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Technical Aspects of Underground Storage Tank Closure

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TECHNICAL ASPECTS
OF
UNDERGROUND STORAGE TANK CLOSURE

by

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural resources to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

The impacts of underground storage tank (UST) closures on public health and the environment is an area of major concern. This document provides information on the quantities and characteristics of residuals found in USTs at closure, the methods used to remove the residuals, and the procedures for cleaning the tanks. The information generated will aid the regulators and assist those overseeing or implementing closure activities.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

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. 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, on-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.

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ABBREVIATIONS AND SYMBOLS

ABN	Acid/base neutrals
API	American Petroleum Institute
BETX	Benzene, ethylbenzene, toluene, xylene (combined analysis)
BOD	Biochemical oxygen demand
Cl^-	Chloride ion
DOT	Department of Transportation
EPA	U.S. Environmental Protection Agency
F	Fahrenheit
Fe^{+2}	Ferrous ion
FeS	Iron sulfide precipitate
Fe_2O_3	Iron oxide
FRP	Fiberglass-reinforced plastic tanks
g	Gram
gal	Gallon/s
HCO_3^-	Bicarbonate
in	Inch/es
kg	Kilogram
L	Liter
lb	Pound/s (weight)
MDL	Minimum Detection Limit
mg	Milligram
MTBE	Methyl tertiary-butyl ether
Na^+	Sodium ion
OUST	Office of Underground Storage Tanks
Pb^{+2}	Lead ion
ppm	Parts per million
RCRA	Resource Conservation and Recovery Act
TCLP	Toxicity Characteristic Leaching Procedure
TPH	Total petroleum hydrocarbons
TSDs	Transportation/storage/disposal facilities (for hazardous waste)
VOC	Volatile organic compounds
UST	Underground storage tank

ACKNOWLEDGMENTS

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SECTION 1

INTRODUCTION

The overall objective of this study of the ***Technical Aspects of Underground Storage Tank Closure*** was to develop 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 hazardous characteristics. This report documents the study findings in order to aid regulators and to assist those implementing/overseeing closure activities. 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 conducted telephone interviews, reviewed selected literature, observed actual tank cleaning/removal operations, surveyed state UST program managers and performed engineering calculations on residual volumes and costs of cleaning/closure.

<u>**Telephone Contacts**</u>

Telephone contacts were made with groups known to have first-hand knowledge of UST residuals in 16 states plus the District of Columbia. Those contacted included state and local agencies (14); tank cleaning companies (20); tank removal/disposal companies (10); tank lining companies (5); analytical service labs (3); petroleum refiners, wholesalers, distributors (8); industry associates (5); environmental consulting firms (8); and others (2). While those called were almost universally cooperative, they could contribute little quantitative information on residual volumes and composition. The interviews revealed that cleaning practices seldom followed formalized procedures. Consequently, most of the information obtained was qualitative, anecdotal or speculative in nature. Since this limited survey may have overlooked major regional differences in UST closure practices, a questionnaire targeted a larger group of State representatives at a National UST Seminar. (See **Survey of State Representatives** below.)

<u>**Literature Review**</u>

Based on expert opinion that literature of interest is limited and generally unavailable, no formal search was undertaken. Instead, telephone surveys of experts elicited citations of published and unpublished data. (See References.)

<u>**Site Visits**</u>

Site visits provided an opportunity to observe tank cleaning and removal operations by two companies at three different sites. Observations continued during a visit to a tank disposal contractor. The cleaning operations involved pumping out liquids and tank entry for manual removal of residual sludge and scale. Two sites provided grab samples of the residual sludge for visual inspection.

Survey of State Representatives

To supplement data from the telephone survey, a supplementary focused survey was conducted during the November 1988 "Workshop for State Tank Program Managers," in Santa Fe, New Mexico, sponsored by the U.S. Environmental Protection Agency's Office of Underground Storage Tanks (OUST). A questionnaire was distributed to elicit information on the following aspects of tank closure:

- the number of FY90 tank closings by jurisdiction;
- the increase in tank closures from FY89;
- the categories and frequency of tank closures by jurisdiction;
- authorized procedures and materials for in situ closure (including fill);
- the types, frequency, and effectiveness of tank cleaning methods used by jurisdiction;
- jurisdictional regulations on tank residues and cleaning by-products;
- status of government-sanctioned tank disposal monitoring programs;
- tank disposal practices; and
- government-sanctioned certification programs for tank removal/closure contractors.

Responses to the questionnaire contributed to this report and are further documented in a separate report [3]. The data collected cannot be deemed entirely accurate because some respondents indicated that they had limited data or firsthand knowledge of the underground storage tank programs in their respective jurisdiction. They had only a limited amount of time to complete the questionnaire during the session; therefore they could not do any research to complete their responses. While the limited number of responses can allow a substantial margin for error, the data provided by the carefully targeted respondents do illuminate some common, jurisdictional, closure practices and indicate which practices are prevalent.

Engineering Calculations

Engineering calculations, detailed in Section 2, provided the following estimates:

- the volume of residuals likely to be found in USTs;
- the amount of water and rust or scale that might be expected in an UST; and
- the costs of UST cleaning and closure.

PHASE II: Field Sampling and Analysis of Residuals at UST Closure Sites

Under an agreement with an UST cleaning/removal contractor and with the permission of UST owners, the Phase II study monitored selected tank cleaning cases and made quantitative measurements of the amounts of residuals left in USTs before and after cleaning. It characterized the nature of the residuals and any rinses generated during the cleaning process using sampling and analysis under a proper QA/QC plan. This field study focused on tanks containing gasoline and No. 2 fuel oil. Time and climatic constraints limited the field program to three tanks for each product.

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.

SECTION 2

CONCLUSIONS/RECOMMENDATIONS

GENERAL COMMENTS

Gasoline and diesel USTs are found to have significant quantities of residuals in them at closure, typically tens to a few hundreds of gallons. However, although there is little explicit guidance available, tank cleaning and removal companies are apparently capable of removing most of these residuals with fairly simple cleaning techniques. The Phase II field observations, and sampling and analysis program, generally confirmed the Phase I findings on the effectiveness of relatively simple cleaning operations.

Quantity of Residuals Found at Closure

Gasoline and diesel USTs can usually be emptied by the owner/operator to within 4"-6" of the tank bottom, and it is this distance which is probably the primary factor regulating residual quantity before cleaning. For a 10,000-gallon tank, this translates into about 100-200 gallons. Both the Phase I preliminary investigation and the Phase II field observations (limited to 6 tanks) indicated the median volume of residuals found in gasoline and diesel USTs before cleaning was slightly below 100 gallons. Some USTs, however, are found to contain several thousand gallons, consisting mostly either of abandoned fuel and/or water which has leaked into the UST.

Composition of Residuals

Based on the findings of both Phase I and Phase II, it is estimated that 70-100% of gasoline and diesel residuals consists of the product itself, probably of somewhat diminished purity. The remaining 0-30% consists mostly of water (with numerous dissolved constituents); product related residuals (e.g., gum, sediment, tars); rust and scale (in steel tanks); dirt and other foreign objects; and a small, but disproportionately-important mass of microorganisms. The importance of the microorganisms comes from the significant internal corrosion that can be due to the action of sulfate-reducing bacteria.

The Phase II field studies indicated 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 will contain 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 any 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 were all above 180°F) or TCLP criteria.

Sludges from both gasoline and No. 2 fuel oil USTs were found to contain significant concentrations of lead, barium, chromium, cadmium, and arsenic. As expected, both fuel residuals 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.

Aqueous rinse solutions generated from tank cleaning operations were found to contain 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.

While most all of the residuals will reside on the bottom of the tank, the presence of some side-wall scale and gum is anticipated. The bottom residuals, while containing some gum and grit, are mostly pumpable liquids and would not properly be considered sludges.

The origins of the various components of the residuals are fairly discernible and this knowledge can be used to help control the quantity and quality of residuals in future times. The growth of microorganisms, for example, 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 Procedures

A variety of tank cleaning and removal procedures appear to be in use, although many are variations of a simple, logical theme. Many of the steps in these procedures are dictated by safety considerations* and state and local regulations rather than a direct concern for strict tank cleanliness. In one way or another, most procedures involve an initial pumping of residuals with a suction line and a subsequent rinse with water with rinse solution removal. The water rinse may involve: (1) filling the tank with water; (2) rinsing with spray from 'garden' hose [low pressure]; (3) rinsing with high pressure water; (4) steam hosing; and (5) possible use of a detergent. The American Petroleum Institute's recommended procedures [1] (API 1604) call for filling the tank with water followed by sequential removal of floating product and water.

For USTs with especially viscous residuals, a light fuel oil (e.g., No. 2) is sometimes sprayed into the tank to assist in cleaning. The suctioned fluid may be filtered and recycled for additional cleaning.

Several tank cleaning companies, after the initial removal of liquid residuals, cut a manhole into the UST allowing a man to enter and physically remove bottom grit and (with a "squeegee") liquids adhering to the side walls. Some companies consider this procedure too dangerous, especially for gasoline tanks; the practice is prohibited in some areas.

With some companies, it is common to put both initially-pumped residuals and aqueous rinse solution into the same tank truck (for off-site treatment and disposal). Other companies segregate the residuals from the rinse solution thus facilitating subsequent treatment. Excluding the API 1604 procedure, which calls for filling the tank with water, the volume of rinse solution generated appears to range from a low of 25 gallons per tank to about one third of the tank's volume.

The Phase I survey did not uncover any data which provide objective evidence of the degree of cleanliness achieved by the procedures used. The field observations and measurements carried out in Phase II (cleaning/closure at three gasoline USTs and three No. 2 fuel oil USTs) did show that a relatively simple cleaning procedure did a good job of cleaning the tanks. Typically, there was a gallon or less of residuals (mostly aqueous rinse solution) left in the UST after cleaning.

*Prevention of human exposure to toxic chemicals, fires and explosions and spillage.

For tanks that are subsequently reused as scrap metal (i.e., crushed or cut up and then remelted), a modest amount of retained residuals may be environmentally acceptable. Worker protection may be the more stringent basis for regulation. 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. This would be related to the small volume of retained residuals, limited environmental mobility for most constituents, and limited toxicological significance for the bulk of the constituents.

Treatment of Secondary Wastes

Little information was obtained on actual methods currently being used to treat and dispose the secondary wastes generated. It is noted, however, that the treatment and disposal of oil/water wastes is a common operation and that numerous treatment processes (demonstrated and commercially available) may be used. Phase separation followed by incineration of the organic phase and a two-step (e.g., physicochemical then biological) treatment of the aqueous phase is appropriate.

RECOMMENDATIONS

Guidance on Cleaning Techniques

There is, at present, no guidance available that is directly pertinent to the cleaning of USTs.* Furthermore, portions of some guidance that is available (e.g., API's Publication 1604) may be providing inadequate or inappropriate guidance on certain key steps in the cleaning process, specifically the water wash step and the need (or lack thereof) for a human to enter the tank for removal of sludge and scale. A short guidance document in the form of a brochure (e.g., 5-10 pages) should be prepared for distribution to interested parties. If the issues of safety, tank removal and disposal, and treatment and disposal of secondary wastes were included, the guidance document would be significantly longer.

