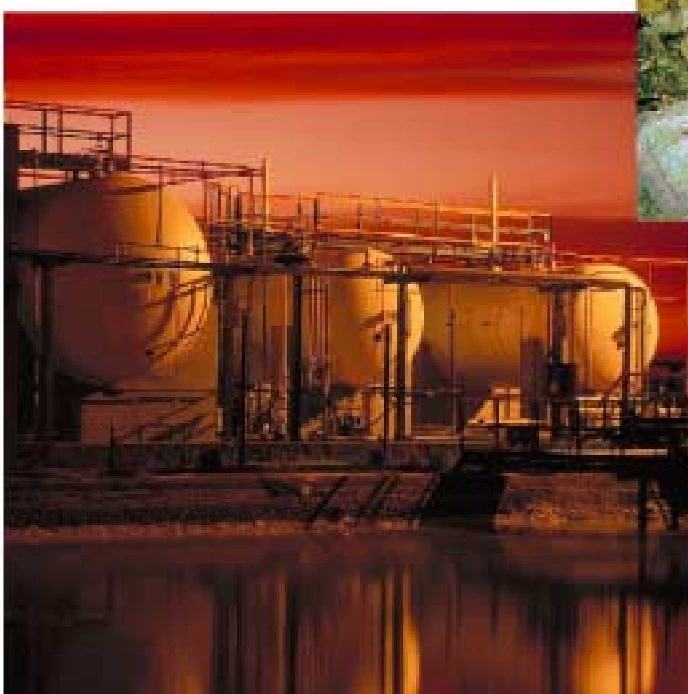
APPENDIX G

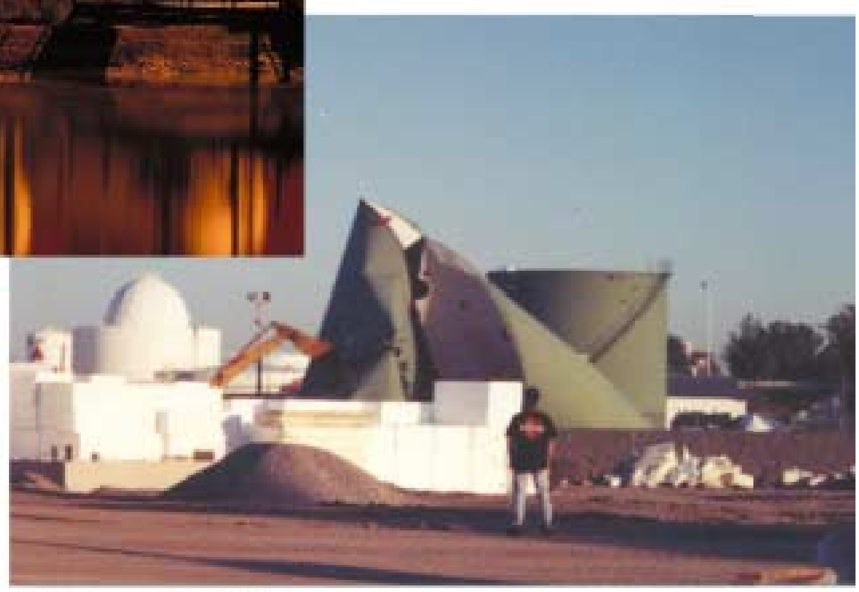
HAZARDOUS MATERIALS STORAGE

Aboveground storage tank

Lifting underground storage tank



Storage tanks



Collapsed storage tank

APPENDIX G

HAZARDOUS MATERIALS STORAGE

MICHIEL P.H. BRONGERS[1]

SUMMARY AND ANALYSIS OF RESULTS

Corrosion Control and Prevention

There are approximately 8.5 million regulated and non-regulated aboveground storage tanks (ASTs) and underground storage tanks (USTs) for hazardous materials (HAZMAT) in the United States. The regulated tanks can be divided into two groups: Spill Prevention Countermeasure and Control (SPCC)-regulated and Office of Underground Storage Tanks (OUST)-regulated. A total of 2.5 million tanks fall under SPCC regulations, 0.75 million tanks fall under OUST regulations, and 5.25 million are non-regulated tanks. HAZMAT tanks represent a significant investment, and maintaining their structural integrity for a longer service life is in the best interest of their owners. The U.S. Environmental Protection Agency (EPA) concerns itself with the environmental impact of spills from leaking tanks. In addition, the tank operators should be concerned about the potential economic impact of penalties and clean-up costs.

The total cost of corrosion for storage tanks is $7.0 billion per year (ASTs and USTs). The cost of corrosion for all ASTs was estimated at $4.5 billion per year. A vast majority of the ASTs are externally painted, which is a major cost factor for the total cost of corrosion. In addition, approximately one-third of ASTs have cathodic protection (CP) on the tank bottom, while approximately one-tenth of ASTs have internal linings. These last two corrosion protection methods are applied to ensure the structural integrity of the ASTs.

The cost of corrosion for all USTs was estimated at $2.5 billion per year. The largest costs are incurred when leaking USTs must be replaced with new tanks. The soil remediation costs and oil spill clean-up costs are significant as well. In the last 10 years, the most common problem associated with USTs occurred at gasoline service stations that did not have corrosion protection on their USTs.

The current sector study shows the following corrosion costs:

	ANNUAL CORROSION COST	DIVIDED OVER:
ALL ASTs	$4.5 billion	$2.8 billion for external coatings $1.2 billion for cathodic protection $0.5 billion for internal linings
ALL USTs	$2.5 billion	$1.4 billion for gasoline stations $1.1 billion for the remaining USTs

Since 1988, the number of OUST-regulated USTs has decreased from approximately 1.3 million to 0.75 million due to stringent regulations. During the same period, a trend of replacing multiple small USTs with fewer larger ASTs was evident. While USTs were being closed, repaired, or replaced to achieve the necessary compliance with regulations, the number of confirmed HAZMAT releases increased. The December 1998 deadline

[1] CC Technologies Laboratories, Inc., Dublin, Ohio.

for UST compliance marked the date that owners were required to have corrosion control systems, overfill protection, and spill protection applied on all of their regulated USTs.

Opportunities for Improvement and Barriers to Progress

Experts have argued that focusing only on corrosion protection on the tanks is insufficient because the connected underground piping should have corrosion protection as well. In order to prevent future leaks, corrosion protection on associated piping and connectors should be applied, as specified in the Code of Federal Regulations.

The largest structural problem with ASTs is external corrosion of the tank bottoms that are sitting on-grade. New tanks are generally designed with a bottom coating and cathodic protection; however, the majority (70 percent) of ASTs have no cathodic protection at all, making them vulnerable to reduction in wall thickness because of external corrosion. Since corrosion of the AST exteriors is not so much a structural problem, exterior painting is repeated every few years at a significant expense. Studies showed that the cost of labor for surface preparation and painting is 80 percent of the total painting cost, and the cost of the paint is 20 percent of the total painting cost.

Internal linings on the walls and the bottoms of ASTs are commonly used to prevent a variety of corrosion problems. The most common problem is the presence of water at the bottom of a tank. Inspection of linings should be performed regularly, including disbondment testing and visual inspection for scratches. Damage to internal linings should be repaired as soon as possible to prevent leaks and to ensure the structural integrity of the tank.

Only 30 percent of existing ASTs have cathodic protection on their tank bottoms. Using cathodic protection in combination with coatings and the installation of tanks on well-draining soils provides good corrosion protection of AST tank bottoms. New tanks are usually designed with these corrosion protection systems; however, older ASTs generally do not have these systems in place. Retrofitting of older tanks with cathodic protection is possible using a variety of methods to place and configure anodes; however, a barrier to installing cathodic protection to existing tanks is that retrofits can be costly. Due to this high cost, retrofitting is often not done, even though the potential costs of oil spill remediation could be many times larger.

Approximately 60 percent (5.2 million) of the total number of HAZMAT tanks (8.5 million) are unregulated. The great majority of these tanks are used for home heating oil, LPG (liquid propane gas)/propane gas, and kerosene. Although the size of unregulated tanks is generally smaller than that of regulated tanks, the potential for more spills exists. The level of corrosion awareness is low with owners of unregulated tanks, and a mentality of “bury it and forget it” is common. This potentially large number of small spills is an invisible problem that affects many sites.

Recommendations and Implementation Strategy

The SPCC program for USTs has shown the effectiveness of a national approach to prevent and remediate HAZMAT releases. The SPCC program has increased awareness that corrosion protection can work, that it prevents environmental problems, and that a substantial cost-savings can be achieved over the life of the tanks.

A similar systematic approach should be applied to protect AST tank bottoms. Technologies to retrofit existing ASTs are available. Research regarding the cost benefits for retrofitting ASTs with cathodic protection, coatings, and well-draining grade soils is recommended to support this work.

The cost of replacing HAZMAT tanks with new tanks can far exceed the cost of repairing existing tanks for continued use. Existing methods can be used and new methods should be developed to measure and evaluate wall loss on aged USTs and AST tank bottoms, with the objective that corroded tanks may be repaired instead of replaced.

Summary of Issues

Increase consciousness of corrosion costs and potential savings.	There are 8.5 million aboveground storage tanks (ASTs) and underground storage tanks (USTs). The cost of corrosion for all ASTs is $4.5 billion per year. The cost of corrosion for all USTs is $2.5 billion per year.
Change perception that nothing can be done about corrosion.	The Spill Prevention Countermeasure and Control (SPCC) program for USTs has shown the effectiveness of a national approach to prevent and remediate hazardous materials releases.
Advance design practices for better corrosion management.	The use of cathodic protection in combination with coatings and the installation of tanks on well-draining soils allow for good corrosion protection of AST tank bottoms.
Change technical practices to realize corrosion cost-savings.	The mentality of "bury it and forget it" is common and should be changed to cost-effective corrosion-focused design, inspection programs at periodic intervals, preventive maintenance, and critical assessment of aged and corroded tanks with remaining safe service life.
Change policies and management practices to realize corrosion cost-savings.	A systematic approach similar to that for USTs should be applied to protect AST tank bottoms.
Advance life prediction and performance assessment methods.	Based on inspection data, engineering integrity assessments can be made to evaluate the integrity of existing USTs and ASTs for continued use.
Advance technology (research, development, and implementation).	A systematic approach should be applied to protect AST tank bottoms. Technologies to retrofit existing ASTs are available. Research to evaluate the cost benefits of retrofitting ASTs with cathodic protection, coatings, and well-draining grade soils is urgently needed.
Improve education and training for corrosion control.	The level of corrosion awareness is low with owners of unregulated tanks. A mentality of "bury it and forget it" is common and should be changed to prevent hazardous materials releases. There are 5.2 million out of 8.5 million tanks that are non-regulated.

TABLE OF CONTENTS

SECTOR DESCRIPTION G1
Background G1
Size of Storage Tank Population in the United States G2
SPCC-Regulated Facilities G2
SPCC-Regulated ASTs and USTs G3
OUST-Regulated USTs G7
Indirect Corrosion Costs – Remediation of UST Spills G7
Unregulated Tanks G8
Summary of Tank Totals G9
Estimating Corrosion Costs G9
AREAS OF MAJOR CORROSION IMPACT G11
Aboveground Storage Tanks G11
Internal Corrosion G12
External Corrosion G13
Underground Fuel Storage Tanks G13

TABLE OF CONTENTS (continued)

CORROSION CONTROL METHODS G13
Aboveground Storage Tanks G13
Internal Coatings G16
External Coatings G16
Cathodic Protection on ASTs G16
Underground Storage Tanks G16
Cathodic Protection on USTs G16
CORROSION MANAGEMENT G17
The sti-P_3® System G18
Polymer Tanks G19
CHANGES FROM 1975 TO 2000 .... G19
CASE STUDIES G20
Case Study 1. How Much Does It Cost to Upgrade, Replace, or Close UST Systems? G20
Cost Estimates to Upgrade USTs G21
Cost Estimates to Replace USTs G21
Cost Estimates to Close USTs G21
Costs of Not Upgrading, Replacing, or Closing Substandard USTs G21
Underground Storage Tanks – Total Cost of Corrosion G22
Case Study 2. Annual Cost of Corrosion Protection for Three USTs at a Gas Station G22
New Installations – Cost of Sacrificial Anode CP G23
Old Installations – Cost of Impressed-Current CP G23
Cost of Internal Lining of USTs G25
Case Study 3. Annual Cost of Corrosion Protection for ASTs G25
Cost of Impressed-Current CP on Tank Bottoms of ASTs G26
Cost of Internal Linings of ASTs G27
Cost of External Coatings on ASTs G27
Case Study 4. Comparison of USTs Versus ASTs G28
REFERENCES G30

