and locations to inspect noted in section B for solid steel tanks above are equally applicable to lined tanks. Tanks may be lined with alloy steel, lead, rubber, glass, coatings, and concrete.

- general condition of lining (holes, cracks, gaps, corrosion, erosion, swelling, hardness, loss of thickness)
- proper positioning of liner
- bulges, blistering, or spalling
- spark testing with rubber, glass, and organic type coatings
- ultrasonic examination of steel outer shell thickness is possible if any deterioration is suspected.

D. Interior Inspection of Fiberglass Reinforced Plastic Tanks

- hardness test of any test specimens exposed to liquid in the tank
- indentations, cracks, exposed fibers, crazing, checking, lack of surface resin, and delamination
- if sufficiently translucent, porosity, air or other bubbles, other inclusions, and thin areas
- ultrasonic examination of laminate thickness is possible if any deterioration is suspected in the polyester matrix.

8.4.1 Pipes, Valves, and Fittings

Inspections of pipes, valves, and fittings are usually conducted to note any leaks, cracks, corrosion, or losses in metal thickness owing to external or internal deterioration. The internals of these equipment parts are subject to erosion or wear because of the effects of high liquid turbulence or velocity. Areas around pipe bends, elbows, tees, and other restrictions, such as orifice plates and throttling valves, are particularly subject to erosion.

Visual inspection techniques include checking for leaks, misalignment, unsound piping supports, vibration or swaying, external corrosion, accumulations of corrosive liquids, and indications of pipe fouling. Thickness measurements while the pipes are in operation can be taken utilizing ultrasonic or radiographic techniques.

If the tank is out of service or if a line can be valved off, with proper safety precautions piping can be opened at various places by removing a valve or fitting or by springing the pipe apart at flanged locations to permit internal visual inspection. A flashlight or extension light is needed in most cases and a probe-type instrument, such as a borescope, or a mirror and light will permit a more detailed view. If corrosion or erosion conditions are noted visually for some parts, radiographic or ultrasonic techniques can be used to inspect the entire length of pipe, if inaccessible to visual examination. Replacement may be more economical than such techniques in some cases if the entire piping run is suspect. Gaskets should often be replaced if the line is broken at flanges.

A brief checklist for inspection of piping, valves, and fittings is presented as Table 8-3.

TABLE 8-3. CHECKLIST FOR INSPECTION OF PIPING, VALVES, AND FITTINGS

- Leaks
- Cracks or corrosion
- Metal thickness (by hammering or caliper)
- Metal thickness (by ultrasonics, radiation, or eddy current
- Gasket condition
- Alignment, distortion, and swaying
- Valve seats
- Pipe rack supports or hangers
- Vibration
- Erosion

Piping systems that cannot be inspected visually are frequently pressure tested. They include:

- Underground and other inaccessible piping
- Complicated manifold systems
- Small pipe and tubing systems
- All systems after a chemical cleaning operation.

The most used media for pressure tests is water. In this type of test the water is pumped into the pipe such that the quantity of gas in the pipe is minimal. When the pressure has reached the test pressure, the system is valved off but with a pressure gage on the closed system. Small leaks of the incompressible water results in a rapid and significant drop in pressure and, thus, the probability of a leak is established. Use of compressible or condensible gases such as steam, air, carbon dioxide, and so forth is generally less reliable; more reliance must be placed on hearing the sound of escaping gas or otherwise detecting leaks.

8.4.2 Pumps and Compressors

Mechanical wear is the predominant cause of deterioration of pumping and compression equipment, although erosion and corrosion are also responsible for an appreciable amount of deterioration. Other deteriorating factors include improper operating conditions, piping stresses, cavitation, and foundation deterioration causing misalignment or vibrations.

Since vibration can rapidly deteriorate a pump or compressor, periodic examination of the vibration level should be made using an electronic vibration meter. Inspection of all assembly bolts, gaskets, cover plates, and flanges should be conducted to detect leaks and cracks as a result of vibration or abnormal operating conditions.

A brief checklist for the visual inspection of pumps and compressors is presented as Table 8-4.

TABLE 8-4. CHECKLIST FOR VISUAL INSPECTION OF PUMPS AND COMPRESSORS

- Misalignment
- Foundation cracks and uneven settling
- Missing or broken anchor bolts
- Leaky piping connections
- Excessive vibrations and noise
- Deteriorating insulation
- Depleted lubrication oil reservoir
- Missing safety equipment such as a pump coupling guard
- Burning odor or smoke
- Excessive dirt
- Excessive corrosion
- Leaks and cracks at assembly bolts, gaskets coverplates, and flanges

Two pumps are often installed in parallel such that one pump may be shut down while the other does all the required pumping. Thus, one pump may undergo a complete internal inspection or replacement while the system remains in operation.

8.4.3 Instruments, Control Equipment, and Electrical Systems

Instruments, control equipment, and electrical systems must be inspected at the minimum required frequencies given in 40 CFR 265.194 and section 8.5 of this manual to ensure that they are in good working order. Level controls, emergency shut-off devices, and alarms are among the most important devices for fail-proof tank operation. Flow rate controls, temperature gauges, pressure gauges, and analyzers are among the less important devices.

A brief checklist of what should be inspected regarding the instruments, control equipment, and electrical systems is presented in Table 8-5.

TABLE 8-5. CHECKLIST FOR INSPECTION OF INSTRUMENTS AND CONTROL SYSTEMS

- Instruments
- Transmission systems
- Power supplies
- Seals
- Panels and enclosures
- Electrical Equipment
- Insulation
- Operating mechanisms (moving parts)
- Insulating and lubricating oils
- Protective relays
- Bearings
- Batteries
- Connectors
- Rectifiers

The visual inspection should specifically watch out for any deteriorating effects of the following on electrical systems:

- Heat
- Dirt
- Moisture
- Chemical attack.

The instruments and controls must be calibrated by qualified personnel as per the methodology and frequency recommended by the vendors.

Inspection of the data gathered by instruments should be included as an integral part of the overall inspection plan for instruments, control equipment, and electrical systems. Any unexpected discontinuities or abnormal peaks in data charts or data logs may indicate that there is some cause for concern in the control systems.

8.5 Inspection Tools and Procedures

When visual inspection suggests that tools are needed for a more detailed inspection, simple hand tools may be used as an initial aid. Tools such as a scraper, digger, flange spreader, knives, paint or crayon, portable lights, and rules are indispensable for visual inspection. Additional tools such as hammers, mirrors, magnifiers, magnets, and internal visual scopes are also helpful.

The mechanical measuring tools include calipers, micrometers, scales and tapes, wire gauges, level and plumb bob and line, depth gage, hook gage, square, and straightedge.

Approved destructive examination methods include drilling a hole through the tank wall or bottom, then using a hook gage to measure thickness, tapping the hole, and inserting a threaded plug. Another method is to cut large (12 inch by 12 inch) test specimens from the tank for detailed examinations; this is often performed for tanks where the bottom cannot be externally inspected. A trepanning saw may be used to remove a portion of a weld from the tank for examination.

Brief descriptions of other inspection tools and methods follow:

8.5.1 Hammering Method

Full blows of the hammer are used and the sound, feel, and imprint of the hammer head noted. Where corrosion or erosion is significant, the sound will be dull, the feel soft, and a dent or hole likely. Hammering is frequently performed on tank roofs, bottoms, and on floating roof components.

8.5.2 Penetrant-Dye Method

Penetrant dyes are often used to define surface cracks on a tank that would not be verified by a visual inspection. The penetrant is applied by either brushing or spraying to a surface carefully cleaned (often by sandblasting), dried, and then the excess is removed. After a few minutes of contact to allow penetration into the crack, a chemical developer is then applied to the surface. The dye stains the developer and exposes the extent and size (but not the depth) of any defects.

8.5.3 Magnetic-Particle Method

The magnetic-particle method is also used to define surface cracks on tanks similar to the penetrant-dye method. The surface must also be carefully cleaned and then iron particles are sprinkled on the surface. A magnetic field is then imposed near the particles either by a permanent magnet (especially if flammable materials are stored nearby) or an electromagnetic device and the particles arrange themselves along the crack and particularly near the ends of the crack. The magnetic field should be imposed in two directions to assure there is no crack or to identify two or more cracks running in different directions. No indication is given about the depth of the crack. This method may be used only on tanks constructed of magnetic materials.

8.5.4 Radiographic Method

Welds are often radiographed during tank fabrication to detect thickness and flaws of the welds. This method may also be used to determine thickness of tank plates. The device may use either X-rays or gamma radiation and must be calibrated prior to use. It is similar in many respects to the X-ray machines used for dental and medical purposes.

8.5.5 Ultrasonic Method

Ultrasonic instruments can be used to measure the tank's thickness and determine the location, size, and nature of defects. They can be used while the tank is in operation as only the outside of the tank needs to be contacted with the device. Two types of ultrasonic instruments, the resonance and the pulse type, are most commonly used for tanks. The pulse type utilizes electric pulses and transforms them into pulses of ultrasonic waves. The waves travel through the metal until they reach a reflecting surface. The waves then are reflected back, converted to electrical pulses, and show up on a time-base line of an oscilloscope. The instrument is calibrated by using a material of known thickness. Therefore, the time interval between the pulses corresponds to a certain thickness.

8.5.6 Vacuum-Box Method

The vacuum box is an open box in which the lips of the open side are covered with a sponge rubber gasket, and the opposite side is glass. A vacuum gauge and air siphon connection are installed on the box. The seam of the tank shell where a leak is suspected is first wetted with a soap solution, then the vacuum box is pressed tightly over the seam. The foam-rubber gasket forms a seal, and a vacuum is achieved inside the box by the air siphon. If a leak exists, bubbles will form inside the box and can be seen through the glass.

8.6 Frequency of Tank Inspection

There are several regulatory requirements regarding tank inspections and, in the case of the detailed assessment of tank condition, other practical considerations.

8.6.1 Regulatory Requirements

The frequency of performing some types of tank inspections is presented in 40 CFR 264.19 and is summarized in Table 8-6.

TABLE 8-6. MANDATED INSPECTION FREQUENCIES

At Least Once Per Normal Operating Day
- Overfilling control equipment
- Data on tank operating conditions
- Level in uncovered tanks
At Least Once Per Week
- Above-ground external portions of tank
- Area surrounding tank

Although the permit applicant is required to present a schedule for the detailed assessment of tank condition, the permit writer is ultimately responsible for specifying the appropriate schedule in the permit issued to the applicant.

Title 40 CFR 264.15(b) states that the frequency of inspection for other items should be based on the rate of possible deterioration of the equipment and the probability of an environmental or human health incident if the deterioration or malfunction goes undetected. Part 264.194(b) requirements for periodic comprehensive tank inspections specify the following additional factors to be used in determining inspection intervals:

- Material of construction of tank
- Type of erosion or corrosion protection used
- Characteristics of waste being stored
- Rate of corrosion or erosion observed during previous inspections.

8.6.2 Practical Considerations

The detailed tank assessment is often a costly requirement for the operator of a hazardous waste storage facility because the tank must be shut down, blocked off, emptied, cleaned, and undergo detailed examination by qualified personnel. Unless the operator has spare tanks, shutdown of the tank may temporarily also necessitate closure of the facility. Adequate tank cleaning for personnel safety may also be a costly step in terms of both elapsed time and other dollar costs. Furthermore, there is always some potential for residual hazardous materials to remain in nozzles or piping associated with the tank. Thus, tank inspections _must_ be frequent enough to avoid leaks and spills but should not become necessarily burdensome to the operator of the facility.

In cases where the corrosion rate data are known at storage temperature for the specific material of construction of the tank with the specific liquid to be stored in the tank and only uniform corrosion has been experienced in prior applications, the expected service life of the tank can be realistically estimated, which can then be used to establish a reasonable inspection schedule. During the initial years, scheduled inspections at 20, 40, and 60 percent of the tank's service life would be reasonable frequency. For example, a tank with an expected service life of 25 years might initially be subjected to a comprehensive inspection every 5 years to establish the actual rate of corrosion or deterioration. However, after shell thickness measurements were made and the existence of any non-uniform corrosion noted, the estimated service life could be re-estimated and the inspection frequency increased if necessary as the tank approaches the end of its service life and the probability of leaks or ruptures increases; for example, the inspection frequency could be increased to every 1 to 2 years.

If non-uniform corrosion has been experienced by a material of construction with the liquid to be contained, much more frequent initial inspections should be scheduled. Pitting and crevice corrosion are particularly obnoxious because not only does there often seem to be an induction period with little observable physical damage, but also the corrosion accelerates once the pit or crevice is formed due to formation of a larger electrolytic cell. Materials subject to pitting or crevice corrosion should normally not be selected unless an economic analysis clearly indicates a preference toward frequent inspections rather than to a more costly material of construction.

8.6.2.1 More Frequent Detailed External Inspections. In some cases where any form of non-uniform corrosion is not expected, the owner or operator may prefer to conduct more frequent comprehensive external inspections of the tank to avoid the expense of frequent internal inspections, providing all portions of the tank are accessible, including the bottom. In the example cited above, the owner-operator could initially conduct annual external inspections, which include intensive measurements of tank shell thickness (i.e, one measurement per square yard of surface area) and reduce the frequency of internal inspections to once every 7 years. As the condition of the tank deteriorates, however, the frequency of internal inspections should increase to every 1 or 2 years.

8.6.2.2 Immersed Test Coupons. In cases where few corrosion data are available or proper tank inspection would be very costly, test specimens (coupons) of material literally from the same heat (or batch) of the metal used to construct the tank may be immersed in the liquid, with some coupons allowed to rest on the bottom of the tank. These test coupons may be stressed by bending and welding to form crevices to simulate problem areas in the tank. Samples can be withdrawn annually and measurements made of thickness and observations made about stress, crevice, and pitting corrosion. The data collected could then be used to suggest an appropriate inspection schedule; of course, an inspection schedule should be established that requires greater frequency than that projected by the data from the coupons.

In the case where a used tank has been installed and no coupons may be taken from the specific heat (or batch) of material from which the steel plate was manufactured, and the specific type of material used is not certain, a small sample of the tank metal may be removed and analyzed by emission spectroscopy to classify the metal used. Then test coupons may be made from this type of metal for immersion in the tank. However, a more conservative inspection schedule should be developed based upon this circumstantial data than indicated in the prior example.

<u>8.6.2.3 Secondary Containment</u>. If the tank operates at close to atmospheric pressure and a leak would not cause undue detriment to personnel, property, or the environment if the leak were collected in a secondary containment system, then some reduction could be considered in the frequency of the internal tank inspection. Obviously, if the material stored were volatile and toxic upon inhalation or if the waste were highly reactive with water (rain) or with the material of construction used for the containment system, then this approach would not be suitable.

Other considerations include the size of the tank or quantity of material which might be leaked to the secondary containment system. Upon detection of a leak it may be possible to rapidly pump the tank's contents to an alternative tank as a temporary measure and thus avoid too large a spill. Of course, good housekeeping combined with frequent inspections would be required to assure that any leaks were detected soon after failure. The difficulty in cleaning up a spill should also be considered. Because of the difficulty in inspecting insulated tanks for leaks, reliance on secondary containment and early leak detection in this situation would not be practical.

Another problem emerges with tanks where the bottom rests directly on a foundation such that the bottom cannot be externally inspected. Obviously, the foundation must be <u>within</u> the secondary containment system. Furthermore, if pitting or other forms of non-uniform corrosion are experienced in the bottom, a leak may be present for a significant period of time before it becomes detected. During this period of time, considerable further deterioration of the tank may continue leading to a major failure.

Particular attention should be given to avoiding ignition of hazardous wastes if they are combustible . Use of expolosision-proof motors and prohibit of nearby motor vehichles and the like near the secondary containment system. Also, there should be no possibility of mixing incompatible wastes in the same secondary containment area if simultaneous leaks were to occur.

APPENDIX F

COST ESTIMATES FOR CONSTRUCTION OF STORAGE TANK SYSTEMS

- Basis and Rationale for Cost Estimates
- Diagram-Typical Underground Storage Tanks
- Cost Estimate for Storage Facility with One 1,000 Gallon Tank
- Cost Estimate for Storage Facility with Two 5,000 Gallon Tanks

BASIS AND RATIONALE
FOR COST ESTIMATES OF SAMPLE UNDERGROUND
STORAGE TANK INSTALLATIONS

1) Cost/Price Data: The Means Building Construction Cost Data, 1983 edition [1], was the primary source of price data, with supplementary information obtained from suppliers of tanks, level indicators and cathodic protection systems. Means cost/price data is based on average figures nationwide as of January 1983. Future costs will escalate due to inflation and will fluctuate upward and downward due to location and construction activity; e.g., when there is a lull in construction activity, bid prices will decrease.

2) We assumed that the storage facility is installed at an existing facility and is installed by a contractor who regularly installs tanks; i.e., the prime contractor does all of the work with his own forces. Scale factor cost considerations are accounted for by adjusting unit prices from Means, including estimates for mobilization and standby costs, and by varying contingency percentages.

3) The tanks are installed under a paved area (parking lot or driveway) to facilitate access by tank trucks that are used to empty the tanks. Typical industrial plants/facilities try to minimize unusable space which would be the case if the tank were installed without pavement protection. Pavement protection is required by NFPA 30 and API 1615 for underground tanks subjected to vehicular traffic (and is also recommended by most tank manufacturers).

4) The liquids to be stored are ignitable or reactive wastes. These classes of wastes were chosen because the cost of storing them underground is less than the added cost of fire protection required for aboveground storage. Corrosive and toxic wastes can be stored aboveground at less cost than underground storage and can be monitored for leaks and easily maintained, compared to underground installation.

5) Steel tanks were chosen due to their (1) compatibility with most flammables and combustibles and (2) lower purchase and installation cost than FRP tanks. FRP tanks must be evaluated for compatibility with flammables and combustibles, especially organic solvents.