Treatment and Disposal of Secondary Wastes

This is a problem for a much smaller group of companies who are in the business of hazardous waste transport, treatment and disposal. There are numerous demonstrated methods available for the proper treatment of oil/water wastes. Additional research in this area is not necessary. It is probably necessary, however, to alert tank cleaning companies to the need to pretreat aqueous rinse solutions (for removal of petroleum hydrocarbons) prior to discharge to a sanitary sewer.

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*API's Publication 2015 (reference 2) appears more suited to large, above-ground petroleum storage tanks; and their Publication 1604 (reference 1) focuses more on the removal and disposal of UST rather than the cleaning.

SECTION 3

UST RESIDUALS

Underground tanks storing gasoline and diesel oil 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 gallons, 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. Table 1 provides a conversion from inches of residuals on the bottom to volume of residuals for varying sizes of tanks. Figure 1 shows the relationship between the two and the equation used to calculate the volumes.

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. These design features leave at least 4 in to 6 in of residuals after a tank has been "pumped dry" by the tank owner. Based on Table 1, this converts to residuals from 95 to 264 gal for a 10,000-gal tank -- a mid-sized UST.

Gasoline

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.

Diesel Oil

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.

Fuel Oil

The majority of the respondents agreed that fuel oil tanks produced a greater amount of residuals than gasoline and 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.

TABLE 1. RESIDUAL VOLUMES CALCULATED FOR TANK SIZES AND LIQUID DEPTHS

Tank dimensions	Tank volume (gal)					
	550	**915**	**5,000**	**10,000**	**10,000**	**20,000**
Diameter (ft)	4	4	8	8	10.5	10.5
Length (ft)	6	10	13.3	27	15.5	31
Depth of residuals remaining in tank (in)	**Volume of residuals (gal)**					
1	3	5	9	18	12	24
2	8	13	25	52	34	68
3	15	24	46	94	62	124
4	22	37	71	145	95	191
5	31	52	99	202	133	266
6	41	68	130	264	175	349
7	51	85	163	332	219	439
8	62	103	199	404	267	535
9	73	122	237	481	318	637
10	85	142	276	561	372	744

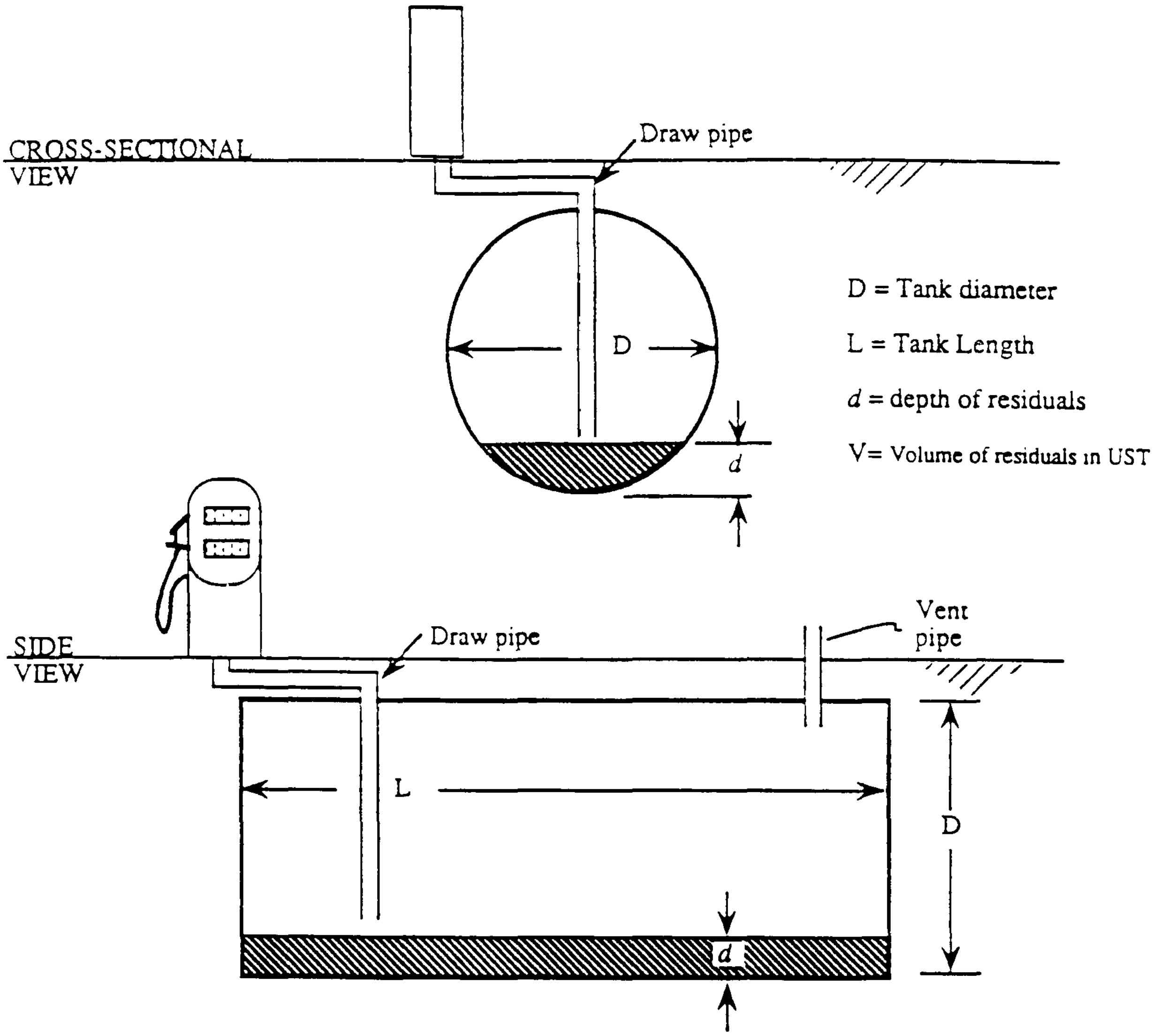
Rinses

The volume of spent 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. These volumes are significantly higher -- in fact an order of magnitude higher -- than the residuals themselves. API's Recommended Practice 1604 [1] calls for the tank to be filled nearly to the top for cleaning and/or vapor removal purposes. This practice would generate much greater volumes of spent rinse residuals than actual product.

A summary of case-by-case estimates obtained during the telephone survey regarding the volume of residuals and rinse solutions for an average-sized tank is included in Appendix A.

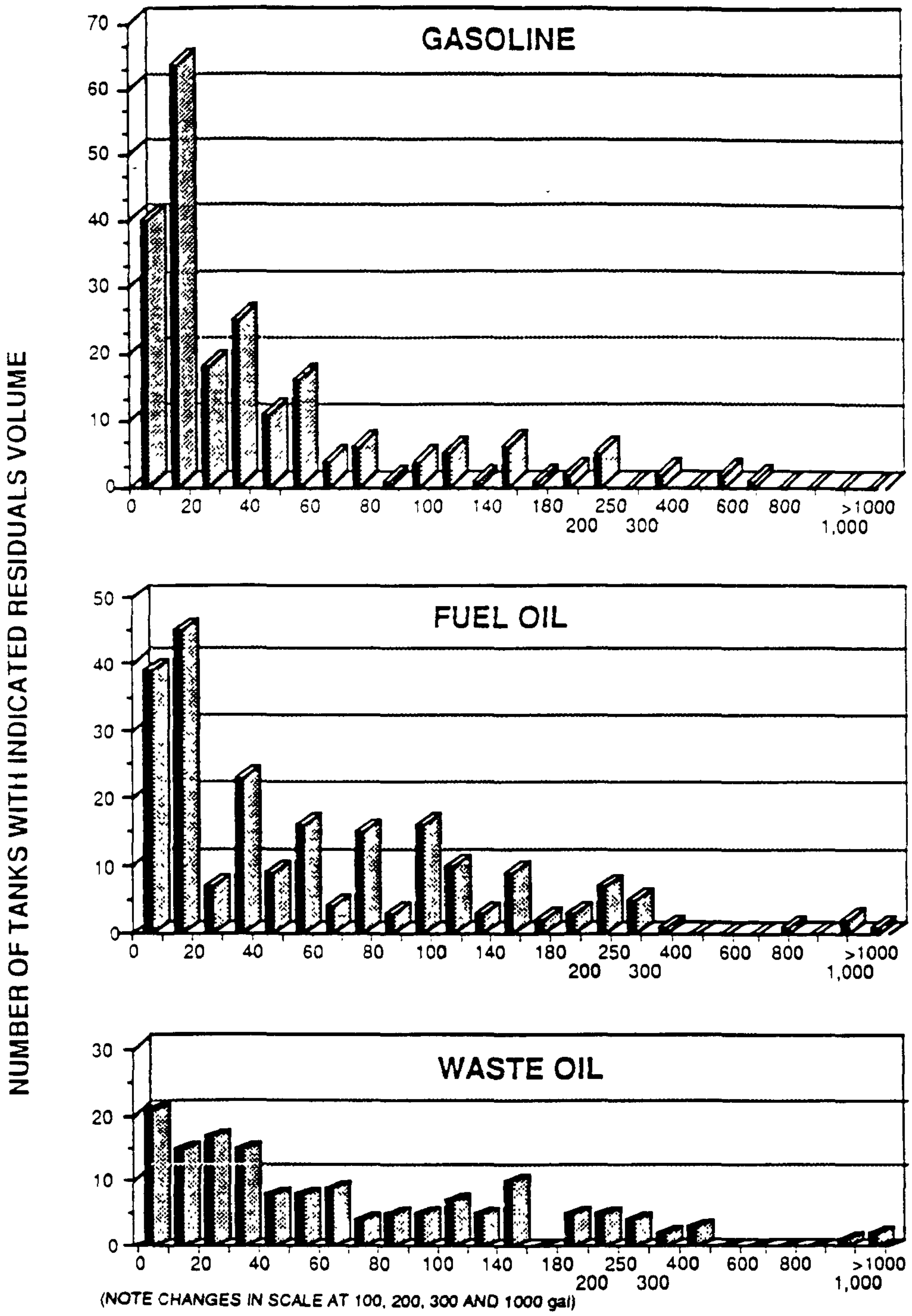
UST Profile

In connection with an UST sediment characterization project for the State of Minnesota, Delta Environmental Consultants, Inc. examined the files of a tank cleaning and removal company that kept detailed records on the depth and volume of residuals in each UST it removed [4]. Figure 2 shows the range of residual volumes the company recorded for gasoline, fuel oil, and waste tanks from 9/1/87 to 8/30/88. Table 2 provides a statistical summary.