LIST OF FIGURES

Figure 1a. Pressurized storage tank G11

Figure 1b. Unpressurized storage tanks G11

Figure 2. Example of an oil storage tank farm, showing multiple tanks of varying sizes G12

Figure 3. Internal and external corrosion modes that may occur at an aboveground storage tank G12

LIST OF TABLES

Table 1. National estimate of SPCC-regulated facilities in 1995, as determined by the EPA G3

Table 2. Summary of 1995 SPCC survey data for both aboveground and underground regulated tanks G4

Table 3. National totals of underground active tanks in the volume category 0.416 to 159 m^3 (110 to 42,000 gal), closed tanks, and confirmed releases, according to OUST G7

Table 4. Total U.S. environmental expenditures (in millions of dollars) from 1990 to 1996, as estimated by the American Petroleum Institute (API) G8

Table 5. Summary of estimated total number of aboveground and underground storage tanks in the United States G9

Table 6. Estimated corrosion control costs for aboveground and underground storage tanks G10

Table 7. Comparison of capital cost for new tanks with a capacity of 37.8 m^3 (10,000 gal) G10

Table 8. Corrosion control methods for aboveground storage tanks, based on Myers............................... G14

Table 9. Corrosion costs for USTs at gas stations.. G18

Table 10. Summary of corrosion costs divided by tank location and corrosion control method G18

Table 11. Approximate costs to add spill, overfill, and corrosion protection, based on a three-tank facility, labor costs, and 24 hours or less of downtime, as reported by EPA G21

Table 12. Calculation of annual cost for impressed-current CP for three underground tanks in the same pit. CP runs at 60 percent efficiency: power consumption is 1 / 0.60 = 1.67 times as much G24

Table 13. Cost of installation and maintenance for impressed-current CP for three underground tanks in the same pit, as estimated by Lary and Garrity G24

Table 14. Estimated total annual cost for impressed-current CP for three underground tanks in the same pit G24

Table 15. Calculation of annual cost for impressed-current CP for one 30.5-m- (100-ft-) diameter aboveground storage tank bottom. CP runs at 60 percent efficiency: power consumption is 1 / 0.60 = 1.67 times as much... G26

Table 16. Cost of installation and maintenance for an AST tank bottom CP, as estimated by Lary and Garrity.. G26

Table 17. Estimated total annual cost for impressed-current CP for a single AST tank bottom. G27

Table 18. Steel Tank Institute comparison of USTs versus ASTs. G28

SECTOR DESCRIPTION

The Code of Federal Regulations, 49 CFR 173,[1] categorizes hazardous materials (HAZMAT) in nine classes: (1) explosives, (2) flammable and compressed gases, (3) flammable liquids, (4) flammable solids, (5) oxidizers, (6) poisonous materials, (7) radioactive materials, (8) corrosive materials, and (9) miscellaneous other HAZMAT. A significant portion of HAZMAT concerns petroleum and petroleum products (Class 3). The petroleum industry processes 65 percent of the energy that Americans consume. This includes vast quantities of transportation fuels, home heating oil, and industrial fuels, as well as petrochemicals used in the manufacture of countless consumer products.[2] Storage of bulk liquids is routinely done in buried and aboveground tanks. Small quantities of corrosive materials are stored in corrosion-resistant drums or containers.

Background

Almost every industry has a need to store hazardous materials. Example industries include farms, coal, metal and non-metal mineral mining, oil production, construction, manufacturing, chemical, petroleum refining, primary metals industry, railroad fueling, bus transportation, trucking, warehousing, water transportation services, air transportation, pipelines, electric utilities, petroleum bulk stations and terminals, fuel oil dealers, and commercial and industrial users. In addition to private and industrial users of HAZMAT tanks, both the state and federal government operate numerous storage tanks.

The federal government has an elaborate and complicated matrix of regulations regarding hazardous substances. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980,[3] the Resource Conservation and Recovery Act (RCRA) of 1976,[4] and the Occupational Safety and Health Act (OSHA) of 1970[5] all provide definitions and classifications of hazardous materials. The Code of Federal Regulations, 40 CFR 280,[6] states that metal piping that routinely contains regulated substances and is in contact with the ground must be cathodically protected. Similarly, 49 CFR 195[7] contains the requirements for the transportation of hazardous liquids by transmission pipelines. Although transportation by transmission pipelines will be discussed elsewhere in this report, it is important that this CFR includes requirements for the associated piping and connectors at terminal facilities and stations that send and receive the hazardous liquids.

In addition to federal regulations, there are state and local regulations that may vary by state or county. There are literally thousands of materials that are regulated as hazardous; however, the largest single materials group in volume are the refined petroleum products. These refined petroleum products are affecting nearly every sector of the U.S. economy.

Underground storage tanks (USTs) for the handling and storage of petroleum and hazardous substances are regulated by the U.S. Environmental Protection Agency (EPA) office of underground storage tanks (OUST), (40 CFR 280).[6] OUST uses a definition of UST as those tanks that are buried underground to at least 10 percent of their height. Aboveground storage tanks (ASTs) that are 2.5 m^3 (660 gal) or larger, and USTs that are 159 m^3 (42,000 gal) or larger are regulated by the EPA oil spill prevention program (OSPP) in conjunction with the Spill Prevention Countermeasure and Control (SPCC) plan (40 CFR 112).[8] Under the EPA-SPCC definition, USTs are those tanks that are 100 percent buried.

Under the Clean Water Act [9] and the Oil Spill Pollution Act of 1990,[10] EPA is responsible for protecting the nation's waters from the adverse effects of oil spills. The SPCC regulation, which implements section 311(j) of the Clean Water Act, is designed to prevent discharges of oil from facilities and to contain such discharges when they occur. The regulation applies to "onshore, non-transportation-related facilities" that could reasonably be expected to discharge oil into navigable waters when such facilities have: (1) an aboveground oil storage capacity of more than 2.5 m^3 (660 gal) in a single container, (2) a total aboveground oil storage capacity of more than 5.0 m^3 (1,320 gal) in multiple containers, or (3) a total underground oil storage capacity of more than 159 m^3 (42,000 gal).

The incentives for good corrosion management are clear: maintaining structural integrity, preventing environmental spills, and preventing product contamination. The total number of aboveground and underground SPCC-regulated, OUST-regulated, and non-regulated HAZMAT storage tanks is approximately 8.5 million tanks. Obviously, these tanks represent an enormous investment, and maintaining their structural integrity for a longer service life is in the best interest of their owners.

The Water Enforcement Division of the U.S. EPA Office of Regulatory Enforcement and Compliance Assurance enforces the Oil Pollution Act of 1990. This law prohibits the discharge of threshold amounts of oil or other hazardous substances into navigable waters and requires facilities that store oil to prepare spill prevention plans and to adopt measures to keep accidental releases from reaching navigable waters.

A civil penalty policy was established for EPA litigation of violations. The settlement costs include dollar amounts for seriousness, culpability, mitigation, and history of prior violations. Penalties easily amount to millions of dollars because the size of the tank, the quantity and duration of the spill, negligence and/or willful misconduct, prompt response and mitigation, and previous incidents are considered as well. In addition, in cases where known economic impact would otherwise be minimal, the penalty amount may be increased to ensure that there is sufficient impact to specifically deter the violator from future violations. Also, the penalty amount may be increased if the violator obtained an economic benefit from avoiding or delaying necessary compliance.

Size of Storage Tank Population in the United States

SPCC-Regulated Facilities

In 1996, the EPA estimated the number of facilities subject to SPCC regulations based on the results of 1991 and 1995 surveys of U.S. oil storage facilities.[11] For the 1995 survey, the data were collected by sampling 215 of the 3,111 counties in the 48 contiguous states. Of the 215 counties, 20 stored large volumes of oil and were therefore considered to be "self-representing" in the sample design. The results obtained from the 20 counties were only extrapolated to the population of those counties. Due to the significant difference in total oil storage capacities in those 20 counties, including them with the other 195 counties as part of the overall extrapolation would have generated significantly lower confidence in the resulting estimates. In the 1995 survey, the EPA randomly selected 30,000 recipient facilities in 23 different industries who were likely to include facilities regulated by the EPA. Facilities using crude oil as well as those using refined petroleum products were included. A summary of the results is presented in table 1.

The facility capacity threshold was 5.0 m^3 (1,321 gal); therefore, the categories of study included 5.0 to 159 m^3 (1,321 to 42,000 gal) (aboveground only), 159 to 3,785 m^3 (42,001 to 1,000,000 gal), and more than 3,785 m^3 (1,000,000 gal). The number of facilities was estimated to be 505,000 in the 1991 survey and 386,661 in the 1995 survey. A 1996 estimate placed the adjusted number of facilities at 437,700. The survey data indicated that two categories constitute about 80 percent of the SPCC-regulated facilities: farms (42.2 percent) and oil production (37.3 percent). Manufacturing, transportation, and gas stations/vehicle fueling constitute 12 percent of facilities. All other industries combined make up 8 percent of the facilities. The farms comprise a sizable portion of the SPCC-regulated facilities, but this represents only 8 percent of the U.S. industry, as farms in general have smaller storage capacity, fewer tanks, and lower throughput levels than other types of facilities.

Table 1. National estimate of SPCC-regulated facilities in 1995, as determined by the EPA.[11]

<table>
<tr><th>TOTAL FACILITIES IN 1991</th><th>TOTAL FACILITIES IN 1995</th><th>TOTAL FACILITIES IN 1996 (ADJUSTED)</th><th>TANK LOCATION</th><th>SPCC-REGULATED FACILITIES</th><th>TANK VOLUME CATEGORY</th><th>TOTAL TANKS IN 1991</th><th>TOTAL TANKS IN 1996 (ADJUSTED)</th></tr>
<tr><td>505,000</td><td rowspan="6">386,661</td><td rowspan="6">437,700</td><td rowspan="3">Aboveground</td><td rowspan="3">> 2.5 m^3 (> 660 gal) in single tank, or > 5.0 m^3 (> 1,320 gal) in multiple containers</td><td>5 – 159 m^3 (1,321-42,000 gal)</td><td rowspan="3">3,141,340</td><td rowspan="3">2,373,276</td></tr>
<tr><td></td><td>159 – 3,785 m^3 (42,001-1,000,000 gal)</td></tr>
<tr><td></td><td>> 3,785 m^3 (>1,000,000 gal)</td></tr>
<tr><td></td><td rowspan="3">Underground</td><td>0.416 – 159 m^3 (110 - 42,000 gal)</td><td colspan="3">Regulated by OUST*</td></tr>
<tr><td></td><td rowspan="2">Combined capacity > 159 m^3 (> 42,000 gal)</td><td>159 – 3,785 m^3 (42,001-1,000,000 gal)</td><td rowspan="2">104,851</td><td rowspan="2">133,400</td></tr>
<tr><td></td><td>> 3,785 m^3 (>1,000,000 gal)</td></tr>
</table>

* OUST = Office of Underground Storage Tanks

SPCC-Regulated ASTs and USTs

The facilities covered in the SPCC studies included small aboveground (~ 10 m^3 on legs) tanks in the 5 to 159 m^3 (1,321 to 42,000 gal) category as well as large underground tanks in the > 159 m^3 (> 42,000 gal) category. The 1996 report separated tank characteristics by industry in the survey of sample facilities. The average number and size of tanks was calculated to provide an overall estimate using this small sample. Based on this estimate, 3,141,340 (1991) to 2,373,276 (1996 adjusted) aboveground tanks and 104,851 (1991) to 133,400 (1996 adjusted) underground tanks were present at facilities that exceed the combined capacity "42,000 gallons total" OUST regulatory limit. A very large number of small-capacity aboveground tanks at military installations, colleges, and oil production facilities are included in the AST estimates above. If industry categories with average tank capacities under 5.7 m^3 (1,500 gal) are removed, there are 1,067,485 (1991) to 1,124,748 (1996) ASTs in the United States. The 1995 SPCC survey data for both aboveground and underground regulated tanks are summarized in table 2.

The unplanned oil discharges reported in the SPCC survey were analyzed by the location of the failure. The survey showed that 138 (19.7 percent) of 702 reported unplanned oil discharges were caused by material damage as follows: 1 percent tank wall, 2 percent tank bottom, 6 percent tank roof, 7 percent tank piping, and 3 percent tank valve. Damage from loading arms, racks, and other parts accounted for 12 percent of the discharges. Valves, pumps, and other equipment caused 39 percent of the discharges. The remaining 30 percent had other discharge causes.