6) The Steel Tank Institute's "sti-P3 System" was chosen for corrosion protection. It provides corrosion protection through a protective coating, cathodic protection (sacrificial anode), and electrical isolation of the tank. NFPA 30 requires cathodic protection of steel tanks if the soil resistricity is less than 10,000 ohm-cm or if there are other corrosive conditions. The sti-P3 system carries a 20 year limited warranty for soil resistivity levels of 2,000 ohm-cm or more (corresponds to medium corrosive soils). Soils which have resistivity of 10,000

ohm-cm or more generally have good internal drainage (high permability and are not saturated) and have low corrosivity.

7) Level indicators are recommended for hazardous waste storage systems to minimize the amount of contact with the liquid being stored. Dip-sticking, the least capital cost method of determining the liquid level, requires the operator to come into direct contact with the waste. A direct-reading, float- type, mechanical level indicator was used for the 1,000 gallon tank installation. This particular class of level indicator, the first step above dip-sticking, allows the operator to readily determine the liquid level at a cost in line with the cost of the facility. We expect that a facility which has a 1,000 gallon storage tank does not generate large volumes of waste. The waste is generated infrequently or at very low rates. Thus, frequent liquid level monitoring is not required. The operator would inspect the level in the tank approximately once per week (if there is a regular flow into the tank) or before and after the waste is transferred to the tank if discharged infrequently.

An electric level indicator system with remote indicator in the industrial plant is considered good practice for the two 5,000 gallon tank facility. The cost of the level indicator is proportional to the cost of the entire storage facility. The electronic system is composed of a level sensor mounted in the tank and a level indicator mounted in a control room inside the industrial plant. This type of level indicating system provides continuous monitoring of the levels in the tanks without the operator having to leave his normal work place. Continuous monitoring is assumed for a facility that has a continuous flow of wastes into the tank(s) or regular, large volumes of wastes being transferred to the tank(s). With these types of operations, the possibility of over filling a tank is higher than the small storage facility. Further, if a tank develops a rupture; more liquid could drain out before the rupture is detected if a convenient remote readout device is not available.

8) With ignitable or reactive wastes being stored, the installation must conform to NFPA 30. The code requires a firm foundation at least 6 in. of non-corrosive inert material (well-drained sand or gravel) surrounding the steel tank and 18 in. of earth with 6 in. of reinforced concrete over the tank when subjected to vehicular traffic. API 1615 and most tank manufacturers recommend 12 in. clearance around the steel tank, 6 in. under the tank and 18 in. over the tank with a 6 in. reinforced concrete slab (for vehicular traffic). The sti-P3 corrosion protection system also prescribes 12 in. of well-drained sand or gravel around and over the tank to isolate the tank from corrosive attack.

9) We assumed that the tank will be installed approximately 20 feet from the industrial plant. The vent is installed against the building for protection and support with the vent opening 12 feet above grade and directed away from the building or any building openings. (as per NFPA 30).

10) A concrete anchor is provided for the two 5,000 gallon tanks to prevent the tanks from "floating" from buoyant forces when empty during periods when the soil is saturated and/or if the water table is high. With the bottom of the tanks being 11 feet deep (8 feet in diameter plus another 2 feet of cover) it is often into a zone which is at least partially saturated, or the ground water might rise to above the tank bottom. Slab-shaped anchors were chosen over concrete deadmen for ease of construction.

On the other hand the 1,000 gallon tank, which is only 4 feet in diameter, will be buried about 7 feet below the surface, a level which normally should be above the ground water and is in a zone which is generally fairly well areated. Thus, no anchor was provided for the 1,000 gallon tank. Furthermore, the weight of cover soil and the pavement slab over the tank provides resistance against buoyant forces.

11) The conductors for the electric level indicating system are installed in conduits to facilitate maintenance and repair under paved areas and for protection inside the building. The conductors are assumed to extend 50 feet inside the plant (including horizontal and vertical runs) to a control room.

12) Cast-iron soil pipe is used for gravity flow from the building to the tank. Cast-iron pipe was chosen due to its long life, compatibility with the waste being transferred, and similar installation requirements as the building drain piping. Plumbing in industrial plants is most commonly cast-iron (for noncorrosives).

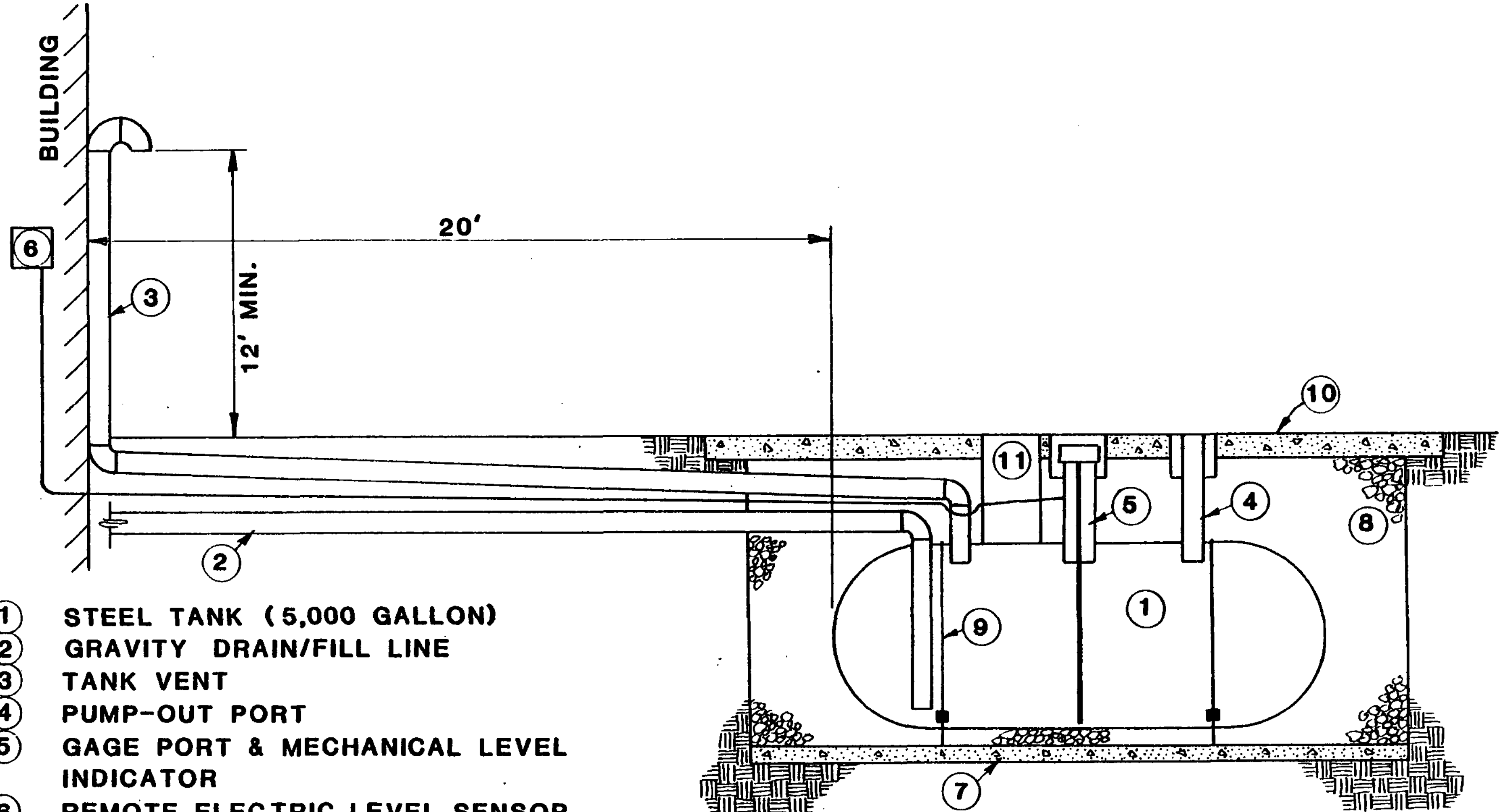
13) The pump-out port is located directly above the tank. The top of the port is enclosed in a valve box that is integral with the concrete pavement slab. The valve box protects the pump-out port from vehicular traffic.

14) Manways are good practice; they allow access to inspect and rehabilitate the tank. In some localities manways are required for larger tanks. Various manufacturers estimate that 20 to 100 percent of their tanks are furnished with manways. We assumed that one manway is provided for each of the 5,000 gallon tanks; the 1,000 gallon tank is not large enough to warrant the additional cost of a manway.

15) All the apparatus used to remove the waste from the storage tank is furnished by the hauler. The hauler drives his truck onto the concrete pavement slab, lifts off the valve box cover, opens the pump-out port, inserts a reinforced suction hose and pumps out the contents using a truck-mounted pump. When the pumping is complete, the hauler shuts off the pump, disconnects the hose at the truck (using dry-disconnect couplings), replaces the suction hose on the tank, closes the pump-out port, replaces the valve box cover, and leaves.

[1] Robert Snow Means Company, Inc. Building Construction Cost Data, 1983. Construction Consultants and Publishers. Kingston, Massachusetts, 1982, 420p.

DIAGRAM OF TYPICAL UNDERGROUND STORAGE TANK



1. STEEL TANK (5,000 GALLON)
2. GRAVITY DRAIN/FILL LINE
3. TANK VENT
4. PUMP-OUT PORT
5. GAGE PORT & MECHANICAL LEVEL INDICATOR
6. REMOTE ELECTRIC LEVEL SENSOR, INDICATOR & ALARM
7. CONCRETE ANCHOR SLAB
8. NON-CORROSIVE, INERT BACKFILL
9. HOLD DOWN STRAP
10. CONCRETE PAVEMENT SLAB
11. MANWAY

COST ESTIMATE FOR STORAGE FACILITY WITH ONE 1,000 GALLON TANK

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	TOTAL
Tank Installation							
1. 1,000 gallon steel tank, with sti-P3 protection system, set in excavation, 49.5" wide x 10' long	1	EA	715	715	160.00	160	
2. Excavation, bulk, medium earth, truck loaded, wheel mounted backhoe, 3/4 CY capacity, 7' deep, minimum 12" clearance around tank, 1' under tank and 2' cover	19	CY	1.40	27	1.30	25	
3. Wood sheeting, wales, braces, salvaged	312	SF	1.35	421	1.00	312	
4. Haul away spoil, 6 CY dump truck, 4 mile round trip	18	CY	2.25	41	1.44	26	
5. Borrow, buy & load at pit, 2 mile haul, place & spread pea gravel	4	CY	8.00	32	2.62	10	
6. Tank bedding, bank sand, 6" deep, 6' wide x 12' long	2	CY	3.00	6	2.62	5	
7. Anchor slab 8" thick mesh reinforced 6' wide x 12' long, cast-in place	8	SY	16.34	131	2.12	17	
8. Backfill pea gravel 12" layers, and compact to top of tank	4	CY	0.46	2	11.47	46	
9. Backfill on-site material and compact, 12"	3	CY	0.46	1	11.47	34	
10. Pavement slab, 6" thick, mesh reinforced, 4,500 psi, 12' long x 6' wide	8	SY	12.38	99	1.60	13	
11. Base course for pavement, crushed stone, 12" deep, 12' long x 6' wide compacted	8	SY	3.69	30	0.70	6	
12. Pump-out port, 4" diameter, black steel, schedule 40	2	LF	10.95	22	8.35	17	
13. Valve box, 6" diameter, cast iron set in pavement	1	EA	65	65	48	48	
Subtotal - Tank Installation				1,592		719	2,311

COST ESTIMATE FOR STORAGE FACILITY WITH ONE 1,000 GALLON TANK (CONTINUED)

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	TOTAL
Level Indicator							
1. Level indicator, float-type, direct reading, in 6" diameter cast iron valve box set in pavement	1	LS	200	200	70	70	
Subtotal - Level Indicator				200		70	270
Piping							
1. Steel pipe, 4" diameter with couplings	20	LF	12.05	241	9.19	184	
2. Excavation, 3' deep, 16" wide, backhoe, wheel mounted, 3/4 CY capacity	9	CY	1.40	13	1.30	12	
3. Pipe trench bedding, 4" deep, 16" wide, in trench, crushed bank, run gravel	1	SY	1.13	1	0.32	1	
4. Back fill, on-site material, compacted in 12" layers, by hand with vibrating plate	2.5	CY	0.46	1	11.47	29	
5. Fill tube, 4" 0, schedule 10, type 6063-T6 aluminum	4	LF	2.85	11	4.46	18	
7. Base Course, 12"	3	SY	3.69	11	0.70	2	
8. Pavement 6" mesh reinforced concrete	6	ST	12.38	74	1.60	10	
Subtotal - Piping				352		256	608
Vent							
1. Pipe, black steel, 2" diameter with couplings	35	LF	3.72	130	5.17	181	
2. Excavation, utility trench, drain trencher, 12" wide, 24" deep, backfill & compact	20	LF	0.36	7	0.30	6	
3. Pipe trench bedding, 4" deep, crushed bank run gravel	0.5	SY	1.13	1	0.32	1	
Subtotal - Vent				138		188	326
Subtotal - Bare Costs				2,282		1,233	3,515

COST ESTIMATE FOR STORAGE FACILITY WITH ONE 1,000 GALLON TANK (CONTINUED)

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	TOTAL
Mobilization, material tax @ 5%, labor mark-up @ 20%, overhead @ 12%, profit @ 8% and contingency @ 15%							2,357
TOTAL							5,872

COST ESTIMATE FOR STORAGE FACILITY WITH TWO 5,000 GALLON TANKS

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	TOTAL
Tank Installation							
1. 5,000 gallon steel tanks with STI-P3 protection system and manway, set in excavation	2	EA	2,570	5,140	645	1,290	
2. Excavation, bulk, minimum 12" clear all around, 12" under tank, 24" cover, 11' deep, 16' wide x 19' long, 1-1/2 CY capacity	124	CY	1.21	150	0.65	81	
3. Wood sheeting, wales, braces, salvaged	770	SF	1.35	1,040	1.00	770	
4. Haul-away spoil, 12 CY dump truck, 4 mile round trip	115	CY	1.77	204	0.81	93	
5. 8" thick, mesh reinforced anchor slab 16' wide x 19' long	34	SY	16.34	556	2.12	72	
6. Borrow, 2 mile haul, place and spread pea gravel	37	CY	8.00	296	2.62	97	
7. Backfill & compact to top of tank, pea gravel	37	CY	0.46	17	11.47	424	
8. Backfill on-site material, 12" and compact	11	CY	0.46	5	11.47	126	
9. Pavement slab 6" thick mesh reinforced 16' wide x 19' long	34	SY	12.38	421	1.60	54	
10. Base course for pavement crushed stone, 12" deep, 16' wide x 19' long	34	SY	3.69	125	0.70	24	
11. Pump-out ports, schedule 40 steel	4	LF	10.95	44	8.35	33	
12. Valve boxes, 6" diameter, cast iron, set in pavement	2	EA	65	130	48	96	
Subtotal - Tank Installation				8,128		3,160	11,288
Level Indicator							
1. Electronic level indicator, sensor and alarm with line control to building	2	EA	1,000	2,000	200	400	
Subtotal - Level Indicator				2,000		400	2,400

COST ESTIMATE FOR STORAGE FACILITY WITH TWO 5,000 GALLON TANKS (CONTINUED)

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	TOTAL
Piping							
1. 4" diameter pipe with steel couplings	40	LF	12.05	482	9.19	368	
2. Excavation, 3' deep, 16" wide, 3/4 CY capacity	6	CY	1.40	8	1.30	8	
3. Pipe trench bedding, bank run gravel	1	CY	1.13	1	0.32	1	
4. Backfill, on-site material, compacted	5	CY	0.46	2	11.47	57	
5. Fill tube, 4" diameter, schedule 40 steel, with couplings	16	LF	12.05	193	9.19	147	
6. Pavement, 6" reinforced concrete	9	SY	12.38	111	1.60	14	
Subtotal - Piping				797		595	1,392
Vent							
1. Pipe, 2" diameter steel	55	LF	3.72	205	5.17	284	
2. Excavate utility trench 12" wide x 24" deep backfill & compact	40	LF	0.36	14	0.30	12	
3. Pipe trench bedding, 4" deep crushed bank run gravel	1.5	SY	1.13	2	0.32	1	
4. Base course, 12" thick, compacted	1.5	SY	3.69	6	0.70	1	
5. Pavement, 6" reinforced concrete	6	SY	12.38	74	1.60	10	
Subtotal - Vent				301		308	609
Subtotal - Bare Costs				11,226		4,463	15,689
Mobilization, material tax @ 5%, labor mark-up @ 20%, overhead @ 12%, profit @ 8% and contingency @ 15%							10,303
TOTAL							25,992

APPENDIX G

Summaries of Selected References

RECENT AND ON-GOING FEDERAL, STATE OR LOCAL AND INDUSTRY OR TRADE ASSOCIATION STUDIES ON UNDERGROUND TANK STORAGE

Federal

REFERENCE: A. T. Kearney, Inc. and PEDCO Environmental, Inc. "A Guide for Preparing RCRA Storage Permit Applications", (Draft). U.S. Environmental Protection Agency, Washington, D.C., 1982, 280 pp.

ABSTRACT: This draft guidance is intended for use by owners/operators of hazardous waste storage facilities in developing Resource Conservation and Recovery Act (RCRA) Part B Permit Applications. Comments from applicants or other persons outside of the U.S. Environmental Protection Agency (EPA) have not been incorporated in this guide. Detailed technical instructions covering the required contents of the RCRA permit applications and explanations concerning administrative procedures in the permitting process are included.

The suggested permit application requires inclusion of the following information related to tanks:

- Tank description;
- Tank corrosion protection;
- Tank management practices;
- Tank inspection;
- Tank spills and leakage; and
- Closure of tanks.

REFERENCE: Franklin Associates, Ltd. "Technological Characterization of Waste Oil Storage", (Draft). Prairie Village, Kansas, February 1983, 54 pp.