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

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



Source: Delta Environmental Consultants (1988)

Figure 2. Quantity of residuals found in USTs by one Minnesota Company [4]

TABLE 2. QUANTITY OF RESIDUALS FOUND IN USTs BY ONE MINNESOTA COMPANY [4]

UST	Gasoline	Fuel Oil	Waste Oil
Number of tanks	214	221	151
Average tank capacity (gal)	5,800	5,900	3,600
Average residuals volume (gal)	49	81	162[a]
Median residual volume (gal)	20	40	50

[a] Excluding one tank with 9,375 gal of residuals.

ORIGIN AND COMPOSITION OF RESIDUALS

The basic components of tank residuals, as depicted in Figure 3, usually include the following components:

- 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 percent of the total weight.

Most residual products and water comprise liquids of relatively low viscosity that can be easily pumped out of the tank. The remaining materials apparently constitute a relatively small volume of side-wall gum and scale, and bottom sediment and grit. They possess varying physical properties, ranging from those of viscous organic sludges to solid inorganic particulates (e.g., the properties of rust flakes and sand). The ease with which this second group of materials can be removed by standard pumping or cleaning techniques varies according to the site-specific contents. Generalization is inappropriate.

Residual Product

This component, thought to comprise 70-90% of total residuals, 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.

In addition to any product that may lie beneath the pump line, additional product residuals can result from the following reasons:

- An owner or operator may have abandoned the tank before pumping it "dry."
- A low-level automatic cut-off pump switch might make the tank seem "empty."

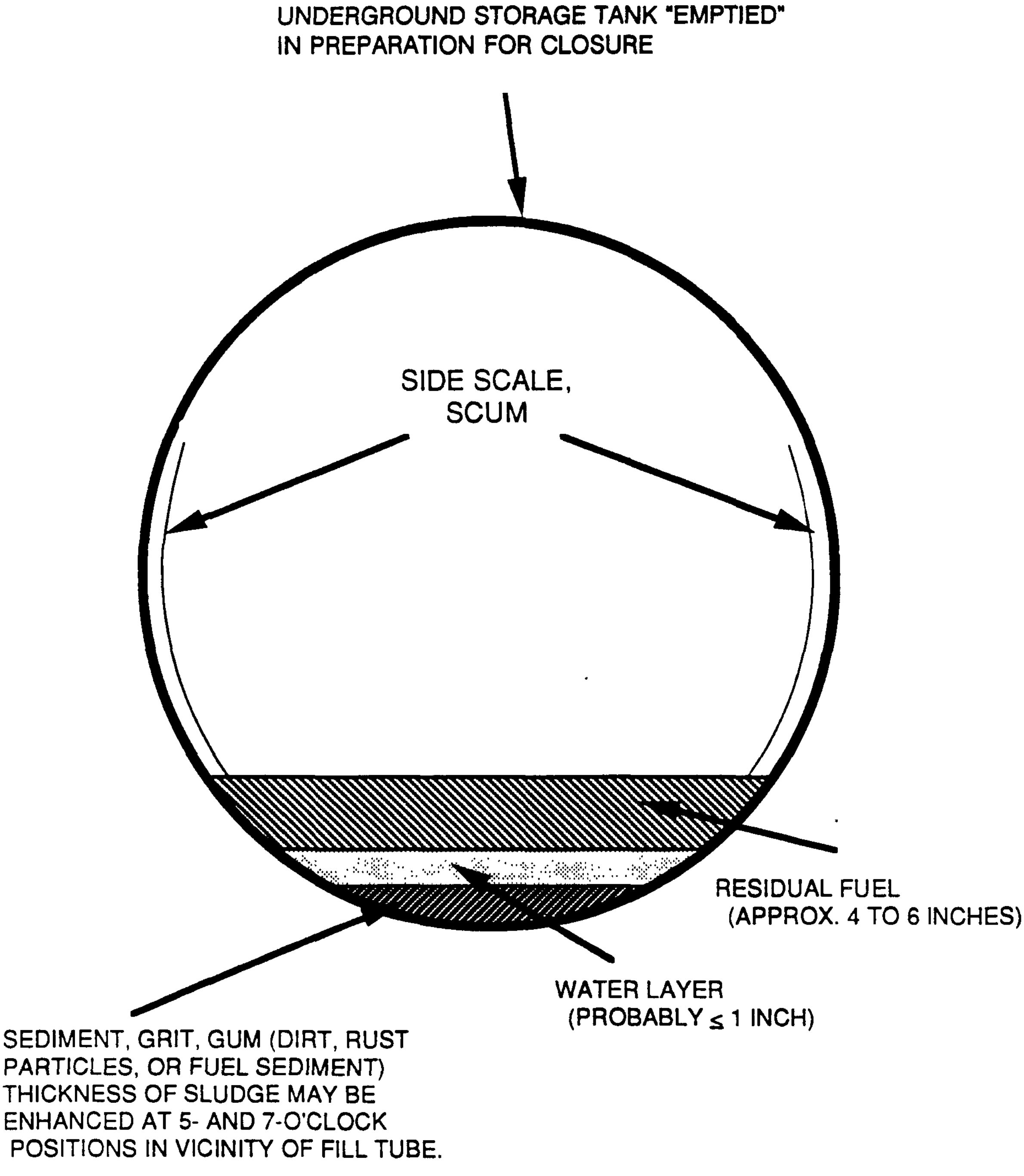


Figure 3. Schematic of UST residuals.

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. Rather they pump it into the same tank truck used to collect rinses and/or residuals from other product tanks. They then send the mixed fuel to a treatment facility which separates the product from the water phase for disposal or incineration.

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. Some interviewees said such materials could be observed on the insides of tanks as discoloration or thin, sticky film.

Gums and Tars--

Gums and tars (high molecular weight organics left by heavy fuels) are constituents of petroleum distillates. A small spill of gasoline on an impervious surface (e.g., a car's fender) will, for example, leave a sticky, viscous film after a few minutes of evaporation. It seems probable that they would build up on the insides of tanks in the area between the high and low level marks. These wall areas would be alternately exposed to fuel when the product level was high and then gradually to vapors as the product level fell. Efforts to obtain quantitative data on the concentration of gums or tars in gasoline and diesel oil from refiners and wholesalers were abandoned when major companies could not provide such data.

Polymers--

Polymers formed in situ from reactive components of the fuel (e.g., unsaturated hydrocarbons) can sink to the bottom of the tank. In the study mentioned earlier, Delta Environmental reported analyses of selected hydrocarbons and total hydrocarbons in composite residuals found at one collection center [4]. Table 3 displays these data.

Sediment--

Sediment present in product upon delivery to an UST would gradually sink to the bottom of the tank. Refiners and wholesalers were unable to give any data about quantities of sediment in their product. Some respondents explained that visual clarity was considered a satisfactory check for excess sediment and water, thus eliminating the need for quantitative measurements.

Sorbed Components--

Certain fuel components can 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 present in product upon delivery;
- condensation in the tank from infiltrating moisture-laden air;
- surface runoff entering fill pipe; and
- groundwater leaking into tank or fill pipe.

TABLE 3. BENZENE, TOLUENE, ETHYLBENZENE, XYLENE, AND TOTAL HYDROCARBONS IN UST BOTTOM RESIDUALS[a]

Sample number	Parent material of sample[b]	Concentration (mg/kg)				
		Benzene	Toluene	Ethylbenzene	Xylene	Total hydrocarbons
MDL[c]		0.12	0.12	0.12	0.12	1.0
1	Gasoline	110	270	30	140	1700
2	Mixed oil	5.1	11	1.8	8.8	120
2[d]	Mixed oil	4.9	10	1.8	8.9	110
3	Mixed oil	39	100	13	67	800
4	Mixed sludge	1.9	12	6.2	19	270
4[d]	Mixed sludge	1.5	8.4	4.4	13	180
5	Mixed sludge	190	310	44	210	2400
6	#6 Fuel oil	1.0	2.4	1.0	6.0	86
7	#2 Fuel oil	3.8	11	1.9	9.4	109
7[d]	#2 Fuel oil	4.0	10	1.7	8.3	110
8	Dried residual	7.1	160	41	210	1800

[a] Data from Reference 4.
[b] Sample descriptions:
1. Sludge at bottom of gasoline storage tank
2. Drying mixed oil residuals in two different tanks
3. Drying mixed oil residuals in two different tanks
4. From mixed sludge drums
5. From mixed sludge drums
6. From drum of #6 fuel oil residuals
7. From drum of #2 fuel oil residuals
8. Composite of dried residual from a number of open tanks

[c] MDL - Method Detection Limit
[d] Duplicate analysis

There are many mechanisms by which water can enter an UST. First, small amounts of water are ubiquitous in nearly all stages of petroleum processing, transport, and storage. It is pumped out of the ground with crude oil, used as ballast in oil tankers, used as a marker (via inclusion of a slug of water) in pipeline transport, and trapped in the large storage tanks at so-called "tank farms" of major refiners and distributors. When approached, such sources did not offer any quantifiable information about the amount of water conveyed to a retail outlet.

Water can accumulate in a tank dissolved in the product delivered to the site. This water is likely to be near the solubility limit and, in summer at least, to be warmer than ground temperatures. As the fuel enters the UST and cools down, the solubility limit falls, causing some water to come out of solution and form, or add to, a separate aqueous phase. This phase separation process can be especially troublesome for aviation fuels which, after being put in aircraft fuel tanks, are subjected to very low temperatures at high altitudes.

The contribution of this phase separation process is estimated to be one gallon of water per tank refill for gasoline USTs. This is based on the following assumptions:

- dissolved water is present at the solubility limit in gasoline (taken as 1 g/L);
- the UST is filled with 40,000 L of gasoline;
- the solubility limit is reduced by 10% as gasoline cools in the UST, causing 0.1 g/L to separate;
- total phase separation = 0.1 g/L x 40,000 L = 4 kg = 4 L (approx. 1 gal).

Water is also suspected to enter USTs via the following means: entry of moist air through the fill tube when open; runoff of surface water into an open fill tube; and infiltration of runoff or groundwater into the tank via pipe joints, cracks or corrosion pit holes.

Water residuals in USTs may play a significant role in the internal corrosion of steel tanks. Several surveys have shown that such corrosion is fairly common, although external corrosion is roughly three times more important. The presence of water enhances corrosion. Water existing as condensate on tank walls or as a layer on the bottom can cause internal corrosion.

Water present in an UST can exist partly as a separate phase and partly in solution with the fuel. Water present as a separate phase may remain in colloidal suspension throughout the volume of fuel or -- if given time to settle -- lie as a separate layer below the fuel.* The solubility limits for water in gasoline and in diesel oil are not known precisely but are judged on the order of 1,000 mg/L and 100 mg/L, respectively. Significantly larger amounts may be present in solution with fuels containing hydrophilic additives such as ethanol or methyl tertiary-butyl ether (MTBE).

It is a common practice for owners of USTs in service to check for the presence of water (and sediment) with a dip stick prior to refilling the tank. The end of the dip stick is coated with a special paste that changes color upon contact with water.

The "rule of thumb" used by some gas stations prescribes limiting the depth of water to 1 in. They pump out any excess over this limit prior to refilling the tank. As shown in Table 1, 1 in of liquid in a 10,000-gal tank represents about 12-18 gal. In places where water input rates are high or in tanks where water is not periodically monitored/removed, the volume of water could clearly be much higher.