The unplanned oil discharges reported in the SPCC survey were further analyzed by the nature of the failure. The survey showed that 116 (16.8 percent) of 691 reported that unplanned oil discharges were caused by material failure as follows: 3 percent general structural failure, 1 percent bottom failure, 0.3 percent cold weather brittle failure, 2 percent weld/joint failure, 6 percent valve failure, and 5 percent corrosion. Failure from overfill, operator error, collision with mobile equipment, electrical malfunction, other mechanical failures, alarm failure, fire/explosion, vandalism, natural phenomena, and other failures accounted for the other discharges. This analysis shows that corrosion or other forms of material degradation in the tank construction account for approximately 17 percent of the large financial losses and environmental spills in SPCC-regulated facilities.

Table 2. Summary of 1995 SPCC survey data for both aboveground and underground regulated tanks.[11]

SIC CODE*	INDUSTRY		1995 SPCC SURVEY ESTIMATED NUMBER OF FACILITIES MEETING STORAGE CRITERIA
1	Farms		163,157
12,14	Coal Mining / Nonmetallic Mining		1,849
131	Oil Production		144,349
16	Contract Construction		7,167
20	Manufacturing	Food and Kindred Products	4,314
28		Chemical and Allied Products	3,281
29		Petroleum Refining and Related Industries	827
33		Primary Metals Industries	664
21-27,30-32,34-39		Other Manufacturing	15,526
401	Transportation	Railroad Fueling	16,492
411,413,414,417		Bus Transportation	
42,449		Trucking & Warehouse / Water Transp. Services	
458		Air Transportation	
491	Electric Utility Plants		2,638
5171	Petroleum Bulk Stations & Terminals		6,845
554	Gasoline Service Stations		12,996
751	Vehicle Rental		
5983	Fuel Oil Dealers		2,160
806	Hospitals		3,408
821	Education		
822	Colleges		
97	Military Installations		988
			386,661 TOTAL

*SIC = Standard Industrial Classification

Table 2. Summary of 1995 SPCC survey data for both aboveground and underground regulated tanks (continued).[11]

INDUSTRY	FACILITIES PERCENTAGE	COMMON PRODUCT	AVERAGE NUMBER OF TANKS PER FACILITY	TOTAL ESTIMATED NUMBER OF TANKS	PER FACILITY AVERAGE CAPACITY	PER TANK AVERAGE CAPACITY	TOTAL CAPACITY
	%		Number	Number	m^3	m^3	m^3 x million
Farms	42.2	Diesel	3.5	571,050	171.7	49.1	98.1
Coal Mining / Nonmetallic Mining	0.5	Diesel	4.9	9,060	8.8	1.8	0.1
Oil Production	37.3	Crude Oil	8.5	1,226,967	44.3	5.2	54.4
Contract Construction	1.9	Diesel	5.9	42,285	40.3	6.8	1.7
Food and Kindred Products	1.1	Other	12.7	54,788	162.3	12.8	8.9
Chemical and Allied Products	0.8	Other	8.5	27,889	492.4	57.9	13.7
Petroleum Refining and Related Industries	0.2	Other	65.0	53,755	5,363.1	82.5	288.3
Primary Metals Industries	0.2	Lube Oil	18.5	12,284	38.2	2.1	0.5
Other Manufacturing	4.0	Lube Oil	6.6	102,472	64.4	9.8	6.6
Railroad Fueling	4.3	Diesel	6.3	103,900	176.5	28.0	18.3
Bus Transportation	0.0	Lube Oil	2.0		1.5	0.8	
Trucking & Warehouse / Water Transp. Services	0.0	Lube Oil	5.1		557.0	109.2	
Air Transportation	0.0	Gasoline	6.8		128.4	18.9	
Electric Utility Plants	0.7	Lube Oil	8.8	23,214	1,792.7	203.7	41.6
Petroleum Bulk Stations & Terminals	1.8	Gasoline	10.4	71,188	618.1	59.4	44.0
Gasoline Service Stations	3.4	Gasoline	6.5	84,474	427.3	65.7	36.1
Vehicle Rental	0.0	Diesel	2.5		11.0	4.4	
Fuel Oil Dealers	0.6	Fuel Oil	5.9	12,744	73.2	12.4	0.9
Hospitals	0.9	Fuel Oil	7.0	23,856	41.2	5.9	1.0
Education	0.0	Fuel Oil	4.0		16.0	4.0	
Colleges	0.0	Fuel Oil	28.4		29.6	1.0	
Military Installations	0.3	Fuel Oil	48.9	48,313	90.6	1.9	4.4
	100.2% TOTAL**		**12.6 AVERAGE**	**2,468,239 TOTAL**	**10,348.6 TOTAL**	**24.4 WEIGHTED AVERAGE**	**618.6 TOTAL**

**Individual values do not add up to 100% due to rounding.

Table 2. Summary of 1995 SPCC survey data for both aboveground and underground regulated tanks (continued).[11]

<table>
<tr><th>INDUSTRY</th><th>AVERAGE AGE</th><th>TANKS WITH INTERNAL PROTECTION</th><th>TANKS WITH INTERNAL PROTECTION</th><th>TANKS WITH EXTERNAL PROTECTION (CP)</th><th>TANKS WITH EXTERNAL PROTECTION (CP)</th><th>TANKS WITH EXTERNAL COATINGS</th><th>TANKS WITH EXTERNAL COATINGS</th></tr>
<tr><th></th><th>Years</th><th>%</th><th>Number</th><th>%</th><th>Number</th><th>%</th><th>Number</th></tr>
<tr><td>Farms</td><td>14</td><td>8.2</td><td>46,826</td><td>84.2</td><td>480,824</td><td>7.7</td><td>43,971</td></tr>
<tr><td>Coal Mining / Nonmetallic Mining</td><td>10</td><td>4.3</td><td>390</td><td>83.3</td><td>7,547</td><td>39.7</td><td>3,597</td></tr>
<tr><td>Oil Production</td><td>17</td><td>14.6</td><td>179,137</td><td>77.0</td><td>944,764</td><td>15.9</td><td>195,088</td></tr>
<tr><td>Contract Construction</td><td>17</td><td>5.6</td><td>2,368</td><td>91.6</td><td>38,733</td><td>43.2</td><td>18,267</td></tr>
<tr><td>Food and Kindred Products</td><td>14</td><td>4.1</td><td>2,246</td><td>81.0</td><td>44,378</td><td>43.6</td><td>23,887</td></tr>
<tr><td>Chemical and Allied Products</td><td>17</td><td>6.2</td><td>1,729</td><td>80.1</td><td>22,339</td><td>39.5</td><td>11,016</td></tr>
<tr><td>Petroleum Refining and Related Industries</td><td>39</td><td>8.7</td><td>4,677</td><td>93.5</td><td>50,261</td><td>20.8</td><td>11,181</td></tr>
<tr><td>Primary Metals Industries</td><td>19</td><td>1.1</td><td>135</td><td>78.4</td><td>9,631</td><td>15.8</td><td>1,941</td></tr>
<tr><td>Other Manufacturing</td><td>13</td><td>4.9</td><td>5,021</td><td>86.8</td><td>88,945</td><td>17.8</td><td>18,240</td></tr>
<tr><td>Railroad Fueling</td><td>21</td><td>15.7</td><td rowspan="4">16,312</td><td>92.0</td><td rowspan="4">95,588</td><td>23.0</td><td rowspan="4">23,897</td></tr>
<tr><td>Bus Transportation</td><td>2</td><td>***</td><td>***</td><td>***</td></tr>
<tr><td>Trucking & Warehouse / Water Transp. Services</td><td>12</td><td>8.9</td><td>76.7</td><td>41.9</td></tr>
<tr><td>Air Transportation</td><td>12</td><td>40.6</td><td>77.9</td><td>20.2</td></tr>
<tr><td>Electric Utility Plants</td><td>23</td><td>6.2</td><td>1,439</td><td>95.2</td><td>22,100</td><td>19.0</td><td>4,411</td></tr>
<tr><td>Petroleum Bulk Stations & Terminals</td><td>20</td><td>11.6</td><td>8,258</td><td>80.5</td><td>57,306</td><td>26.5</td><td>18,865</td></tr>
<tr><td>Gasoline Service Stations</td><td>18</td><td>16.8</td><td rowspan="2">14,192</td><td>85.3</td><td rowspan="2">72,056</td><td>16.9</td><td rowspan="2">14,276</td></tr>
<tr><td>Vehicle Rental</td><td>3</td><td>20.0</td><td>80.0</td><td>0.0</td></tr>
<tr><td>Fuel Oil Dealers</td><td>24</td><td>17.8</td><td>2,268</td><td>77.0</td><td>9,813</td><td>29.5</td><td>3,759</td></tr>
<tr><td>Hospitals</td><td>11</td><td>25.0</td><td rowspan="3">5,964</td><td>92.9</td><td rowspan="3">22,162</td><td>35.7</td><td rowspan="3">8,517</td></tr>
<tr><td>Education</td><td>13</td><td>22.4</td><td>74.5</td><td>19.1</td></tr>
<tr><td>Colleges</td><td>13</td><td>5.0</td><td>89.4</td><td>15.5</td></tr>
<tr><td>Military Installations</td><td>13</td><td>11.8</td><td>5,701</td><td>55.8</td><td>26,959</td><td>15.3</td><td>7,392</td></tr>
<tr><td></td><td>16.78 WEIGHTED AVERAGE</td><td>12.0% AVERAGE</td><td>296,663 TOTAL</td><td>80.8% AVERAGE</td><td>1,993,406 TOTAL</td><td>16.5% AVERAGE</td><td>408,304 TOTAL</td></tr>
</table>

***No value reported.

OUST-Regulated USTs

The Code of Federal Regulations, 40 CFR 280,[6] contains the requirements for underground storage tank (UST) systems. The principal objective of the federal closure requirements is to identify and contain existing contamination and to prevent future releases from UST systems that are no longer in service. These federal regulations became effective on December 22, 1988. The deadline for compliance was December 22, 1998. Although this deadline has passed, many USTs still do not meet the requirements for leak detection, spill and overfill protection, and corrosion protection. UST owners or operators having these non-compliant USTs can be cited, as the result of official UST inspections, for violations and can be subject to penalty fees. To protect human health and the environment, UST owners and operators must take immediate action to upgrade, replace, or close any substandard USTs for which they are responsible.

USTs are not regulated by the Office of Underground Storage Tanks (OUST) when they are smaller than 0.416 m^3 (110 gal) in capacity and are not used to store heating oil that is utilized on the premises. Storage facilities that have a combined underground capacity larger than 159 m^3 (42,000 gal) are also not included in OUST's jurisdiction because they are regulated under the SPCC program. UST owners are required to notify the U.S. EPA of their tanks through EPA Form 7530-1. The information on this form includes the status of the UST (in use, temporarily closed, or permanently closed), the installation date, the estimated total capacity, the materials of construction, the piping material, the piping type, the substance currently stored, the installed release detection systems, and spill and overfill protection systems.

Based on the information supplied on the forms located on the U.S. EPA website,[6] OUST maintains a running total of the number of active tanks in their program, the total number of closed tanks, and the total number of confirmed releases (see table 3). The word "release" in this context refers to a gasoline or oil spill from a leaking UST. The vast majority of this population of regulated tanks are at retail gasoline stations.

Table 3. National totals of underground active tanks in the volume category 0.416 to 159 m^3 (110 to 42,000 gal), closed tanks, and confirmed releases, according to OUST.[6]

REPORTING TIME	NUMBER OF ACTIVE TANKS	ANNUAL CHANGE	NUMBER OF CLOSED TANKS	ANNUAL CHANGE	CONFIRMED RELEASES	ANNUAL CHANGE
1st Half FY 00	742,805	-	1,417,711	-	405,030	-
2nd Half FY 99	760,504	81,656	1,377,115	91,882	397,821	19,103
1st Half FY 99	824,461		1,325,829		385,927	
2nd Half FY 98	891,686	95,079	1,236,007	139,488	371,387	27,628
1st Half FY 98	919,540		1,186,341		358,269	
2nd Half FY 97	969,652	112,420	1,150,824	75,075	341,773	28,329
1st Half FY 97	1,031,960		1,111,266		329,940	
2nd Half FY 96	1,064,478	61,058	1,074,022	67,829	317,488	15,220
1st Half FY 96	1,093,018		1,043,437		314,720	
	AVERAGE	**87,553**	**AVERAGE**	**93,569**	**AVERAGE**	**22,578**

Indirect Corrosion Costs – Remediation of UST Spills

As a comparison to the OUST data, a 1997 American Petroleum Institute (API) survey, published in 1998,[2] was reviewed. In that API survey, the 14 participating companies reported on their 19,000 gasoline service station facilities with almost 74,000 tanks (average 3.9 tanks per station). In comparison with the 1,031,960

OUST-regulated tanks in 1997, the API numbers indicated that approximately 7.2 percent (74,000 / 1,031,960 x 100 percent) of the national UST population was represented.

