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Technology Study of Gunite Tank Sludge Mobilization at Oak Ridge National Laboratory, Oak Ridge, Tennessee

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ABBREVIATIONS

D & D	Decontamination and decommissioning
DOE	Department of Energy
GAAT	Gunite and Associated Tanks
HIEE	Hydraulic impact end effector
INEL	Idaho National Engineering Laboratory
LDUA	Light duty utility arm
LLNL	Lawrence Livermore National Laboratories
LRM	Long-reach manipulator
MDS	Mobile Deployment System
MVST	Melton Valley Storage Tanks
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OU	Operable unit
PNL	Pacific Northwest Laboratories
SPAR	Spar Aerospace Limited
SRP	Savannah River Plant
SRS	Sludge removal system
TRIC	Tank Riser Interface and Confinement System
UHPW	Ultrahigh-pressure water
UMR	University of Missouri-Rolla
USTID	Underground Storage Tank Integrated Demonstration
VPL	Vertical Positioning Mast
WVDP	West Valley Demonstration Project

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EXECUTIVE SUMMARY

The Oak Ridge National Laboratory (ORNL) Gunite Tank Sludge Mobilization Technology Study was initiated to support the Gunite Tank Treatability Study effort. The technology study surveyed the methods and technologies available for tank cleaning and sludge mobilization in a radioactive environment. Technologies were identified and considered for applicability to the Gunite and Associated Tanks (GAAT) problems. These were then either accepted for further study or rejected as not applicable.

Technologies deemed applicable to the GAAT sludge removal project were grouped for evaluation according to (1) deployment method, (2) types of remotely operated end effector equipment applicable to removal of sludge, (3) methods for removing wastes from the tanks, and (4) methods for concrete removal. There were three major groups of deployment technologies: "past practice" technologies, mechanical arm-based technologies, and vehicle-based technologies. The different technologies were then combined into logical sequences of deployment platform, problem, end effector, conveyance, post-removal treatment required (if any), and disposition of the waste.

Many waste removal options are available, but the best technology in one set of circumstances at one site might not be the best type to use at a different site. No single technology is capable of treating the entire spectrum of wastes that will be encountered in GAAT. None of the systems used in other industries appears to be suitable, primarily because of the nature of the sludges in the GAAT Operable Unit (OU), their radiation levels, and tank geometries. Other commercial technologies were investigated but rejected because the authors did not believe them to be applicable.

Of the past practice methods, single-point jet sluicing is the main one with institutional experience. In addition, this method lends itself to combination with a mechanical arm-based deployment system as an end effector. Single-point jet sluicing would be a good method for removing wastes from tanks in the system that have not yet been cleaned, but it probably would not be effective on tanks W-5 to W-9, which were partially cleaned in the 1982–83 clean out campaign.

Of the mechanical arm-based deployment methods, the Light Duty Utility Arm (LDUA) system appears to be the best choice because development activities are progressing rapidly. Modifications to increase the payload and reach of the LDUA system would need to be incorporated to tailor the system to the needs of GAAT cleanup activities. No mechanical arm-based system has been demonstrated in the environment in which it would be used at ORNL. However, LDUA has the advantage of several years of intense design and development activities specifically for geared toward this purpose.

Of the vehicle-based deployment methods, the Remotec "Andros" series of vehicles appears to be the best of those examined. The other vehicle manufacturers either do not have direct nuclear experience or have products that are too undeveloped to warrant serious consideration. Other vendors of vehicle-based deployment methods could also exist but were not identified in this study; therefore, competitive procurement is possible.

The end effector technologies rated may all be used at one time or another depending on the type of waste encountered. End effector technologies are applicable to either vehicle-based or mechanical arm–based deployment methods. End effectors that had the highest scores were the high/medium-pressure confined sluicing and the backhoe or clamshell buckets.

The conveyance technologies may also all be used, depending on the end effector selected. The three-phase air conveyance appears to be superior and more versatile than other methods, but the details of the post-removal processing required are not yet available. This is because these systems have not been engineered for a radioactive application but only for development of the confined sluicing/three-phase air conveyance system. All types of pumps rated should give acceptable service for the soft sludge wastes but not for other types. Some type of drum removal system will probably be required for the removal of in-tank equipment, debris, and failed waste removal equipment.

Although dry methods generally were rated superior to wet methods for concrete removal, the confined sluicing method could double as a concrete removal method. The only variable in this is the water pressure used. It is possible that the concrete in the tank liners has deteriorated to the point that mechanical scraping with a bucket may be all that is required. Concrete removal technologies should be selected after more data is obtained on the condition of the tank walls.

The study did not consider post-removal sludge processing because the authors were instructed to assume that the sludges would be transported to the Melton Valley Storage Tanks as a final disposition. There should be additional studies made to determine the final disposition of the material as well as the processing required to convert it into a waste form that is compatible with this disposition. Post-removal sludge processing is an integral part of the GAAT OU cleanup effort.

1. INTRODUCTION[1]

The U.S. Department of Energy (DOE) Oak Ridge Reservation (ORR) is located in eastern Tennessee, approximately 25 miles (40 km) west of Knoxville. ORR is the site of the Oak Ridge National Laboratory (ORNL), one of three DOE facilities in the immediate area.

Liquid radioactive wastes generated by ORNL operations were initially stored in underground tanks built in 1943 as part of the original construction. Most tanks are located in two separate areas designated as the North Tank Farm and the South Tank Farm, but two tanks are at separate locations in close proximity to the South Tank Farm. Most of these tanks (also called the Gunite tanks) were constructed of reinforced concrete using the Gunite process, in which a Portland cement/sand mixture was applied through a spray nozzle over a preconstructed form of reinforcing metal bars (rebar) and wire mesh. Additional stainless steel underground tanks were added later in the North Tank Farm to support continuing ORNL operations. These Gunite and stainless steel tanks, along with the associated appurtenances—transfer lines, valve boxes, and dry wells required for the transfer and monitoring of wastes—define the Gunite and Associated Tanks (GAAT) Operable Unit (OU).

The ORNL Gunite Tank Sludge Mobilization Technology Study was initiated to support the Gunite Tank Treatability Study effort. The technology study surveyed the methods and technologies available for tank cleaning and sludge mobilization in a radioactive environment and recommends preferred alternatives for accomplishing these tasks. Technologies were identified by interviewing knowledgeable personnel in the field, surveying previous Energy Systems work on the subject, and conducting a literature survey to determine if any new commercial technologies existed. Many technologies were considered for applicability to the GAAT problems. These were then either accepted for further study or rejected as not applicable. The accepted technologies were evaluated using a graded scoring approach that takes into account the technologies' technical applicability, technical maturity, technical complexity, versatility, amount of development required, technical risk, potential for waste generation reduction, and compliance with regulatory and Environmental Safety and Health requirements. The technologies were then ranked and recommended for further investigation and evaluation. Lists of the information generated from the investigations are presented in Appendixes A-E.

2. PROBLEM DEFINITION

The liquid and solid materials initially stored in the GAAT OU tanks included mixed hazardous wastes containing heavy metals, and organics in trace quantities. The solids in some of the tanks contained uranium, plutonium, thorium, and other wastes that are now classified as transuranic. Although all liquids and most solids were removed from the tanks in the South Tank Farm and disposed of in 1982 and 1983, an estimated 70,000 gal of solids and soft and hard sludges (approximately 95% of the radionuclide inventory in the inactive storage system at ORNL) remain in them. Because their structural integrity cannot be verified and leaking tank appurtenances are allowing infiltration of water into several tanks, DOE and federal and state regulatory agencies have assigned a high priority to remediation of the tanks.

3. DESCRIPTION OF THE GUNITE AND ASSOCIATED TANKS OPERABLE UNIT[1]

The GAAT OU includes eight tanks in the North Tank Farm, six tanks in the South Tank Farm, Tanks W-11 and TH-4, and two Decontamination and Decommissioning (D & D) buildings (Buildings 3506 and 3515). These two buildings were not part of this study and will not be discussed further. The North Tank Farm and the South Tank Farm are in the approximate center of ORNL on both sides of Central Avenue. (Central Avenue is the main east-west thoroughfare for ORNL.) The North Tank Farm, shown in Fig. 3.1, is a 150-ft × 180-ft (45.7-m × 54.9-m) lot near the intersection of Third Street and Central Avenue. It is bordered on the north by the Surface Science Laboratory (Building 3137), on the east by a lot where the Solid State Research Facility is to be constructed, on the south by Central Avenue, and on the west by Third Street.

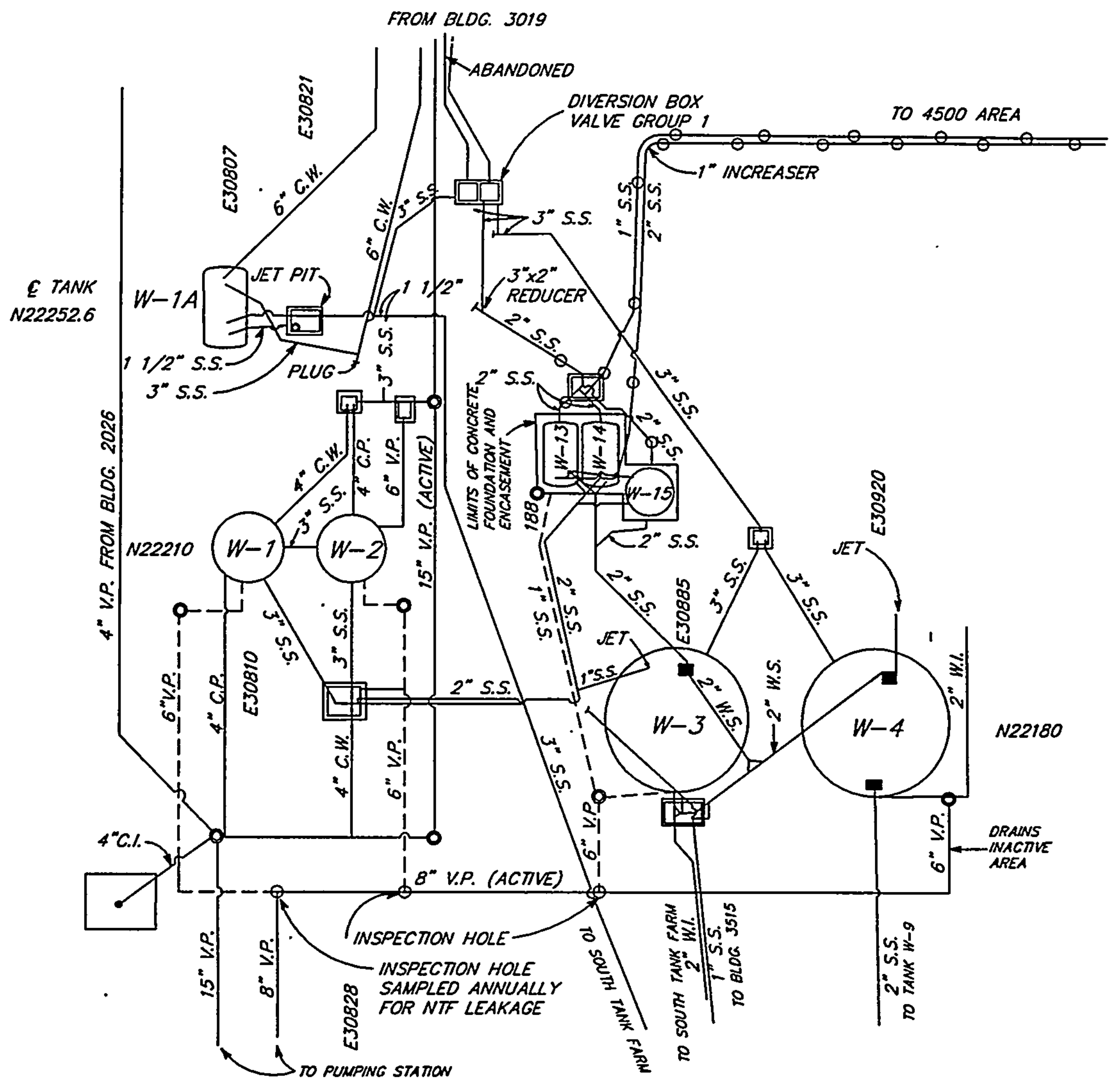

Fig. 3.1 North Tank Farm plan view.

The South Tank Farm, located across Central Avenue south of the North Tank Farm, is shown in Fig. 3.2. It is bordered on the north by Central Avenue, on the east by Fourth Street, on the south by the Metal Recovery Facility (Building 3505), and on the west by Third Street. Tank W-11 is southeast of the South Tank Farm. Tank TH-4 is adjacent to the southeast corner of the Instrumentation and Controls Building (Building 3500), approximately 440 ft (135 m) east of the South Tank Farm.

Four tanks in the North Tank Farm (W-1 through W-4) are constructed of Gunite, and four tanks (W-1A, W-13 W-14, and W-15) are constructed of stainless steel. Tanks W-1 and W-2, shown in Fig. 3.3, have an approximate capacity of 4,800 gal (18,170 L) each and are in the west side of the tank farm.

Tanks W-3 and W-4, shown in Fig. 3.4, have capacities of 42,500 gal (160,860 L) each and are in the southeast part of the farm. Each tank has an array of inlet and outlet lines that lead to valve boxes where waste transfers are controlled. Each tank also has an associated dry well that drains the immediate area around a tank and is intended to control potential leaks. Waste Tanks W-13, W-14, and W-15 have approximately 2,000-gal (7,570-L) capacity each. Located in the center of the tank farm, and including an array of piping and valve boxes, Tanks W-13, W-14, and W-15 are set inside a concrete cell that extends to the surface. Drainage from the cell is diverted to a single dry well. Tank W-1A, a 4,000-gal (15,140-L) stainless steel tank in the northwest corner of the tank farm, rests on a concrete pad but is not encased in cast concrete. This tank has an associated dry well and an array of pipes and valve boxes.

The South Tank Farm contains six Gunite tanks (W-5 through W-10). Tanks W-5 through W-10, shown in Fig. 3.5, are 170,000-gal (643,450-L) tanks arranged in two rows of three with a 60-ft (18.3-m), center-to-center distance. The domed waste storage tanks are 50 ft (15.2 m) in diameter, with a vertical height of 12 ft (5.5 m) at the center and 15 ft (4.6 m) at the walls. Each tank has an associated dry well and an array of pipes and valve boxes.

Two tanks, W-11 and TH-4, are outside the perimeter of the tank farms. Tank W-11 is a 1,500-gal (6,434-L) underground Gunite tank located south of Tank W-10. TH-4 is a 14,000-gal (15,140-L) underground Gunite tank located southwest of Building 3500. Each tank has an array of pipes, valve boxes, and associated drainage dry wells. The surface of the North Tank Farm, the South Tank Farm, and the area around Tanks W-11 and TH-4 are covered with grass lawns. Each area is roped off and posted as a restricted access area.

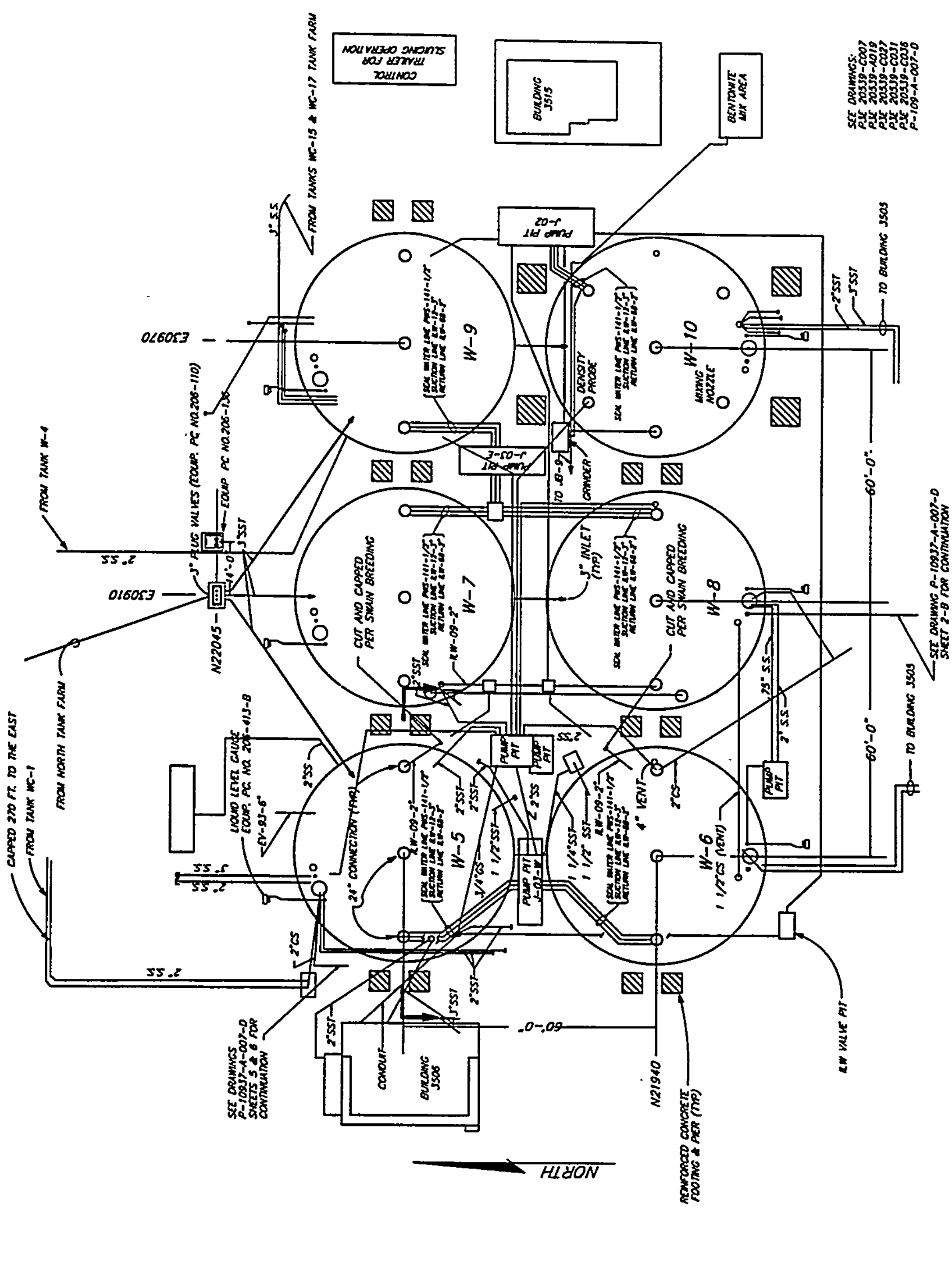

Fig. 3.2 South Tank Farm plan view.

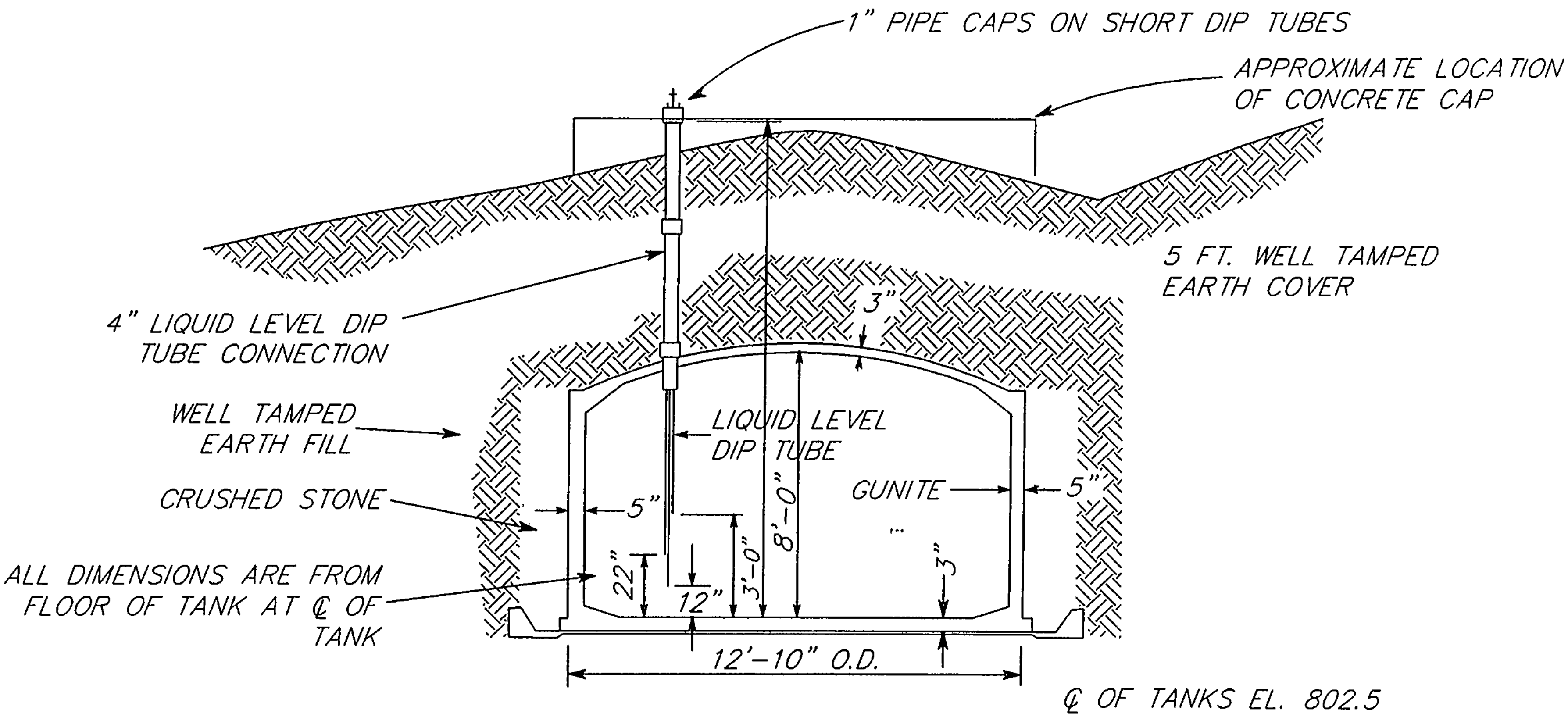

Fig. 3.3. Cross section of tanks W1 and W-2.

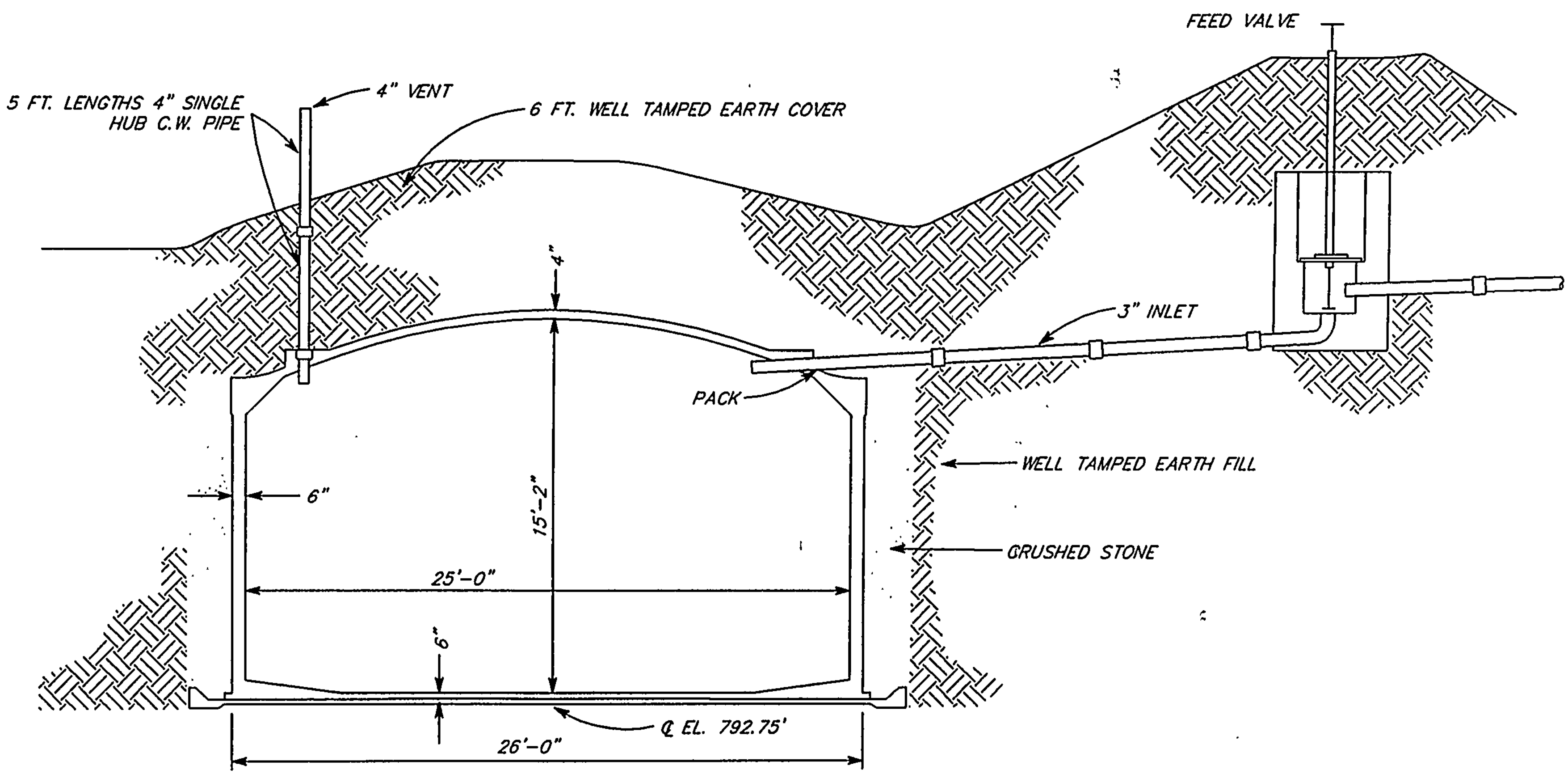

Fig. 3.4. Cross section of tanks W-3 and W-4.

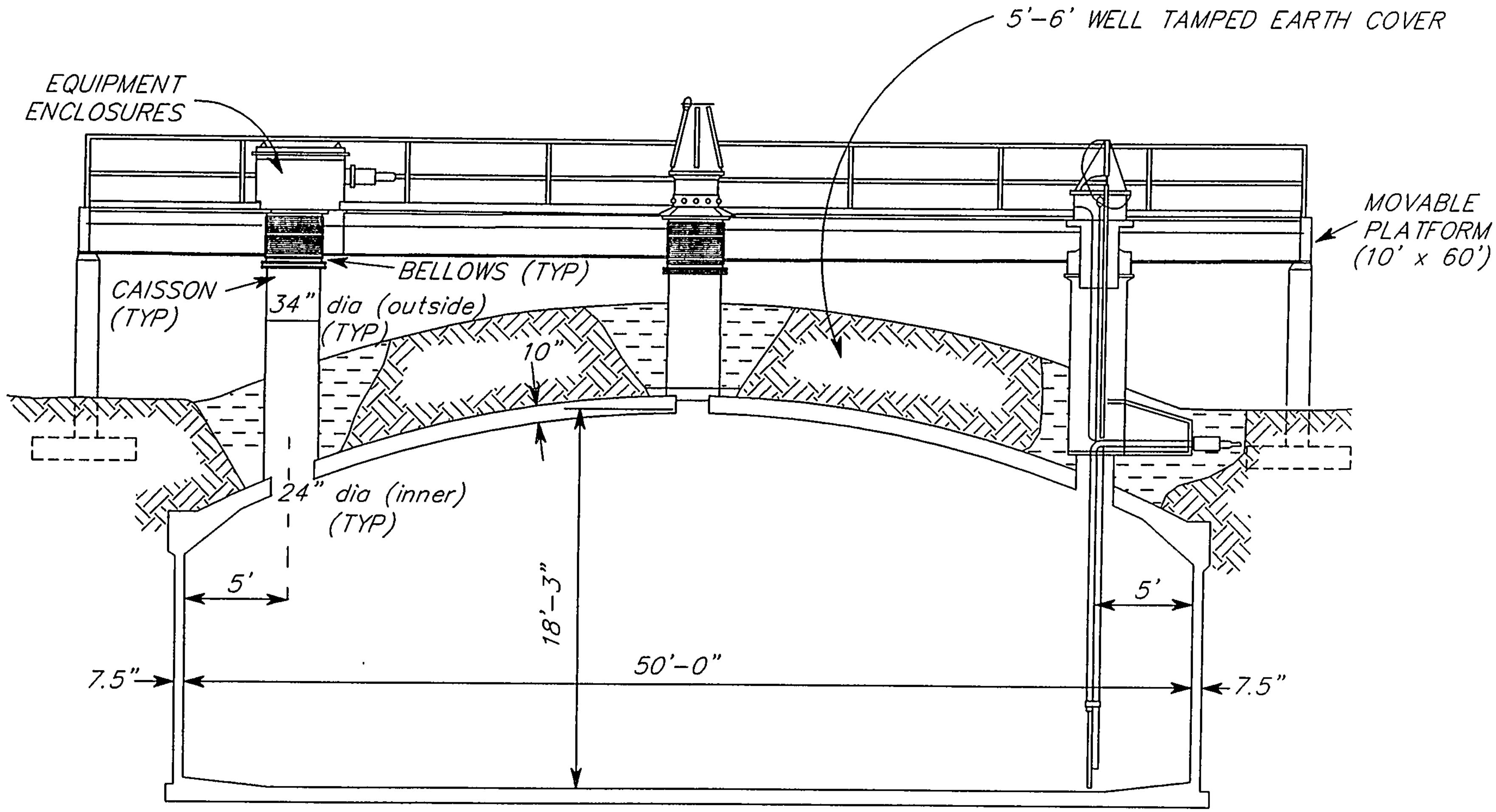

Fig. 3.5. Cross section of tanks W-5 to W-10.

4. HISTORY OF OPERATIONS[1]

From the beginning of ORNL, radioactive waste management required classification of the waste into categories based both the level and type of radioactivity in the waste (e.g., alpha- or beta-emitting) and the volume of the waste. The category names and the divisions between the categories have changed over time, reflecting changes in the system of categorization. Despite this, the early categories are generally recognizable in nature and can be correlated to current categories. Initially, liquid wastes were divided into three main categories: metal, radiochemical, and process. A fourth category, referred to as warm waste, was also used during early operations.

Radioactive metal wastes contained primarily uranium with small quantities of plutonium and/or thorium. These elements are all long-lived radionuclides and are a fissionable source material as well. Metal wastes were generated and collected from a variety of facilities throughout the laboratory.

Radiochemical waste contained primarily fission product radionuclides that have significantly shorter half-lives than the metal waste radionuclides. Radiochemical liquid wastes were also referred to as "hot" chemical wastes and intermediate-level wastes and are currently referred to as Low Level Liquid Waste. Radiochemical waste was discharged from process vessels in laboratories and Radiochemical Processing Pilot Plant cells into hot drains or via hot sinks (glove boxes). They contained ^{137}Cs and ^{90}Sr, which have relatively long half-lives, in addition to other radionuclides with short half-lives, various metals, and small amounts of organics. The wastes usually originated as nitrate solutions, although some wastes were acidic chlorides or other corrosives. The acidic solutions were generally neutralized by the addition of solid sodium hydroxide before the wastes were sent to the Gunite tanks.

The process waste was considered to be nonradioactive or to have very low activity. Current guidance classifies process waste as containing total beta-gamma activity not to exceeding 10,000 Bq/L (0.27 μCi/L). Process waste is derived from cooling water, laboratory sinks (other than hot sinks), and floor drains from facilities devoted to hot work.

A fourth category, referred to as warm waste, was in use during early operations. Warm waste was moderately radioactive and was an intermediate between process waste and radiochemical waste. Depending on the level of radioactivity present, warm waste was handled as either radiochemical waste or process waste.

The Gunite tanks were initially constructed to store all the radioactive liquid (radiochemical and metal) wastes generated by the ORNL site operations over a 3-year period. However, before the Graphite Reactor first went critical on November 4, 1943, expansion of the scope of work required that the period of operation be extended past three years. Due to expanding requirements for managing the radioactive waste liquids, the capacity of the tanks proved inadequate for permanent storage, and it became necessary to consider disposal of some portion of the waste. Various approaches were used to manage the increasing volumes of waste, with the Gunite tanks remaining the central facility for most of ORNL's waste management activities into the 1970s.

The first waste management approach used in the 1940s was to separate the different waste streams, as much as practical, and concentrate the radioactive components in the liquids through precipitation. The large Gunite tanks in the South Tank Farm were used for the precipitation process, and the smaller Gunite tanks in the North Tank Farm were used either for the storage of metal waste or the collection of waste for characterization before transfer to the appropriate system. At that time the tanks in the South Tank Farm were operated in pairs. The three tanks on the north side of the South Tank Farm (W-5, W-7, and W-9) received the waste stream and overflowed to the corresponding tanks on the south side (W-6, W-8, and W-10, respectively). Tanks W-5 and W-6 were used for the collection and treatment of the radiochemical waste stream, while Tanks W-7, W-8, W-9, and W-10 were used for the collection and treatment of the metal waste stream. The precipitation step concentrated most of the radionuclides in the precipitate (sludge) at the bottom of the tank and significantly reduced the level of activity in the remaining liquid (supernatant). The sludge was stored in the bottom of the tanks until a process was developed to recover the uranium, plutonium, and/or thorium. The supernatant was discharged to a settling basin (Waste Holding Basin 3513, completed in July 1944) and then diluted with large volumes of process waste before discharge into White Oak Creek.

In 1945, precipitation was discontinued, and Tanks W-5 and W-6 were used to collect and hold the radiochemical waste so that radionuclides with short half-lives could decay, which significantly reduced the total radioactivity of the waste. Tanks W-5 and W-6 held the radiochemical waste for about one month, on average, after which it was discharged to the settling basin for dilution with process waste. Tanks W-7, W-8, W-9, and W-10 continued to be used to collect metal waste. However, the original piping for the transfer system was modified so that waste in any one tank in the South Tank Farm could be transferred to any other tank. Tank W-9 was used as the initial collection tank for metal waste, which was then transferred to either Tank W-7 or W-10 for precipitation. The supernatant from the precipitation process was transferred to the radiochemical waste system. At this time, Tank W-8 was used only for the temporary storage of metal waste.

Beginning in 1949, the radiochemical waste stream was treated by concentration using a pot type evaporator. In 1950, further ORNL expansion required additional modifications in the waste management system to handle the increased waste volumes and levels of radioactivity. Underground stainless steel tanks were installed near each building or area that was a source of radiochemical or metal waste. These tanks (W-lA, W-13, W-14, and W-15), installed in the North Tank Farm, permitted better collection and segregation of the waste types as well as sampling and measurement of waste volumes and rates of accumulation from each source. From 1952 to 1957, a metal recovery plant (Building 3505) extracted approximately 130 tons of uranium from the accumulated metal waste in storage in the Gunite tanks. Residual waste from this process was incorporated into the radiochemical waste stream. Continuous improvements and modifications to the ORNL waste management system eventually eliminated the need for most of the older tanks. Tanks W-1, W-2, W-3, W-4, W-13, W-14, and W-15 in the North Tank Farm were removed from service in the late 1950s or early 1960s. After the tanks were removed from service, the liquid waste was taken from the tanks, while sludge and a small volume of residual liquid remained in the tanks. The large Gunite tanks in the South Tank Farm were removed from service in the late 1970s. Accumulated sludge precipitated from solution and residual solutions remained in these tanks until they were removed in 1982 and 1983; however, some liquid and sludge still remain.

5. PRESENT SITE-SPECIFIC CONDITIONS AND PROBLEMS[1]

The Gunite tanks contain about 95% of the documented radionuclides in inactive waste management units in Waste Area Grouping 1. As previously mentioned, the GAAT OU facilities are near the center of ORNL, which continues to operate as a large, multifunctional research and development facility. Remediation of the GAAT OU facilities will be conducted concurrently with ongoing operational and maintenance activities, resulting in a technically and logistically complicated remediation.

Given the age and uncertain physical condition of some of the tanks and the infiltration of water into several of them, there is potential for release of the tanks' contents into the surrounding environment. Structural failure of the tanks could result in the discharge of the liquid contents into surface and subsurface areas, including storm drains, buildings, soils, surface water, and groundwater. Contaminated solid materials could be exposed to the atmosphere if structural failure occurs from the collapse of a dome. The removal of the existing barrier (soil cover and tank domes) could potentially allow direct radiation exposure outside the tanks. The probability of catastrophic structural failure or slumping of the tank domes and/or walls has been evaluated, but results are inconclusive.

Leaks could also occur from tanks that currently contain liquid contents, resulting in a discharge of the liquid contents to the subsurface. Such a release would induce an increased hydraulic gradient emanating from the tank farms and would result in the discharge of contaminated water to the surrounding subsurface. Due to the presence of numerous utilities and subsurface foundations, elevated groundwater levels at the tank farms might result in the drainage of contaminated groundwater through utility backfills and potentially into buildings with subsurface foundations and/or basements. Both radiological and chemical contamination is presently noted in the soils and groundwater in the area of the GAAT OU; however, the exact source of the contamination is unknown. Even if the tanks do not presently leak, a release of hazardous material could result from liquid waste penetrating cracks in the tank walls.

6. PAST PRACTICE SLUDGE MOBILIZATION AT OAK RIDGE NATIONAL LABORATORY

Sludges were mobilized in the past at ORNL by using various technologies. A description and a discussion of these existing technologies follows.

6.1 PUMPING TECHNOLOGY

Progressing cavity pumps have been used successfully by the Waste Operations group for the past several years. These pumps can easily handle abrasive slurries and have proven reasonably reliable in service with radioactive solutions. However, because of abrasion and extrusion of the stator into the discharge pipe, wear of the elastomeric stator due to external tube-to-stator bond failure has been observed. Failures have also been experienced with the bearing (there is only one), the universal joints, the coupling, and the shear pin. These pumps have a mechanical seal with a flush water connection, and failures have been experienced when the pump suction pressure is greater than the seal water pressure, which allows particles to get into the seal and causes seal failure.[2]

6.2 SINGLE-POINT JET SLUICING TECHNOLOGY

The six large Gunite tanks in the South Tank Farm were cleaned by single-point jet sluicing[3,4,5] over a period of about 18 months during 1982 and 1983. During this time the sludges in these tanks were sluiced and resuspended, and the resuspended slurry was pumped to another site for disposal. The sluicing operation used a mixture of bentonite and water that was pumped from a feed tank through a sluicer nozzle to impinge on and resuspend the sludge in the tank being sluiced. Resuspended sludge was pumped from the tank through a grinder to break up oversized particles, producing a slurry. Analyses of sludge samples showed great variability between tanks and between samples in a given tank. The major radionuclide was ^{90}Sr. About half the sludge consisted of very small particles (less than 10 μm). The other half appeared to be agglomerates of the smaller particles. Laboratory tests demonstrated the feasibility of breaking the agglomerates in a grinder and suspending the fragments in a 2.5% bentonite suspension. Field tests demonstrated that a sluicer could be used for slurry resuspension and that the resuspended slurry could be pumped at concentrations up to 20% by weight.

The slurry was resuspended in a series of batch operations, as illustrated in Fig. 6.1. A 40,000-gal (150,000-L) batch of 2.5% bentonite and water was mixed and collected in a nearly empty waste tank. This suspension was then pumped through a sluicer nozzle to impinge on and resuspend the sludge in the tank being sluiced. The resuspended sludge was pumped from the tank through a grinder and returned to the feed tank. This operation was continued until the slurry concentration approached 15% to 20% by weight. At this point the slurry was pumped to storage at the Melton Valley Storage Tanks (MVST) site, pending disposal. This cycle was repeated until the sluiced tank was virtually empty.

