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The Gunite and Associated Tanks Remediation Project Tank Waste Retrieval Performance and Lessons Learned

September 2003

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Nuclear Science and Technology Division

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ACRONYMS

ac	Alternating current
ALARA	As low as reasonably achievable
ASME	American Society of Mechanical Engineers
ATIE	At-Tank Instrument Enclosure
BJC	Bechtel Jacobs Company LLC
BOP	Balance of plant
BVEST	Bethel Valley Evaporator Storage Tank
CARP	Collimated Analyzing Radiation Probe
CEE	Characterization End-Effector
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CMM	Conductivity monitoring method
CPM	Counts per minute
CSEE	Confined Sluicing End-Effector
CZT	Cadmium-Zinc-Teluride
DOF	Degree of freedom
DOE	U.S. Department of Energy
DSR	Decontamination spray ring
ECR	Effective cleaning radius
EPA	Environmental Protection Agency
ES&H	Environment, safety, and health
FCE&CB	Flow Control Equipment and Containment Box
FCEE	Floor-Cleaning End-Effector
FFA	Federal Facilities Agreement
FY	Fiscal year
GAAT	Gunite and Associated Tank(s)
G-Alpha	Gross alpha
G-Beta	Gross beta
GEE	Gripper End-Effector
GIMP	Gunite Isotopic Mapping Probe
GSEE	Gunite-Scarifying End-Effector
HASP	Health and safety plan
HEPA	High-efficiency particulate air
HMA	Hose Management Arm
HMS	Hose Management System
HMI	Human-machine interface
HP	High pressure
HWRS	Heavy Waste Retrieval System
ILW	Intermediate level waste
IROD	Interim Record of Decision
LDUA	Light-Duty Utility Arm

LSEE	Linear Scarifying End-Effector
LMER	Lockheed Martin Energy Research Corp.
LMES	Lockheed Martin Energy Systems, Inc.
LLLW	Liquid low-level waste
M&I	Management and integration
M&O	Management and operation
MDS	Mobile Deployment System
MET	Mast Elevation Table
MLDUA	Modified Light-Duty Utility Arm
MMES	Martin Marietta Energy Systems, Inc.
MPD	Microwave preparation date
MPI™	Multi-Point Injection
MVST	Melton Valley Storage Tank
N/A	Not applicable
NTF	North Tank Farm
NTS	Nevada Test Site
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge Operations (DOE)
ORR	Oak Ridge Reservation
OU	Operable unit
PAM	Pulsair mixer
PCS	Primary Conditioning System
PDCU	Power Distribution and Control Unit
PM	Preventative maintenance
PMP	Pulsating Mixer Pump
PNNL	Pacific Northwest National Laboratory
PPE	Personal protective equipment
PVC	Polyvinyl chloride
R&D	Research and development
RI	Remedial Investigation
RI/BRA	Remedial Investigation/Baseline Risk Assessment
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
ROV	Remotely operated vehicle
RP	Radiation Protection
RTCS	Radioactive Tank Cleaning System
RWP	Radiation work permit
SCS	Sludge-Conditioning System
SFMP	Surplus Facilities Management Program
SMTL	Slurry Monitoring Test Loop
SPS	Supernatant Pumping System
SREE	Sludge Retrieval End-Effector
SS	Stainless steel
STF	South Tank Farm
SWSA	Solid Waste Storage Area

TDEC	Tennessee Department of Environment and Conservation
TDS	Total dissolved solids
THS	Tether Handling System
TMADS	Tether Management and Deployment System
TMS	Topographical Mapping System
TPGAT	The Providence Group Applied Technologies
TRI	Tank Riser Interface
TRIC	Tank Riser Interface Containment
TRU	Transuranic
TS	Total solids
TSD	Treatment, storage, and disposal
TSS	Total suspended solids
TSS50	Total suspended solids <50 µm
TSS100	Total suspended solids <100 µm
TTCTF	Tanks Technology Cold Test Facility
UHPP	Ultra-high-pressure pump
UM-R	University of Missouri at Rolla
UST	Underground storage tank
Vac	Volts alternating current
VPM	Vertical Positioning Mast
WAC	Waste acceptance criteria
WaRTS	Waste Retrieval and Transfer System
WCS	Waste-Conditioning System
WD&CS	Waste Dislodging and Conveyance System
WHC	Westinghouse Hanford Corporation
WIPP	Waste Isolation Pilot Plant
WSCS	Waste Stream Consolidation System
WTI	Waterjet Technologies Inc.
WTP	Waste transfer pump

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Cleanup of the Gunite and Associated Tanks (GAATs) at Oak Ridge National Laboratory (ORNL) has involved a diverse group of dedicated and talented individuals. Many of these individuals have been recognized during the initial phases of the cleanup operations, in which the majority of the GAAT waste was removed. The focus of the GAAT Remediation Project has been the retrieval and transfer of the residual wastes from the tanks in preparation for final closure. The individuals acknowledged below had a significant role in the success of this project. Various members of the GAAT Remediation Project Team have also assisted in the preparation of this report.

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ABSTRACT

The Gunite and Associated Tanks (GAAT) Remediation Project was the first of its kind performed in the United States. Robotics and remotely operated equipment were used to successfully transfer almost 94,000 gal of remote-handled transuranic sludge containing over 81,000 Ci of radioactive contamination from nine large underground storage tanks at the Oak Ridge National Laboratory (ORNL). The sludge was transferred with over 439,000 gal of radioactive waste supernatant and ~420,500 gal of fresh water that was used in sluicing operations. The GAATs are located in a high-traffic area of ORNL near a main thoroughfare.

A phased and integrated approach to waste retrieval operations was used for the GAAT Remediation Project. The project promoted safety by obtaining experience from low-risk operations in the North Tank Farm before moving to higher-risk operations in the South Tank Farm. This approach allowed project personnel to become familiar with the tanks and waste, as well as the equipment, processes, procedures, and operations required to perform successful waste retrieval. By using an integrated approach to tank waste retrieval and tank waste management, the project was completed years ahead of the original baseline schedule, which resulted in avoiding millions of dollars in associated costs.

This report is organized in two volumes. Volume 1 provides information on the various phases of the GAAT Remediation Project. It also describes the different types of equipment and how they were used. The emphasis of Volume 1 is on the description of the tank waste retrieval performance and the lessons learned during the GAAT Remediation Project. Volume 2 provides the appendixes for the report, which include the following information:

A—Background Information for the Gunite and Associated Tanks Operable Unit
B—Annotated Bibliography
C—Comprehensive Listing of the Sample Analysis Data from the GAAT Remediation Project
D—GAAT Equipment Matrix
E—Vendor List for the GAAT Remediation Project

The remediation of the GAATs was completed ~5.5 years ahead of schedule and ~$120,435,000 below the cost estimated in the Remedial Investigation/Feasibility Study for the project. These schedule and cost savings were a direct result of the selection and use of state-of-the-art technologies and the dedication and drive of the engineers, technicians, managers, craft workers, and support personnel that made up the GAAT Remediation Project Team.

1. INTRODUCTION

The Gunite and Associated Tanks (GAAT) Remediation Project was the first of its kind performed in the United States. Robotics and remotely operated equipment were used to successfully transfer almost 94,000 gal of remote-handled transuranic sludge containing over 81,000 Ci of radioactive contamination from nine large underground storage tanks (USTs) at the Oak Ridge National Laboratory (ORNL). The sludge was transferred with over 439,000 gal of radioactive waste supernatant and ~420,500 gal of fresh water that was used in sluicing operations. The GAATs are located in a high-traffic area of ORNL. Figure 1-1 shows the waste retrieval equipment positioned in the South Tank Farm (STF), which is located south of Central Avenue, the main thoroughfare through ORNL. Some of the waste retrieval equipment is shown installed on platforms constructed over the tanks, near the center of the photograph. The control room for the equipment was located in a temporary building shown to the right and slightly behind tank W-6.

Fig. 1-1. Overview of the South Tank Farm during waste retrieval operations in tank W-6 (middle of photograph) in 1998.

A phased and integrated approach to waste retrieval operations was used for the GAAT Remediation Project. The project promoted safety by obtaining experience from low-risk operations before moving to higher-risk operations. This approach allowed project personnel to become familiar with the tanks and waste, as well as the equipment, processes, procedures, and operations required to perform successful waste retrieval. By using an integrated approach to tank waste retrieval and tank waste management, the project was completed years ahead of the original baseline schedule, which resulted in avoiding millions of dollars in associated costs.

This document provides background information on the various phases of the GAAT Remediation Project. It also describes the different types of equipment and how they were used to retrieve the wastes from the tanks. The primary emphasis of this document is on the tank waste retrieval performance and the lessons learned during the GAAT Remediation Project. The remainder of this section provides background information on the tanks, including their construction, location, and physical characteristics. It also briefly discusses how they were used during their years of service and the initial bulk sludge removal operations conducted during the 1980s.

1.1 BACKGROUND

ORNL is located ~25 miles northwest of Knoxville, Tennessee, on the Oak Ridge Reservation, which is managed by the U.S. Department of Energy (DOE). ORNL was established in 1943 and served as a model for plutonium production facilities constructed during the Manhattan Project of World War II. Since its establishment, ORNL has provided major leadership and scientific contributions in nuclear research and development. Radioactive waste is a by-product of this research, and waste management has been and continues to be a primary concern.

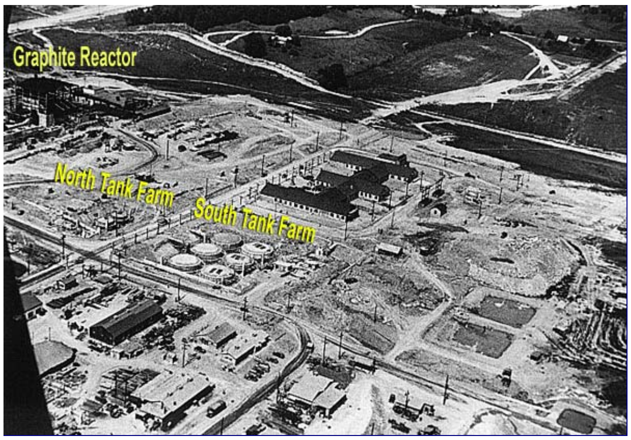

Fig. 1-2. Aerial photo of central ORNL in 1943, showing construction of the initial eight gunite tanks in the North and South Tank Farms.

Fig. 1-3. Construction of the ORNL South Tank Farm in 1943, showing workers spraying gunite on the dome of tank W-6, which is located in the southwest corner of the South Tank Farm.

During the construction of ORNL, a liquid low-level waste (LLLW) system was built to manage liquid radioactive and chemical wastes. This system included underground pipelines, which were used to transfer waste from research facilities into USTs that stored liquid waste. Several USTs were constructed in the North and South Tank Farms (Fig. 1-2) as part of the ORNL LLLW system. These tanks later became part of the GAAT Operable Unit (OU). The GAAT OU was an important part of ORNL's waste management system. These tanks received and stored liquid wastes from a variety of research and development programs.

1.1.1 Tank Construction and Physical Characteristics

The tanks in the GAAT OU were constructed between 1943 and 1951 and were designed to store liquid radioactive chemical wastes generated by ORNL operations. A total of 12 gunite tanks and 4 stainless steel tanks were constructed, primarily in two main tank farms known as the North and South Tank Farms.

All of the gunite tanks were constructed of gunite, a mixture of portland cement, sand, and water, which was sprayed over a wire mesh and steel reinforcing rod frames as shown in Fig. 1-3. The tank walls were composed of three distinct layers consisting of an outer gunite wall over a steel reinforcing rod frame, a layer of tar-based mastic, and an inner layer of gunite over wire mesh (Fig. 1-4). The tank construction sites were excavated down to bedrock. The gunite tanks were constructed on concrete pads up to 50 ft in diameter with raised lips (Fig. 1-5). After the frames were set up over the concrete pad, the tank walls were constructed and construction of the tank domes followed. Each tank has an associated dry box connected to its footer that drains the base of the tank. The dry boxes were used for leak detection. All tank domes were covered with ~5 to 6 ft of soil and seeded with grass to prevent erosion.

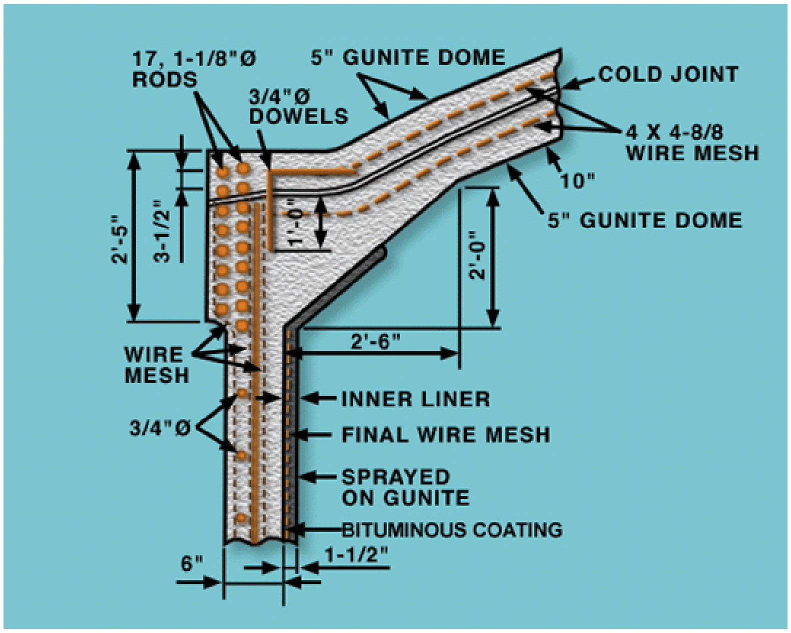

Fig. 1-4. Schematic of the cross section of a typical gunite tank wall and dome junction.