The API survey reported the total estimated U.S. environmental expenditures and the expenditures on remediation and spills for the years 1990 through 1996 (see table 4). In 1996, the petroleum industry spent a total of approximately $8.2 billion on the environment, or $83 per U.S. household. The annual costs for remediation and spills were reported to vary between $947 million and $1.334 billion, as specified by the participants in the API survey. Between 1990 and 1996, on average, the remediation and spill costs were $1.171 billion, which is 12.4 percent of the total environmental expenditures. The remediation and spill costs in the API survey did not include the environmental expenditures for air, water, wastes, and other types of pollution, in exploration and production, transportation, refining, marketing, and research and development.

Table 4. Total U.S. environmental expenditures (in millions of dollars) from 1990 to 1996, as estimated by the American Petroleum Institute (API).[2]

	Exploration & Production	**Transportation**	**Refining**	**Marketing**	**Research & Development**	**Corporate Programs**	**Subtotal**	**Remediation & Spills***	**Total**
1990	1,525	666	3,710	440	175	147	6,663	1,124 (14.4%)	7,787
1991	1,553	737	4,118	646	227	121	7,402	1,332 (15.3%)	8,734
1992	1,566	966	5,808	641	214	78	9,273	1,250 (11.9%)	10,523
1993	1,563	972	5,698	742	227	246	9,448	1,198 (11.3%)	10,646
1994	1,559	872	5,933	732	175	194	9,465	1,177 (11.1%)	10,642
1995	1,322	809	5,509	508	156	141	8,445	1,169 (12.2%)	9,614
1996	1,582	1,013	3,958	432	103	187	7,276	947 (11.5%)	8,222
AVG	**1,524**	**862**	**4,962**	**592**	**182**	**159**	**7,425**	**1,171 (12.4%)**	**9,453**

*Aggregate amounts reported by participants in API's survey.

The report did not specify the origin of the remediation costs in terms of the root causes that lead to the remediation efforts; therefore, the remediation costs could not be directly related to corrosion costs. However, remediation is the term used for the clean-up of oil products and other hazardous materials that is necessary after leaking equipment is located. Leaks originate from holes and cracks in the tanks, pipes, and piping as they are formed by corrosion. Therefore, it is reasonable to assume that the environmental remediation costs are an indirect cost of corrosion. The API survey showed an estimate of these indirect annual corrosion costs as $1.171 billion per year.

Unregulated Tanks

Unregulated USTs are more difficult to quantify than the regulated tanks. There are a very large number of unregulated small USTs used for heating oil in homes, small businesses, utility backup generators, and for use on the premises in large businesses. In the March 2000 Hazardous Materials Program Evaluation (HMPE) report,[12] basic home heating oil survey data were reported, based on data provided by the Department of Energy. These data included the number of households in each category and the average cubic meters consumed annually by each household. The average delivery size (transport) and the annual number of deliveries were estimated by the Research and Special Programs Administration (RSPA) of the Office of Hazardous Materials Safety based on its understanding of home heating oil (distillate) and propane tank sizes.

The HMPE data showed that an estimated daily total of 89,420 deliveries (482,081 barrels) are made for distillate home heating oil, 56,057 deliveries (268,069 barrels) are made for liquid propane gas (LPG), and

7,712 deliveries (21,637 barrels) are made for kerosene. These estimates include single-family homes and mobile homes, and account for pick-up and delivery.

If the assumption is made that the average unregulated tank size is 1.893 m^3 (500 gal), and a tank is three-quarters filled [1.420 m^3 (375 gal)] with each delivery, the total number of unregulated tanks can be estimated as follows:

Heating oil tanks:	482,081 barrels/day x 365 days/year x 159 liters/barrel x 1 delivery / 1,420 liters x 1 tank / 6 deliveries per year = 3,283,752 tanks
LPG/propane tanks:	268,069 barrels/day x 365 days/year x 159 liters/barrel x 1 delivery / 1,420 liters x 1 tank / 6 deliveries per year = 1,825,984 tanks
Kerosene tanks:	21,637 barrels/day x 365 days/year x 159 liters/barrel x 1 delivery / 1,420 liters x 1 tank / 6 deliveries per year = 147,383 tanks

Summary of Tank Totals

The total estimated number of tanks is summarized in table 5. The regulated tanks are divided into SPCC-regulated and OUST-regulated tanks, and the numbers are based on several reports. The estimates for non-regulated tanks were determined based on the sales of various heating fuels.

Table 5. Summary of estimated total number of aboveground and underground storage tanks in the United States (see references 6, 11, 12, and 13).

	REGULATED BY	YEAR	PRODUCT	LOCATION	NUMBER OF TANKS
REGULATED TANKS	SPCC	1996	Petroleum products	ASTs	2,373,276
				USTs	133,400
	OUST	2000	Petroleum & HAZMAT	USTs	742,805
UNREGULATED TANKS	-		Heating oil	ASTs and USTs	3,283,752
			LPG/propane	mostly ASTs	1,825,984
			Kerosene	mostly ASTs	147,383
				TOTAL	**8,506,600**

Estimating Corrosion Costs

In order to estimate the total cost of corrosion for hazardous materials storage, corrosion experts Lary and Garrity[14-15] were asked to estimate the value of corrosion measures commonly taken for tanks. Table 6 summarizes these values, both for aboveground and underground tanks. Table 7 gives estimates of the purchase costs for new tanks as a comparison to the relative corrosion control costs per tank.

For aboveground storage tanks, the corrosion experts[14-15] estimated that 30 percent have cathodic protection (CP), 10 percent have internal linings, and 100 percent are externally coated. An internal lining is generally only applied for tanks that often change products, or that contain products with a large water ballast.

Table 6. Estimated corrosion control costs for aboveground and underground storage tanks.[14-15]

	CORROSION CONTROL	**COST**
ABOVEGROUND	External coating / painting	\$86 / m^2 (\$8 / ft^2)
	Internal flake glass polyester lining	\$689 / m^2 (\$64 / ft^2)
	CP for tank bottom on grade	\$15,000 for 30.5-m- (100-ft-) diameter tank
UNDERGROUND	Impressed-current CP	\$10,000 - \$12,000 / 3 tanks, inc. assessment
	Electricity for CP	\$234 / year for three tanks
	Inspection impressed-current CP	\$25 every 60 days, voltage and current reading
	Inspection impressed-current CP	\$800 / year for three tanks
	Sacrificial anode CP	\$250 / anode, design life is 20 years
	Inspection sacrificial anode CP	\$800 / 3 years, some states every year
	Internal lining	\$3,500 - \$7,000 / tank, inc. surface preparation
	Structural integrity assessment	\$2,000 - \$3,000 / three tanks in same pit
	Gain access to tanks	\$1,500 - \$2,000 / tank
	External coating	\$10.76 m^2 (1.00 / ft^2), appearance coating on new tanks, to prevent flash rusting during transport

Table 7. Comparison of capital cost for new tanks with a capacity of 37.8 m^3 (10,000 gal).[14-15]

	MATERIAL	**NEW COST PRICE**
UNDERGROUND	Fiberglass tank	\$7,500
	Steel – single-wall tank, sti-$P_3^{®}$	\$5,000 - \$6,000
	Steel – double-wall tank, sti-$P_3^{®}$	\$10,000 - \$12,000
	Glass steel tank, heavily coated	\$8,000 - \$12,000

To simplify the calculations, they indicated that gas stations generally have three grades of gasoline (regular, plus, and premium), which are stored in three separate underground tanks. In most new installations, these three tanks are equipped with a single rectifier for impressed-current CP. They noted that the percentage (85.3 percent) of gasoline service stations with CP mentioned in the 1995 SPCC survey was probably a high estimate because, in recent years, many tanks have been replaced with fiberglass tanks. The SPCC survey data reported that of all reported ASTs and USTs included in the survey, the following forms of external protection were present: 18 percent no external protection, 65 percent painted / asphalt coating, and 10 percent CP. Lary and Garrity[14-15] estimated that at gasoline service stations, the current percentage of tanks with CP is approximately 30 percent.

A concern expressed by the experts was that, in many cases, the CP design is only focused on the tanks themselves, and not on the connected piping. They indicated that future corrosion leaks are likely in the piping between the tanks and the gasoline dispensers due to this lack of attention. For comparison, the 1995 SPCC survey showed that the location of piping of ASTs and USTs was as follows: 29 percent both aboveground and underground, 43 percent aboveground, 12 percent underground, and 16 percent reported to have “no piping.” The data further showed that more than half of the piping is steel or iron, and about one-quarter is galvanized steel piping. The other piping materials used are fiberglass (FRP), copper, lead, aluminum, and a variety of plastics.

In general, tanks at gasoline service stations are USTs that are too small [< 159 m^3 (< 42,000 gal)] to be included in the SPCC survey. All piping (100 percent) of USTs at gasoline service stations is located underground. Similar to what the SPCC data showed, most piping at gasoline service stations is made of steel, iron, or galvanized steel. Galvanizing is only a temporary form of corrosion protection because the thin zinc layer is sacrificial, and after the zinc is consumed, the pipe has turned into bare, unprotected steel. A corrosion concern in the underground piping system is the presence of flexible couplings with an external stainless steel jacket. If these couplings are not isolated from the adjacent piping, galvanic corrosion may result from the more noble stainless steel at the expense of the piping. Similar concerns arise from stainless steel swing joints, fittings, and impact valves.

The SPCC data showed that the piping reported in that survey had the following forms of external protection: 35 percent painted / asphalt coating, 9 percent CP, 12 percent jacketed or wrapped, 42 percent "no protection," and 3 percent other forms of external protection.

AREAS OF MAJOR CORROSION IMPACT

Bulk storage of hazardous liquid and gaseous materials is normally done in large steel tanks. The largest aboveground tanks are used at refineries and manufacturing plants. These range from 15 m (50 ft) to more than 61 m (200 ft) in diameter and may have a capacity of more than 3,785 m^3 (1 million gal). Transportation and distribution terminals of storage facilities for these materials can have a mix of aboveground and underground tanks. Liquid petroleum products at the point of sale and at the point of use are normally stored in direct buried underground tanks ranging from 1.9 to 114 m^3 (500 to 30,000 gal) in capacity. Gases are typically stored in similarly sized aboveground tanks at the point of use. Hazardous chemicals are usually stored in vaulted underground tanks or aboveground facilities. Storage tanks for pressurized materials can be spherical in shape, while storage tanks for unpressurized materials can be constructed from welded steel plate (see figures 1a and 1b, respectively).

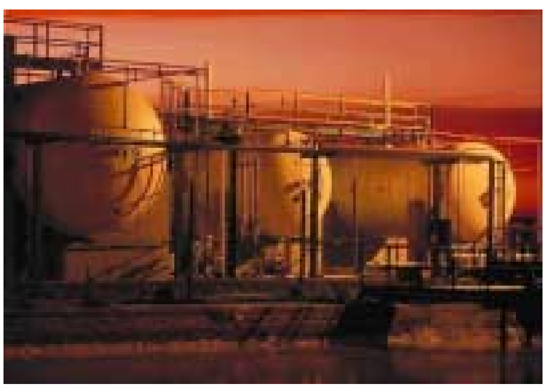


Figure 1a. Pressurized storage tanks.

Figure 1b. Unpressurized storage tank.

Aboveground Storage Tanks

Large steel aboveground storage tanks (ASTs) are generally located on large tank farms of oil producers (see figure 2). Maintenance teams take care of external painting and internal and external corrosion inspections. Corrosion protection of ASTs is important for the preservation of large capital investments, the reduction of maintenance and inspection costs, and the assurance of system integrity for release prevention. ASTs are subject to a variety of internal and external corrosion mechanisms. In his book on ASTs,[16] Myers describes the different corrosion mechanisms and causes of corrosion (see figure 3).

Figure 2. Example of an oil storage tank farm, showing multiple tanks of varying sizes.

