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Project Summary

Technical Aspects of Underground Storage Tank Closure

The U.S. Environmental Protection Agency (EPA) is currently evaluating several technical and regulatory aspects of UST closures, such as appropriate tank cleaning upon its removal from service. This study has developed a deeper understanding of Underground Storage Tank (UST) residuals at closure: their quantities, origins, physical/chemical properties, ease of removal by various cleaning methods, and their environmental mobility and persistence.

The investigation covered only underground storage tanks that held the following products: gasoline, diesel oil, and fuel oil. It obtained information in two phases. Phase I elicited data via telephone contacts with knowledgeable individuals including tank cleaning companies, from literature cited by these experts, in site visits, and from questionnaires completed by state representatives.

Phase II monitored selected tank cleaning cases and made quantitative measurements of the amounts of residuals left in USTs before and after cleaning, characterizing the nature of the residuals and any rinses generated during the cleaning process. To support the objectives of the study, the following information was collected for each UST site included in the study: estimates of volumes of tank residuals and secondary wastes, hazardous characteristics and chemical composition of the residuals and secondary wastes, detailed descriptions of the cleaning methods used, and background information on the UST site that relates to the nature of the residuals.

This report documents the study findings in order to aid regulators and to assist those implementing/overseeing closure activities. This report covers a period from August 1988 to May 1990, and work was completed as of May 1990.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH 45268, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The overall objective of this study was to develop a deeper understanding of UST residuals at closure: their quantities, origins, physical/chemical properties, ease of removal by various cleaning methods, and their environmental mobility and persistence. The investigation covered underground storage tanks containing: gasoline, diesel oil, and fuel oil. The work progressed in two phases.

Phase I: Preliminary Investigation of UST Residuals and UST Cleaning/Closure Methods

To obtain preliminary information on UST residuals, researchers employed the following sources: telephone interviews, review of literature cited by expert telephone contacts, observation during site visits to four tank cleaning/removal operations, a survey of various state representatives at a National UST seminar, and engineering calculations on residual volumes and costs of cleaning/closure.

The telephone surveys of experts elicited citations of published and unpublished data that were subsequently reviewed. Site visits provided an opportunity to observe tank cleaning and removal operations by two companies at three different sites.

To supplement data from the telephone survey, a focused survey was conducted at the November 1988 "Workshop for State Tank Program Managers Conference," in Santa Fe, New Mexico, sponsored by the U.S. Environmental Protection Agency's Office of Underground Storage Tanks (OUST). The data provided by the tar-

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geted respondents illuminated some common, jurisdictional, closure practices and indicate which practices are prevalent.

Engineering calculations, detailed in the full report, provided estimates on the volume of residuals likely to be found in USTs, the amount of water and rust or scale that might be expected in a UST, and the costs of UST cleaning and closure.

Phase II: Field Sampling and Analyses of Residuals at Sites Undergoing UST Cleaning/Closure

Under an agreement with a UST cleaning/removal contractor and with the permission of UST owners, Phase II monitored selected tank cleaning cases and made quantitative measurements of the amounts of residuals left in USTs before and after cleaning, characterizing the nature of the residuals and any rinses generated during the cleaning process. To support the objectives of the study, the following information was collected for each UST site included in the study: estimates of volumes of tank residuals and secondary wastes, hazardous characteristics and chemical composition of the residuals and secondary wastes, detailed descriptions of the cleaning methods used, and background information on the UST site that relates to the nature of the residuals.

UST Residuals

Gasoline and diesel oil USTs have been found to contain significant quantities of residuals at closure, typically tens to hundreds of gallons. The tanks can usually be emptied by the owner/operator to within 4-6 in. of the tank bottom. This dimension, which determines residual quantity in an "empty" tank before cleaning, translates into about 100-200 gal for a 10,000-gal tank. Both the Phase I and Phase II findings indicated that the median volume of residuals found in gasoline and diesel oil USTs before cleaning was slightly below 100 gal. Some USTs, however, are found to contain several thousand gal, consisting of abandoned product and/or water which has leaked into them.