ABSTRACT: This draft report prepared for the U.S. Environmental Protection Agency (EPA) discusses waste oil losses in aboveground and underground storage tanks. Estimates of the frequency and magnitude of leaks in waste oil storage tanks are provided. Underground tanks have a much greater probability of loss than aboveground tanks. The probability of leakage in an underground tank is conservatively estimated at 12 to 14 percent, compared to 1.7 percent for aboveground tanks. Two approaches were used to estimate the probability of leaks in underground waste oil tanks, while a "fault-tree" analysis was used for aboveground tanks.

REFERENCE: Fred C. Hart Associates, Inc. "Facilities Storing or Treating Hazardous Waste in Tanks, a Technical Resource Document for Permit Writers", (Draft). U.S. Environmental Protection Agency, 1982, 130 pp.

ABSTRACT: Fred C. Hart Associates, Inc. prepared this report for the U.S. Environmental Protection Agency as part of a series of technical resource documents on standards for facilities that treat, store and dispose of hazardous waste. The documents were designed to assist permit writers in evaluating facilities against standards (40 Code of Federal Regulations, Part 264) issued under Subtitle C of the Resource Conservation and Recovery Act (RCRA) of 1976, as amended. Included in this report is information concerning the design, inspection, common treatment processes, closure, and costs of hazardous waste tanks. A checklist of questions and bibliographies of additional information sources are also included for the permit writer.

REFERENCE: Fred C. Hart Associates, Inc. "Assessment of Hazardous Waste Mismanagement Damage Case Histories", (Draft). U.S. Environmental Protection Agency, December 1982, Approximately 355 pp.

ABSTRACT: This report provides technical support to the U.S. Environmental Protection Agency (EPA) for promulgating, implementing, and revising hazardous waste disposal regulations. It contains a compilation of damage case histories associated with mismanaged land and non-land based hazardous waste facilities. These case histories are the results of the first phase of a two-phase study.

Damage Incident Summary Forms (DISFs) were completed for 929 sites across the country as documented in Field Investigation Team (FIT), Surveillance and Analysis (S&A) files at each of the 10 EPA Regions. Each completed DISF identified each site by name, location and facility type, media exposed to contamination, the extent and severity of damage, the event(s) and wastes causing the incident, the status of remedial activities and information sources used. Value judgments were made for many DISF questions.

If one of the 929 sites possessed more than one facility type, a DISF was completed for each type (e.g., landfill, surface impoundment, land treatment, storage/treatment containers, storage/treatment tanks, and other categories). Of the 1,722 facility types tabulated, 197 or 11 percent were storage/treatment tanks.

Approximately 70 percent of the tanks recorded in this study were aboveground facilities. Underground tanks evaluated were presumably constructed without liners or protective coatings. Tank capacities ranged from 500 to 200,000 gallons on sites typically containing multiple tanks and other facility types.

REFERENCE: JRB Associates. "Failure Incident Analyses: Evaluation of Storage Failure Points", (Draft). U.S. Environmental Protection Agency, Washington, D.C., March 1982, 69 pp.

ABSTRACT: JRB Associates prepared this report as part of a larger study of hazardous waste storage and storage-related issues. This report attempts to identify and quantify risks associated with hazardous waste storage facilities. To overcome the present lack of complete data concerning accidental releases of hazardous waste, JRB selected two methods for performing the analysis. The first method involved the analysis of two data bases set up as requirements of the Clean Water Act:

- The Spill Prevention Control and Countermeasure (SPCC) data base containing all spills affecting inland waters as reported to the U.S. Environmental Protection Agency (EPA); and
- The Pollution Incident Reporting System (PIRS) with spills affecting navigable waters as reported to the U.S. Coast Guard.

The second method chosen for the failure incident analysis involved the use of a fault-tree; i.e., a probabilistic logic network that portrays the credible accident sequences by which hazardous wastes could be released. Since both methods had several limitations associated with their use in this study, certain assumptions had to be made.

The analysis of the SPCC and PIRS data bases revealed two key points. First, the vast majority of spills occur due to operations or failure in ancillary equipment. Second, the size distribution of spills is relatively independent of cause, with spills over 5,000 gallons accounting for 2 to 13 percent of spills for a given cause (i.e., failure due to containment device, operations, ancillary equipment, or other causes of spills).

The fault-tree analysis showed that the most likely cause for release of stored hazardous waste is the "loss from tank (and ancillary piping inside the diked area)" and "dike does not retain spill" sequences of events. Tank overflows and manhole leaks were the chief contributors of losses from the tank and ancillary piping.

REFERENCE: The MITRE Corporation. "Tanks and Containers for Hazardous Wastes: Evaluation of Standards", (Draft). McLean, Virginia, November 1981, 126 pp.

ABSTRACT: This working paper drafted for the U.S. Environmental Protection Agency (EPA) reviews and evaluates existing design and operational standards of non-EPA organizations for containers and tanks to hold hazardous substances. The focus of this study was to identify areas not covered in current EPA regulations and items suggested for potential inclusion in EPA tank/ container regulations. The main sources of information were 37 professional, trade, and industrial standards-setting organizations, five State environmental agencies, and four non-EPA Federal agencies.

One of the recommendations pertaining to the EPA regulations for hazardous waste vessels is to allow storage of ignitable wastes in underground tanks. (OSHA regulations allow storage of flammables in underground tanks.) However, MITRE recommends that the underground storage of toxics and possibly corrosives be prohibited because of waste escape hazards and leak detection difficulties.

State or Local

REFERENCE: California Department of Health Services. "Criteria for the Siting of Treatment Technologies for Hazardous Waste Management", (Draft). Sacramento, California, November 1982, 43 pp.

ABSTRACT: This report was developed within the California Department of Health Services as part of the Southern California Hazardous Waste Management Project. The criteria were intended for use by facility planners as recommended guidelines in the waste management or generating industries and State or local government agencies. Typical characteristics of hazardous waste treatment technologies are provided for five types of facilities other than landfills, including waste transfer and storage facilities.

REFERENCE: California Department of Health Services. "Siting Criteria for Hazardous Waste Treatment Facility". Sacramento, California, October 1981, 7 pp.

ABSTRACT: This document was developed within the California Department of Health Services as part of the Southern California Hazardous Waste Management Project. It is a collection of concerns regarding the siting of hazardous waste treatment facilities. Storage tanks are not specifically discussed.

REFERENCE: California Department of Health Services. "Variances From Hazardous Waste Facility Permit Requirements" (Memo to Operators of Hazardous Waste Facilities). Sacramento, California, 1982, 6 pp.

ABSTRACT: This memo from the Hazardous Waste Management Branch of the California Department of Health Services to operators of hazardous waste facilities outlines the procedures required for a variance request. The Department of Health Services has the authority to grant variances under the California Administrative Code as long as such action will not result in a hazard to public health and safety or to the environment. Operators of hazardous waste facilities must submit a variance application and supporting documentation (Attachments A and B) to the appropriate regional office. Facilities with underground tanks must attach information (Attachment B) on a proposed ground water monitoring program to be considered for a variance request. The monitoring program must meet the requirements specified in the applicalton.

REFERENCE: California Legislature. "1983-84 Regular Session, Assembly Bill No. 1362". Introduced by Assemblyman Sher, March 2, 1983, 16 pp.

ABSTRACT: Assemblyman Sher introduced a bill to regulate the underground storage of hazardous substances. The bill requires that all tanks installed after June 30, 1984 comply with certain design, construction, monitoring system and drainage requirements; tanks installed prior to this date have a monitoring system installed, a means of inspection, and a permit before January 1, 1985 and be upgraded to comply with new criteria by January 1, 1994. Each county is to be responsible for implementation of the program to handle a list of hazardous substances developed by the State Department of Health Services. In addition, each local agency will be responsible for inspecting tanks at least once every 3 years. Permit fees are to be collected to cover the costs of administering the program.

A list of a few of the key requirements proposed in the regulation include:

- <u>For Tanks Installed After June 30, 1984</u>:
  - Provision for primary and secondary containment;
  - Installation of a monitoring system to detect leaks into the secondary containment structure;
  - Provision for overfilling protection either through a prevention device or an alarm or both; and
  - Storage of different substances that cause fire, poisonous gas, and/or deteriorate primary or secondary containment when intermixed in separate primary and secondary containment structures.
- <u>For Tanks Installed Prior to June 30, 1984</u>:
  - Installation of a monitoring system to detect leaks on or before January 1, 1985;
  - Maintenance of a monitoring and recordkeeping program as specified by the local agency;
  - Provision for visual inspection of tanks whenever practical;
  - Adherance to spill reporting and clean up as specified in the bill;

- Adherance to permanent or temporary closure practices as specified in the bill; and
- Provisions for upgrading tanks before January 1, 1994.

REFERENCE: California Regional Water Quality Control Board. "Mandatory Facility Questionnaire". Oakland, California, 1982, 14 pp.

ABSTRACT: The California Regional Water Quality Control Board decided to implement a program starting in March 1982, to determine the overall magnitude of numerous subsurface leaks from sumps and subsurface tanks in the San Francisco Bay Region. This mandatory questionnaire was sent to approximately 1,400 facilities thought to contain potential sources of leaks to the area of concern. The facilities were asked to answer by May 31, 1982 questions describing any existing or former sumps, subsurface tanks or subsurface piping. The responses will be used to determine which facilities will be required to implement a leak detection program.

REFERENCE: California Regional Water Quality Control Board. "Water Quality Control Plan, San Francisco Bay Basin", (Toxic Waste and Hazardous Waste Section). Oakland, California, July 1982, pp. 4.23-4.24

ABSTRACT: This excerpt from the Water Quality Control Plan for the San Francisco Bay Basin provides general background information concerning the program initiated by the California Regional Water Quality Control Board to deal with the problem of hazardous material subsurface leakage in the Santa Clara Valley, Niles Cone, and Livermore-Amador Valley ground water basins. The Regional Board is currently developing a policy for minimum underground fuel storage management practices.

REFERENCE: California Regional Water Quality Board. "205(j) Proposal Assessment of Contamination from Leaks of Hazardous Material in the Santa Clara Valley Ground Water Basin". Oakland, California, 1982, 6 pp.

ABSTRACT: The California Regional Water Quality Control Board proposed numerous site investigations in the Santa Clara Valley ground water basin to determine the extent of hazardous material contamination from underground tanks. This proposal outlines the task requirements, including time estimates and a tentative budget to perform the analysis within Fiscal Year 1983-1984. The proposal study team includes the Regional Board and Santa Clara Valley Water District staffs and a private consultant.

REFERENCE: Cape Cod Planning and Economic Development Commision. (S. Horsley) Barnstable, Massachusetts. Personal communications with SCS Engineers, May 1983.

ABSTRACT: The Cape Cod Planning and Economic Development Commission (CCPEDC) developed two model ordinances which directly address the ground water contamination problem. These ordinances were designed for enactment by the area towns since the county government has no regulatory authority in Massachusetts. As of September, 1982, 14 of the 15 Cape Cod communities had adopted at least one of the three types of local protection measures, as follows:

- Zoning bylaws to protect aquifer recharge areas;
- Health regulations to prevent leaking of underground fuel and chemical storage tanks; and
- Regulations to control the storage, use and disposal of toxic and hazardous materials.

The two model ground water ordinances are called "Model General Bylaw/Regulation to Control Toxic and Hazardous Materials" (December, 1981) and "Model Health Regulation to Prevent Leaking of Underground Fuel and Chemical Storage Systems" (revised February, 1982). The latter ordinance has three major provisions which are registration of underground storage tanks, inventory control and leak testing, and regulation of new tank installations.

The first provision of the underground storage tank regulation requires that all tanks in excess of a certain size must be registered. Information required for tank registration includes size, type, age, location, and material stored. The second provision requires daily inventory recordkeeping and annual leak testing of tanks which are 15 years or older. Non-conforming steel tanks must also be removed and inspected after 20 years. The third provision of the model ordinance dictates the installation of new tanks which must have an approved design and be protected from internal and external corrosion. The placement of tanks is also regulated with respect to proximity of water supplies.

After two years of implementing the underground tank regulation, dozens of leaking underground tanks were discovered. Many of these tanks were situated within ground water recharge areas. All of the leaking tanks were removed and replaced. Local officials have been able to effectively administer the ordinance.

REFERENCE: F.G. Bercha and Associates Limited. "Bulk Plant Risk Optimization". Department of the Environment, Environment Protection Service, Hull, Quebec, Canada, December 1982, 232 pp.

ABSTRACT: This report analyzes risk-cost optimization of oil bulk storage plants using conventional fault tree techniques. Seven major types of accidents are examined, as follows:

- Tank overflow;
- Tank Leakage;
- Tank rupture;
- Ancillary equipment leak;
- Ancillary equipment spill;
- Fire or explosion; and
- Other.

Of the seven major types of accidents, the primary cause of spills is due to operator error during tank filling. Failures due to engineering design errors are the least likely to occur. Repair, service, and inspection are each essential in preventing releases from tanks.

Recommendations for optimizing bulk plant operations are as follows:

- Workers should take periodic refresher courses to review operating procedures and introduce new industrial innovations;
- A high level alarm should be installed on every tank to reduce the number of overflow incidents;
- Specialized equipment should be installed if cost effective; and
- Though engineering design errors lead to the fewest spills of petroleum, small improvements in design may reduce the primary cause of spills, i.e., operator errors.

REFERENCE: Michigan Department of Natural Resources. "Study on the Underground Storage of Gasoline". Water Quality Division, Lansing, Michigan, September 1981, 153 pp.

ABSTRACT: This study looks at the problem of ground water contamination from the underground storage of gasoline and how it relates to the state of Michigan. The report summarizes known incidents of pollution from underground storage of petroleum products in Michigan and provides general information on the practice of and problems caused by underground storage.

The study gives recommendations for underground storage in existing tanks and new tanks and for the testing of tanks and piping. Highlights of the recommendations include:

- State laws should provide the authority for spill coordinators to order tank testing;
- Work should concentrate on prevention of ground water contamination rather than depending solely on cleanup measures;
- Preventive measures should include education of the public concerning proper underground storage techniques and the potential dangers from a leak;
- Leak detection methods should include the placement of ground water monitoring wells near all storage tanks;
- All tanks should be registered and equipped with overfill protection;
- Daily inventory of tanks should be mandatory and spills and leaks reported immediately;
- All newly installed tanks should be tested before use and constructed of either fiberglass reinforced plastic, epoxy coated steel with cathodic protection, or a similar system approved by the state;
- All existing tanks must be replaced or destroyed if they do not conform with the approved standards; and
- Tank testing should be performed with the Kent-Moore Tightness Tester or an equivalent method approved by the state.

REFERENCE: New York State Department of Environmental Conservation (NYDEC). "Bulk Storage of Hazardous Liquids, Five Proposed Regulatory Concepts". Albany, New York, November 1980, 63 pp.

ABSTRACT: This document contains summaries of five regulatory concepts for bulk storage of hazardous liquids as proposed by the NYDEC. These proposals, if implemented, would require owners/operators of hazardous liquid storage facilities to:

- Maintain stock inventory control records;
- Post storage plans prepared by a qualified professional engineer;
- Register their storage facilities;
- Submit facility plans, specifications and an application for a certificate to operate a bulk storage system; or
- Obtain permits and certificates to operate storage facilities.

REFERENCE: New York State Department of Environmental Conservation (NYDEC). "Bulk Storage of Hazardous Liquids Study Program, Paper No. 5, Problem Assessment Report", (Draft). Albany, New York, April 1981, 83 pp.

ABSTRACT: As part of New York States' Bulk Storage Study Program, NYDEC reviewed spill case reports in New York, pertinent literature sources and information from NYDEC Regional Oil Spill Engineers and other personal communications. The results contained in this report describe problems and issues associated with storing, handling and preventing leaks of hazardous liquids. The report also characterizes the type and number of hazardous liquids spills with any associated environmental damage and gives case histories of petroleum spills that occurred in each of the nine regions designed by NYDEC.

Findings pertaining specifically to underground tanks include:

- Approximately 20 percent or 16,600 of the estimated 83,000 functioning underground tanks in New York State leak;
- To replace or rehabilitate the 16,600 leaky underground tanks would cost around $90 million initially and $14 million annually thereafter;
- Underground steel tanks have an extremely variable (between 5 and 45 years) life depending on several factors and an average life expectancy of 15 years; and
- About 28,000 underground tanks have been abandoned over the past 10 years and many were left with 6 inches of product which will eventually leak.

REFERENCE: New York State Department of Environmental Conservation (NYDEC). "Bulk Storage of Hazardous Liquids, Paper No. 6, Leak Prevention Programs of Other States and Localities", (Draft). Albany, New York, April 1981, 168 pp.

ABSTRACT: As part of New York States' Bulk Storage Study Program, NYDEC researched a number of out-of-state programs to prevent leaks and spills of hazardous liquids. New York officials requested information on manpower intensity, overall success, and degree of compliance or cooperation by industry concerning the prevention programs. This report contains summaries of leak and spill prevention programs for the States of Massachusetts, Maryland, and Pennsylvania; the Province of Manitoba, Canada; and Prince George's County, Maryland. Names, addresses, and telephone numbers of program contacts who can provide additional information are included immediately following each program discussion.