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).

* Pure water has a density of about 1.0 g/ml and seawater about 1.028 g/ml. Automotive gasoline and No. 2 fuel oil are lighter, with respective densities of 0.71-0.75 g/ml and 0.87-0.90 g/ml.

Tank Rust or Scale

The survey and information cited by respondents indicated that steel tanks are likely, over time, to shed rust particles (iron oxide, Fe_2O_3), and iron scale. This internal corrosion may be caused by galvanic action* or bacterial action. (See **Microorganisms** below.)

Concentrated internal corrosion often occurs directly under the fill tube where the gauge stick strikes the bottom of the UST. The use of a strike plate, thicker steel under the fill tube, or limitation of "sticking" measurement can easily prevent tank failure due to corrosion in this location.

As noted above, surveys of UST removals have clearly demonstrated the importance of internal corrosion to UST failures. In one review of 1,900 failures, for example, 29% had holes due to internal corrosion, 90% due to external corrosion [5]. Other surveys have indicated that internal corrosion constituted only 5% of corrosion incidents in tanks [6]. A study in Suffolk County, NY, indicated that a 20-year-old steel tank had about a 3% probability of failing due to internal corrosion [7].

Some rust and scale may remain on tank walls, while portions will drop and accumulate on the bottom. The total volume of side and bottom scale is thought to be relatively small, perhaps no more than one liter.

Table 4 presents one set of speculative estimates on the amount of rust generated in old steel tanks. It assumes that 0.1% of the mass of the steel tank is converted from Fe to Fe_2O_3. The 0.1% value is arbitrary but perhaps not unreasonable, given that corrosion usually occurs in concentrated spots (pits), and that any larger average loss would probably imply leakage through corrosion holes. These calculations forecast 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.

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.

* Galvanic action occurs when dissimilar metal surfaces at different places in the tank are linked electrically by water.
**Much information in this subsection is drawn from Reference 8.

TABLE 4. CALCULATED AMOUNTS OF INTERNAL CORROSION FOUND IN STEEL TANKS OF DIFFERENT SIZES[a]

Capacity (gal)	Diameter (in)	Length (in)	Wall thickness (in)	Calculated weight (lb)	Weight of corrosion product if 0.1% loss[b] (lb)
300	38	60	.1046	280	0.40
550	48	72	.1793	736	1.05
1,000	48	128	.1793	1,165	1.66
2,000	64	144	.1793	1,800	2.57
4,000	64	288	.1793	3,270	4.67
6,000	72	341	.25	6,050	8.64
8,000	96	256	.25	6,500	9.29
10,000	96	324	.25	7,950	11.36
12,000	96	384	.25	9,240	13.20
20,000	126	372	.3125	15,300	21.86
30,000	126	558	.375	24,200	34.57

[a] Calculations are rough estimates of what might be found inside a steel tank after many years of service, assumption of 0.1% weight loss due to internal corrosion.

[b] Corrosion products assumed to be in form of iron oxide (Fe_2O_3).

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. They perform anaerobic respiration by oxidizing certain organic compounds or H_2 , and reducing sulfate -- and often other reduced sulfur compounds -- to hydrogen sulfide. The sulfide can then react with iron to form an iron sulfide (FeS) precipitate that may expand the solid portion of UST residuals. During the course of hydrocarbon metabolism, other microorganisms can produce organic acids, such as acetic acid, which can also contribute to corrosion.

Corrosion is usually evidenced as pits below microbial mats. There are numerous unproven theories about the biochemical and chemical basis for this corrosion. No data were available on the rates of microbial corrosion to be expected in USTs.

Tank/Site Factors Affecting Residual Quantity and Composition

It is possible to identify a number of tank and site factors that control the nature, quantity, and composition of UST residuals. Some of these factors include tank design, use, cleaning procedures, repair practices, age, total volume throughput, site factors, hydrogeology, meteorology, product type, and product composition. For example, the distance from the bottom of the suction line (or submersible pump intake) to the tank bottom is a key aspect of tank design. It defines the minimum volume the owner/operator can leave at closure. The location of pipes and pumps, materials of construction, corrosion protection, and tank tilt all will affect residuals throughout the tank's useful life and at closure.

Age and volume throughput are related to the accumulation of rust, sediment, and gum, etc. However, a large volume throughput might tend to flush out some residuals, since they are stirred up (and dispersed throughout the product) every time the tank is filled. The hydrogeological and chemical profiles of the site will affect residual composition, as will the rainfall, humidity, and temperature in the area. Finally, the product itself, its additives, the residuals present at delivery, and the suitability of the material for microbial growth will increase or lessen the accumulation of non-product residuals.

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;
- frequent testing for water, with removal as necessary, can prevent the buildup of a water layer;
- corrosion prevention measures (e.g., cathodic protection, protective coatings, and use of biocides in the product) will reduce amounts of rust and scale generated; and
- use of biocides and/or elimination of tank water will control growth of microorganisms.

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 use of biocides and elimination of water can control the growth of microorganisms. This would lessen corrosion and rust generation in addition to reducing residual mass. New tank design could reduce infiltration of foreign objects found in bottom residuals.

SECTION 4

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 should entail minimization of the following:

- environmental/health hazards presented by the tank and its residuals;
- explosion hazard of removing the UST;
- volume of secondary waste generated; and
- cost of UST closure.

Tanks in Use

Although USTs are emptied or cleaned for decommissioning and removal or for closure in place, tanks still in use are cleaned for reasons such as the following:

- to adhere to a regular maintenance program;
- to clean up contents of a tank that has become contaminated; or
- to ready a tank for storage of a different product.

General Procedures

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. The American Petroleum Institute's recommended procedures (API 1604) [1] call for filling the tank with water followed by sequential removal of floating product and water.

The "rinse cycle" may involve the following steps or a combination of some of them:

- filling the tank with water;
- rinsing the tank with spray from a low-pressure hose;
- rinsing the tank with high pressure water;
- steam hosing;
- addition of a detergent.

For USTs with especially viscous residuals, a light fuel oil (e.g., No. 2), sprayed into the tank, may assist in the cleaning. This fluid, when suctioned out of the tank, may then be filtered and recycled for additional cleaning cycles.

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.

Cutting manholes in tanks is a dangerous procedure. Several contractors stated that they do not cut open tanks because of the explosive potential, and at least one regulatory agency (Sacramento County, CA) requires that no tank be cut open on-site because of the risk of explosion. This risk 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. Worker protection may be the more stringent basis for regulation. 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.

Most often, disposal facilities use a hydraulic press to crush the tank. Steel tanks are then sold as scrap iron, while FRP tanks (after shredding) are landfilled. Occasionally, steel tanks are cut into pieces using saws or torches, before being sold as scrap iron, although this method seems to present more hazards than the press.

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" [1] and API's Publication 2015 "Cleaning Petroleum Storage Tanks" [2]. Publication 1604 does not address cleaning methods explicitly, but it does describe the removal process. A summary of the steps recommended in API's Recommended Practice 1604 is illustrated in Figure 4 and presented in Appendix B.

Publication 2015 describes a recommended cleaning process in the format given below:

1. Completing preliminary preparations
   - externally inspecting the tank
   - surveying the immediate area
   - training/indoctrinating the crew
   - inspecting equipment

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 [This is probably the most commonly used procedure, but other methods may be employed.]

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
   - removing sludge
   - sending sludge 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. Appendix C lists the various cleaning procedures identified through the survey. Some interesting variations suggest the following:

- 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. This was presented as an alternative to the use of a manhole.

- Using a degreaser or detergent as the rinse agent (e.g., Citrikleen or Slix).

- Circulating filtered fuel from the UST back to the tank, possibly for several cycles, rather than introducing additional volumes of wash water.

- Rinsing with a caustic (high pH) detergent solution that acts as an emulsifier (e.g., Mark Clean 55).

The selection of such variations may depend on factors such as the type of residuals, the future use or disposal of the tank, the tank's size and design, and the availability of water.

Secondary Wastes

Secondary waste streams from UST cleaning operations consist of the tank residuals and rinses. Spent rinses are generated 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.

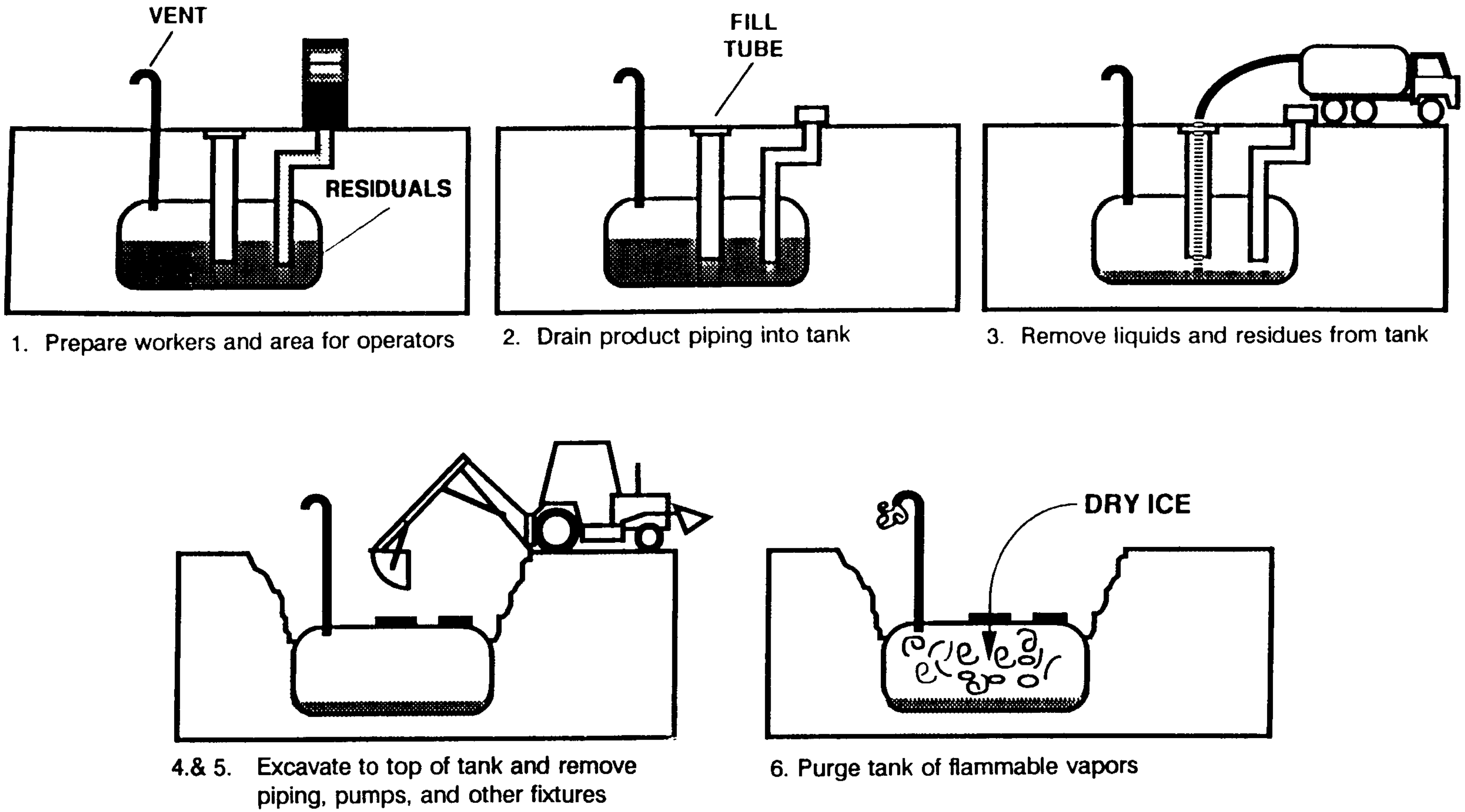
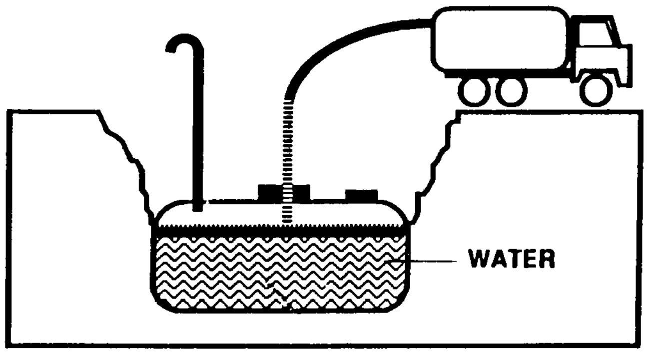
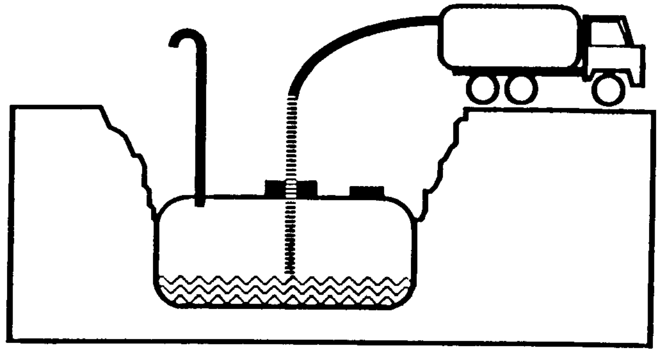