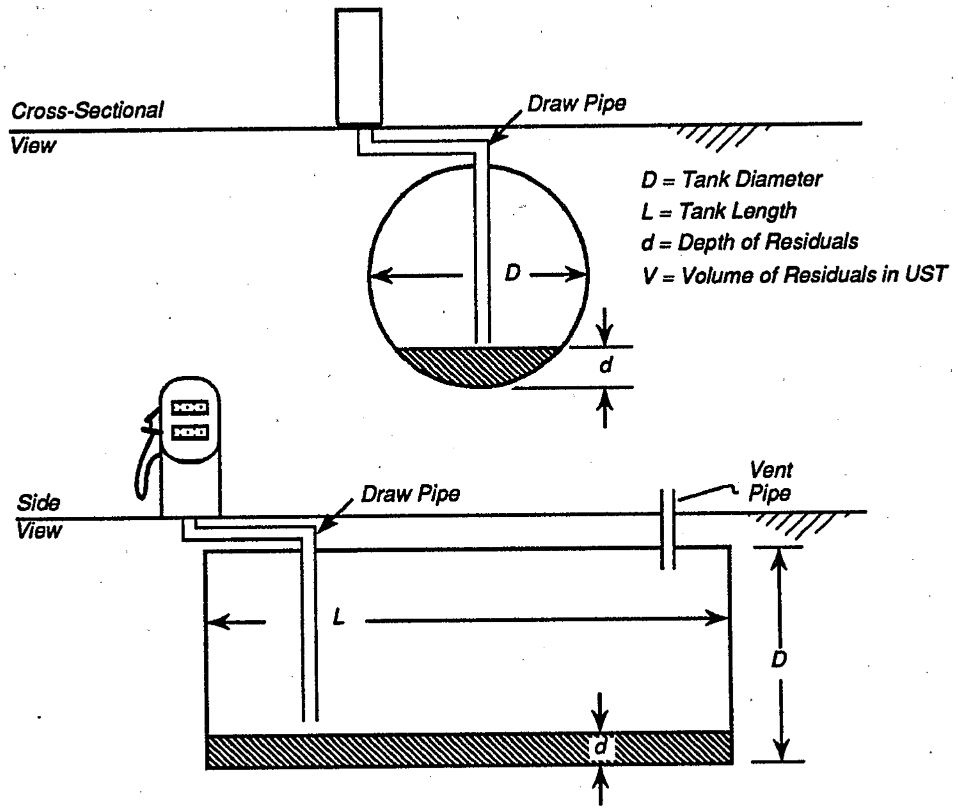
Quantity

Field personnel often describe the volume of a tank's contents in terms of inches of residuals on the bottom of the tank. Figure 1 illustrates the residuals in a UST and the formula for calculating the volume of residuals.

By design, the submersible pump systems used to supply product, drop down no farther than 4 in. above the tank bottom in steel tanks. This provides 4 in. of dead tank space, used to trap sediments and water in the tank to ensure that they will not be pumped out to the customer. For fiberglass-reinforced plastic (FRP) tanks, the tube usually ends 6 in. above the tank bottom to allow for any settling and deformation of the FRP tank. This design feature leaves at least 4 in. of residuals in steel tanks and 4-6 in. of residuals in FRP tanks after the tank has been "pumped dry" by the tank owner. This represents residuals from 95 to 264 gal for a 10,000-gal tank — a mid-sized UST.

The volume of residuals found in gasoline tanks at any one site can vary significantly. The majority of the reporting participants estimated residual quantities up to 1,000 gal. The mean of the values reported was 160 gal; the median, 75 gal. Most respondents agreed that diesel oil tanks contained more residuals than gasoline tanks, with a range of up to 200 gal and a mean value of 58 gal. The median estimate was approximately 75 gal. They also concurred that fuel oil tanks produced a greater amount of residuals than oil tanks. The two respondents that provided numbers for this product reported 500 and 1,000 gal, averaging to 750 gal — significantly higher than gasoline and diesel oil.

The volume of used rinse solutions generated during the cleaning procedures can vary widely with the type of cleaning procedure used. Estimates ranged from 100 to 3,300 gal, with an average of 1,200 gal. The American Petroleum Institute (Recommended Practice 1604) calls for filling the tank nearly to the top for cleaning and/or vapor removal purposes. This practice would generate much greater volumes



$$V = 0.5\left[\frac{D}{2}\right]^2 \left[2\arccos\left(\frac{\left[\frac{D}{2}\right] - d}{\frac{D}{2}} \right) - \sin\left[2\arccos\left(\frac{\left[\frac{D}{2}\right] - d}{\frac{D}{2}} \right) \right] \right] L$$

Figure 1. *Schematic of UST tank for estimate of residuals volume.*

of used rinse solutions than actual product.