Highlights of each leak and spill prevention program investigated by New York State and related specifically to underground storage tanks are as follows:

- <u>Massachusetts</u>:
  - Outlaws unprotected underground steel tanks and pipes except where tests prove soils are non-corrosive;
  - Requires a permit from local officials and possibly an inspection for storage of more than 165 gallons of gasoline or for installation, removal or relocation of an underground gasoline storage tank; and
  - Requires that an accurate daily stock inventory control record be maintained by the operator of each underground storage facility.
- <u>Maryland</u>:
  - Requires a permit for aboveground and buried oil storage of 10,000 gallons or more; and
  - Requires that gasoline station owners maintain daily stock inventory control records.
- <u>Prince George's County, Maryland</u>:
  - In addition to requirements for daily stock inventory control, requires that all tanks, except fiberglass tanks, which have been buried for 10 or more years be tested every 5 years.
- <u>Pennsylvania</u>:
  - Requires a permit for all facilities that store hazardous liquids but has no rigorous requirements for tank testing, leak monitoring or tank replacement.
- <u>Province of Manitoba, Canada</u>:
  - Requires that operators of an underground storage tank maintain daily stock inventory control records and report any losses above normal;
  - Requires one time tightness tests in critical areas, on new systems and on rehabilitated systems; and
  - Requires the removal of an abandoned storage system after 1 year of disuse.

REFERENCE: New York State Department of Environmental Conservation (NYDEC). "Number and Distribution of Bulk Storage Tanks in New York State", (Draft and Addendum). Albany, New York, August 1980 (Draft) and April 6, 1981 (Addendum), 22 pp.

ABSTRACT: This report supports the two-year program conducted by the NYDEC to identify and implement state-of-the-art technology and regulatory controls to prevent leaks of hazardous liquids. Ballpark estimates of the numbers and locations of hazardous liquid storage facilities in New York that may be affected by any proposed regulations are provided. Facilities are broken down into four categories:

- Gasoline stations;
- Major petroleum facilities;
- Home heating oil distributors; and
- Industries storing other hazardous liquids.

Included are the different methodologies used to approximate the number of each facility type.

REFERENCE: New York State Department of Environmental Conservation (NYDEC). "Siting Manual for Storing Hazardous Substances: A Practical Guide for Local Officials". Albany, New York, October 1982, 98 pp.

ABSTRACT: This is one of a series of manuals to support New York States' Bulk Storage Program. This manual provides guidance to local officials who need help in making prudent decisions for the siting of bulk storage facilities for hazardous substances. Included topics are:

- Types of hazards;
- Causes of leaks and spills;
- Site evaluation procedures;
- Risk assessment methods; and
- Practices for spill prevention and mitigation.

Precautionary designs and practices are provided for different types of storage facilities, including both above and underground tanks. A precautionary storage design (a drawing showing simple and effective designs to reduce the risk and liability in case of an accident) is illustrated for a pre-engineered underground storage tank.

O'Brien and Gere Engineers, Inc., staff from NYDEC, Bureau of Water Resources, and a review committee comprised of planning representatives contributed to this manual. Fred C. Hart Associates, Inc. provided precautionary storage design drawings.

REFERENCE: New York State Department of Environmental Conservation (NYDEC). "Technology for the Storage of Hazardous Liquids, A State-of-the-Art Review". Albany, New York, January 1983, 223 pp.

ABSTRACT: This is one of a series of manuals to support New York States' Bulk Storage Program. The report provides timely information to industry and government officials who must face problems concerning the storage of hazardous liquids. This manual also encourages the use of the best technology and practices for preventing spills and leaks.

Three parts make up the report. Part I presents background information associated with underground or aboveground storage of hazardous liquids. Parts II and III address the state-of-the-art for underground and aboveground storage systems, respectively. At the end of each chapter within each part, references are provided for further information.

Part II describes the components and concerns associated with the storage of hazardous liquids in underground facilities. Seven chapters detail underground storage systems, including:

- The types of storage tanks available;
- Piping and pumping system components and their performance;
- Underground spill containment systems;
- The types of overfill prevention systems and their performance;
- Leak monitoring and surveillance;
- The testing and inspection of underground storage systems; and
- The closure and abandonment of underground storage facilities.

Fred C. Hart Associates, Inc., staff from NYDEC, Bureau of Water Resources, and a review committee comprised of industrial representatives, a State engineer and a local health official contributed to this manual.

REFERENCE: Santa Clara County City Managers' Association. "Petroleum Product Review Committee: Notes from Meeting held in the Sunnyvale City Council Chamber". Sunnyvale, California, February 17, 1983, 8 pp.

ABSTRACT: Notes from the meeting of the Petroleum Product Review Committee of the Santa Clara County City Managers' Association held on February 17, 1983, outline the purpose of the association and topics of discussion for upcoming meetings. The purpose of the group is to review information on:

- Monitoring systems;
- Single- and double-walled containment systems; and
- Available alternatives for storage of petroleum products.

One of the topics of concern is scheduled to be discussed at one of three above meetings in March 1983. The end result will be a factual presentation of current systems, proposed systems, alternatives, costs and any other related information to the Santa Clara County Intergovernmental Council.

Attendees at the meeting included representatives from the 24 petroleum and petroleum-related industries, a municipal water quality control plant, a citizens activist group, and a local fire department.

Attached to the meeting notes is a blank survey form on existing equipment testing and replacement programs for use by the Committee.

REFERENCE: Santa Clara County Hazardous Materials Model Code Task Force. "Model Hazardous Materials Storage Permit Ordinance". Santa Clara County, California, February 3, 1983, 45 pp.

ABSTRACT: The Santa Clara County Hazardous Materials Model Code Task Force drafted this model permit for local entities enacting the hazardous materials storage permit ordinance. The permit is composed of

14 parts, including containment standards, a hazardous materials management plan and inventory, inspections and records, etc.

REFERENCE: Suffolk County Department of Health Services. (J. Pim), Farmingville, New York. Personal communications with SCS Engineers, March 1983.

ABSTRACT: The Suffolk County Board of Health in New York enacted Article 12 of the Suffolk County Sanitary Code, "Toxic and Hazardous Materials Storage and Handling Control", effective January 1, 1980. The regulation was developed as a result of the increasing number of wells contaminated from leaks and spills of hazardous materials, especially fuels, in Suffolk County. This region was one of the first areas in the nation to be designated as a sole source aquifer by the U.S. Environmental Protection Agency, Suffolk County was also the first to develop comprehensive regulations concerning the storage of toxic and hazardous materials in the nation.

Many countries in Europe (Germany, France, Switzerland and other Scandinavian countries) have developed regulations to prevent spills and leaks from tanks. Europeans have been concerned about the use of hazardous and toxic materials in ground water recharge areas longer than Americans. They have already designated recharge protection zones and installed over 70,000 underground double-walled tanks.

Article 12 was developed around the concept of double-walled containment to provide maximum protection of hazardous material stored underground, aboveground, in portable containers, or at transfer facilities. By the time the law was passed, however, there were two exceptions. First, small heating oil tanks were exempted because of the dificulties in administration. Second, single-walled tanks were allowed for underground storage as long as they met certain conditions. Some of the key requirements of Article 12 concerning underground storage include:

- All new storage facilities constructed on or after November 1, 1982, must be double-walled or some approved equivalent for use with all non-floatable toxic or hazardous materials. For use with floatable materials, acceptable designs are cathodically protected steel, glass fibre reinforced plastic, steel clad with glass fibre reinforced plastic, double-walled steel or plastic or some approved equivalent;

- All existing storage facilities constructed before November 1, 1982, must comply with all the provisions for new storage facilities by January 1, 1987, for use with all non-floatable toxic or hazardous materials and by January 1, 1995, for use with all floatable materials;

- All existing storage facilities which do not comply with all the provisions for new storage facilities must be tested and inspected; and

- Accurate records must be kept of all deliveries and consumption and the figures reconciled daily.

After Article 12 had been in effect for three years, testing of over 1,000 underground tanks resulted in the discovery of 98 leaks. More than 2,000 new or replaced tanks were inspected and over 900 tanks were removed or abandoned in these first three years of enactment. Consent orders signed by 158 violators led to the collection of over $83,000 in fines.

REFERENCE: Texas Department of Health Services, Office of Solid Waste (K. Schoenfelt), Austin, Texas. Personal communication with SCS Engineers, March 1983

ABSTRACT: Texas Department of Health Services has hard copy files of facilities which store hazardous wastes, but no readily accessible inventory on aboveground or underground tanks. The Department has a checklist for aboveground tank leak assessment, but none for underground tanks.

Industry or Trade Association

REFERENCE: American Petroleum Institute. "API Industry Recommended Practice for the Prevention and Detection of Leaks from Underground Tanks and Piping". Washington, D.C., May 6, 1980, 6 pp.

ABSTRACT: This document prescribes the requirements for the detection and prevention of leaks of flammable or combustible liquids from underground tank and piping systems. The practice excludes:

- Storage tanks with capacities under 2,000 gallons which are located on farms or isolated construction projects; and
- Fuel oil tanks or containers connected with burning equipment.

The prescribed requirements cover five areas of concern. Highlights from each area include these requirements:

- Inventory Control:
  - An accurate daily inventory; and
  - Prompt reporting to the authority having jurisdiction of abnormal losses.
- Tank Selection and Installation:
  - Use of tanks constructed of non-corrosive materials in corrosive areas or at sites where no corrosion tests have been conducted;
  - Placement of at least 12 inches of non-corrosive inert material around steel underground tanks; and
  - Replacement or interior-coating of all underground steel tanks at a facility which are the same age or older if a corrosion induced leak occurs.
- Piping:
  - Use of pipes constructed of non-corrosive materials in corrosive areas or at sites where no corrosion tests have been conducted; and
  - Placement of at least 6 inches of non-corrosive inert material around all underground piping.
- Pumping Systems:
  - Installation of a product line leak detector for all new remote pumping systems;

- Installation of a listed rigidly anchored emergency shut-off value; and

- Placement of at least 6 inches of non-corrosive inert material around all underground piping.

- Pumping Systems:

  - Installation of a product line leak detector for all new remote pumping systems;

  - Installation of a listed rigidly anchored emergency shut-off value; and

  - Discontinuation of a pumping system until corrective action for a leak is completed.

- Testing:

  - Hydrostatic or pneumatic testing of all piping before being placed in use to 150 percent or 100 percent of the anticipated pressure of the system, respectively;

  - Hydrostatic tightness or pneumatic testing of all new underground tanks at not less than 3 pounds per square inch and not more than 5 pounds per square inch after installation but before being placed in use; and

  - Use of an on-going preventative maintenance program for systems cathodically protected.

REFERENCE: American Petroleum Institute. "Results of API Tank and Piping Leak Survey, February 5, 1981 Memorandum and Updated Statistical Data". Washington, D.C., 1981, 22 pp.

ABSTRACT: The American Petroleum Institute (API) conducted a nationwide voluntary survey of tank and piping leaks from approximately the fall of 1977 to the summer of 1980. The February 5, 1981 memorandum to the members of the Operations and Engineering Committee and Underground Leakage Task Force summarizes the results of 1,717 completed survey questionnaire forms. The updated statistical results compiled in about June of 1981 include an additional 236 reports or a total of 1,953 questionnaires from API member companies and tank and pump contractors.

The API survey results provide the number of tank and piping leaks by state and by category of tank construction material (steel or fiberglass) and tank protection (sacrificial anodes, impressed current cathodic protection, or interior coated steel). Detailed statistical data are also provided for three categories of leaks, i.e., piping, fiberglass tank, and steel tank leaks. For each category of leaks, a breakdown is given for the number of responses, the causes of leaks, the type of backfill material, the age of the piping or tank, and how the leak was detected. In addition, information is provided on the disposition of a leaking tank, the product stored, the tank size and location, the type of corrosion, and the location of leak points.

Of the 1,953 survey responses, the most reported leaks occurred in California, Pennsylvania, and Virginia. Corrosion caused the most leaks in underground equipment. Proper inventory control procedures detected the majority of leaks. Other survey highlights include the reporting of no leaks caused by corrosion or dissolving of fiberglass tanks. Almost one half of all leaking steel tanks are interior coated instead of being replaced or

abandoned. About 80 percent of the leaking tanks had a capacity of 4,000 gallons or less. The peak age at which leaks occurred in tanks was 20 years.

REFERENCE: Dames and Moore. "Subsurface Investigation to Evaluate the Integrity of Subsurface Tanks at Van Waters and Rogers' Facility in San Jose, California", (Letter). San Francisco, California, February 2, 1983, 13 pp.

ABSTRACT: This letter from Dames and Moore summarizes their investigation to evaluate the integrity of subsurface tanks containing solvents at the Van Waters and Rogers' facility in San Jose, California. The California Regional Water Quality Control Board in Oakland required Van Waters and Rogers to perform the investigation as part of the State program to determine the overall magnitude of subsurface leaks from sumps and subsurface tanks in the San Francisco Bay Region. Included are soil sampling results and chemical analyses of soil and ground water at three monitoring wells. Solvents were detected in the soil and ground water at the site.

REFERENCE: Exxon Corporation. (G. Gartyser), Houston, Texas. Personal communications with SCS Engineers, May 1983.

ABSTRACT: In a detailed study of tank corrosion, Exxon found that the most important factors influencing the rate of corrosion are tank age and soil corrosiveness. The soil corrosion index which was developed during the study is fully described in a proprietary report entitled "Underground Leak Study" (MERP 7103). This index provides the basis of Exxon's Tankage Upgrading Program started in January 1980, and expected to be completed in 1984. The objectives of the Tankage Upgrading Program are to:

- Establish the criteria for selecting the appropriate upgrading action; and
- Implement a company wide program for protection, repair, or replacement of all underground steel tanks.

The program encompasses four possible treatment categories at each facility as follows:

Category	Average Cost
A - Interior lining	\$29,000 - 31,000
B - Cathodic protection	\$ 3,500 - 5,000
C - Tank tightness testing	\$ 2,000 - 3,000
D - Fiberglass replacement	\$55,000 - 77,000

Details of the guidelines developed for the Tankage Upgrading Program are described in an Exxon document written in December 1981, and revised in July 1981. However, the revised document is proprietary information.

REFERENCE: IBM. "Corporate Facilities Practice 1401 A: Containment of Industrial Liquids". May 1982, 16 pp.

ABSTRACT: This document describes the containment criteria which apply to all newly constructed or replaced IBM facilities which store, transport, treat or otherwise handle industrial liquids. The criteria refer to primary containment, i.e., tanks, pipes, and drums, and secondary containment. The containment criteria is based on the type of industrial liquids handled:

- Group I - Liquids which have no environmental hazard potential require monitoring but not secondary containment;
- Group II - Liquids which have a moderate environmental hazard potential require secondary containment consisting of a single layer of chemical/ physical resistant coating, liner or equivalent; and
- Group III - Liquids which have a high environmental hazard potential require secondary containment consisting of a double layer for bulk liquid storage and a single layer for other liquid handling facilities.

Underground siting of systems is used only when necessitated by safety or fire protection codes, the liquid properties, or construction constraints. Guidelines are presented for two types of underground secondary containment systems (concrete and tank jacket).

REFERENCE: IBM Corporation (R. B. Jabblonski), Tarrytown, New York. Personal communication with SCS Engineers, March 1983.

ABSTRACT: IBM was going to conduct an internal survey of all underground tank storage sites to evaluate current practices, identify problems and solicite field suggestions for improvements. This survey has not been undertaken due to resource limitations and shifts in priorities.

REFERENCE: Motorola. (J. Hinchey and N. Hild), Phoenix, Arizona. Personal communications with SCS Engineers, May 1983.

ABSTRACT: Motorola has recently had problems with underground storage tanks leaking solvents. As a result, Motorola developed guidelines for storage of hazardous materials (products and wastes) in tanks. The specifications vary depending on the type of tank and location of the facility. The primary features of the guidelines developed by Motorola include:

- All tanks shall be located aboveground or underground in level cement vaults with steel cradles to support the tanks;
- Where production lines depend on receiving materials from tanks, double-walled tanks shall be used to prevent an interruption in production in case the inner tank wall fails; and
- Currently the guidelines are in effect for only the semiconductor division, but they have been proposed for use by all Motorola divisions.

REFERENCE: Petroleum Association for Conservation of the Canadian Environment (PACE). "Bulk Plant Guidelines for Oil Spill Prevention and Control". PACE Report No. 80-3, Ottawa, Ontario, Canada, September 1980, 63 pp.

ABSTRACT: This report provides design guidelines for oil spill prevention and control at bulk plants and terminals. The guidelines detail a step-by-step procedure for containment, collection, conveyance and treatment to cover the majority of potential oil spill situations at bulk plants or terminals. At certain locations, however, some modifications may be required.

A Task Force of the Product Storage and Handling Committee at PACE prepared the report. Members on the Task Force included six oil company representatives.

REFERENCE: Petroleum Association for Conservation of the Canadian Environment (PACE). "Report on Investigations and Research to Develop a Service Station Underground Tank Leak Detector". PACE Report No. 81-3, Ottawa, Ontario, Canada, October 1981, 36 pp.

ABSTRACT: This report records the investigation and research involved by B. C. Research of Vancouver, British Columbia in developing the PALD-2 Underground Tank Leak Detector. Findings from numerous field tests lead to the conclusion that it is impossible to design an apparatus to measure small leak rates (0.05 gallons per hour) in a 15 to 30 minute test. External factors such as the nature of soil mechanics, random ground motion and expansion of trapped air greatly affect the accuracy of leak rate measurement. B. C. Research prepared the report for PACE.

REFERENCE: Petroleum Association for Conservation of the Canadian Environment (PACE). "Guideline Specification for the Impressed Current Method of Cathodic Protection of Underground Service Station Tankage". PACE Report No. 79-4, Ottawa, Ontario, Canada, June 1979, 23 pp.

ABSTRACT: This report provides a guideline specification for cathodic protection of underground service station tanks. The guideline specification details requirements for the design, materials, installation, inspection and commissioning, and maintenance of cathodic protection and is intended for use by any PACE member company.

Corrosion Service Company Limited, corrosion engineering specialists in Toronto, Ontario, prepared the report for PACE.

REFERENCE: Petroleum Association for Conservation of the Canadian Environment (PACE). "Proceedings Underground Tank Testing Symposium". Park Plaza Hotel, Toronto, Ontario, Canada, May 25-26, 1982, 257 pp.