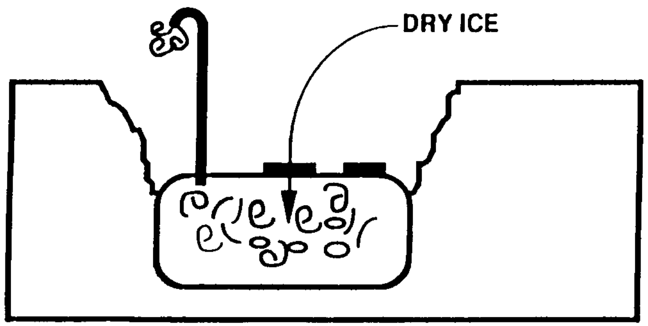
Figure 4. Schematic of standard UST cleaning procedure (API Recommended Practice 1604, Refer to Appendix B for description of steps).



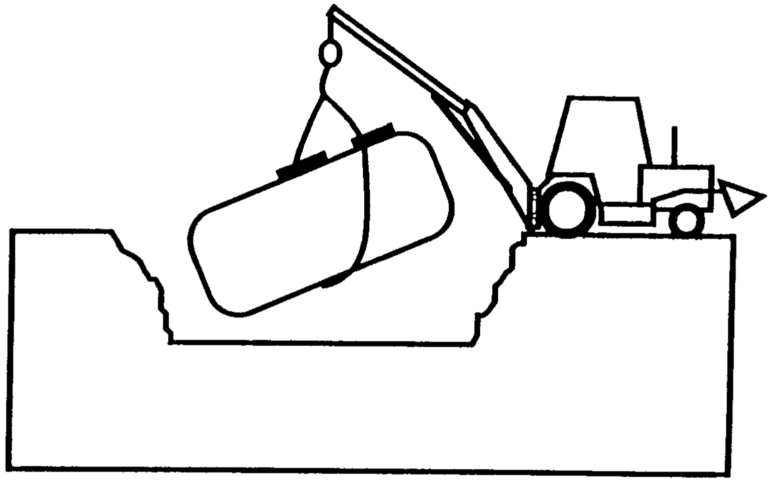
7. Fill tank with water



8. Pump out water



9. Test tank atmosphere for vapors



10.& 11. Plug all holes, excavate, and remove tank

Figure 4 (Continued). Schematic of standard UST cleaning procedure (API Recommended Practice 1604, Refer to Appendix B for description of steps).

Treatment--

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.

Quantity and Composition--

Secondary wastes from UST cleaning operations fall into three groups:

- "Pure" residuals removed from the UST (and stored separately) before cleaning begins [70-90% product, e.g., gasoline or diesel oil];

- Spent rinse solution -- usually a simple water wash sprayed into the UST, with detergents sometimes added; and

- Combined wastes -- produced when some cleaning companies pump the raw residuals and rinse/s into the same tank truck at the UST site.

No reliable data were received on the composition of the secondary wastes. A "combined waste," for example, might be a mixture of fuel, water, detergent, side scale, gum, and bottom sediment. Depending on the cleaning method, some of these components might not be transferred from the UST to the secondary wastes. All waste groups are likely to have emulsion characteristics, i.e., small droplets of one phase dispersed throughout the other phase. The use of detergents would increase the degree of emulsification.

Available Treatment Techniques--

Very little information has been obtained on actual treatment of UST secondary wastes. However, an initial separation of hydrocarbon liquids from aqueous phases (in a large settling tank) is a potential solution. The aqueous phase, after varying degrees of pretreatment, may be acceptable to a sanitary sewer leading to a municipal biological treatment plant. The hydrocarbon phase could be treated as a waste oil (i.e., shipped to an oil re-refiner), incinerated, or drummed and sent for proper disposal.

Based upon industry's long experience with oil/water wastes, there are numerous treatment techniques available for secondary waste streams from UST cleaning. Some of the more important treatment categories and schemes are listed in Figure 5, while Table 5 lists potential treatments for each residual phase. Nearly all of these unit operations have been demonstrated in full scale operations and many can be purchased in standard sizes and designs from vendors of pollution control equipment. There is, at present, limited capacity for the incineration of hazardous wastes in the United States (approximately 300,000,000 gal. per year [10]); the total volume of UST residuals that might be removed in the next five years, perhaps 10,000,000 gal, would not significantly stress this capacity.

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.

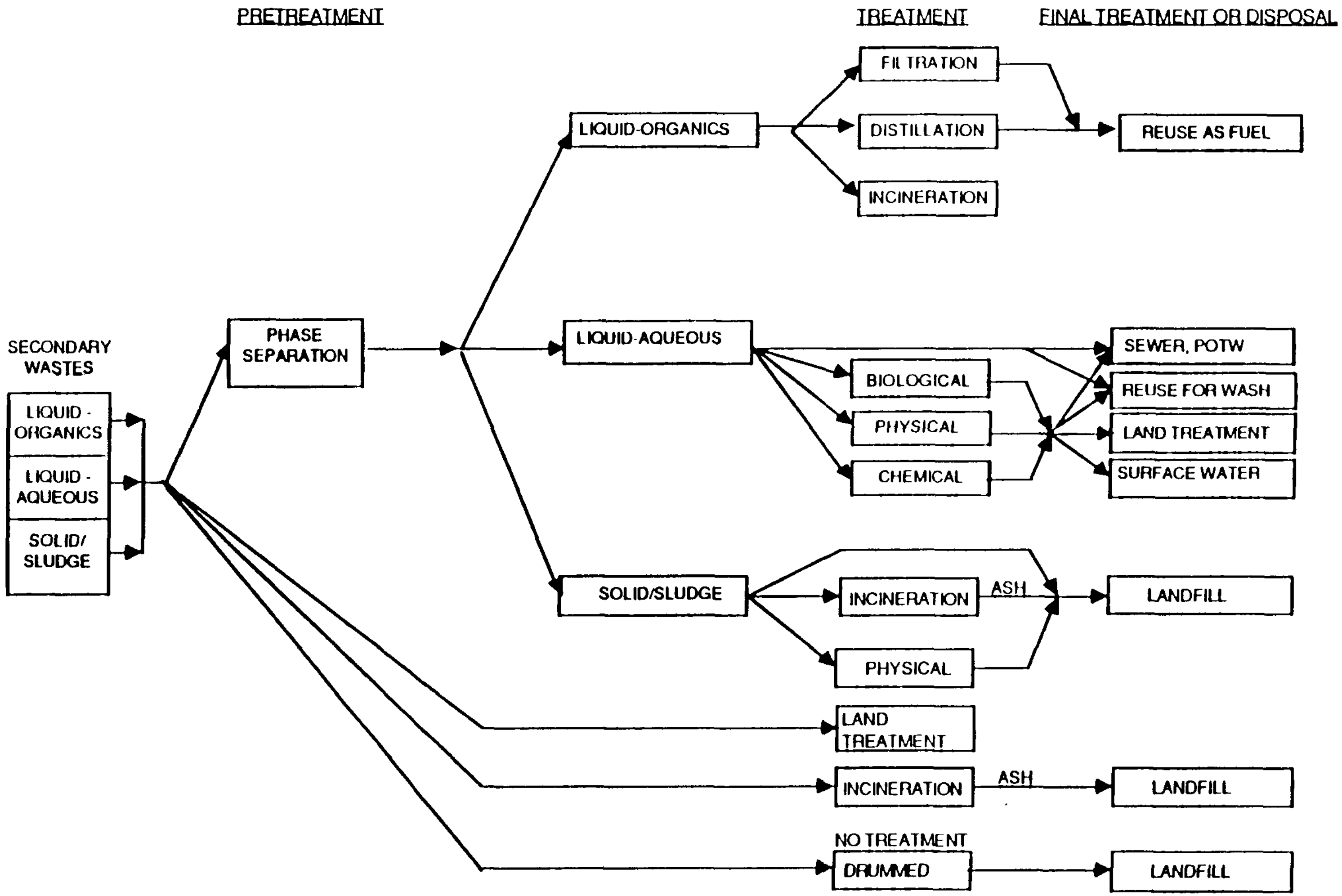


Figure 5. Potential treatment scheme for secondary wastes.

FIELD STUDIES OF UST CLOSURES

As previously indicated, the Phase I assessment of closure activities found that the tank cleaning methods currently in use appear to be able to satisfactorily clean most gasoline and light oil tanks. This assessment was made on the basis of interviews and limited observations; no data indicated just how clean the tanks actually were. Furthermore, the survey found that there was no generally accepted method of tank cleaning, nor were there any generally accepted criteria for assessing tank cleanliness. Accordingly, Phase II was formulated to collect information at actual UST closure sites to determine:

- Background information on USTs/sites that relates to the nature of the residuals;
- Detailed descriptions of 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.