Origin and Composition of Residuals

The basic components of tank residuals usually include residual product, water, product-related residuals, tank rust and scale, soil, dirt and other foreign objects, and microorganisms. Residual product probably constitutes 70-90% of total residuals in an aged tank. The other components make up the remaining 10-30%, with microorganisms represented in large numbers but a very small percentage of the total weight.

Product

Residual product would represent approximately 100 gal in a 10,000-gal tank. The purity of the product must be determined in each case. Resale of gasoline, for example, might require filtration, dewatering, or further treatment. If the tank being removed was abandoned for a long time (months to years), significant changes in the nature or composition of the residuals might take place due to volatilization, water infiltration, rust formation or biological action. Some tank cleaners do not attempt a separate recovery of this residual product to facilitate reuse; they pump it into the same tank truck used for rinses and/or residuals from other tanks. They then send the mixed fuel to a treatment facility which separates, treats, and/or disposes of the components.

Product-Related Residuals

Survey respondents discussed the presence of some product-related residuals (e.g., gums, sediment) but estimated their total amounts to be relatively small. These include gums and tars (high molecular weight organics left by heavy fuels), polymers formed in situ from reactive components of the fuel (e.g., unsaturated hydrocarbons) that can sink to the bottom of the tank, sediment present in product on delivery that sinks to the tank bottom, and certain fuel components that attach to tank walls or other solid residuals through sorption.

Water

Significant amounts of water lie at the bottom of many, if not most, USTs. The sources of such water include accumulated water delivered in the product, condensation in the tank from infiltrating moisture-laden air, surface runoff entering fill pipe, and groundwater leaking into tank or fill pipe.

Water residuals in USTs may play a significant role in the internal corrosion of steel tanks. Water present in a UST can exist partly as a separate phase and partly in solution with the fuel. It is a common practice for owners of USTs in service to periodically check for the presence of water (and sediment), pumping out any excess over 1 in. prior to refilling the tank (about 12-18 gal in a 10,000-gal tank). Water found in USTs prior to cleaning generally would contain a significant amount of dissolved hydrocarbons (~100-300 mg/L), dissolved salts (e.g., Na^+, Cl^-, Fe^{+2}, HCO_3^-, Pb^{+2}) and other soluble components or additives in the fuels (e.g., ethanol, MTBE, detergents).

Tank Rust or Scale

The survey and information cited by respondents indicated that steel tanks are likely, over time, to shed rust particles (Fe_2O_3), and iron scale. This internal corrosion may be caused by galvanic action or bacterial action. Concentrated internal corrosion often occurs directly under the fill tube where the gauge stick strikes the bottom of the UST. Several measures can prevent tank failure in this location. Nevertheless, surveys of UST removals have clearly demonstrated the importance of internal corrosion to UST failures. Study calculations estimate about 10 lb of rust generation in a 10,000 gal tank.

Soil, Dirt and Other Foreign Objects

The Phase I survey and field trips provided evidence of the following foreign objects in USTs: soil, dirt, rubber hoses, soft drink cans, and similar trash. Although this material probably entered via the fill tube, some may have been discarded in the tank prior to its initial use. There is also potential for the entry of foreign objects at other times (e.g., repairs).

Microorganisms

Like water, microorganisms appear to be fairly ubiquitous in petroleum storage and distribution systems. They can reside in the tank before it is used, and enter from the outer environment via an open fill tube or cracks. While they may appear to be present in large numbers (10^2 to 10^3 organisms/L), their combined mass is small. At times, however, large flocs can form, clogging fuel lines and filters. The microorganisms in USTs include several varieties of bacteria and fungi. One especially important class (sulfate-reducing bacteria) can cause significant iron and steel corrosion.

Microorganisms need water to thrive and, in storage tanks, are usually found at the fuel-water interface. The mix of hydrocarbons, water, oxygen (low for anaerobes), nutrients, and a compatible pH all contribute to their growth. They apparently thrive better in fuel oil than in gasoline.

Tank/Site Factors Affecting Residual Quantity and Composition

A number of tank and site factors control the nature, quantity, and composition of UST residuals, such as tank design, use, cleaning procedures, repair practices, age, total volume throughput, site factors, hydrogeology, meteorology, product type, and product composition. These factors also suggest ways to reduce the volume — and/or control the composition — of UST residuals. For example, lowering the suction tube deeper into the tank increases the maximum pumpable by the owner/operator, and therefore lowers the volume of remaining product. The origins of the various components of the residuals are fairly discernible. This knowledge and information on relevant site/tank factors can help to control the future quantity and quality of residuals. For example, the growth of microorganisms can be controlled by the use of biocides and/or the elimination of water; this would reduce the microbiological mass as well as the amount of internal corrosion and rust generation.