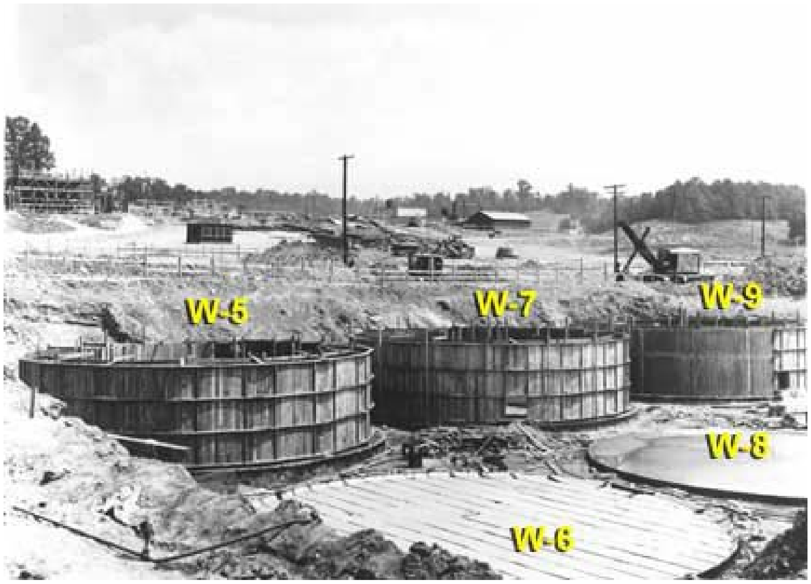

Fig. 1-5. Photo of the 50-ft-diam tanks in various stages of construction in the South Tank Farm, ca. 1943.

The GAAT OU tanks range in capacity from 1500 to 170,000 gal and were constructed of various materials as shown in Table 1-1.

Table 1-1. Physical characteristics of the tanks located in the GAAT OU

Tank number	Construction material	Orientation	Inside tank diameter (ft)	Sidewall length/ height (ft)	Dome height (ft)	Nominal capacity (gal)	Notes
W-11	Gunite	Vertical	8.0	4.6	1.0	1,500	Maximum 6 ft of soil cover
TH-4	Gunite	Vertical	20.0	6.5	2.6	14,000	Maximum 6 ft of soil cover
North Tank Farm Tanks							
W-1 and W-2	Gunite	Vertical	12.0	8.0	1.6	4,800	Maximum 5 ft of soil cover
W-3 and W-4	Gunite	Vertical	25.0	12.0	2.6	42,500	Maximum 6 ft of soil cover
W-1a	347SCb SS[a]	Horizontal	7.5	13.5	N/A[b]	4,000	Maximum 5 ft of soil cover
W-13 and W-14	347SCb SS	Horizontal	6.0	11.0	N/A	2,000	Encased in concrete box
W-15	347SCb SS	Horizontal	8.0	6.0	N/A	2,000	Encased in concrete box
South Tank Farm Tanks							
W-5 thru W-10	Gunite	Vertical	50.0	12.0	6.0	170,000	Maximum 6 ft of soil cover

[a]SS = stainless steel.
[b]N/A = not applicable.

1.1.2 Location of the Tanks in the GAAT OU

The GAAT OU includes eight tanks in the North Tank Farm (NTF), six tanks in the STF, and tanks W-11 and TH-4. Each area was roped off and posted as a restricted-access area prior to and during remediation. Figure 1-6 shows the location of the tanks included in the GAAT OU. The tank farms are located near the ORNL cafeteria, on the north and south sides of ORNL's Central Avenue, which serves as the main east-west thoroughfare for ORNL (Fig. 1-7).

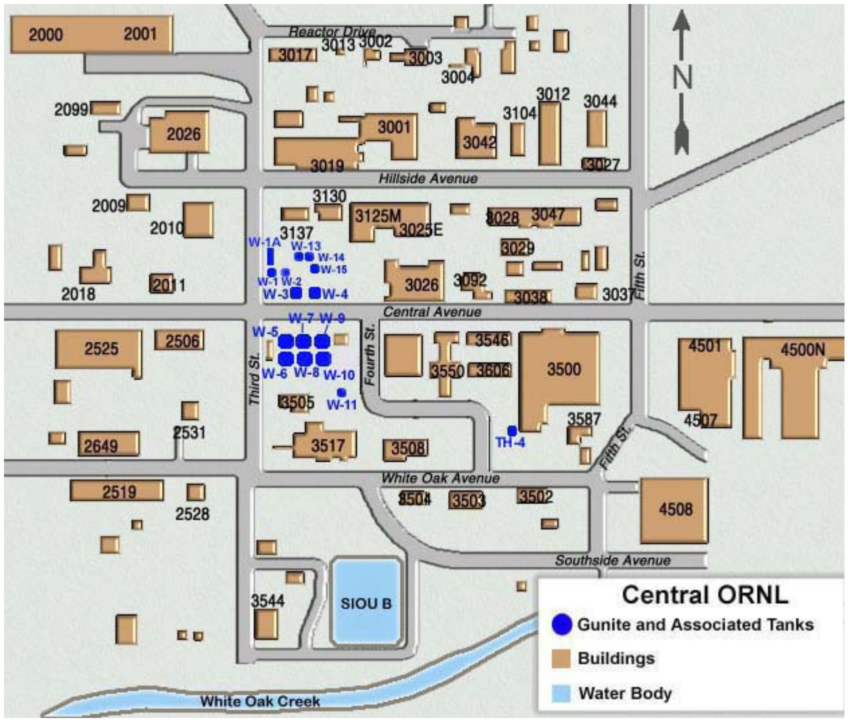

Fig. 1-6. Diagram of the 16 tanks in the GAAT OU.

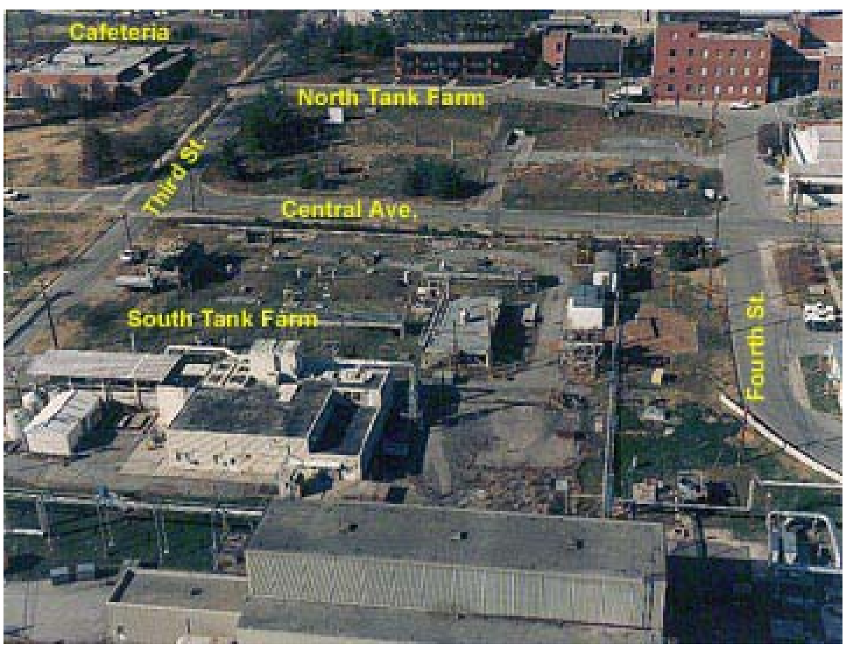

Fig. 1-7. Aerial photo taken in 1943, showing the locations of the North and South Tank Farms at ORNL relative to the ORNL cafeteria.

The NTF measures 150 by 180 ft and is located on the northeast corner of Central Avenue and Third Street, across from the ORNL cafeteria. The NTF contains four gunite tanks (W-1 through W-4) and four stainless steel tanks (W-1A, W-13, W-14, and W-15).

The STF is located south of the NTF across Central Avenue. It is bordered by Fourth Street to the east, Third Street to the west, and the Metal Recovery Facility (Building 3505) to the south. The STF contains the six largest gunite tanks (W-5 through W-10) included in the GAAT OU. Tank W-11 is a gunite tank located southeast of the STF, and tank TH-4 is a gunite tank located adjacent to the southwest corner of Building 3500, ~440 ft east of the STF.

1.1.3 Tank Usage and Years of Service

The gunite tanks were originally constructed to store all the radioactive liquid wastes generated by ORNL operations for a period of 1 year. The period of operations was extended to 3 years as the Graphite Reactor, which is located north of the tank farms (Fig. 1-7), began operation. Due to the expanding research scope of the laboratory, the gunite tanks in the STF served as the primary LLLW waste management storage facility for ORNL into the 1970s.

Historically, the gunite tanks in the GAAT OU served as LLLW holding tanks so that short-lived radionuclides could decay before the LLLW was transferred to downstream treatment operations. Three tanks on the north side of the STF (W-5, W-7, and W-9) received LLLW streams and overflowed to the corresponding tanks on the south side of the STF (W-6, W-8, and W-10, respectively). The original underground piping that served as the STF LLLW transfer system was modified many times, so that eventually waste in any tank could be transferred to any other tank. Tanks W-5 and W-6 were used for the collection and precipitation of LLLW streams. Some of these waste streams were acidic wastes from fuel reprocessing operations. These wastes were typically neutralized before they were transferred into the gunite tanks. Tanks W-7, W-8, W-9, and W-10 were used for the collection and treatment (precipitation) of the metal-bearing waste streams. The Metal Recovery Facility was located south of the STF and performed operations to recover metals from the waste streams. Through the years, precipitants from the waste treatment processes settled out of the LLLW, forming a thick layer of sludge on the bottom of the tanks.

Improvements to ORNL's waste management system eliminated the need for some tanks. In the late 1950s, or early 1960s, four of the gunite tanks (W-1, W-2, W-3, and W-4) and three of the stainless steel tanks (W-13, W-14, and W-15) were removed from service in the NTF but continued to store waste supernatant and sludge. The largest gunite tanks in the STF were removed from active service in the 1970s but continued to store legacy radioactive liquid and sludge waste.[1]

The Remedial Investigation/ Baseline Risk Assessment for the tanks in the GAAT OU provides an excellent historical review of their use at ORNL.[2] Excerpts from this historical review are provided in Appendix A (Vol. 2). All waste retrieval activities associated with the GAAT OU were performed over an 18-year period beginning in 1982. Throughout this period a variety of reports and supporting documentation have been written describing the GAAT OU and the efforts to remediate these tanks. An

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[1] J. H. Coobs and T. Myrick, *The ORNL Surplus Facilities Management Program, Maintenance and Surveillance Plan for Fiscal Year 1984*, ORNL/TM-10268, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1986.

[2] Jacobs Environmental Restoration Team, *Remedial Investigation/Baseline Risk Assessment for the Gunite and Associated Tanks Operable Unit at Waste Area Grouping 1 at Oak Ridge National Laboratory, Oak Ridge, Tennessee*, DOE/OR/02-1275&D1, Jacobs Engineering Group, Inc., Oak Ridge, Tennessee, May 1994.

annotated bibliography of the published documents about the tanks included in the GAAT OU is provided in Appendix B (Vol. 2).

1.1.4 Bulk Sludge Removal Operations

Bulk sludge removal operations were performed in the early 1980s in the six largest gunite tanks located in the STF (tanks W-5, W-6, W-7, W-8, W-9, and W-10). These operations removed about 90% of the sludge present in these tanks. The waste was retrieved during 18 months of sluicing operations from August 1982 through January 1984.[3] These waste retrieval operations used single-point sluicing (Fig. 1-8) to break up and mobilize the sludge present in the tanks.

Fig. 1-8. Single point sluicing cold test at ORNL prior to bulk sludge removal in the early 1980s.

A 2.5% bentonite clay suspension in water was prepared in tank W-10 and used as the sluicing and suspension agent. The single-point sluicing technique used a remotely controlled, articulated fire-hose-type nozzle positioned near the top of each tank to break apart the sludge layers in the tanks. The jet stream from the nozzle impinged on the sludge and resuspended the sludge particles. The suspended bentonite clay in the sluicing water held the sludge particles in suspension while the slurry was continuously pumped from the tank, through a grinder, and back into the tank. The grinder was used to break up any oversized particles. This operation continued until the solids concentration approached about 15 to 20% by weight (wt %).[3] At this point, sluicing was stopped and the resulting waste slurry was transferred through underground piping to the Melton Valley Storage Tanks (MVSTs). This process was repeated until most of the sludge was removed from the tanks. At the end of the sluicing operations in 1984, an estimated 2,195,400 lb of sludge was removed from the STF tanks and transferred to the MVSTs.[3]

The gunite tanks in the STF were visually inspected with a remote video camera following the 1980s bulk sludge removal operations. A quantity of residual radioactive sludge, debris, and abandoned sluicing equipment remained in the tanks, as shown in Fig. 1-9. Some of the tanks continued to fill with groundwater because of in-leakage through the domes of the tanks. The visual inspections of the tank interiors showed varying degrees of deterioration approaching the point that the structural integrity of the tanks could not be guaranteed (Fig. 1-10).

[3] H. O. Weeren, *Sluicing Operations at Gunite Waste Storage Tanks*, ORNL/NFW 84/42, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, Oak Ridge, Tennessee, September 1984.

Fig. 1-9. Interior view of tank W-5 after bulk sludge removal operations in 1984, showing residual radioactive sludge and other debris.

Fig. 1-10. Interior view of tank W-5, showing deterioration and exposure of the underlayers of wire mesh in some areas.

The Federal Facilities Agreement (FFA), between DOE, the Environmental Protection Agency (EPA), and the Tennessee Department of Environment and Conservation (TDEC), regulates the environmental cleanup of ORNL, including the remediation of tanks in the GAAT OU. The GAAT OU was identified as a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site when the FFA became effective on January 1, 1992. A high priority was placed on the remediation of the GAAT OU, and the associated activities and operations required for the remediation of these tanks were carried out in compliance with CERCLA and the FFA.

2. STEPS TO SUCCESSFUL WASTE RETRIEVAL—OVERVIEW OF INVESTIGATIONS, STUDIES, RETRIEVAL OPERATIONS, AND TANK STABILIZATIONS

This section identifies the major steps taken by the GAAT Remediation Project team to successfully retrieve the residual sludge and debris from the gunite tanks. It also provides an overview of the events that occurred over the course of ~10 years, which resulted in the successful remediation and stabilization of the tanks in the GAAT OU.