The equipment required for the sluicing operation included the bentonite makeup system, the remotely controlled sluicer assembly, a grinder to break up oversized slurry

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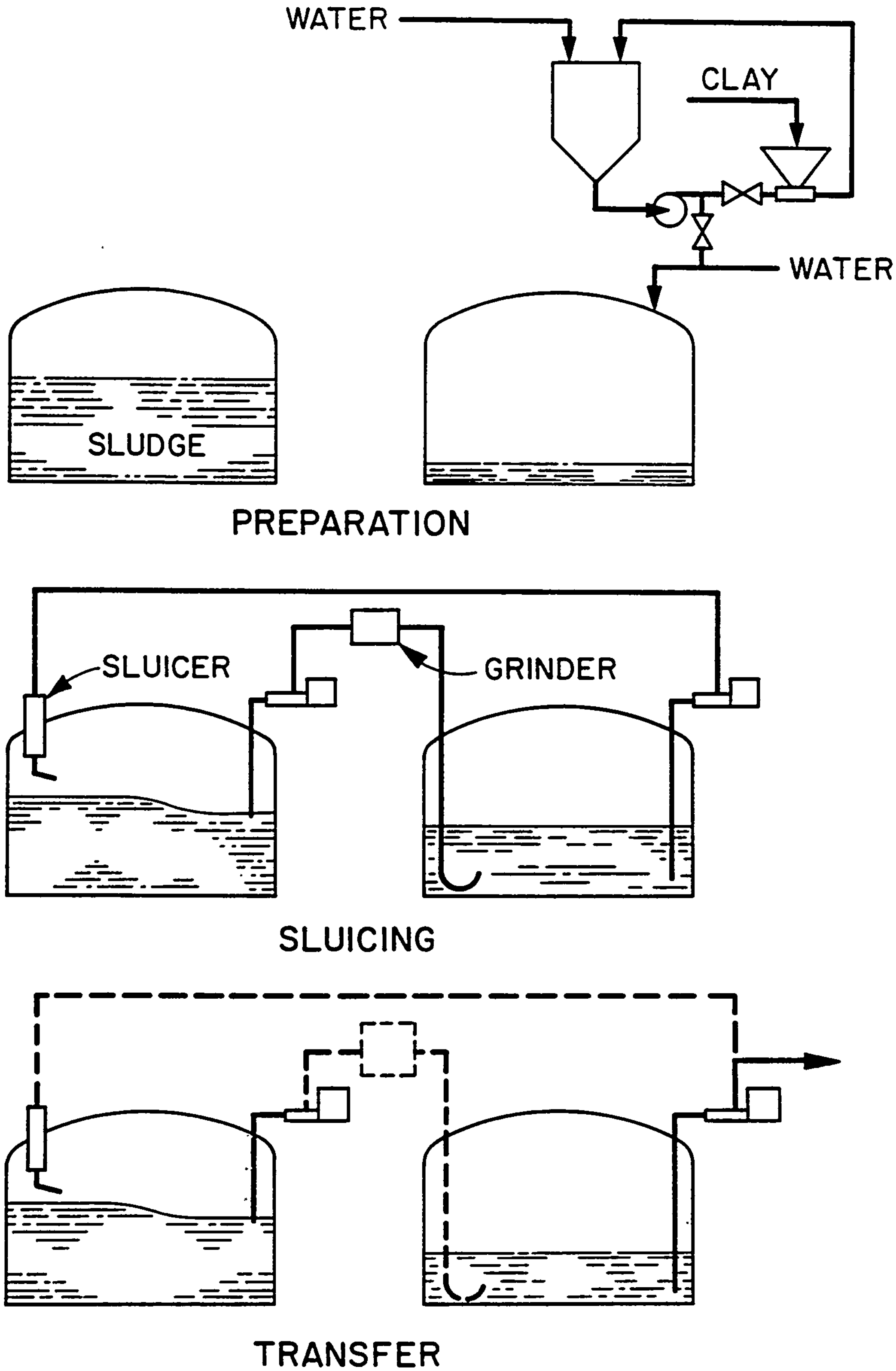


Fig. 6.1. Process concept for single-point jet sluicing.

particles, and two Moyno pumps for slurry transfer between tanks. The equipment layout is illustrated in Fig. 6.2. An adjustable suction leg was provided for one of the pumps so that this leg could be extended as the sludge was removed from the tank. Because the structural strength of the tank domes was unknown, all equipment that had to be mounted above a tank was supported on a platform that straddled the tank. The necessary penetrations into the tanks were made by a drilling rig mounted on the platform through a caisson cemented to the tank dome. The grinder and the two slurry pumps were installed in pits adjacent to the tanks. All slurry piping was contained within larger piping to limit the spread of contamination in the event of a leak. Most slurry lines were buried, and those that were not were shielded to minimize radiation exposure.

The tanks were sluiced in sequence. While sluicing of the first tank was in progress, the penetrations were drilled in the next tank to be sluiced. Upon completion of the sluicing of the first tank, the sluicing equipment (sluicer, pump suction leg, and TV camera) was moved to the next tank and connections to process piping, service piping, and instrument lines were made. The platform for the first tank was then moved to the third tank in the sequence and operations were resumed.

The resuspended sludge concentration in the transferred slurry was quite low during the first few sluicing operations but was raised to the design values thereafter as operator experience increased and equipment modifications were made. Circulating slurry particles caused difficulties by eroding pump rotors and grinder blades. This situation had been anticipated, and spare parts were available for replacement. Other difficulties were the partial settling of the resuspended slurry in the hold tank and the greater than anticipated resistance of some of the sludge agglomerates to the impact of the sluicer jet. These difficulties were only partially overcome.

The slurry was pumped to the MVST site and stored there until it could be prepared for final disposal at the New Hydrofracture Facility. An estimated 2,195,400 lbs (995,646 kg) of sludge was removed from the tanks and transferred to the New Hydrofracture Facility (Weeren 1984). About 90% of the sludge was resuspended and transferred in 36 batches. A 4-month facility shutdown occurred during the winter of 1982–1983 because the disposal well at the hydrofracture site was plugged. Sluicing operations were resumed in April 1983 and continued without serious difficulty until completion in January 1984.

Single-point jet sluicing[6] can remove the majority of sludge from a tank, but is largely ineffective in the removal of hard sludges, and it cannot remove all the soft sludges. Therefore, the GAAT OU tanks that have only small quantities of sludge in them probably cannot be sluiced effectively. Determining the feasibility of single-point jet sluicing for those GAAT OU tanks that still contain significant quantities of sludge involves sampling the sludge to ascertain its physical properties and then deciding from these measurements if grinding will be necessary or if additional studies are needed to determine the minimum transport velocity necessary for the pipeline transport of the slurry loop from the GAAT OU tanks to MVST.

6.3 SUBMERGED JET SLUICING TECHNOLOGY[6]

Some of the tanks at ORNL have built-in jets designed to mobilize the tank contents. These jets consist of 3-in. Schedule 40 pipe with a 90° elbow located in a position horizontal to the bottom of the tank. If connected to a pump, these lines could be used to suspend

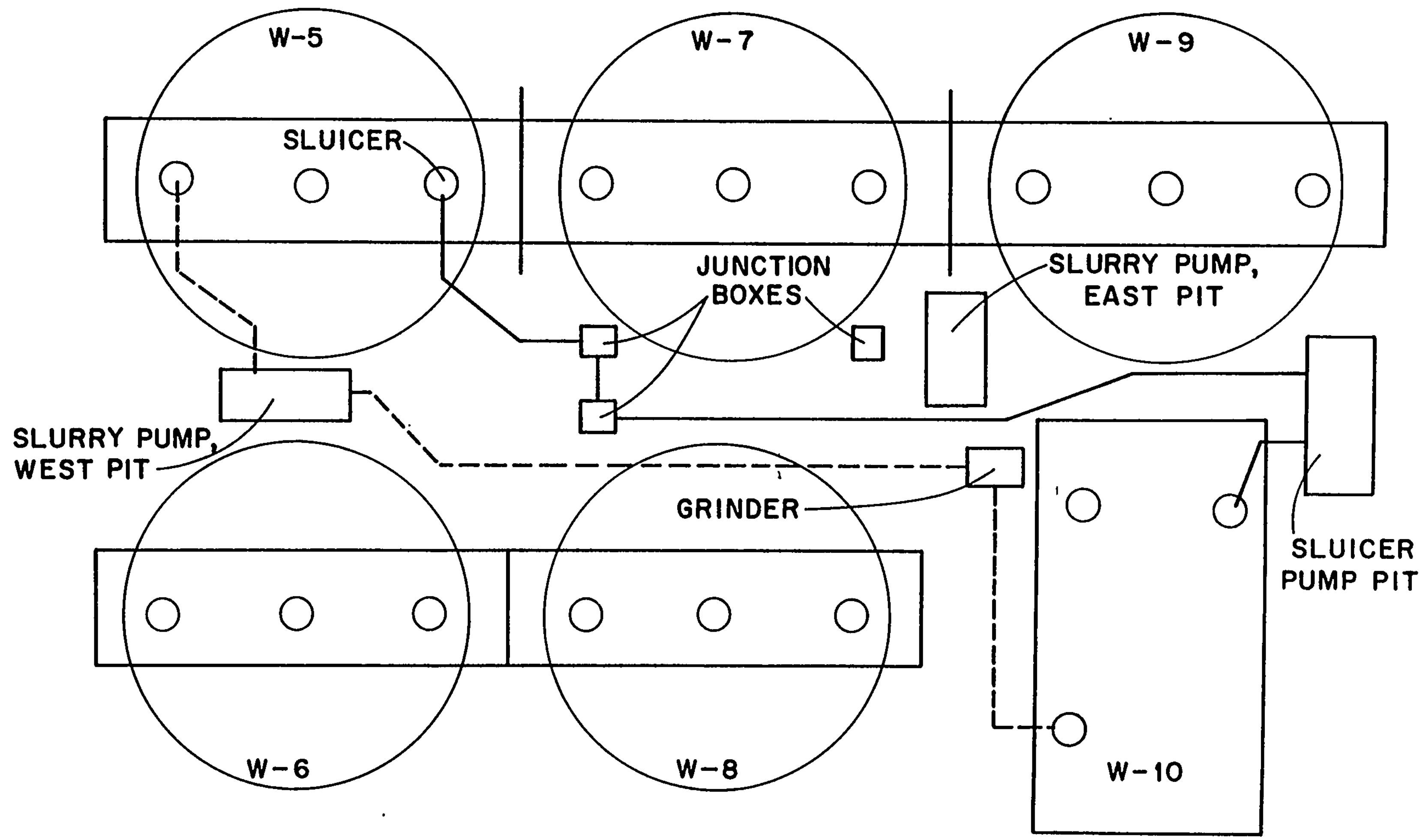


Fig. 6.2. Single-point jet sluicing process piping layout.

sludge in the tank. Each of the active evaporator service tanks is equipped with six internal sludge jets constructed in this manner, with the discharge nozzle located in a position horizontal to the bottom of the tank and with the center line 8 in. from the bottom. Opposing sets of jets are located about 17 ft apart. Sludge jets in the Gunite tanks could be put into service by installing them into one or more of the tank penetrations and connecting a prefabricated manifold (with valves in the lines to the individual jets) between the pump discharge and the lines to the sludge jets. This would permit slurry to be pumped from a suction nozzle located near the center of the tank and discharged through any of the sludge jets. The use of the sludge jets would be beneficial in mixing the contents of the tank, and depending on the cohesiveness of the sludge, the jet system may be adequate for mobilization of the sludge from the entire tank. Once the solids are mobilized, the slurry could be transferred to MVST using the existing Moyno pumps and transfer lines. This option also is dependent on the availability of storage volume in MVST to accommodate the sludge from the Gunite tanks.

A limited number of tests of a scaled-down version of the sludge jets have been done with sand and fly ash in a 1/6 dimensional scale Plexiglas model of the MVST units (2 ft in diameter) by matching Reynolds and Froude numbers. The results of these tests did not appear promising for mobilizing all of the sludge. While sludge was moved from the front of the jets, solids were not removed from the center of opposing jets. However, the effectiveness is dependent on the characteristics of the sludge. Also, better methods are now available to study and predict mixing and mobilization characteristics. Pacific Northwest Laboratories (PNL) has developed a computer program (TEMPEST) to permit simulation of submerged jet mixing and sludge mobilization in waste storage tanks. Modification of the program to model horizontal tanks was done under a subcontract with the Chemical Technology Division. Mixing and mobilization tests, completed during 1993 in the 1/6 scale with 25,000-gal tanks, validated the computer model. The computer model, along with physical property data obtained from samples, can then be used to predict the conditions necessary to mobilize the sludge with a sludge jet.

Determining the feasibility of using the internal sludge jets for mobilization of the sludge in GAAT involves sampling the sludge to determine its physical properties, employing the PNL TEMPEST computer program, and studying the physical property data to the predict conditions (flow rates) necessary for mobilization of sludge.

Use of sludge jets would create the same concerns regarding pipeline transport of the slurry as are raised for single-point jet sluicing.

7. CONVENTIONAL TANK CLEANING TECHNOLOGIES

Technologies that exist at ORNL, at other DOE sites, and in other industries, such as the petroleum industry, were examined for suitability of use for GAAT OU sludge mobilization. These technologies are not recommended for GAAT sludge mobilization tasks. A list of them and the reasons for not considering them is given in Table 7.1. Some of the technologies were deemed worthy of discussion but not worthy of further consideration. For a description of these technologies, together with a discussion of their expected effectiveness, see Appendix E.

Table 7.1 Technologies not recommended for GAAT sludge mobilization tasks

Technology	Reason for not considering the technology
Nitric acid dissolution	Additional volume added to waste system; effects of acid on large tanks unknown
Oxalic acid dissolution	Additional volume added to waste system; effects of acid on large tanks unknown; unknown chemical reactions possible
Dispersing agents	Requires forced mixing; extensive evaluation program needed
Fuel storage basin sludge removal	Nature of sludges different from fuel basin sludges; inability of crawler to maneuver in sludges; tank geometry different from fuel basin geometry
Commercial tank cleaning systems	Nature of sludges different; radiation levels too high for contact operation or maintenance; tank geometry different
Screw pump	Small internal clearances; poor performance when pumping abrasive liquids
Piston pump	Check valves vulnerable; poor performance when pumping abrasive liquids
Membrane pump	Potential for chemical and radiation damage to elastomers; tendency to plug check valves
Diaphragm pump	Potential for chemical and radiation damage to elastomers; tendency to plug when pumping lumpy materials
Commercial mining equipment	Available equipment size too large for accessing tank through the risers
Bucket elevator	Inability to handle wet, sticky materials
Plasma arc cutter	Difficulty in maintaining arc; tendency for plugging or penetration of high-efficiency particulate air filters with fine particles
Gas cutting torch	Difficult to establish and maintain flame in waste-encrusted material
Skid-steer excavator	Too large to access tank through riser
Rotary saw	Blades sensitive to binding and breaking in the workpiece
Arc saw	Difficult to maintain arc; excessive temperatures
Laser	High power requirement; sophisticated control system; high costs
Super scavenger	Inability to maneuver in the depth of sludge found in the tanks
Shear	Requires large equipment sizes to shear large pieces
Abrasive cutoff saw/grinder	Sensitive to workpiece flexure or movement that may result in blade binding, kickback or breakage
Floating dredge (flump)	Must have designated depth of supernate in the tanks at all times to allow equipment to float

8. MECHANICAL ARM-BASED TANK DEPLOYMENT TECHNOLOGIES

The principal component of a mechanical arm-based waste retrieval system is the mechanical arm device used for moving or maneuvering discrete pieces of equipment within the tank. This component is the base that all other components are designed around. The relationship of the mechanical arm to the remainder of the system equipment required for retrieval is depicted in Fig. 8.1.

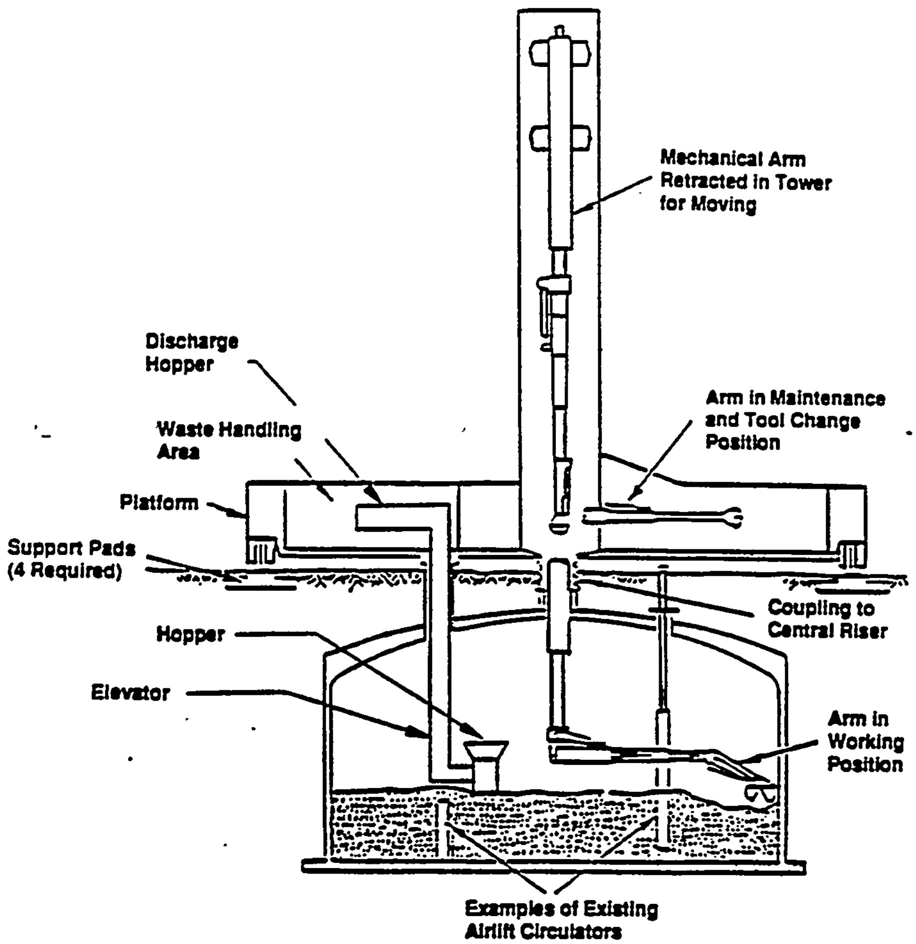


Fig. 8.1. Mechanical arm-based retrieval system schematic.[7]

Mechanical arm-based systems are a means of moving tools and retrieval equipment inside the tanks to assist in waste retrieval. The mechanical arm, when equipped with suitable end effectors, can remotely cut up in-tank hardware, remove debris, recover solid wastes, clean the tank walls, and convey waste from the tank. Common to all mechanical arm-based system designs is an aboveground facility to control, service, and operate the system. The facility would probably contain remote handling areas for minor maintenance, equipment decontamination (washdown), and possibly, waste loadout in preparation for transport.[7]

There are no mechanical arm–based *commercial* systems available that can meet GAAT retrieval requirements without equipment development and testing. However, some basic equipment configurations that could be developed to provide the necessary deployment movement or articulation required for waste retrieval operations will be discussed in the next few sections. In addition, a number of development efforts are currently in progress for mechanical arm–based deployment technologies that could meet the GAAT sludge removal requirements with some modifications. These will be discussed later.

8.1 ARTICULATED ARM

One example of an articulated arm design is shown in Fig. 8.2. This design consists of a four-section arm that can be installed through a center riser in the tank. The articulated arm is mounted on a rotating vertical extension column. The end of the arm has provisions for remotely attaching waste retrieval end effectors. Internal tank coverage is accomplished by articulating and maneuvering the arm and the tooling. A control system provides the means to avoid obstacles within the tank and deliver the tools to the desired location. The arm, with its articulation, will be able to perform dexterous tasks and maneuver around suspended in-tank obstacles and obstacles uncovered during waste removal.[7]

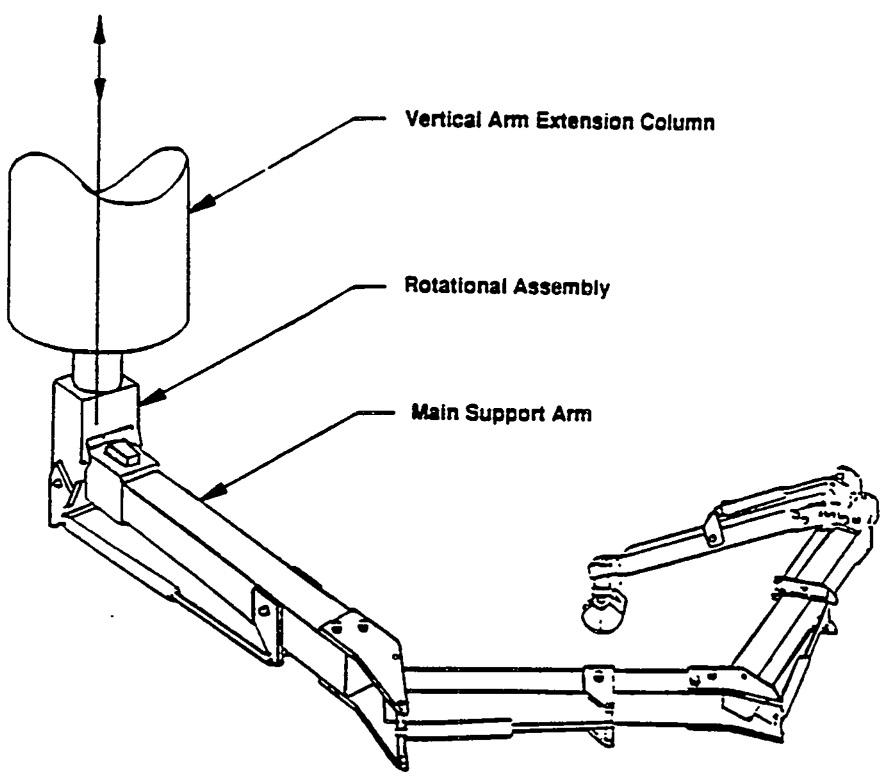


Fig. 8.2. Articulated arm.[7]

This four-section design is dictated by the limited operating space above the waste in a full tank. However, it is a good basic example of an articulated arm-based design.

8.2 TELESCOPING ARM

The telescoping arm design is similar to the telescoping booms used in the construction industry. The arm is mounted on a vertical, rotating column or support tube. The support tube provides vertical movement for the arm and the telescoping feature provides horizontal coverage, as shown in Fig. 8.3. This arm also has provisions for remotely attaching waste retrieval end effectors to the end of the arm. The telescoping arm could be operated through a central riser.

The telescoping arm operates in a straight line (extension or retraction) and does not possess the dexterous characteristics of the articulated arm design.[7]

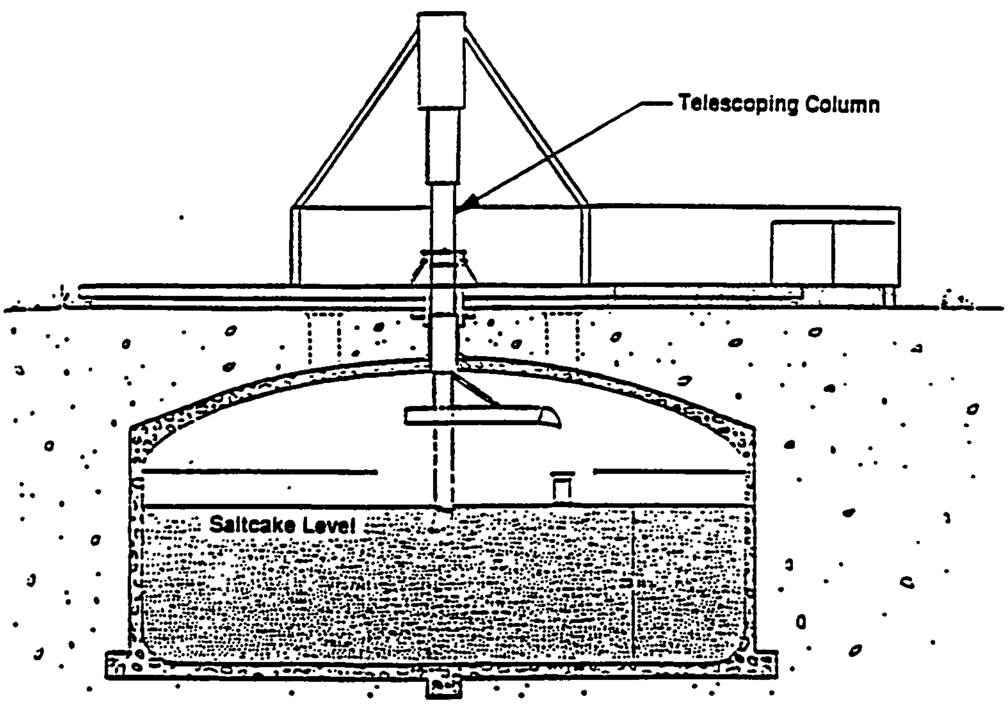


Fig. 8.3. Telescoping arm.[7]

8.3 LINK ARM

A third mechanical arm design is the link arm, which consists of individual links that lock into place as they are deployed from a retractable mast assembly. An operating facility, located above the tank, supports the retractable mast assembly and link drum that contains the mechanism to retract or extend the links through the mast and into the tank. The mast assembly is rotated within a centrally located riser. Various waste removal end effectors can be remotely attached to the end of the arm for waste retrieval. (See Fig. 8.4.) The link also operates in a straight horizontal line and also does not possess the dexterous characteristics of the articulated arm.[7]

To overcome any unknown solid debris or radioactive waste form that may be located in the tanks, a *flexible* mechanical arm system should be pursued for removal of the waste in the GAAT units. The system should include an articulated arm system that can perform

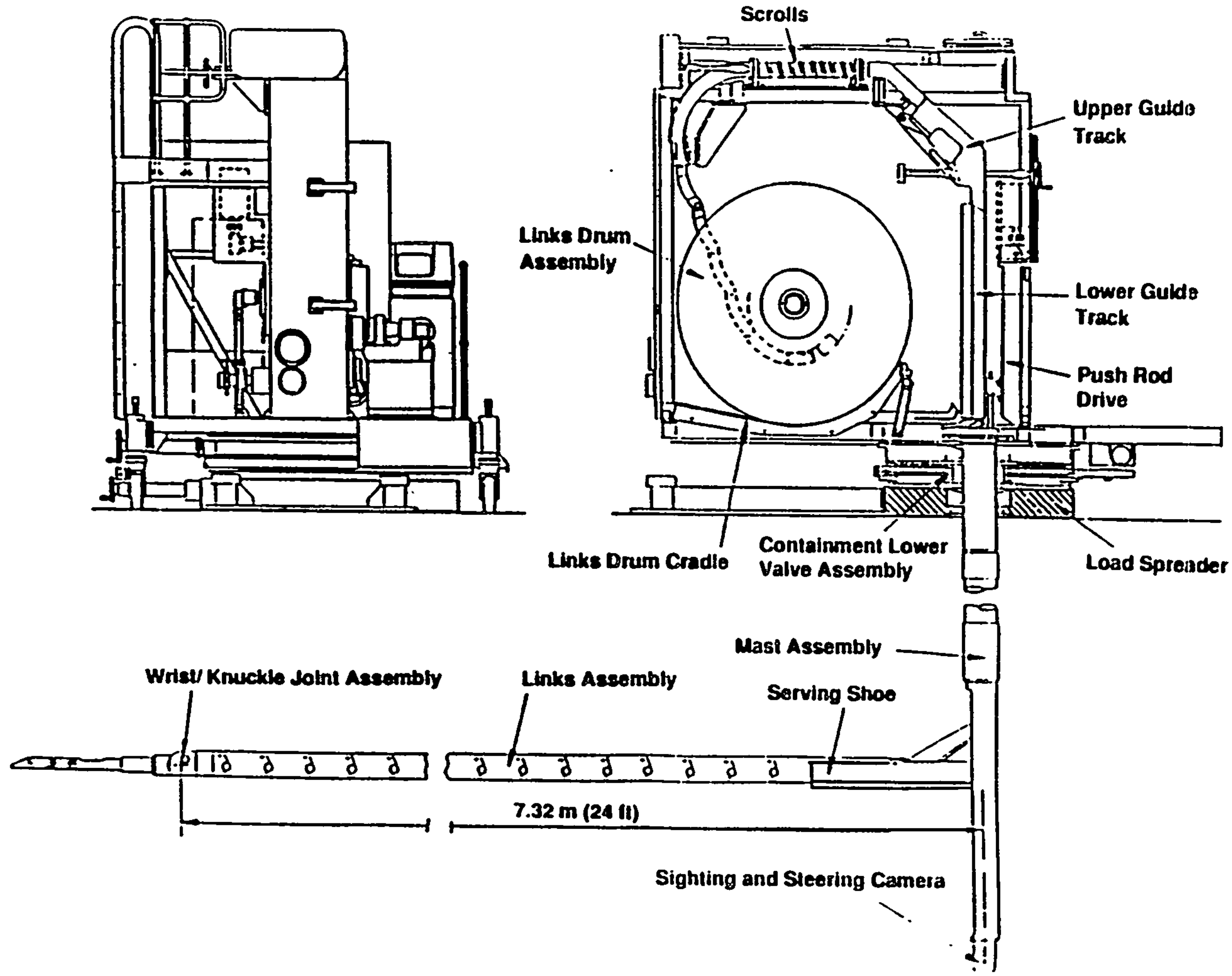


Fig. 8.4. Link arm.[7]

dexterous retrieval tasks and have adequate capacity and degrees of freedom. The system might include a telescoping section to deploy the articulated arm system. The following sections will discuss a number of DOE development efforts regarding mechanical arm-based systems currently under development for underground storage tank remediation.

8.4 LONG-REACH ARM SYSTEMS

The DOE Office of Technology Development Underground Storage Tank Integrated Demonstration (USTID) and the Robotics Technology Development Program are tasked with the development and demonstration of technologies and equipment for underground storage tank remediation, from characterization through retrieval and treatment. Because of the volume of waste in underground storage tanks at the DOE Hanford site in Richland, Washington, the USTID and the Robotics Technology Development Program have focused almost exclusively on the technology needs of the Hanford single-shell tanks.[8]

The Hanford single-shell tanks contain over 37 million gallons of radioactive waste generated as part of the production of nuclear materials for the nation's defense. The consistency of the waste varies from liquid to pastelike sludge to very hard, brittle salt cake. Removal of these wastes from single-shell tanks is necessary to minimize contamination of the soil surrounding the tanks resulting from tank leakage. Many of the tanks are either known or are suspected to leak. Because of this problem, it is desirable that the technologies used to retrieve the waste from the leaking single-shell tanks be designed specifically to reduce the potential for waste leakage. Waste retrieval methods used in the past required that large volumes of water be pumped into the tank and the resulting waste slurry pumped out. This technique cannot be used in the leaking single-shell tanks.[8]

Since 1990, the Robotics Technology Development Program has been studying system design requirements for a high-capacity, long-reach manipulator system capable of deployment in the Hanford underground storage tanks. A technology development and evaluation test bed was assembled in FY 1991 using an existing floor-mounted, 30-ft reach, 5000-pound capacity, SPAR RMS 2500 manipulator system (see Figs. 10.17 and 10.19). In FY 1994, procurement was initiated for a kinematically correct replacement manipulator system for this test bed. This system will be completed and operational in the test bed approximately mid FY 1996. A similar system focused on the remediation of underground storage tank C-106 at Hanford will be procured starting in FY 1995. This system will be operational in approximately 1998. This long-reach manipulator system will have a reach of approximately 40 ft, with a payload of 1000 to 2000 pounds. A modified version (decreased reach and payload) of either of these systems could meet GAAT sludge mobilization needs.[18]

In addition to the long-reach, high-capacity systems, USTID is developing an arm system with lower capacity and decreased reach called the Light Duty Utility Arm (LDUA). Because this system is several years ahead of the others discussed in development and availability, a more detailed description of it will be presented in the following sections.

8.5 LIGHT DUTY UTILITY ARM SYSTEM

During FY 1994, USTID is broadening its scope to include storage tank remediation technology needs at DOE sites other than Hanford, in particular, the Idaho National Engineering Laboratory (INEL) and ORNL. The approach being followed is to leverage existing projects at INEL and ORNL by adding a task to each that investigates site-specific needs relevant to current USTID initiatives. The two areas that will be addressed at ORNL in FY 1994 are waste-dislodging tools and applicability of the LDUA system.[8]

LDUA is a manipulator system (Fig. 8.5) being procured by Westinghouse Hanford Company to support the deployment in Hanford single-shell tanks of characterization, inspection, and surveillance tools developed by USTID. Spar Aerospace Limited (SPAR) of Toronto, Canada, was selected to receive the LDUA contract (placed in September, 1993). The first LDUA system will be delivered in approximately March 1995. The contract with SPAR includes options to buy several additional units. The DOE EM-30 organizations at Hanford and INEL have already committed funds for additional LDUA units.[8]

The LDUA system is being developed to provide a mobile, robotic deployment platform with the capability to perform tank surveillance and inspection, in situ waste analysis, and small-scale retrieval operations. Surveillance and inspection activities include: remote in-tank visual inspections and photography, inspection of tank walls using a high resolution laser scanner, and topographical mapping of the waste surface and tank structure.

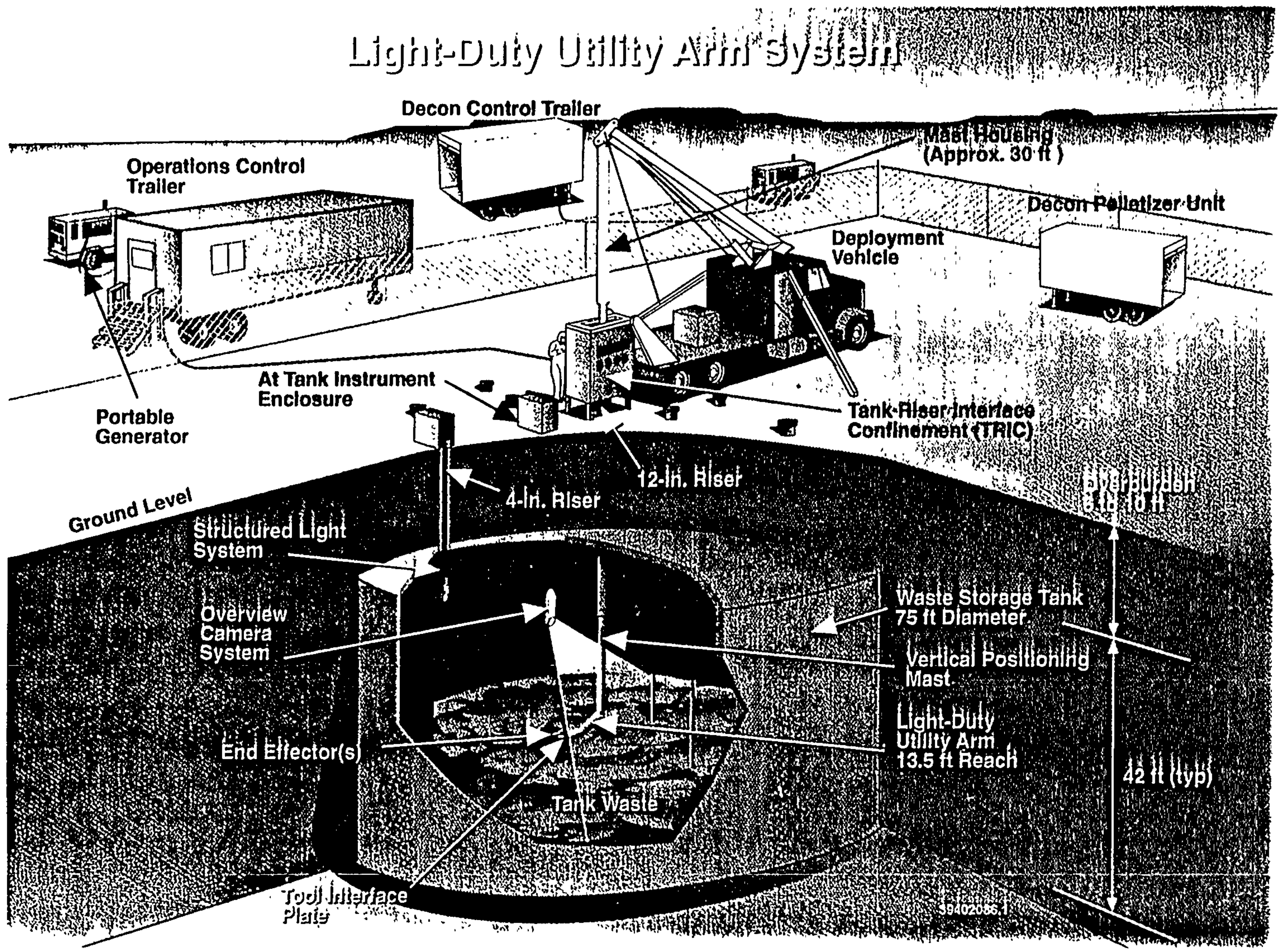


Fig. 8.5. LDUA system.[16]

The LDUA project is slated for field deployment and testing of an initial unit in Hanford single-shell tanks. The major equipment subsystems (Fig. 8.6) of the LDUA system are:

- LDUA Arm and Deployment System
- Tank Riser Interface and Confinement System (TRIC)
- Operations Control Center
- Arm and Riser Mounted End Effector Systems[9]

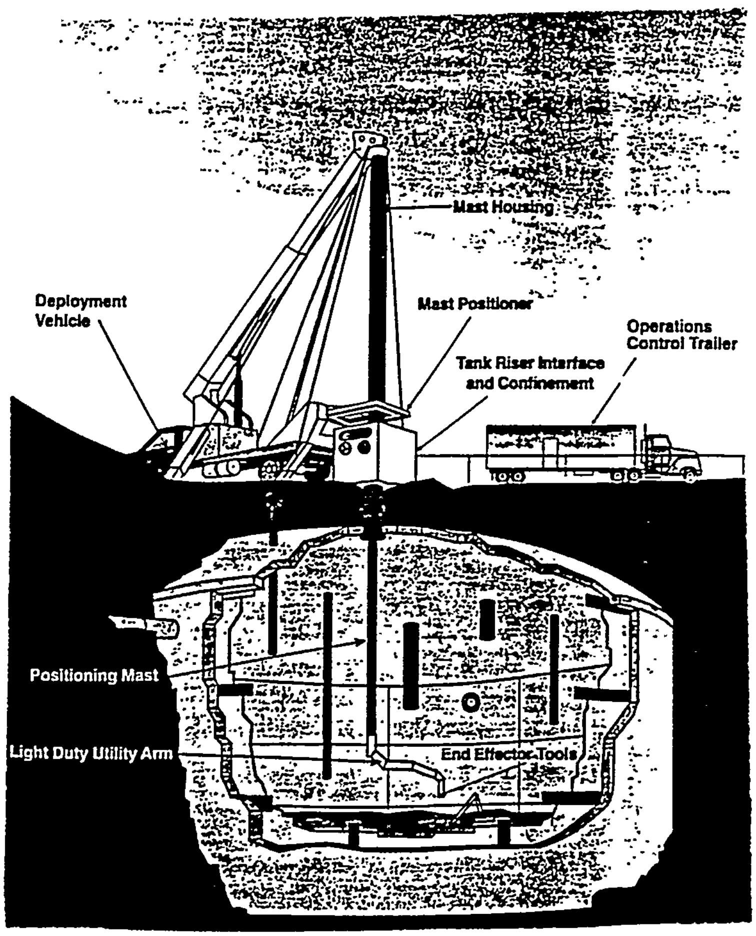


Fig. 8.6. LDUA major subsystems.[16]