Cleaning and Closure

Cleaning Procedures

A variety of tank cleaning and removal procedures appear to be in use; many are variations on a simple, logical theme. Many steps are dictated by safety considerations and state and local regulations, rather than concern for tank cleanliness. The guiding set of objectives in emptying/cleaning USTs (whether they are actively in use or set for closure) should entail minimizing the environmental/health hazards presented by the tank and its residuals, the explosion hazard of removing the UST, the volume of secondary waste generated, and the cost of UST closure.

Rinses

In one way or another, most procedures begin by pumping residuals with a suction line, then rinsing the tank with water, and finally removing the used rinse solution. For USTs with especially viscous residuals, a light fuel oil (e.g., No. 2), sprayed into the tank, may assist in the cleaning.

Manholes

Several tank cleaning companies, after the initial pumping of liquid residuals, cut a manhole into the UST so that a workman can enter, and then manually remove bottom grit and, with a "squeegee," wipe liquids adhering to the side walls. The risk of explosion is significant, particularly for tanks which have not been properly purged. However, benefits gained from the increased cleaning efficiencies and closer inspection of the tank may sometimes outweigh the hazards.

Disposal of Residuals

Some companies put both initially-pumped residuals and used aqueous rinses in the same tank truck for off-site treatment and disposal. Other companies segregate the residuals from the rinses, thus facilitating subsequent treatment.

Disposal of Tanks

For tanks that will be crushed/cut and remelted, a modest amount of retained residuals may be environmentally acceptable. For tanks that are filled in place or landfilled, the retained residuals are likely to pose only a small-to-negligible risk of adverse environmental impact due to the small volume of retained residuals, limited environmental mobility for most constituents, and limited toxicological significance for the bulk of the constituents.

American Petroleum Institute Recommendations

The basis of most UST cleaning methods identified through the survey is API's Publication 1604, "Removal and Disposal of Used Underground Petroleum Storage Tanks," and API's Publication 2015, "Cleaning Petroleum Storage Tanks." Publication 1604 does not address cleaning methods explicitly, but it does describe the removal process. Publication 2015 describes a recommended cleaning process, using the following format:

1. Completing preliminary preparations
2. Determining that the dike area is free of flammable or toxic materials before personnel are permitted to enter the tank
3. Controlling sources of ignition in, around, and on the tank
4. Emptying the tank by pumping out residual liquid and floating it with water
5. Blinding off the tank and de-energizing electrical circuits after as much of the contents as possible have been removed
6. Vapor-freeing the tank (mechanical, steam, and natural ventilation are alternatives)
7. Testing the tank for oxygen, hydrocarbon vapors, and toxic gases
8. Opening the tank for entry
9. Removing bottom residuals and sending them for appropriate disposal

The UST is then transported to a licensed UST disposal facility for ultimate disposal.

Additional Practices Reported

The Phase I survey of tank cleaning and tank removal contractors provided a variety of cleaning procedures in addition to that described above. The full report lists some of the more interesting variations, such as cleaning residuals from the tank while it is still in the ground by spraying rinse through fill or vent pipes and then pumping the rinse out (an alternative to a manhole). Such variations may depend on many factors, e.g., residual type, future tank fate, tank size/design, and the availability of water.

Secondary Wastes

Secondary waste streams consist of the tank material and rinse solutions. Spent rinse solutions are generated in the cleaning procedure when water, steam, detergent, or some other agent is used to clean the tank. The rinse volumes may vary depending on the nature and volume of residuals found in the USTs. As noted above, survey respondents reported rinse volumes ranging from 100 gal/tank to one third of the tank volume. Little information was found on methods used to treat and dispose of the secondary wastes generated. However, the treatment and disposal of oil/water wastes is successfully accomplished by numerous demonstrated and commercially available processes, such as phase separation followed by incineration of the organic phase and a two-step (e.g., physical/chemical and biological) treatment of the aqueous phase.