ABSTRACT: Eight technical papers were presented at the Underground Tank Testing Symposium sponsored by PACE from May 25-26, 1982 at the Park Plaza Hotel in Toronto, Ontario, Canada. Three Canadian and five United States promotors of different tank testing systems spoke at the two-day symposium.

Topics covered include:

- The PALD-2 Underground Tank Leak Detector developed by B. C. Reserch and the behavior of underground tanks;
- The accuracy of finding small leaks in underground gasoline storage tanks using a method tested by SRI International in California;
- A subatmospheric pressure test for detecting leaks in underground hydrocarbon storage tanks developed by Athabasca Research Corporation;
- A system invented by Joseph Mooney, PE, to determine the condition of an underground petroleum product storage tank;
- The Sun Leak Lokator patented by Sun Refining and Marketing Company to test underground tanks;
- Petro-Tite Tank and Line Testing Equipment (formerly known as the Kent-Moore system) manufactured by Heath Consultants, Inc.;
- "Ethyl" Tank Sentry underground tank leak detector developed by Texaco and licensed by Ethyl; and
- On-going developmental work being conducted by Shell Canada Limited to innovatively test underground tanks.

REFERENCE: Warren Rogers Associates. Report on the Statistical Analysis of Corrosion Failures in Unprotected Underground Steel Tanks. American Petroleum Institute, Washington, D.C. 1982. 76 pp. excluding Appendix E.

ABSTRACT: This statistical analysis of external and internal corrosion failures in unprotected underground steel storage tanks was performed for the American Petroleum Institute. The purpose of the analysis was to determine if the age at which tank failure occurs is related to measurable characteristics of the tank environment. The study concludes that, although unprotected underground steel tanks should have a trouble-free lifetime of over 20 years, unforeseen processes initiated during installation can greatly reduce the useful life of a tank. Localized corrosion may occur in one tank or all tanks installed at a given site, so the findings of this study are applicable to a site and not particular tanks at a site. A small subset of data collected at approximately 10,000 sites throughout the U.S. and Canada was used to estimate tank age failure.

About three-quarters (77 percent) of the sites had tanks experiencing localized external corrosion. The remaining one-quarter (23 percent) of the sites had tanks which were corroded uniformly and thus were not corrosion failure problems. Failure was observed in tanks ranging from as low as 5 to as high as 45 years of age.

REFERENCE: Warren Rogers Associates (W. Rogers), Newport, Rhode Island. Personal communications with SCS Engineers, May through July 1983.

ABSTRACT: Warren Roger Associates developed a computerized data base on tanks used in the petroleum industry. Information on tank age is maintained for approximately 46,000 sites. Data concerning tank leaks is included for about 18,000 facilities. Statistics on leak cause and volume of release show that 6 percent of the leaks are due to internal corrosion and that 85 percent of all leaks are confined on-site, 10 percent migrate off-site but near the immediate vicinity, and the remaining 5 percent penetrate a large area. Cleanup costs average $20,000 for on-site leaks, $150,000 for nearby off-site contamination, and over $1 million for widespread leaks. Some of the data is not available because of their confidentiality.

Warren Rogers also discussed several leak detection methods. He feels that both the Kent-Moore and Sunmark Leak Lokator methods are good, but that the leak locator is better because it is usually administered by competent crews. Warren Rogers found that the Kent-Moore method is 95 percent reliable with a good operator and only 10 to 15 percent reliable otherwise. The laser beam leak detection method is expensive and difficult to administer. Cathodic protection of tanks works well in preventing leaks if installed and maintained correctly.

Warren Rogers estimates that between 50,000 to 75,000 leaks go undetected in the United States. The major oil companies are concerned about the independent companies who do not often have the resources or incentive to test or replace tanks. The large oil companies favor mandatory recordkeeping of inventories.

Another concern is the proposed methanol additives which react with the resins used in FRP tanks currently in use. Warren Rogers suggests that either a federal national fund to handle leaks or an insurance program be developed.

APPENDIX H

LEAK TESTING METHODS

APPENDIX H

LEAK TESTING METHODS FOR UNDERGROUND STORAGE TANKS

INTRODUCTION

Approach

The following approach was taken to determine the state-of-the-art in leak testing methods for underground storage tanks:

- review literature;
- review manufacturers' and contractors' brochure information;
- telephone conversations with testing contractors; and
- telephone conversations with test method developers.

Leak test methods are becoming more and more sophisticated. The early stand pipe test method, which requires only a standpipe and a measuring tape, is being replaced by complicated measurement devices and microcomputers for analyzing the measurement data. Test methods are now being developed which use lasers to measure small liquid level variations, and hydrophones to detect the sound of bubbles ingressing through holes in a tank shell.

The state-of-the-art in leak testing methods is changing rapidly. The major oil companies and other concerned bodies are striving for more accurate, more reliable, and quicker test methods. The leak test methods discussed below are those which have been field tested in the United States and Canada, in contrast with those which are still in the developmental stage.

Background

Most of the underground storage tank facility leak testing methods have been developed primarily for detecting and measuring leaks in underground gasoline storage facilities. Current information on testing methods for storage tanks containing non-petroleum products, such as hazardous wastes, is limited. In some applications the leak test methods used for petroleum storage tanks can be and have been applied to tanks storing liquids other than petroleum products. Material considerations, the availability of excess stored product, or the stability of the stored product may preclude the application of certain test methods. Table H-1 gives an overview of the leak testing methods discussed in this chapter. Emphasis is given to assessing the applicability of the various leak test methods to underground storage tanks and piping systems used for hazardous waste storage.

The American Petroleum Institute (API), the Petroleum Association for Conservation of the Canadian Environment (PACE), and

Type of Test	Description	Applicability	Accuracy	Remarks
Pneumatic leak test	Air or other gas is used to pressurize the system. A drop in pressure is indicative of a leak	Underground tanks and piping systems	Pneumatic tests are often inconclusive	Air pressure tests are not recommended for tanks and piping systems containing flammable or combustible waste. With air testing, there is also a serious danger of rupturing the tank
Hydrostatic (standpipe) leak test	Water (or another liquid) is used to pressurize system. A drop in liquid level is indicative of a leak	Underground tanks and piping systems	Hydrostatic tests are more sensitive than pneumatic tests	This procedure is useful where it is desired to check the tightness of any underground storage tank and its connected piping for gross leaks. Does not compensate for thermal expansion or contraction of the stored waste.
Petro-Tite (formerly Kent-Moore test)	Accurate type of hydrostatic test	Underground tanks and piping systems	0.05 gallons/hour	Test is approved by the National Fire Protection Association (NFPA). Requires well-trained operator. Requires several hours for completion of accurate test
Ethyl Tank Sentry Leak Detector	Manometer-type instrument that detects leaks by measuring small changes in product level	Underground tanks	Detects change in liquid level as small as 0.02 inches. Accuracy depends upon the time period over which the level charge is observed (leak of 0.02 inches over 1 hour is larger than leak of 0.02 inches over 10 hours in same tank)	Easy to transport, assemble and operate. Does not require a contractor crew to operate. Several tanks can be tested simultaneously. Tank, piping and dispenser openings need not be sealed
*Sunmark leak test	System operates on the principle of hydrostatic head and uses an analytical balance to measure small changes in liquid mass displacement	Underground tanks and piping systems	0.03 gallons/hour	The time for the equipment to be set up and the test to be completed is at least 2 hours. Compensates for temperature and pressure
Laser-interterometry	An experimental device for detecting leaks. Operates on the principle of laser interferometry	Underground tanks	Threshold of detection has not yet been established	API has specified that it wants the device to be able to detect leaks as small as 0.05 gallons/hour instantaneously
ARCO HTC leak test	Systems use a float and light-sensing system to detect volume changes	Underground storage tanks and their distribution lines	Less than 0.05 gallons/hour	System works on tank 75 percent full. It does not detect leaks in the upper 25 percent of the tank or in the fill line

TABLE H-1. COMPARISON OF VARIOUS TANK LEAK TEST METHODS

Type of Test	Description	Applicability	Accuracy	Remarks
Vacu tect leak test	Leak test method based on creating bubbles at leak ingress point which produce distinct and detectable sounds	Underground tanks	Detects presence of leak, not rate, and relative location of leak	Limited test data to date (200 tests by 1982). Not effected by pressure temperature or tank configuration changes. Subject to problems similar to pneumatic test
Smith and Denison leak test	Helium is used to pressurize tanks and piping system. Mass spectrometer used to monitor for leaks	Underground tanks and piping systems	Detects presence of leak, not rate, and relative location of leak	Pressurized testing system. See preumatic test method remarks. Tank must be empty for tank test, can be partically full for pipe test

Key:

* - Method being used in unspecified underground storage tanks for commercial clients (stored material unspecified), method being used in underground solvent storage tanks

† - See text for explanations

≠ - See text for references

TABLE H-1. COMPARISON OF VARIOUS TANK LEAK TEST METHODS, CONT.

the major oil companies have played a major role in the development of most of the test methods now on the market. These organizations are continuing their efforts to develop more reliable, cost effective, and quicker methods for determining leaks in underground storage tanks and piping systems.

Measurement Techniques and Criteria

There are numerous approaches presently marketed for determining the presence of leaks in piping systems and underground tanks. Some of the leak test methods measure volume changes with time to determine leakage rates, while others test only for the presence and location of leaks.

The National Fire Protection Association (NFPA) has published standards and recommended practices for testing piping systems and underground storage tanks containing flammable and combustible liquids for leaks. NFPA 329 "Recommended Practice for Handling Underground Leakage of Flammable and Combustible Liquids" is generally accepted as one of the most authoritative documents on the subject of leak test methods. The following excerpt is from this publication:

> "The Final Test will conclusively determine whether or not an underground liquid storage and handling system is leaking. Any testing devices used for the Final Test shall be capable of detecting leaks as small as 0.05 gal in one hour, adjusted for variables, a limiting criterion widely accepted by most authorities."[2]

The Petro-Tite test method (formerly the Kent-Moore Test) is believed to be the Final Test referred to in NFPA, although any test method meeting the NFPA criteria would be acceptable. The 0.05 gal/h criterion has been established based on the most accurate of the reliable test methods. Some people question whether any test method can reliably measure to 0.05 gal/h given all the variables which affect tank testing results. Regardless, the 0.05 gal/h limit is a reference point.

Other leak test method approaches should also be considered. For example, two test methods discussed in this chapter, the Vacutect and Smith & Denison leak test methods, merely detect the presence and general location of leaks rather than measuring the leakage rate. These methods are based on a philosophy that no leak, small or large, is acceptable. These methods, though mainly used for testing tanks and piping systems containing petroleum products, may be well suited for application to hazardous waste underground storage tanks and piping systems, where the primary concern is identifying the presence of a leak. This is not to discount the importance of determining the rate of a leak. Such information is important in estimating the volume of leakage and the impact the leak may have on the environment. Economic considerations will determine whether the test method developers will invest the monies necessary to adapt their systems to non-petroleum storage tank and piping systems (e.g. hazardous wastes).

API's and PACE's research efforts have established tentative performance objectives for new leak test methodologies and equipment, key elements of which are summarized below [3],[4].

- sensitivity limits of 0.05 gal/h;
- fully automatic operation;
- capable of identifying location as well as rate of leak;
- test duration: 15 to 30 minutes (not including set up);
- simple to operate;
- intrinsically safe;
- easy maintenance through replaceable parts.

Some of these performance objectives may be unrealistic given the degree of accuracy desired. For example, the equipment and instrumentation required to measure leaks at 0.05 gal/h within a 15 to 30 minute period will be costly and skilled labor will be required to insure the reliability of the test results. Also, the statistical reliability of any measured test result diminishes with decreasing measurement time. Most of the leak testing methods currently available take anywhere from 30 minutes to a day to complete. API's and PACE's performance specifications represent goals to achieve, but at the present time no leak testing method meets them all.

Special Considerations in Testing Underground Storage Tanks

According to NFPA 329, the "Final Test" method used to determine if a tank is leaking must compensate for the affects of temperature variations on the volume of the stored product and tank deformation due to pressure surcharges resulting from the test procedure. Temperature is an important variable to compensate for because of the significant affect it has on the volume of the liquid stored. Gasoline, for instance, has a coefficient of expansion of 0.0006 per degree F. A 1 degree F change in temperature in a 10,000 gal tank will result in a net change in volume of 6 gal A 0.01 degree F change in temperature will result in a 0.06 gal change. If the 0.01 degree change occurs over a one hour testing period, a 0.05 gal/h leak would go undetected without temperature adjustments to the liquid volume.

In tests conducted by Shell Canada Ltd., it was found that the maximum temperature stabilization time was 4 hours [5]. Other researchers contend that temperature stabilization may not occur for hours or even days after the last product delivery [6]. Internal product temperature variations are impacted by the temperature of the stored and delivered product (and the resultant mixing) and the ground temperature (which varies throughout the year and leads to temperature stratification in the tank). This complexity is addressed by most of the newer leak test methods.

Another important variable that must be considered in volume-based measurement techniques is tank deformation under surcharge conditions. Underground storage tanks deform considerably under surcharge conditions. A surcharge condition occurs when the pressure applied to a tank is greater than the tank's normal operating or design pressure. Most underground storage tanks are designed as low-pressure or atmospheric tanks.

A hydrostatic standpipe type test, which increases the liquid level above the top of the tank during the test,places significant surcharge pressures and resultant forces on the ends of a tank. Under these surcharge pressures, the ends of a tank will bulge out, resulting in an apparent loss of product. Figure H-1 and H-2 are presented to demonstrate the significance and magnitude of this phenomenon.

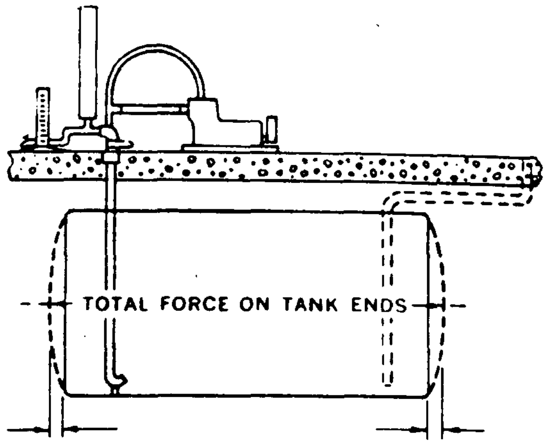
The deformation may occur immediately, and thus pose no problem in the volume measurements, or it may take hours or days to stabilize. Tank deformation can be compensated for by either of the following methods:

- slightly surcharging the tank prior to testing and then relaxing the pressure during the testing; or
- through tables and graphs relating the extent of bulging anticipated as a function of the height of storged liquid; or
- testing the tank under normal operating conditions (this approach assumes that tank deformation has stabilized over time).

Other variables which impact the accuracy of most test methods include product density, product expansion coefficient, trapped air in the tank, and ground vibrations. Each of these variables impact the testing methods in different ways, depending on the measurement technique and equipment employed. The variables of product density and product expansion coefficient can be easily determined in the field with a hydrometer and other chemical tables. The presence of air pockets in a full tank test can render the results of a test totally invalid. Air pockets can compress or expand in volume significantly, depending on temperature and the applied pressures. This compressibility characteristic can set up a spring type action in the fluid which can be reflected in an increase or decrease in the fluid level in the tank. This variation could be interpreted as a loss or gain of product if the frequency of the level variation is greater than the testing period [8].

LEAK TESTING METHODS

Petro-Tite Test (Formerly Kent-Moore Test)



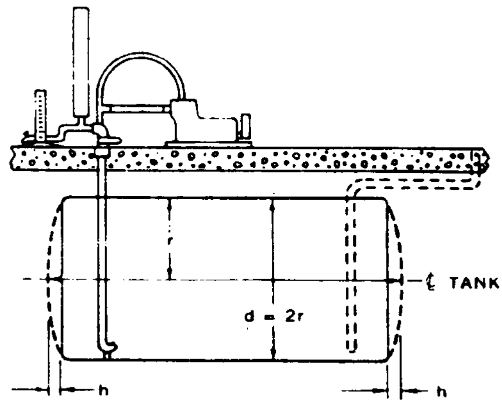
Total Force on Tank Ends

Formula: Force Area X Pressure (Lbs./Sq. In.)

Total Force in Tons at:

Tank Dia.	1 Psi.	2 Psi.	3 Psi.	4 Psi.	5 Psi.
48"	0.9	1.8	2.7	3.6	4.5
64"	1.6	3.2	4.8	6.4	8.0
72"	2.0	4.0	6.0	8.0	10.0
84"	2.8	5.6	8.4	11.2	14.0
96"	3.6	7.2	10.8	14.4	18.0

Figure H-1. Total Force on Tank Ends [7]



FORMULA FOR COMPUTING VOLUME CHANGE DUE TO TANK HEAD DEFLECTION

$$V_T = \left[\frac{\pi}{2} \left(r^2 + \frac{h^2}{3} \right) h \right] (2)$$

V_T = Total Volume in Cubic Inches

r = Radius of Tank in Inches

h = Deflection of Tank Ends in Inches

Gallon = 231 in.^{3}

Gallons = $(V_T)\left(\frac{\text{Gal.}}{231 \text{ in.}^3}\right)$

EXAMPLE COMPUTATION:

Tank Diameter - d 96"

Tank Radius - r 48"

Head Deflection - h .125"

1. $V_T = \frac{\pi}{2}\left[(48)^2 + \left(\frac{.125}{3}\right)^2\right](.125)\,2 = 904.78 \text{ in.}^3$

2. $(904.78 \text{ in.}^3)\left(\frac{\text{Gal.}}{231 \text{ in.}^3}\right) = 3.92$ Gallons increase in tank capacity due to tank head deflection

Figure H-2. Formula for Computing Volume Change Due to Tank Head Deflection

The Petro-Tite leak test method is a hydrostatic test capable of detecting leaks in both storage tanks and connecting piping. The test adjusts for temperature, pressure, and viscosity variations. The test was originally developed by F. Ronald McLean of the Mobil Oil Corporation. The Petro-Tite test method has a reported accuracy of 0.05 gal/h. The principle application of the test method has been on underground gasoline storage tanks and piping systems.