2.1 CERCLA REMEDIAL INVESTIGATION/BASELINE RISK ASSESSMENT

A CERCLA Remedial Investigation/Baseline Risk Assessment (RI/BRA) was conducted through early 1994 to consider potential remedial approaches and to conduct additional tank and waste characterization activities to determine the risks associated with the condition of the tanks in the GAAT OU.[2] The tank and waste characterization activities revealed uncertainties about the residual waste in the tanks and the structural integrity of the tanks.

Several potential remedial alternatives were evaluated during the RI/BRA, and the risks of implementing each of the alternatives were estimated. The alternatives included the following:

- no action with institutional controls;
- tank structural stabilization with no sludge treatment;
- in situ sludge fixation in each tank;
- sludge removal with in situ fixation in a consolidation tank;
- sludge removal with ex situ treatment and storage at Oak Ridge;
- sludge removal with treatment and disposal as part of the DOE Transuranic Waste Program; and
- sludge, tank shells, and solid removal for treatment and storage at Oak Ridge.

Various tank inspections were performed to assess the condition of the tank interiors. Samples were collected from the tanks and analyzed to determine their chemical, radiological, and physical nature. Figure 2-1 is an example of a crystalline sludge sample that was collected from tank W-6. Other sludge samples revealed debris, such as chunks of gunite and other material, which made the waste difficult to retrieve. The RI/BRA indicated significant uncertainties about the effectiveness and cost of potential remedial alternatives. There were also uncertainties with the risks associated with the retrieval of the wastes contained in the gunite tanks.

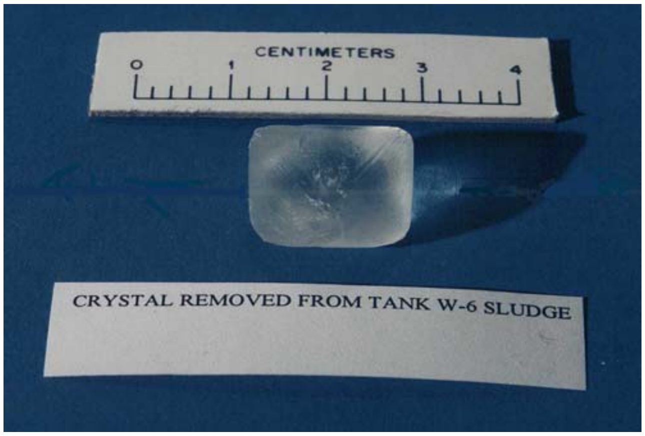

Fig. 2-1. Crystalline sludge sample from tank W-6.

To resolve these uncertainties, DOE, the EPA, and the TDEC agreed to perform additional sampling and characterization activities that would be published as an addendum to the RI/BRA.[4] They also agreed to conduct a CERCLA Feasibility Study[5] to assess the feasibility of the remedial alternatives and to develop a Proposed Plan that would meet the risk criteria identified in the RI/BRA Addendum.

Results from additional sampling activities and visual inspections indicated that ~88,000 gal of difficult-to-retrieve radioactive sludge remained in tanks W-3, W-4, W-5, W-6, W-7, W-8, W-9, W-10, and TH-4. The push tube sample shown in Fig. 2-2 was taken from tank W-7 in 1994 and indicated that this tank contained about 6 in. of sludge, covered by ~3 in. of LLLW. Additional sampling and calculations conducted later during waste retrieval and transfer operations revealed that the actual amount of sludge retrieved and transferred from these tanks was over 94,000 gal.

Fig. 2-2. Push tube sample taken from tank W-7 in 1994.

Waste characterization results and risk calculations indicated that the tank contents presented potential off-site and on-site risks to personnel and the environment. The RI/BRA documented that at least 90% of the remaining sludge waste and contamination should be removed to reduce the CERCLA risk probability of developing cancer during a lifetime to 10^{-4}, or 1 of 10,000 individuals. The results of the risk evaluation revealed that the risks varied significantly from tank to tank.

The tanks in the GAAT OU were grouped according to risk based on the size, condition, and levels of radioactivity contained in the tanks (Table 2-1). The Group 1 tanks had the lowest risk based on their waste characterization data. Most of the tanks in Group 1 were located in the NTF. These tanks were also the smallest and showed no signs of interior deterioration. Tanks W-5 through W-10, the six 50-ft-diam tanks located in the STF, were placed in Group 3. These tanks were the most contaminated and had the largest waste volumes, and some of the tanks showed signs of interior deterioration. Tanks W-3 and W-4, in the NTF, and TH-4, located east of the STF, showed less signs of contamination but still contained sludge waste. These tanks were placed in Group 2.

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[4] *Addendum to the Remedial Investigation/Baseline Risk Assessment for the Gunite and Associated Tanks Operable Unit at Waste Area Grouping 1 at the Oak Ridge National Laboratory, Oak Ridge, Tennessee,* DOE/OR/02-1275&D2/A1, Prepared by Jacobs ER Team and Lockheed Martin Energy Systems, Inc., Oak Ridge, Tennessee, March 1996.

[5] Jacobs Environmental Restoration Team*, Feasibility Study/Proposed Plan for Sludge Removal from the Gunite and Associated Tanks Operable Unit, Waste Area Grouping 1, Oak Ridge National Laboratory, Oak Ridge, Tennessee*, DOE/OR/02-1509/V1&D2, Jacobs Engineering Group, Inc., Oak Ridge, Tennessee, May 1996.

Table 2-1. Tank risk groups based on total activity, size, and interior condition of the tanks

Group and tank number[a]	Sludge radioactivity (Ci)	Supernatant radioactivity (Ci)
Group 1 – Smaller gunite and steel tanks with no sign of deterioration		
W-1, W-1A, W-2, W-11, W-13, W-14, W-15		
Group 2 – Midsize gunite tanks with no sign of deterioration	**1,258**	**14**
W-3	16	1
W-4	324	13
TH-4	918	0
Group 3 – Larger gunite tanks – Some show signs of deterioration of the interior walls	**61,947**	**4,012**
W-5	34	10
W-6	1,383	364
W-7	3,849	238
W-8	4,386	2,065
W-9	3,055	212
W-10	49,240	1,123

[a] Levels of contamination indicated in this table are based on initial waste characterization data. Later waste and tank characterization conducted during waste retrieval operations indicated contamination levels that varied from the original data used to develop the risk groups.

The GAAT Feasibility Study/Proposed Plan[6] began to focus on waste retrieval operations for the gunite tanks containing significant levels of radioactivity and quantities of waste or those showing significant deterioration. The Feasibility Study indicated significant uncertainties about the effectiveness and cost of potential remedial alternatives. There were also uncertainties with the risks associated with the retrieval of the wastes contained in the gunite tanks. To resolve these uncertainties, DOE, the EPA, and the TDEC agreed to perform a CERCLA Treatability Study. The Treatability Study was performed in two phases. Phase 1 was conducted to select, develop, and cold test remotely operated waste retrieval equipment that could retrieve the residual sludge heels in the largest gunite tanks. The second phase of the Treatability Study was conducted to prove the viability of the integrated waste retrieval systems during operations in a radioactive environment. Because of the lower contamination levels of the wastes remaining in tanks W-3 and W-4, these tanks were selected for hot testing the GAAT waste retrieval systems. The hot tests helped to determine the extent to which the tanks could be cleaned and the cost and schedule for cleanup operations in the STF. Sections 3 through 9 provide more information about the equipment that was tested and the operations performed during the Treatability Study.

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[6] U. S. Department of Energy, *Feasibility Study/Proposed Plan for Sludge Removal from the Gunite and Associated Tanks Operable Unit, Waste Area Grouping 1, Oak Ridge National Laboratory, Oak Ridge, Tennessee*, DOE/OR/02-1509/V2&D2, Oak Ridge, Tennessee, 1997.

2.2 STEPS TO SUCCESSFUL WASTE RETRIEVAL OPERATIONS IN THE GAAT OU

The major steps described in this section were required to achieve the goal of retrieving >90% of the residual waste in the gunite tanks. Planning and performing these steps formed the basis of operations during the GAAT Treatability Study and are typical of successful tank waste retrieval processes.

2.2.1 Step 1—Tank Inspections, Waste Sampling, and Characterization

This first step was necessary to assess the volume and characteristics of the residual wastes contained in the tanks. Tank waste sampling and analysis helped determine the waste's radiological and physical characteristics. Waste-sampling operations were performed in all of the tanks in the GAAT OU. Figure 2-3 shows workers collecting a waste sample from tank W-7 using a clamshell-type sampling device. The information obtained from the analysis of the samples was important in determining the risks and in selecting waste retrieval equipment. Remote video inspections of the tank interiors helped determine the internal condition of the tanks and verified the volume and location of the waste in the tanks. Tank and waste sampling continued even after the waste retrieval equipment was selected and deployed, so that waste retrieval performance could be determined and safe waste transfers could be made. Specialized tools and technologies allowed the project team to sample and characterize the waste and the tank interior walls to ensure that cleanup goals were met.

Fig. 2-3. Waste-sampling operations in tank W-7 during the 1995 characterization effort.

2.2.2 Step 2—Selection and Testing of Waste Retrieval Equipment

This step was important to successful waste retrieval because of the deteriorating conditions inside some of the tanks and the physical characteristics of the remaining sludge heels. New and off-the-shelf technologies were researched, selected, and tested. Figure 2-4 is a photograph of the Houdini I Remotely Operated Vehicle (ROV) holding the Confined Sluicing End-Effector (CSEE) while the Modified Light-Duty Utility Arm (MLDUA) maneuvers overhead at ORNL's Tanks Technology Cold Test Facility (TTCTF). During this step a variety of waste retrieval tools and technologies were integrated into a robotic and remotely operated system that addressed the unique waste characteristics and conditions found in the tanks. Procedures for equipment mobilization, operations, and maintenance were developed for the integrated waste retrieval system.

Fig. 2-4. Houdini I ROV manipulating the CSEE, with the MLDUA positioned overhead at ORNL's TTCTF.

2.2.3 Step 3—Tank and Tank Farm Modifications

This step prepared the tanks and the tank farms for waste retrieval operations. Modular facilities for equipment controls, frisking stations, personnel offices, and a break room were added to the tank farms. Modifications were made to provide stable foundations and platforms for the waste retrieval equipment. Additional utilities and contamination control features were installed to support waste retrieval operations. The tank domes were modified to add tank risers that would provide access for the waste retrieval equipment. Figure 2-5 shows workers installing additional tank access risers in Tank W-4 (bottom left) to allow deployment of the waste retrieval equipment in the tanks. The dome of Tank W-3 (top right) is also exposed for the installation of additional tank risers.

Fig. 2-5. Photograph of workers installing an additional tank access riser in tank W-4 (bottom left) and standing on the dome of tank W-3 (top right).

2.2.4 Step 4—Sludge Heel Retrieval and Wall Cleaning

During this step, excess liquid waste was transferred from the tank to permit efficient sludge retrieval. The residual sludge was removed with remotely operated and robotic waste retrieval equipment, which was installed on an equipment platform positioned over the tanks. The interior tank walls were cleaned by water scarifying techniques to ensure that sufficient wall contamination was removed to satisfy tank waste retrieval goals.

2.2.5 Step 5—Waste Mixing

This step ensured that the sludge and liquid wastes were properly mixed prior to transfer. The contents of the waste consolidation tank (W-9) were mixed to keep the retrieved sludge from resettling on the bottom of the tank.

2.2.6 Step 6—Waste Conditioning and Transfer

This step prepared the waste for safe transfer. The characteristics and quality of the waste slurry were monitored, and the necessary transfer operations were performed to successfully convey the waste to its designated storage facility.

2.3 OVERVIEW OF GAAT RESIDUAL WASTE RETRIEVAL AND TANK STABILIZATION

Residual waste retrieval operations and tank stabilizations were planned and performed in various stages to optimize the remediation schedule. Operations were approached in a phased manner, with each phase focusing on tanks with similar risks requiring similar operations. An overview of the various stages of tank remediation and stabilization activities is presented in the following sections.

2.3.1 Waste Removal and Stabilization of the Risk Group 1 Tanks

According to the risk analysis performed during the RI/BRA and the Feasibility Study, the tanks in Risk Group 1 were considered low risk based on their size, waste volume, and estimated levels of radioactivity. As a result of these findings, the ORNL Inactive Tanks Program first performed waste retrieval and stabilization operations in the Risk Group 1 tanks. The three stainless steel tanks (W-13, W-14, and W-15) in the NTF were stabilized in place in fiscal year (FY) 1998 by filling them with grout. There were no waste retrieval operations performed in tanks W-13, W-14, and W-15. The smaller gunite tanks (W-1 and W-2) in the NTF and tank W-11 (located southeast of the STF) were stabilized in 2000. Waste retrieval operations were performed in these three tanks and over 750 gal of sludge was retrieved using a single-point, high-pressure sluicing method (Fig. 2-6).

Fig. 2-6. Remediation and stabilization of tanks W-1 and W-2 during a separate project conducted by the ORNL Inactive Tanks Program.

Tank W-1A, a stainless steel tank located in the NTF, is associated with an underground plume source known as the Corehole 8. This tank is being remediated under a separate Remedial Action.

2.3.2 North Tank Farm Treatability Study and Waste Retrieval Operations

The CERCLA Treatability Study for the higher-risk gunite tanks in the GAAT OU began in 1996 and ended in 1998. The Treatability Study was initiated to develop and test waste retrieval equipment that could be used for residual waste retrieval operations in the larger gunite tanks. Systems integration and cold testing operations were conducted at the ORNL TTCTF and were completed in May 1997. These tests allowed operators time to become familiar with the waste retrieval equipment; develop operating procedures, strategies, and maintenance schedules; and integrate the waste retrieval equipment into a system that could effectively remove the difficult-to-retrieve sludge heels from the large 42,500- and 170,000-gal tanks located in the North and South Tank Farms.