TABLE 5. POTENTIAL UNIT TREATMENT PROCESSES FOR SECONDARY WASTES

Phase separators	
Physical	Gravity oil/water (e.g., API separator) Dissolved air flotation Induced air flotation Fabric filtration Ultrafiltration
Chemical	pH adjustment Emulsion breakers Solvent extraction
Aqueous phase treatment	
Physical	Adsorption on carbon (or other sorbent) Filtration (fabric or granular media) Air stripping
Chemical	Flocculation Coagulation Oxidation
Biological	Activated sludge Trickling filtration Lagoons
Organic phase treatment/use	
Incineration Reuse as fuel Use of asphalt manufacture	
Sludge/solids phase treatment	
Incineration (ash to landfill) Landfill Solidification/encapsulation (product to landfill)	

Field case studies were conducted in concert with a company that offers a range of environmental services, including UST cleaning and removal. The company agreed to compile a list of representative UST closure jobs that would meet the objectives of the field study. If the UST and proposed cleaning technique at a particular job were of interest to the study, the study group requested permission from the site owner/operator to monitor the job and perform sampling during the normal course of the closure. Monitoring and sampling activities followed the requirements of a Quality Assurance Program Plan (QAPP). Cleaning techniques were not modified for the study; however, normal variations in procedures were made in response to site-specific conditions, including the nature and amount of residuals found within the tank.

The field study focused on tanks containing gasoline and No. 2 fuel oil. Time and climatic constraints limited the field program to three tanks for each product. Where available, the following background information was recorded for each of the six USTs:

- Product content
- Dimensions
- Capacity
- Material of construction
- Details about installation
- Age
- Condition upon removal
- Depth in ground
- Water table depth

Much of the background information associated with the six tanks is similar, especially the material of construction, condition, and product. Table 6 presents a summary of this data.

UST Removal and Cleaning Procedures Observed

Observers noted the following common steps in cleaning procedures:

1. Residual product (No. 2 fuel oil or gasoline) vacuumed from UST to tank truck.

2. For gasoline tanks, dry ice added to displace oxygen with carbon dioxide.

3. Overlying soil excavated (some tanks pulled from excavation pit at this point).

4. Manhole cut into top or side of tank to allow worker entry.

5. Tank interior scraped (manually) to remove residual sludge. (Saw dust added in one case to absorb residual sludge.)

6. Tank interior rinsed with tap water and rinsed water vacuumed into tank truck. After rinse, UST pulled from excavation pit.

7. Tank exterior scraped clean before transport to tank yard.

Details of the actual procedures used at each tank were recorded. Visual estimates of the cleaning effectiveness were also recorded.

TABLE 6. SPECIFICATIONS OF UNDERGROUND STORAGE TANKS (USTs) SAMPLED

Site No.	Size (gal)	Fuel type	Material type	Condition	Age (yrs)	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

Sampling and Analysis Procedures Employed in Characterizing Residuals

Residual Volume--

Estimates of the volumes of residuals in the UST before and after cleaning (and of secondary waste generated) were calculated using dip sticks, simple volume levels observed, pumping rates and durations, or visual proportions. (Inch measurements in cylindrical tanks can be converted to fluid volumes by standard trigonometric functions as described in Section 2.) Where possible, volume estimates were obtained for the following:

- Liquid organic phase: before and after cleaning
- Aqueous phase: before and after cleaning
- Rinse solutions: amount used for cleaning

Samples Collected--

In general, three (3) types of samples were collected from each UST for laboratory analysis:

- Original fuel product (if present)
- Bottom residuals
- Aqueous rinse

Sampling Points and Tools--

Original fuel product remaining in the UST was sampled prior to removal using a clear, plexiglass bailer. Once the fuel product was removed via pumping, bottom residuals were sampled with plastic buckets. Once these sludge-like materials were completely removed, rinse water was added to the UST and a workman entered the tank to scrub the inside walls. The rinse water containing the residuals from the walls was pumped out of the tank and sampled. For this study, a final rinse was performed on each of the six "cleaned" USTs to evaluate cleaning effectiveness. This "final rinse," with tap or bottled water, was not part of the regular cleaning procedure. In addition, measurements of vapor concentrations inside the UST were made at various stages in the cleaning/closure procedure.

Laboratory Parameters and Analytical Methods--

The residual product, bottom residuals, and used rinses were analyzed for a series of chemical parameters. Table 7 outlines these parameters and the respective analytical methods used. Table 8 lists the specific RCRA metals and the reported detection limits for which the tests were run. Table 9 shows the specific VOCs targeted in the analyses. Generally, detection limits for VOC water blanks were in the range of 0.005-0.010 ppm. However, when 100- or 200-fold dilution of fuel samples (or TCLP extracts) was required, VOC detection limits ranged from 500-1000 ppm.

TABLE 7. LABORATORY PARAMETERS AND ANALYTICAL METHODS USED

Parameters	Fuel Product	Sludge	Aqueous Rinse	EPA Method No. [11,12,13]	Method Description
Total Petroleum Hydrocarbons	X	X	X	418.1	Freon extraction/IR
Oil and Grease			X	413.2	Extraction/IR
Flash Point	X	X		1010	Pensky-Martins Closed Cup
5-day Biochemical Oxygen Demand			X	405.1	
Total Organic Carbon			X	415.1	Combustion
pH			X	150.1	Electrometric
Metals	X	X	X	6010 700 7471	ICP AA CV
Volatile Organic Compounds	X	X	X	624 8240	Purge and trap GC/MS
TCLP Extraction:					ZHE
Metals		X			
Volatile Organic Compounds		X			
Semivolatile Organic Compounds		X			

TABLE 8. RCRA METALS AND THEIR DETECTION LIMITS

Metal	Detection Limit (ppm)				
	Aqueous and TCLP Blanks	Fuel Blanks		Sludge Blanks	
		Base oil[1] (Site 1)	Kerosene[2] (Sites 2-6)	Soil (Site 1)	Solid (Sites 2-6)
Arsenic	0.02	0.50	0.1	0.02	0.4
Barium	0.02	2.0	0.25	2.0	2.0
Cadmium	0.10	1.25	0.5	0.1	1.0
Chromium	0.25	3.125	1.0	0.25	2.5
Lead	0.25	6.25	1.0	0.5	2.5
Mercury	0.0005	0.5	0.05	0.5	0.2
Selenium	0.02	0.1	0.10	0.01	0.4
Silver	0.10	0.3	1.0	0.03	1.0

(1) Base oil is the oil used to dissolve the metals.

(2) Kerosene is the petroleum base used to dissolve the metals for analytical purposes.

TABLE 9. LIST OF CHEMICALS TARGETED FOR IN VOC ANALYSIS

CAS Number	Compound
74-87-3	Chloromethane
74-83-9	Bromomethane
75-01-4	Vinyl chloride
75-00-3	Chloroethane
75-09-2	Methylene chloride
75-69-4	Trichlorofluoromethane
67-66-3	Chloroform
107-06-2	1,2-Dichloroethane
71-55-6	1,1,1-Trichloroethane
56-23-5	Carbon tetrachloride
79-01-6	Trichloroethene
124-48-1	Dibromochloromethane
79-00-5	1,1,2-Trichloroethane
71-43-2	Benzene
10061-01-5	cis-1,3-Dichloropropene
110-75-8	2-Chloroethyl vinyl ether
75-35-4	1,1-Dichloroethene
75-35-3	1,1-Dichloroethane
156-60-5	trans-1,2-Dichloroethene
75-27-4	Bromodichloromethane
79-34-5	1,1,2,2-Tetrachloroethane
78-87-5	1,2-Dichloropropane
10061-02-6	trans-1,3-Dichloropropene
75-25-2	Bromoform
127-18-4	Tetrachloroethene
108-88-3	Toluene
108-90-7	Chlorobenzene
100-41-4	Ethylbenzene
1330-20-7	Total xylenes
95-50-1	1,2-Dichlorobenzene
541-73-1	1,3-Dichlorobenzene
106-46-7	1,4-Dichlorobenzene

Hazardous Characteristics and Chemical Composition--

Various UST residuals were sampled and analyzed for both hazardous characteristics (e.g., ignitability and corrosivity) and chemical composition. The analyses specifically included the following:

Characteristics	Composition
Ignitability	Volatile Organic Analysis (VOA)
Corrosivity	Total Petroleum Hydrocarbons (TPH)
Toxicity Characteristic Leaching Procedure (TCLP)	Oil and Grease
	Biochemical Oxygen Demand (BOD)
	Total Organic Carbon (TOC)
	pH
	RCRA Metals (As, Ba, Cd, Cr, Pb, Hg, Ag, and Se)

Modifications to this sampling and analysis program were made on a case-by-case basis after considering site-specific conditions. For example, in some cases there was no material present to sample (e.g., no aqueous phase present before cleaning, or no aqueous rinse generated).

Field Study Results

The results of the preliminary tank cleaning survey are based on three types of measurements: (1) the volume of residual sludge and aqueous rinse associated with the USTs after cleaning; (2) the concentration of chemical constituents found in these residuals; and (3) the organic vapor concentrations found inside the USTs after cleaning.

Because chemical constituents in the residuals may originate from scaling and rusting of the tank body, it is important to note that the six tanks analyzed in this survey were all of steel construction, that their ages ranged from 11 to 20+ years and that they all contained petroleum distillates, either No. 2 fuel or gasoline (Table 6). Therefore, it may be inferred that the type and quantity of tank-related contamination in the UST residuals sampled in this survey should be similar.

Volume of Residuals Remaining in USTs 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. As indicated in Table 10, the residual volume estimates of either organic liquid, sludge or rinse vary between negligible amounts and 3 gallons of residual. These residual volumes are less than 1% of the total tank volumes. (Tank volumes were indicated in Table 6.) In addition, the volume of residual appears to be independent of the tank volume. 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. There were three types of samples collected and analyzed from the USTs in this survey: (1) fuel product remaining in the tank before removal and cleaning; (2) sludge remaining in the tank after the fuel product was pumped out of the tank; and (3) aqueous rinse used to clean the tank after the sludge was removed.

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 11). 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 in No. 2 fuel. Metal concentrations were either below the detection limit or exhibited 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 non-fuel 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.

TABLE 10. RESIDUAL VOLUME ESTIMATES IN USTs BEFORE AND AFTER CLEANING

Site No.	Volume of Residual Before Cleaning (gal)			Amount of Rinse Used in Cleaning (gal)	Volume of Residuals After Cleaning (gal)		
	Organic Liquid	Aqueous Liquid	Sludge		Organic Liquid	Sludge	Rinse
1	4,400	17	<1	25	1	None	1-2
2	800	None	1	None*	None	1	None*
3	94	None	70	49	None	None	None
4	90	10	7	28	<<1	<<1	3
5	5	5	1	10	None	None	1
6	55	5	None	25	None	None	<1

* Sawdust used instead of water.