The Petro-Tite test requires specialized equipment, including a circulation pump, a thermister (a temperature sensing devise accurate to 1/60th degree F), a hydrometer, a standpipe, and a graduated cylinder (See Figure H-3) [9]. The test can be conducted by one trained person. Eight hours are generally required to complete a test on one underground storage tank. The cost for testing one tank (including equipment and labor) ranges between $500 to $600 (assuming no leaks are detected). Discount rates generally apply for multiple tank installations. [10]. If a leak is detected during a full system test (piping and tanks), another test must be run to determine whether the tank or the piping is the source of the leak. This additional testing will increase the fee above the $500 to $600 range. Labor costs for a skilled testing operator can range between $300 and $400 per day.

The Petro-Tite system has the following advantages and disadvantages:

- advantages:
  - available throughout the country
  - accuracy to 0.05 gal/hr
  - temperature affects accounted for;
  - tank deformation accounted for;
  - tests both tank and piping systems;
  - detects leaks throughout tank depth.

- disadvantages:
  - full tank required and extra product must be available
  - requires specially trained personnel;
  - equipment is expensive;
  - all product transfers must be halted during testing;
  - affects of trapped air not accounted for; and
  - duration of test

The Petro-Tite leak test method has been used primarily on underground gasoline storage tanks. It appears that the test method could be used to test tanks containing hazardous wastes as long as the stored product was compatible with the testing equipment and extra product was available to raise the liquid level above the top of the tank. The requirement of additional product may limit the extent to which this testing method can be used to test hazardous waste underground storage tanks for leaks.

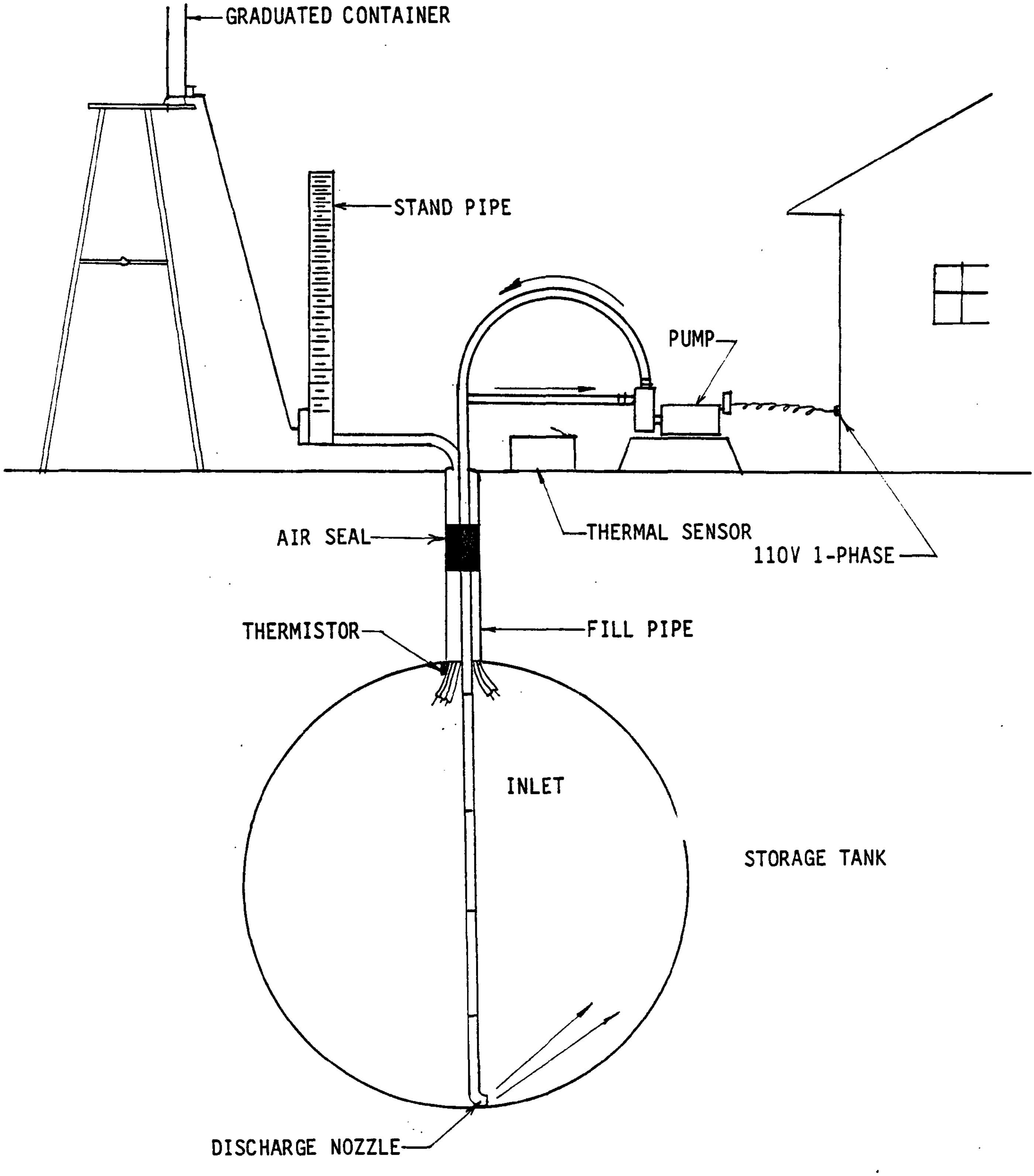


Figure H-3. Petro-Tite Test Schematic Diagram [9]

Also, handling or disturbing the stored waste may not be desireable for many types of hazardous wastes stored in underground tanks.

Stand Pipe Test Method

The Stand Pipe test method is capable of detecting the presense of gross leaks in underground storage tanks and connecting piping systems [11]. The detected leaks must be significantly greater than the volume variations due to tank deflection and temperature change or they may not be detected. The hydrostatic Stand Pipe method has an unspecified accuracy.

The Stand Pipe test method does not require any specialized equipment or personnel. The test procedure can be conducted by the owner or operator of an underground storage tank system. A standpipe, a measuring device (i.e. measuring tape), and extra product are the only items required for the test. Special precaution should be taken to insure that pumps in siphon sytems are taken out of service, and that manifolded vent lines (in the case of multiple tank installations) are disconnected.

The Stand Pipe test method has the following advantages and disadvantages:

- advantages:
  - available throughout the country;
  - detects leaks throughout tank depth;
  - no specialized equipment or personnel required; and
  - inexpensive to run.
- disadvantages:
  - full tank required and extra product must be on end;
  - does not account for volume changes due to product temperature changes;
  - does not account for volume changes due to tank deflection;
  - only applicable to tanks with gross leaks; and
  - not recommended as a final test method by NFPA.

As stated above, the Stand Pipe leak test method is only useful for detecting large leaks. The .accuracy of the test results are questionable, since temperature changes and tank deformation are not accounted for. As with the Petro-Tite test method, the Stand Pipe test method requires filling the tank above the top of the tank. As such, sufficient product must be available to attain this liquid level. The Stand Pipe test method could be used on underground storage tanks containing hazardous wastes to detect gross leaks, but it will not meet the final test performance standards suggested by NFPA.

Air Test Method (Pneumatic)

The Air Test method is a pneumatic pressure testing procedure for testing both tanks and connecting piping systems. In general, only leaks above the liquid level in storage tanks can be detected by this method. NFPA 329 states that pressure tests with air shall not be used on tanks storing flammable and combustible liquids [12]. The inherent risks of tank and pipe connection failures due to increased pressure during the test are well documented concerns [13].

Air tests should only be performed by qualified personnel. Application of the test should be restricted to new tanks which have not been installed or filled with liquid. According to NFPA, air testing is more suitable for testing pipelines than underground storage tanks [12].

The accuracy of air test results is questionable. The pressure loss in a tank is dependent on the volume of air in the tank or piping system. For example, the volume of air in a half-full tank is such that the pressure loss due to a small leak could go undetected. The air test method also does not compensate for pressure changes due to temperature variations and tank deflections.

The Air Test method is not recommended for testing of hazardous waste underground storage tanks due to the inherent safety problems associated with the test.

Ethyl Tank Sentry Method (J-Tube Manometer Test)

The Ethyl Tank Sentry leak test method was developed by the Ethyl Corporation and marketed by Texaco Inc. for leak testing underground gasoline storage tanks. The test procedure is able to detect small changes in product level with an indicator fluid which magnifies tank level changes. The devise used to measure liquid level changes consists of a J-tube manometer attached to a 3-inch pipe reservoir. The basic principals and equipment used in the testing procedure are shown in Figure H-4. The density of the indicator fluid must be such that it will not mix with the product in the tank. This factor limits the extent to which this method can be used for testing storage tanks containing liquids other than gasoline.

It is reported that the test method is accurate to 0.02 gal/h [15]. The test results are valid only if the temperature differential during the testing period is less than 1 degree F. Product temperature in underground storage tanks usually stabilizes within 24 hours; therefore, a 24 hour waiting period following the last product delivery is suggested before commencing the testing procedure. Since the tank is tested at normal operating conditions and generally 24 hours after the last

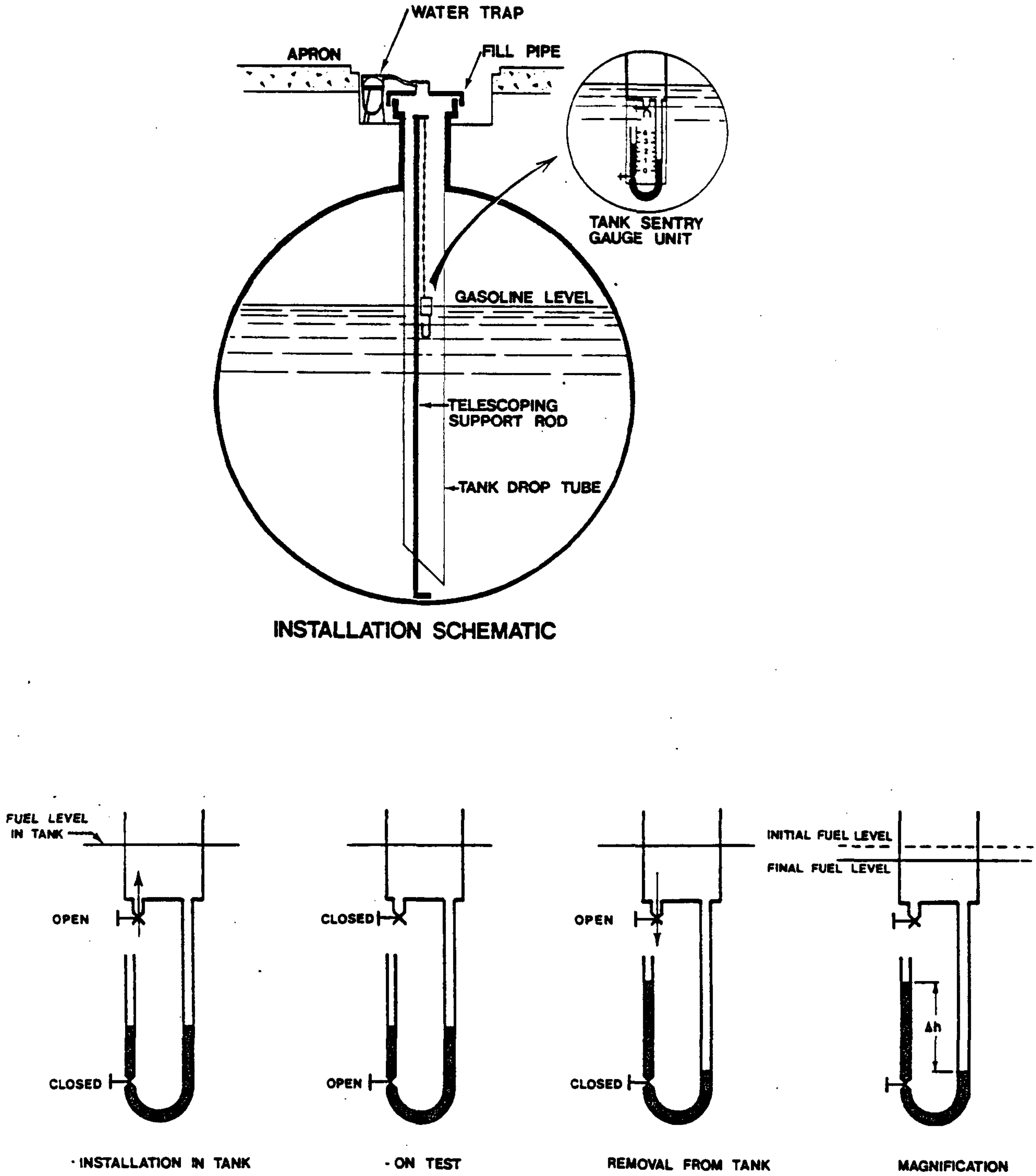


Figure H-4. Ethyl Tank Sentry Leak Detector Schematic Diagram [14] product deliver, measurement errors due to tank end deflections and temperature changes are considered insignificant.

The Ethyl Tank Sentry leak testing method should be conducted by personnel skilled in gasoline equipment maintenance. Two to three days training is required in order to properly use the test equipment. Only one man is needed to conduct the test. Set up requires approximately 30 minutes per tank. A 12 to 24 hour test period is recommended. During the testing period, the testing equipment can be left unattended. The method is ideal for over night testing. This is convenient to many service station operators who do not want to be shut down during normal operating hours.

The Ethyl Tank Sentry test equipment costs approximately $5,000; therefore, it may not be economical for an owner or operator of a storage tank to own his own testing devise. Testing costs range between $300 to $400 per tank and $600 for a three tank installation [16].

The Ethyl Tank Sentry method has the following advantages and disadvantages:

- advantages:
  - available throughout the country;
  - accurate to 0.02 gal/h;
  - easy to set up;
  - temperature changes monitored;
  - test performed under normal operating conditions;
  - small level changes easily measured; and
  - can be performed overnight unattended.

- disadvantages:
  - specially trained operator required;
  - testing results invalid if temperature differential greater than 1 degree F;
  - will not detect leaks above product level;
  - test duration; and
  - piping systems cannot be tested along with tanks.

The Ethyl Tank Sentry leak test method is mainly applicable to testing underground gasoline storage tanks. The Ethyl Corp. has tried to use the method on other petroleum distillates with limited success [16]. The indicator fluid is the key to the test. The specific gravity of the indicator fluid must be strictly controlled and be slightly greater than the specific gravity of the stored product to prevent mixing.

It can be expected that the physical characteristics of hazardous wastes will vary greatly from facility to facility, in contrast with gasoline which has well defined physical characteristics. As such, the Ethyl Tank Sentry leak test method has limited application in the leak testing of underground hazardous waste storage tanks.

Sunmark Leak Test Method

The Sunmark leak test method, the Leak Lokator, was developed by the Sunmark Corporation, which is a subsidary of the Sun Oil Corporation. The test can be used to detect leaks in underground storage tanks and associated piping. The Leak Lokator measures mass displacement in a tank via bouyancy changes in a calibrated apparatus. Any bouyancy change is an indication of a leak.

The principal equipment components used in the test include an open top-hollow tube sensor filled with the stored product, a mass balance, a strip chart recorder, a thermister, and a hydrometer (See Figure H-5) [16],[17]. Test personnel measure the specific gravity of the stored product prior to beginning the test. The calculated density is used to relate the mass displacement to volume displacement. The sensor is partially suspended in the stored tank from the analytical balance. As the volume in the tank changes, the bouyancy of the sensor changes. The resulting mass displacement is recorded by the balance, and a permanent record of the test results is produced on the chart recorder. Temperature is monitored throughout the testing period at mid-tank level. Product mixing is discouraged. The test assumes that tank deformation is insignificant, since the test procedure does not surcharge the tank.

The test can be conducted on any tank which has a fillport 2-inches or larger. Tank configuration or volume do not affect the accuracy of the test. The test method was developed for testing underground gasoline storage tanks; however, the test is presently being applied to underground tanks storing products other than gasoline (e.g. solvents) [19].

The accuracy of the method depends on the product level in the tank. The higher the product level, the more accurate the test results. Sunmark recommends conducting the test under full tank conditions. At this level, test results are reported as accurate as 0.03 gal/h [18].

The Sunmark leak test method requires the use of a skilled operator and specialized equipment. To set up and run the Sunmark test requires approximately 2 hours per tank. Actual testing, once all the equipment is in place, takes only 15 to 20 minutes. A typical system test, which might include 4 underground tanks and associated piping, would cost approximately $500. If a tank is tested alone, the cost is approximately $300 [19]. Sunmark has a different pricing schedule for commercial clients which they were not free to disclose.