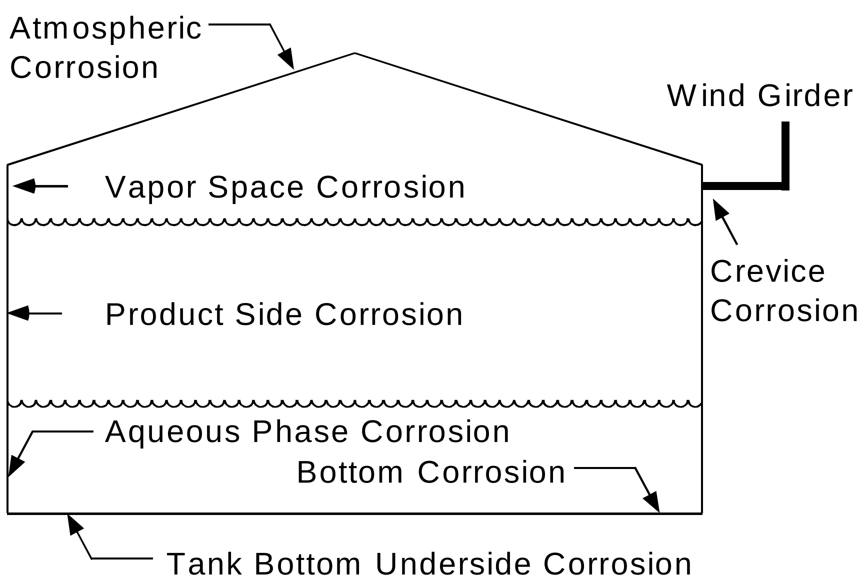


Figure 3. Internal and external corrosion modes that may occur at an aboveground storage tank.[16]

Internal Corrosion

There are several different corrosion conditions in the interior areas of an aboveground tank. Vapor phase corrosion can occur in the areas exposed to the vapor above the stored product, and includes general, crevice, and pitting corrosion, depending on the temperature and the characteristics of the material. Product side corrosion can occur on the internal wall plate when corrosive materials are stored. This type of corrosion includes general and pitting corrosion. At the interface of liquid and gas in a tank, the corrosion rate is often accelerated because the oxygen or moisture concentration gradient at the interface varies with depth into the liquid. Aqueous phase corrosion can occur when water contamination and settling in petroleum products result in a layer of water on the bottom of the tank. Although the product may be non-corrosive, the presence of contaminants such as sludges and deposits may result in internal bottom and wall general corrosion, crevice corrosion, and pitting corrosion damage. In addition, microbiologically influenced corrosion (MIC) can be a problem under anaerobic conditions. The internal corrosion problems are exacerbated by the stresses and flexing that the metal undergoes during fluctuations in product levels.

External Corrosion

Atmospheric corrosion of the external wall and the roof is a result of general corrosion and crevice corrosion damage. Aboveground tanks suffer from external corrosion as a result of the tank bottom sitting on a grade with a variety of corrosive padding materials or on a back-filled concrete ring wall. Both types of tank bottom supports can cause external pitting of the bottom plate steel. Small aboveground tanks suffer from external atmospheric corrosion, but to a lesser degree because they can be supported off the ground and the rounded surface minimizes crevice corrosion opportunities.

Underground Fuel Storage Tanks

Underground fuel storage tanks are a very large and dominant portion of the hazardous materials storage sector. Corrosion is estimated to be responsible for approximately 65 percent of tank failures, while 35 percent is due to other causes such as third-party damage.[13] Experience has shown that the vast majority of underground storage tanks (USTs) and piping failures are associated with external corrosion, while a small percentage can be attributed to internal corrosion.

One of the primary causes of external corrosion is exposure to corrosive soils. The electrical and chemical characteristics of soil and water are closely related to corrosivity. Variations in soil characteristics due to soil type, fill compaction, moisture content, bacteria, chloride concentration, etc. help establish corrosion cells. Over time, if untreated, this process can result in significant wall-thickness reduction and can cause leaks. The six o'clock position of USTs is one of the most critical locations because that is the rest point where the tank bottom touches the bottom of the hole dug for the tank. At that location, the layer of backfill is relatively thin; therefore, the soil characteristics can be different than in the adjacent soil, setting up conditions for macro-cell corrosion.

Similar to the aboveground tank phenomena, internal corrosion can occur from contaminants that settle on the tank bottom, under the stored product. Vapor phase corrosion is usually limited due to the relatively constant temperature. A particular tank failure type, which is sometimes reported for gasoline service stations, is localized internal corrosion at the location where the internal lining is damaged. The inspector’s level-stick may cause mechanical damages to the lining, resulting in corrosion. Generally, a wooden pole is used to check the gas level in the UST. Lining damage occurs at the location where the pole hits the bottom of the UST.

CORROSION CONTROL METHODS

Aboveground Storage Tanks

Corrosion of tank bottoms, walls, roofs, and roof structures can pose dangers to their structural integrity. Corrosion may cause leaks that result in loss of product or pollution of the soil and water around a tank. Leaks can also make it possible for water to penetrate into the tank and contaminate the product itself.

Corrosion control and prevention can take many forms. It may take the form of a design detail, such as the application of a corrosion allowance to sophisticated lining systems and cathodic protection devices. Myers[16] listed the most common methods of corrosion control and prevention:

- linings ("bladder") / coatings (paints),
- corrosion allowances,
- design (avoidance of dissimilar metals, galvanic couples, improper materials, high fluid velocities in inappropriate places, caulking or seal welding of areas susceptible to crevice corrosion, roof design, etc.),
- sacrificial anodic systems,
- impressed-current cathodic protection, and
- use of high-alloy (corrosion-resistant) materials.

Tanks designed for materials that produce corrosive vapors often include roof and roof support structures (pontoons for floating roofs) that are made of corrosion-resistant materials. Petroleum tanks that are subject to a contaminated water layer are internally coated and cathodically protected on the bottom and partially along the wall. The external bottom corrosion of site-fabricated tanks (most tanks more than 4 m in diameter) can be controlled with a combination of select sand/concrete foundation pads, impervious liners, and cathodic protection. A list of corrosion control methods for aboveground storage tanks, as described by Myers,[16] is given in table 8.

Table 8. Corrosion control methods for aboveground storage tanks, based on Myers.[16]

CORROSION TYPE	CONTROL METHOD
UNIFORM CORROSION	Inhibitors Protective coating Cathodic protection
INTERGRANULAR CORROSION	Avoiding temperatures that can cause contaminant precipitation during heat treatment or welding
PITTING CORROSION	Protective coating Allowing for corrosion in wall thickness
STRESS CORROSION CRACKING	Reducing residual or applied stresses Redistributing stresses Avoiding misalignment of sections joined by bolts, rivets, or welds Use of materials of similar expansion coefficients in one structure Protective coating Cathodic protection
CORROSION FATIGUE	Minimizing cyclic stresses and vibrations Reinforcing critical areas Redistributing stresses Avoiding rapid changes in load, temperature, or pressure Inducing compressive stresses through peening, swagging, rolling, vapor blasting, chain tumbling, etc.

Table 8. Corrosion control methods for aboveground storage tanks, based on Myers[16] (continued).

CORROSION TYPE	CONTROL METHOD
GALVANIC CORROSION	Avoiding galvanic couples Completely insulating dissimilar metals (paint alone is insufficient) Using filler rods of same chemical composition as metal surface during welding Avoiding unfavorable area relationships Using favorable area relationships Cathodic protection Inhibitors
THERMOGALVANIC CORROSION	Avoiding non-uniform heating and cooling Maintaining uniform coating or insulation thickness
CREVICE CORROSION; CONCENTRATION CELLS	Minimizing sharp corners and other stagnant areas Minimizing crevices, especially in heat transfer areas and in aqueous environments containing inorganic solutions or dissolved oxygen Enveloping or sealing crevices Protective coating Removing dirt and mill scale during cleaning and surface preparation
EROSION; IMPINGEMENT ATTACK	Decreasing fluid stream velocity to approach laminar flow Minimizing abrupt changes in flow direction Streamlining flow where possible Installing replaceable impingement plates at critical points in flow lines Filters and steam traps to remove suspended solids and water vapor Protective coating Cathodic protection
CAVITATION DAMAGE	Maintaining pressure above liquid vapor pressure Minimizing hydrodynamic pressure differences Protective coating Cathodic protection Injecting or generating larger bubbles
FRETTING CORROSION	Installing barriers that allow for slip between metals Increasing load to stop motion, but not above load capacity Porous protective coating Lubricant
HYDROGEN EMBRITTLEMENT	Low-hydrogen welding electrodes Avoiding incorrect pickling, surface preparation, and treatment methods Inducing compressive stresses Baking metal at 93 to 148 °C (200 to 300 °F) to remove hydrogen Impervious coating such as rubber or plastic
STRAY-CURRENT CORROSION	Providing good lubrication on electric cables and components Grounding exposed components or electrical equipment Draining off stray currents with another conducting material Electrically bonding metallic structures Cathodic protection
DIFFERENT-ENVIRONMENT CELLS	Underlaying and backfilling underground pipelines and tanks with the same material Avoiding partially buried structures Protective coating Cathodic protection

Internal Coatings

Internal coatings protect the structural integrity of the tank by preventing internal corrosion. These coatings generally have a design life of 10 years or more for larger tanks. A coating system is selected based on the location within the tank: bottom, water layer, product exposed, vapor space, and roof structure. In addition, coatings are sometimes used to maintain product purity. Often, the internal bottom surface must be able to withstand the abrasive effects of slurry movement caused by internal flow patterns, mixers, or inlet and outlet flows, or by mechanical actions, such as by the movement of roof drain hoses lying on the tank bottom. A benefit of a bottom liner is that it reduces the cleaning effort when the tank is removed from service for repairs or for inspection.

External Coatings

Painting the exposed external surfaces of an aboveground storage tank provides corrosion protection, improved appearance, and reduced evaporation loss. Selection of the coating type depends on the tank operating temperature and the presence of insulation that contains minerals and salts that may cause corrosion. External coatings must be able to withstand the effects of weather, ultraviolet light, and industrial or marine atmospheres.

Cathodic Protection on ASTs

Aboveground storage tank (AST) farms have a network of CP rectifiers and anodes to protect the tank bottoms. The design of cathodic protection (CP) for new or existing ASTs can be done according to the API Recommended Practice for Cathodic Protection of Aboveground Storage Tanks.[(17)] Design considerations include the proximity to other metallic structures and existing CP systems, the type of grounding, the estimated remaining service life of the tank, the type and temperature of the stored product, the amount of product stored, the cycling rates, the method of tank bottom plate construction, the type of tank foundation, the type of secondary containment, if any, and the backfill soil characteristics. There are two types of CP: (1) sacrificial anode CP, by zinc or magnesium ribbon or ingot anodes, and (2) impressed-current CP, using perimeter, deep-buried, angle-drilled anodes or vertical, loop, or string under-tank anodes. Depending on the above parameters, the CP type, and the diameter of the tank, CP installation costs for an AST tank bottom may range from $10,000 to $25,000 per tank. Based on recent quotes, $15,000 would be considered average.

Underground Storage Tanks

Corrosion control of the external surfaces of underground storage tanks[2] can be achieved with a combination of cathodic protection and dielectric coating. However, an external coating must be applied when the tank is new. A buried tank cannot be retrofitted with an external coating unless it is removed from the ground. Internal corrosion protection, where required due to contamination or corrosive products, is commonly maintained with an internal liner, sometimes in combination with galvanic cathodic protection.

Cathodic Protection on USTs

CP is based on the reversal of the electrochemical current that occurs in the corrosion process. Two systems of CP are used: (1) sacrificial anode systems and (2) impressed-current systems.

The first system is based on the burial of anodes in the electrical proximity of the tank. The anodes are generally made of magnesium or aluminum, both of which are metals less noble than the steel of the tank. This forces the current to flow from the sacrificial anode (Al or Mg) to the cathode (tank). Over time, the anodes are consumed and must be replaced for continued corrosion protection of the tank.

[2] Federal regulations define an underground storage tank as a tank system having a volume at least 10 percent of the system underground.

The second system is based on the application of an impressed current that is forced through anodes to the protected structure (the tank) by a current source of sufficient potential. Properly designed CP systems that are well-maintained and operate at the correct current density are a proven method of protecting tanks from the corrosive effects of contact with corrosive soils. In addition to protection of underground tanks, CP is also useful for aboveground double-bottom tanks and for internal corrosion protection.

CORROSION MANAGEMENT

The optimum corrosion methods for ASTs and USTs depend on the materials stored and on the exposure of the tanks to corrosive environments. Most tanks are constructed using welded steel, which must be protected from internal corrosion due to the tank content and from external corrosion due to exposure to moisture-rich environments such as soils or the atmosphere. This can be addressed with internal linings, external coatings, and cathodic protection. If designed, installed, and maintained properly, the life of a tank can be almost indefinite. However, tanks may experience unforeseen problems such as damaged coatings or long intervals between CP inspections.