The Hanford version of LDUA will be designed to fit within a 10.5-in. diameter positioning cylindrical mast, which will be deployed through a 12-in. I.D. tank riser and extend about 62.5 ft vertically downward (Fig. 8.7). The articulated arm will have 7 degrees of freedom and will have a 13.5-ft length from the mast centerline. The LDUA payload will be about 75 lb, fully extended.[8] This dexterous arm (see Figs. 8.8, 8.9, and 8.10) is needed for application at Hanford because of the numerous obstacles in the tanks. The LDUA will have a positioning accuracy of 0.5 in. with a repeatability of 0.2 in. LDUA will be designed to operate in a 2000 rad/h radiation field, with a cumulative equipment dose of 10^8 rads. The system will be explosion proof and resistant to chemical attack. Almost all joints on the arm are hydraulically driven and designed with fail-safe hydraulic lock valves and limp valves to allow the arm to droop vertically for retrieval purposes (see Figs. 8.11, 8.12, and 8.13). All joints are booted to seal the components and prevent contamination. LDUA will be of a modular design for ease of maintenance (Fig. 8.14). A camera, light, and pan/tilt unit (Fig. 8.15) will be located in the shoulder yaw joint to provide viewing of end effector operations.[18]

The LDUA deployment system consists of a Vertical Positioning Mast (VPM) and a Mobile Deployment System (MDS). VPM deploys LDUA in the tank and provides an airtight container for arm storage and shipment (Fig. 8.16). VPM uses two telescoping tubular sections to provide the required stroke of 62.5 ft, with the outer tube having a diameter of 10.5 in. (Fig. 8.17). VPM will have independent hydraulic winch motors, which will allow various deployment sequences with the retraction of the outer cylinder always occurring first to ensure proper decontamination. The VPM system will be equipped with dual cables, hydraulic locks, fail-safe friction brakes for safety, and the provision for retracting the system manually.[18]

MDS is a truck-based LDUA transport vehicle and is stabilized using outriggers. The MDS erects the VPM (pitch direction) and provides accurate alignment with the tank riser in the X&Y direction (roll). It is designed to operate with any combination of 10 degree ground slope and 5 degree riser misalignment. The overall truck plus VPM length is 35 ft, with a maximum stowed and deployed height of 13.5 ft and 43.75 ft respectively. The MDS design can be easily adapted to a trailer-based or skid-mounted configuration (see Figs. 8.18 and 8.19).[18]

TRIC provides an interface between the tank riser and VPM. TRIC provides contamination control, remote handling/maintenance access, and atmospheric confinement. Key TRIC design features are an automated end effector exchange system; an automated decontamination system for the LDU arm, mast, and end effectors; a ventilation system that maintains atmospheric pressure balance and filters exhaust and inlet air to prevent radiological emissions; and two compliant joint interfaces to minimize loading on the tank riser (see Figs. 8.20 and 8.21).[18]

The Operations Control Center is located in a mobile operations control trailer and provides remote operation of all LDUA equipment and end effector systems (Fig. 8.22). The Arm and Riser Mounted End Effector Equipment will be discussed later in the report.[18]

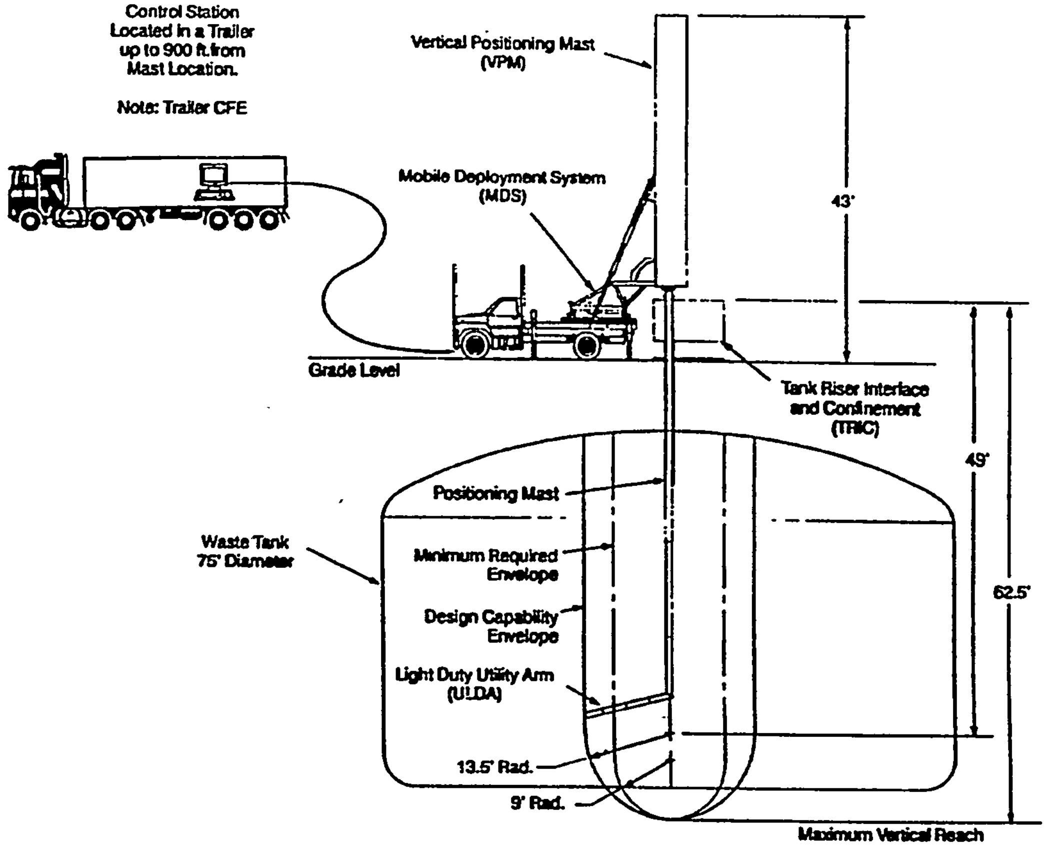


Fig. 8.7. LDUA system configuration.[16]

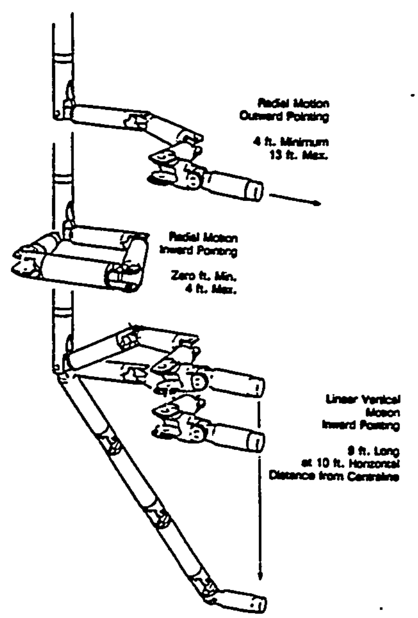


Fig. 8.8. LDUA dexterity—articulation capabilities.[16]

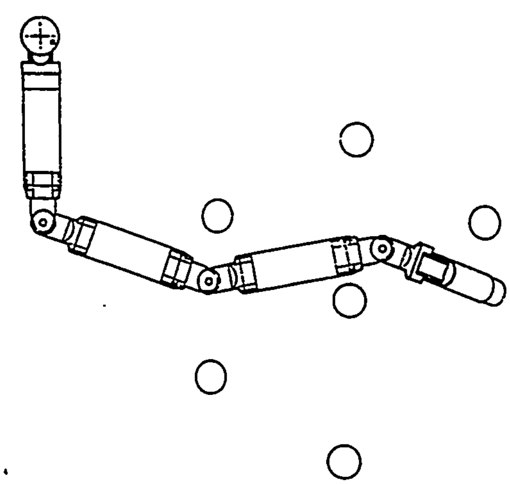


Fig. 8.9. LDUA dexterity—plan view.

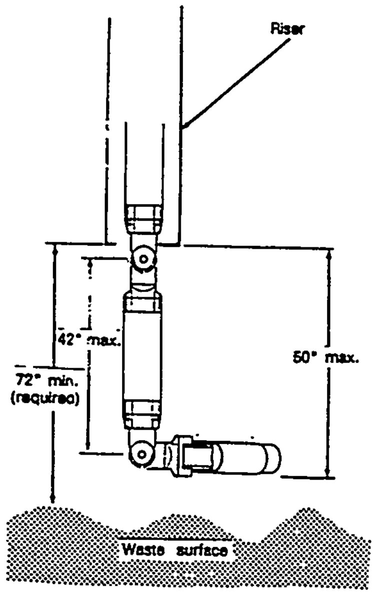


Fig. 8.10. LDUA dexterity—elevation view.[16]

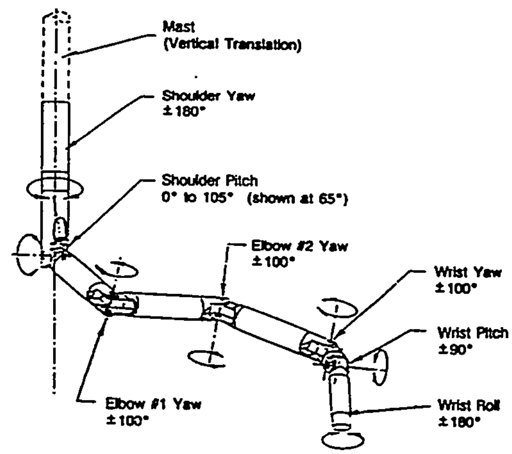


Fig. 8.11. LDUA manipulator configuration.[16]

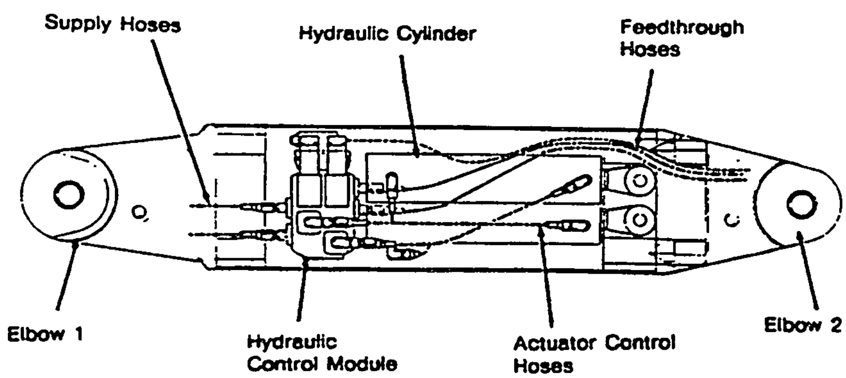


Fig. 8.12. LDUA hydraulic system packaging.[16]

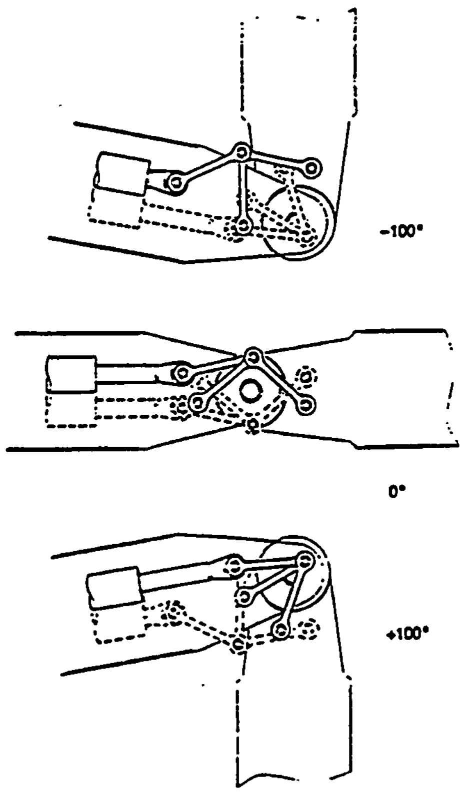


Fig. 8.13. LDUA elbow joint action.[16]

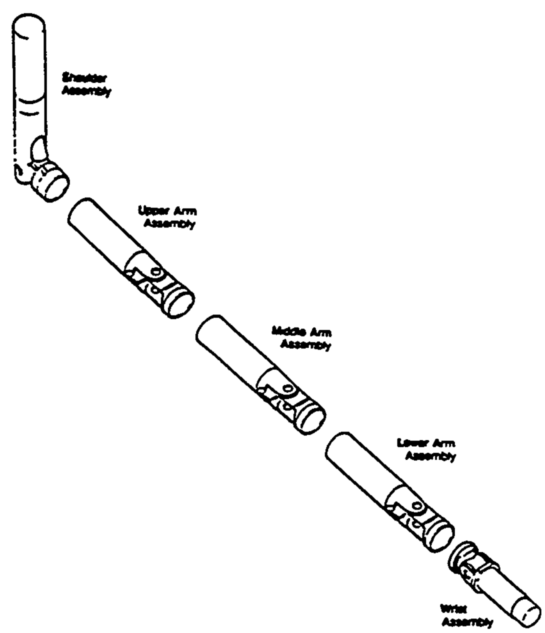


Fig. 8.14. LDUA modular construction.[16]

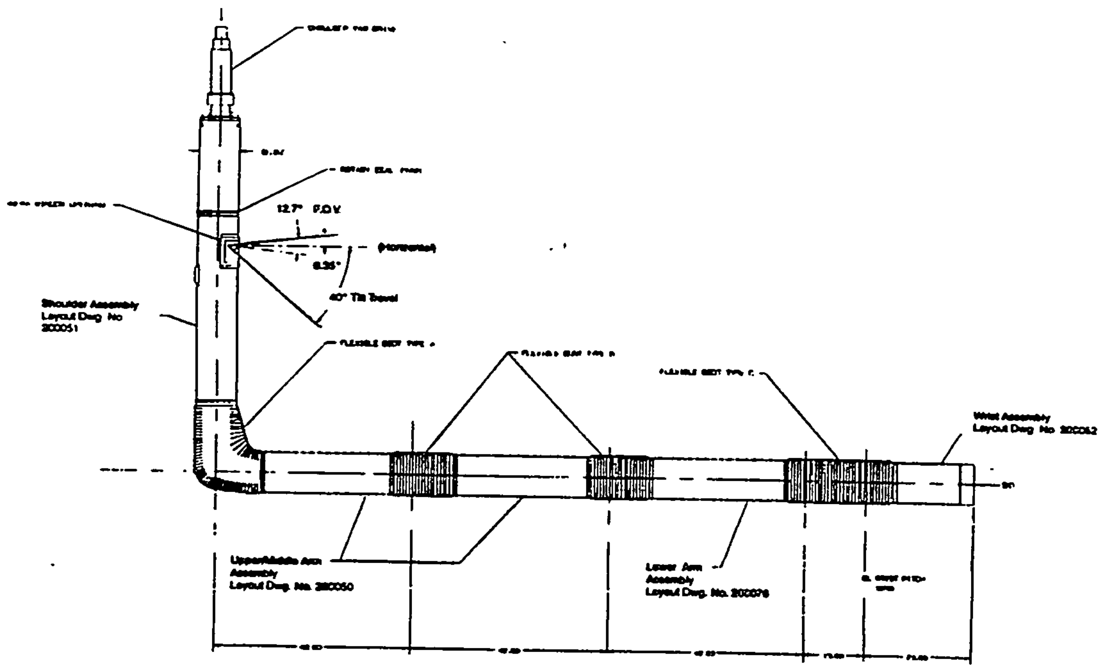


Fig. 8.15. LDUA manipulator layout.[16]

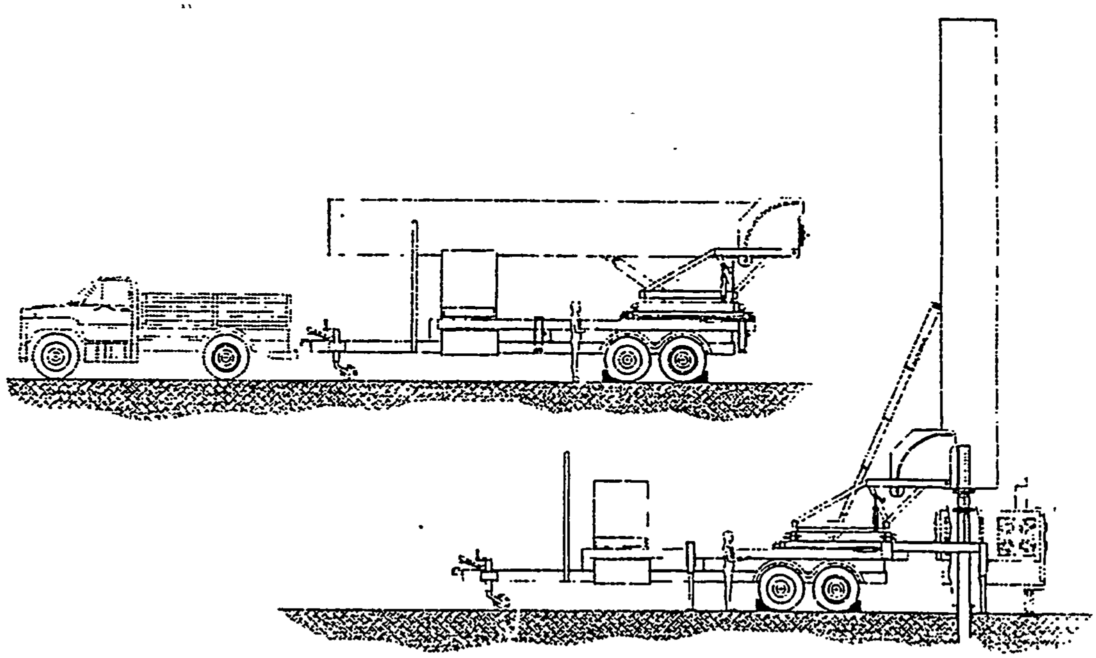


Fig. 8.16. LDUA VPM layout—trailer based.[16]

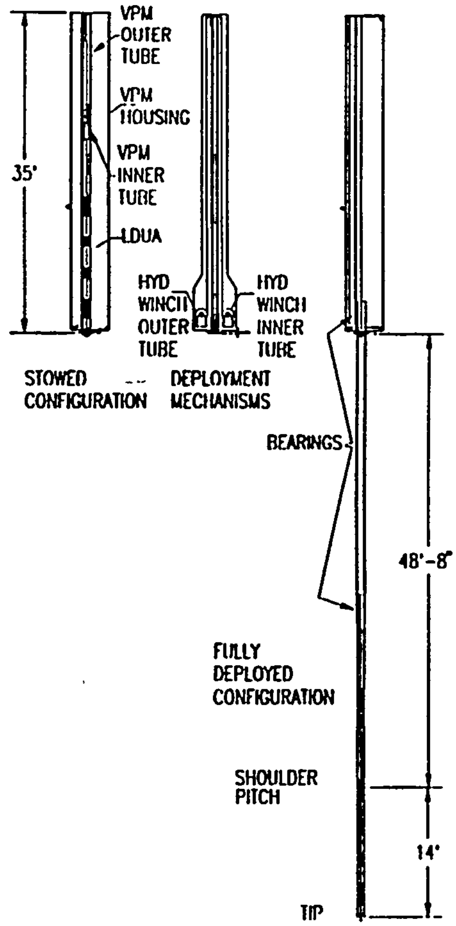


Fig. 8.17. LDUA VPM configuration.[16]

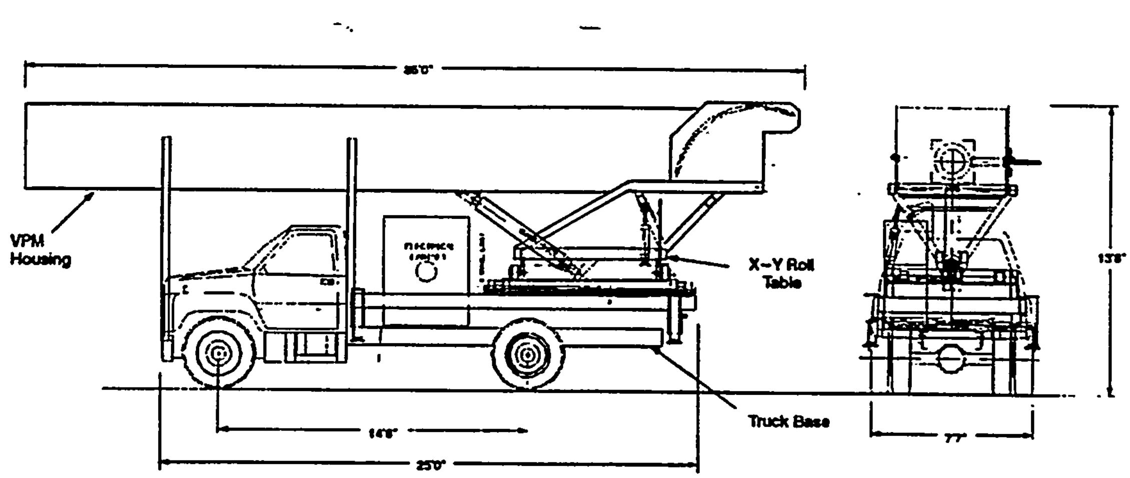


Fig. 8.18. LDUA MDS—trailer-based configuration (stowed).[16]

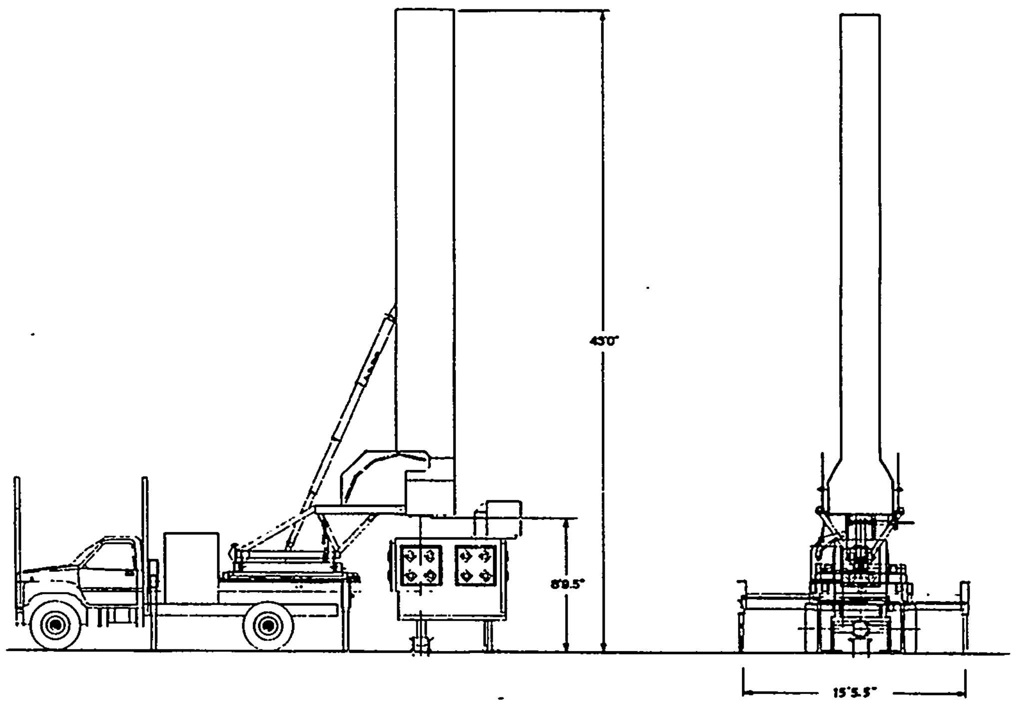


Fig. 8.19. LDUA MDS—trailer-based configuration (deployed).[16]

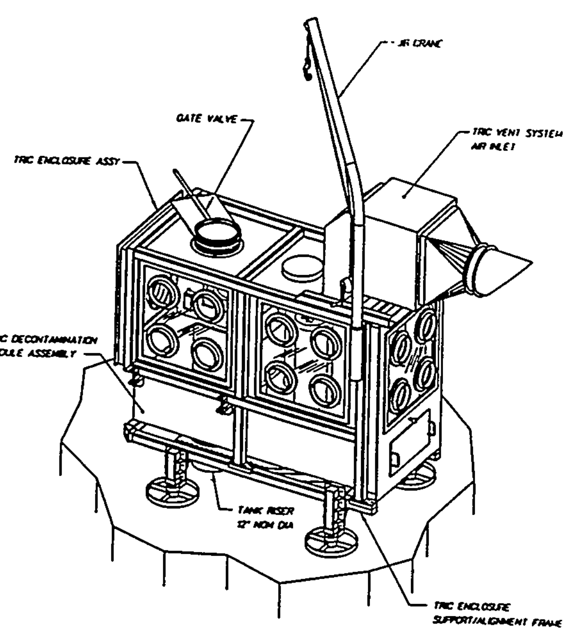


Fig. 8.20. LDUA tank riser interface and confinement enclosure.[16]

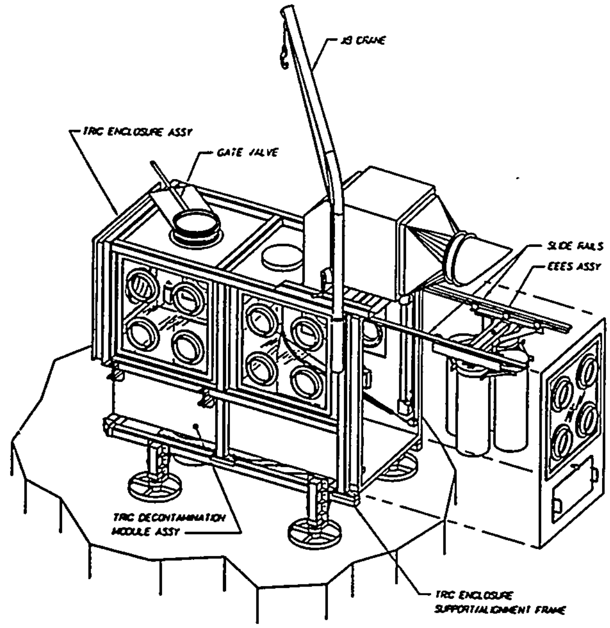


Fig. 8.21. LDUA tank riser interface and confinement enclosure.[16]

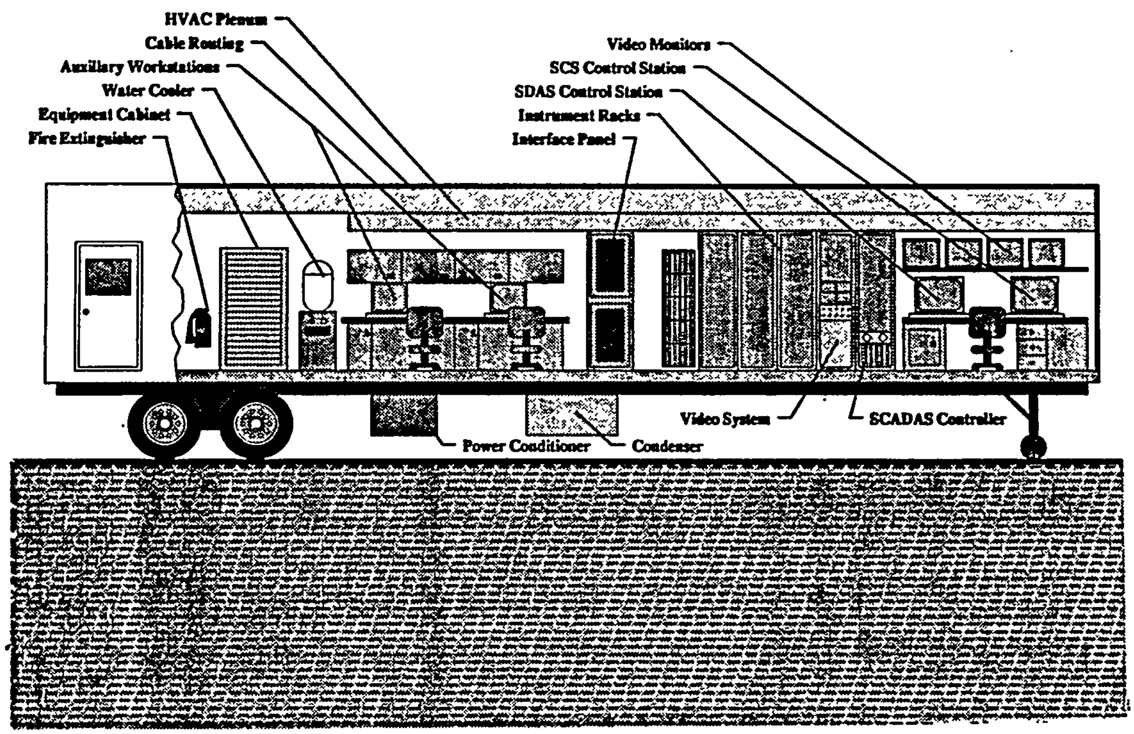


Fig. 8.22. LDUA operations control trailer schematic.[16]

8.6 MODIFIED LIGHT-DUTY UTILITY ARM SYSTEM

LDUA is referred to as a "light duty" arm because the payload and reach are not sufficient for the baseline Hanford site retrieval scenarios. As previously stated, the baseline concept for retrieval of Hanford single-shell tanks is a long-reach, high-capacity manipulator system (LRM) deployed through a central riser. Development and testing of this concept are currently being pursued. Development and testing of the waste dislodging and conveyance tools that would be deployed by the LRM are currently being performed by the USTID program.[8]

As stated earlier, the LDUA system offers a means for remotely deploying a variety of small, lightweight end effectors for characterization, inspection, surveillance, and sampling inside highly radioactive waste storage tanks. Again, development of this system, including tank riser interface, decontamination systems, and the many end effectors, is being funded by USTID. Based on the number of sites with storage tank remediation problems, there are many opportunities to reuse the equipment or designs to benefit DOE environmental restoration and waste management programs. Although LDUA was primarily designed to support a characterization mission at Hanford, the payload and reach might be sufficient for retrieval applications at other sites, such as ORNL, especially if minor modifications can be accommodated at low cost. There is no articulated arm-based commercial system available that can meet GAAT retrieval performance requirements without further development and testing.[8]

ORNL should evaluate sludge waste mobilization end effector requirements to determine feasibility of using the LDUA system to dislodge waste in ORNL tanks. ORNL should investigate functional and operational requirements for deployment of the LDUA system at ORNL and provide input to the LDUA subsystem cognizant engineer on specific design requirements that may impact LDUA design. This approach would determine the LDUA modifications required, the expected payload, the reaction forces, and the deployment approach. (It will not be possible at ORNL to drive a vehicle onto a tank farm as envisioned at Hanford). Because the ORNL tanks are shallower (30 ft) and tank risers are much larger (30 in.) than at Hanford, it should be possible to increase the allowable LDUA payload considerably with minor modifications. For example, one of the biggest constraints at Hanford is side loading on the risers, therefore, mast flexure is constrained to within a 10.5-in. diameter cylindrical volume. At ORNL, much greater flexure can be tolerated because the risers are large enough that side loading will not occur for moderate loads. Also, the mast can be shortened, and hence, stiffened considerably. These initial conclusions indicate that with appropriate modifications to the deployment approach and with stiffening to increase the payload, it would be reasonable to consider the use of an LDUA system at ORNL for retrieval-based tasks.[8]

A primary benefit of a retrieval system demonstration is the development and field testing of robotics technology that will be required for waste tank remediation at ORNL. Because of the hazards associated with these wastes, remote equipment will be required for nearly all foreseeable closure options. If the final results from the LDUA feasibility evaluation for the ORNL waste retrieval tasks are promising, ORNL has an opportunity to leverage the multiyear, multimillion dollar investment of USTID in development of the LDUA system. In particular, ORNL has an opportunity to minimize procurement and contract efforts by exercising an existing option on the Hanford contract with SPAR.[8]

9. VEHICLE-BASED TANK CLEANING TECHNOLOGIES

9.1 REDZONE "HOUDINI"

A vehicle-based bulldozer/backhoe unit, HOUDINI, has been proposed by Carnegie Mellon University and RedZone Robotics, Inc. of Pittsburgh, PA for tank waste mobilization and retrieval. This in-tank mobile robot is in the developmental stages and is not presently commercially available. The 4 x 5-ft unit is depicted in Fig. 9.1 and is designed to fit through 19-in. manway openings in tanks when in its collapsed-frame position, as shown in Fig. 9.2. The HOUDINI tracked unit provides a platform for appropriate work capability. The vehicle is remotely operated and equipped with a deployment pod. The primary tooling equipment for the vehicle consists of a bulldozer blade, a backhoe shovel, a gripper, and a manipulator with a 6-ft reach and a 250-lb payload. A Schilling Titan II manipulator is specified to be used on the HOUDINI system. The overall vehicle weighs less than 500 lbs, and the tether weight is 1 lb/ft. Material handling rates are designed to be greater than 1000 lbs/hr, with digging rates of greater than 500 lbs/hr. HOUDINI can be equipped with an end effector camera and audio unit. This remotely operated vehicle can operate at speeds up to 3 mph.[10]

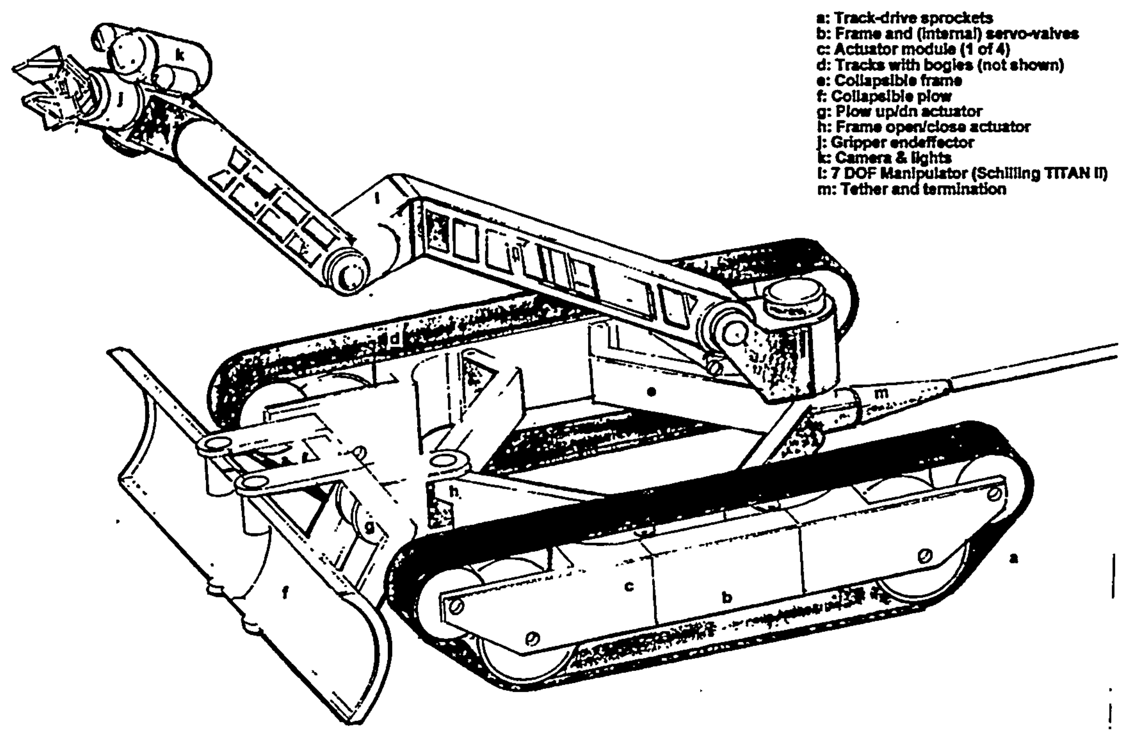


Fig. 9.1. HOUDINI robot crawler—system view.