TABLE 11. SUMMARY OF TYPICAL ANALYTICAL RESULTS FOR FUEL PRODUCT IN USTs BEFORE CLEANING

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

[a] See Tables 8 and 9 for list of chemicals analyzed.
[b] BDL - below detection limit.
[c] Average of two values.
[d] No analyses performed.

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 12) 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. Higher concentrations of arsenic, barium, cadmium, chromium, lead and silver were found. 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. According to the removal company, 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 13) 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 (Federal Register, Vol. 55, No. 61, March 29, 1990), bottom residuals from two of the gasoline tanks would be considered hazardous waste sludges by the EPA. The regulatory levels and exceedances are shown in Table 14. The only unexplained TCLP result is the presence of methylene chloride at site No. 1; the chemical may have been introduced during the laboratory analysis.

Aqueous Rinse--

The rinse analyzed in this survey was intended to simulate the rinse water used during the final rinse of the fuel tanks. As indicated in Table 15, 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 compared its quality with the guidelines for discharge of industrial waters containing the following materials to sewers serving POTWs (Publicly Owned Treatment Works): oil and grease, 5-day BOD, TOC, and pH. The oil and grease measurements reflect the presence of high molecular weight organics in the fuel. BOD (Biochemical Oxygen Demand) is used as a measure of the amount of degradable organic material present in the waste, and TOC (Total Organic Carbon) 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 low 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 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 lower flammable limits for gasoline (> 1.2% by volume).

TABLE 12. SUMMARY OF ANALYTICAL RESULTS FOR BOTTOM RESIDUALS IN USTs DURING CLEANING

Site No.	Fuel Type	TPH (ppm)	Flash Point (°F)	Metals Detected[a] (ppm)		VOCs Detected[a] (ppm)	
1	No. 2	237,000	181	Arsenic	0.83[b]	Toluene	110
				Barium	5.7[b]	Ethylbenzene	196
				Lead	20.9[b]	Total xylenes	993
2	No. 2[d]						
3	No. 2	355,000	205	Arsenic	2.7[b]	Benzene	17
				Barium	157[b]	Toluene	133
				Cadmium	2.3[b]	Ethylbenzene	138
				Chromium	12.7[b]	Total xylenes	640
				Lead	59.2[b]		
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[b]	Benzene	624
				Barium	22.8	Toluene	639
				Cadmium	13.5[b]	Ethylbenzene	284
				Chromium	50.4[b]	Total xylenes	765
				Lead	232[b]		
				Silver	264[b]		
6[c]	Gasoline						

[a] See Tables 8 and 9 for list of chemicals analyzed.
[b] Average of two values.
[c] No bottom residuals in tank.
[d] No analyses performed.

TABLE 13. SUMMARY OF TCLP ANALYSES ON UST BOTTOM RESIDUALS

Site No.	Fuel Type	Metals Detected[a] (ppm)		VOCs Detected[a] (ppm)		Semi-VOCs Detected (ppm)	
1	No. 2	Barium	3.23	Methylene chloride	0.24	Naphthalene	0.10
		Cadmium	0.019	Acetone	20	2-Methylnaphthalene	0.41
		Chromium	0.005	Benzene	0.23	Acenaphthylene	0.002
		Lead	0.047	Tetrachloroethane	0.49	Diethylphthalate	0.033
				Toluene	0.69	Di-n-butylphthalate	0.044
				Ethylbenzene	0.15	Bis(2-ethylhexyl) phthalate	0.044
				Total xylenes	0.82		
2	No. 2[d]						
3	No. 2	Barium	10.5	Benzene	0.15[b]	Naphthalene	0.170
		Lead	0.83	Toluene	0.40[b]		
				Ethylbenzene	0.158[b]		
				Total xylenes	0.87[b]		
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-Dimethylphenol	0.39
		Lead	23.2	Total xylenes	14.3	Naphthalene	0.22
						2-Methylnapthalene	0.83
5	Gasoline	Barium	2.6[b]	Benzene	23.1	Phenol	0.51
		Lead	0.34[b]	Toluene	32.1	Benzyl alcohol	0.024
				Ethylbenzene	4.8	2-Methylphenol	0.63
				Total xylenes	23.2	4-Methylphenol	0.81
						2,4-Dimethylphenol	0.26
						Naphthalene	0.20
						2-Methylnaphthalene	0.028
6[c]	Gasoline						

[a] See Tables 8 and 9 for list of chemicals analyzed.
[b] Average of two values.
[c] No bottom residuals in tank.
[d] No analyses performed.

TABLE 14. 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

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, ethyl benzene 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.

The aqueous rinses resulting 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.

While most of the residuals lie on the bottom of the tank, some scale and gum may adhere to the side walls. The bottom residuals, although containing some gum and grit, consist mostly of pumpable liquids and therefore would not properly be considered sludge.

Despite the limits of explicit guidance available, tank cleaning and removal companies are apparently capable of removing most UST residuals with fairly simple cleaning techniques. The Phase II field observations, and sampling and analysis program, generally confirmed the Phase I findings on the effectiveness of relatively simple cleaning operations.

TABLE 15. SUMMARY OF ANALYTICAL RESULTS FOR AQUEOUS RINSE SAMPLES

Site No.	Fuel Type	TPH (ppm)	5-day BOD (ppm)	TOC (ppm)	Oil & Grease (ppm)	pH	Metals Detected[a] (ppm)	VOCs Detected[a] (ppm)
E1[c]	No. 2							
2	No. 2	156[b]	210	109		6.6	BDM[d]	Chloroform 0.016 Bromodichloromethane 0.009 Benzene 0.009 Toluene 0.082 Ethylbenzene 0.087 Total xylenes 0.332
3	No. 2	379[b]	330	646	405[b]	6.1	BDM	Chloroform 0.009[b] Benzene 0.015[b] Toluene 0.54[b] Ethylbenzene 0.039[b] Total xylenes 0.395[b]
4	Gasoline	20.3[b]	240	150	23.9[b]	6.0	Arsenic 0.047 Chromium 0.27 Mead 12.6	Benzene 4.98 Toluene 12.0 Ethylbenzene 3.57 Total xylenes 14.0
5	Gasoline	4.4[b]	2,165	1,168	12.5[b]	5.4	Cadmium 0.17 Chromium 0.33 Mead 4.2	Benzene 11.5 Toluene 28.1 Ethylbenzene 7.32 Total xylenes 24.0
6	Gasoline	74.3	35.0	33.7	83.1	4.7	BDM	Benzene 0.848 Toluene 31.4 Ethylbenzene 1.28 Total xylenes 3.89

[a] See Tables 8 and 9 for list of chemicals analyzed.
[b] Average of two values.
[c] No sample collected.
[d] Below detection limit.

CLOSURE

Participants in Tank Closure Operation

Like many construction or demolition jobs, the closure of an UST can involve several participants employed by a variety of private and public institutions. Figure 6 provides a schematic diagram of the potential participants in a tank closure operation. Certain entities shown as separate in this Figure (e.g., the waste hauler, TSD operator and dirt contractor) may in common practice be employees of the UST removal contractor or the subcontractors. The use of a single contractor prevents logistical and safety problems in collecting such a large number of individuals with minimal risk of harm to workers or the public from fires, explosions or toxic chemical vapors. A principal contractor can better institute and enforce a comprehensive health and safety plan (including proper communications and personnel protective equipment), while operating an efficient closure operation.

Wisconsin Survey--

In May 1988, the editors of Underground Tank Technology Update (UTTU) sent out about 130 tank closure questionnaires to state agencies. The results of this survey were published in August 1988 [9]. They indicated that some inappropriate UST closures and residuals disposal were suspected to have taken place in the past. The respondents at that time estimated that the number of USTs being abandoned in place equalled those being removed. By contrast, PEI's more recent survey of state UST officials showed tank removals to be far more common than closure in place by about a 10 to 1 ratio [3].

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 for individual tanks in the 1,000-10,000 gal range. The range of costs per unit tank size is a little narrower, $0.3-1.0/gal of tank capacity in most cases. Table 16 lists examples of actual costs paid, according to results of surveys done by the University of Wisconsin [9] and CDM in 1988. As noted in this table, extreme values of up to $36,700/tank and $8/gal of capacity were reported.

The cost variability represents the fact that the time and equipment requirements for tank cleaning and closure are very specific to the site and the situation. Key variables include the nature and depth of covering material (concrete, asphalt, soil), proximity to structures and underground utilities, amount of residuals remaining in the tank, level of worker protection required, equipment availability, inspection logistics and sample collection requirements. The type of cleaning method does not appear to play a significant role in the total cost.

Tables 17 and 18 present information on the total costs of cleaning and removal. Table 17 provides a compilation of price estimates for seven components in a tank closure sequence. Again, respondents reported costs with wide variability.

Table 18 provides estimates for labor, equipment and materials costs for three major steps in tank cleaning and removal. The total estimated cost ($10,920), which is at the high end of the range of actual 1988 costs (Table 17), indicates either a more complete coverage of all costs (e.g., some Table 17 costs may have excluded backfill or tank disposal, etc.) or an overly conservative approach. In this hypothetical example, labor accounts for 33% of the costs, equipment charges are 61%, and materials are 6%.