Larger companies have corrosion experts as part of their staff and usually maintain schedules for regular inspection and maintenance. In recent years, however, the process industry, and particularly the oil and gas industry, has continuously and purposely decreased their research centers that had the necessary level of awareness and expertise. Currently, larger companies tend to outsource this type of work to contractors that work at a cheaper price. Although not proven, in the long run, this procedure may prove to be more costly as corrosion defects may go undetected for longer periods of time.

The incentives for better corrosion management are clear: improved structural integrity, fewer leaks to soil or water, and a decreased probability of moisture being introduced into the product. In general, new tank construction has some forms of corrosion design built in. The sti-$P_3^{®}$ tanks, polymer tanks, fiberglass tanks, and externally painted tanks are just a few examples. However, these tanks age and will need continued maintenance and inspection. Older tanks may not have these corrosion control systems, or the systems may be ineffective.

In recent years, the federal government has given a lot of attention to the environmental impact of leaking ASTs and USTs. The EPA Spill Prevention Countermeasure and Control (SPCC) plan and the EPA Office of Underground Storage Tanks (OUST) maintain databases on the number of active tanks. The remediation and spill costs for cleaning soil and water around leaking tanks can be significant. For example, according to the 1998 API report, these indirect corrosion costs were estimated in table 4 at $1.171 billion per year and are attributed to leaks caused by corrosion.

For this sector, three case studies were performed to estimate the total cost of corrosion for different types of tanks. The numbers are summarized in tables 9 and 10. The direct corrosion costs ($2.5 + $4.5 = $7.0 billion per year) are paid by the commercial owners of the tanks because they benefit from the structural integrity and long service lives of the tanks. The federal government regulates those tanks that have a potential environmental impact in an effort to recover the indirect costs of remediation and spills. The API report shows that this recovery method results in an annual spending of $1.171 billion by the oil industry.

Table 9. Corrosion costs for USTs at gas stations.(2,14-15)

WHICH TANKS	CORROSION ITEM	CORROSION COST ($ x million / year)	REFERENCE
USTs at gasoline service stations	Sacrificial CP	52	Case study 2 [Refs. 14-15]
	Impressed-current CP	137	
	Internal linings	79	
	Remediation and spill costs	1,171	1998 API report [Ref. 2]
	TOTAL	**$1,439**	

Table 10. Summary of corrosion costs divided by tank location and corrosion control method.(14-15,18)

WHICH TANKS	CORROSION ITEM	CORROSION COST ($ x million / year)	REFERENCE
All USTs	**TOTAL**	**$2,458**	Case study 1, EPA website [Ref. 18]
All ASTs	Tank bottom CP	1,231	Case study 3 [Refs. 14-15]
	Internal linings	472	
	External coatings	2,803	
	TOTAL	**$4,506**	

The sti-P$_3$® System

The Steel Tank Institute (STI) developed a specification for underground steel storage tanks, the so-called the sti-P$_3$® system.(19) This now popular specification was first developed in 1969 for STI by leaders in the field of corrosion engineering. It covers an external corrosion control system (termed sti-P$_3$®) for underground steel storage tanks. The system is a practical and economical means of extending the service life of underground tanks from a minimum of 30 years in corrosive soil conditions to an indefinite term in less severe environments. The design includes a safety factor that will allow for somewhat more than ordinary damage to the external coating of the tank from shipping and handling and other accidental coating holidays.

Traditionally, steel tanks used for underground storage of petroleum products have been protected with an inexpensive coating to prevent corrosion of the tank during storage of the tank aboveground and after installation underground. This practice has been adequate in some soils, but has invariably been unsatisfactory in corrosive soils. Previously, the known methods of applying stringent corrosion control to tanks were not feasible because they required handling by experienced corrosion personnel.

The sti-P$_3$® method of corrosion protection overcomes these problems and still retains all the advantages of a steel tank with its structural strength. The sti-P$_3$® system combines three basic methods of underground corrosion control, all of which are installed on the tanks during manufacture: (1) cathodic protection, (2) protective coating, and (3) electrical isolation of the tank from other underground metallic structures by use of non-conductive bushings or similar methods that isolate the tank electrically from the piping.

The salient feature of the design is that it is pre-engineered and is provided by the tank fabricator as an integral part of the tank. This aspect eliminates costly on-site engineering, misunderstood installation requirements, and concern over the effectiveness of the corrosion control used. Furthermore, the sti-$P_3^{®}$ system turns itself on after the tank has been buried and provides cathodic protection for a minimum pre-determined length of time in a given soil.

The methods employed by the sti-$P_3^{®}$ system to prevent exterior corrosion were developed by corrosion engineers and have been successfully used on pipelines and other underground structures for more than 50 years. Although the basic methods are quite different in their way of protecting steel underground, they are related and must be used in combination with each other to achieve complete protection. For example, protective coating should not be used alone because, in practice, no coating will be free of holidays. Some corrosion engineers submit that coating alone is approximately 75 percent effective against corrosion, whereas coating supplemented with cathodic protection results in a combined effectiveness that approaches 100 percent corrosion control.

The only practical approach to a pre-engineered CP system for this application is using sacrificial anodes attached to the tank in a manner similar to that employed for ship hull protection. The protective coating serves to reduce the amount of protective current needed for cathodic protection. Electrical isolation bushings or flange isolators are installed in each tank opening to prevent contact between the tank and other nearby metal structures, and to reduce the chance of stray current corrosion or excessive CP current demand.

Galvanic anodes develop their own protective current because of the natural potential difference between the anode metal and the metal being protected. This means that the anode system is self-activated after the tank is buried and that the CP current will continue to provide corrosion control until the anode is consumed by corrosion. Based on the estimate of the average current produced by the anodes in a given soil, the useful life of the anode system can be readily calculated.

Polymer Tanks

Polymer tanks are commonly used when people do not want to deal with the maintenance issue. The philosophy is to start from scratch with a corrosion-resistant material and to prevent corrosion altogether. The use of polymer tanks is an option if the stored quantity is less than 5.7 m^3 (15,000 gal). The tanks can then be constructed of molded polymers or fiber-reinforced thermoset polymers. High-density polyethylene (HDPE) is commonly used for chemical storage tanks and for chemicals that contain water. However, HDPE is not applicable for the storage of hydrocarbons or for long-term storage at temperatures higher than 50 ^oC. In this case, or if higher temperatures (50 to 200 ^oC) are a problem, fiberglass reinforced tanks made with resins, such as vinyl ester or epoxy, can be used. For more elevated temperatures (> 200 ^oC), metal storage tanks are the only solution.

Polymer storage tanks may be susceptible to forms of material degradation such as cracking and pinholes; therefore, they should be inspected regularly. Many fiberglass tanks that were produced in the early 1980s are not compatible with additive substances such as methanol or ethanol. Today, these liquids are commonly blended into gasoline and, therefore, many service stations are removing their fiberglass tanks to replace them with tanks constructed of corrosion-resistant materials.

CHANGES FROM 1975 TO 2000

In the last 25 years, the federal government has developed more and more regulations for HAZMAT storage. Rules that served as a foundation for current regulations include the Clean Water Act;[(9)] the Resource Conservation and Recovery Act;[(4)] the Comprehensive Environmental Response, Compensation, and Liability Act;[(3)] and the Oil Spill Pollution Act.[(10)]

After initial periods of survey studies, task force recommendations, and interim regulations, many of the ideas have matured into the current code of federal regulations. Examples are the regulations for USTs in 40 CFR 280,[(6)] the regulations for spill prevention countermeasures and control in 40 CFR 112,[(8)] and the regulations for transportation of hazardous liquids by pipeline in 49 CFR 195.[(7)]

In interviews with people from the HAZMAT storage industry, the opinion was expressed that the federal government is likely to expand from an exploratory function to a more strict enforcement function. Voluntary surveys, such as the 1995 SPCC survey, are expected to be replaced with mandatory questionnaires and inspection intervals appropriate to high-consequence areas. This predicted trend for tanks is already visible in efforts in the transmission pipeline industry, where risk-based assessment is based on failure probability and the location of pipelines in high-consequence areas.

The changes in regulations towards HAZMAT storage are mostly related to their environmental impact in case of an unplanned release. Schenke(20) reviewed these changes in a recent presentation. The EPA's oil pollution prevention regulation 40 CFR 112,(8) otherwise known as the Spill Prevention Countermeasure and Control (SPCC) regulation, applies to non-transportation-related facilities that have oil storage capacities above certain thresholds and are located such that a release could reasonably be expected to reach U.S. waters. The EPA estimated in 1996 that there were approximately 435,000 SPCC-regulated facilities.

In recent years, analyses of the causes and responses to large oil spills and other events have demonstrated the need to revise the regulation addressing the storage, transportation, and handling of oil and petroleum products, including the SPCC regulation that requires preparation and implementation of SPCC plans.

On January 2, 1988, the collapse of a 15,120-m^3 (4-million gal) aboveground storage tank owned by Ashland Oil Company resulted in a spill of approximately 2,839 m^3 (750,000 gal) of diesel fuel into the Monongahela River. Approximately 11,356 m^3 (3 million gal) of the diesel fuel, however, was contained in a secondary containment dike required by the existing SPCC regulation. This spill led to the formation of an interagency SPCC task force to review federal regulations governing oil spills from aboveground storage tanks and to recommend actions to improve the program.

In 1996, the EPA published the results of the 1995 Spill Prevention Countermeasure and Control (SPCC) plan survey. The data from this survey indicated that when a facility replaces a UST, the trend is toward replacing USTs with ASTs. In the 2 years before the survey, approximately 8 percent (5,062) of the SPCC-surveyed facilities replaced a total of 27,462 USTs with 17,195 new tanks, of which 56 percent were ASTs and 44 percent were USTs. The analysis also indicates that fewer tanks are being used to replace USTs. There are two possible explanations for this occurrence. If the amount of oil stored is unchanged, the majority of USTs are being replaced with ASTs of greater storage capacity. Another explanation is that the amount of oil stored has decreased and the USTs that were removed were not replaced.

For the period 1996 to 2000, the data from the EPA Office of Underground Storage Tanks showed this trend as well, in the form of the number of closed tanks per year (see table 8). In the last 5 years, the rate of closing USTs has been, on average, 93,000 USTs per year.

CASE STUDIES

Case Study 1. How Much Does It Cost to Upgrade, Replace, or Close UST Systems?

The information in this case study was taken from the website of the U.S. EPA Office of Underground Storage Tanks.(18) On this website, the EPA supplies "cost estimates" to upgrade USTs. All "cost estimates" are educated guesses. First, it is noted that cost estimates vary significantly depending on the circumstances of the specific UST site. Some of the controlling factors include:

- the nature of the surrounding soil and structures,
- labor costs (rural vs. urban, regional variations),
- length of downtime (installation may last several days),

- amount of labor required (especially time to break through existing site "covering pads"),
- reductions based on having work done at the same time (for example, having spill, overfill, and corrosion protection all installed at the same time), and
- differences between vendors, and inflation over time (these estimates reflect costs in early 1998).

Cost Estimates to Upgrade USTs

Table 11 shows cost estimates for upgrading USTs, as estimated by the EPA. For example, a cost estimate for a three-tank upgrade using spill buckets, butterfly valves, and impressed current alone would be approximately $12,700. With additional retrofits of an automatic overfill system, float valves, and internal linings, the total cost as illustrated in table 11 is $33,000.

Table 11. Approximate costs to add spill, overfill, and corrosion protection, based on a three-tank facility, labor costs, and 24 hours or less of downtime, as reported by EPA.[18]

COST	EQUIPMENT / LABOR
$1,200	3 Spill buckets
$1,500	3 Automatic shutoff (butterfly) devices
$5,000	Automatic overfill alarm (includes 3 probes and 1 automatic tank gauging system)
$300	3 Ball float valves
$15,000	Interior lining of 3 tanks (more than 24 hours downtime)
$10,000	Impressed-current system, including an assessment for three tanks (assuming no interfering structures)
$33,000	**TOTAL**

Cost Estimates to Replace USTs

Replacing an existing three-tank facility (gasoline service station) with three new USTs and piping would cost approximately $80,000 to $100,000 (includes closing the existing USTs and putting in new USTs), assuming that no cleanup is necessary. Replacement would also involve about 2 to 3 weeks of downtime.

Cost Estimates to Close USTs

Temporarily closing a UST involves no more expense than the costs for the required corrosion monitoring. If a UST is closed for more than 3 months, then the capping of all lines is required, except the vent lines. Closing USTs permanently, however, requires emptying and cleaning the tank, and either removing the UST or leaving it in place filled with an inert solid, all of which would cost approximately $5,000 to $11,000 (not including site assessments or cleanup).