9.2 REMOTEC "ANDROS"

The ANDROS Mark VI-A is a commercially available multitracked vehicle specifically designed for use in indoor and outdoor hazardous environments. The ANDROS robot was developed by Remotec in Oak Ridge, Tennessee. The ANDROS Mark VI-A is 19 in. wide

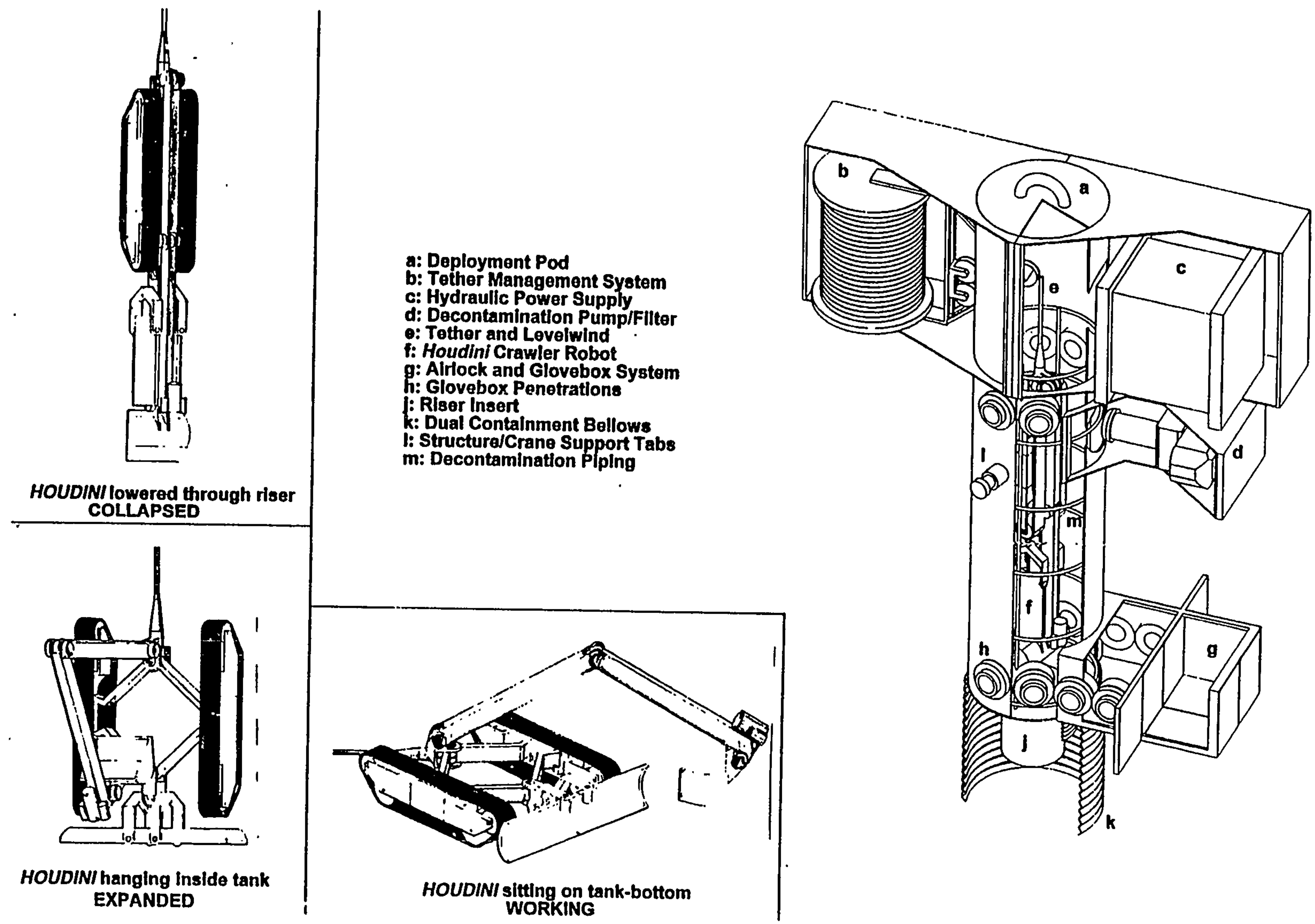


Fig. 9.2. HOUDINI deployment pod and deployment sequence.[10]

× 33 in. high × 46 in. long. and is shown in Fig. 9.3. The length of the vehicle with the tracks fully horizontal is 58 in. The standard unit weight is 275 lbs. The remote-controlled robot can climb 45° stairs and slopes, maneuvers with 180° center turns, clears 12 in. obstacles, and reaches up to turn off valves. This unit is capable of cleaning plugged nozzles in radioactive waste tanks. At a 41 in. reach, its manipulator arm can lift 25 lbs. The ANDROS Mark VI-A is suitable for all dry and wet surfaces and can operate in all types of weather.[11]

The ANDROS Mark V-A is the largest and strongest Remotec robot available. The ANDROS Mark V-A is 28 in. wide × 41.5 in. high × 31 in. long. This robot is equipped with articulated tracks to maneuver over rough terrain and obstacles, traverse slopes, and cross ditches up to 24 in. wide. The manipulator can lift 35 lb at a 66 in. reach. This system can be equipped with a closed circuit TV with 6:1 zoom and two-way audio function. An optional VCR attachment is also available. This vehicle is also capable of such cleaning or treatment processes as handling process filters, hydroblasting, and vacuuming contaminated water. The ANDROS Mark V-A has additional options, as a heavy-duty gripper, a contaminant smear fixture, infrared cameras, dual monitors, a color TV arm mount, and a double pincer end effector. Both ANDROS robots can descend stairs going forward at 45°.[11]

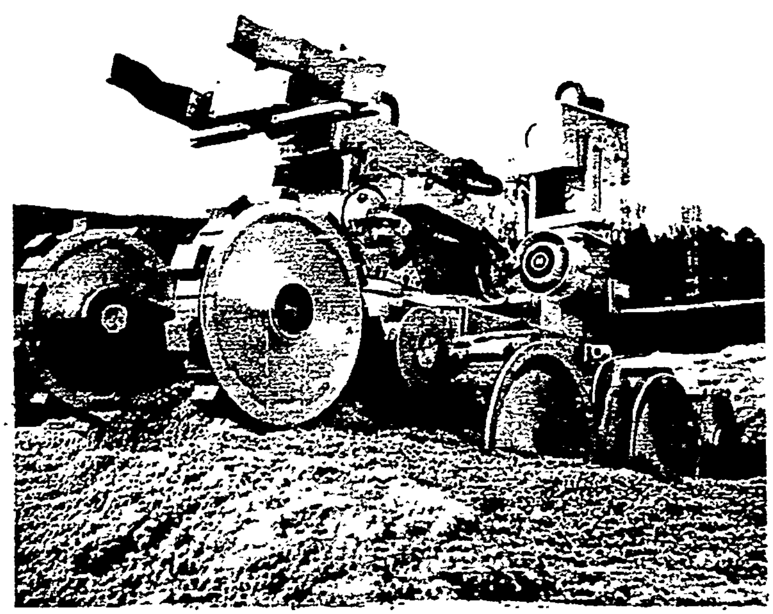


Fig. 9.3. ANDROS Mark VI-A.[11]

9.3 INDUSTRIAL INNOVATIONS, INC. "SLUDGE BUG"

The Industrial Innovations, Inc. (3I) of Stockton, California, has developed a commercially available mobile excavating machine for the removal of sludge from storage tanks. The vehicle, called the Sludge Bug, is maneuvered by an operator physically seated on the "dune-buggy-type" vehicle as shown in Fig. 9.4. The front section of the Sludge Bug is equipped with a hydraulic retrieval arm and scraping device. The vehicle arm can reach outward and upward approximately 5 ft. As the waste is pushed forward to a sloped metal pan surface, a rotating auger device moves the waste into the hydraulic removal system. The Sludge Bug weighs approximately 2000 lbs and is 8 ft long and 5 ft wide. The Sludge Bug unit breaks down into sections for entry into tanks with manway openings of 20 in. diameter. The maximum speed of the vehicle is 3 mph and estimated digging rate is 50 gal/min. This vehicle would need to be remotely controlled and modified for use in the Gunite tanks.[12]

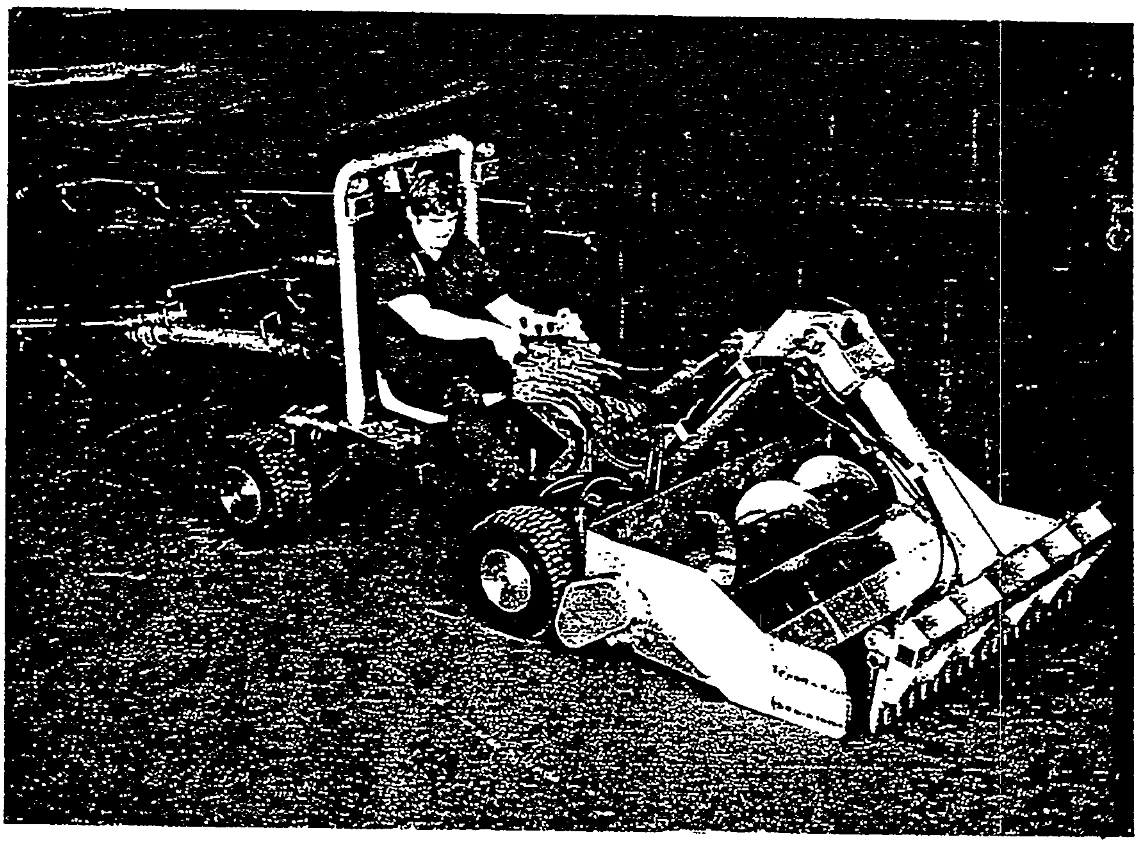


Fig. 9.4. Sludge Bug.[12]

9.4 H & H PUMP AND DREDGE COMPANY "TRAC PUMP"

The "TRAC PUMP" is a commercially available, remote-controlled, mobile dredging system that removes sludges from tanks, canals, ponds, lagoons, digesters, and ditches. The TRAC PUMP was developed by the H & H Pump and Dredge Company in Clarksdale, Mississippi. The general design of the TRAC PUMP consists of a motorized, track-driven carriage equipped with a hydraulic submersible pump; a hydraulic power hose assembly; a diesel/hydraulic power unit with trailer and operator station; a set of controls; and a 4-in. discharge tube with line floats. Dimensionally, the TRAC PUMP is approximately 6 ft long × 2.5 ft wide × 1.5 ft high, and it weights approximately 700 lbs.[13] The TRAC PUMP, shown in Fig. 9.5, moves by crawling along on individually controlled dual tracks. The rotating cutter head excavates, liquefies, and feeds material into the 4-in. sludge pump, which moves sludges at an average rate of 400–500 gal/min through the 4-in. tubing. Pump performance rates can reach 800 gal/min, but the performance varies with solids content and the viscosity of the material being pumped. The TRAC PUMP is powered and controlled by a hydraulic hose connected to the diesel/hydraulic power unit. The operator station unit controls all unit functions, including steering, forward/reverse operation, pump speed, and cutter head speed. The TRAC PUMP can be fit through 24-in. diameter openings by folding the crawler tracks underneath the carriage assembly. Insertion of the TRAC PUMP is enabled by hydraulically actuated links between the pontoon assemblies and pump platform. These links allow the pontoon assemblies to fold under the platform, reducing the effective width of the TRAC PUMP.[13]

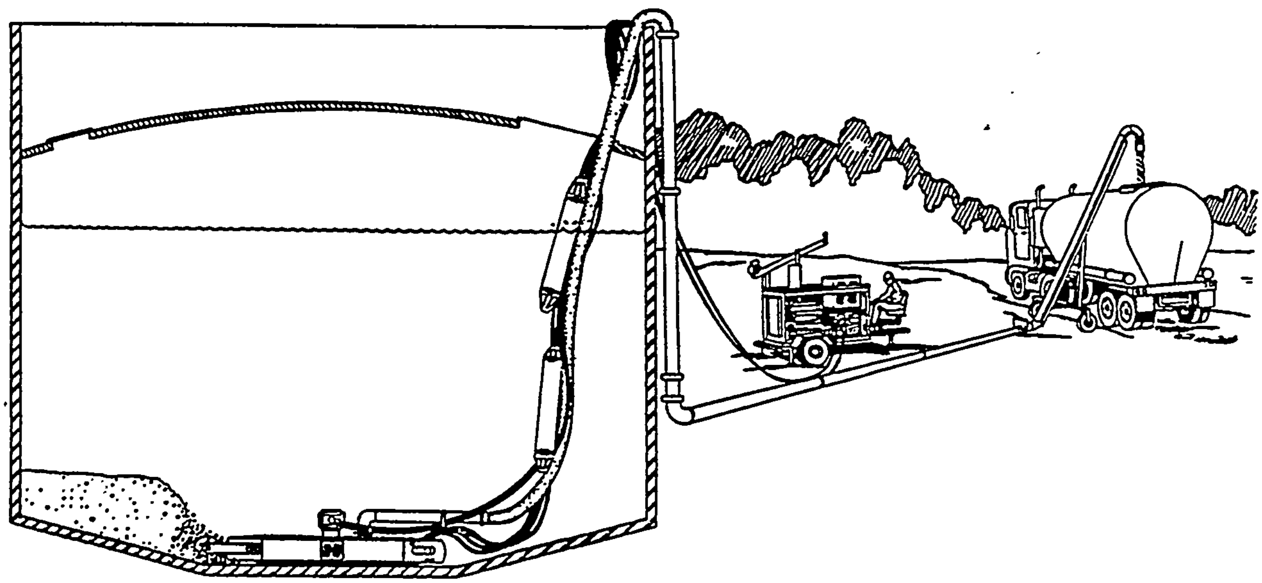


Fig. 9.5. TRAC PUMP.[13]

9.5 BNFL SLUDGE REMOVAL MACHINE

BNFL Inc.'s parent company, BNF plc, has experience in the research and development, engineering, construction, and operation of sludge retrieval systems. BNF plc uses retrieval systems for its fuel storage pond, B31, at its Sellafield facility in the United Kingdom. The BNFL retrieval system is a pre-assembled unit consisting of a desludging machine, a large desludging head, a control cabin, a drag chain assembly, a swivel box and hose assembly, and a camera surveillance system. The desludging head is raised and lowered into the sludge by a cab unit mounted on a rail system above the pond. Gamma monitors ensure that radiation levels at the surface are kept within the safe range.[14]

The retrieval system was designed to minimize exposure to external radiation and airborne contamination. A special desludging head is lowered below the sludge surface where liquid jets impinge on the sludge, causing local resuspension within the volume bounded by the desludging head. The process then produces a net flow into the head, minimizing any sludge disturbance outside the head.[14]

10. END EFFECTOR TECHNOLOGIES

This section provides a general description and functions of a variety of end effectors that seem applicable to characterize and mobilize the radioactive waste and solid debris located in the Gunite tanks.

The various end effectors will be mounted on, deployed and maneuvered inside the tank by some type of maneuvering system (mechanical arm-based system or vehicle-based system). One end effector alone will not be able handle all the sludge mobilization tasks. A combination of end effectors that perform different tasks will need to be used. The required combinations are not yet known and cannot be finalized until the waste in the tanks has been adequately characterized and waste retrieval equipment performance requirements have been established.

10.1 LDUA AND RISER-MOUNTED END EFFECTORS

The LDUA system will perform surveillance and inspection activities related to tank structural integrity assessment and leak investigations as well as waste characterization/analysis activities of the Hanford single-shell tanks. A number of arm-mounted end effector systems that can be remotely engaged with a quick-disconnect tool interface plate on the robot arm are being developed under the USTID program to perform these activities. These systems include remote video and photography systems (stereo and mono vision), a laser range finder mapping system, a Raman spectrometry end effector system (Fig. 10.1), a Mini-Lab sensor head (which automatically analyzes physical and chemical properties by the insertion of a penetrometer into the waste—see Figs. 10.3 and 10.4), and a nondestructive examination end effector system (Fig. 10.2). In addition, riser-mounted end effector systems that provide independent deployment mechanisms and environmental enclosures are also being developed, including tank overview systems (stereo and mono vision) and a topographical mapping system. If deemed appropriate, ORNL should use this end effector development effort because the initial development costs are being provided under the USTID program.[18]

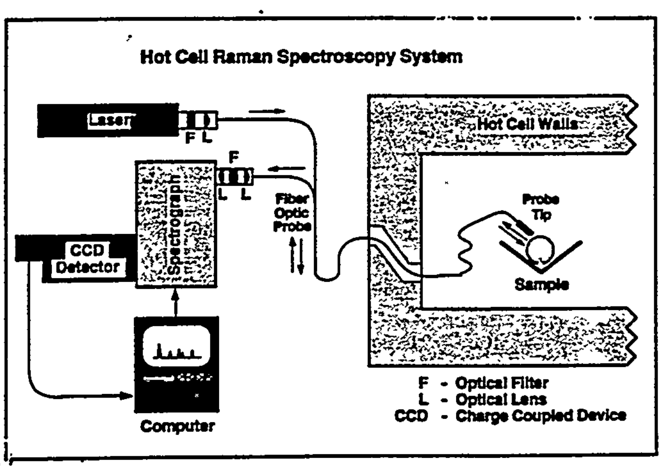


Fig. 10.1. Laser Raman spectroscopy system (hot cell).[9]

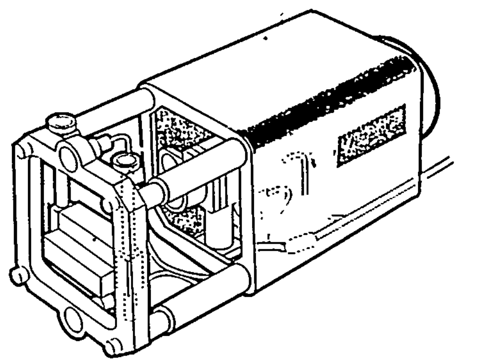


Fig. 10.2. Nondestructive examination end effector.[16]

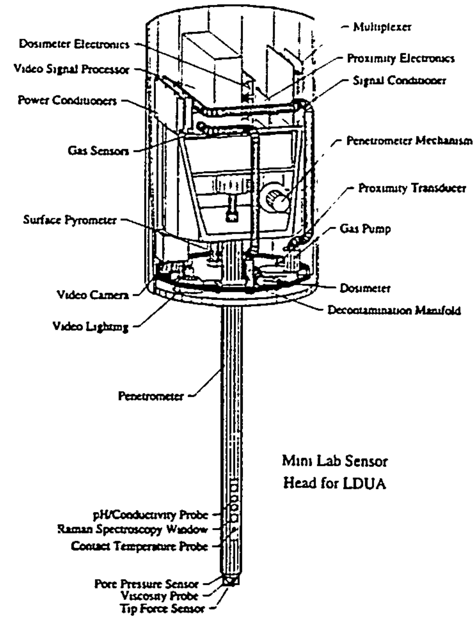


Fig. 10.3. Mini-Lab sensor head end effector.

Fig. 10.4. Insertion of Mini-Lab penetrometer into simulated waste.[16]

10.2 USTID MEDIUM/HIGH-PRESSURE CONFINED SLUICING SHROUD

The USTID program is funding Waste Dislodging and Conveyance activities to develop baseline dislodging and conveyance technologies for the retrieval of waste inside the Hanford single-shell tanks. This includes understanding the fundamental aspects of waste dislodging and conveyance technologies so that the effort can support design of systems to retrieve sludge and hard pan (salt cake) from the Hanford tank C-106 (the first tank to be cleaned) and also support the tank clean-up activities at other DOE sites. Extensive reviews were conducted by Hanford of the available technologies that might be applied to Hanford single-shell tank waste retrieval. The most promising technologies for Hanford were identified during 1993.

The underground storage tanks at Hanford contain three basic material types, both individually and in combination: liquid supernatant, sludge, and hard salt cake. Removal of the sludge and salt cake has presented a technological challenge. A water jet cutting/scarifying method for dislodging the tenacious sludge and salt cake waste is being developed and tested. Combined with a conveyance system operating simultaneously, this confined sluicing has been determined to be an effective waste removal technique for the Hanford site (Fig. 10.5).[17]

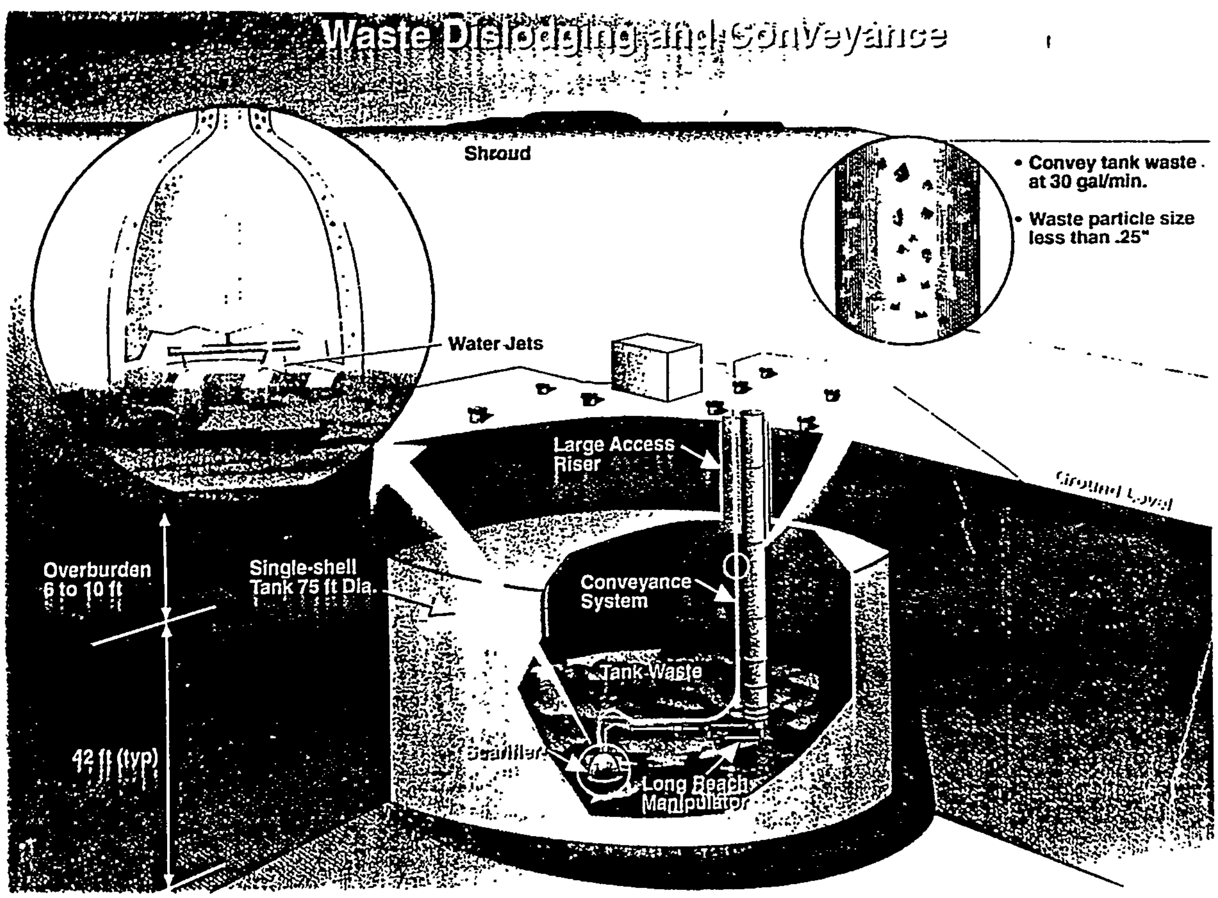


Fig. 10.5. Waste dislodging and conveyance system.[16]

In the confined sluicing concept (Figs. 10.6 and 10.7), a series of high-pressure water jets are used to cut into and break out the material in the tank. The jets rotate around the edge

The basic scarifier concept for the use of high pressure waterjets uses two jets which rotate around the edge of a disc.

As the disc rotates it moves forward, so that the jets cut a series of slots into the surface. The spacing between the cuts is related to the speed at which the disc turns and how fast it is moving forward.

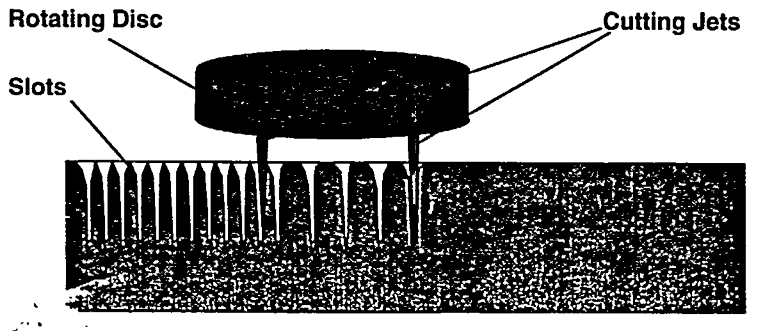
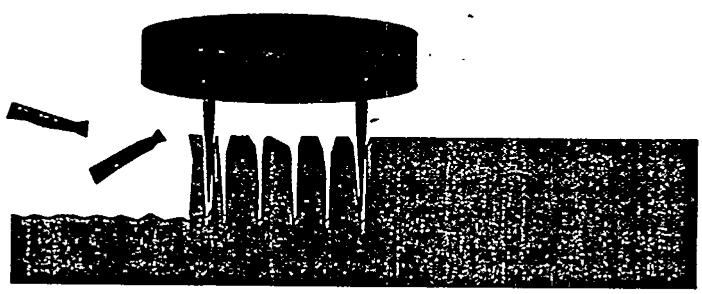


Fig. 10.6. Mechanics of confined sluicing.[16]

If the spacing is right then the intervening ribs break off either with the second cut



or, if the material is weak enough, with the first. In the latter case the second jet will now deepen the cut depth achieved.

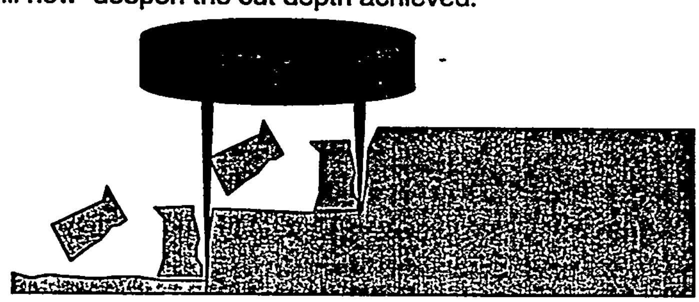


Fig. 10.7. Mechanics of confined sluicing.[16]

of a disc cutting into the waste. As the disc rotates it moves forward, so that the jets cut a series of slots into the waste. The spacing between the cuts is related to the speed at which the disc turns and how fast it is moving forward. If the spacing is right, the intervening ribs break off either with the second cut, or if the material is weak enough, with the first. The cutting head operates within a surrounding shroud, with the shroud connected to the intake line of the conveyance system (Fig. 10.8). Thus, as the water jets cut and dislodge material, the excavated material is immediately aspirated into the conveyance system intake and transferred out of the tank.[11]

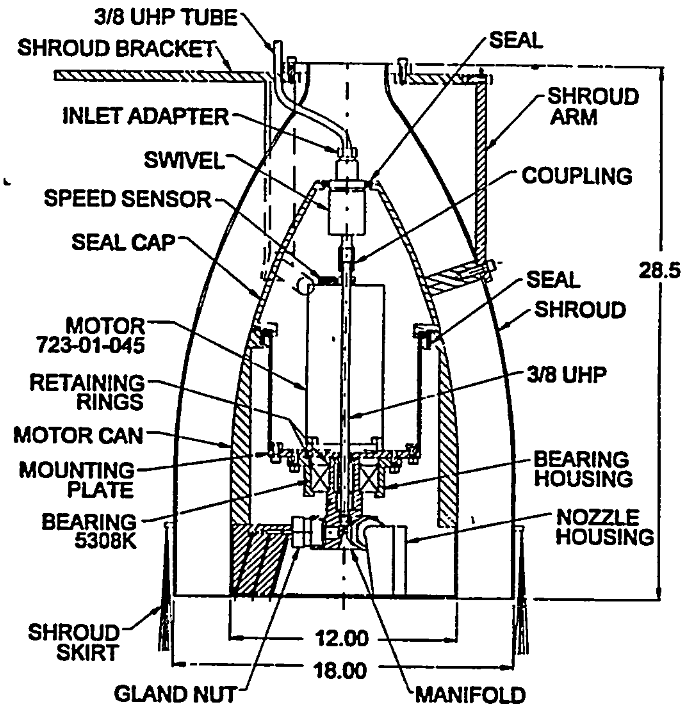


Fig. 10.8. Confined sluicing scarifier cross section.[16]

Under the USTID program, a medium-pressure (5-15 ksi) and a high-pressure (50-60 ksi) confined sluicing shroud are being developed. The University of Missouri–Rolla (UMR) team led by Dr. David Summers is developing a medium-pressure scarifier and a jet pump capable of conveying the dislodged waste material. The medium-pressure scarifier concept is similar to the high-pressure scarifier being developed jointly by Pacific Northwest Laboratory (PNL) and Quest Integrated, Inc. The primary difference lies in the selection of the jet pressure and nozzle diameter. The medium-pressure scarifier uses jet pressures on the order of 10 ksi, while the high-pressure scarifier uses about 50 ksi. Both systems will likely be operated similarly. In addition to the medium-pressure scarifier, UMR is developing a jet pump capable of conveying the dislodged waste material at the retrieval rates required by Hanford.[15]

The UMR development work for Hanford to date has focused on demonstrating the applicability of the medium-pressure confined sluicing concept to the dislodging of simulated waste forms. This experimental work has demonstrated that water jets at about 10 ksi pressure do effectively excavate both salt cake and sludge simulants. The depth to which the water jets cut into the salt cake simulant was found to be directly proportional, approximately, to jet pressure, nozzle diameter (to the 3/2 power), and traverse velocity (to the 1/3 power). Based on this data, it was projected that a cutting head supplied with 40 gal/min of 10 ksi water should be able to meet the Hanford target waste dislodging rate of 30 gal/min. Such a device would cut a 20-in. wide, 1-in. deep swath through the waste when moved across the waste surface at about 30 ft/min.[15]

A commercially available jet pump was modified to improve its performance and then used to demonstrate its ability to pump 80 gal/min (30 gal/min simulated waste, 40 gal/min cutting water, and 10 gal/min jet pump water) through a vertical lift of 60 feet. This shows that the jet pump is capable of providing the required Hanford flow rates and pressures to effectively convey the dislodged waste particles. The use of the jet pump is not dependent on the type of end effector used. The jet pump can be used with any type of waste-dislodging unit that is capable of producing pieces of dislodged waste in the size range appropriate for the jet pump. A jet pump conveyance system could be used in place of the air conveyance system that is being considered. During FY 1993, a demonstration was conducted in which the jet pump was used to convey the simulant dislodged by the medium-pressure scarifier. This combination could extract waste (salt cake and sludge simulants) from a tank without any net water flow into the tank.[9]

The medium-pressure scarifier testing has also revealed that the salt cake simulant will not break easily under the forces generated by the water jets alone if the distance between adjacent jet cuts is 0.5 in. or more. This is important because it establishes the maximum allowable distance between jet passes. This distance will have a significant influence on the design of a prototypic scarifier, so it must be determined whether this observation is expected to apply to actual salt cake in addition to the simulants. Because this distance between cuts is thought to be a function of primarily the tensile strength of the salt cake simulant, the simulant development task will investigate methods for estimating the tensile strength of single-shell tank salt cake and comparing it with that of the salt cake simulants.[29]

The high-pressure confined sluicing shroud/conveyance project is developing design specifications for a hydraulic dislodger (scarifier) coupled with a pneumatic (three-phase) conveyance system that minimizes water accumulation during retrieval of salt cake, sludge, and viscous fluids from Hanford single-shell tanks (Figs. 10.9 and 10.10). The development is being accomplished through a multiyear analytical and experimental investigation consisting of experimental phases.[15]

The confined high-pressure sluicing shroud subcontract for Hanford with Quest Integrated, Inc. was approved in January 1993. Quest has been chartered to develop a high-pressure (55 ksi) mining strategy for waste dislodging and mobilization that is compatible with the anticipated long reach arm and conveyance systems while minimizing water usage. Since then, Quest has developed test fixtures and conducted experimental investigations of the interactions between the salt cake and sludge simulants (Figs. 10.11 and 10.12).[9]

A nearly full-scale waste conveyance test facility has been designed and constructed to acquire parametric data for three-phase flow testing of simulant. The key features of the high-pressure water jet are that it uses a minimal amount of water, has a compact equipment design, has the ability to handle "off-normal" events (surface variations, obstacles, wall cleaning), produces an acceptable waste size for effective air conveyance, and is

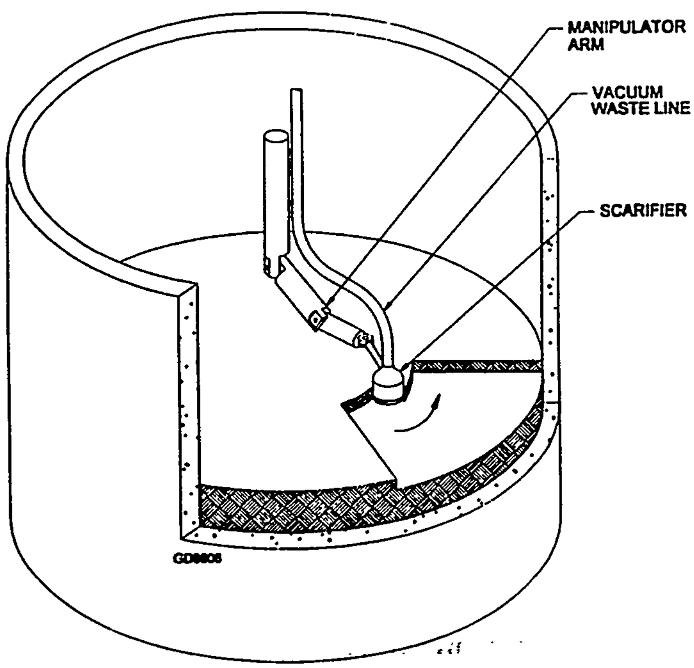


Fig. 10.9. Sludge mining strategy.[16]

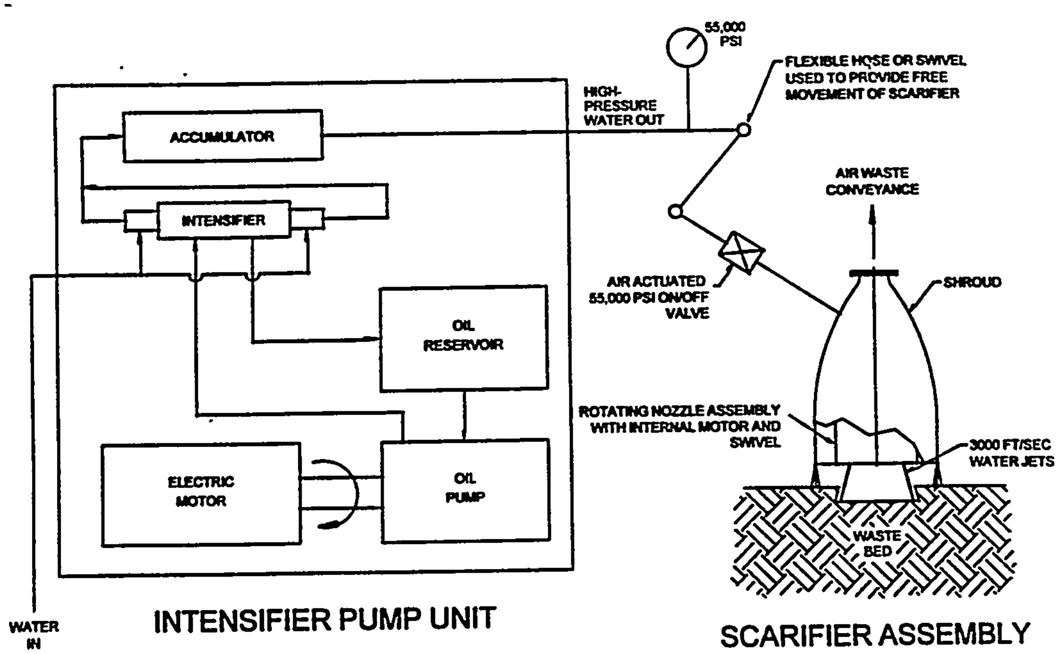


Fig. 10.10. Ultrahigh-pressure technology elements.[16]

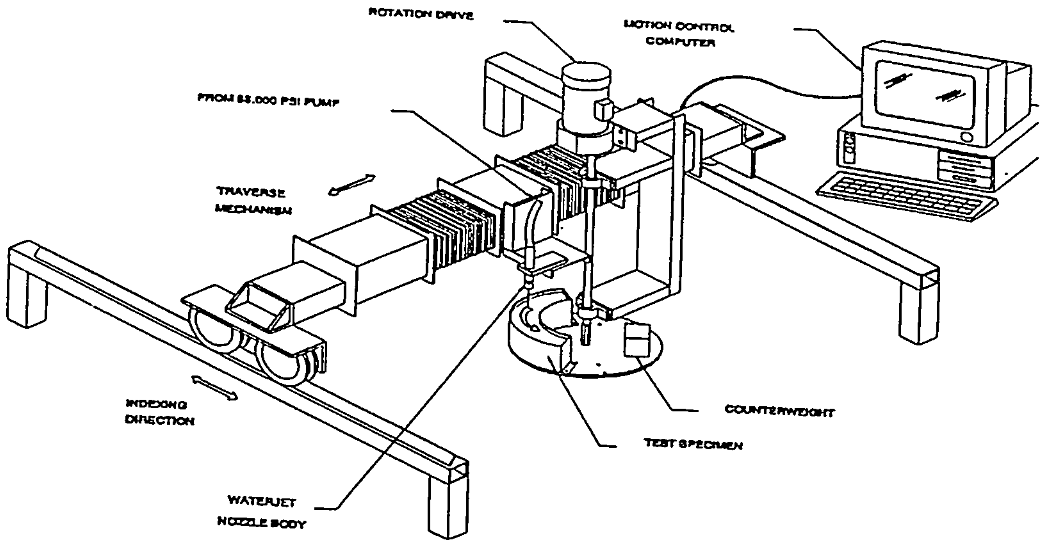


Fig. 10.11. Test fixture for confined sluicing concept (schematic).[16]

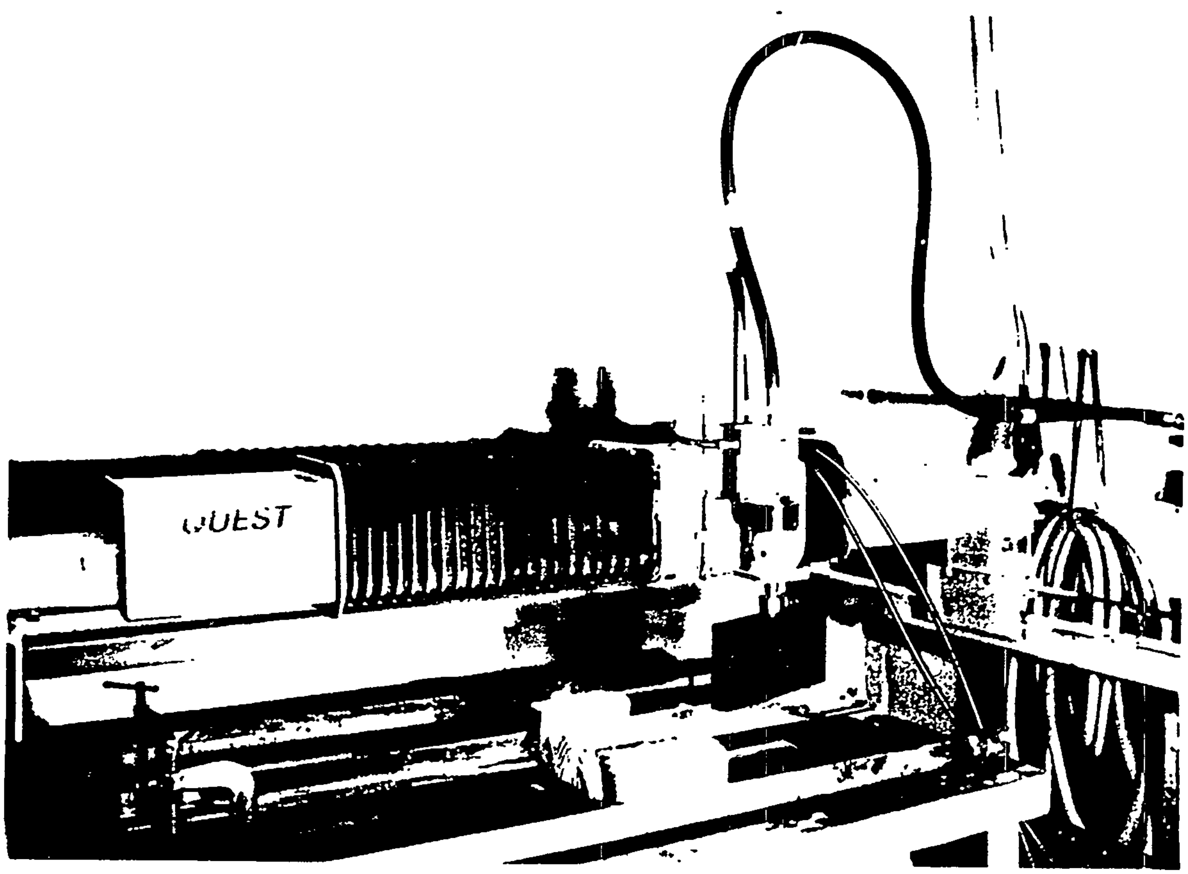


Fig. 10.12. Test fixture for confined sluicing concept.[16]

nondirectional (does not require a specific milling pattern). Testing at Hanford to date has shown that the high-pressure confined sluicing shroud is capable of meeting the waste fracture and dislodging rates for the single-shell tank retrieval program at Hanford (Fig. 10.13). A prototype unit will weigh less than 200 pounds and will be delivered for testing in 1994.[16]

Also at Hanford, a hydraulic testbed is being designed and fabricated to investigate waste dislodging and conveyance system deployment strategies to determine appropriate mining strategies, level of control, and sensor requirements. The hydraulic testbed will achieve these objectives by providing longer duration, multiple pass tests, sluicing shroud tests on large waste fields, and a 3-D deployment platform (see Figs. 10.14, 10.15, and 10.16).[11]

ORNL should take full advantage of the medium/high-pressure confined sluicing shroud development and testing facilities at Hanford. The confined sluicing shroud is an extremely attractive end effector to consider because of its ability to dislodge waste of any form, soft sludge to hard salt cake. Because Hanford is working with competent industrial partners in their design and development efforts, the appropriate sluicing shroud for ORNL could be designed and developed by these partners once ORNL has established the performance/retrieval criteria for GAAT sludge dislodging/mobilization and waste characterization/sampling efforts have been completed.