The hot demonstration of the integrated tank waste retrieval equipment was performed in parallel with waste retrieval operations in the lower-risk 25-ft-diam tanks (W-3 and W-4) beginning in June 1997. The combined hot demonstration and waste retrieval operations in these tanks was completed in 1998, with the waste being transferred to the waste consolidation tank (W-9) in the STF.[7] Results of the treatability

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[7] V. A. Rule, B. L. Burks, and S. D. Van Hoesen, *North Tank Farm Data Report for the Gunite™ and Associated Tanks at Oak Ridge National Laboratory Oak Ridge, Tennessee*, ORNL/TM-13630, Lockheed Martin Energy Research Corp., Oak Ridge National Laboratory, Oak Ridge, Tennessee, May 1998.

study hot demonstration showed that the tank waste retrieval equipment could successfully remove more than the required 90% of the remaining tank waste, a requirement based on the tank risk calculations in the RI/BRA. Figure 2-7 is a photograph of the waste retrieval operations in tank W-3 during the hot demonstration of the MLDUA, CSEE, and Hose Management Arm (HMA). The MLDUA is shown manipulating and guiding the CSEE during sludge-mining operations. The HMA helps guide and support the waste transfer hose that is connected to the end-effector. Waste retrieval operations in the NTF tanks are discussed in more detail in Sect. 9.

Fig. 2-7. Photograph of the waste retrieval operations in tank W-3.

2.3.3 South Tank Farm Waste Retrieval and Transfer Operations

The GAAT Remediation Project Interim Record of Decision,[4] published at the end of the Treatability Study, designated that waste retrieval operations were to be performed in the STF tanks as a CERCLA Remedial Action. These operations were performed from March 1998 through September 2000. The conditions in each tank were unique; therefore, the project team optimized waste retrieval operations by deploying specialized tools and equipment to maximize the amount of waste retrieved from each tank.

Tank W-8 served as a consolidation tank for retrieved LLLW, which was used for sludge waste mixing and dilution during some waste retrieval operations. The sludge wastes from tanks W-5, W-6, W-7, W-8, and W-10 were consolidated into tank W-9 to await batch waste transfers to the MVSTs.

Pulsed-air mixers and a Waste-Conditioning System (WCS) circulated the retrieved waste slurry in tank W-9. The conditioning system provided real-time monitoring of the total suspended solids (TSS) content and particle size in the retrieved waste slurry. The TSS content was required to be less than 5 wt % and the particle size was required to be less than 100 μm before the waste could be transferred to the MVSTs. Waste slurry meeting these criteria was transferred in batches through a 2-in.-diam underground, double-contained waste transfer line that is about 1 mile long. The waste acceptance criteria (WAC) for the transfer line to the MVSTs allowed higher TSS content waste to be transferred if data showed that settling would not be a problem during the transfer operation. However, a decision was made to establish conservative transfer criteria for the GAAT waste to avoid plugging the transfer line. Batch transfers were made to the MVSTs from tank W-9, as the waste retrieval operations were performed in the other gunite tanks, to ensure that tank W-9 would not be overfilled.

Once waste retrieval operations were completed in tanks W-5, W-6, W-7, W-8, and W-10, the consolidated sludge in tank W-9 was retrieved and transferred to tank W-23, one of the Bethel Valley Evaporator Service Tanks (BVESTs). Tank W-23 served as the batch tank for the waste retrieved from tank W-9 before it was transferred to the MVSTs.

2.3.4 Tank TH-4 Waste Retrieval and Stabilization

Waste retrieval from tank TH-4 was completed in early 2001. Operations in this tank were conducted separately from the STF operations. A Russian-fabricated Pulsating Mixer Pump (PMP) was used to mobilize the sludge waste. During the preparation for waste retrieval operations in tank TH-4 in October 2000, the PMP Tank Riser Interface Containment (TRIC) structure was positioned on top of the equipment platform at the TH-4 remediation site (Fig. 2-8). A diaphragm pump transferred the waste slurry out of the tank. The slurry was pumped through the WCS in the STF and then on to BVEST W-23. Tank W-23 served as the batch tank for all waste retrieved from tank W-9 before waste slurry transfers were made to the MVSTs. In April 2001, after waste retrieval and equipment demobilization activities were completed, the ORNL Inactive Tanks Program stabilized tank TH-4 in-place by filling it with a low-strength grout as part of a separate project.

Fig. 2-8. Russian PMP installed at tank TH-4.

2.3.5 Stabilization of Tanks W-3 through W-10

After stabilizing tank TH-4, the remaining gunite tanks (W-3 through W-10) were stabilized in place, by filling them with a low-strength grout (Fig. 2-9), as part of a separate CERCLA Removal Action. The ORNL Inactive Tanks Program began stabilization activities in July 2001 and completed them in September 2001.

Fig. 2-9. Beginning of tank stabilization operations in the STF.

3. TREATABILITY STUDY PHASE 1—WASTE RETRIEVAL EQUIPMENT SELECTION, DESIGN, INTEGRATION, AND TESTING

Waste characterization and risk assessment evaluations performed during the GAAT RI/BRA and the Feasibility Study indicated that it would be necessary to remove at least 90% of the residual waste from the gunite tanks to meet the CERCLA risk criteria. During the GAAT treatability study, supplemental tank characterization, investigations, and risk assessments of remedial technologies were performed. These efforts were undertaken in parallel to evaluate the extent to which the tanks could be cleaned and the cost and schedule for potential cleanup options. The GAAT treatability study helped establish the relationship between the residual tank waste and the CERCLA cleanup requirements so that the implications of incomplete waste removal could be determined. This section discusses the first phase of the treatability study, which focused on equipment selection, design, testing, modification, and integration to optimize the performance of the various systems that would be required for residual waste retrieval from the gunite tanks. Appendix C (Vol. 2) includes a summary table of information on the various components and systems used during the GAAT Remediation Project. The information in Appendix C (Vol. 2) includes the system attributes; the applicable waste form(s) that the equipment can address; information on maintenance requirements and reliability; operability information (i.e., minimum riser size for access, liquid volumes used, tank dome loads, production rates, infrastructure needs, etc.); environmental considerations (i.e., secondary waste considerations, permit requirements, regulatory acceptance, etc.); public/worker health and safety considerations; and the estimated life-cycle costs.

3.1 TREATABILITY STUDY: PHASE 1 OBJECTIVES

The major goals of the first phase of the GAAT treatability study were to

- define the functions and requirements of waste retrieval and transfer systems;
- test the capabilities of several advanced technologies to retrieve and treat the gunite tank waste (Fig. 3-1);
- integrate the technologies and equipment to optimize the retrieval of the sludge heels remaining in the tanks;
- develop and test operating procedures and maintenance schedules for the waste retrieval and transfer system; and
- modify the tanks and tank farms so that the waste retrieval operations could be performed.

The main requirements for the integrated waste retrieval system were as follows:

- deploy through 24-in.-diam tank access risers;
- allow equipment operators to visually monitor the in-tank operations;
- perform additional tank and waste characterization activities;
- dislodge and retrieve the thick sludge heels and debris;
- clean the tank walls;
- convey waste out of the tanks;
- keep retrieved sludge from resettling before final waste transfer to the MVSTs; and
- provide remote capability for equipment controls and process instrumentation.

3.2 OVERVIEW OF COLD TESTS

Phase 1 of the GAAT Treatability Study provided an opportunity to research and cold test the capabilities of several technologies to retrieve a simulated waste having physical characteristics similar to the waste sampled in the gunite tanks. ORNL and Pacific Northwest National Laboratory (PNNL) led the effort to cold test a variety of waste retrieval technologies. Figure 3-1 shows the CSEE during testing with surrogate waste slurry in the TTCTF.

Fig. 3-1. CSEE during tests with a surrogate waste slurry in the ORNL TTCTF.

Several new and off-the-shelf technologies with specialized capabilities were compared during cold testing. The technologies were developed or modified to meet the requirements of waste retrieval operations in the larger gunite tanks. Most of the waste retrieval and support equipment used during the GAAT Remediation Project was a special design or was used in a unique way. The equipment and technologies selected during the initial assessments and cold tests were integrated into the robotic and remotely operated Radioactive Tank Cleaning System (RTCS) (Fig. 3-2). The RTCS consisted of various subsystems that performed specific functions. These subsystems included

Fig. 3-2. Main components of the RTCS during tests with a surrogate waste slurry at the ORNL TTCTF.

- the MLDUA,
- the Houdini I and Houdini II remotely operated vehicles (ROVs), and
- the Waste Dislodging and Conveyance System (WD&CS).

The integrated technologies that comprised the RTCS went through additional testing to quantify the system's ability to safely meet the performance requirements established in the GAAT RI/BRA. The ORNL TTCTF was set up to imitate the unique waste characteristics and physical conditions found in the gunite tanks. The cold tests provided a low-risk environment in which the project team could evaluate the performance of the selected system components, both individually and as a comprehensive waste retrieval system.

Major in-tank components of the RTCS were designed to deploy through 24-in.-diam tank access risers, which were duplicated at the cold test facility. Figure 3-3 shows the Houdini ROV (left), MLDUA (center), and HMA (right) inserted through mock 24-in.-diam tank risers at the TTCTF. Workers controlled the RTCS equipment and subsystems from a remotely situated control room.

Fig. 3-3. Cold testing of the Houdini ROV (left), MLDUA (center), and HMA (right) using mock 24-in.-diam tank risers.

The RTCS subsystems were designed for deployment on and around an equipment platform placed over the tank undergoing waste removal operations. This feature was created for the cold tests, as shown in Fig. 3-4. This photograph shows equipment containment and support structures setup on the platform constructed over the TTCTF pit. The tent shown on the right covered the test pit's entrance and viewing area. The platform is a steel structure with removable floor grids, which allowed access to the tank risers. The platform provided a stable area for placement of the equipment containment structures and for performing maintenance and decontamination activities.

Fig. 3-4. RTCS components set up on a work platform installed at the ORNL TTCTF.

During the cold testing, procedures were developed for equipment operations and system mobilizations. Decontamination features were built into the tank access risers and the aboveground equipment containment structures. Field operators practiced maintenance operations on the equipment in protective clothing to ensure that the operations could be performed once the equipment was contaminated. They also developed maintenance schedules for the equipment and inventory lists for spare parts. Phase 1 of the treatability study was completed in May 1997.

The various types of equipment developed and tested during the cold tests are described in Sects. 4 through 8. Each section focuses on equipment used to perform specific functions during the GAAT Remediation Project. Section 9 discusses Phase 2 of the treatability study.

4. TANKS INSPECTIONS, WASTE SAMPLING, AND ASSOCIATED EQUIPMENT

This section discusses the equipment and methods used to inspect the tanks, monitor waste retrieval operations, and sample and characterize the tanks and the tank waste. One of the first steps in successful tank waste retrieval is determining the condition of the tanks, the characteristics of the tank waste, and the amount of waste present. Tank inspections and waste sampling provide important information for planning waste retrieval and tank stabilization operations. During tank remediation activities, it is important that equipment operators have the ability to observe the remote waste retrieval operations and monitor waste transfer activities. Collecting samples of waste during the various phases of waste retrieval and transfer operations keeps the tank remediation team informed of any unique tank waste characteristics and helps ensure that waste transfers are performed safely and successfully.

4.1 REMOTE VIDEO CAMERAS AND LIGHTING FOR TANK INSPECTIONS

Remote video cameras with integrated lighting served as the "eyes" of the Gunite Tanks Remediation Project. A variety of remote-controlled video cameras and lighting systems were used to inspect the tanks and monitor the operation and performance of the waste retrieval systems. Remote cameras and lighting features were an integral part of various components of the waste retrieval system, including the MLDUA, Houdini I and Houdini II ROVs, and the Waste Retrieval and Transfer System (WaRTS). Each of these systems included special controls and monitors for its integrated cameras. Figure 4-1 is a view of the control room monitors used to observe the operation of the Houdini I during cold testing.

Fig. 4-1. View of control room monitors used to observe the operation of the Houdini I during cold testing.

For preliminary surveys, a single remote-controlled video camera, with a light integrated into the camera housing was mounted on a 3-DOF (degree-of-freedom) deployment system (pan, tilt, and vertical extension), which was inserted through a tank access riser. Figure 4-2 shows workers preparing to install a remote video camera into tank W-3. The housing for the camera included a single high-intensity light, which illuminated the tank. The camera was mounted on a 3-DOF extended-reach mount that could be inserted through a 4-in.-diam riser but was usually deployed through a 12-in.-diam riser. The camera and integrated light were used to perform tank inspections in each of the gunite tanks. A video cable from the camera ran through the center of the vertical extension and connected with the remote control unit, which in turn was connected to a monitor and video tape recorder. The remote control unit contained a clock to monitor the time; indicators for the degree of pan and tilt; and a text generator to label important information, such as the tank number and date of inspection. The pan and tilt features on the control unit allowed the camera operator to pan and tilt the camera nearly 360° in any direction. The illumination intensity was controlled by the operators. The camera included a zoom feature with both automatic and

Fig. 4-2. Workers preparing to install a remote video camera into tank W-3.

manual focusing capabilities. This feature turned out to be important when performing tank inspections, because manual adjustments of the focus were sometimes needed to provide a clear picture of interesting tank or waste features, especially when the auto focus focused on water droplets on the lens. Methodical visual inspections of the interior and monitoring of some waste-sampling operations provided important information on the interior condition of the tanks and gave an indication of the amount of waste the tanks contained.

Before the waste retrieval equipment was deployed into the tanks, four remote-controlled video cameras and lighting systems were positioned in 12-in.-diam access ports installed in the tank domes. A multiplexed pan, tilt, and zoom controller was installed in the GAAT operations control room. Control and video cables from the cameras were connected to this unit. The controller allowed the equipment operators to conveniently and rapidly select and control the various cameras.