Costs of Not Upgrading, Replacing, or Closing Substandard USTs

After the December 22, 1998 deadline, owners and operators of substandard UST systems who continue to operate their systems that are not in-compliance risk fines of up to $11,000 per day per violation. Owners and operators may also face potential soil and groundwater clean-up costs (which can exceed $1 million), financial liability for third-party damages, and legal fees.

Underground Storage Tanks – Total Cost of Corrosion

The EPA, through OUST, provides corrosion cost and spill clean-up information. The information posted on the EPA OUST website(18) indicated that the cost for upgrading USTs averages $2,700 for overspill protection ($400 for spill bucket + $500 for shut-off valve + $1700 for shut-off alarm + $100 for float valve) and $3,400 ($10,000 / 3 tanks) for impressed-current cathodic protection (CP) per tank. The average cost to permanently close a tank is $8,000 and the average cost of clean-up, when groundwater is contaminated (approximately one-half of the releases), is $125,000.

If these estimates are applied to the average annual change between 1996 and 2000, the annual cost of corrosion from regulated USTs can be calculated based on the information in table 3 as follows:

Installing impressed-current CP:	87,553 tanks/year x $3,400/UST	= $298 million/year
Closings:	93,569 tanks/year x $8,000/UST	= $749 million/year
Contamination cleanup:	22,578 tanks/year x 0.5 x $125,000/UST	= $1,411 million/year
	Average for 1996 to 2000	= $2,458 million/year

Based on the data reported for the first half of 2000, the estimated cumulative corrosion costs since the program began in 1988 can be calculated based on the information in table 3 as follows:

Installing impressed-current CP:	742,805 tanks x $3,400/UST	= $ 2.5 billion
Closings:	1,417,711 tanks x $8,000/UST	= $11.3 billion
Contamination clean-up:	405,030 tanks x 0.5 x $125,000/UST	= $25.3 billion
	Total since 1988	= $39.1 billion/program

Case Study 2. Annual Cost of Corrosion Protection for Three USTs at a Gas Station

The objectives of this case study are to estimate the average annual corrosion costs for a typical gas station and to estimate the total national corrosion costs for all gas stations combined. Gas stations generally have three grades of gasoline, which are stored in three separate underground tanks with a typical size of 37.8 m^3 (10,000 gal). According to the December 22, 1998 deadline, all installations of the underground tanks at gas stations have to be in compliance with the SPCC regulations. In the current project, estimates were made for the types of corrosion protection on underground tanks at gas stations. Most steel tanks (90 percent) have some form of CP, either sacrificial (estimated 60 percent) or impressed current (estimated 30 percent), while a small portion (10 percent) have an internal lining, and less than 1 percent have both modes of protection. These estimates assume that all USTs (100 percent) have some form of corrosion protection as required by the December 22, 1998 deadline under the SPCC regulations.

The corrosion protection estimates are consistent with the data reported in a 1997 API survey published in 1998.(2) In that API survey, the 14 participating companies reported that at the end of July 1997, 83 percent of their 19,000 gasoline service station facilities with almost 74,000 tanks (average 3.9 USTs per station) met the 1998 corrosion protection standards for USTs and associated piping. API reported that its members operate more than 35,000 gasoline service stations, approximately 20 percent of the U.S. total. This brings the national total to 175,000 gasoline service stations, which when multiplied by 3.9 (average number per station) results in a total of 682,500 USTs.

The number of large [> 159 m^3 (> 42,000 gal)] underground storage tanks can be estimated from the 1995 SPCC survey data, in which 12,996 facilities were designated as gasoline service stations meeting the criteria under the SPCC regulations, with a total of 84,474 tanks (see table 2). The number of smaller [0.416 to 159 m^3 (110 to

42,000 gal)] underground storage tanks can be estimated from the "1st Half of Fiscal Year 2000" data from EPA OUST as a total of 742,805 tanks (see table 3).

If it is assumed that all these tanks are located at gas stations, they are grouped as three per station, all tanks under the SPCC and OUST regulations are made of steel, 60 percent have sacrificial CP and 30 percent have impressed-current CP, and 10 percent have an internal lining, the following numbers would result, based on the information in table 3:

Total USTs:	742,805 + 84,474	=	827,279	tanks
Total gas stations:	827,279 / 3	=	275,760	gas stations
Stations with sacrificial CP:	275,760 x 60%	=	165,456	stations
Stations with impressed-current CP:	275,760 x 30%	=	82,728	stations
USTs with internal lining:	827,279 x 10%	=	82,728	tanks

New Installations – Cost of Sacrificial Anode CP

New installations are currently made using fiberglass tanks or steel tanks (sti-$P_3^{®}$ tanks). The sti-$P_3^{®}$ system combines three basic methods of underground corrosion control (all of which are installed on the tanks during manufacture): (1) cathodic protection, (2) protective coating, and (3) electrical isolation of the tank from other underground metallic structures by use of non-conductive bushings or similar methods that isolate the tank electrically from the piping. The CP system on sti-$P_3^{®}$ tanks is included by the manufacturer in the form of attached sacrificial anodes (two per tank at $250 each with a design life of 30 years). In most states, sacrificial anodes must be inspected once every 3 years, while in some states, this inspection is conducted once every year. The cost of the actual inspection is estimated at $800. All new tanks include a test station, making it possible to inspect them from the top of the tank without digging up the anodes. For older tanks and tanks that do not have a test station attached to them (estimated 20 percent), a one-time cost for gaining access to anodes connected to the tank and installing a test station is estimated at $2,500. This large cost is because the tanks are buried and the tanks are generally located under the concrete or asphalt pavement of the gas station. If the one-time installation costs are not included, the annual costs are estimated as follows:

$$6 \times \$250 / 30 \text{ years} + \$800 / 3 \text{ years} = \$317 / \text{year}$$

Nationally, the annual corrosion cost estimate is 165,456 stations with sacrificial CP x $317 per year = $52 million per year.

Old Installations – Cost of Impressed-Current CP

Older installations of the three tanks at gas stations can be equipped with a single rectifier for impressed current CP. Corrosion experts Lary and Garrity[14-15] were interviewed for the current project, and they estimated that, at gasoline service stations, the current (year 2000) percentage of tanks with impressed current CP is approximately 30 percent. The cost of electricity to operate the impressed-current system is calculated from the potential and current output, efficiency, and electricity costs (see table 12). After the initial costs of a new installation, the impressed-current CP system must be inspected annually by a corrosion expert. In addition, every 60 days, the current and potential readings must be taken from the rectifier. This last type of checking is generally done by a clerk working at the gas station. These values of installation and inspection are given in table 13. It is noted that these costs are minimum costs because they assume that the system operates well and that no additional maintenance is required. Table 14 combines the previous values to calculate a total annual corrosion cost.

Table 12. Calculation of annual cost for impressed-current CP for three underground tanks in the same pit. CP runs at 60 percent efficiency: power consumption is 1 / 0.60 = 1.67 times as much.[15]

Volts	20
Amps	10
Efficiency	60%
kW	0.333
$/ kWh	$0.08
$/ hour	$0.027
$/ day	$0.64
$/ month	$19.84
$/ year	$233.60

Table 13. Cost of installation and maintenance for impressed-current CP for three underground tanks in the same pit, as estimated by Lary and Garrity.[14-15]

INSTALLATION OF IMPRESSED-CURRENT CP	
$12,000	For three tanks, excl. assessment, design life 30 years
$2,000	Structural integrity assessment, for new construction of three tanks (one time for 30 years)
$467	Depreciation per year, average
BIMONTHLY INSPECTION IMPRESSED-CURRENT CP	
$25	Every 60 days, voltage and current reading
$150	Per year
ANNUAL INSPECTION IMPRESSED-CURRENT CP	
$800	Every year for three tanks, complete review

Table 14. Estimated total annual cost for impressed-current CP for three underground tanks in the same pit.

CORROSION ITEM	**COST PER YEAR**
Depreciation of UST CP	$467.00
Electric power	$233.60
Bimonthly inspection of impressed-current CP	$150.00
Annual inspection of impressed-current CP	$800.00
TOTAL	**$1,650.60**

Nationally, the annual corrosion cost estimate is as follows: 82,728 stations with impressed-current CP x $1,650.60 per year = $137 million per year.

Cost of Internal Lining of USTs

The cost of applying an internal lining in a UST is estimated at \$86 / m^2 (\$8 / ft^2). The size for a 37.8-m^3 (approximately 10,000-gal) tank can be approximated as follows: 2.5 m diameter x 7.6 m length. The internal surface for this tank is: (2 x 3.14 x $(2.5\ m)^2$ / 4) + (3.14 x 2.5 m x 7.6 m) = 69.5 m^2. This would bring the installation cost per tank to: 69.5 m^2 x \$86 = \$5,977 / tank. Similar estimates (\$5,000 to \$8,000) were made by Lary and Garrity[(14-15)] and by the EPA (\$15,000 /3 tanks) (see table 11).

Internal linings can last a long time, presumably more than 30 years. However, according to the SPCC regulations, internal linings require inspection after the initial 10 years and then every 5 years following that. This visual inspection requires a person to physically enter the empty underground tank. The estimated cost per inspection is \$2,500. Similar to the problem of gaining access to the underground sacrificial anodes, there is a problem with access to the manhole at the tank's 12 o'clock position. The cost of gaining access to the underground manhole of the tank is estimated at \$2,000. This cost is because the tanks are buried are generally located under the concrete or asphalt pavement of the gas station; therefore, in the initial 30 years of the internal lining, a total of five inspections are required at a cost of 5 x (\$2,500 + \$2,000) = \$22,500.

Nationally, for underground storage tanks with internal linings, the annual corrosion cost estimate is 82,728 tanks x (\$5,977 + \$22,500) / 30 years) = \$79 million / year.

In summary, the national annual total corrosion costs for underground tanks at gas stations is approximately \$268 million divided as follows:

60 percent USTs with sacrificial CP:	\$52 million / year	Average: \$317 / tank / year
30 percent USTs with impressed-current CP:	\$137 million / year	Average: \$1,656 / tank / year
10 percent USTs with internal linings:	\$79 million / year	Average: \$950 / tank / year

Case Study 3. Annual Cost of Corrosion Protection for ASTs

Corrosion experts Lary and Garrity[(14-15)] estimated that, from all aboveground storage tanks, 30 percent have CP on their tank bottom, 10 percent have internal linings, and 100 percent are externally coated (painted). Only the internal linings value is consistent with the 12 percent weighted average calculated from the 1995 SPCC survey data (see table 3). The values for CP and external linings are not consistent with the SPCC data of 80.8 percent and 16.5 percent, respectively. The apparent discrepancy comes from the fact that the SPCC data includes many sizes of ASTs and the largest USTs. For the following calculations, the percentages estimated by the experts are used rather than the derived SPCC values.

The 1995 SPCC survey data further showed that an estimated total of 2,468,239 aboveground and underground tanks are regulated under that program (see table 2). Table 5 shows that, of this number, approximately 95 percent are ASTs (EPA estimate = 2,373,276 tanks) and 5 percent are USTs (133,400 tanks). This is consistent with the earlier observation that SPCC-regulated USTs are mostly located at gasoline service stations, which in 1995 ccounted for an estimated 84,474 tanks.

If it is assumed that all ASTs are regulated under the SPCC, all these tanks are made of steel and are externally coated, 30 percent have impressed-current CP, and 10 percent have an internal lining, the following numbers would result, based on the information in table 2 and table 5:

Total ASTs:	2,468,239 - 133,400	=	2,334,839 tanks
ASTs with CP on tank bottoms:	2,334,839 x 30%	=	700,452 tanks
ASTs with internal linings:	2,334,839 x 10%	=	233,484 tanks
ASTs with external coatings:	2,334,839 x 100%	=	2,334,839 tanks

Cost of Impressed-Current CP on Tank Bottoms of ASTs

The cost of installing CP on the tank bottom is estimated at $15,000 for an AST of 30.5 m (100 ft) diameter (see table 6). In the current calculation, a design life for a tank bottom CP is approximately 30 years. It is also assumed that a single rectifier protecting one tank bottom runs at approximately the same output current and potential as a rectifier used for a gasoline service station with three tanks. The cost of electricity to operate the impressed-current system is calculated from the potential and current output, efficiency, and electricity costs (see table 15). After the initial cost of a new installation, the impressed-current CP system must be inspected annually by a corrosion expert. In addition, every 60 days, the current and potential readings must be taken from the rectifier. These values of installation and inspection are given in table 16. It is noted that these costs are minimum costs because they assume that the system operates well and that no additional maintenance is required. Table 17 combines the previous values to calculate a total annual corrosion cost.