10.3 USTID SOFT WASTE DISLODGING END EFFECTOR

This section discusses the Westinghouse Hanford Company's development and testing program for soft waste dislodging and conveyance technology for the Hanford single-shell tanks under the USTID program. The program was initialized to investigate methods of dislodging and conveying soft waste. Heavy sludge presents many problems from the standpoint of its varying consistency, and a system was needed that could adapt to the changing sludge consistency and still effectively and efficiently remove and convey the sludge from the tanks. The main focus was on using air jets, water jets, and/or mechanical blades to dislodge the waste in conjunction with air conveyance to remove the dislodged waste[17] from the tanks.

A development unit end effector (Fig. 10.17) was designed and fabricated for testing and then mated with a three-phase air conveyance system. The development unit could be configured in several ways. The development unit was also designed to allow for variation of key parameters, such as nozzle size, to determine their effect on waste dislodging. The system was designed so that it can be attached as an end effector to a long-reach, remotely controlled manipulator arm.[17]

The development unit was tested in varying configurations. The main configurations were the scarifier and the mechanical agitator. The scarifier used air or water jets to dislodge the soft waste. The mechanical agitator used these jets and blades to dislodge the waste. The other parameters that were varied within those configurations were the radial blade/nozzle position, nozzle size, nozzle style, nozzle angle, dislodging media (air or water), dislodging media pressure, tool rotation speed, and tool translation speed.[17]

The engineering data gathered from these tests included tool torque, tool translation loads, waste removal rate, and volumetric effluent dilution ratio. The data were used to evaluate the performance of the development unit.[17]

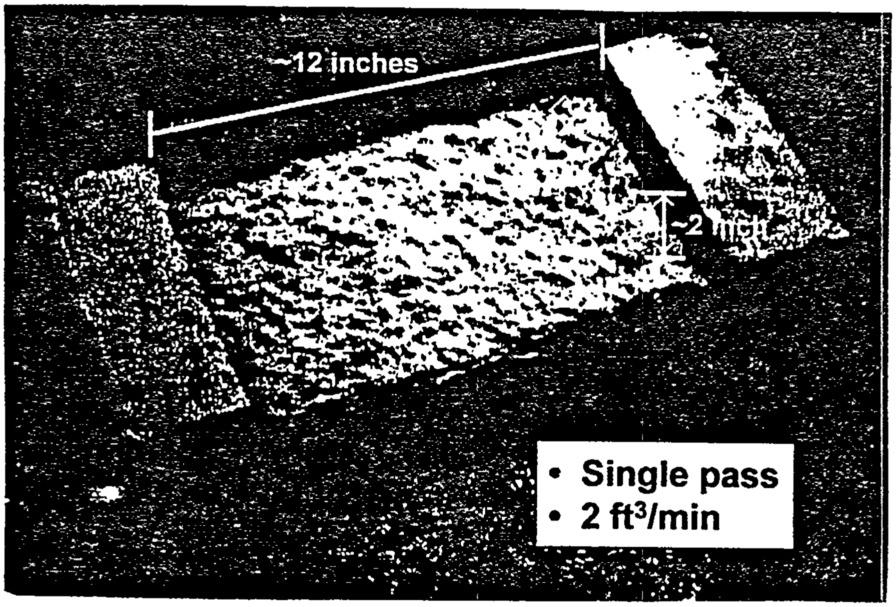


Fig. 10.13. Example of a scarification kerf.[16]

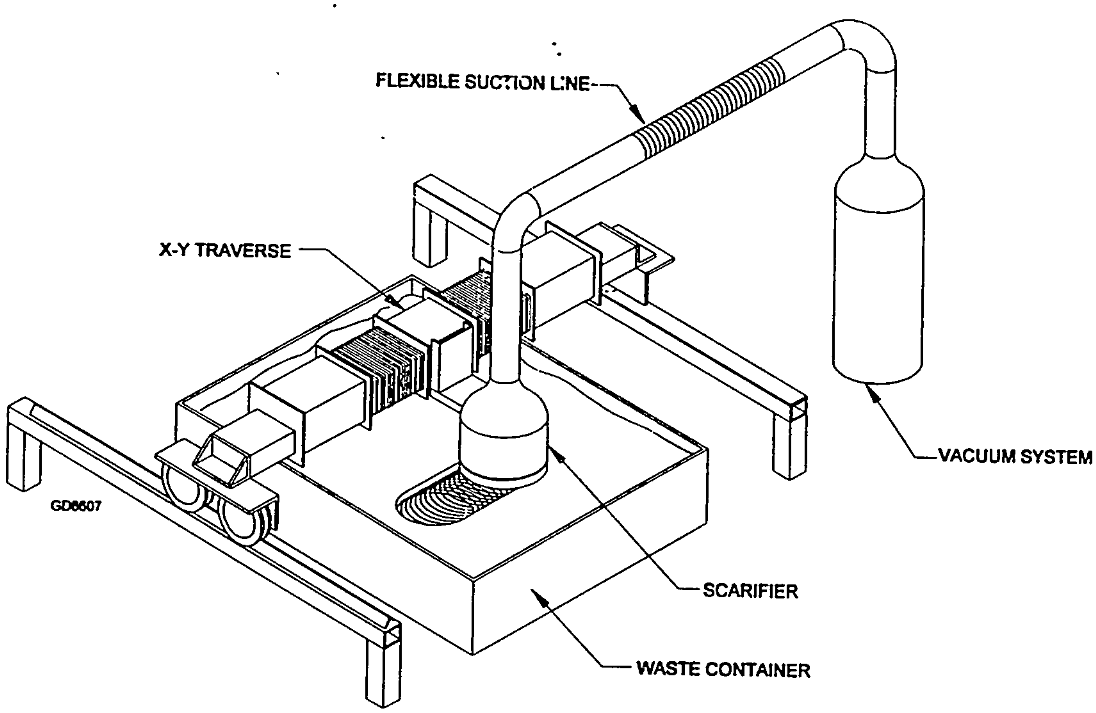


Fig. 10.14. Hydraulic test bed schematic.[16]

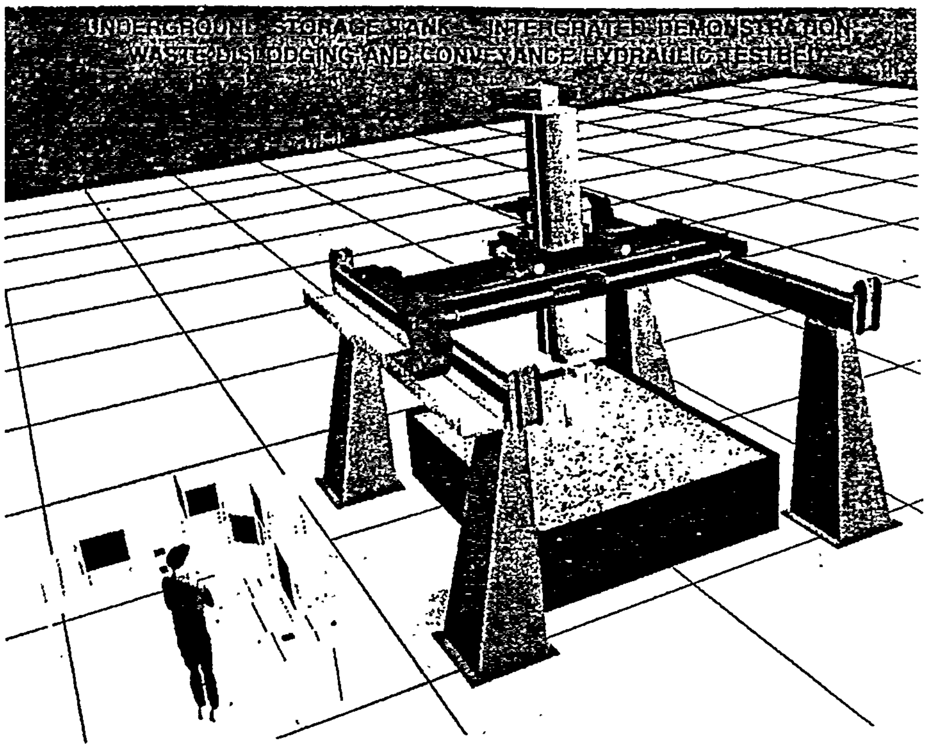


Fig. 10.15. Hydraulic test bed concept.[16]

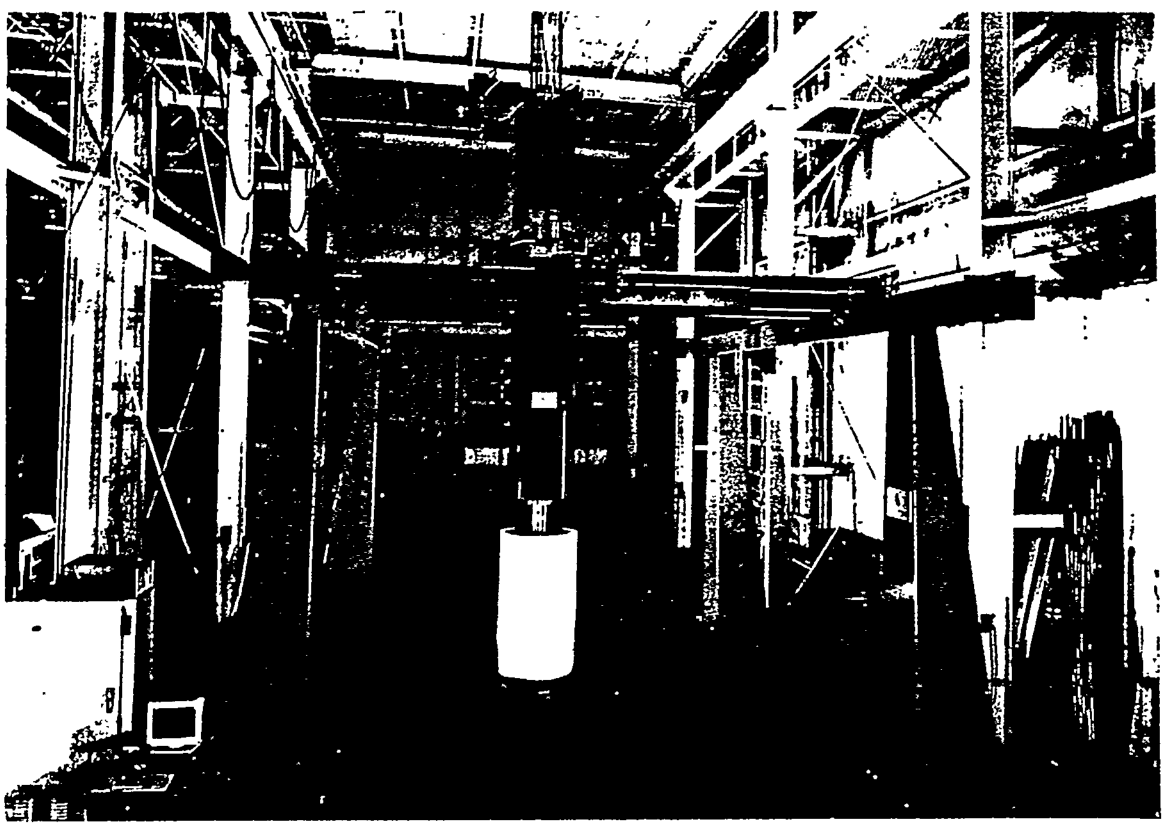
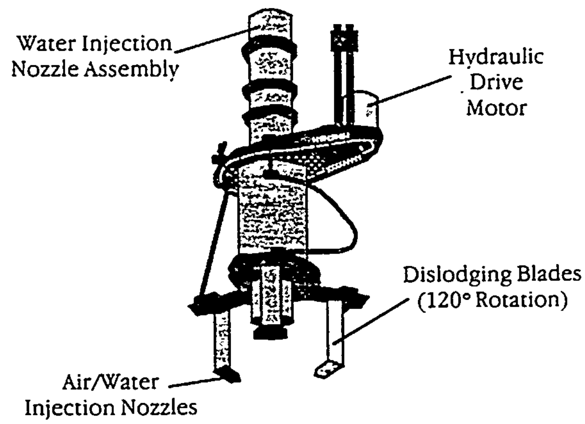


Fig. 10.16. Hydraulic test bed gantry system.[16]



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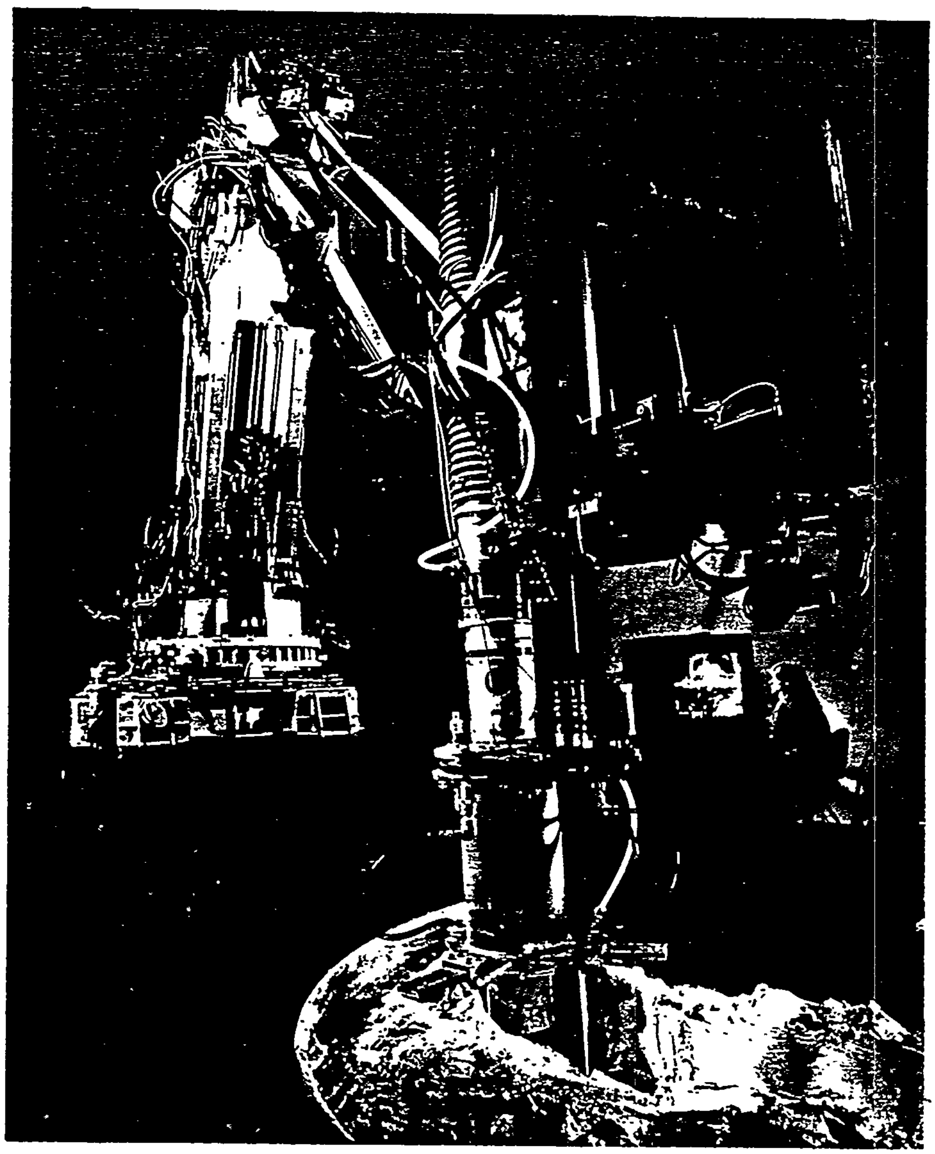


(b)

Fig. 10.17. Soft sludge dislodging end effector.[9] *(a) Schematic (b) in use.*

The development unit and air conveyance system were tested using two claylike simulants: bentonite and kaolin. Tests were performed on flat, homogeneous surfaces; uneven surfaces; and using a mixed waste form. Tests of off-normal conditions were also performed.[17]

The main performance indicators were the Hanford waste removal rate, target of 0.11 m^3/min (30 gal/min), and volumetric effluent dilution ratio (waste generated:waste removed), target of 5:1. The testing showed that the development unit, under certain configurations, can far exceed both of these values. The waste removal rate peaked at 0.38 m^3/min (100 gal/min), with the dilution ratio dropping to as low as 1.06:1.[17]

The testing program was a success. Many things were accomplished and learned during this program. Some of the highlights of the testing program are listed below.

1. The program determined the important parameters that affected the dislodging and conveyance processes and found that translation speed, nozzle size, nozzle radii, and dislodging media pressure had the most affect on tool performance.

2. It demonstrated a sludge retrieval rate in excess of 0.36 m^3/min (95 gal/min) versus the target rate of 0.11 m^3/min (30 gal/min) in a prototypic environment. This technology was not believed to be able to achieve the target rate.

3. It demonstrated use of minimal water addition (secondary waste generation) to dislodge and convey waste. Water addition in a tank is a safety issue for the Hanford tanks. This technology has proven that it can be used with very little water addition, and only small quantities are needed for the air conveyance system. The dislodging process requires little water to dislodge waste. Very small amounts of residual water are left in the tank during dislodging.

4. The program demonstrated robotic deployment of an end effector in a sludge simulant.

The proven air conveyance system will handle wet materials and convey them 18 m (60 ft) vertically. This is a commercially available system (manufactured by Hi-Vac) normally used to convey dry materials. This testing program has proven that the system will work with wet materials as well.[17]

Based on the knowledge gained during this testing program, some key recommendations for future testing under the USTID program were provided and are listed below.

1. Investigate a slurry retrieval method. This involves using water jets to slurry the waste prior to conveyance rather than cutting the waste in chunks.

2. Continue use of water as the dislodging medium, rather than air.

3. Investigate the use of spin-jet technology to potentially eliminate the need to rotate the tool, thus simplifying the design.

4. Perform testing of all technologies in longer duration tests (greater than one minute).[17]

Based on the testing performed, the USTID soft waste dislodging end effector is a potential end effector candidate for the GAAT sludge removal project at ORNL. Again, once sludge removal performance requirements are established and the waste characterization (physical, radiological, and chemical) of the sludge in the Gunite tanks is completed, the applicability of the soft waste dislodging end effector can be determined.

10.4 SINGLE-POINT JET SLUICING NOZZLE

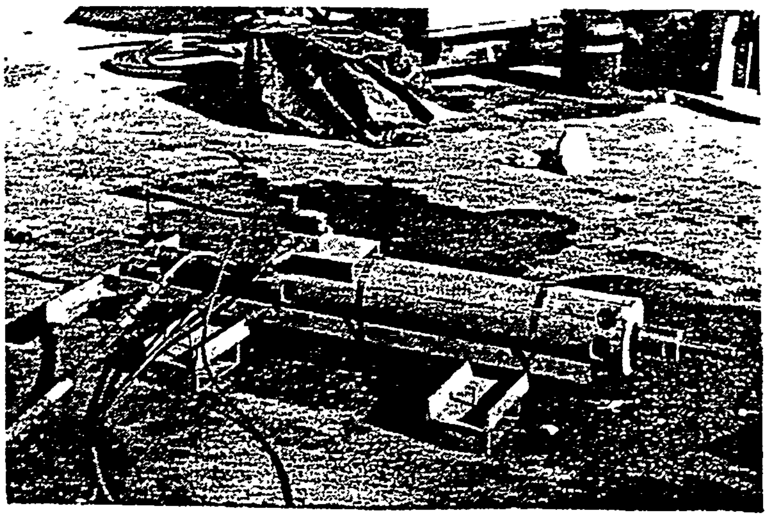
As previously discussed, six large Gunite tanks in the South Tank Farm were cleaned by a single-point jet sluicing system over a period of 18 months during 1982 and 1983. In this process, a remotely controlled sluicer assembly was used to impinge on and resuspend the sludge in the tank being sluiced. A single-point jet sluicer nozzle assembly could indeed become an end effector for either the mechanical-based or vehicle-based deployment system. The nozzle could be held by a manipulator arm or rigidly attached to the deployment system. A flexible feed hose would probably be required to provide the sluicing medium to the nozzle. This application would enable the relatively simple concept of single-point jet sluicing to be applied but with an increased ability to access and mobilize the hard-to-reach waste located in the tank heel.

10.5 USTID HYDRAULIC IMPACT END EFFECTOR (WATER CANNON)

Many DOE sites have stored high-level radioactive wastes in underground tanks. Interim stabilization activities have removed much of the liquid from the tanks, leaving waste deposits in the form of sludge and hard salt cake. Removal of this salt cake from the tank equipment requires breaking up monolithic or large pieces of the salt cake into smaller fragments that can be easily handled and removed by other end effectors. The rubblizer requires a less complex and forgiving positioning system than water jet technology, allowing for a simpler control system.[9]

One of the tools being developed under the USTID program for dislodging and fragmenting the hard salt cake waste in the single-shell nuclear waste tanks at Hanford is the hydraulic impact end effector (HIEE) (Fig. 10.18). This tool operates by discharging 11 $in.^3$ of water at ultrahigh pressures to fragment and dislodge radioactive waste material. HIEE was previously designed, built, and initially tested by Lawrence Livermore National Laboratories (LLNL). A program was established with LLNL and Quest Integrated, Inc. for the advanced development of HIEE to further investigate its waste material fragmentation abilities and to determine more-effective waste material removal operation procedures. The results of the advanced development tests for HIEE have shown that increased fragmentation of the waste material can be achieved by increasing the charge pressures of 40,000 psi to 55,000 psi and through implementing different operating procedures.[14]

Two of the major factors involved in material fragmentation are the size of the material and the impact energy of the water slug fired from the HIEE unit (Fig. 10.19). The material's ability to fracture appears to be also dependent on the distance a fracture or crack line has to travel to a free surface. Thus, large material is more difficult to fracture than small material. Discharge pressures of 40,000 psi resulted in little penetration or fracturing of the material. When the discharge pressures were increased to 55,000 psi, however, the size and depth of the fractures increased. The use of different HIEE nozzle geometries resulted in



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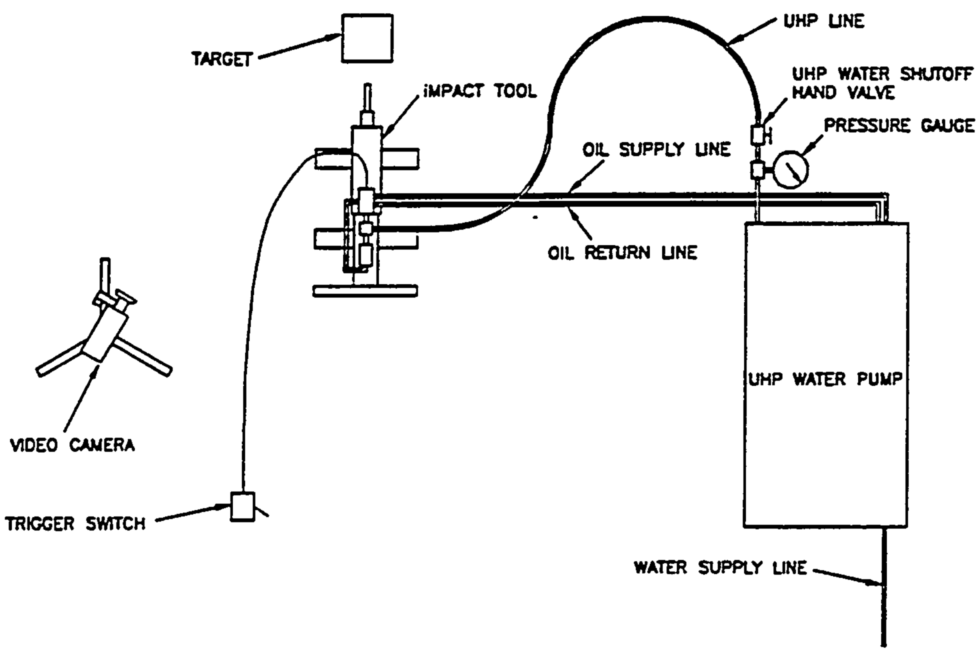


(b)

Fig. 10.18. HIEE.[18] *(a) Photo (b) schematic.*

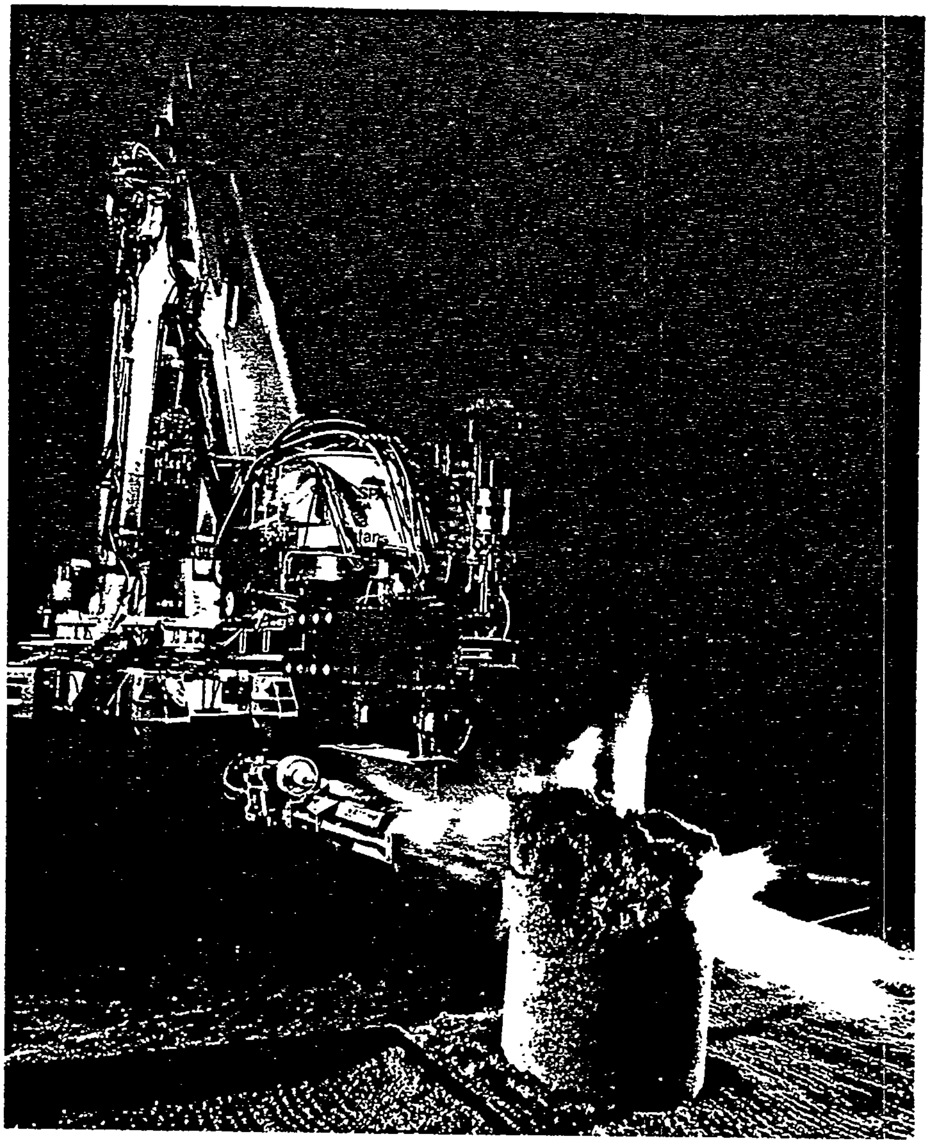


Fig. 10.19. HIEE.[16]

greater material fragmentation, thus indicating that nozzle geometry has a significant effect on material fragmentation. When the HIEE material fragmentation operating method was changed from surface shots to discharging HIEE into pre-drilled holes, the material fragmentation increased an order of magnitude. Since surface shots tend to create craters, a multi-shot operation procedure, along with an advanced nozzle design, was used to drill (crater) deep holes into large-sized material. This procedure successfully resulted in rubblizing a 600-lb block into smaller-sized pieces of material without the use of any additional equipment.[18]

As a result of this advanced development program, HIEE has demonstrated that it can quickly fragmentate salt cake material into small-sized, easily removable fragments. HIEE has also demonstrated that its material fragmentation ability can be substantially increased through the use of different nozzle geometries and operation procedures.[18] If unusually large monolithic pieces of salt cake are found in the Gunite tanks, HIEE is a potential end effector candidate to rubblize this salt cake.

10.6 CLAMSHELL BUCKET

A clamshell bucket consists of two pivoting bucket halves suspended from a housing. Each bucket half is operated by a hydraulic cylinder, as shown in Fig. 10.20. The bucket assembly (bucket halves and housing) could be suspended from the end of a support arm by means of a universal joint and a rotation joint. A universal joint would allow the bucket to hang vertically from the end of the support arm and automatically adjust to angular positions as the support arm pivots and the bucket halves dig into waste material. The rotation joint, operated by a hydraulic rotary actuator, is capable of rotating the bucket assembly 180 degrees about its vertical axis, thus allowing the bucket to be oriented before it is lowered into the waste material.[7]

The clamshell bucket would have a capacity of approximately 4 ft^3. The bucket would be capable of handling thick slurry sludge, salt cake, or miscellaneous debris.

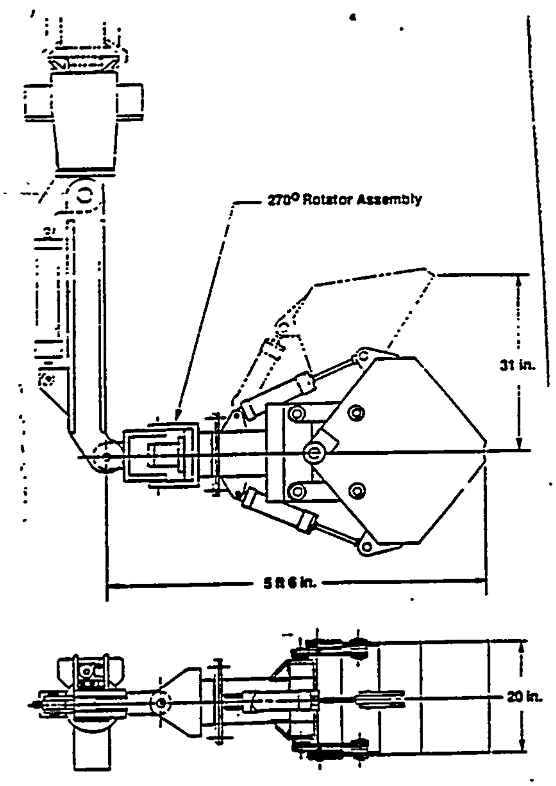


Fig. 10.20. Clamshell bucket schematic.[7]

10.7 SMALL IMPACT HAMMERS

Modern small impact hammers developed for the construction industry (Figs. 10.21 and 10.22) do not impart forces back into the handling equipment. Impact hammers are ideal for breaking up large pieces of matter but are not adaptable for general size reduction before transporting. Impact hammers would be used to break up hard layers or deposits of salt cake. Impact hammers would be hydraulically or pneumatically operated and would be able to work in both the horizontal and vertical positions. Minimal development and testing would be required for the impact hammers.[7]

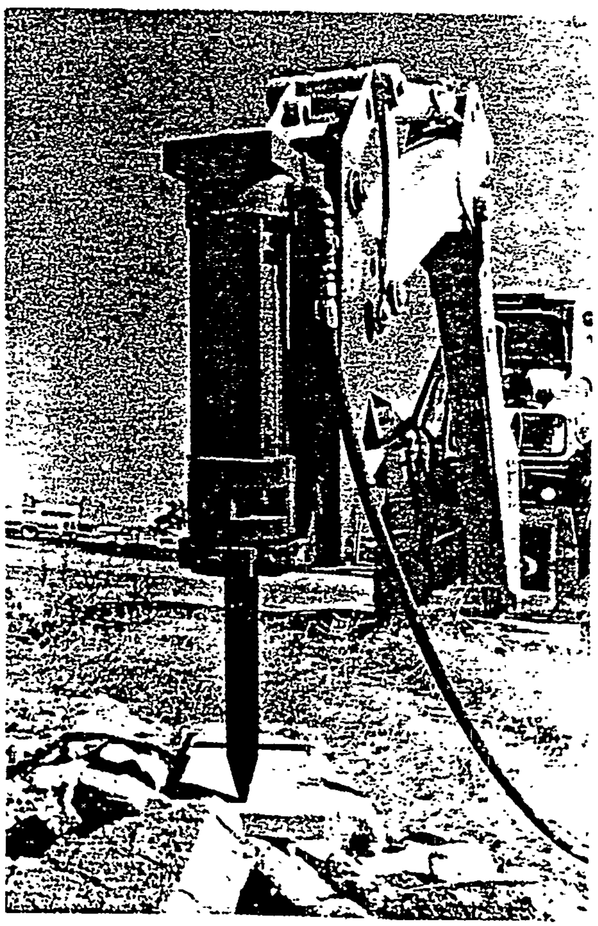
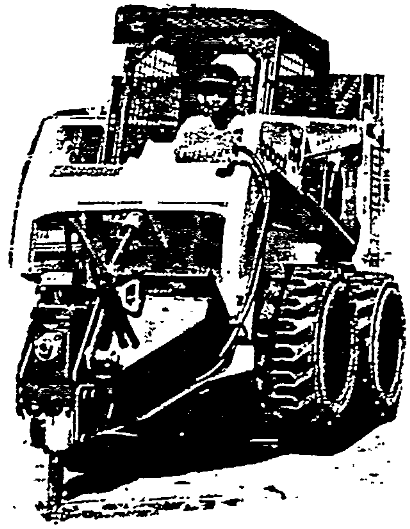
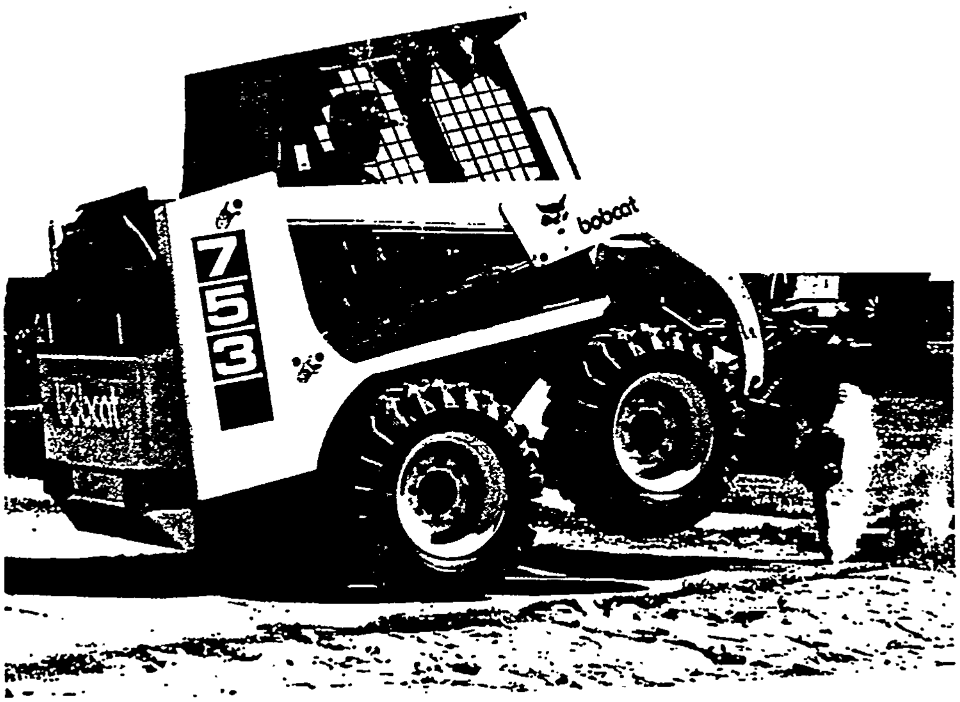


Fig. 10.21. Small impact hammer.[40]



(a)



(b)

Fig. 10.22. Small impact hammer.[40] *(a) Front (b) side.*

10.8 PULVERIZERS

Pulverizers are grabbing mechanisms designed to break up material by crushing it between two arms (Fig. 10.23). Pulverizers are used in the construction industry to break up bridge decks and reinforced concrete floors. Pulverizers can also be used for gross crushing and cutting of pipes, lumber, and construction debris.[7]

Pulverizers are typically hydraulically operated and mounted on the end of booms. Pulverizers are commercially available in numerous sizes and are generally considered maintenance free or requiring only a minimum of maintenance. Most commercially available pulverizers transmit large structural loads back into the handling boom and, as such, are not directly adaptable to salt cake retrieval operations. Development and testing of a modified pulverizer would be required for salt cake retrieval tasks, with the modifications reflecting the need to reduce the loads transmitted to the handling system.[7]

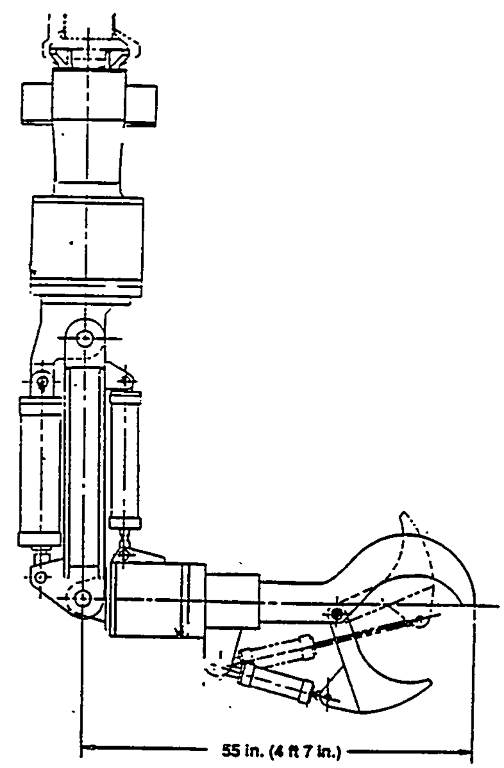


Fig. 10.23. Pulverizer schematic.[7]

10.9 GRABBER/GRAPPLE

A grabber, or object handling tool, (Fig. 10.24) would be used to pick up and transfer miscellaneous debris for removal from the tank. The grabber would be hydraulically operated and capable of handling a load of 500 lb in any position. Various sizes of grabbers may be required to handle unknown objects that may be entombed within the waste.[7]

Another end effector that might be used is the grapple. A number of commercially available grapples exist for handling specific materials. Examples are the standard grapple, the loader/orange peel grapple, and the rake grapple. The loader/orange peel grapple (Fig. 10.25) is lowered onto the material from a boom. It has several sharp, hinged tines that protrude downward like the fingers on a hand. It usually has three or four tines and a equal number of cylinders. When the grapple is in position, the "hand" closes, gripping the material to be lifted. The standard grapple is similar to the grabber discussed above and is shown in Fig. 10.26. The rake grapple has a blade, with long teeth at the bottom for raking, and a top clamp, as shown in Fig. 10.27. Grapples in general would be used to gather and transfer loose scrap and other bulky debris that might be found in the tanks.[19]

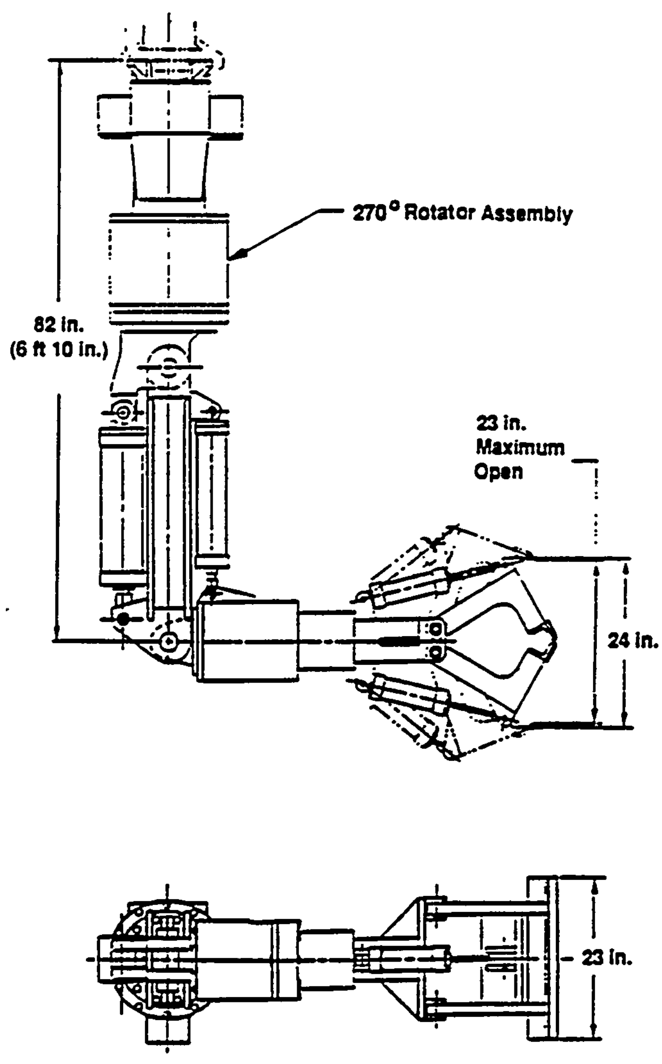


Fig. 10.24. Grabber schematic.[7]

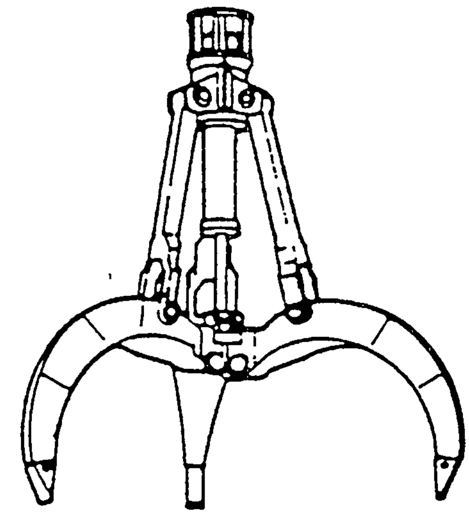


Fig. 10.25. Loader/orange peel grapple schematic.[19]

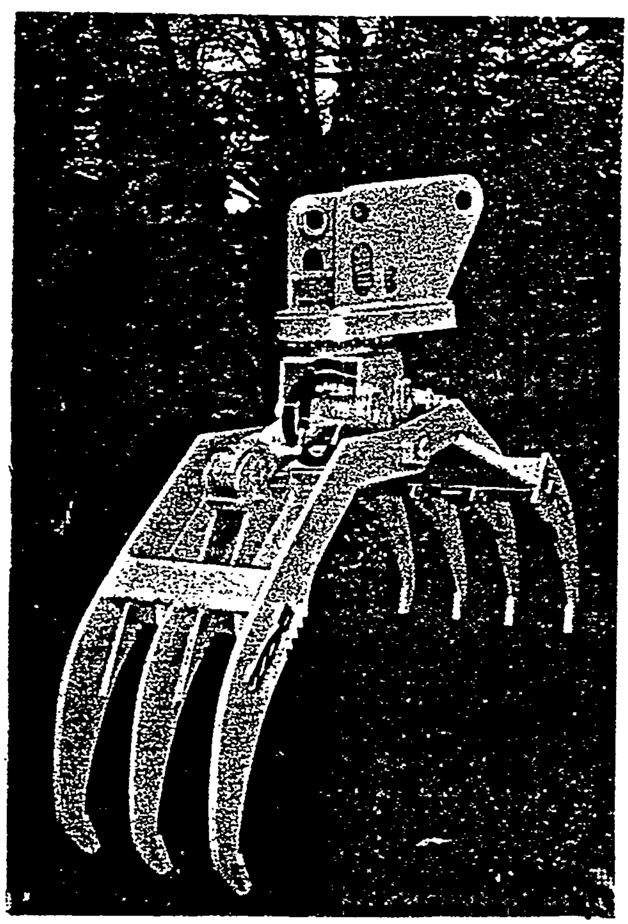


Fig. 10.26. Standard grapple.[19]

Fig. 10.27. Rake grapple.[19]

10.10 PUMPS

Pumping systems are synonymous with the transport of liquids and slurries. There are numerous pump designs for pumping almost any type of material under a variety of conditions. The major portion of the radioactive waste in the Gunite tanks is expected to be pumpable. Some sludge may be pumpable in the "as is" condition, and other waste may have to be slurried with a liquid before it becomes pumpable. Because the exact nature and physical properties of the waste in the Gunite tanks has not yet been determined, it might be prudent to select different types of pumps that could be used as end effectors to determine their capability and retain the flexibility to handle waste with unexpected properties. The weight of the pump and the dynamic operating forces that it will impose on the deployment/maneuvering system should be studied very closely along with the general operating/performance specification of the pumps.[7] Applicable pumps that could be used in the mobilization of the sludge in the Gunite tanks will be discussed in the next section.