Effectiveness of Cleaning Procedures

The Phase I survey revealed no contractor contacted knew just how clean a tank their procedure(s) could achieve. Most contractors believe that if they follow the company's standard cleaning procedures, then the tank will be "clean." Visual inspections of "clean" are also common. When UST closure procedures preclude the use of a manhole in the UST, visual inspection of "clean" is quite difficult. At present, no standard measure of the cleaning effectiveness seems to have been set. Phase II attempted to resolve this question by actually visiting tank cleaning/removal operations and characterizing the residuals before and after cleaning.

Field Studies of UST Closures

This phase collected information at actual UST cleaning/removal sites, including:

- Background information on the UST site that relates to the nature of the residuals
- Detailed descriptions of the cleaning methods used
- Estimates of volumes of tank residuals and secondary wastes
- Hazardous characteristics and chemical composition of the residuals and secondary wastes
- Costs of cleaning and closure

Field case studies were conducted in concert with a company that offered a range of environmental services, including UST cleaning and removal. The company provided a list of six representative UST closure jobs that met study objectives. Permission was obtained from the site owner/operator to monitor the job and perform sampling during the normal course of the closure; cleaning techniques were not modified for the study. The study focused on tanks containing gasoline and No. 2 fuel oil. Table 1 summarizes background information on these tanks.

UST Removal and Cleaning Procedures

Observers noted common steps in cleaning procedures, e.g., vacuuming residual product (No. 2 fuel oil or gasoline) from the UST into a tank truck; adding dry ice to gasoline to displace oxygen with carbon dioxide; excavating overlying soil (at this point, pulling some tanks from the pit); cutting a manhole in the top or side of the tank to allow worker entry; scraping tank interior (manually) to remove residuals; rinsing the tank interior with tap water and vacuuming it into the tank truck during rinsing; pulling the UST from the excavation pit; and scraping tank exterior clean before transport to a tank yard.

Characterizing Residuals

In general, 3 types of samples were collected from each UST for laboratory analysis: original fuel product (if present), bottom residuals, and aqueous rinse solutions. These samples were analyzed for a series of chemical parameters and hazardous characteristics, including specific RCRA metals and VOCs.

Table 1. *Specifications of Underground Storage Tanks (USTs) Sampled*

Site No.	Size (gal)	Fuel Type	Material Type	Condition	Age (yr)	Depth to Groundwater (ft)	Depth to Tank (ft)	Product Volume in Tank (gal)
1	±4,000	No. 2	Steel	Very good, no rust	15	Unknown	20	4,400
2	1,000	No. 2	Steel	Fairly rusted	15	Unknown	4	800
3	10,000	No. 2	Steel	Good, some rust at ends	20	Unknown	±3	94
4	±1,000	Gasoline	Steel	Rusty, but intact	11+	±20	±4	±90
5	±500	Gasoline	Steel	Rusty, but intact	20+	4	±2	±2
6	±2,000	Gasoline	Steel	Very good, no rust	11+	4	±3-4	±55

Field Study Results

Volume of Residuals After Cleaning

The first direct indication of effective UST cleaning is the visual examination of residual organic liquid, sludge, or aqueous rinse remaining in the UST after it was cleaned. The residual volume estimates of either organic liquid, sludge or rinse varied between negligible amounts and 3 gal of residual. These residual volumes were less than 1% of the total tank volumes. In addition, the volume of residuals appeared to be independent of the tank volumes. Any variation in volumes of residuals is probably dependent upon the daily variations in field conditions and operating procedures followed at a given site.

Analyses of UST Residuals

The second measure of effective UST cleaning is the concentration of chemical constituents found in the residuals remaining in the USTs after cleaning.

Product

Laboratory analyses of the two types of fuel products removed from the USTs in this survey (i.e., gasoline and No. 2 fuel oil) did not yield any unusual results (Table 2). VOCs, metals, TPH, and flash point measurements were all within ranges that are consistent with those for No. 2 fuel or gasoline. As expected, the BTEX concentrations for gasoline were higher than those for No. 2 fuel. Metal concentrations were either below the detection limit or exhibit some lead. The fact that the reported TPH measurements on the fuel products did not match 100% TPH (1,000,000 ppm) does not necessarily reflect non-TPH contamination in the fuel, since the specified analytical procedure used a synthetic nonfuel standard for instrument calibration. The flash point measurements indicate that the gasoline would be considered a hazardous waste because of its ignitability characteristics (flash point below 140°F). The fuel oil would not be considered hazardous by this characteristic.