4.2 WASTE-SAMPLING AND CHARACTERIZATION METHODS AND ASSOCIATED EQUIPMENT

Waste sampling helped determine the physical and radiological characteristics of the tank waste during all phases of the GAAT Remediation Project. During the GAAT RI/BRA, the tank wastes were sampled using various methods and sampling devices, which are briefly described in Sects. 4.3.1 through 4.3.4. Waste-sampling operations were also performed during waste retrieval and transfer operations. The methods and equipment are discussed in Sects. 4.2.5 and 4.2.6. Appendix D (Vol. 2) provides a comprehensive listing of the sample data collected for STF tanks W-5 through W-10 for the period of August 1997 through September 2000.

Fig. 4-3. Workers performing tank-sampling operations in 1988 with a push tube sampler.

4.2.1 Push Tube Sampler

Cylindrical push tube samplers, mounted on vertical extension poles, were used to collect core samples of the tank waste. Figure 4-3 shows workers performing tank-sampling operations in 1988 with a push tube sampler. The push tube samplers (see Fig. 2-2) were manually deployed through a tank access riser and pushed down through the sludge until resistance was met. A stainless steel cover could be triggered to close off the bottom of the sampler. The sampler was removed from the tank, safely packaged, and transported to the on-site analytical laboratory for waste characterization and analysis.

4.2.2 Ponar Sampler

The ponar sampler was a clamshell-type grasping device that was deployed through a tank access riser. The two shells of the sampler were opened and lowered into the sludge layer on the bottom of the tank. The sampler had a trigger that closed the shells to collect the sludge sample. This type of device was used to sample tank W-7 because the interior video inspections of this tank showed what appeared to be possible crystals and chunks of sludge, or possibly gunite, from the tank walls or dome.

The ponar sampler was supported and deployed with a simple hoisting rig. A system of steel cables and pulleys was assembled on a wooden frame that was mounted on top of the tank riser. The sampler was lowered and retracted by a cable, as shown in Fig. 4-4.

Fig. 4-4. The ponar sampler.

4.2.3 Floating Boom, Camera, and Sampling Device

Initial tank inspections revealed that the supernatant limited the visibility of the underlying sludge layer. The integrated floating boom, camera, and sampling device was developed to aid inspections of the sludge. It was cold tested in an outdoor test facility at ORNL (Fig. 4-5).

The floating boom was made up of lightweight material linked together to form a long chain (~50 ft) that would float on the supernatant. The boom was operated via a platform mounted over a tank riser, which allowed the operator to lengthen or shorten the boom extension in the tank. The platform rotated 360° so that the boom could be positioned as needed.

The boom was initially outfitted with a rotating remote-controlled camera, encased in a waterproof clear plastic bubble, and a clamshell-type sampling tool. The encased camera was intended for visual inspections of the sludge beneath the supernatant. Cables carrying the control and video signals to and from the camera were integrated through the links of the boom and were connected to the remote control unit and a video monitor. The rotating camera had the ability to tilt up and down, functions that were controlled remotely.

Fig. 4-5. Remote camera and sampling device mounted on a flexible floating boom at an outdoor testing facility at ORNL.

A clamshell-type sampling tool was positioned in a floating foam harness, which was attached to the end of the boom. The sampler could be positioned at a desired location, lowered into the sludge, closed to collect a sample, and then raised back up into the harness. This operation was similar to the ponar sampler.

The floating boom and the sampler appeared to work well. However, the dark interior of the tanks and the murky conditions of the supernatant were not ideal conditions for visual inspection of the sludge.

4.2.4 Sludge-Mapping Tool

The floating boom was outfitted with a depth-finding device and inserted into the tanks to map the varying depths of the sludge (Fig. 4-6). The initial estimates of the sludge in the gunite tanks were determined through the use of a sonar device, which indicated the distance of the top of the sludge from the device. These data were used in conjunction with the known height of the tank walls and the position of the sonar device within the tanks to develop maps indicating the depth of sludge on the bottom of the tanks. This information was used to estimate the sludge volume contained in each tank.

Fig. 4-6. Retrieval of the floating boom and depth finder from tank W-6 during sludge-mapping operations.

4.2.5 Waste Sampling with the Houdini ROVs

The Houdini I and Houdini II ROVs were used to sample tank waste during waste retrieval operations. Figure 4-7 shows the Houdini I ROV sampling sludge in tank W-3. The remote-controlled manipulator arm and grasping end-effector were effective in obtaining samples from various locations within the tank. Sampling tools were held by the grasping end-effector and positioned by the manipulator arm. A camera on the wrist of the manipulator arm provided close-up views of the sampling operations. The samples were placed in a container suspended from a line inserted through one of the tank risers.

Fig. 4-7. The Houdini I ROV preparing to take a sludge sample during hot tests in tank W-3.

4.2.6 In-Line Samplers

In-line samplers were provided as part of three different systems. One sampler was included in the Flow Control Equipment and Containment Box (FCE&CB) (Fig. 4-8) and was used to monitor the waste slurry as it was transferred from a tank. Three samplers were installed in the Sludge-Conditioning System (SCS), with two in the Primary Conditioning System (PCS) module upstream and downstream of the solids classifier units and one in the Slurry Monitoring Test Loop (SMTL) module.

Fig. 4-8. FCE&CB for the WD&CS.

In-line samplers strategically placed in the waste transfer and conditioning equipment were used to extract waste slurry samples from the waste stream as it was retrieved and transferred from each tank.

These samples were used to

- confirm information obtained by the SMTL instruments,
- assess the performance of the waste retrieval equipment, and
- assist with material balance calculations.

4.3 TANK SAMPLING AND CHARACTERIZATION METHODS AND ASSOCIATED EQUIPMENT

During waste retrieval operations, the walls of the tank were sampled to determine the amount of contamination trapped in the tank walls and the depth to which the contamination had penetrated. Specialized tools were developed and used to characterize the type and amount of contamination contained in the walls. Other tools were used to assess structural inconsistencies in the tank walls.

4.3.1 Gunite Isotope Mapping Probe (GIMP)

The GIMP was used to determine and map the contamination in the walls of the gunite tanks. The GIMP's electronics were housed in the enclosure shown in Fig. 4-9. The probe was fitted with an array of beta and gamma radiation detectors that were contained in an assembly that was mounted to a vertical extension pole. The GIMP was deployed through the tank access risers by a crane. Information, including a video signal, was fed through cables, which connected to monitoring equipment in a small motor home that had been converted to a mobile control room.

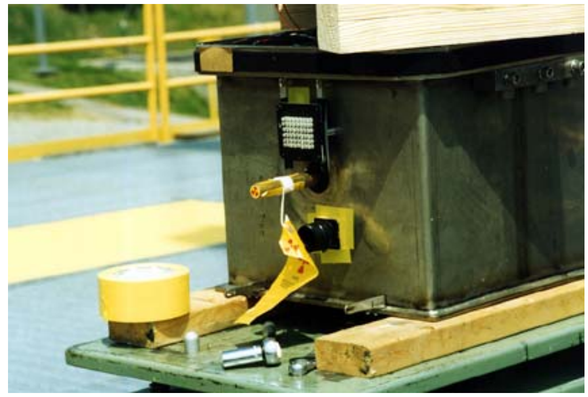

Fig. 4-9. Close-up view of the GIMP signal-processing equipment during preparation for installation into tank W-3.

4.3.2 Characterization End-Effector

The Characterization End-Effector (CEE) was deployed by the MLDUA (Fig. 4-10) to determine radiation levels inside the tanks. The CEE was comprised of two primary characterization components. The first component was the signal-processing electronics, which included an array of beta and gamma detectors capable of radiation readings up to 200 rad. The other component was a probe for collecting samples from the tank walls. A Tether Handling System (THS) with a slip ring was used to transmit power, data, and control signals to the CEE. The THS was attached to the TRIC or could be attached to the TMADS. Problems were identified with the CEE from its first deployment. The probe did not work, and the housing for the radiation detectors was quite large. The CEE was cannibalized for the radiation detector, which was reused in the Collimated Analyzing Radiation Probe (CARP), described in the Sect. 4.4.3.

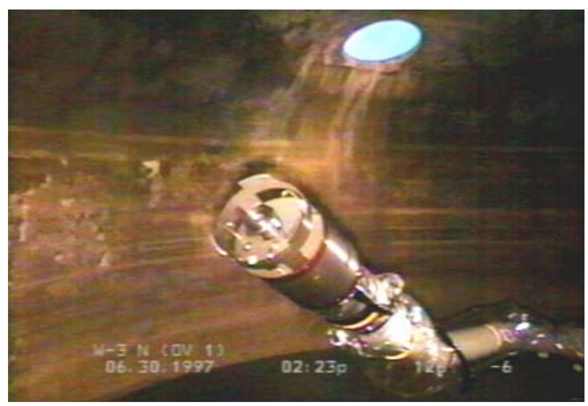

Fig. 4-10. The CEE during hot tests in tank W-3.

4.3.3 Collimated Analyzing Radiation Probe (CARP)

The collimated radiation detector from the CEE was reused in the CARP and placed in a small box that included exterior data displays. The unit was battery operated and included a sonar-based range detector to determine the distance to the tank wall, which was used with the data from the radiation detector to calculate the radiation levels at the tank wall surface. After problems with the CEE had been identified, the CARP was used to collect tank wall contamination data. The unit was equipped with a handle that could be grasped by the MLDUA. The MLDUA deployed the CARP in the tanks and worked in set patterns, sweeping vertically and radially through the tank. The MLDUA's integrated camera provided a video signal in the operations control room so that the data display on the probe could be read.

4.3.4 Feeler Gauge

The feeler gauge was deployed by the MLDUA, as shown in Fig. 4-11. This simple tool was run vertically up and down the tank walls in order to determine if the walls were smooth or if there were variations in the gunite. The tool was also used to assess the consistency and depth of the sludge in the tanks.

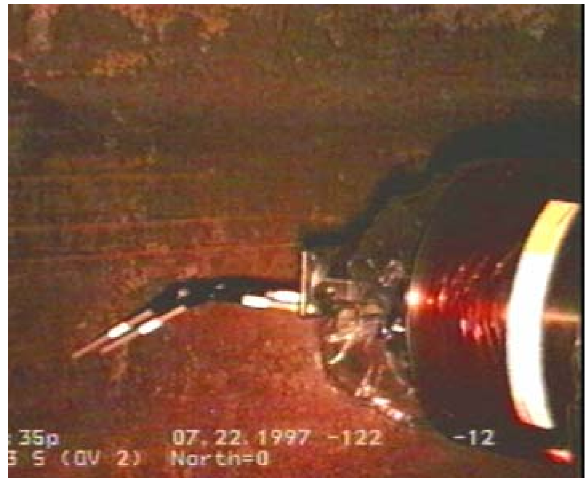

Fig. 4-11. The MLDUA-deployed feeler gauge in tank W-3 during tank characterization activities.

4.3.5 Wall-Scraping Tool

The wall-scraping tool was deployed on a vertical extension pole, or by the MLDUA or Houdini ROVs, and used to collect scale from the interior walls of the gunite tanks. The tool was a simple flat metal bar fabricated from unistrut stock that was beveled on one end with a series of cavities machined on one side. The metal bar was attached to a stiff spring and an X-handle that could be grasped by the MLDUA. When the surface of the tank wall was scraped with this tool, portions of the wall and scale were captured in the collection cavities and placed in a bag for transport to the laboratory for analysis. The scale was analyzed to help determine the amount of contamination that was adhering to the tank walls.

4.3.6 Wall-Coring Tool

The wall-coring tool consisted of a modified electric drill and collection system (Fig. 4-12). This tool was used to collect wall core samples that had a length of ~1.5 to 3 in. and a diameter of 0.75 in. Figure 4-13 is a photograph of a core sample taken from the inner wall of tank W-3, showing the inner tank shell covered with a layer of asphalt-type material and coated with an additional 1-in. layer of gunite. The cores were released from the drill into a collection bucket that was lowered into the tank on a line. The core samples were analyzed to determine the types of radioactive contaminants and how far

Fig. 4-12. The Houdini-deployed wall-coring tool, showing a core being discharged from the tool.

they had migrated into the tank walls, so that plans could be made for cleaning the walls. The wall-coring tool was also used after the wall-cleaning operations to determine if the cleanup goals had been met. The Houdini ROVs deployed the wall-coring tool in the tanks.

Fig. 4-13. Core sample taken from the inner wall in tank W-3.

4.3.7 Topographical Mapping System (TMS)

The TMS is a laser-based measurement system designed to provide three-dimensional mapping of the interior of the USTs (Fig. 4-14). It was designed and developed to operate in hazardous and radioactive environments. The TMS is a self-contained, reconfigurable system capable of providing rapid, variable-resolution mapping information in poorly characterized workspaces with a minimum of operator intervention. Such topographical information was useful for providing operators with the location and depth of sludge deposits and for estimating the volume of sludge within a tank.[8]

The TMS was deployed in tanks W-5 and W-6 to assess the depth of degradation of the tank walls over the areas where the interior gunite layer had apparently been damaged.

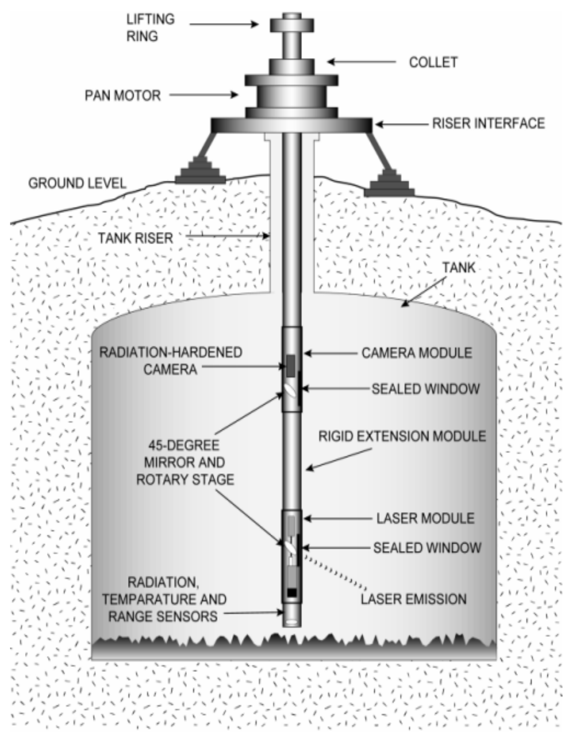

Fig. 4-14. Graphical representation of the TMS deployed in a UST.