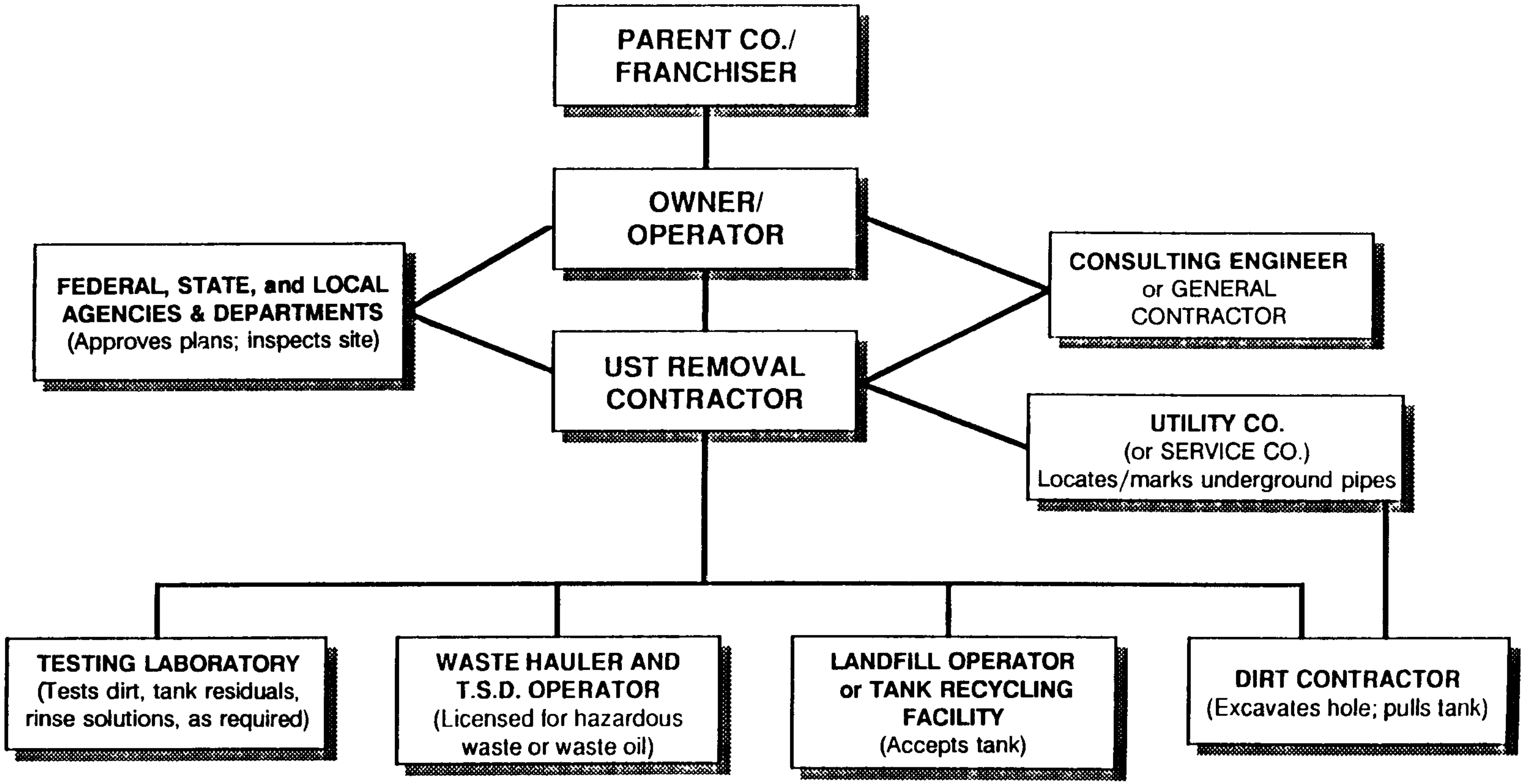


Figure 6. Schematic diagram of potential participants in tank closure operations.

TABLE 16. EXAMPLES OF COSTS FOR UST CLEANING AND REMOVAL[a]

Tank capacity (gal)	Cleaning and removal cost	
	$ per tank	$/gal of capacity
1,000	1,200-1,600	1.2-1.6
	5,000	5.0
	8,000	8.0
	805	0.8
≤2,000	1,400	0.7
	625	0.3
10,000	3,000	0.3
	5,100	0.51
	8,000	0.8
	3,500-5,000	0.35-0.5
	2,500-4,000	0.25-0.4
	2,000-4,000	0.2-0.4
	36,700	3.7
Unknown or mixed sizes	--	1.0-1.5
	3,000-3,500	--
	1,000-1,500	--
	6,500	0.54
	5,000	0.29
	6,500	1.0

[a] Data are a combination of survey results from contacts made by CDM in December 1988, and by the University of Wisconsin in mid-1988 [9]. Individual data points represent from one to six tanks.

TABLE 17. COST ESTIMATES FOR UST REMOVAL AND CLOSURE COMPONENTS[a]

Item/component	Cost estimate
	($)
Excavation	400-500 650 2,000-2,500[b]
	($)
Tank cleaning and removal	2,500-3,000[b]
Empty/purge/rinse/removal	3,000
Empty/inert/squeeze/removal	5,500-6,000
	($/gal)
Disposal of liquids and sludges	
Gasoline tank	1.25 1.49 1.75 1-3
Diesel tank	0.50 0.50
	($/tank)
Tank hauling	600 350[c]
Tank cut up	1,200 600 3,000
	($ for <40 drums for <100 miles)
Waste hauling (drums)	150
	($/gal)
Tank disposal in landfill	0.04 0.05 0.06 $250/tank
	($/sample)
Soil testing (TPH Analysis)	100 90 50 50 40

[a] Price estimates in December 1988 survey of tank cleaning and disposal companies (supplemented by CDM estimates) and analytical service laboratories. Each entry represents a price estimate from a different company.
[b] For a typical 10,000 gal gasoline tank.
[c] For a typical 10,000 gal tank.

TABLE 18. COST ESTIMATES FOR UST REMOVAL AND CLOSURE COMPONENTS[a]

Component	Cost item	Hours	Cost ($)
1	Preparation and excavation	4	
	Labor		
	1 Foreman		200
	1 Operator		340
	1 Operator		140
	2 Laborers		220
		Subtotal	900
	Equipment		
	Backhoe		200
	Loader		1,100
	Compressor		195
	Jackhammer		55
		Subtotal	1,550
		Component 1 total:	$2,450
2	Tank removal and shipping	4	
	Labor (same as #1)		900
	Equipment		
	Cascade		500
	Respirators		40
	Tractor trailer truck		250
	Explosion meter		70
	Vacuum tanker		340
		Subtotal	2,100
	Materials		
	Dry ice		200
	Oil absorbent pads		150
	Drums		150
		Subtotal	500
		Component 2 total:	$2,600
3	Cleaning and Backfill	8	
	Labor (two times #1)		1,800
	Equipment (two times #1)		3,100
	Bobcat		470
	Compactor		300
	Materials (miscellaneous)		200
		Component 3 total:	$5,870

[a] Costs based on conversations with CDM engineers and tank cleaning/removal companies in December 1988.

SECTION 4

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APPENDIX A

CASE BY CASE QUANTITIES OF UST RESIDUALS ESTIMATED BY PHONE SURVEY RESPONDENTS

Gasoline: Tank cleaning/removal contractor

- Approx. 1" of rusty water sitting on top of 1" of solids; nothing clinging to sides or bottom.
- About 10% of tank size.
- About 75 gallons for 20 yr old 10,000 gallon tank.
- More than 15-20 gallons/10,000 gallon tank of sludge that cannot be pumped out.
- About 2% of tank volume.
- Usually no residuals.
- Less than 75-100 gallons.
- 4" to 5" remaining in tank.
- 75 gal for 20 yr old 10,000 gallon tank; 0 gal for 5 yr old 10,000 gallon tank.
- 100-200 gallon for a 10,000 gallon tank.

Gasoline: Petroleum industry organization

- Little to no sludge; water removed throughout life of tank as operating procedure.

Diesel: Tank cleaning/removal contractor

- Approx. 55 gallons for 20 yr old 10,000 gallon tank; almost always <100 gallons.
- More than 15-20 gallons/10,000 gallon tank of sludge that cannot be pumped out.
- Typically no heavy sludges.
- Approx. 75 gallons for 10,000 gallon, 20 yr old tank.
- Approx. 2% of tank volume.
- Little sludge

Fuel Oil: Tank cleaning/removal contractor

- No. 2 and No. 6 fuel oil produce more sludges than gasoline.
- Tanks containing No. 4 and No. 6 have approx. 500 gallons of sludge.
- No. 6 fuel oil in a 10,000 gallon 20 yr old tank will have 1-2 feet of sludge.
- Most sludge found in No. 4 and No. 6 fuel tanks.

Spent Rinse Solutions: Tank cleaning/removal contractor

- 200 gal for 10,000 gallon tank.
- 100 gal for 10,000 gallon tank.
- 1/3 total of tank volume.

APPENDIX B

SUMMARY STEPS RECOMMENDED BY API FOR REMOVAL OF USED UNDERGROUND PETROLEUM STORAGE TANKS[a,b]

1. Prepare workers and area for safety operations:
   - Instruct/train workers
   - Eliminate sources of ignition
   - Prevent accumulation of vapors at ground level
   - Check for hazardous vapor concentrations

2. Drain product piping into tank:
   - Also cap or remove product piping.

3. Remove liquids and residues from tank:
   - Use explosion proof or air-driven pumps with proper bonding to tank or grounding
   - Monitor and evaluate all vapor emissions during process

4. Excavate to top of tank

5. Remove tank piping, pumps and other fixtures:
   - Cap or remove all non-product lines
   - Leave vent line connected; plug other tank openings

6. Purge tank of flammable vapors:
   - Can purge with inert gas (e.g., N_2), or carbon dioxide from dry ice; or
   - Can ventilate tank with air; or
   - Can fill tank with water.

7. Fill tank with water until floating product nears the fill opening:
   - Remove floating product

8. Pump out water

9. Test tank atmosphere for flammable or combustible vapor concentrations
   - Purge again, if necessary

10. Plug or cap all accessible holes except 1/8" vent hole

11. Excavate and remove tank

[a] Source: Reference 1 (Note: Several details relating to safety and regulatory compliance have been omitted for brevity).

[b] See Figure 4 for Illustration of Steps.

APPENDIX C

SUMMARY OF CLEANING PROCEDURES DOCUMENTED IN PHONE SURVEY

Source[a]	Comment
A, B, C	API 1604[b]
D	1. Empty tank as much as possible. 2. Triple rinse, with high pressure water (gasoline tank) or detergent (diesel tank). 3. Inert tank with N_2 or CO_2. 4. If necessary, enter tank and physically remove sludge. 5. Punch 6 holes, each 1 ft^2, to render tank useless. 6. Remove tank from ground.
E	1. Empty tank as much as possible. 2. Purge tank. 3. Cut opening(s) in tank. 4. Rinse, pump out rinse solution. 5. Remove tank from ground.
F	Proprietary process involving pumping fuel out of tank, filtering through vacuum, spraying fuel back into tank through nozzle, pumping, filtering, etc. May take numerous cycles to clean tank.
G	Warm water and detergent used as rinse agent; high-pressure not used because of safety hazard.
H	1. Empty tank as much as possible. 2. Inert with CO_2. 3. Cut opening in tank. 4. Worker enters tank, physically removes any sludge or scum. 5. Remove tank from ground.
I	1. Empty tank as much as possible. 2. Purge tank. 3. Cut 2-ft^2 opening in tank. 4. Worker enters tank: squeegees sides and bottoms; scrapes sides and bottoms; washes with water. 5. Rinse solution is pumped out. 6. Tank is removed from the ground.

Source[a]	Comment
J	1. Empty tank as much as possible. 2. Purge tank. 3. If tank has a manhole: rinse with caustic (high pH) detergent. 4. Pump out residuals and rinse solution. 5. Remove from ground, lay on its side.
K	1. Empty tank as much as possible. 2. Inert with CO_2. 3. Cut opening in tank. 4. Physically clean residuals. 5. Inert tank. 6. Remove from ground.
L	1. Empty tank as much as possible. 2. Triple rinse with high pressure steam. 3. Inert with CO_2. 4. Remove from ground.
M	1. Empty tank as much as possible. 2. Remove tank from ground. 3. Cut manhole in tank. 4. Worker physically removes residuals.

[a] Most of the sources are tank cleaning and removal companies who are describing their own standard procedures. In two instances, the procedures are those specified by a county agency.

[b] "Removal and Disposal of Used Underground Petroleum Storage Tanks," API Recommended Practice 1604, Second Edition, December 1987 (American Petroleum Institute, Washington, D.C.).

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16. ABSTRACT

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. 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, on-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.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
UST Residuals Tank Closure UST Clean Up Methods UST Physical/Chemical Properties		

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