Bottom Residuals

These materials were probably a combination of settled petroleum products, tank scale, and accidentally introduced soil. The results of laboratory analyses performed on this material (Table 3) were consistent with its sources. TPH and VOC concentrations were slightly lower than the fuel products, flash points were roughly similar to fuel products, and metals concentrations were higher than the fuel product. The origin of the metals could either be from settled impurities or additives in the gasoline (such as tetraethyl lead), impurities in the tank steel, or constituents of soil that was accidentally introduced into the tank. (Laboratory personnel indicated that high barium concentrations are often seen in analyses of petroleum products.)

In addition to the routine TPH, metals, and VOC measurements, the bottom residuals were also subjected to a TCLP extraction to assess what concentration of metals, VOCs, and ABNs (Acid/Base Neutrals) could potentially become mobile in the presence of an acidic leachate. TCLP results (Table 4) indicated that only a fraction of the metals and VOCs present were potentially mobile as aqueous solutes. Based upon these TCLP results and the recently revised TCLP criteria, bottom residuals from two of the gasoline tanks would be considered hazardous waste sludges by the EPA. The regulatory levels and exceedances are as shown in Table 5. The only unexplained TCLP result is

Table 2 *Summary of Typical Analytical Results for Fuel Product in USTs Before Cleaning*

Site No.	Fuel Type	TPH (ppm)	Flash Point (°F)	Metals Detected (ppm)	VOCs Detected (ppm)	
1	No. 2	788,000	>200	BDL[a]	Toluene	743
					Ethylbenzene	222
					Total xylenes	2,810
2	No. 2	702,000[b]	185	BDL	Benzene	37
					Toluene	220
					Ethylbenzene	150
					Total xylenes	977
3	No. 2[c]					
4	Gasoline	518,000[b]	25	Lead 5.3	Benzene	12,000
					Toluene	30,800
					Ethylbenzene	53,700
5	Gasoline	485,000[b]	21	Lead 1,370	Benzene	17,700[b]
					Toluene	39,400[b]
					Ethylbenzene	13,900[b]
					Total xylenes	78,600[b]
6	Gasoline	634,000[b]	23	BDL	Benzene	13,000[b]
					Toluene	37,000[b]
					Ethylbenzene	14,500[b]
					Total xylenes	75,500[b]

[a] BDL - below detection limit.
[b] Average of two values.
[c] No analyses performed

Table 3. *Summary of Analytical Results for Bottom Residuals in USTs During Cleaning*

Site No.	Fuel Type	TPH (ppm)	Flash Point (°F)	Metals Detected (ppm)		VOCs Detected (ppm)	
1	No. 2	237,000	181	Arsenic	0.83[a]	Toluene	110
				Barium	5.7[a]	Ethylbenzene	196
				Lead	20.9[a]	Total xylenes	993
2	No. 2[c]						
3	No. 2	355,000	205	Arsenic	2.7[a]	Benzene	17
				Barium	157[a]	Toluene	133
				Cadmium	2.3[a]	Ethylbenzene	138
				Chromium	12.7[a]	Total xylenes	640
				Lead	59.2[a]		
4	Gasoline	114,000	45	Arsenic	25.8	Benzene	5.2
				Barium	23.9	Toluene	370
				Cadmium	19.8	Ethylbenzene	774
				Chromium	51.3	Total xylenes	334
				Lead	2,230		
				Silver	2.2		
5	Gasoline	—	—	Arsenic	8.4[a]	Benzene	624
				Barium	22.8	Toluene	639
				Cadmium	13.5[a]	Ethylbenzene	284
				Chromium	50.4[a]	Total xylenes	765
				Lead	232[a]		
				Silver	264[a]		
6	Gasoline	—	—	—			

[a] Average of two values. [b] No bottom residuals in tank. [c] No analyses performed

the presence of methylene chloride at site No. 1; the chemical may have been introduced during the laboratory analysis.

Aqueous Rinse

The rinse solutions analyzed in this survey were intended to simulate the rinse water used during the final rinse of the fuel tanks. As indicated in Table 6, the TPH concentrations ranged from 4 to 379 ppm, and metals concentrations were either below the detection limit or a fraction of the concentrations found in the bottom residuals. For example, at Site No. 4 the concentration of lead in the rinse was 12.6 ppm whereas the concentration of lead in the bottom residuals was 2230 ppm. VOC concentrations in the aqueous rinse reflected the VOC concentrations in the fuel product stored in the tank. Tanks that stored gasoline had higher VOC concentrations than those that contained No. 2 fuel. The presence of low levels of trihalomethanes, such as chloroform and bromodichloromethane, in some of the aqueous rinse samples probably reflects the presence of trihalomethanes in the public drinking water used to clean the tanks in Sites 1, 2, and 3.