[8] U.S. Department of Energy, *Innovative Technology Summary Report: Topographical Mapping System*, DOE/EM-0478 September 1999.

5. MODIFICATIONS TO THE TANKS, TANK FARMS, AND ASSOCIATED EQUIPMENT

This section discusses modifications that were made to the North and South Tank Farms to prepare for tank waste retrieval activities and some of the equipment that was used to perform the modifications. It also presents some of the lessons learned associated with these activities.

Modifications included adding temporary buildings that would serve as the waste retrieval operations control room, offices for safety and Radiation Protection (RP) personnel, storage areas, frisking stations, and personnel break and meeting rooms. Modifications to the NTF and tanks W-3 and W-4 were conducted in parallel with early Treatability Study activities to prepare for the hot tests that would be conducted in these tanks as part of the Treatability Study. NTF modifications were completed in December 1996. Modifications to the STF started during the hot tests in the NTF and were completed in February 1998. Figure 5-1 is an aerial photograph of the STF, taken prior to modification in 1996. This photograph shows the inactive evaporator building in the southwest corner of the STF and equipment platforms from past practice sluicing operations (ca. 1982) over tanks W-8, W-9, and W-10. Figure 5-2 is a photograph of the STF after site modifications were completed. This photograph shows the new equipment platforms installed over tank W-6 and the old platforms over tank W-10. The site was leveled and covered with about 1 ft of compacted gravel to provide a clean surface for a buffer area during waste retrieval operations.

Fig. 5-1. Aerial photograph of the STF, taken prior to modification in 1996.

Fig. 5-2. Photograph of STF after completion of site modifications.

Some of the underground piping located in the tank farms was excavated (Fig. 5-3) and removed or relocated so that it would not interfere with tank modifications and facility upgrade activities. All of the gunite tanks in the North and South Tank Farms were excavated to expose their domes so that additional tank access risers could be installed in the tanks.

Workers used large-diameter hole saws to cut holes in the tank domes, with diameters ranging from 12 to 30 in. The hydraulically operated hole saws were equipped with diamond-tipped core bits. Tank access risers were installed over the holes and sealed in place. Figure 5-4 shows workers installing an additional riser on tank W-4 while the workers standing on tank W-3's dome mark the location for a hole in the center of the dome to provide additional access to this tank. The additional risers provided tank access for the remote video cameras, lighting, and waste retrieval and transfer equipment. Once tank modifications were completed, the exposed tank domes were backfilled with the excavated soil and covered with compacted gravel to provide a level surface for tank remediation activities.

Fig. 5-3. Workers (left) excavate underground piping (right) in the NTF for either removal or relocation to prepare the site for additional modifications to the tanks and the tank farm.

Fig. 5-4. Workers install an additional tank access riser in tank W-4.

5.1 CONSTRUCTION OF EQUIPMENT PLATFORMS AND SUPPORT FACILITIES

Fig. 5-5. Installation of the steel beams for the work platform constructed over tanks W-3 and W-4.

Modifications in the NTF included the construction of a large work platform over tanks W-3 and W-4 that was used to support the waste retrieval equipment. The platform was constructed with steel beams (Fig. 5-5) and removable steel grating panels, which allowed access to the tank risers. Additional utilities and lighting were added to the NTF to support waste retrieval operations. Modular buildings (trailers) were brought to the site to serve as the equipment control room and offices for support services. After waste retrieval activities in tanks W-3 and W-4 were completed in 1998, the utility buildings (prefabricated wood-frame and plywood construction) were relocated to the STF and used as a frisking station, storage for RP personnel, and general parts/equipment storage. The platform materials were cleaned, broken down, and recycled. The modular buildings that served as offices and the control room were left at the site for an upcoming project (Tank W-1A and Corehole 8 Plume Source Remediation Project).

Fig. 5-6. Installation of a process water line in the STF during modifications and facility upgrades.

In the STF new equipment platforms were first constructed over tanks W-6 and W-10. A process water line was added to the STF (Fig. 5-6), and the electrical supply was upgraded with the addition of two power poles and other electrical equipment to provide adequate power for the remediation activities. A modular building was placed in the southwest corner of the tank farm to serve as the equipment and operations control room, and other portable buildings were strategically placed on the perimeter of the northwest corner of the tank farms to provide office space and a frisking station near the entrance to the STF (Fig. 5-2). A tent in the northwest corner of the STF had been constructed to provide a confined area during the demolition of the evaporator building. The tent was left in place after completion of the demolition to provide storage space for miscellaneous equipment. An equipment maintenance tent was placed in the southeast corner of the tank farm.

Modifications to the STF also included pollution prevention measures, such as removing and recycling the old platforms used during earlier single-point sluicing operations in the 1980s. Some of the soil excavated from the tank domes during modification activities was found to be contaminated. Rather than disposing of this soil, it was used to backfill the excavated areas and then covered with approximately 1 ft of gravel to provide a clean level area for the waste removal operations in the STF.

5.2 MODIFICATIONS TO THE TANK INTERIORS

Some modifications to the tank interiors were needed to remove obstructions that could hinder waste retrieval operations or to plug pipes that protruded into the tanks. These modifications were made using the MLDUA and Houdini ROVs to deploy specialized tools designed for specific jobs. The remainder of this section discusses the equipment and methods used to perform modifications to the tank interiors.

Fig. 5-7. Modifications in tank W-6 using the hydraulic shear deployed by the Houdini ROV.

5.2.1 Hydraulic Shear

A small hydraulic shear was deployed by the Houdini I ROV manipulator arm. The vehicle was partially inserted into a tank (Fig. 5-7) and the hydraulic shear was used to cut away small diameter pipes (less than 1-in. diam) that were blocking the deployment and landing area of the ROV. Overview cameras in the tank and cameras integrated into the Houdini I ROV provided equipment operators with a view so that they could perform the operations.

Fig. 5-8. Modifications in tank W-7 using the pipe-cutting tool deployed by the MLDUA.

5.2.2 Pipe-Cutting Tool

The pipe-cutting tool (Fig. 5-8) consisted of a modified electric band saw that could be deployed by either the MLDUA or the Houdini ROV. This tool was used to cut away pipes that obstructed operations of the waste retrieval equipment in the tanks.

5.2.3 Pipe-Plugging Tool

The pipe-plugging tool was a disposable tool that could be deployed by the MLDUA. It was used to plug pipes that protruded into the tanks to improve the isolation of the tank interiors from the environment. This tool was utilized in tanks W-6, W-8, and W-9 in the STF. The stainless steel tool consisted of a grab-bar mounted to a cup slightly larger in diameter than the diameter of the pipe. The interior of the cup contained a cone that protruded from the cup, which helped to position the cup over the pipe. The interior of the cup was filled with a quick-setting epoxy to provide a good seal when the assembly was placed over a protruding pipe. Figure 5-9 is an in-tank view of the pipe-plugging tool being used to plug a 3-in.-diam overflow line in tank W-6. After giving the epoxy a few minutes to harden, the MLDUA released the tool's grasp-bar so that the disposable tool remained in position over the protruding pipe opening, effectively sealing it. Locking devices behind the cone assisted in holding the cup in place as the epoxy cured.[9]

5.2.4 Modified Wrecking Ball

A heavy steel wrecking ball, outfitted with a steel skirt attached to the ball's lower hemisphere, was used in tank W-4 to compact the sludge that had been added to this tank from waste retrieval operations in tank W-3. The sludge was compacted to make space for the deployment of the HMA during preparation for waste retrieval operations.[7]

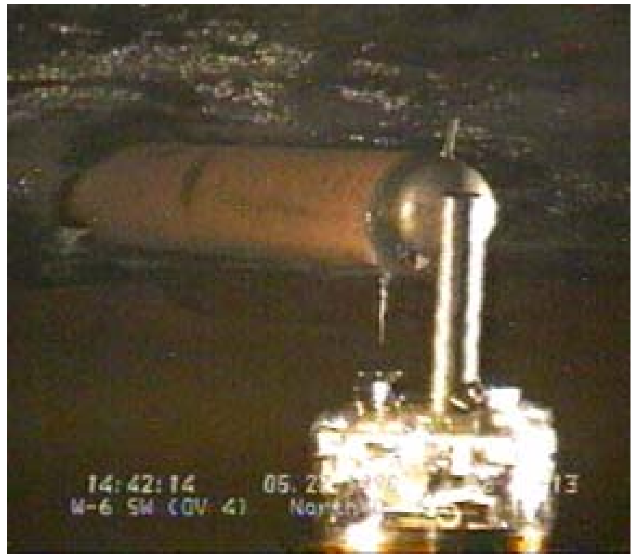

Fig. 5-9. Modifications in tank W-6 using the pipe-plugging tool deployed with the MLDUA.

[9] U.S. Department of Energy, *Innovative Technology Summary Report: Pipe Cutting and Isolation System*, DOE/EM-0448, August 1999.

6. SLUDGE HEEL RETRIEVAL AND WALL-CLEANING EQUIPMENT

During the GAAT Remediation Project, various technologies were integrated into the remotely controlled RTCS, which was used to perform waste retrieval and tank-cleaning operations. The RTCS (Fig. 6-1) was comprised of several subsystems, with each subsystem providing unique capabilities. The equipment and systems were designed, manufactured, and/or procured from various commercial and government organizations. A listing of the major organizations providing hardware and services for the GAAT Remediation Project is provided in Appendix E (Vol. 2).

Fig. 6-1. RTCS components installed on the tank W-6 equipment platform during waste retrieval operations.

The RTCS used confined sluicing technology to break up and retrieve sludge heels from the tanks. Sludge heel retrieval and wall cleaning were key activities in the tank remediation process, and the MLDUA and the Houdini I and II ROVs played an important role in these operations. These systems were used to operate various tools and equipment in the gunite tanks. The MLDUA and ROVs worked well together, with each performing complementary operations that helped speed up waste retrieval operations.

This section discusses the RTCS subsystems and equipment that were used to safely and efficiently clean the tank walls and remove radioactive sludge and debris from the gunite tanks.

6.1 WD&CS, ASSOCIATED END-EFFECTORS, AND EQUIPMENT

The WD&CS was a major subsystem of the RTCS. This system included several components that worked together to break up sludge and remove the waste slurry from the tanks. The system was also capable of cleaning the tank walls. WD&CS components included

- the water power eductor (jet pump), which was used to vacuum wastes from the tanks;
- a waste transfer hose;
- the CSEE, which helped break up the sludge waste;
- the Gunite-Scarifying End-Effector (GSEE), which was used to clean the tank walls;
- the HMA, which supported the hoses connecting the CSEE and the jet pump; and
- the FCE&CB, which contained the control hardware for the WD&CS and waste slurry sampling equipment.

The components of the WD&CS were the primary tools used in waste retrieval activities at the GAATs. These components were used to perform various special functions, which are described in the following sections.

6.1.1 Jet Pump and Waste Conveyance System

A commercially available axial-flow pump was used to convey all the waste retrieved via the CSEE. The jet pump generated the vacuum required at the CSEE inlet to retrieve the waste slurry and sufficient discharge pressure to remove the slurry from the tanks. The jet pump was rated at a motive pressure of 10,000 psig and 12 gal/min but was typically operated at 7000 psig, consuming about 10 gal/min of filtered process water for the motive jets.

The jet pump was installed near the bottom of the HMA mast and discharged through a pipe straight to the top of the mast. A flexible-hose jumper was used to connect the jet discharge to the balance-of-plant (BOP) piping.

A commercial jet pump was modified with a hardened stainless venturi nozzle after cold testing revealed that the standard aluminum bronze nozzle was prone to rapid erosion. Figure 6-2 is an illustration of the components of the axial-flow jet pump.

Each of the three motive jet nozzles included a hardened steel insert with a short, steeply tapered inlet, set in hex-socket threaded inserts, with the jet discharging through the hex sockets. The pump was drilled for six nozzles, but no performance advantage was obtained with six versus three. Therefore, only three equally spaced nozzles were used and the three remaining nozzle ports were plugged.

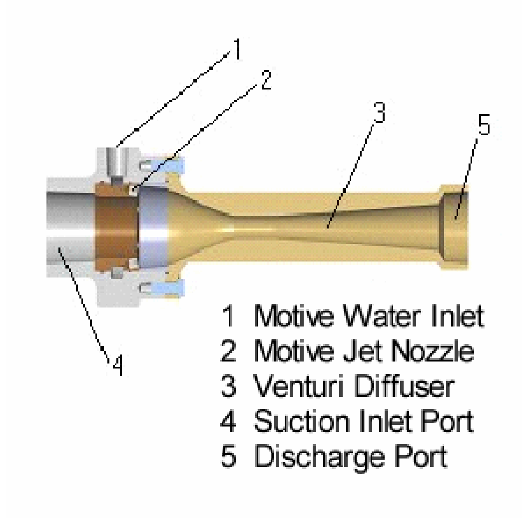

Fig. 6-2. Schematic of the axial-flow jet pump.

6.1.2 CSEE

The CSEE contained a rotating manifold with three water jets that were supplied with 200–7000-psig process water. The water jets were rotated at a rate of 0–500 rpm to cut through and break up sludge (Fig. 6-3), dilute soft wastes into a pumpable slurry, or wash tank walls. The CSEE rotating cutting jets combined with the vacuum power from the axial-flow jet pump was very effective for removing sludge waste from the tanks.

Fig. 6-3. View of the CSEE held by Houdini I and showing the operation of the rotating cutting jets used to mobilize waste material from the GAATs.

The CSEE's rotating manifold was a 15-5 stainless steel weldment with the rotor section cut from a single block of plate and welded to the shaft. The manifold arms were normal to the rotation axis and the jets converged at an angle of 35° to the axis and a 5.5° lead angle with respect to the counterclockwise rotation. The water jet nozzles were Leech & Walker type carbide inserts (0.032-in. diam) selected for their high-velocity coherent cutting-jet capability. They were mounted in a custom compression-seal holder that could be installed with just a socket wrench, and were contained in-line flow straighteners placed behind the jets. The flow straighteners were used to enhance the jet coherence and compensate for the acute bend in the water path upstream of the jet.