10.11 IN-TANK EXCAVATION

During sludge removal from the tanks, miscellaneous debris of all shapes, materials, and sizes will probably be encountered. The need for in-tank excavation or heavy pushing of this debris or sludge will likely be required. Equipment to perform these tasks will not be operated by a mechanical arm–based system because of payload and dynamic loading restrictions of the system. A vehicle-based system (which was earlier discussed) would be the most probable candidate for these retrieval tasks. The vehicle could be equipped with conventional (probably scaled-down) excavation equipment. This equipment could be (but is not limited to) a bulldozer or backhoe blade (Fig. 10.28), a dredge, a snow dozer blade, or a multipurpose loader bucket (Fig. 10.29).[19] The push/pull capacity of the vehicle based retrieval system will be the limiting factor in the in-tank excavation tasks.

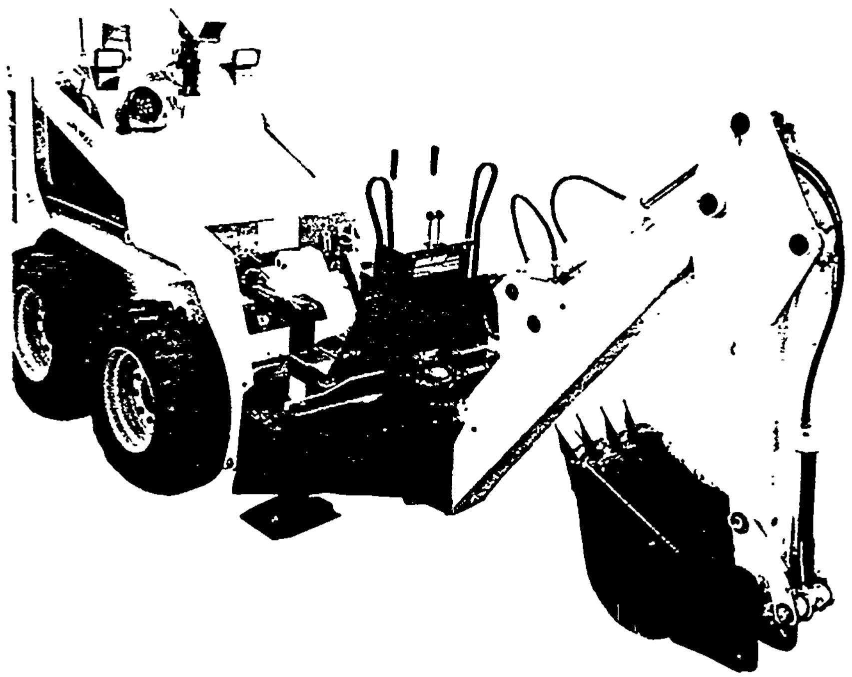


Fig. 10.28. Backhoe bucket.[39]

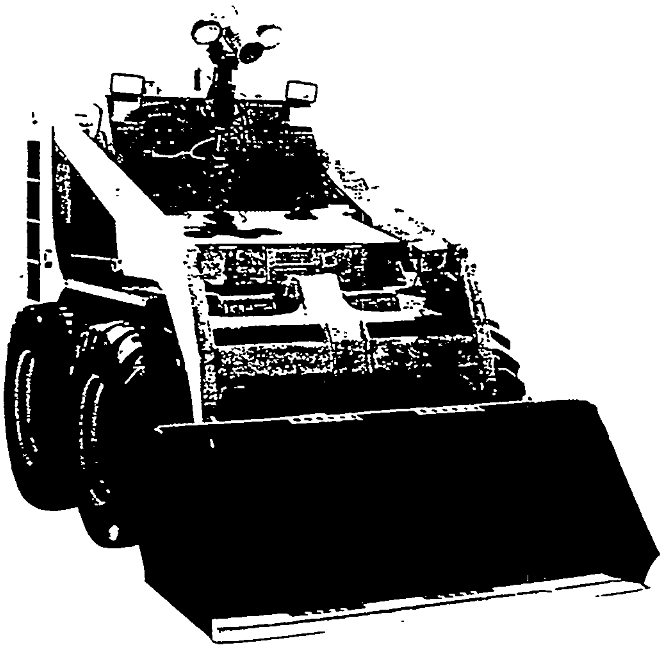


Fig. 10.29. Loader bucket.[39]

10.12 SUBMERGED JET SLUICING NOZZLE

Submerged jet sluicing was described previously. The use of submerged-jet sluicing as an end effector is precluded for vehicle-based platforms because the material sluiced must be submerged in liquid. The mechanical arm–based system could be used for sluicing by this method, but it is probable that the single-point jet sluicing method would be more easily integrated to the arm.

10.13 RADIATION-HARDENED MANIPULATOR ARM

As previously discussed for the mechanical arm–based deployment technologies, a radiation hardened manipulator (articulated) arm system is strongly recommended. The vehicle based deployment system will most likely require the need for a radiation-hardened manipulator arm system mounted on the vehicle chassis (Fig. 10.30). This telerobotic arm is a mechanical equivalent of arms and hands because of its ability to perform dexterous tasks and manipulate objects under direct human or computer control.

A number of commercially available radiation-hardened manipulator arms exist in today's market. The arms can come with standard manipulator grippers, for grasping objects, and end effectors; or they can be equipped with interchange tool/end effector systems that would enable the grippers to be removed and various end effectors to be mounted directly to the arm. Commercial arms are available with 6 degrees of freedom. The degrees of freedom required for the arm should correspond to the anticipated difficulty of the tasks to be performed by the manipulator system.

A good example of a commercially available radiation-hardened manipulator arm with a successful track record in hazardous environment applications is the Titan II, manufactured by Schilling Development (Fig. 10.31). The Titan II manipulator arm is a dexterous, 6 degrees-of-freedom, servo-hydraulic, telerobotic arm designed for tasks requiring extended reach, dexterity, and lift capacity. The Titan II has a maximum gripper jaw closure force of 300 lb; a maximum reach of 76 in.; a maximum capacity of 1200 lb, with a capacity of 240 lb

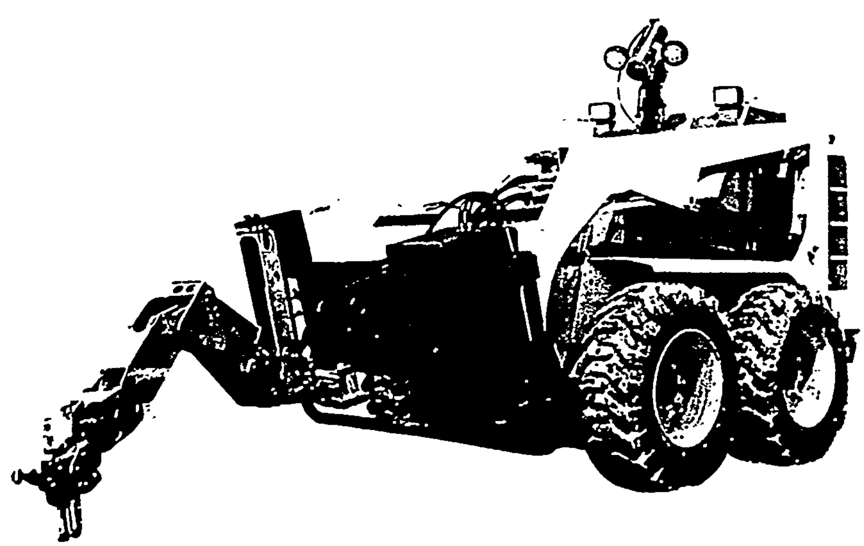
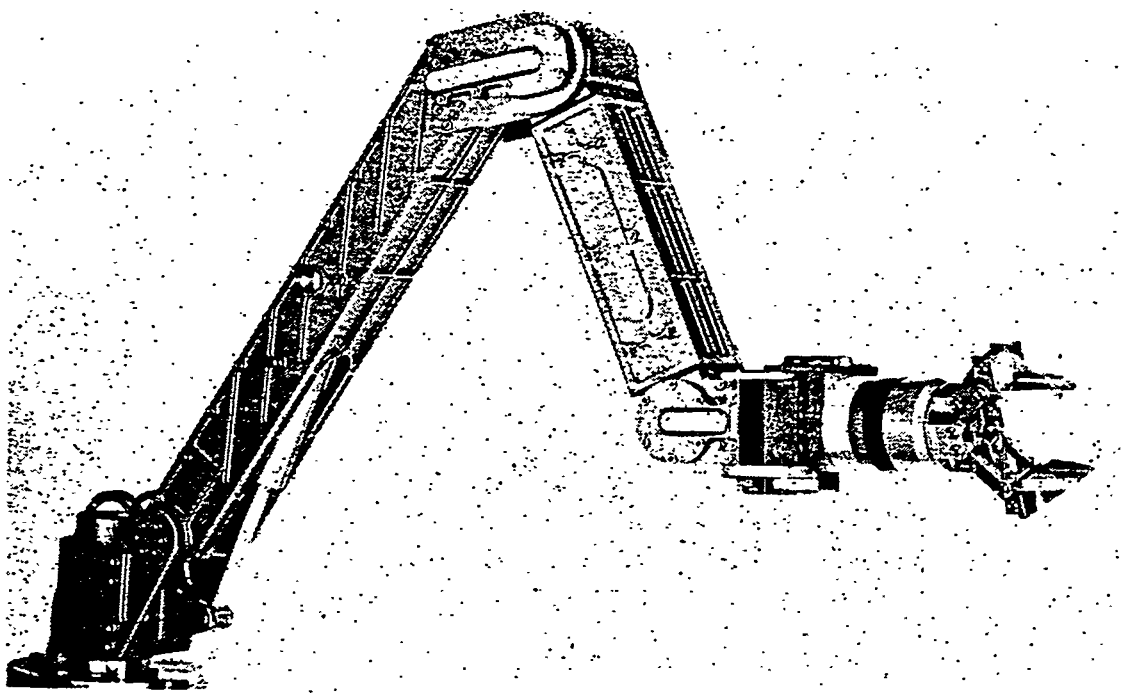
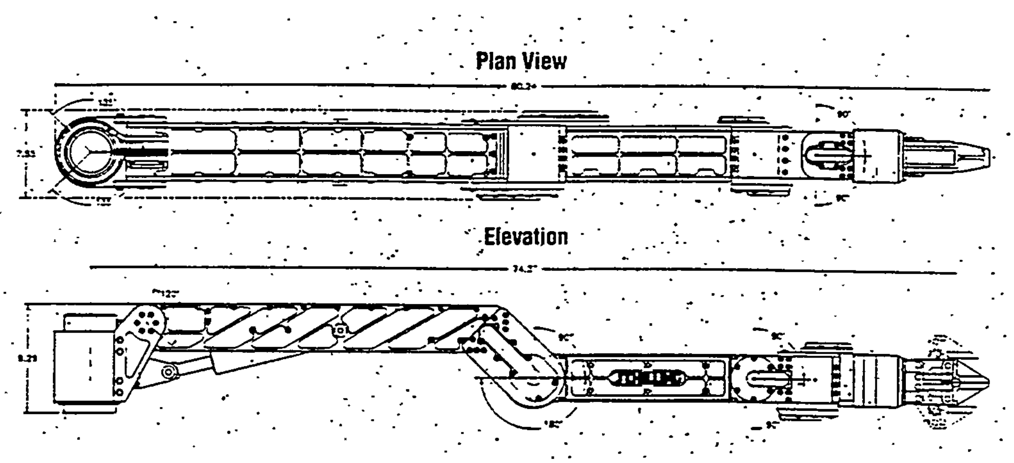


Fig. 10.30. Manipulator arm mounted on remotely operated vehicle.[39]

at full extension; and a physical weight of 175 lb. Construction is primarily of 6-4 titanium. The Titan II is available with options such as a tool interchange system, bilateral force feedback, host computer interface, and an advanced telerobotic controller. Force feedback directly reflects motions and forces at the slave arm to an electrically actuated master arm. The radiation-hardened version of the Titan II is capable of withstanding 10^7 rads gamma accumulated exposure with no performance loss.[20]



(a)



(b)

Fig. 10.31. Schilling TITAN II manipulator arm.[16] *(a) Photo (b) plan view.*

11. MIXING, PUMPING, AND CONVEYANCE TECHNOLOGIES

11.1 AGITATORS

Mechanical agitators are used extensively across many industries for suspending solids within tanks. As long as there is sufficient liquid in the tank, suspension of solids with these devices is superior to suspension with circulation pumps because much higher turbulence can be generated with lower power input. There are several types of impellers available, ranging from marine type to axial and radial flow turbines to airfoil designs. Mixers of this type could be introduced into the penetrations in the GAAT OU tanks; the tanks would then be filled with solutions, and the suspended solutions pumped out. An obvious disadvantage to this method is the quantity of liquid required to effect suspension and the fact that when the liquid level drops below the impeller, operations cannot continue.

11.2 SUBMERSIBLE SEWAGE/CHOPPER PUMPS

There are several suppliers of submersible sewage/chopper pumps suitable for the GAAT OU sludges. This type of pump is used for pumping materials such as sewage, pulp and paper mill wastes, and other materials where comminution of the pumpage is required. They are low-speed (1150 rpm) pumps that have a cutter cone whose blades are a continuation of the impeller vanes. The cone, together with a fixed external cutter knife, cuts up solid materials in the pumpage and improves performance. An illustration of the impeller is shown in Fig. 11.1.

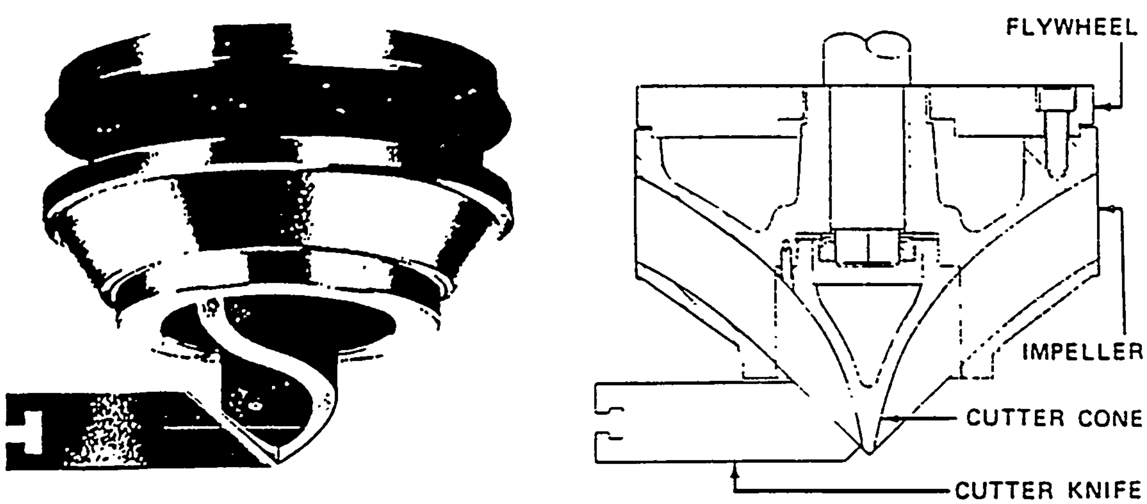


Fig. 11.1. Cutter impeller.[21]

The motor is an oil-filled, sealed electric motor directly attached to the annulus case and operates at a 120, 240 or 460 VAC. A typical model of this pump type could be 60-gal/min at 40 ft head, 240-V single phase, 2-HP, and able to pass a 2-in. spherical particle.[21,22]

11.3 FLOATING DREDGE

The floating dredge is based on the concept of a self-propelled floating barge and dredge. The dredge consists of a submersible pump and spray ring combination fitted with floatation devices, sonar and propulsion motors. It is illustrated in Fig. 11.2. This concept has also been called a "flump," for floating pump.

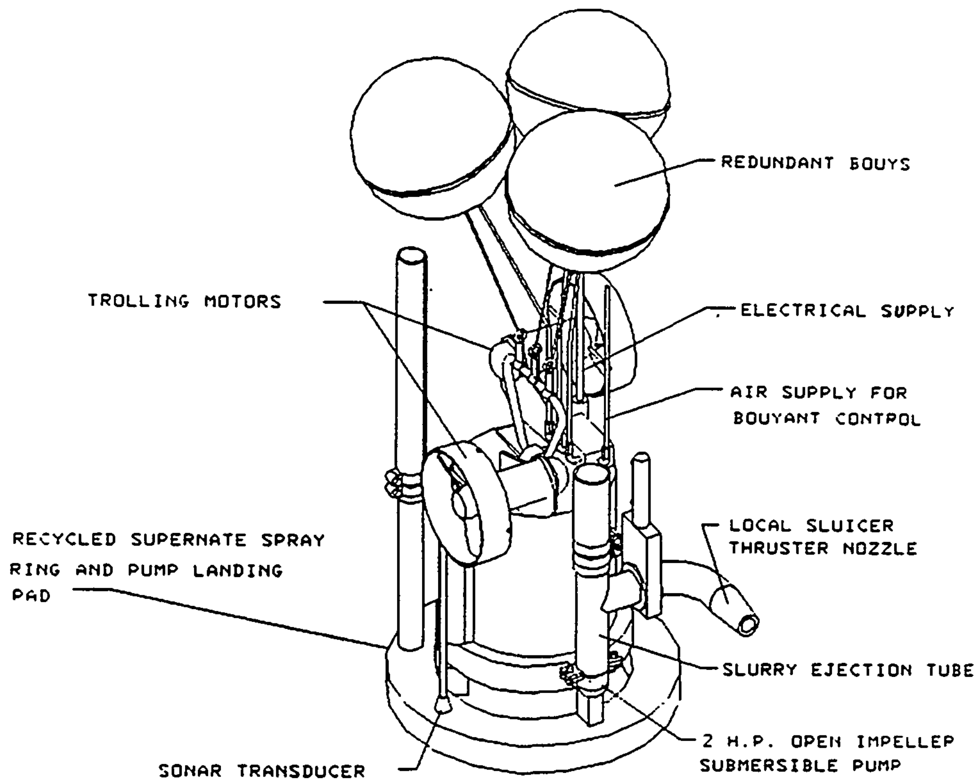


Fig. 11.2. Floating pump (flump).[22]

The submersible pump is similar to the submersible sewage/chopper pump discussed above. The discharge riser is connected to an air-operated gate valve that diverts some of the discharge to a thruster nozzle. This nozzle serves to counter the initial pump torque that would otherwise cause the pump motor housing to spin, and in addition, causes some local sluicing action. If the pump clogs, flow can be reversed through the discharge to clear it. A combination spray ring and landing pad is attached to the bottom of the pump. This spray ring has nozzles distributed around the periphery to produce sludge mobilization and irrigation of the pump inlet and ejects recycled supernate at 250 psi. Floatation is provided by three 18-in. diameter fabric-reinforced spherical neoprene bladders. The bladders are inflated by an air line from the surface, which has reverse flow capability to deflate the bladders as well. They are deflated when hoisting the submersible unit through the manhole for clearance. Each bladder is individually tethered to the pump lifting bail. Propulsion is provided by two submersible trolling motors, which are supported by spring-loaded hinged struts attached to the top of the pump assembly. Shrouds protect the propellers and enhance their thrust ability. Propulsion and steering are provided by varying the speed and direction of each motor independently. The propulsion units must provide enough thrust to tow 45 ft of umbilical assembly around the tank, but final thrust capacity is a design optimization task. Dual sonar transducers would be mounted on the pump assembly to provide depth or obstacle clearance information. The umbilical assembly would be supported on the surface by additional buoys and would contain hoses for pump discharge; spray ring supernate supply; air lines for operating the air valve and inflating/deflating the bladders; and electrical cables for the propulsion motors, sonar and pump power. A powered cable reel with a fluid coupling swivels on the axle, and slip-ring boxes for all electrical connections provide storage and tension control. Lowering and raising the unit within the tank would be done by an overhead hoist.[22]

The liquid supernate level in the tank would be adjusted by operations to allow the equipment to float on the top of the sludge and over any obstacle. A balance of buoyancy, pump inlet suction, and spray ring flows would need to be modulated during operation over soft sludges to prevent the pump from burrowing itself in. For firmer sludges, the pump could be allowed to rest on the sludge, with the buoys providing vertical stabilizing forces to prevent the pump from overturning.[22]

11.4 PROGRESSING CAVITY PUMPS

Progressing cavity pumps have been used by the Waste Operations group successfully for the past several years. These are positive displacement pumps that are self priming and can handle gases, liquids, abrasive slurries, and multiphase mixtures. The key components of the pump are the rotor and the stator. The rotor is a single external helix with a round cross section machined from stainless steel. The stator is a double internal helix molded from an abrasion-resistant elastomer encased within an alloy steel external tube. As the rotor turns within the stator, cavities form that progress from the suction end to the discharge end of the pump. The continuous seal between the rotor and stator helices keeps the fluid moving steadily at a flow rate proportional to the rotational speed of the pump. The pump will operate in either direction of shaft rotation and in any orientation. This type of pump has application for conveyance of sludge removed from GAAT OU tanks. Some solids within the tank could require size reduction prior to pumping, and an in-line device such as a grinder or macerator could be required.[23]

11.5 THREE-PHASE AIR CONVEYANCE

As earlier discussed, a three-phase air conveyance system is being developed for Hanford under the USTID program for use with the high-pressure confined sluicing shroud and the soft-waste-dislodging end effector. The conveyance system will eventually transport the dislodged waste out of the Hanford single-shell storage tanks.

The objective of the pneumatic conveyance development program is to develop correlations describing the retrieval of the three-phase Hanford single-shell tank waste: solids (either sludge or salt cake); liquid (viscous interstitial fluid in the tank, scarifier cutting fluid, and water used to lubricate the inside of the conveyance line); and air (the carrier medium). Activities completed in 1993 in this effort were the development of a scaling methodology for pneumatic conveyance, the preparation of a test plan for pneumatic conveyance separate-effects experiments, and the design and construction of a test fixture for the pneumatic conveyance separate- and integrated-effects experiments.[24]

The scaling methodology was developed to allow the effect of varying transport line diameter to be investigated. A dimensional analysis was conducted to quantify the effects of increasing retrieval rate and pipe diameter. The dimensional analysis showed that the ratio of mass flow rate of particulate to the mass flow rate of gas is a function of several parameters.[24]

The effect of pipe diameter appears in the Reynolds number and the Stokes number. Scaling to larger pipe diameters would affect these two variables. One would not expect that a slightly higher Reynolds number would have a significant effect. A larger Stokes number would lead to a longer acceleration length, which would be significant if the acceleration distance is comparable to the pipe length.[24]

The pneumatic transport test plan focuses on providing mechanistic performance data to develop performance correlations for retrieval. Pneumatic transport usually concerns the transport of dry solids in air. The transport associated with single-shell tank retrieval will involve transport of wet material. The waste is wet, and cutting liquid from the scarifier will further lubricate the waste. A test plan was developed to investigate the effects on transport of dry and wet wastes of particle diameter, solids loading, air flow rate, and liquid addition for the two simulant types.[24]

A pneumatic conveyance test fixture (see Figs. 11.3, 11.4, and 11.5) was designed and constructed in the PNL 336 Building at Hanford. The test fixture is instrumented to develop mechanistic pressure drop and transport data for waste transport during both pneumatic conveyance separate-effects experiments and when the system is integrated with the scarifier. The test fixture will permit tests at two pipe diameters: 3 in. and 4 in. Initial tests will be conducted over a conveyance length of 20 ft. In its current location, the system can be lengthened to a prototypic length of 60 ft by addition of pipe segments into an existing pit in the building. These experiments are being conducted in FY 1994.[24]

The air conveyance system used in the testing program is a commercially available system. ORNL should take full advantage of the design and development work being carried out to support the Hanford single-shell tank clean-up efforts under the USTID program, should this be the technology chosen to convey the waste out of the Gunite tanks.

11.6 DRUM REMOVAL

Considering that a 55-gal drum will fit through the openings in most of the GAAT OU tanks, consideration was given to the removal of waste materials in drums. It has been calculated that sludges, when contained in a 55-gal drum, would have a contact dose rate of up to 135 rad/h with the W-10 hard sludge. Drums reading this level would be difficult (but not impossible) to handle. The drums could be removed either by direct means, such as hoisting through the tank opening with a crane into a concrete cask, or by removal into a bottom-loading shielded cask, which could be transferred into another facility for unloading and reloading into a concrete cask. In either event, the final waste storage form would be in a transuranic retrievable storage bunker in a concrete shield cask. The drum would require remote decontamination while still in the tank.

This method would work best for in-tank debris that could not be removed in any other way, considering that most of the sludges would be removed by other means. Radiation dose

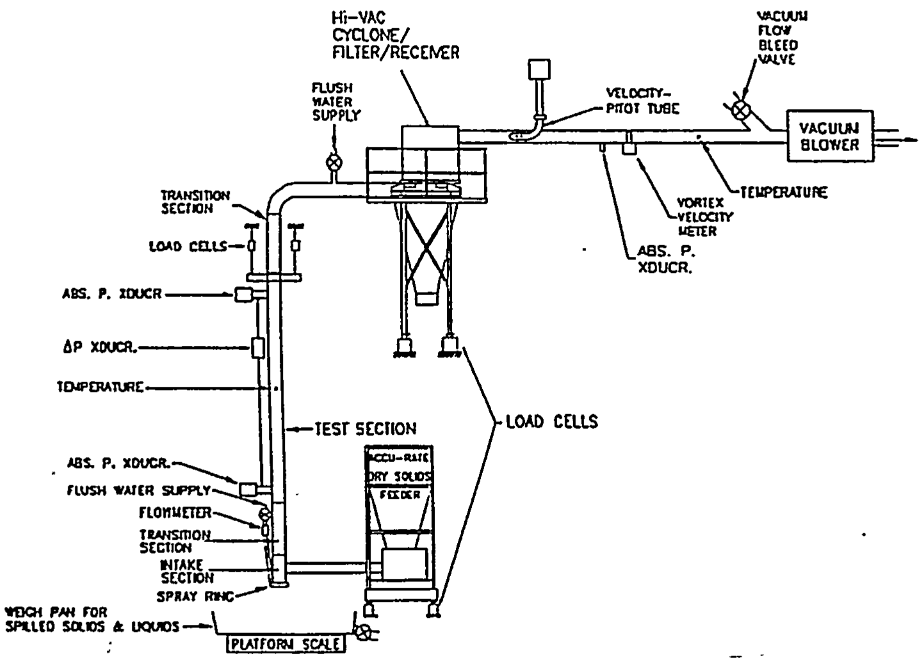


Fig. 11.3. Three-phase air conveyance test fixture.[16]

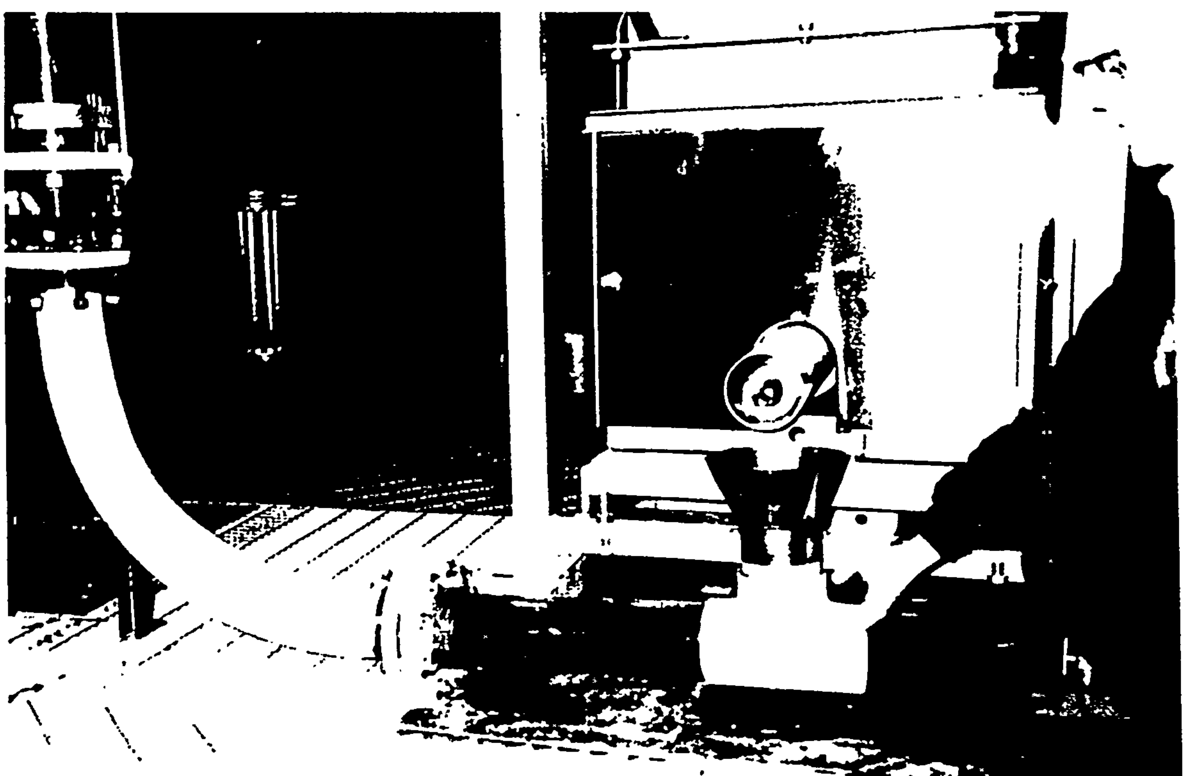


Fig. 11.4. Three-phase air conveyance test fixture.[16]

Fig. 11.5. Three-phase air conveyance test fixture.[16]

rates could be expected to be below the calculated value, because the W-10 sludge is a worst case scenario, and debris should not have the same radionuclide content as sludge.

11.7 VACUUM CLEANING

The dry concrete removal technologies discussed below lend themselves to vacuum cleaning to remove the concrete fines and aggregate removed during concrete decontamination. There are commercial vacuum systems available for this purpose, but the three-phase air conveyance equipment described above could also be used in a two-phase mode.

12. CONCRETE REMOVAL TECHNOLOGIES

The Gunite tanks were constructed of reinforced concrete using the Gunite process. The interior surfaces of the tanks would need to be decontaminated. Concrete removal technologies applicable to the GAAT OU tanks can be subdivided into two decontamination methods: wet and dry. Wet decontamination techniques include ultrahigh-pressure water and supercritical CO_2 removal. Dry decontamination techniques include mechanical techniques such as grinding, honing, and scraping; microwave scabbling; automated brushing; and mechanical scabbling.

12.1 WET DECONTAMINATION METHODS

Ultrahigh-pressure water (UHPW) is a surface cleaning technology. In the UHPW decontamination process, an ultrahigh-pressure intensifier pump pressurizes water up to 55,000 psi and forces it through small-diameter nozzles, generating high-velocity water jets at speeds up to 3,000 ft/s.[25] The nozzles may be mounted in various types of cleaning heads. The water jets thoroughly penetrate and remove surface contaminants. Care must be taken not to damage the substrate. In the use of the UHPW decontamination technology, the UHPW cleaning head, attached as an end effector to a manipulator arm, may be moved about on the surfaces being decontaminated. The decontamination efficiency depends on the applicator translation speed. The UHPW decontamination technology is available and has been used by industry. The existing vacuum systems, which recover water from the cleaning (or power) head of the unit, need to be developed. For waste minimization, a water treatment system is needed for decontamination of the wastewater so that it can be recycled and reused in the UHPW cleaning operation.

Supercritical CO_2 (above its critical temperature of 87.8°F and at high pressure) is pressurized by an ultrahigh-pressure intensifier pump up to 55,000 psi and forced through nozzles, generating high-velocity CO_2 jets at speeds up to 3,000 ft/s. The nozzles would mounted similarly to the UHPW system. The CO_2 jets thoroughly penetrate and remove surface contaminants without damaging the substrate. The removed contaminants, any of the substrate surface layer that may be removed, and the CO_2 would need to be captured by a vacuum recovery system. This technology is being developed by a private company and is in the predemonstration phase.

12.2 DRY DECONTAMINATION METHODS

Grinding, honing, and scraping is a mechanical decontamination method used for concrete removal. Power-driven grinding equipment is used to remove the surface from the contaminated object. Grinding has been successfully used for small-scale decontamination at the Oak Ridge K-25 Plant using hand-held power grinders. There are no references or experience with remote operation of grinding equipment at K-25. The heat generated by the grinding operation causes organic compounds to vaporize and decompose. Grinding has been accepted in the past because the generation of these vapors was overlooked. The technology needed to control these vapors has not been identified.[25]

Microwave scabbling technology directs microwave energy at a concrete surface using a specialized wave guide applicator and heats the concrete and the free water present in the concrete matrix. Continued heating produces thermal- and steam-pressure-induced mechanical stresses that cause the concrete surface to burst. The concrete particles from this steam explosion are small enough to be removed by a vacuum system, yet less than 1% of the debris is small enough to pose an airborne contamination hazard. The process is fast and dry, it generates little dust, and it avoids mechanical impacts. In the use of the microwave scabbling technology, the microwave applicator head may be manually moved about on the concrete surfaces being decontaminated. Because the rate and depth of surface removal depend on the applicator translation speed, remote operation of the mobile microwave would be desirable. The adaptation of the equipment to a robotics control system would be necessary. In FY 1991, ORNL demonstrated reliable removal of noncontaminated concrete surfaces using microwave energy.[26] At microwave frequencies of 2.45 GHz and 10.6 GHz, continuous concrete removal rates of 1.1 cm^3/s at 5.2 kW and 2.1 cm^3/s at 3.6 kW, respectively, were obtained. Removal rate and removal depth are controlled by choosing the proper frequency and varying the power and translation speed of the applicator on the concrete surface.

Automated brushing is another mechanical removal method for surface decontamination. Brushing is effective for removing smearable contamination and less effective for fixed contamination. The automated brushing equipment would need to be attached as an end effector on a manipulator arm. Brushing has been used to clean the interior of plutonium-contaminated pipe at the DOE Rocky Flats site in Colorado. The piping at Rocky Flats was cleaned to shiny metal. For the cleaning of pipe interiors at Rocky Flats, costs were $12,000/ft, including costs for remote operation, containment, and remote viewing. Capital cost is estimated at about $50-$250K; operating costs at >$1 ft^2; development cost at $200-$1000K.[25]

Mechanical scabbling technology decontaminates a concrete substrate by using mechanical impact methods to remove the contaminated surface. Many vendors market units that use high-speed reciprocating tungsten/carbide-tipped pistons to pulverize protective coatings, laitance, and concrete substrate in a single-step process. Other types of units use a shrouded needle scaler to remove concrete from outside edges and inside corners as well as from wall surfaces. These units are also used for removing lead-based coatings and contamination from steel surfaces. The solid debris produced by mechanical scabbling is removed and collected by a vacuum system. Mechanical scabblers are usually operated manually, so the units would need to be adapted for remote-controlled operation.