Table 15. Calculation of annual cost for impressed-current CP for one 30.5-m- (100-ft-) diameter aboveground storage tank bottom. CP runs at 60 percent efficiency: power consumption is 1 / 0.60 = 1.67 times as much.(15)

Volts	20
Amps	10
Efficiency	60%
kW	0.333
$/ kWh	$0.08
$/ hour	$0.027
$/ day	$0.64
$/ month	$19.84
$/ year	$233.60

Table 16. Cost of installation and maintenance for an AST tank bottom CP, as estimated by Lary and Garrity.(14-15)

INSTALLATION OF IMPRESSED-CURRENT CP	
$15,000	For one 30.5-m- (100-ft-) diameter tank, excl. assessment, design life 30 years
$2,000	Structural integrity assessment, for new construction of one AST
$567	Depreciation per year, average
BIMONTHLY INSPECTION IMPRESSED-CURRENT CP	
$25	Every 60 days, voltage and current reading
$150	Per year
ANNUAL INSPECTION IMPRESSED-CURRENT CP	
$800	Every year for each tank, complete review

Table 17. Estimated total annual cost for impressed-current CP for a single AST tank bottom.

CORROSION ITEM	COST PER YEAR
Depreciation of AST CP	$567.00
Electric power	$233.60
Bimonthly inspection of impressed-current CP	$150.00
Annual inspection of impressed-current CP	$800.00
TOTAL	**$1,750.60**

Nationally, the annual corrosion cost estimate is as follows: 700,452 tanks x $1,750 / year = $1.226 billion / year.

Cost of Internal Linings of ASTs

Calculating the internal lining costs of ASTs is similar to calculating the internal lining costs for USTs done in the previous case study. For simplicity, it is assumed that all tanks have a volume of 37.8 m^3 (10,000 gal) and the cost of downtime is assumed to be zero.

The cost of applying an internal flake glass polyester lining is estimated at $689 / m^2 ($64 / ft^2) and the cost of applying an external coating is estimated at $86 / m^2 ($8 / ft^2) (see table 7). The internal surface for a 2.5-m-diameter, 7.6-m-long tank [37.8 m^3 (10,000 gal)] is 69.5 m^2. This would bring the internal lining installation cost per tank to 69.5 m^2 x $689 = $47,891 / tank.

Internal linings can last a long time, presumably more than 30 years. However, according to SPCC regulations, internal linings require inspection after the initial 10 years and then every five years following that. This visual inspection requires a person to physically enter the empty tank, at an estimated cost of $2,500 per inspection. Access to aboveground tanks is generally no problem; however, the tank must be empty. Therefore, in the initial 30-year period for the internal lining, a total of five inspections are required at a cost of 5 x $2,500 = $12,500.

Nationally, for tanks with internal linings, the annual corrosion cost estimate is 233,484 tanks x ($47,891 + $12,500) / 30 years) = $470 million per year.

Cost of External Coatings on ASTs

Calculating the external coating costs of ASTs is similar to calculating the internal lining costs for USTs and ASTs in the previous and the current case study.

The cost of applying an external coating is estimated at $86 m^2 ($8 / ft^2) (see table 6). The external surface for a 2.5-m-diameter, 7.6-m-long tank [37.8 m^3 (approximately 10,000 gal)] is 69.5 m^2. This would bring the external coating installation costs per tank to: 69.5 m^2 x $86 = $5,977 per tank. It is estimated that ASTs must be painted an average of once every 5 years.

Nationally, for tanks with external coatings, the annual corrosion cost estimate is 2,334,839 tanks x $5,977 per tank = $2.791 billion per year.

In summary, the national annual total corrosion cost for aboveground tanks is approximately $4.5 billion, as reported earlier in table 10 and as shown below:

30 percent ASTs with tank bottom CP:	$1,226 million / year	Average: $1,750 / tank / year
10 percent ASTs with internal linings:	$ 470 million / year	Average: $2,013 / tank / year
100 percent ASTs with external coatings:	$2,791 million / year	Average: $1,195 / tank / year

To put these average corrosion costs per tank in perspective, the inspection costs for AST tank bottoms, according to API Standard 653 "Tank Inspection, Repair, Alteration, and Reconstruction,"[21] are estimated at $30,000 to $50,000 per inspection. The cost for total replacement of one tank bottom is estimated at $200,000 to $500,000. The cost to build one 30.5-m- (100-ft-) diameter AST is estimated at several million dollars.

Case Study 4. Comparison of USTs Versus ASTs

The Steel Tank Institute (STI) compares USTs with ASTs on their website.[22] The comparison is made from the viewpoint of EPA regulations. Table 18 is a copy of the information on the STI website, without comments. The objective of including this information in the current report is to provide a direct comparison of the two types of tank regulations described in the chapter titled "Sector Description".

Table 18. Steel Tank Institute comparison of USTs versus ASTs.

UST (40 CFR 280)	**AST (40 CFR 112, SPCC)** **Based on SPCC Phase I proposed rules of October 22, 1991.**
<u>Definition</u> • Device constructed of non-earthen materials containing an accumulation of regulated substances, the volume of which is 10 percent or more underground.	<u>Definition</u> • Any tank not completely buried, including bunkered tanks.
<u>Exemptions</u> • Farm or residential less than 416 L (110 gal) • Heating oil used on premises • Flow-through process or separator • Stormwater or wastewater collection • Equipment for operational purposes such as hydraulic lift tanks and electrical equipment • Airport hydrant tanks	<u>Exemptions</u> • USTs under 40 CFR 280 • Onshore facilities that, due to their location, could not reasonably be expected to discharge oil into waterways • Vessels under DOT requirements
<u>Size Limitations</u> • Greater than 416 L (110 gal) (excluding field-constructed tanks)	<u>Size Limitations</u> • Individual containers greater than 2.5 m^3 (660 gal) • Container aggregates greater than 5.0 m^3 (1,320 gal) • UST aggregates greater than 159 m^3 (42,000 gal)
<u>Primary Charter</u> • Prevent release of regulated substances that can harm the environment, including soils and groundwater	<u>Primary Charter</u> • Prevent spills of oil by non-transportation-related onshore and off-shore facilities into U.S. surface waters and surrounding shorelines, including wetlands
<u>Regulated Substance</u> • Petroleum, including crude oil in its various natural or processed states, and motor and jet fuels, lubricants, petroleum solvents, distillate fuel oils • Substances defined in CERCLA, excluding hazardous wastes under Subtitle C	<u>Regulated Substance</u> • Oil in any form, including petroleum, sludges, oil refuse, crude oil, animal and vegetable oils

Table 18. Steel Tank Institute comparison of USTs versus ASTs (continued).

UST (40 CFR 280)	**AST (40 CFR 112, SPCC)** **Based on SPCC Phase I proposed rules of October 22, 1991.**

Corrosion
• Tank protected per code of practice developed by nationally recognized association or independent testing lab, includes:
  • FRP
  • Composites
  • Cathodic Protection
  • Protection includes piping system
	Corrosion
	• Partially buried tanks protected using coatings and cathodic protection
	• Piping protected as in 40 CFR 280
	• Compatible with stored product

Structure • Prevent releases due to structural failure	Structure • Construction and materials must conform to industry standards in application of good engineering practices
Containment • Chemicals and other hazardous substances must include secondary containment to hold releases until detected and to prevent release into the environment • Some states also require containment of petroleum liquids	Containment • All facilities must be contained to prevent discharged oil from reaching navigable waters (includes double-wall steel, under recent interpretation) • Containment impervious to oil for 72 hours • Dike, curbs, and pits to contain largest tank, plus sufficient freeboard for bulk storage containers
Testing / Release Detection • Must detect release from any portion of tank and connected piping • Monitor every 30 days for tanks with automatic tank gauging, vapor and groundwater monitoring, and interstitial monitoring • Pressurized piping tests every year unless monitored monthly with tanks AND automatic line leak detection • Suction piping tested every 3 years unless monitored monthly • Testing for tightness every 5 years; if tank is not in conformance with other requirements, then annual tightness testing is required • statistical inventory reconciliation allowed as monthly release detection check	Testing / Release Detection • Integrity test of tanks every 5 years, and piping every year • Those with secondary containment must have integrity test every 10 years • Piping and valves examined monthly
Financial Responsibility • $1 million insurance	Financial Responsibility • No insurance required, although U.S. Senate and U.S. House are introducing language similar to 40 CFR 280

Table 18. Steel Tank Institute comparison of USTs versus ASTs (continued).

UST (40 CFR 280)	**AST (40 CFR 112, SPCC)** **Based on SPCC Phase I proposed rules of October 22, 1991.**
Clean-up • Report suspected and confirmed releases to implementing agency • Must take immediate action to prevent further release (within 24 hours) • Submit report of initial actions within 20 days and remove free product • Develop corrective action plan to clean-up contaminated soils and groundwater	Clean-up • Report spills immediately to National Response Center (40 CFR 110) • Materials and manpower for control and removal must be provided for facilities without secondary containment when secondary containment not practical. Professional engineer required to develop strong oil spill contingency plan • Owners/operators of large tank sites may have to submit a facility response plan for approval under 7-1-94 EPA's definition of "significant and substantial harm"
Overfill Prevention and Containment • Spill prevention equipment that prevents releases of product when transfer hose is detached • Overfill prevention equipment • Shut-off at 95% capacity • Alert operator at 90% capacity by restricting flow or triggering high-level alarm	Overfill Prevention and Containment • Fail-safe engineered to avoid spills
Other Requirements	Other Requirements • Security to minimize vandalism • Training for facility personnel to minimize operator error

REFERENCES

1. Code of Federal Regulations, 49 CFR 173, U.S. Government Printing Office, U.S. Environmental Protection Agency (EPA), Office of Underground Storage Tanks (OUST), October 1999.

2. *6th Annual Report on Petroleum Industry Environmental Performance (PIEP)*, American Petroleum Institute (API), 1998.

3. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 1980.

4. Resource Conservation and Recovery Act (RCRA), 1976.

5. Occupational Safety and Health Act (OSHA), 1970.

6. Code of Federal Regulations, 40 CFR 280, U.S. Government Printing Office, U.S. Environmental Protection Agency (EPA), Office of Underground Storage Tanks (OUST), July 1999.

7. Code of Federal Regulations, 49 CFR 195, U.S. Government Printing Office, U.S. Department of Transportation, Washington, D.C., October 1999.

8. Code of Federal Regulations, 40 CFR 112, U.S. Government Printing Office, U.S. Environmental Protection Agency (EPA), Office of Underground Storage Tanks (OUST), Spill Prevention Countermeasure and Control Plan, July 1999.

9. Clean Water Act, 33 USC 1251 et seq., 1977.

10. Oil Spill Pollution Act, 33 USC 2701 et seq., 1990.

11. *Results of 1995 Survey of Oil Storage Facilities*, U.S. Environmental Protection Agency (EPA), July 1996.

12. *Department-Wide Program Evaluation of the Hazardous Materials Transportation Programs*, Final Report U.S. Department of Transportation, Washington, D.C., March 2000.

13. Environmental Protection Agency, Office of Underground Storage Tanks (EPA-OUST), *Quarterly Report With Data on Number of Active and Closed Tanks*, www.epa.gov/swerust1/cat/camarchv.htm, December 2000.

14. J. Lary, Vice President, Corrpro Companies, Inc., Medina, OH, Personal Communication, October 2000.

15. K.C. Garrity, Vice President, CC Technologies Services, Inc., Dublin, OH, Personal Communication, October 2000.

16. P.E. Myers, Aboveground Storage Tanks, McGraw-Hill, March 1997.

17. API Recommended Practice 651, Cathodic Protection of Aboveground Storage Tanks, 2nd Edition, (ANSI/API Std 651-1991), December 1997.

18. U.S. Environmental Protection Agency (EPA), *How Much Does It Cost to Upgrade, Replace, or Close UST Systems?*, www.epa.gov/swerust1/1998/urccosts.htm, December 2000.

19. Steel Tank Institute, *Steel Tank Institute Specification for Sti-P3® System of External Corrosion Protection of Underground Steel Storage Tanks*, http://205.243.101.87/steeltank/library/pubs/p3sum.html, December 2000.

20. Presentation on EPA's SPCC Regulation, L. Diane Schenke, Partner at Brown, McCarroll & Oaks Hartline, date unknown.

21. API Standard 653, Tank Inspection, Repair, Alteration, and Reconstruction, 2nd Edition, December 1995.

22. *USTs vs. ASTs From the Viewpoint of EPA Regulations*, http://205.243.101.87/steeltank/library/pubs/ustast.html, November 2000.