A frameless dc servomotor was used to drive the manifold rotation. The motor stator was pressed into the aluminum canister and the bearings and seals at the canister bottom and upper end cap supported the rotor. The manifold armature passed through the large central bore of the rotor, to which it was keyed to transfer torque.

A 10,000-psig rotary coupling adapted the manifold to the supply hose and was supported against bending moments by an external cage mounted on the motor case. The manifold and motor case were mounted to the main chassis, which included the protective fiberglass shroud ring, grab handles, and conveyance suction port. An inlet shroud with a 3/8-in. hex screen was fitted to the manifold. Figure 6-4 is a schematic of the CSEE assembly.

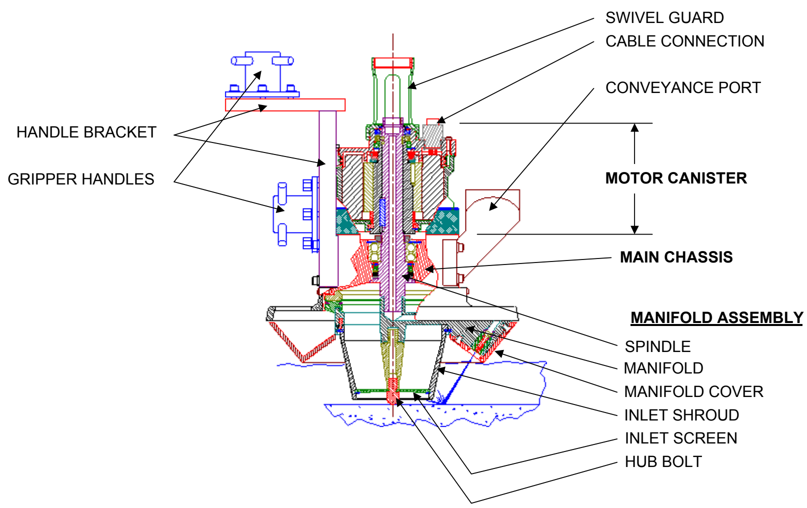

Fig. 6-4. Schematic cross section of the CSEE assembly.

The CSEE motor was powered by a 300-Vdc 10A (continuous), 45-A (peak) power supply operating through a dc servoamplifier. The motor included Hall-effect sensors for feedback. The motor was able to achieve rotational speeds from 60 to 600 rpm. During normal confined sluicing operations 300 rpm was adequate. The motor umbilical was routed along with the waste transfer line through the HMA vertical deployment mast; therefore, no deployment reel was required.

The rotating cutting jets surrounded a vacuum head that connected to the waste conveyance system, integrated with the HMA. The dislodged waste was aspirated into the conveyance line through the central inlet system. Sludge retrieval rates as high as 8 gal/min were observed during cold testing. The CSEE consumed about 10 gal/min of process water, most of which was needed to drive the jet pump.

CSEE controls and instrumentation included a power switch and emergency stop, rotational direction and speed controls, speed and torque (inferred from current) indicators, and data connections. The local CSEE controls, amplifier, and power supply were housed in a splash-proof enclosure on the equipment platform and interfaced to remote controls and instrumentation at the control room. The CSEE was demonstrated to tolerate 2000-psi wash-down and to be readily decontaminated by a tank riser decontamination spray ring (DSR) and a handheld spray wash gun inside the deployment system glove box.

The CSEE, including one grab handle, weighed 46 lb. It generated only moderate dynamic forces during cold testing, so it was compatible with the structural capability of the MLDUA. The CSEE is made of aluminum, stainless steel, and selected polymers. It proved sufficiently resistant to the radiation levels and chemical environment of the tanks in the STF.

6.1.3 Hose Management System (HMS)

The HMS was designed to minimize the load on the MLDUA and the Houdini ROV by providing a positioning system for the CSEE umbilical, especially the heavy conveyance line. The system also minimized the radiation exposure to the MLDUA by separating the waste discharge line from the MLDUA during waste retrieval operations. The HMS was comprised of an HMA, storage tube, confinement box, and Mast Elevation Table (MET). The HMS provided 4 DOF for deployment and positioning of the CSEE and management of cables and hoses.[10] It delivered power and process water to the CSEE and incorporated the conveyance system that was used to transfer waste out of the tank.

The base link of the HMA was a heavy vertical mast that could be rotated and vertically positioned by the MET above the tank riser. The mast could be retracted into the storage tube above the MET using an integral hoist. Two rigid pipe intermediate links extend from a deployment position (folded up against the mast) to a horizontal working position with motorized swivel joints. The distal link to the CSEE is a short umbilical hose and cable bundle. The CSEE power cables and water supply hose are routed along the rigid links and up conduits in the mast to jumper connections to the BOP at the platform. The conveyance hose connects to the rigid pipe links, which double as structural sections and conveyance conduit. The conveyance conduit continues inside the mast to the jet pump and up to the above-grade platform.

The HMA was retracted from the tank through a DSR and into its containment structure located on the tank platform. Eight glove ports on the HMA containment structure provided access for maintenance operations and to electrical power controls and hose connections. The HMA containment structure housed the jet pump and was also used to isolate the system from workers and the environment. The HMA could be retracted and secured in its containment structure and then moved to the next tank scheduled for remediation as shown in Fig. 6-5.

Fig. 6-5. Use of two cranes to move the HMA containment structure.

A cleaning tool for the CSEE was added to the HMA system after its initial deployment to facilitate the removal of blockages from the inlet nozzle of the CSEE.

6.1.4 The Gunite-Scarifying End-Effector (GSEE)

The GSEE was a simplified, medium- to high-pressure version of the CSEE that shared many common design features (Fig. 6-6). The GSEE did not have a waste transfer line connection or suction port and could therefore operate with the cutting jets at a minimal standoff distance from the surface. Its spray jet manifold and swivel connection were designed for a maximum allowable working pressure of 30,000 psig. The GSEE spray jets diverged from the manifold's axis of rotation (Fig. 6-7) to cover a wider swath than was possible

[10] P. D. Lloyd, C. L. Fitzgerald, H. Toy, J. D. Randolph, R. E. DePew, D. D. Falter, and J. A. Blank, "Performance Assessment of the Waste Dislodging and Conveyance System During the Gunite and Associated Tanks Remediation Project," presented at the American Nuclear Society Ninth International Topical Meeting on Robotics and Remote Systems, Seattle, Washington, March 4-8, 2001.

with the CSEE. In cold testing, the GSEE was capable of removing a 0.25- to 0.33-in. layer of gunite simulate, when operated at 22,000 to 30,000 psig.

The GSEE used a separate umbilical that bundled the motor control/power cables and the high-pressure supply hose. The umbilical was managed by a THS, which could be attached to either the TRIC or the Houdini ROV Tether Management and Deployment System (TMADS). The TMADS and the GSEE utilized rotary couplings for the water circuit and a mercury-wetted rotary coupling for the power/control circuits. The GSEE manifold was fitted with the same style nozzles as the CSEE. The reaction force from the jets was great enough at 20,000 psig to require care in operations to avoid overloading the shoulder yaw joint on the MLDUA.

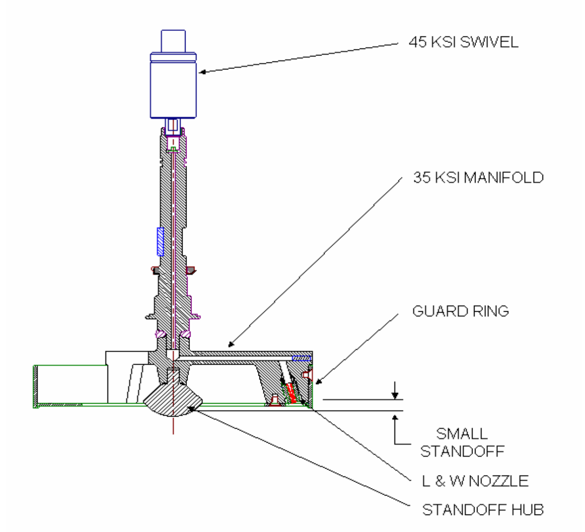

Fig. 6-6. Schematic cross section of the GSEE assembly.

6.1.5 FCE&CB

The FCE&CB served as the interface between the tanks and the waste transfer piping. The FCE&CB housing contained the WD&CS control hardware. Sampling equipment contained in the FCE&CB was used to monitor the characteristics of the waste slurry being removed from the tanks. The FCE&CB was positioned on the equipment platform over the tanks (Fig. 6-8).

Fig. 6-7. Diverging jets from the GSEE while scarifying inside a GAAT.

6.1.6 The Medium/High-Pressure Pumps

Two medium-pressure (up to 10,000-psig) triplex plunger pumps fed clean filtered process water to the CSEE and the jet pump. A third ultra high-pressure pump (UHPP) was used with the GSEE. The UHPP (Fig. 6-9) was a skid-mounted pumping system that was capable of providing process water at pressures up to 40,000 psig. The system consisted of a pump assembly, diesel engine, high-pressure hose, pump and engine controls, and local and remote control panels.

Fig. 6-8. FCE&CB positioned on the equipment platform at the cold test facility during testing of the in-line sampling features of the system.

6.2 THE MLDUA

The MLDUA provided reach and mobility during waste retrieval operations in the gunite tanks. The MLDUA was an 8-DOF robotic arm with a reach of 15 ft and a payload capacity of ~200 lb (Fig. 6-10). The end of the MLDUA contained a tool plate that could accommodate a Gripper End-Effector (GEE) that was used to grasp and hold the various tools used to modify the interiors of the tanks and remove the liquid and sludge waste from the tanks. The GEE extended the MLDUA reach to 16 ft.

Cameras mounted on the wrist and mast of the MLDUA provided a remote video feed to monitors positioned in the MLDUA's control console. The cameras helped operators grasp tools and end-effectors and to monitor the waste retrieval operations. The robotic arm could be programmed to perform specific operations or could be operated remotely from the control room. The robotic control functions were particularly useful when operating in heavy mists and other low-visibility conditions.

Fig. 6-9. UHPP skid in the STF prior to installation.

The MLDUA's containment structure was mounted on the equipment platform above the tank riser. This structure housed the MLDUA when it was moved and helped prevent the spread of contamination. A TRIC system was located on the work platform between the riser top and MLDUA storage structure for the Vertical Positioning Mast (VPM). Glove ports in the TRIC provided operators with access to the equipment for maintenance and repair activities and for attachment of end-effectors such as the gripper and sampling tools. A DSR was mounted on the bottom of the TRIC for decontamination of equipment as it was retracted from the tank. A spray wand mounted inside the TRIC was used to further decontaminate the MLDUA.

Fig. 6-10. The MLDUA during cold test operations at ORNL.

6.3 THE HOUDINI I AND HOUDINI II ROVS

The Houdini I and Houdini II ROVs were tethered vehicles that could perform a wide variety of operations. The ROV frame had the ability to fold up and fit through the 24-in.-diam tank access risers (Fig. 6-11). The tracked vehicles had a parallelogram-shaped frame that could be expanded to a ~4- × 5-ft work platform. Each vehicle weighed ~1000 lb and was equipped with a plow blade; a dexterous, high-payload manipulator; and four remote camera systems.

The versatility and mobility of the Houdini I and Houdini II ROVs allowed operators to remotely perform many types of in-tank operations. Each Houdini vehicle was equipped with an integrated manipulator arm. The 6-DOF arm had a payload capacity of 250 lb at full extension. The arm was used to pick up and organize debris so that it could be retrieved from the tanks and to deploy a variety of tools and end-effectors, which were used to modify the interiors of the tanks, sample the tank waste, and retrieve the waste. The ROVs were also equipped with a plow blade on the front of the frame. The plow blade was used for breaking up sludge heels at the junction of the tank wall and floor and to push sludge towards the CSEE as it was held by the MLDUA to accelerate waste retrieval operations. Cameras mounted on the arm and rear panel of the vehicle near the tracks provided a video feed to monitors mounted at the vehicle's control console (Fig. 6-12). Operators could adjust the camera views to help them grasp tools and to perform intricate operations.

The Houdini ROVs were housed in containment structures that were positioned on the equipment platform above a tank access riser. The containment structure included glove ports, which provided operators with vehicle access during maintenance or repair activities.

Fig. 6-11. The Houdini I ROV as it was deployed through a 24-in.-diam riser during the cold tests at ORNL's TTCTF.

The tether for the ROVs was comprised of hydraulic pressure and return hoses; a water line for camera cleaning; and electrical conductors for the on-board cameras, manipulator, track servo valves, limit switches, and pressure switches. The tether was rated at 10,000 lb_f breaking strength, which allowed it to be used as a structural member during insertion and removal from the tanks. The combination of the tether reel and vehicle containment structure was called the TMADS, which also served as the interface with the tank riser. The TMADS provided the vehicle with a sealed compartment in which to store the vehicle; a hydraulically powered, remotely operated tether reel; and included glove ports, a spray wand, and access features for maintenance and decontamination operations.[11]

The skid-mounted Power Distribution and Control Unit (PDCU) shown in Fig. 6-13 was used to convert and condition the site electrical power to the proper voltages for use with the Houdini ROV. The PDCU also contained the computer control hardware and hydraulic power supply for the ROV.

6.4 SUPPORTING EQUIPMENT

Several types of support equipment were used to enhance waste retrieval in the gunite tanks. The following sections describe this equipment and their functions.

Fig. 6-12. Performing waste retrieval operations in the gunite tanks via the Houdini II ROV's control console.

6.4.1 Decontamination Spray Rings

DSRs were installed in the main tank access risers under the equipment where the waste retrieval equipment was located. Figure 6-14 is a view of a DSR during cold testing at the TTCTF. The spray rings were activated during the retraction of the waste retrieval equipment from the gunite tanks to remove gross contamination from the equipment as it was retracted from the tanks. Spray from the eight nozzles mounted on the 40-in.-diam ring fell back inside the tank. By removing as much contamination as possible from the equipment during retraction, contamination in the equipment containment boxes was reduced, which reduced the risk of exposure to workers during maintenance operations. Each DSR weighed ~600 lb and required an external high-pressure water pump capable of providing up to 50 gal/min at 2200 psi.