The Sunmark leak test method has the following advantages and

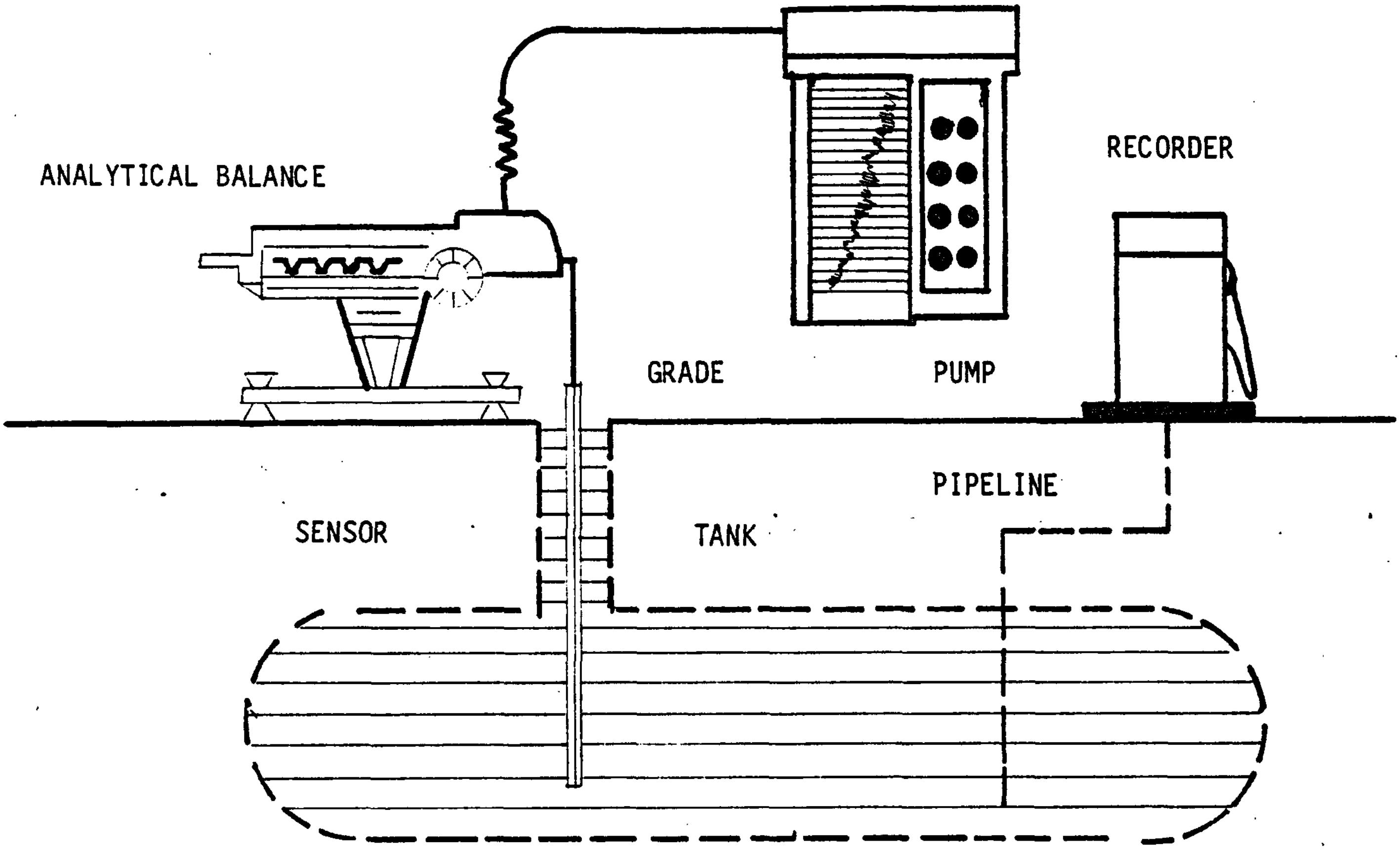


Figure H-5. Sunmark Leak Test Method Schematic Diagram [17] disadvantages:

- advantages:
  - test results not dependent on tank configuration or volume;
  - test both tank and piping systems;
  - detects leaks throughout tank depth;
  - accurate to 0.03 gal/h;
  - compensates for temperature changes;
  - application to tanks storing various products;
  - permanent record of test results; and
  - short set-up and testing time.

- disadvantages
  - requires specially trained personnel;
  - currently only available on the east coast, Texas, and California (Sunmark is expanding their testing fleet);
  - tank should be full for most reliable results;
  - qualified personnel required to operate equipment; and
  - equipment is expensive (approximately $52,000 which includes truck) [21].

Sunmark claims to be using its testing method to test various underground chemical (e.g. solvents) storage tanks for commercial clients. The sensor in contact with the stored product is made of aluminum, which is resistant to many corrosive liquids. Sunmark states that they need to know the nature of the stored liquid prior to testing to insure material compatibility. Aluminum is not compatible with alkalies, potassium hydroxide, sodium hydroxide, and mineral acids [20]. The Leak Lokator appears promising with regard to testing underground storage tanks containing a wide range of hazardous wastes.

Laser Interferometry Test Method

The Laser Interferometry test method was developed by SRI International under contract with API [22]. It is not so much a test method as it is a very precise liquid level measuring devise. The measurement technique was developed to demonstrate that very small liquid level changes (e.g. 1 micron) could be detected very quickly through the use of laser interferometry. The method is presently not marketed by any firm or used by any commercial testing contractors.

The measurement technique developed by SRI uses a low-powered, double-tube laser devise (See Figure H-6). One of the tubes is closed to the liquid in the tank (simulating a no leak condition), while the other tube is open to the stored liquid. The laser beam is reflected off the liquid surface back to a detecting device, which computes the travel time of the laser

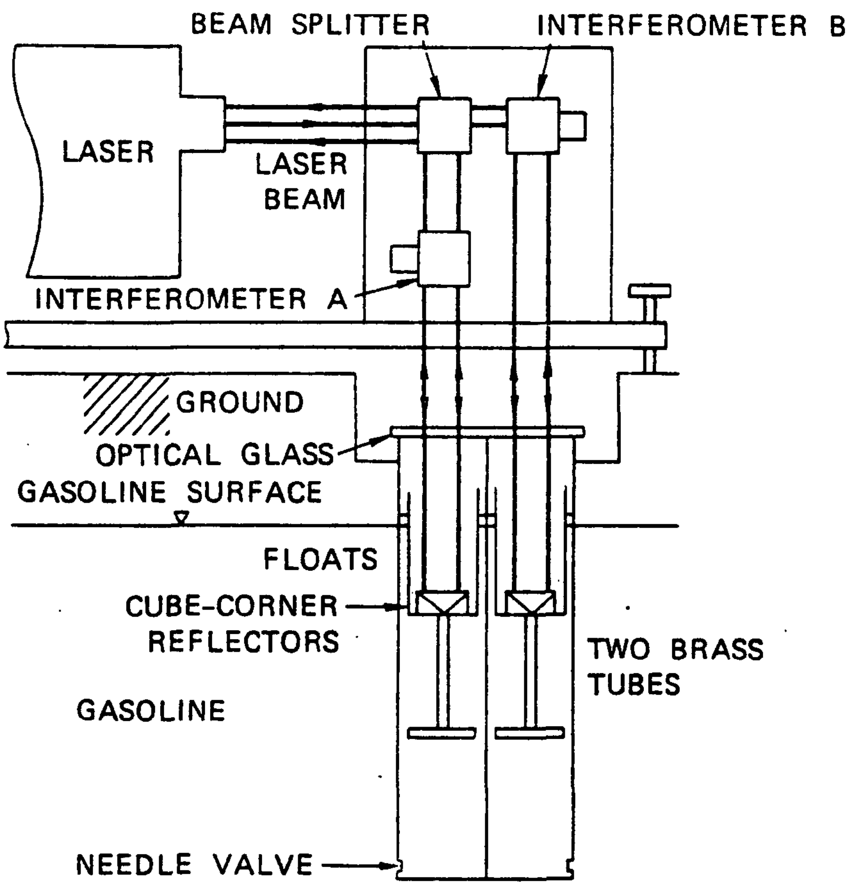


Figure H-6. Laser Interferometry Test Method Schematic Diagram [22] beam. Variations in travel time relate to variations in liquid levels in the storage tank. Using this device, changes in liquid levels can be detected almost instantaneously.

The measurement results must be statistically evaluated to determine whether a detected level change is due to a leak or to some other background noise. SRI has completed extensive statistical studies on their test results and concluded that the laser interferometry device could produce results meeting the 0.05 gal/h criteria over a 2 hour test period. The results from a one hour test period were not considered statistically reliable [22].

The SRI laser measuring device has been primarily used to detect liquid level changes in underground gasoline storage tanks. According to the SRI, the device could be used on virtually any liquid stored in underground tanks, including hazardous wastes.

<u>ARCO HTC Leak Test Method</u>

The ARCO HTC leak test method was developed by ARCO, Inc. and has been used exclusively by ARCO in testing their underground gasoline storage tanks [24]. The test is applicable to tanks storing liquids of a known density. The reported accuracy of the method is 0.02 gal/h. Liquid levels must be between 66 to 75 percent of the tank depth to assure reliable test results [24],[25].

The equipment used in the test method include a specially fabricated float mechanism, a photo cell, and a voltage meter. The photo cell and float apparatus are inserted into the tank at the beginning of the test. The fillport must be at least 3-inches in diameter. The float is placed at a pre-specified level in the tank, where temperature changes will not impact the float level.

A one hour waiting period is recommended to allow for the temperature of the equipment to stabilize. With changing liquid levels, the float raises or lowers in the tank. The float movement forces an ink type solution into or out of the photo cell. The change in light transmittance in the photo cell results in a voltage drop across the cell. The voltage change, which is a function of the liquid level change in the tank, is measured by a voltage meter. The voltage meter is calibrated prior to testing with a known quantity of product. The leak test is performed for one hour. The meter is then calibrated a second time and another one hour test is run. Testing continues until two consecutive readings correspond (insures reliablility of test results, i.e. steady state conditions).

The ARCO HTC test method has the following advantages and disadvantages:

advantages

- accurate to 0.02 gal/h;
- compensates for temperature variation and tank deformation; and
- test conducted under normal operationg conditions.

disadvantages:

- equipment is expensive (approximately $4,000);
- unable to detect leaks in upper 25 percent of a tank;
- density of fluid must be known;
- piping systems cannot be tested along with tanks;
- requires specially trained personnel; and
- used on only ARCO tanks.

ARCO has not pursued other commercial applications for their test method, although they indicate that the method could be used for testing tanks containing non-petroleum products [24]. Material compatibility would have to be considered when applying the method to other products. The density of the float, which is presently designed for gasoline, is also an important factor. The float density would have to be adjusted for liquid densities different than gasoline.

VacuTect Leak Test Method

The VacuTect leak test method was developed by the Anthabasca Research Corp., Ltd, Edmonton, Ontario. During the test the tank is placed under a negative pressure. A special hydrophone probe installed in the tank monitors for the sound of ingressing air bubbles. The test procedure is based on the observation that bubble formation resulting from the ingress of air into a tank under vacum conditions produces a distinct and detectable sound (See Figure H-7)[27].

The method does not have the drawbacks of conventional leak testing methods such as temperature variation, tank deformation, or product instability (i.e. vibration). The method does not measure leak rates, but rather the presence of leaks. In addition, the method can detect the location of a leak and the presence of water in the tank. Water is detected with a device attached to the hydrophone.

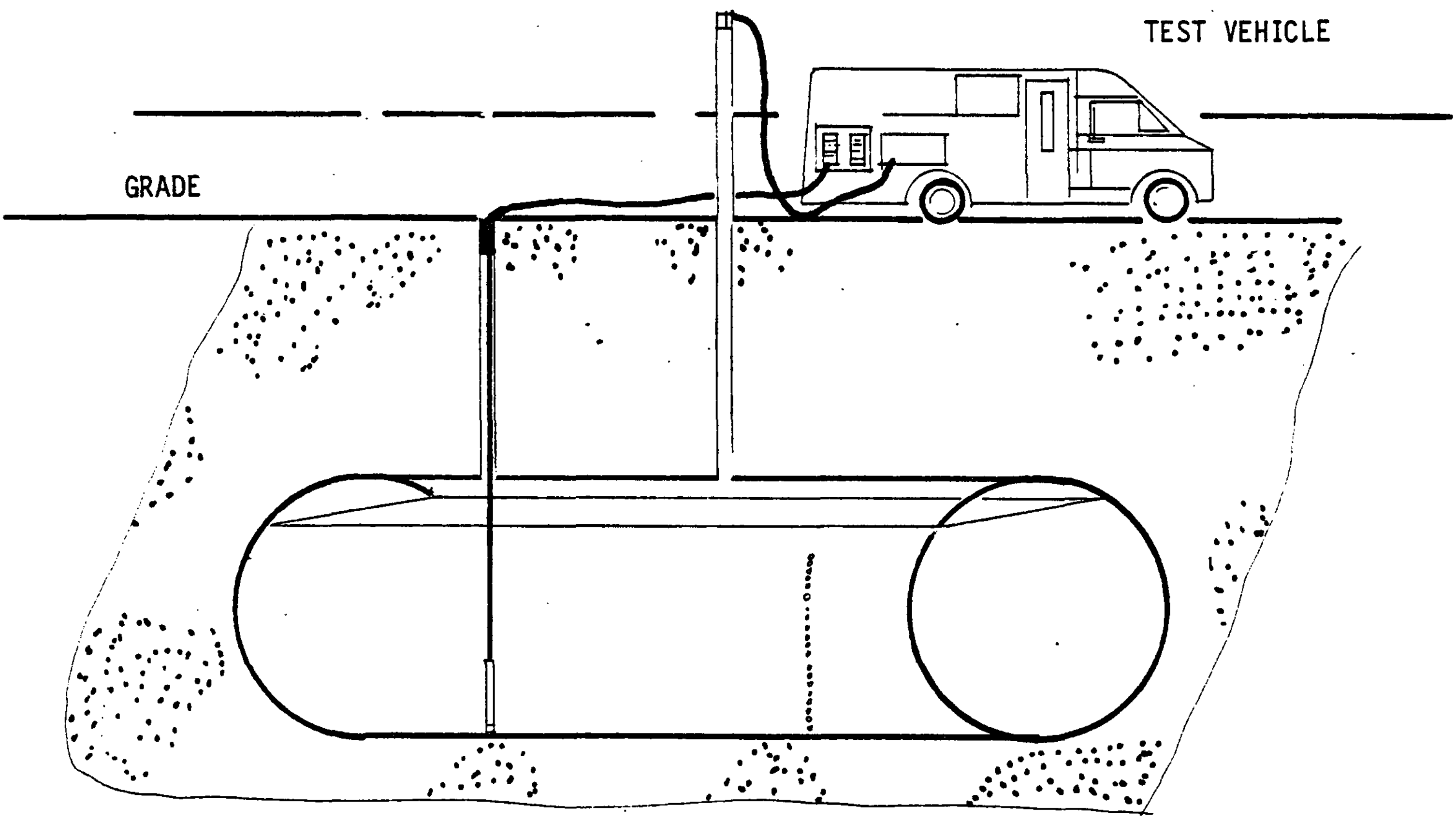
The method includes the following equipment:

- specially fitted vehicle;
- vacuum pump;
- instrumented probe;
- microprocessor;
- hoses & fittings; and
- other misc. special tools.

The equipment is presently designed for use on tanks with 4-inch diameter fillports. However, Anthabasca is developing a-

TESTING STEPS

1. PROBE IS SUBMERGED
2. VACUUM LINE IS APPLIED.
3. PRESSURE WITHING THE TANK ULLAGE IS INCREMENTALLY REDUCED EQUIVALENT TO FLUID HEAD.
4. BUBBLE SIGNATURES OF INGRESSING AIR DETECTED BY HYDROPHONE.
5. INGRESSING WATER LEVEL IS DETECTED BY WATER SENSOR.
6. DATA IS ACCUMULATED AND PRINTED BY MEANS OF A MINICOMPUTER IN THE TANK TESTING VEHICLE.
7. TANK PRESSURE IS RESTORED TO ATMOSPHERIC WITH THE INJECTION OF NITROGEN.



(Probe includes hydrophone, pressure sensor, temperature sensor, and water sensor)

Figure H-7. VacuTect Test Method Schematic Diagram [25] dapters to fit 3-inch diameter fillports. This adaptation may allow for testing commercial underground waste and product storage tanks [28].

The VacuTect test method requires skilled personnel to operate. Before the the test is conducted, the test personnel records the operational history of the tank. Inventory records are evaluated to determine if leaks can be detected from the data. The vacuum pump and hoses are connected to the tank, and the probe is lowered into the tank. Pertinent information is entered into the microprocessor (i.e. tank location, stored product, name of owner, etc.) and then the test is started. The tank pressure is lowered step by step to the static head at the bottom of the tank. In this way the leak can be located with respect to depth in the tank. Testing costs range between $400 to $500 per tank[24].

The VacuTect test method has the following adavantages and disadvantages:

- advantages:
  - available throughout the country;
  - not affected by temperature changes;
  - tank deformation not a factor;
  - short testing time;
  - product transfer from tank can continue during test;
  - tanks and piping can be tested;
  - detect leaks throughout tank depth; and
  - full tank not required.

- disadvantages:
  - leakage rate not measured;
  - sophisticated equipment required (costly); and
  - requires specially trained personnel.

The VacuTect Test Method may be adaptable to use on underground storage tanks containing commercial chemicals and hazardous wastes. At the present time, the VacuTect leak test method has only been used to test petroleum product storage tanks.

Anthabasca has indicated that if a substantial market for the testing underground waste storage tanks emerges, then they may invest the capital necessary to modify their equipment for use on non-petroleum storage tanks (e.g. hazardous wastes) [29]. Chemical storage tanks in general are not constructed like gasoline storage tanks. Fillports are usually 2 inches and less as compared to the standard 4 inch fillports on gasoline storage tanks. Changes to their probe would be necessary to be lowered through small diameter fillports. Also, the viscosity of some waste liquids may inhibit the formation of free bubbles. In this case the VacuTect test method would not be suited for testing for leaks. The market does not appear to justify such expenditures at this time. Anthabasca feels that if a liquid can be stored in a steel tank or glass lined tank, their testing system will be compatible.

Smith & Denison Leak Test Method (Helium Testing)

The Smith & Denison leak test method uses helium to test for leaks in underground storage tanks and piping systems. This method does not determine leak rate; it merely indicates the presence and approximate location of leaks.

The Smith & Denison leak test is usually conducted in in two steps. The first step involves testing the piping system. The tank can either be empty or partially full during this testing stage (preferably partially full in order to isolate the leaks to the piping system). The piping system is pressureized with helium. A gas mass spectrometer and gas probe is used to measure the concentrations of helium in the soild surrounding the piping system. If the piping system and tank(s) are under pavement, a grid of 1/2 inch holes are drilled through which a gas probe can be lowered.