Mechanical scabbling technology has been used for decontamination purposes in numerous applications involving hazardous and/or radioactive contaminants. Because the technology involves removal of contaminated surfaces, the decontamination efficiency should be 95% or higher. The waste generated is the pulverized surface layer that is collected by a vacuum system. Vacuum cleaning equipment would be needed as a conveyance method for further removal of contamination by the dry decontamination methods. The amount of waste generated depends upon the depth of the surface layer that needs to be removed to achieve decontamination. Remote operation will require the adaptation of the scabbler to a robotic control system.[25]

13. VENDOR-BASED TECHNOLOGIES

13.1 SONSUB-LOCKHEED (INEL PIT 9)[27]

An integrated site remediation program is being conducted by a consortium of companies headed by Sonsub, Inc. of Houston Texas and Lockheed Environmental Systems and Technology Company of Arlington, Virginia. This project consists of the retrieval of wastes from disposal Pit 9 at INEL, which was used for the disposal of approximately 2.7 million ft^3 of waste, which contains transuranics along with other radionuclides and machine oils, solvents, and PCBs. Also included in the project is the 5-10 million ft^3 of intermixed soil. The companies were signed on a fixed-price contract and were instructed to use proven systems for retrieval and treatment of the wastes. The facility to be built will center around a glass melter, which will produce a vitreous waste form suitable for disposal at WIPP. The facility will not be DOE-owned but will be built on the DOE reservation near the remediation site and will be financed with private funds to be repaid as the waste is processed. At the conclusion of the project, the facility would be available for treating commercial nuclear wastes.

Sonsub has considerable remote handling expertise, mostly in the undersea oil field area. They were also the contractor that handled the Kerr Hollow Quarry remediation at the Y-12 facility during FY 1992-93. At Pit 9 they have designed a moveable building that will provide containment for the remotely operated digging equipment, which will remove the waste from the ground and supply it to the treatment facility. The facility consists of an overhead retrieval system comprising four bridge cranes, each with two trolleys, a soil "sweeper," an "orange peel" grapple, and a shear. The containment building is designed for a nitrogen atmosphere and for remote operation of all equipment. This is a relatively large building designed to be moved over the remediation site during the course of remediation activities.

A proposal was made by Sonsub for removing the GAAT units from the ground and is included as an alternative in the GAAT Feasibility Study document.

13.2 ORNL ROBOTICS AND PROCESS SYSTEMS DIVISION

Several years ago, the ORNL Robotics and Process Systems Division prepared a feasibility study for the removal of the GAAT OU tanks from the ground using an contained gantry crane system. This system envisioned constructing a containment structure above the tanks that had a series of remote overhead cranes and advanced servomanipulators. In this proposal, the tank domes would be removed. Sludges would then be taken out of the tanks and packaged with the enclosure. The tanks would then be removed and packaged and the excavation filled. Upon completion of the process, the enclosure would be moved to another tank and the process repeated.

This technology, although applicable to sludge removal, would be very expensive. However, there could be no other method available to both meet confinement and low radiation dose requirements if it is decided that the tanks should be removed from the ground.

14. ANALYSIS OF THE APPLICABLE TECHNOLOGIES

Technologies deemed applicable to the GAAT sludge removal project were grouped for evaluation according to (1) deployment method, (2) types of remotely operated end effectors applicable to the removal of sludge, (3) methods for removing wastes from the tanks, and (4) methods for concrete removal. There were three major groups of deployment technologies: "past practice" technologies, mechanical arm–based technologies, and vehicle-based technologies. The different technologies were then combined into logical sequences: deployment platform, problem, end effector, conveyance, post-removal treatment required (if any), and disposition of the waste. These sequences are shown in Fig. 14.1 to 14.3 for each deployment technology.

14.1 WEIGHTING FACTORS

Ranking of the technologies was done on a numerical scale with appropriate weighting factors. The weighting factors used are shown in Table 14.1. The factors for technical feasibility included the ability to implement the technology, the technical maturity of the technology, the overall technical risk, the effectiveness of waste removal, the ability of the technology to minimize secondary waste generation, and the ability of the technology to interface with existing pumping systems. The factors for health and safety included effects of the technology on the site personnel (workers and other persons on the site), the public, and the environment. The factors for flexibility and complexity included the ability to mobilize all waste forms; the ability to retrieve the wastes with no pretreatment; the ability to interface with all tanks; and the ease of operation, maintenance, and decontamination. The factors for cost and schedule included capital, operating and start-up costs, and expected length of time that the inventory of sludge within GAAT could be mobilized. Also included were two other factors: (1) regulatory compliance, which measures the relative ease of complying with the applicable regulations, and (2) stakeholder acceptance, which measures the relative acceptance of the technology by various groups, such as project managers and regulators. However, these two factors were not varied because differences between technologies could be readily distinguished. The factors were assigned a weight, which represents the relative importance of each factor.

14.2 SCORING AND RANKING

Scoring of the different factors was done on a 0 to 10 basis, with 0 representing unsatisfactory and 10 representing outstanding. The score was assigned based on the relative strength or weakness of a particular technology. This score was then multiplied by the relative weight, and this product, along with the products from other areas, were summed to arrive at the total score for the technology. The results of this process are the rankings of the technologies, which are listed in Table 14.2 to 14.5.

The different technologies were grouped in logical sequences in which each technology could be used to remove waste. The rating for the highest individual technology in a group (connected together) was summed with the highest individual technology in its adjacent groups to arrive at a total score for each sequence. The scores for the technology sequences are tabulated in Table 14.6.

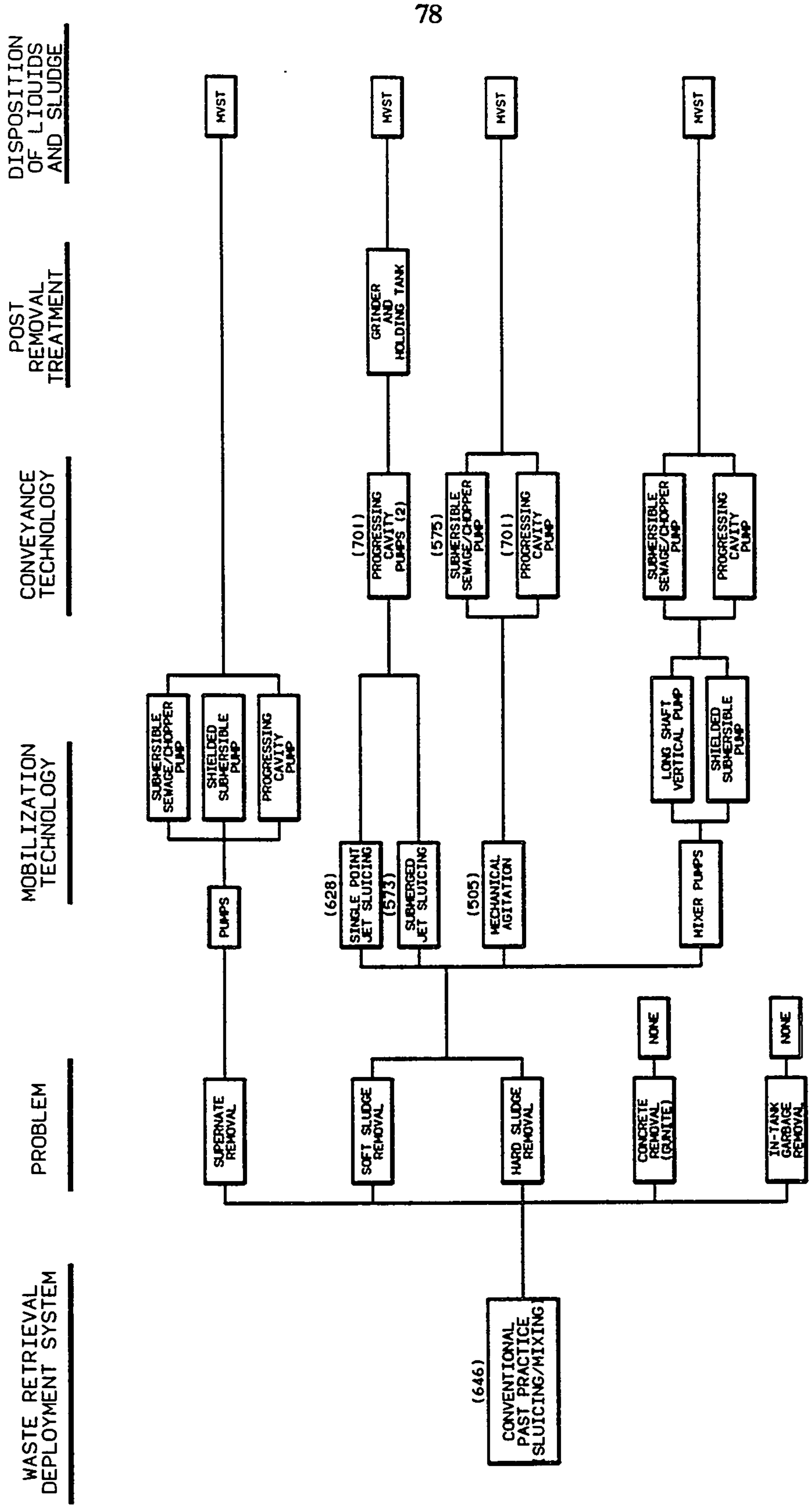


Fig. 14.1. Sludge mobilization technology flowsheet—conventional past practice.

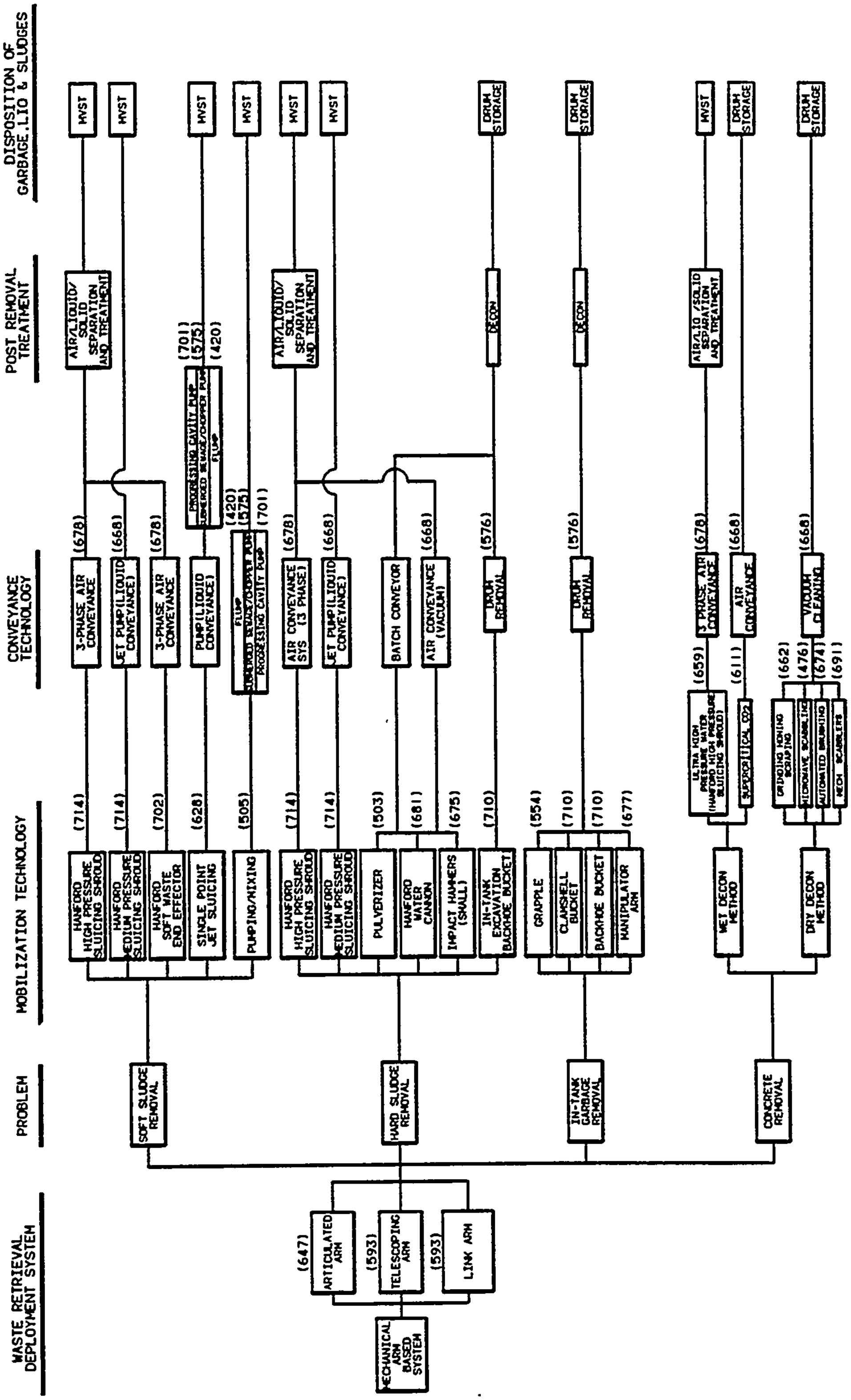


Fig. 14.2. Sludge mobilization technology flowsheet mechanical arm-based.

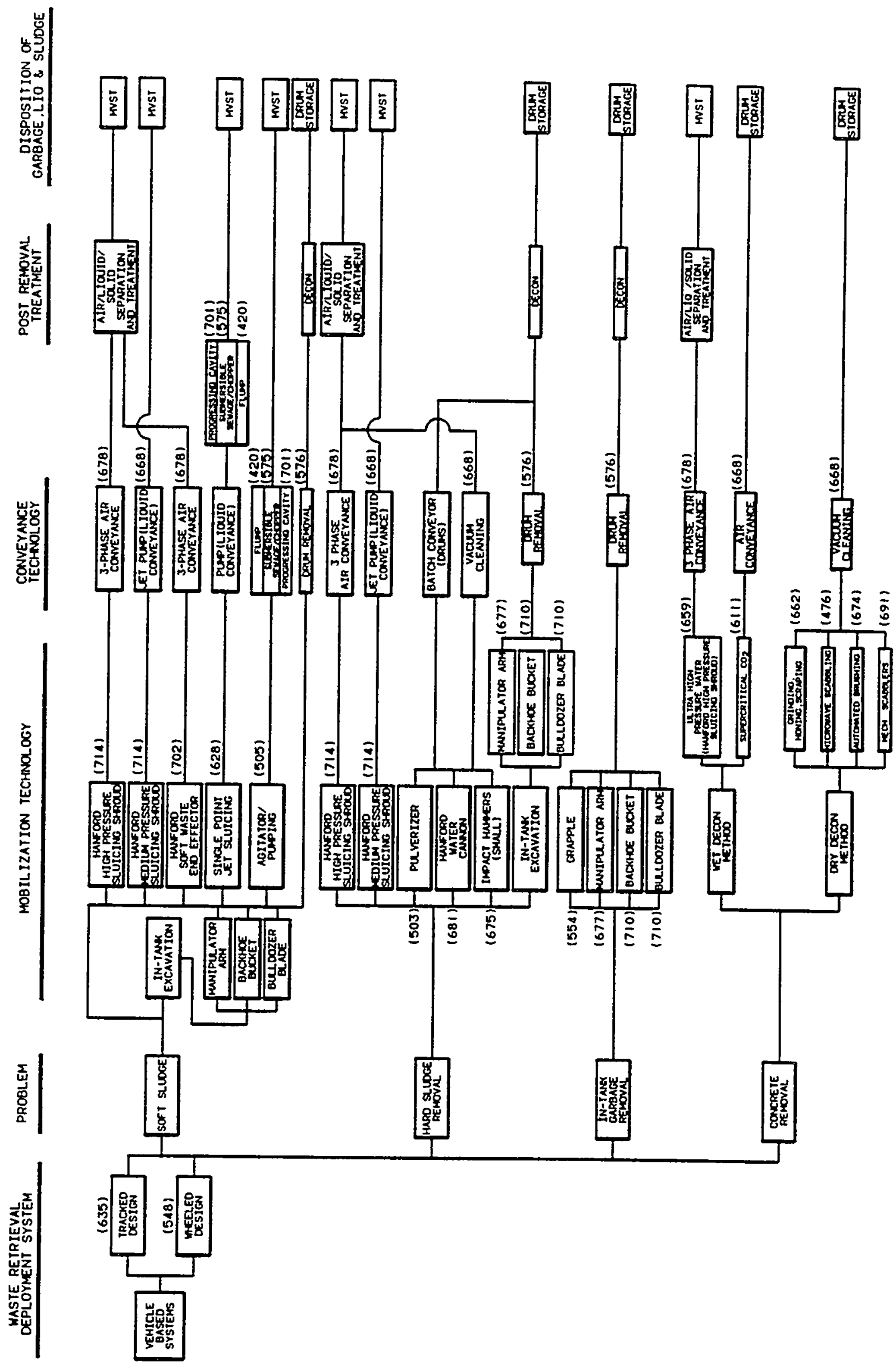


Fig. 14.3. Sludge mobilization technology flowsheet—vehicle based.

Table 14.1. Sludge mobilization technology study—technology evaluation criteria

Technology/Vendor: ______________________

Evaluator: ______________________

Date: ____________

	CRITERIA:	Weight	x	Rating	=	Score
	(1) Technical Feasibility (30 points)					
a)	Ability to implement the technology	6	x	____	=	____
b)	Technical maturity (development required, availability)	6	x	____	=	____
c)	Technical risk	6	x	____	=	____
d)	Waste removal effectiveness	6	x	____	=	____
e)	Waste generation reduction (minimize the addition of diluent materials)	3	x	____	=	____
f)	Transfer system compatibility (pump to MVST)	3	x	____	=	____
	(2) Health and Safety (ALARA Implementation) (25 Points)					
a)	Site personnel	12	x	____	=	____
b)	Public	8	x	____	=	____
c)	Environment	5	x	____	=	____
	(3) Flexibility (Versatility) and Complexity (15 points)					
a)	Ability to mobilize all of the tank waste forms	2	x	____	=	____
b)	Ability to retrieve the wastes with no pretreatment	3	x	____	=	____
c)	Ability to interface (access) with all of the tanks	5	x	____	=	____
d)	Ease of operation	3	x	____	=	____
e)	Ease of maintenance (reliability, availability and maintainability characteristics)	2	x	____	=	____
	(4) Cost and Schedule (15 points)					
a)	Capital costs	6	x	____	=	____
b)	Operational costs	4	x	____	=	____
c)	Start-Up costs	3	x	____	=	____
d)	Inventory work-off	2	x	____	=	____
	(5) Regulatory Compliance (10 points)					
a)	Compliance with the applicable requirements: 5820.2A, 6430.1A, CERCLA, etc.	10	x	____	=	____
	(6) Stakeholder Acceptance (5 points)					
a)	DOE Headquarters, DOE-ORO, Energy Systems, State of Tennessee, EPA, Employees, and Pressure Groups	5	x	____	=	____

Total Score: (1000 Points Maximum) Rating: 10 = Outstanding, 8 = Superior, 5 = Satisfactory, 2 = Poor, 0 = Unsatisfactory

Table 14.2. Evaluation of deployment technologies

Technology	Technical Feasibility (300)	Health and Safety (250)	Flexibility (150)	Cost and Schedule (150)	Regulatory Compliance (100)	Stakeholder Acceptance (50)	Total Score (1000)
Mechanical arm–based articulated arm	195	200	120	57	50	25	647
Past practice	204	200	80	87	50	25	646
Vehicle-based Remotec	213	125	114	108	50	25	635
Mechanical arm–based telescoping	159	200	102	57	50	25	593
Mechanical arm–based link	159	200	102	57	50	25	593
Vehicle based-H&H	186	125	100	99	50	25	585
Vehicle based-3i	177	125	90	81	50	25	548
Vehicle based-BNFL	150	125	75	75	50	25	500
Vehicle based-Redzone	105	125	105	81	50	25	491

Table 14.3. Evaluation of end effector technologies

Technology	Technical Feasibility (300)	Health and Safety (250)	Flexibility (150)	Cost and Schedule (150)	Regulatory Compliance (100)	Stakeholder Acceptance (50)	Total Score (1000)
Confined sluicing	237	200	121	81	50	25	714
Bucket (clamshell, backhoe), dozer blade	228	200	81	126	50	25	710
Soft waste remover	241	200	111	75	50	25	702
Water cannon	210	200	82	114	50	25	681
Rad hardened manipulator	240	200	105	57	50	25	677
Small impact hammers	210	200	82	108	50	25	675
Single-point jet sluicing	177	200	80	96	50	25	628
Submerged jet sluicing	141	200	65	92	50	25	573
Grappler	186	125	60	108	50	25	554
Pulverizer	174	125	54	75	50	25	503

Table 14.4. Evaluation of mixing, pumping, and conveyance technologies

Technology	Technical Feasibility (300)	Health and Safety (250)	Flexibility (150)	Cost and Schedule (150)	Regulatory Compliance (100)	Stakeholder Acceptance (50)	Total Score (1000)
Progressing cavity pump	231	200	114	81	50	25	701
Three-phase air conveyance	222	200	96	85	50	25	678
Vacuum cleaning	198	200	75	120	50	25	668
Jet pump	222	200	90	81	50	25	668
Drum removal	243	99	66	93	50	25	576
Submersible sewage/chopper pump	177	125	90	108	50	25	575
Agitator/pump	171	125	65	69	50	25	505
Flump	114	89	73	69	50	25	420

Table 14.5. Evaluation of concrete removal technologies

Technology	Technical Feasibility (300)	Health and Safety (250)	Flexibility (150)	Cost and Schedule (150)	Regulatory Compliance (100)	Stakeholder Acceptance (50)	Total Score (1000)
Mechanical scabbling	222	200	120	74	50	25	691
Automated brushing	204	200	99	96	50	25	674
Grinding/ honing/ scraping	198	200	102	87	50	25	662
UHP water	222	200	105	57	50	25	659
Supercritical CO_2	174	200	105	57	50	25	611
Microwave scabbling	114	125	105	57	50	25	476

Table 14.6. Evaluation of technology combinations

Deployment Method	Problem	Technology Combinations	Score
Past practice	Soft/hard sludge	Single-point jet sluicing progressing cavity pumps	1975
Mechanical arm-based	Soft sludge	Articulated arm High/medium pressure confined sluicing Three-phase air conveyance	2039
	Hard sludge	Articulated arm High/medium pressure confined sluicing Three-phase air conveyance	2039
	Debris	Articulated arm Clamshell/backhoe bucket Drum removal	1933
	Concrete	Articulated arm Dry mechanical scabbling Vacuum cleaning	2006
Vehicle based	Soft sludge	Tracked vehicle High/medium pressure confined sluicing Three-phase air conveyance	2027
	Hard sludge	Tracked vehicle High/medium pressure confined sluicing Three-phase air conveyance	2027
	Debris	Tracked vehicle Clamshell/backhoe bucket Drum removal	1921
	Concrete	Tracked vehicle Dry mechanical scabbling Vacuum cleaning	1994

15. CONCLUSIONS AND RECOMMENDATIONS

After studying the tank cleaning technologies, it is evident that there are many options available and the best technology in one set of circumstances at one site might not be the best type to use at a different site. This study has undertaken to reduce the number of technologies requiring consideration to a few so that a reasonable number of options could be tested. The following are recommendations of technologies that should be investigated further in treatability studies, upon funding. No single technology is capable of treating the entire spectrum of wastes that will be encountered in GAAT.

Of the past practice methods, single-point jet sluicing is the main one with institutional experience. In addition, this method lends itself to combination with a mechanical arm-based deployment system as an end effector. Single-point jet sluicing would be a good method for removing wastes from tanks in the system that have not yet been cleaned, but it probably would not be effective on tanks W-5 to W-9, which were partially cleaned in the 1982–83 cleanout campaign.

Of the mechanical arm-based deployment methods, the LDUA system appears to be the best choice because development activities are progressing rapidly. Modifications to increase the payload and reach of the LDUA system, as previously discussed, would need to be incorporated to tailor the system to the needs of GAAT cleanup activities. No mechanical arm-based system has been demonstrated in the environment it would be used in. However, LDUA has the advantage of several years of intense design and development activities specifically geared toward this purpose.

The vehicle-based deployment methods could be a more cost-effective method for sludge removal. This is because the vehicle can be adapted to use the same end effectors as the manipulator arm and can be transferred from tank to tank with relative ease using simpler equipment. The manipulator arm, on the other hand, requires construction of a platform or other support structure because of its weight and stiffness requirements. Of the vehicle-based deployment methods investigated, the Remotec "ANDROS" series appears to be the best. The other vehicle manufacturers either do not have direct nuclear experience or have products that are too undeveloped to warrant serious consideration. Although the capabilities of the Redzone "HOUDINI" vehicle could be superior both in capability and ruggedness, the number of uncertainties that have not been resolved in its development are greater than in the Remotec "ANDROS" vehicle, which is now in production. Modification of an existing equipment platform that has been demonstrated in high radiation applications should be much easier than the development of a completely new system. Other vendors of vehicle-based deployment methods could also exist but were not identified in this study; therefore, competitive procurement is possible.

The end effector technologies rated may all be used at one time or another depending on the type of waste encountered. Listed end effector technologies are applicable to either vehicle-based or mechanical arm-based deployment methods. End effectors which had the highest scores were the high/medium-pressure confined sluicing and the backhoe or clamshell buckets.

Although dry methods generally were rated superior to wet methods for concrete removal, the confined sluicing method could double as a concrete removal method. The only variable in this is the water pressure used. It is possible that the concrete in the tank liners has deteriorated to the point that mechanical scraping with a bucket may be all that is required. Concrete removal technologies should be selected after more data is obtained on the condition of the tank walls.

The conveyance technologies may also all be used, depending on the end effector selected. For example, confined sluicing could require the use of three-phase air conveyance or jet pump conveyance, but dry scabbling of concrete could only require vacuum cleaning conveyance. Three-phase air conveyance appears to be superior and more versatile than other methods, but the details of the post-removal processing required are not yet available. This is because these systems have not been engineered for a radioactive application but only for development of the confined sluicing/three-phase air conveyance system. All types of pumps rated should give acceptable service for the soft sludge wastes but not for other types. Some type of drum removal system will probably be required for the removal of in-tank equipment, debris, and failed waste removal equipment.

The study did not consider post-removal sludge processing because the authors were instructed to assume that the sludges would be transported to MVST as a final disposition. There should be additional studies made to determine the final disposition of the material as well as the processing required to convert it into a waste form that is compatible with this disposition. Post-removal sludge processing is an integral part of the GAAT OU cleanup effort.

The study makes the following recommendations.

- Single-point jet sluicing should be used to remove soft sludges from to the tanks that were not cleaned during the 1982-83 cleanout campaign.

- A modified version of the LDUA system should be procured for use in the tanks for the major portion of waste removal.

- A commercially available remote vehicle should be procured for tasks that fall outside the area of LDUA capabilities, as a backup in case of LDUA failure, and to enable comparison of the cost of the two methods.

- Confined sluicing should be adopted for the removal of hard sludges and soft sludges that cannot be removed with single-point jet sluicing. More attention should be given to the design of the post-treatment system.

- The project should retain the flexibility to modify end effectors or develop other end effectors as the situation warrants.

- Samples of the concrete should be removed to determine its structural integrity and the depth of penetration of the radioactive materials. Methods of concrete removal can be adopted after this is determined.

- A drum handling system should be developed.

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Appendix A

UNDERGROUND STORAGE TANK
INTEGRATED DEMONSTRATION, MARCH 1994
MIDYEAR REVIEW DOCUMENTS

Listed below are presentational documents that were obtained from the Underground Storage Tank Integrated Demonstration (UST-ID) Midyear technical review in Oak Ridge, Tenn., (March 29 to March 31, 1994). These documents can be obtained from the UST-ID, Westinghouse-Hanford Company, P.O. Box 1970, MS L5-63, Richland, WA 99352, attention: Kathy Bryson; fax: 509-372-2445; phone: 509-376-6008.

- Strategic Plan for the Underground Storage Tank—Integrated January 1994, Pacific Northwest Laboratory
- UST-ID Program Monthly Report, February 1994
- UST-ID Technology Summary, February 1994, DOE/EM-0122P
- Test Requirements and Evaluation, Mike Rinker, Pacific Northwest Laboratory
- Mechanics, Judith Bamberger, Pacific Northwest Laboratory
- Waste Dislodging and Conveyance System, Jim Yount, Westinghouse-Hanford
- Medium Pressure/Mining Strategy, David Summers, University of Missouri, Rolla
- High Pressure System, Steve Knowles, Quest Integrated, Inc.
- Integrated Testing, Brian Hatchell, Pacific Northwest Laboratory
- Deployment Systems and Intake Video/Photography For Underground Storage Tanks Integrated Demo, Frank M. Heckendorn, Savannah River Technology Center
- Simulant Development, Gita Golcar, Pacific Northwest Laboratory
- Light Duty Utility Arm (LDUA) and Deployment System, G. Cunliffe, Spar
- LDUA System Introduction, Betty A. Carteret, Westinghouse Hanford Company
- LDUA Subtask #1, Betty A. Carteret, Westinghouse Hanford Company
- LDUA Topographical Mapping System Integration, Dr. Barry L. Burks, ORNL
- LDUA Technical Integration and End Effector Testing, Christopher M. Smith, Pacific Northwest Laboratory
- LDUA Surveillance and Inspection, Frank M. Heckendorn, Savannah River Technology Center
- LDUA Technology Transfer to INEL (Decontamination/Ventilation and End Effectors), Cal Christensen, Idaho National Engineering Laboratory
- LDUA Supervisory Data Acquisition System, Barry L. Spletzer, Sandia National Laboratories
- LDUA Supervisory Control System, Brady Davies, PhD, P.E., Sandia National Laboratories

Appendix B

VENDOR LIST

Company name	Address	Phone/fax	Product
Abel Pumps Corp.	79 N. Industrial Park Sewickley, PA 15143-2394	412/741-3222 412/741-2599	Spherical membrane pumps Slurry pumps Vertical plunger pumps
Air Technical Industries	7501 Clover Ave. Mentor, OH 44060	216/951-5191 800/321-9680	Reversible boom cranes/manipulators
APV Crepaco, Inc.	9525 W. Bryn Mawr Ave. Chicago, IL 60018	708/678-4300 708/678-4407	Process/refrigeration/automation Equipment/systems Tanks/processors/blenders
ARC	500 Chastain Center Blvd. Kennesaw, GA 30144	404/429-1188 404/428-3090	Decontamination systems Crystalline ice blast
Benthos, Inc.	49 Edgerton Dr. North Falmouth, MA 02556	508/563-1000 800/446-1222 910/997-0666	Vehicles/remotely operated vehicle articulators
Branford Vibrator Co.	New Britain, CT 06051	203/224-3183 203/826-4115	
Butterworth Tank Cleaning Machines, Inc.	16737 W. Hardy St. Houston, TX 77060	713/812-7300 713/821-5550	Tank cleaning machines
Cambelt International Corp.	2420 W. 1100 S Salt Lake City, UT 84104	801/972-5522 801/972-5511	Belt/gallery/vertical conveyors
Caterpillar Inc./ Balderson, Inc.	600 Balderson Blvd. P.O. Box 6 Wamego, KS 66547	913/456-2224 910/749-6524	Hydraulic hammers Quick couplers Buckets/blades/scoops Land clearing
Chicago Conveyor Corp.	330 La Londe Ave. Addison, IL 60101	708/543-6300 708/543-2308	Dense phase conveying systems

Company name	Address	Phone/fax	Product
Cimcorp, Inc./Precision Systems	899 W. Hwy. 96 Shoreview, MN 55126	612/484-7261 612/483-2689	Series overhead gantry robots/telerobot systems/manipulators/
Continental Diversified	900 Sixth Ave. SE Minneapolis, MN 55414	612/379-0606 fax 612/378-3741	Forklifts/masts/attachments Beekeeper lift trucks
Continental Screw Conveyor Corp.	4343 Easton Rd. St. Joseph, MO 64503	816/233-1800 816/233-8315	Bulk material handling equipment Screw conveyors Bucket elevators Drag conveyors
Conveyors, Inc.	P.O. Box 50817 Fort Worth, TX 76105	817/477-3151 817/473-3024	Vertical screw conveyors
Crane Co./Deming Div.	1453 Allen Rd. P.O. Box 450 Salem, OH 44460-0450	216/337-7861 216/337-8122	Solids handling centrifugal pumps
Deere & Co.	John Deere Rd. Moline, IL 61265	309/765-8000 309/765-5772	Tractors/high-pressure washers
Dresser Industries Inc./ Dresser Pump Div.	150 Allen Rd. Liberty Corner, NJ 07938	908/647-6800	Slurry process pumps Solids handling pumps Positive displacement pumps Screw pumps
Dynamic Air, Inc.	1125 Wolters Blvd. Saint Paul, MN 55110-5193	612/484-2900 612/484-7015	Vacuum/pressure unloaders
Franklin Miller	60 Okrer Parkway Livingston, NJ 07039	201/535-9200 201/535-6269	Size reduction equipment
Goodman Conveyor Co., Inc.	Rt. 178 S P.O. Box 866 Belton, SC 29627	803/338-7793 803/338-8732	Ropebelt conveyors Screw conveyors

Company name	Address	Phone/fax	Product
Gough Econ, Inc.	9400 North Lakebrook Rd. P.O. Box 668583 Charlotte, NC 28266	704/399-4501 fax 704/392-8706	Rota-Feed systems
Goulds Pump, Inc.	240 Fall St. Seneca Falls, NY 13148	315/568-2811	Slurry/solids/abrasives pumps
H&H Pump and Dredge Co.	P.O. Box 486 Clarksdale, MS 38614	601/627-9631 601/627-9660	Remote controlled tank sludge removal equipment
Hi-Vac Corp.	117 Industry Rd. Marietta, OH 45750	614/374-2306 800/752-2400	Vacuum loading systems HEPA Vac Pac vacuum cleaners
Hotsy	2100 University Ave. Knoxville, TN 37921	615/525-1515	Pressure cleaning equipment
Hutchinson Will-Rich/MFS/York Div.	2928 E. HWY 30 P.O. Box 2105 Grand Island, NE 68802	308/384-9320 800/247-6621	Model 8 Compact Jr. bucket elevators
Hydra-Mac, Inc.	1110 Pennington Ave. Thief River Falls, MN 56701	218/681-7130 fax 218/681-7134	Skid steer/crawler loaders
Idex Corp./Viking Pump, Inc.	406 State St. P.O. Box 8 Cedar Falls, IA 50613-0008	319/266-1741 319/273-8157	Viking pumps
IKA-Works, Inc.	11895 Kemper Springs Dr. Cincinnati, OH 45240	513/851-8200 513/851-8489	Processing equipment
Industrial Innovation, Inc. (3I) (Gina Morelli)	P.O. Box 830 Stockton, CA 95201	209/462-8241 209/462-2860	Sludge excavation and recovery equipment Tank cleaning equipment
Ingersoll-Rand Co./Water Jet Cutting Systems Div.	23269 Industrial Park Dr. Farmington Hills, MI 48335	313/471-0888 800/826-9274	Water jet cutting/slitting systems Streamline water jet intensifiers

Company name	Address	Phone/fax	Product
Ingersoll-Rand Co./Automated Production Systems Div.	23400 Halstead Rd. Farmington Hills, MI 48335	313/477-0800 313/464-2710	Robotic systems Water jet cutting systems Cleaning/deburring/automation systems
ITT Corp./ITT Fluid Technology Corp./ ITT Flygt	129 Glover Ave. Norwalk, CT 06856	203/846-2051 203/846-9199 203/849-0679	Wastewater pumps/mixers
Joy Technologies, Inc./Joy Environmental Equipment Co.	10700 N. FWY Towerpark North Houston, TX 77037	713/878-1000 713/591-2295	Hydraulic/pneumatic/mechanical materials handling equipment/systems Unloaders
Ketema Corp./ Schutte & Koerting	2233 State Rd. Bensalem, PA 19020	215/639-0900 215/639-1597 (Schutte)	Scrubbers
Komatsu Dresser Co./ Dresser Marketing	200 Tri State Intl. P.O. Box 1422 Lincolnshire, IL 60069-1422	708/831-6700	Heavy construction equipment
Kraft Telerobotics (Steve Harbor)	11667 W. 90th St. Overland Park, KS 66214	913/894-9022 913/894-1363	Remote manipulator systems
Lake Shore, Inc.	P.O. Box 809 Iron Mt., MI 49801	906/774-1500 800/338-9281	Guide systems/shaft arrangements
Landsenkamp Co., Inc.	3120 N. Shadeland Ave. Indianapolis, IN 46219	317/636-4321	Panel-coil vessels/centrifugal/sump pumps Chopper-pumps Can crushers/openers Conveyors/elevators
Melroe Co.	112 N. University Dr. P.O. Box 6019 Fargo, ND 58108-6019	701/241-8700 701/678-6363 (plant)	Bobcat skid-steer Bobcat attachments Bobcat compact hydraulic excavators

Company name	Address	Phone/fax	Product
Morgen Manufacturing	117 W. 3rd St. P.O. Box 160 Yankton, SD 57058-0160	605/665-9654 800/952-4726 fax 605/665-7071	Crane-mounted conveyors Self-handling conveyors
Netzsch, Inc.	119 Pickering Way Exton, PA 19341-1393	215/363-8010 215/363-0971	Nemo progressive cavity pumps NT immersible Reciprocating/diaphragm pumps
NLB Corp.	29830 Beck Rd. Wixom, MI 48393-2824	313/624-5555 313/624-0908	High-pressure cleaning systems/equipment High-pressure water jet cutting system/cleaning cab
Oceaneering International, Inc./ Oceaneering Technologies, Inc.	501 Prince George Blvd. Upper Marlboro, MD 20772	301/249-3300 301/249-4022	Sea floor mapping/custom transportable shelters
Peabody Myers Corp.	1621 S. Illinois St. Streator, IL 61364-0908	815/672-3171 815/672-2779	Vactor sewer/catch basin cleaning systems Vactor landfill vacuum loaders Vactor mobile industrial vacuum loaders
Redzone Robotics, Inc. (David M. White)	2425 Liberty Ave. Pittsburgh, PA 15222-4639	412/765-3064 412/765-3069	Robotic inspection/work systems Intelligent vehicles
Remotec, Inc. (Bradley E. Callahan) (Sammy Jones)	114 Union Valley Rd. Oak Ridge, TN 37830	615/483-0228 615/483-1426	Robotic/remote vehicles
Rexnord Corp.	4701 W. Greenfield Ave. Milwaukee, WI 53214	414/643-3000 414/643-3078	Centrifugal sewage/water pump vertical drive couplings
Robbins & Myers, Inc./ Fluids Handling Group	1895 W. Jefferson St. P.O. Box 960 Springfield, OH 45501	513/327-3553 513/327-3082	Moyno Down Hole oil well pumps Moyno SP positive displacement pumps Moyno sanitary pumps
Schilling Development (Lisa Nishikawa)	1632 DaVinci Ct. Davis, CA 95616	916/753-6718 916/753-8092	Remote manipulator systems (radiation hardened)