Additional tests of the aqueous rinse solutions compared its quality with the guidelines for discharge of industrial waters containing the following materials to sewers serving Publicly Owned Treatment Works (POTWs): oil and grease, 5-day Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC), and pH. The oil and grease surements reflect the presence of high molecular weight organics in the fuel. BOD is used as a measure of the amount of degradable organic material present in the waste, and TOC is a surrogate measure of organic carbon present. The pH range of the samples collected, 4.7-6.6, is consistent with the range in natural waters. The tanks at sites 5 and 6 were washed with non-municipal groundwater, which may account for the lower pH measurements (4.7 and 5.4, respectively).

Organic Vapor Concentrations

The concentration of organic vapors found inside the tanks after cleaning indicates the effectiveness of the cleaning as well as the potential explosion hazard that the tank may present. The concentration of organic vapors was measured in three of the tanks following the cleaning procedures using an HNu organics analyzer equipped with a photo-ionization detector. The organic vapor concentrations in the tanks ranged from 26 ppm to 250 ppm. These concentrations are well below the

Table 4. *Summary of TCLP Analyses on UST Bottom Residuals*

Site No.	Fuel Type	Metals Detected (ppm)		VOCs Detected (ppm)		Semi-VOCs Detected (ppm)	
1	No. 2	Barium	3.23	Methylene chloride	0.24	Naphthalene	0.10
		Cadmium	0.019	Acetone	20	2-Methyl-naphthalene	0.41
		Chromium	0.005	Benzene	0.23	Acenaphthylene	0.0002
		Lead	0.047	Tetrachloro-ethane	0.49	Diethylphthalate	0.033
				Toluene	0.69	Di-n-butyl-phthalate	0.044
				Ethylbenzene	0.15	Bis(2-ethylhexyl) phthalate	0.044
				Total xylenes	0.82		
2	No. 2[c]						
3	No. 2	Barium	10.5	Benzene	0.15[a]	Naphthalene	0.170
		Lead	0.83	Toluene	0.40[a]		
				Ethylbenzene	0.158[a]		
				Total xylenes	0.87[a]		
4	Gasoline	Arsenic	0.031	Benzene	29.7	Phenol	0.14
		Barium	3.58	Toluene	23.6	2-Methylphenol	1.12
		Cadmium	0.19	Ethylbenzene	2.3	2,4-Dimethyl-phenol	0.39
		Lead	23.2	Total xylenes	14.3	Naphthalene	0.22
						2-Methyl-naphthalene	0.83
5	Gasoline	Barium	2.6[a]	Benzene	23.1	Phenol	0.51
		Lead	0.34[a]	Toluene	32.1	Benzyl alcohol	0.024
				Ethylbenzene	4.8	2-Methylphenol	0.63
				Total xylenes	23.2	4-Methylphenol	0.81
						2,4-Dimethyl-phenol	0.26
						Naphthalene	0.20
						2-Methyl-naphthalene	0.028
6[b]	Gasoline						

[a] Average of two values. [b] No bottom residuals in tank. [c] No analyses performed

Table 5. TCLP Regulatory Levels and Exceedances

EPA/TCLP		Exceedances	
Chemical	Criterion (ppm)	Tank	Conc. (ppm)
Arsenic	5		None
Barium	100		None
Cadmium	1.0		None
Lead	5.0	4	23.2
Benzene	0.5	4	29.7
Benzene	0.5	5	23.1

lower flammable limits for gasoline (>1.2% by volume).

Hazardous Composition of Residuals

The Phase II field studies indicated that residuals from gasoline tanks would typically be classed as hazardous waste because of their ignitability characteristic (flash point below 140°F) and Toxicity Characteristic Leaching Procedure (TCLP) values for lead and benzene. In addition, USTs containing gasoline residuals typically present vapors in concentrations above the lower explosive limit and above levels that would impair human health after even short-term exposures. Removal of these vapors is absolutely essential to eliminate risk from fires, explosions, and the inhalation of toxic vapors. By contrast, No. 2 fuel oil residuals were not found to be hazardous based on ignitability (flash points above 180°F) or TCLP criteria.