If helium is detected above background levels, a leak is assumed. The location of the leak(s) can be identified by further refining the hole grid system until the highest concentration of helium is found. The piping system should be repaired prior to testin the tank itself.

To test the tank requires placing it under approximately 5 psig pressure and sealing all the opening to the tank. An even distribution of helium at the surface would indicate a leak near the bottom of the tank, since the helium concentration will vary inversely with distance from the leak source. Sharp concentration peaks would indicate leaks near the surface.

The test can take anywhere from 1 hour to 24 hours to complete. Equipment needed for the Smith & Denison test include a mass spectrometer, a gas probe, and a hydraulic jack to drill through any pavements. Specialized personnel are required to conduct the test. The mass spectrometer requires care in handling and set-up. Testing fees are approximately $500 per 10,000 gallon tank [29]. The test is available throughout the United States.

The Smith & Denison system is not approved by NFPA. It is subject to the same safety constraints as the air test method, which tests tanks and piping systems under pressure. Smith & Denison do not feel the pressure tests are unsafe, and as such, feel their system is suitable for testing underground storage tanks and piping systems, including hazardous waste storage tanks and piping systems [29].

The Smith & Denison leak test method has the following advantages and disadvantages:

- advantages:

  - short testing duration;
  - location of leaks can be determined;
  - not affected by temperature changes;
  - tank deformation not a factor; and
  - available throughout the country.

- disadvantages:

  - pressurized testing system;
  - tank must be completely empty for testing;
  - leakage rate not measured; and
  - requires specially trained personnel.

Pressurized helium pipe testing has been used for many years to test natural gas pipelines. Application to storage tanks and appurtenant piping systems has been limited. Where the Smith & Denison system has been used on tanks and piping systems, the tanks have been primarily gasoline storage tanks.

Since helium is an inert gas, compatibility with a hazardous waste is not a concern. Smith & Denison feel that their system could be used for testing hazardous waste storage tanks and piping systems [29].

CONCLUSIONS

Table H-1, in addition to the discussion in the text, gives an overview of the of the various underground storage tank and piping system leak test methods. The major concern expressed by the various test method developers is in reference to test equipment material compatability with the stored product and the tank type (i.e. large enough fillports). The equipment used to test gasoline storage tanks may not be suitable for certain aggressive hazardous waste environments.

The most promising methods for testing underground hazardous waste storage tanks appear to be the following:

- Sunmark Leak Test Method (detection limit of less than 0.05 gal/h);
- Petro-Tite Test Method (detection limit of 0.05 gal/h);
- VacuTect Leak Test Method (detects presence of leak not rate);
- Smith & Denison Leak Test Method (determines presence of leak not rate).

The Sunmark leak test method is the only leak test method currently being used to test commercial chemical storage tanks for leaks. It is currently available on the East Coast, California, and Texas. The other three are mentioned because of their application potential. Testing fees for all the tests are roughly the same, approximately $500 per tank.

All but the VacuTect test method can test both tank and piping systems for leaks. The VacuTect test method can only test for leaks in tanks. The Sunmark and Petro-Tite test methods test for leakage rates, while the VacuTect and Smith & Denison leak test methods test for the presence of leaks (one via a vacuum and the other via pressure). Although only four of the leak test methods are recommended as most promising, this does not preclude the possibility of the other test methods being used to test hazardous waste underground storage tanks.

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APPENDIX I

Procedures Used to Estimate the Number of Underground Tanks in New York State

APPENDIX I

PROCEDURES USED TO ESTIMATE THE NUMBER OF UNDERGROUND TANKS IN NEW YORK STATE

The number of underground tanks associated with four types of hazardous liquid storage facilities (gasoline stations, major petroleum facilities, home heating oil distributors, and industries storing other hazardous liquids) were estimated using the methods presented below. [1]

- Gasoline Stations - Three methods were used to estimate the total number of operating gasoline stations in the State by county.

  - The first method used population distribution data and the number of operating service stations in the State (as estimated by the Gasoline Retailers Association of Northeastern New York) to calculate the number of service stations as a function of the percent of State population represented in each county. For example, assume that Dutchess County contains 10 percent of the State's population and assume that the State has a total of 10,000 service stations. The resulting number of service stations in Dutchess County would be 1,000 (.10 x 10,000 service stations).

  - The second method uses the gasoline consumption rates by county per year (as estimated by the New York State Department of Energy (NYS DOE)), and the typical annual volume (gallons) of sales for a typical station to calculate the number of stations in each county as a function of gasoline consumption. For example, if a typical facility sells 500,000 gallons per year and the total consumption of gasoline in Tioga County is 4,000,000 gallons per year then the number of service stations in Tioga County would be 8 (4,000,000 divided by 500,000).

  - The third method was similar to method two except gasoline consumption was calculated by determining the average number of motor vehicles per square mile in each county.

  The results of these methods turned out to be very similar so an average of the three values was used to determine the number of stations per county. These numbers were then totaled to arrive at the total number of service stations in the State (17,475 which includes 10,589 operating and 6,886 closed or abandoned stations) which, in turn, was multiplied by an assumed number of 4 tanks per service station to arrive at the total number of tanks in the State (approximately 68,900 tanks of which 27,544 are closed or abandoned).

- o Major Petroleum Facilities - The number of major petroleum facilities in the State totals 390, as evidenced by the number of licenses issued by Department of Transportation (NYS DOT).

- o Home Heating Oil - The number of home heating oil facilities per county was estimated using NYS DOT's estimates of the number of heating oil distributors in the State, subtracting out the major petroleum facilities and distributing them proportionally by population.

- o Industries Storing Other Hazardous Liquids - The number of industries storing other hazardous liquids were estimated using the DEC's report "An Iventory of Industrial Hazardous Waste Generation in New York State" and judgement to select the types of industries likely to be using underground storage for their hazardous wastes.

The number of closed or abandoned facilities were estimated using the methods described above and assumptions as to the number of facility closings in the past ten years (as provided by the Gasoline Retailers Association of Northeastern New York, NYS DOE and NYS DOT).

The estimate of the number of leaking tanks was determined using judgement based on results of Prince George's County, Maryland, American Petroleum Association and Suffolk County, New York tank testing programs. [2]

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APPENDIX J

Underground Protected Steel Tank Study
Statistical Analysis of Corrosion Failures

PREFACE

The following is a reprint of a paper prepared by Warren Rogers Associates which discusses one type of statistical analysis used to study corrosion failures in underground unprotected steel tanks.

UNDERGROUND UNPROTECTED STEEL TANK STUDY: STATISTICAL ANALYSIS OF CORROSION FAILURES

STATISTICAL ANALYSIS

Under contract with the American Petroleum Institute, Warren Rogers Associates has completed a statistical analysis of data on the occurrence of corrosion failures in unprotected underground steel storage tanks. The purpose of the analysis was to establish whether the ages at which failure occurred were related to measurable characteristics of the tank environment. The ages at which failures were observed varied from as low as five years to as high as forty-five. It was determined that measurements of soil resistivity, moisture, pH, sulphides and tank size can be incorporated into a mathematical model which explains approximately 75 percent of that variability. In addition, it was found that the statistical properties of the remaining 25 percent unexplained variability, are such, that knowledge of the residual error distribution permits the determination of confidence limits for estimates obtained from the model.

RESULTS OF ANALYSIS

The immediate practical consequences of the statistical analysis are as follows:

1. Tank Site Failure Probabilities -

   With data on the variables mentioned above, estimates can be made of the probability of a failure occurring in a tank at a specific age, or the probability that a tank may have already developed a corrosion induced perforation.

2. Decision Tree Modeling -

   In addition to determining a tank failure probability, there are other factors to be considered when making site-specific decisions. By incorporating relevant costs, environmental risk assessment, alternative courses of action and such factors as the economics of continued station operation, the results of this study provide a management tool to aid in determining a course of action. For example, a fully automated decision tree model can be developed to provide the short and long term cost and benefits of the alternative courses of action.

3. Leak Prevention Priority Setting -

   It has been determined that locations can be prioritized on the basis of greatest to least probability of corrosion failure along with other relevant factors mentioned above. This capability is particularly important in view of the practical and physical constraints on the time to manage and execute a tank testing or upgrading program at a great number of sites. In the absence of site specific data and probability estimates based on the data, it is difficult and in many cases impossible to determine the probability of a corosion failure at specific locations. Therefore, locations having the greatest likelihood of failure may go untreated while locations having tanks with a greater life expectancy rceive unwarranted tank testing or upgrading. It should be emphasized that tank age is, by itself, a very poor predictor of a corrosion induced failure. As mentioned above, failures due to external or internal corrosion have been observed at ages as low as five years and as high as forty-five.

BACKGROUND

To place this subject in context and to understand the nature of the statistical analysis and the conclusions that have been reached, it is important to understand the unexpected nature of underground tank corrosion failure and the novelty of the technical means required to solve it. When unprotected underground steel tanks were installed, engineering state-of-the-art indicated that a trouble-free lifetime of over 20 years could be anticipated. Data gathered for the statistical analysis study show that under certain circumstances that belief was justified. However, the study's conclusions show that unforeseen processes could be initated during installation, which could greatly reduce the useful life of an underground tank. The use of improper backfill material, an impurity in otherwise good backfill (a foreign substance such as a cinder), physical damage which scraped away a tank's coating or mill-scale, or any one of several other essentially random events could serve to create a localized anode on the tank surface. Whenever a localized anode occurred and either chemical, biological or other influence created a galvanic cell consisting of the tank and its surroundings, corrosion was concentrated at one or a few points. Localized tank corrosion proceeds at a pace determined by the properites of the backfill in the vicinity of the anode and can ultimately cause a failure.

Previously no body of theory existed which could serve to predict the age at which an underground steel tank would develop a corrosion induced failure. The chemistry of corrosion was well known but a mathematical model of the particular process which leads to tank corrosion failure had not been developed.

In an attempt to develop a predictive tool of that kind, the petroleum industry launched large scale data collection efforts to gather information on the factors which the theory of corrosion chemistry indicated would be relevant. To date, data has been collected at approximately 10,000 sites throughout the United States and Canada.

STATISTICAL MODELING DEVELOPMENT

The first age-to-failure statistical model developed provides estimates of the average age at which a tank at a site may fail due to external corrosion. In addition, it provides estimates of the probabilities that a tank has experienced corrosion failure or may fail at any specific age. These estimates are derived from physical site measurements of resistivity, pH, moisture, and sulphides in the immediate backfill and knowledge of tank age and size.

The measurements are combined in the model to provide the mean, or average age, of a corrosion failure in the specified environment. In addition, it was found that the pattern of departures from that mean age conform very well to a well-known mathematical form, the so-called normal distribution. Because of this, the probabilities mentioned can be calculated to determine confidence limits for estimates obtained from the model.

A second model has been generated to predict internal corrosion induced failures which most often initially develop directly beneath a tank's fill tube. Such metal failures, the result of the combined process of erosion and corrosion, have been found to be linearly related (proportional) to volume of sales and refill rate. Again, as with external corrosion, both the average age of failure for a given volume and refill rate and the probabilities of failure at any specified ages can be estimated.

MODEL VALIDITY

In the initial stages of the research, the approach followed was to concentrate analytical efforts on one data set and develop a predictive model. Validation of the model was then sought by reestimating its parameters from an independently collected data set. With the exception of a provision which must be made for differences in Canadian and U.S. tank installations, two essentially identical models have been derived from the independently collected data sets.

Confidence in recommending the use of these models is based on several factors:

1. Successful validation using an independently collected data set.

2. Semi-empirical structure of the model relates to known physical process of corrosion.

3. The model explains 75 percent of the variation in the field data.

4. Accuracy of predictions derived from the two models were verified. Both models were applied to data on non-leaking tanks and it was found that they predicted future failures at times consistent with the reported physical condition of the tanks.

CONCLUSIONS

Statistical analysis of tank site data leads to two basic conclusions. First, that tank sites fall into two categories: approximately one quarter (23 percent) of the sites had tanks which were corroded uniformly and did not present corrosion failure problems; tanks at the remaining three quarters (77 percent) of the sites experienced localized external corrosion. Second, the age at which a locally corroded tank will leak is a normal random variable whose mean and variance can be estimated from data on the variables noted earlier.

This means that if data is collected on the variables listed and the calculations for determining the mean age are carried out, the result is the age at which, on the average, a tank with localized anodes will fail due to external corrosion. Note that this implies that of a population of tank sites in similar environments, roughly half will fail before the mean age and half after.

However, in accordance with recognized statistical formulas, if the computed mean is subtracted from the actual age and the result is divided by the standard deviation, then with tables of the standard normal distribution it is possible to compute the probability that a tank at a site has developed a perforation, the probability that it will fail at or before any predetermined age, or the age at which any level of probability of failure will be attained.

For example, consider an installation with the following characteristics.

age	resistivity	pH	size	moisture	sulphides
10 yrs.	2000 ohms	6.5	3000 gal.	1 level	0 constant

From the model, the estimated mean age to external leak is 10.5 years.

To compute probabilities of leak at or before specified ages, it is necessary to first normalize and then use the standard normal tables.

$$\frac{\text{age} - \text{mean age}}{\text{standard deviation}} = \frac{10 - 10.5}{2.5} = \frac{-5}{2.5} = -.2$$

The probability that this tank is now leaking is thus 0.42.

Again using the standard normal distribution tables, the probabilities of a failure developing at the ages listed are computed.

Age	5.00	6.20	7.70	8.30	10.50
Probability of failure	0.01	0.04	0.13	0.19	00.42

Note that these probabilities are conditioned on the existence of localized corrosion which was observed in the data to occur in 77 percent of the cases examined. The unconditional probabilities can thus be estimated by multiplying by 0.77.

ROLE OF INVENTORY MONITORING

It is, of course, impossible to determine directly whether a tank is uniformly corroding or corroding at a point anode without physical inspection. However, a statistical procedure has been developed to assess the probabilities of either condition. Returning to the example given earlier, it is now assumed that the tank has been closely monitored by accurate daily inventory control to detect leakage until the tank is 15 years old and has not lost product.

It can be calculated, as before, that if point corrosion existed, the probability of failure would be:

$$P(\text{leak} \,/\, \text{point corrosion}) = 0.96$$

This suggests that point corrosion is extremely unlikely.

It is possible to be more definitive. With knowledge of the characteristics of the method used to determine tank tightness and the use of what are called Bayes estimation procedures, an estimate of the probability that the tank is corroding uniformly can be produced. As the tank ages past the mean age to leak for a locally corroded condition, this probability will grow very rapidly.

DECISION TREE MODELING

It must be emphasized that knowlege of the failure probabilities, while useful, does not provide a complete basis for deciding among the various courses of action which might be pursued. To form a basis for rational decison, it is necessary to array all alternatives, estimate all relevant costs of an undetected failure and compute the expected costs of each action and outcome combination.

This form of decision tree modeling is, however, well within the state-of-the-art once failure probabilities can be calculated. Thus with the ability to calculate probabilities, such a decision making procedure is feasible.

To implement a program based on this procedure requires four activities which can proceed concurrently.

1. Data collection and analysis, probability estimation and development of a prioritized list of installations, e.g., highest to lowest probability of leak.

2. Tank tightness integrity determination at highest priority locations.

3. Alternatives evaluation and optimal course of action determination.

4. Model revision and update to reflect newly acquired data.

1) Data Collection

Much of the difficulty encountered in conducting the statistical analysis was due to problems in the data. This was to be expected in that the data was collected in the absence of a model so that the required accuracy, extent of collection and ultimate sensitivity could only be estimated. As a result of this research, procedures can be suggested which should improve future data collection.

In general, the best data was generated whenever data collection was supervised by someone technically qualified and familiar with what the end use would be. It is recommended therefore that whoever is assigned responsibility for data gathering become extremely familiar with the statistical procedures developed and with the relevant aspects of soil chemistry. This latter should include as a minimum familiarity with the reasonable ranges of values to be expected in a given geographical region.

Continuing quality control of field measurements can be maintained by periodic laboratory analysis. Although it is felt that field measurements are adequate if they are taken in a reasonably accurate manner, it is recommended that samples be preserved for further backup laboratory analysis should anomalous measurements be reported.

Deep cores, down to tank bottom, are preferred since soil from shallow cores can be reported dry when the tank bottom is in ground water.

A carefully monitored pilot program at a few locations can be productive in ironing out the mechanisms of data collection, lab analysis, reporting and in developing specifications and procedures for routine implementation.

2) Leak Prevention Priority Setting

In a leak detection and prevention program involving one or more measures such as inventory control, tightness testing, interior lining, cathodic protection retrofit, tank replacement, and the like, the site deserving priority attention can be determined immediately from the current probabilities of a corrosion induced failure generated by the appropriate model.

In general, tank testing, replacement or similar measures, when based on age alone is not recommended. Such actions are arbitrary, costly and their immediate value questionable at sites which display extremely low probabilties of failure.

3) Alternative Evaluation

The conclusions of this project lead to the recommendation of the development of decision procedures concurrent with data collection and modeling. There are many leak prevention alternatives which include taking little action at one extreme and closing the facility at the other. Many complex interacting factors, economic and otherwise, must be considered in choosing among them. Our analysis to date provides one essential element, the probability of failure. What remains to be determined is the acceptability of any specific probability at any given location and the proper and efficient course of action if it is not acceptable.

The criteria for such decisions are necessarily specific to a location since they involve several factors such as environmental risks and the economics of continued station operation. However, once the probabilities of possible outcomes are known, the other relevant factors can be determined. Known procedures can then be implemented to provide facility owners with the expected relative costs, benefits and risks of any alternative course of action.

4) Model Revision and Update

As soil data is collected and tank condition results become available, an ongoing reestimation of parameters and model update is recommended. This would provide immediate evidence of anomalies. Also, it would serve as a method to discover the emergence of any previously undetected phenomena not revealed in the data analyzed to date.