Company name	Address	Phone/fax	Product
Serfilco, LTD	Glenview, IL	708/559-1777	
Shanley Pump & Equipment Inc./Allweiler Pumps	2525 S. Clearbrook Dr. Arlington Heights, IL 60005	708/439-9200 708/439-9288	Screw/cavity pumps/macerators
Shred Pax Corp.	136 West Commercial Ave. Wood Dale, IL 60191	708/595-8780 708/595-9187	Size reduction equipment
Smoot Co.	1250 Seminary St. P.O. Box 3337 Kansas City, KS 66103	913/362-1710 800/748-7000	Bulk materials handling equipment/systems Airlock feeders/accessories Dense phase conveying
Sonsub, Inc. (Louise Cranek) (Charles Yemington)	10905 Metronome Houston, TX 77043	713/984-9150 713/984-2109	Subsea engineering and remote systems technology
SSI Shredding Systems	9760 SW. Freeman Dr. Wilsonville, OR 97070	503/682-3633 503/682-1704	Shredding systems
Sugino USA, Inc.	2246 N. Palmer Dr. Schaumburg, IL 60195	312/397-9401 fax 312/397-9490	Automatic tank cleaning and water blasting systems
Svedala Industries Inc./Allis Mineral Systems/Grinding Division	240 Arch St. P.O. Box M-312 York, PA 17405	717/843-8671 fax 717/845-5154	Vibrating ball mills Ring hammermills
Tarby, Inc.	2205 E. Anderson Blvd. P.O. Box 838 Claremore, OK 74018-0838	918/341-8282 800/854-1879	Progressing cavity pumps/replacement parts
Tenneco Inc./JI Case	700 State St. Racine, WI 53404	414/636-6011	Wheel loaders
Vaughan Co., Inc.	364 Monte-Elma Rd. Montesano, WA 98563	206/249-4042 206/249-6155	Chopper pumps

Appendix C

CONTACT LIST

Contact	Company	Phone	Specialization area
Peter Brazier	AECL Research	613/584-3311 ext. 6264	AECL Chalk River D&D manager
David Chamberlain	Argonne National Laboratory	708/252-7699	
George Vandergriff	Argonne National Laboratory	708/252-7252	
Loren Eyler	Batelle—PNL	509/375-3740	Sludge mobilization and mixing simulations
Val Bouchard	Bechtel National, Inc.	615/220-2654	
F. Bzorgi	Bechtel National, Inc.	615/220-2238	
Clay Davis	Bechtel National, Inc.	615/220-2577	
Mahmoud A. Haghighi	Bechtel National, Inc.	615/220-2288	
Andy Kelsey	Bechtel National, Inc.	615/220-2885	
Rick Robertson	Bechtel National, Inc.	615/220-2383	
Ed Walker	Bechtel National, Inc.	615/220-2202	
Walter Haetgens	Bowrett-Haentgens	717/455-7711	Pumps
Craig Johnson	Bristol Equipment Co.	312/553-7161	Railroad tank car cleaning systems; supplier of Gunite project sluicing nozzle
David Swale	British Nuclear Fuel Ltd.	303/694-0700	BNFL Sellafield, England site, Hanford WRAP facility
Philip F. Spelt	Energy Systems—ORNL	615/574-7472	Cognitive systems/human factors; autonomous robotic control systems
Bob Mason	Energy Systems	615/574-1365	
Barry Burks	Energy Systems	615/576-7350	Manipulator development for Hanford
Herman Weeren	Energy Systems (retired)	615/483-6639	

Contact	Company	Phone	Specialization area
Lloyd Youngblood	Energy Systems—Chemical Technology	615/574-6814	
Don Box	Energy Systems—Chemical Technology	615/574-6940	
Joe Perona	Energy Systems—Chemical Technology	615/576-9280	
Jim Snider	Energy Systems—Chemical Technology	615/574-9873	
Jerry Stapleton	Energy Systems—Mechanical Design	615/576-3898	
Clay Wynn	Energy Systems—Mechanical Design	615/576-1279	WHPP sludge mobilization design
Dave Richards	Energy Systems—Mechanical Engineer	615/574-9878	
Dave Burstein	Engineering Science	404/235-2305	Engineering Science vice president, Duratek; contract with SRP
Jean Marie Astruc	Insitut Laue-Langevin (France)	33-76-96-11-43	
Carl Ragan	Jacobs Engineering Group	615/220-4847	
Dan Evans (GOCO)	Kaiser Engineers/Hanford	509/376-6259	Sludge removal from 10 double-shell tanks—conceptual design
Eric Depew	Ogden/Enserch	615/481-5111	WAG-1 work for Enserch
Mike Rinker	Pacific Northwest Laboratory (Hanford)	509/375-6623	Waste dislodging and conveyance system
Judith Bamberger	Pacific Northwest Laboratory	509/375-3898	Sludge mobilization in double-shell tanks

Contact	Company	Phone	Specialization area
Jack Scott	Parson Environmental Services	818/440-6000	Parson Environmental vice president, Duratek; contract with SRP to build vitrification plant
Robert Minnitti	Puget Sound Naval Shipyard Bremerton, Wa.	206/476-3711	Land and sea disposal methods
Walt Ray	Radar-Sonics	714/630-7288	Sonar (200kHz)
Gary Johnson	Savannah River Plant	803/557-9689	SRP operations
Bob Stokes	Savannah River Plant	803/557-9689	SRP retrieval project manager
Lisa Nishikawa	Schilling	916/753-6718	Telerobotic manipulation systems
Louis Cranek	Sonsub, Inc. (Field Operations)	713/984-9150	
Vince Goyette	Sulzer Canada	416/674-2034	
Laszio Joavorik	Ultrasonic Power	815/235-6020	Manufacturing of ultrasonic power excitation system for cleaning and cutting
Tom Vadakin	Vadakin, Inc.	614/373-7518	High-pressure water cleaning systems and service
Tom Hoenigman	Weatherford, Inc.	305/678-0664	High-pressure water cleaning systems
Tom Kocialski	West Valley Demonstration Project (WVDP)	716/942-4275	WVDP vitrification project manager
Dave Kurasch	WVDP	716/942-4155	WVDP Phase 2 (heels removal)
Dan Meess	WVDP	716/942-4950	WVDP sludge washing engineering manager
Mark Schiffhauer	WVDP	716/942-4279	WVDP development engineer
Cal Christensen	Westinghouse—Hanford (WH)	509/372-3284	Sludge simulants/end effectors
Kurt Rieck	WH	509/372-2913	Tank bulk removal—90% of sludge

Contact	Company	Phone	Specialization area
Jim Yount	WH	509/372-3284	Sludge simulants/end effectors
Gita Golcar	WH	509/372-3284	Sludge simulants/end effectors
David Ramsower	WH	509/372-2383	Tank heel removal/clean-out
John Bailey (GOCO)	WH	509/372-0045	Sluicing 43 single-shell tanks/106-C sluicing activities (500,000 gal tank)
Dennis Crass (GOCO)	WH	509/373-2034	Sludge mobilization in double-shell tanks
Dale Waters (GOCO)	WH	509/372-0145	Joint mixer pump development WH WSRC
Betty Carteret	WH	509/376-7331	LDUA
Carl Hanson	WH	509/376-4810	Shielded submersible pump
Mark Henderson	WH	509/372-0377	Tank heel removal/clean-out 99
Ed Norguist	WH	509/372-2923	Tank bulk removal 90% of sludge
Dirk Wiggins (GOCO)	WH	509/373-1286	Single-shell tank farm

Appendix D

DISCUSSION OF CONVENTIONAL TANK CLEANING TECHNOLOGIES

Chemical Cleaning Technology—Dissolution with Nitric Acid[6]

Samples were taken from the gunite tanks in the 1980s. These samples were not analyzed for gross chemical composition; however, the samples are expected to be somewhat similar to the sludges in W-21, W-23, and MVST, which were sampled in 1990. The major insoluble components were generally composed of calcium and magnesium carbonates and hydroxides, along with uranium and thorium compounds. The supernate and the solution in the interstitial area of the sludge were composed of sodium and potassium nitrate (about 4 M in the supernate) with a pH of about 13.

Physical property measurements have also been made of the sludge samples. During sludge washing tests using samples from the waste tanks, it was determined that after washing with water the soft sludge appeared to dissolve readily (within 10 min) at room temperature in 2 M nitric acid, with little solid residue remaining. This indicated that dissolution might be useful in removing solids from tanks. However, the proposed use was primarily sludge removal from small tanks containing relatively small amounts of solids for which other sludge removal methods would be difficult, rather than removal from large tanks that contain significant quantities of solids. Also, it is known that one of the evaporator tanks (W-21) reached a pH of 1 during operation, and the tank still contained solids under the relatively strong acid conditions. Tests with actual sludge samples are needed to determine the acid requirement and the solubility of the sludge. Information that should be determined before the acid dissolution option can be used includes the fraction of solids that can be dissolved, the quantity of acid required, the gas and heat generation rate, the corrosion rate, and the amount of mixing required.

Chemical Cleaning Technology—Dissolution with Oxalic Acid

Oxalic acid is effective in removing rust from iron. In decontamination of reactor systems it is an excellent complexer for niobium (when present) and fission products.

Oxalic acid was used at the Savannah River Plant[28] (SRP) to decontaminate stainless steel heat exchangers. The process consisted of filling the system with water, adding a corrosion inhibitor (ferric sulfate 2.6 g/L), steam heating to 70°C, adding oxalic acid to 2% wt, and recirculating the mixture. The system was then drained, water rinsed, and neutralized with 50% KOH. The system was drained and rinsed again with water and decontamination factors of 3 to 20 were achieved. At temperatures of about 90°C the oxalic acid reacted with the stainless steel to form a tenacious film of highly insoluble ferrous oxalate. Subsequent treatment with sulfuric and nitric acid was necessary to remove the precipitate. It is used as the second step with AP preconditioning, but because of the precipitate, it is not of significant interest.

Also at the Savannah River Plant, exploratory dissolution tests were made with small volumes (1 to 2 mL) of sludge from SRP Tank 16H using an 8% wt oxalic acid or oxalic acid-based cleaning solution (Turco Decon 4518, Turco Products, a Division of Purex Corporation, Ltd., Carson, California). These were effective in dissolving most of the sludge. Kinetic studies showed that the reaction was first order with respect to the quantity of sludge present, and that the reaction appeared to be controlled, at least partially, by diffusion of reagent to the sludge particle surface. The dissolving mechanism is probably a reaction between oxalic acid and the oxides and hydrous oxides in the sludge, forming soluble metal oxalates. Operating under optimal conditions, as defined by kinetic studies, it was found that at least 96% of a sample of sludge was dissolved in oxalic acid in an agitated, two-step process of 50 h per step, with an initial reagent-to-sludge volume ratio of 20. The principal isotopes of concern in the sludge are ^{137}Cs, ^{90}Sr, and ^{239}Pu. The ^{137}Cs is in the supernate phase and is already in solution and easily washed from the sludge. The ^{90}Sr appears to be adsorbed onto the hydrous oxides in the sludge and dissolves roughly in proportion to the amount of sludge dissolved in the oxalic acid. Analyses for ^{239}Pu were inconclusive due to small sample sizes; however, there is some indication that a portion of the ^{239}Pu is in a highly insoluble form. Use of hydraulic slurrying in addition to the chemical dissolving process should remove greater than 99% of the plutonium.

Although sludges from waste tanks could be dissolved in concentrated mineral acids, oxalic–acid based cleaning solutions will not attack the carbon steel waste tanks. This is required to assure containment during the tank cleaning process. Oxalic acid–based cleaning solutions will also not attack existing processing equipment in the present SRP waste system and are compatible with processes for waste volume reduction and conversion to high-integrity solid forms for final disposition.

At ORNL, oxalic acid–based cleaning has been used for hot cell decontamination, but no tests have been performed to determine if the technique would work for sludge dissolution.

Oxalic acid–based cleaning solutions[29] would add additional volume to the waste system, not only from the acid, but also from the additional sodium hydroxide required to neutralize the resulting solution. The effect of the acid on GAAT OU concrete should be investigated, and in addition, studies are required of the radiolysis of the neutralized sodium oxalate solutions. An evaluation is required to assure that no excessive exothermic reactions could occur if the oxalate is mixed with nitrate in the waste. Also, evaluation of chemical dissolution rates for sludges from ORNL waste tanks and detailed studies of the kinetics of the sludge dissolution process using nonradioactive, simulated sludge components should be performed.

Chemical Cleaning Technology—Dispersing Agents

Chemical agents[6] that dissolve or assist in mobilization and suspension of sludge particles are potentially useful if they do not cause detrimental effects, such as increased corrosion, increased explosion hazards, or interference with the final disposal of the waste. Bentonite clay was used to suspend the slurry for transport from the Gunite tanks, but the use of bentonite was not favored by Waste Management for the waste evaporator feed tank cleanout because of the increased waste volume and the increased difficulty in sludge removal after settling.

Proprietary chemical additives developed by Nuclear Technology Corporation have been used for removing scale and cleaning boilers and lines in nuclear power plant systems. Company product bulletins indicate that the company markets chemicals for removal and dissolution of calcium sulfate scale; metal oxides; carbonates; and other inorganic compounds of calcium, magnesium, copper, and iron; as well as cleaning detergents. The bulletins indicate that polycarboxylic acid and polyamines are used. The company has not been reached to determine if any of the additives are potentially suitable for dispersing large quantities of sludge such as those found in GAAT.

Haliburton Corporation markets many additives for use in the oil industry and is a potential source of additives in waste tanks. Specific information on products available from Haliburton has not been identified. PNL is also considering the use of additives to assist in the dispersion of sludge in the Hanford tanks, but only a limited amount of effort has been put into this approach thus far. The main interest is the use of additives to aid jet mixing. PNL does not expect the additive to penetrate and disperse the sludge without forced mixing.

Additives should be used only after an extended study is conducted to determine potential problems, such as the effect on the final disposal of the waste. Additives used to dissolve or disperse the GAAT solids that have not been previously used in similar nuclear applications would require an extended testing and evaluation program. It is also expected that if additives are used, some type of mixing would be required to disperse the additive in the sludge. If additives are found that have been successfully used in similar applications, laboratory testing with actual sludge samples should be performed.

Mixer Pump Technology

Long-shaft centrifugal pumps inserted through flanges located at the top of the tanks have been used successfully for many years for the mobilization of sludge in large vertical waste tanks. The slurry is pulled into the bottom suction port of the pump and discharged at high velocity through horizontal discharge jets located 180° apart. Advantages of this method are that no external piping is required, and high flow rates and discharge pressures can be achieved. Performance data are available for pumps with shaft lengths of 32 ft and shaft diameters of 22 in. A pump of this diameter could be inserted in the GAAT penetrations.

The basic concept of the low-pressure sludge slurrying technique using mixer pumps was developed at the SRP.[6,28] This technique is to immerse the slurrying pump in the sludge layer so that a recirculating mixture of sludge and supernate will serve as feed to the pump, in place of fresh water. The high-pressure, positive-displacement pumps previously used for sludge slurrying operations at SRP could not be operated and maintained in the radioactive environment of the sludge layer. However, a simpler low-pressure (100 psi) single stage centrifugal pump was considered feasible as a recirculating pump for use in the sludge. Initial studies were focused on the basic criteria for a low-pressure centrifugal pump designed to produce a liquid jet that would have a sludge slurrying capacity at least equivalent to that of a previously demonstrated high-pressure jet system (similar to the single-point jet sluicing discussed above). Two design factors considered potentially important for a liquid jet to be able to resuspend sludges were the velocities of eddies in the jet stream and the impact of the stream on the sludge. Both these design parameters are dependent on the velocity of the stream. The ability of the jet to keep the solids fluidized is also directly related to the velocity; therefore, the velocity of the jet at any distance from the nozzle was taken as the measure of the slurrying efficiency of the jet.

Tests performed at SRP have shown that, for slurries that have a yield stress (e.g., Bingham plastic fluids), the effective cleaning radius in round tanks is proportional to the jet velocity times the jet diameter. In round vertical tanks the pump is generally rotated at 1/2 to 1/5 rpm to sweep a circular area in the tanks. Typically, pumps rated at 150 hp or higher are required for a cleaning radius of 20 to 40 ft with a sludge of the consistency of kaolin clay. Because of the weight of the pump (on the order of 3 tons), a supporting structure would likely be required above the tank. Also, the use of high-volume, high-velocity jets could put stress on the internal piping and tank components; therefore, the structural strength of the tank and piping should be evaluated.

The single-stage, volute-type centrifugal pump[6] (Bingham-Willamette Co., Portland, Oregon) of the type illustrated in Fig. D.1 has a capacity of 600 gal/min for each of two 1.5-in. diameter nozzles positioned 180° apart. This 3.5-ton pump was designed to fit into existing 2-ft. diameter tank risers. It is 32.2 ft long and has a maximum diameter of 22 in. In actual use, the pump and the motor are mounted on a turntable with a maximum rotational speed of 1/2 rpm. The pump consists of six casing sections, each 53 in. long and 16 in. in diameter. The cases are flanged on both ends and provide rigid structural support. Each casing section contains a 4-in. diameter cooling water pipe and a shaft alignment bushing.

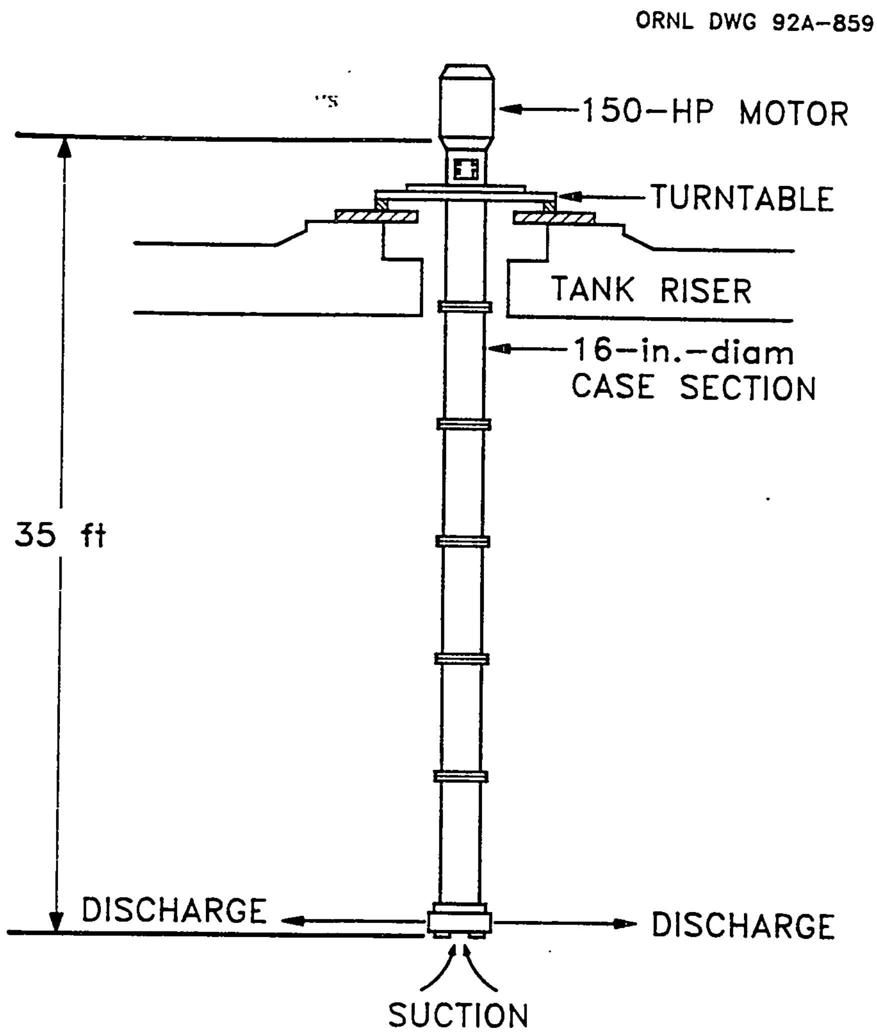

Fig. D.1. Schematic of long-shaft centrifugal pump.[6]

The shaft alignment bushings are cooled and lubricated by water (1 gal/min) flowing through triangular grooves cut in the bushings parallel and adjacent to the pump shaft. The pump is constructed of carbon steel, except for the stainless steel shaft and impeller. The shaft consists of three 10-ft sections, each 1.5 in. in diameter. The 15-in. diameter impeller is a 4-vane, semi-open type. The pump is driven by a 150-hp induction motor. The motor operates on 460-volt, 3-phase alternating current and is controlled at speeds between 600 and 1,800 rpm. by a variable-speed control unit. Electrical power is fed to the rotating motor and pump through a slip-ring device. This pump was used only for experimental tests with nonradioactive simulated sludge.

Tests of mixer pumps have also been performed at the West Valley Demonstration Project (WVDP).[30] Their tanks are 70 ft in diameter × 27 ft high, with an 850,000-gal volume. These tanks do not have as much sludge as either SRP or Hanford, but there is about 2 ft of a slow-settling sludge in each tank. This consists of ferric hydroxide and very fine particles and is thought to be a non-Newtonian fluid. WVDP has performed sludge washing to remove cesium, treat the salts, and finally, grout them. The WVDP tank system has a complex I-beam-and-plate internal structure, so sludge resuspension was driven to using mixer pumps. Their approach was to cut nine openings into the tank top and use several mixer pumps to resuspend the sludge for pumping to a vitrification plant. They have encountered problems with mixer pumps, mainly in the mechanical bottom seal, which can't be replaced. They are using SRP-style mixer pumps, and the concept is based on high flow–low pressure (600 gal/min at a 1-1/2 in. nozzle size).

A shielded, submersible mixer pump was developed for a tank at Hanford that has been dubbed the "burping tank." This tank had developed a crust of material above the sludge while also generating hydrogen from radiolysis of organics. The hydrogen would build up over a 60-90 day period, and there would be a violent gas release. Hanford personnel did not think that a long shaft pump would work under these conditions, and they needed a pump sooner than one could be procured. The pump developed was a modified version of a submersible pump they had on hand that was modified to fit into the tank. Since the mixer pump has been installed the violent gas releases have not recurred, and when this pump requires replacement, standard long-shaft vertical design pumps will be used.

Barrett-Haentjens[31] of Hazelton, Pa. is the manufacturer of Hanford's and SRP's long-shaft vertical pumps and has been working with both for 25 years. The pumps are highly instrumented and have strain gages on the pump column to detect nozzle plugging (two nozzles at 180° apart). The pumps monitor bearing temperature and winding temperature. Barrett-Haentjens does not mass produce of this type of pump because each one is unique.

Fuel Storage Basin Sludge Removal

Several sites have used a small crawler robot that functions like an underwater vacuum cleaner to remove sludge from fuel storage basins. This technology was used at the Atomic Energy of Canada, Ltd., Chalk River facility to clean out the fuel bays at the NRX reactor.[32] These bays were concrete and tile lined and had been abandoned for as long as 40 years. The bays were used for both fuel storage and as an experimental disassembly area where cutting was performed of both experiments and fuel. There was 4 in. of sludge in the bottom o the bays, which consisted of uranium oxides; sand; and assorted debris, like gloves, nuts, bolts, and scrap metal. The water also contained algae. Both a commercial and an internally-developed system were used to remove the sludge. The commercial unit was a German built underwater vacuum system that used a bay-side filter system with a solids separator. The other system was a modified pool vacuum with brushes that had water turbine–driven wheels, the water being moved by the suction from the vacuum pick-up system. Similar systems have been employed at ORNL for the cleanout of the Graphite Reactor canal and at other DOE sites.

At the Hanford site, several spent fuel storage basins are maintained to support operation of the N-Reactor.[33] These basins have systems to filter and demineralize the basin cooling water but have no facilities to remove accumulated radioactive sludge. A portable Sludge Removal System (SRS) was built to remove accumulated sludge and decant, solidify, and package it in a form suitable for disposal. SRS is designed to pick up the sludge, mix it with a stabilizing agent, decant the mixture, and package it in a form suitable for transuranic or non-transuranic disposal. The system is portable, it handles material of moderate dose rate, and it employs automated equipment to reduce hazards to the operators. The sludge is generally composed of silt, activated and nonactivated corrosion products, oxidation products from reactor fuel and fuel assembly components, and activated and nonactivated carbon steel corrosion products. Repeated sampling and analysis indicated that in no case could the sludge be demonstrated to be free of transuranic isotopes; however, the SRS was designed with the ability to process and package the material as transuranic waste. SRS is illustrated in Fig. D.2.

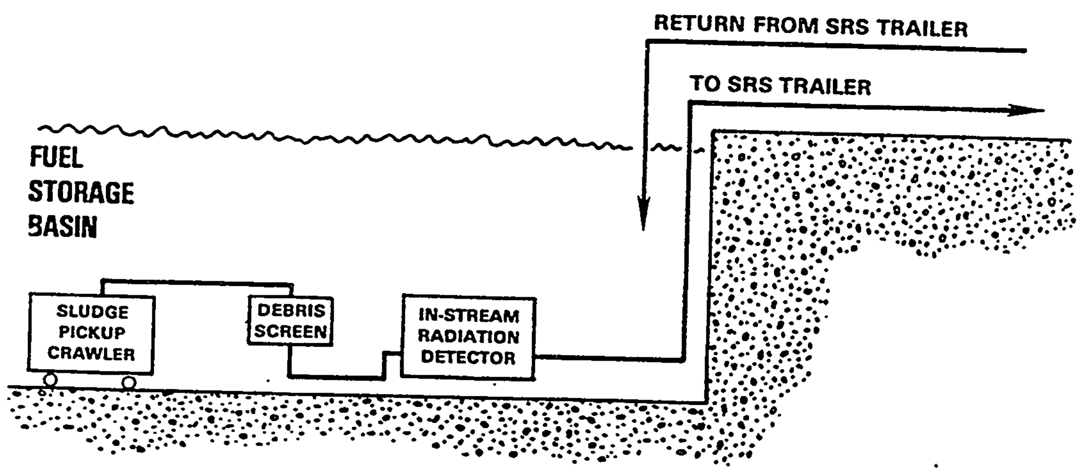

Fig. D.2. SRS schematic.[33]

The sludge pickup crawler is a highly maneuverable tracked vehicle approximately 0.6 m square × 0.3 m tall. It is remotely manipulated by a joy stick on the operator's control pendant, which allows speed control and forward, reverse, and turning movements. A vacuum nozzle is mounted in the center of the crawler. The height of the sludge pickup head can be varied from the control pendant to adjust the crawler's performance for differing sludge depths and consistencies. Wipers on the crawler's bottom scrub the basin floor and dislodge loosely bound material. The crawler is equipped with high-intensity lights and can be fitted with a video camera for working in areas that are not directly observable. Attachments, such as manipulator arms or rotary brushes can also be added. For those areas of the basin that the crawler cannot adequately cover, a wand, manipulated by hand from the surface, can be substituted. A flexible 50-mm (2-in.) hose connects the crawler to a debris trap that rests on the basin floor. This trap contains a disposable strainer element that traps > 5 mm (3/16 in.) particles. Its body is proportioned to provide a safe geometry for criticality purposes, as is all equipment in the system. A differential pressure gauge monitors solids loading in the strainer. Once full, the strainer is changed out by workers on the operating floor using specially designed tools. Another flexible 50-mm (2-in.) hose runs from the debris trap to the sludge processing trailer. The hose passes through an in-stream radiation detector that monitors the dose rate of the sludge stream. This dose rate information, along with other operating parameters, is displayed to the process trailer operator and is recorded. If this dose rate exceeds a preset level, the control system immediately shuts down the sludge pump and prevents this hotter-than-expected material from leaving its shielded position in the basin. The material can then be flushed back into the strainer for special handling or processed through the system at a reduced flow rate. The hose is routed underwater as far as is practical to take advantage of natural shielding and minimize the consequence of a leak in the line. All hose runs between the basin and the sludge processing trailer are double contained and shielded.

The sludge processing equipment is housed in a 45-ft long semitrailer, illustrated in Fig. D.3. The trailer is divided into six major compartments: control room, electrical room, fluid power center, maintenance cell, process cell, and transfer cell. The operator controls all equipment and monitors process parameters from the trailer's control room. The operator can also monitor equipment operation visually on a closed-circuit television connected to four cameras placed strategically in the trailer. Two-way radio headsets are used to keep the trailer operator in constant communication with the crawler operator in the basin and the forklift operator who loads and removes drums at the rear door of the trailer. There is an electrical room and a fluid power center that provide the necessary control and hydraulic power for the system. The maintenance cell contains the solidifier mixing and pumping equipment and provides a path for maintenance access to the process. The process cell houses the sludge pump, a centrifuge to decant the sludge slurry, packaging, and other support equipment. The solids discharge port of the continuous decanting centrifuge directs the solidified waste into a steel pail. The liquid discharge port is connected through a small surge tank to a 75-mm (3-in.) diameter flexible hose that returns to the basin. The capping and transfer cell contains several remotely operated devices that can extract a grab sample of decanted sludge, cap the pail, move the pail from the process cell to a shielded burial drum and replace it, and secure a lid to the burial drum. The rear door of the trailer opens remotely to provide forklift access to the drum. All the contaminated equipment in the trailer is shielded and is watertight to a depth of approximately one meter. Fans and high-efficiency filters maintain positive air flow into the cells.

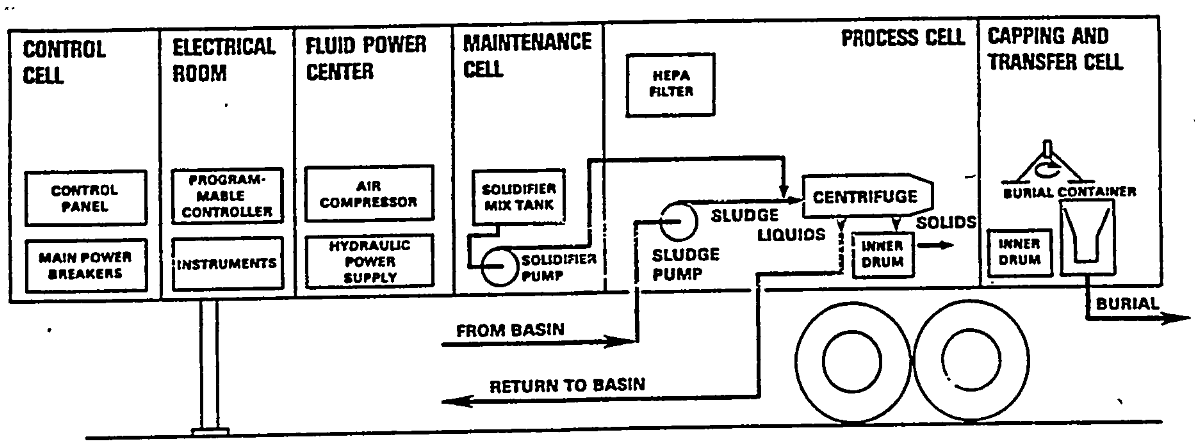

Fig. D.3. Schematic of fuel storage basin cleaner equipment trailer.[33]

The SRS equipment is designed to be set up relatively quickly. Once in operation, the crawler is maneuvered over the floor of the basin in a pattern that provides the most efficient coverage of the floor. Sludge and small debris in the crawler's vicinity are vacuumed into the nozzle on the crawler, which also collects material stirred up by movements of the crawler and prevents the generation of clouds that hamper visibility. The sludge is mixed with a large volume of basin water and ends up as a free-flowing, low-dose-rate mixture.

Transporting the sludge in a suction line as a low-dose-rate liquid greatly simplifies containment and shielding for the hose runs between the basin and the processing trailer. A disadvantage of transporting the sludge by this method is the limited suction head available as a motive force for the liquid. This has not impacted the use of the system because the sludge pump is never more than 2 m above the water level in the basin, and hose runs are fairly short. The equipment has been operated with up to 75 m of hose between the crawler and the trailer with no noticeable loss in performance.

The diluted sludge passes through the sludge pump and into the centrifuge at flow rates up to 32 gal/min. If higher flow rates are required the flow can be diverted to a cyclone separator in the process cell, which can accept flows up to 80 gal/min. The cyclone concentrates the sludge and directs it to the centrifuge at a flow rate that does not exceed 32 gal/min. The overflow from the cyclone is returned to the basin. While some applications require this excess flow capability, its use is avoided because the cyclone's separation efficiency for small, light particles is much less than that of the centrifuge. Using the cyclone often results in a cloudy discharge returning to the basin.

Just before the waste stream enters the centrifuge, it is mixed with a stabilizing/solidifying agent pumped from equipment in the maintenance cell. The ratio is adjusted, based on the sludge dose rate, to minimize the number of pails required while maintaining dose rates of the final burial drums at manageable levels.

Portland cement and calcium sulfate have both been used as solidifying agents. The solids are separated from the liquid in the centrifuge and deposited into a steel pail. The clarified liquid flows by gravity through a small surge tank and back to the basin. While a large volume of water may pass through the system in the course of cleaning the basin, the volume of water removed from the basin at any moment is typically less than 80 gal. This small volume of liquid enhances the safety of the system. When the pail is full, it is sampled, capped, and removed from the process cell. It is placed in a shielded burial drum that is then capped and sealed. The rear door of the trailer is opened, and a forklift equipped with a drum grabber removes the drum from the trailer.

Commercial Tank Cleaning Systems

There are several commercial technologies available for cleaning tanks. Generally, they all involve spraying water, possibly mixed with some kind of dispersant material, followed by pumping the mixture out of the tank through a processing system. Also available are in-tank robots for sludge removal.

One commercial system for cleaning crude oil storage tanks[12] involves placing a water cannon in the center of a cylindrical tank and a pump at the tank wall. After a radial slot is cut into the sludge, the water cannon is started, and the sludge is washed to the pump where it is removed. The sludge/water mixture is then pumped to a processing system where the residual oil is separated, along with the solids, cleaning the water for recycling into the tank.

As the cleaning progresses, the water cannon is rotated, and the pump is moved manually around the circumference of the tank until the tank has been cleaned.

A commercial system[34] for cleaning ocean-going crude oil carrier tanks involves using the vessel's cargo pumps to spray water, crude oil, or other cleaning solution from a set of fixed spray nozzles located in strategic positions in the tank. The nozzles are movable and are rotated to the proper orientation with a programmer to ensure cleaning all areas of the tank. The resulting mixture is then pumped into a separator system, and the water is discharged.

The inside surfaces of railway tank cars[35] are difficult to clean, and the operations rank among the most potentially hazardous jobs encountered in the coke and chemical industry. Mechanized chemical cleaning equipment has been installed at the Russian Railway Ministry's shunting yards for cleaning tank cars contaminated with petroleum, fat, and vegetable oil residues. The degree of cleaning is very high, and the cars can be used afterwards to carry edible products, alcohol, and refined petroleum derivatives. The detergents used to wash tankers and tank wagons consist of various synthetic surfactant mixtures in aqueous solution.

An experimental unit has been installed and tested at the Kharkov Coke and Chemical Works for cleaning railway tank wagons by the same technique as has already been adopted by the Russian Merchant Navy at its petroleum pipeline bases. The aqueous detergent solution is prepared and preheated in the clarifier, which holds 12.5 m^3 of solution at 55-60°C. A centrifugal eddy pump transfers it to the preheater, where its temperature is raised to 70-85°C before it enters the washing head suspended in the tank. The nozzles in the head rotate about a horizontal axis while the head itself rotates about a vertical axis, thereby spraying every part of the internal surface with detergent and washing the contaminants down. The washing head is designed and constructed from suitable materials to exclude the risk of static discharges. The contaminated detergent emulsion is pumped back to the clarifier. Clarified solution is circulated continuously and the contaminants (motor spirits, tar, etc.) that float to the top of the clarifier are drained off through an overflow into another container for subsequent recovery and use. The flowsheet includes provision for circulating the detergent solution from the preheater straight back to the clarifier. A flexible hose is used for convenience in connecting the washing head to the detergent solution pipeline. The tank outlet is similarly connected to the pumping line by a flexible hose.

Another commercial system[36] using an internal mechanized rotary cleaner and an external cleaner is used in the petrochemical industry for cleaning tank cars. The internal cleaner head is illustrated in Fig. D.4 and is typical of most commercial tank cleaning equipment.

The cleaner is capable of washing the interior surface of the tank in 6 to 15 minutes. This system is a "once through" system and uses detergents for cleaning, along with a waste water treatment system that adds flocculating agents to assist separation of the oils and water.

A commercial system[37] is used in the beverage and food industries for cleaning brewery kettles, tank trucks and other similar tanks. This system consists of a machine with two rotating jets that can spray water or other cleaning solutions at high pressure in a programmed, repeatable pattern to clean the inside surface of tanks. The rotational speed of the jets and the flowrate are controlled by the pressure of the fluid, as is the degree of cleaning. A pump transfers the cleaning solutions from a supply tank through the cleaning machine into the tank to be cleaned. The cleaning solution flows into a drain tank, where another pump returns it to the supply tank for recycling.

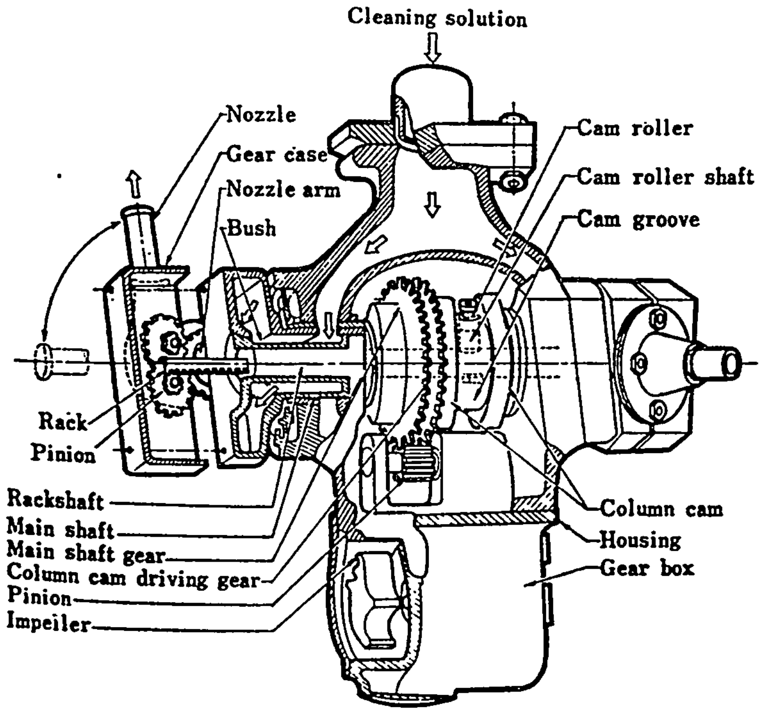

Fig. D.4. Cutaway view of rotating jet cleaner.[36]

One process for the formation of petroleum coke[38] (which is the material in the bottom of the barrel in crude oil refining), is known as delayed coking. In this process the bottoms of a fractionation column are sent through a furnace and into a "coke drum" (which is a tank that can be 20-30' diameter by 90' long) for further processing and solidification. After completion of this processing the coke drum is cooled to the point that it can safely be opened. The top and bottom covers are removed, and a drilling lance is inserted. The lance has a spray nozzle in it that sprays vertically downwards to cut into the coke and upwards to keep the cut coke fluidized. A high-pressure (3000 psi) pump is started, and water is sprayed through the nozzle into the coke to cut a 3' diameter hole through the length of the bed. When the hole is completed, the water/coke mixture is allowed to fall out of the bottom of the drum into a catch basin. The drilling lance is then raised back to the top of the drum and another set of jets (also on the same lance) is used to radially cut the remaining coke from the drum, using a flowrate of 1000 gal/min. The coke falls out into the catch basin for dewatering before being transferred as product. Water is filtered and recycled to the high pressure pump. The pump, spray nozzles, and piping system could have application for GAAT OU cleaning, but given the geometry of the tanks, the application becomes more like a sluicing method previously discussed.

None of the commercial systems investigated appeared to be suitable, primarily because of the nature of the sludges in the GAAT OU, their radiation levels, and tank geometry. Other commercial technologies were investigated but rejected because the authors did not believe them to be applicable to GAAT. The technologies determined to be not applicable are listed in Table 7-1.

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