Bottom residuals from both gasoline and No. 2 fuel oil USTs contained significant concentrations of lead, barium, chromium, cadmium, and arsenic. As expected, product residuals from both also contained significant concentrations of benzene, toluene, ethylbenzene and xylene (BTEX). The BTEX fraction comprised 10-15 percent of the gasoline residuals and 0.1-0.4 percent of the No. 2 fuel oil residuals. Used aqueous rinses from tank cleaning operations contained levels of total petroleum hydrocarbons (up to 480 ppm) and BTEX (up to 70 ppm) that would likely bar their direct discharge to sanitary sewers.

UST Cleaning and Closure Costs

The costs of cleaning and closing (by removal) USTs are highly variable, ranging from under $1,000 to over $10,000 (1988) for individual tanks in the 1,000-10,000 gal range. The range of per unit tank size is a little narrower, 0.3-1.0/gal of tank capacity in most cases. Extreme values of up to $36,700/tank and $8/gal of capacity have been reported. The cost variability relates to the site-specific time and equipment requirements for tank cleaning and closure, as well as the nature and depth of covering, proximity to structures and utilities, residuals volume, required level of worker protection, equipment availability, inspection logistics, sampling needs, etc.

The cleaning method does seem to play a significant role in the total cost. Costs of labor, equipment and materials for 3 major steps in tank cleaning and removal have been estimated as high as $10,920—

Table 6. Summary of Analytical Results for Aqueous Rinse Samples

Site No.	Fuel Type	TPH (ppm)	5-day BOD (ppm)	TOC (ppm)	Oil and Grease (ppm)	pH	Metals Detected (ppm)		VOCs Detected (ppm)	
1[b]	No. 2									
2	No. 2	156[a]	210	109	—	6.6	BDL[c]		Chloroform	0.016
									Bromodichloromethane	0.009
									Benzene	0.009
									Toluene	0.082
									Ethylbenzene	0.087
									Total xylenes	0.332
3	No. 2	379[a]	330	646	405[a]	6.1	BDL		Chloroform	0.009[a]
									Benzene	0.015[a]
									Toluene	0.54[a]
									Ethylbenzene	0.039[a]
									Total xylenes	0.395[a]
4	Gasoline	20.3[a]	240	150	23.9[a]	6.0	Arsenic	0.047	Benzene	4.98
							Chromium	0.27	Toluene	12.0
							Lead	12.6	Ethylbenzene	3.57
									Total xylenes	14.0
5	Gasoline	4.4[a]	2,165	1,168	12.5[a]	5.4	Cadmium	0.17	Benzene	11.5
							Chromium	0.33	Toluene	28.1
							Lead	4.2	Ethylbenzene	7.32
									Total xylenes	24.0
6	Gasoline	74.3	35.0	33.7	83.1	4.7	BDL		Benzene	0.848
									Toluene	31.4
									Ethylbenzene	1.28
									Total xylenes	3.89

[a] Average of two values. [b] No sample collected. [c] Below detection limit.

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the high end of the range of reported 1988 costs — indicating either a more complete coverage of all costs (e.g., 1988 costs may have excluded backfill, tank disposal, etc.) or an overly conservative approach. In this hypothetical forecast, labor accounts for 33% of the costs; equipment, 61%; and materials, 6%.

Conclusions

This study has developed greater understanding of the technical aspects of UST cleaning and closure. The information collected from the Phase I interviews indicated that current tank cleaning methods appear to satisfactorily clean most gasoline and light oil tanks, even though little to no formal guidance is available on UST cleaning. The sampling, analysis, and physical measurements from the Phase II study verified the effectiveness of the cleaning procedures and documented the steps used to meet 3 criteria:

- Avoiding hazards from explosions and toxic vapors;
- Complying with the requirements of the Department of Transportation (DOT); and
- Meeting the cleanliness and explosion hazard requirements of the disposal facility.

The Phase II study also quantified the volumes of tank residuals and secondary waste, in addition to characterizing the contents. After cleaning, only one to three gallons of unrecovered rinse remained in USTs, posing a relatively low level of hazard. Post-cleaning vapor levels were safe in terms of explosion potential and acute toxicity.

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The complete report, entitled "Technical Aspects of Underground Storage Tank Closure," (Order No. PB92-161199/AS; Cost: $19.00, subject to change) will be available only from:
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