[11] U.S. Department of Energy, *Innovative Technology Summary Report: Houdini™-II Remotely Operated Vehicle System*, DOE/EM-0495, December 1999.

6.4.2 Mobile Modular Power Distribution System

The Mobile Modular Power Distribution System (Fig. 6-15) was a custom-designed, trailer-mounted, 60-Hz electrical power distribution system designed to facilitate convenient delivery of alternating current (ac) power to field systems. The system had two 480-Vac, 400-A breaker panels that were fed by a pair of cables fitted with connectors to match the appropriate receptacles. One panel fed a 75-kVA, 480-to-208Y/120-Vac transformer, which in turn delivered power to a 200-A lighting panel. Breakers in each panel fed an array of pin-and-sleeve type receptacles. The demobilization, movement and redeployment of the field systems were enhanced by the convenient method that power was distributed. Efficiency of maintenance activities was improved because of the proximity of the distribution system to the field systems. Significant cost and schedule savings were realized by use of a mobile modular power distribution system in conjunction with temporary cable trays versus a typical fixed power distribution system.

Fig. 6-13. Skid-mounted PDCU after dismantlement of the site.

6.4.3 Floor-Cleaning End-Effector (FCEE)

The FCEE was used briefly in the NTF to scrape and vacuum a very thin layer (<0.25 in.) of sludge and supernatant remaining on the floor in tank W-3. The FCEE was constructed of 1/8-in. sheet metal and included a T-bar handle for manipulation by the Houdini ROV, a connection point on one end for a 2-in.-diam vacuum hose, a scoop on the opposite end for scraping sludge from the tank floor, and a necked-down region in the middle that created a differential pressure (~5-in. water) that was used to vacuum shallow layers of water from the tank floor. The FCEE was initially attached to a commercially available 35-gal wet/dry shop vacuum that was deployed inside the waste tank inside a drum. The FCEE was also deployed by the HMA using the WD&CS jet pump and waste transfer capabilities to remove sludge and water from the tank.

Fig. 6-14. DSR during cold testing at the TTCTF.

Although the FCEE was successfully used in tank W-3, as the GAAT project team gained experience, it was concluded that the efforts to remove the final remnants of waste from the tanks were of questionable value. This conclusion was based on the fact that in-leakage of groundwater was continuing to occur, that secondary wastes were being added to the waste stream by the WD&CS jet pump, and that nontrivial amounts of water would be added back into the tank by the decontamination systems upon withdrawal of the equipment from the tank. Therefore, the FCEE was not used in any of the other GAATs.

Fig. 6-15. Mobile modular electrical power distribution system positioned near tank W-6.

6.4.4 Linear Scarifying End-Effector (LSEE)

Separate versions of the LSEE were deployed in tanks W-8 and W-9, which were used to perform high-pressure washes of the tank walls.[12] The LSEE was designed near the end of the GAAT Remediation Project with the following primary requirements:

- utilize the available pneumatic, hydraulic, and electrical interfaces,
- deploy using the containment structure for the MLDUA,
- extend the reach of the existing ROV from 6 to 10 ft to allow cleaning of the entire wall of the STF gunite tanks from floor to ceiling,
- ensure that the combined weight and thrust was manageable by the Houdini ROV manipulator, and
- follow an autonomous scarifying path so that the ROV had to reposition the unit only at the end of each pass.

High-pressure water (up to 20,000 psig) was provided to the LSEE and was emitted from its two nozzles while they moved up and down the 10-ft vertical track of the end-effector. The manipulator on the Houdini II ROV was used to hold the tool by the tee handle manifold assembly (Fig. 6-16) during deployment and operation.

The LSEE was used to wash the walls of tanks W-8 and W-9 by making vertical sweeps of its high-pressure nozzles at a set location. Once this area of the wall was cleaned, the tool was repositioned by the ROV and the process repeated. The benefit of the LSEE was to allow wall cleaning without relocation of the MLDUA to all four of the peripheral risers. This saved more than 1 month of time per tank.

During the initial deployment in tank W-8, an effective scarifying strategy was developed. Although the water supply pressure was limited to 1500 psig during the deployment in tank W-8, it was determined that the Houdini manipulator was capable of handling the thrust produced by the high-pressure spray nozzles. Electrical problems with the prototype system used in tank W-8 resulted in abandoning the unit in place and the subsequent fabrication of a second unit for deployment in tank W-9. The second unit was designed for water pressures up to 30,000 psig. To minimize the amount of mist generated and to view the operation of the system as long as possible, the water pressure used in tank W-9 was limited to 3000 psig. Approximately 40 % of the vertical wall in tank W-9 was cleaned during ~7 h of operation. Control problems with the Houdini Titan III manipulator resulted in dropping the LSEE into the sludge on the bottom of tank W-9. Once the LSEE had been dropped and retrieved from the sludge a couple of times, the drive screw for the spray nozzles became coated with sludge, which eventually prevented the system from operating and resulted in abandoning the second prototype in place.

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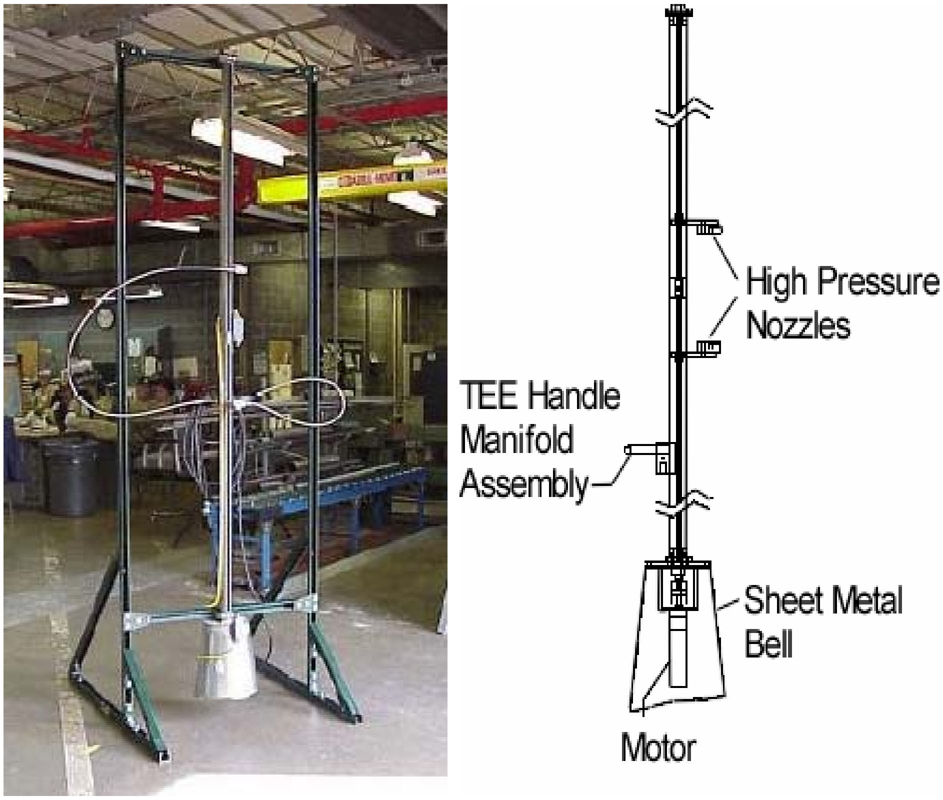
[12] C. L. Fitzgerald, D. Falter, and R. E. Depew, "Linear Scarifying End-Effector Developed for Wall Cleaning in Underground Storage Tanks," presented at the American Nuclear Society Ninth International Topical Meeting on Robotics and Remote Systems, Seattle, Washington, March 4-8, 2001.



Although limited success was achieved with the actual deployments of the scarifying end-effectors, the LSEE concept was demonstrated to be a viable concept for extending the wall-scarifying reach of vehicles like the Houdini up to 10 ft or more. The prototype systems deployed in the GAATs would have benefited from a more complete cold test program, including realistic deployment scenarios and extended operational time in the grasp of the ROV's manipulator.

Fig. 6-16. On the left: a photograph of the LSEE mounted on a test stand prior to cold testing; on the right: a diagram of the system.

7. WASTE-MIXING EQUIPMENT

Waste mixing was an important part of successful waste retrieval in the gunite tanks. Waste mixers were used in three of the gunite tanks to agitate the sludge and mix it with the supernatant to form a waste slurry that could be transferred out of the tanks. This section describes the equipment and technologies that were used for mixing and bulk retrieval operations during the GAAT Remediation Project.

7.1 PULSAIR™ MIXERS

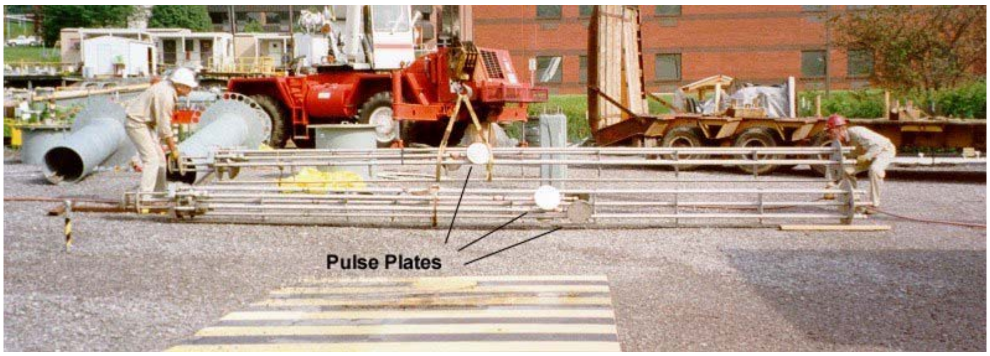


Fig. 7-1. Photo of the PAMs prior to their installation in tank W-9, showing the circular pulse plates attached to the piping, which was folded for installation through the 24-in.-diam tank access risers.

During waste retrieval operations, three Pulsair mixers (PAMs) were used in waste consolidation tank W-9 (Fig. 7-1) to keep retrieved sludge from resettling to the bottom of the tank. The PAMs were installed in June 1998 and used to mix the consolidated waste slurry from the other gunite tanks to maintain a suspended solids concentration that was acceptable for pipeline transfer to the MVSTs.

The mixers used a method known as pulsed-air mixing to mobilize, mix, and suspend sludges and sediments in the supernatant. In this method, pulses of air produce large bubbles near the tank floor to induce a mixing action as they rise to the surface of the liquid. Mixing is achieved as liquid is drawn into the low-pressure area under the bubble while liquid above is forced up and away from the rising air bubble. As the bubble breaks at the surface, horizontal forces move the liquid to the tank walls. The liquid travels along the tank walls to the bottom of the tank to complete the mixing cycle before the next pulse occurs.

The mixers had the ability to fold up and fit through the 24-in.-diam tank access risers. The PAM system consisted of three in-tank mixing assemblies, a controller, and necessary tank interface hardware. Each mixing assembly consists of a central accumulator plate with three or four satellite accumulator plates located at the ends of folding arms. The arms provide structural support and also functioned to convey air from a pressurized air source to the circular pulse plates at the end of each arm. Each pulse plate for the ORNL PAMs consisted of two circular parallel metal plates spaced ~0.25 in. apart. Once the mixer assembly was placed inside the tank, the arms unfolded to position the pulse plates at predetermined locations on the floor of the tank. Figure 7-2 is a view of the PAM assembly with its arms unfolded prior to installation in tank W-9. The pulse plates were positioned a few centimeters from the tank floor. Control equipment and pulsing valves were used to control the pulse frequency, duration, pressure, and sequencing to create optimal mixing conditions within the tank. A total of 13 pulse plates, ~1 ft in diameter, were positioned around the bottom of tank W-9 to agitate the waste slurry and maintain suspension of the solids using pressurized air.

The PAM system operated for more hours with less maintenance or interruption than any other system used during the remediation of the GAATs. The system was installed in tank W-9 in June 1998 and was first used for remedial operations in December 1998. The system continued in service through the entire MVST waste transfer campaign to the end of March 2000. The system logged a total of ~2390 h of operations.[13]

Fig. 7-2. PAM assembly with arms unfolded.

Only one maintenance action was required on the PAM system. One of the air supply pipes became clogged with sludge during installation. At that time, the sludge in tank W-9 was probably >2 ft deep and would eventually accumulate to a depth of >4 ft. The system was forced down into the sludge and was not operated for several months between the initial testing phase in June and routine operation beginning in December. It was thought that sludge hardened in the air supply pipe to one of the pulse plates and blocked the air supply. The air supply line to the plugged pulse plate was temporarily refitted for a process water supply, and the line was cleared using hydrostatic pressure. Resumption of continuous positive air pressure to the PAMs prevented the recurrence of this problem.

The PAMs should be operated continuously for improved results. It was determined during operations that the PAMs were better at maintaining solids in suspension than in mobilizing settled solids. The best results were obtained with the PAM system when the system was operated during waste consolidation operations. The system also performed well during waste transfers, which were completed near the end of the waste consolidation operations in tank W-9.

Lightning was also suspected of disrupting the PAM system by causing the control system to stop functioning. This situation was observed several times during inclement weather. It was never determined precisely how the system was disrupted, perhaps by power surges. After each outage, the control system was reset and the mixer restarted.

7.2 FLYGT MIXERS

Flygt mixers were successfully used in tanks W-5 and W-9 to mobilize the solids for transfer to the MVSTs. The mixers successfully agitated the sludge, forming a waste slurry, which was then transferred out of the tank. Two Flygt mixers were installed in tank W-5 to mobilize the sludge rather than using the RTCS (Fig. 7-3). The decision was made to use Flygt mixers in tank W-5 due to the visible deterioration of the tank walls in this tank. Using the Flygt mixers to mobilize the sludge for the retrieval operations in tank W-5 avoided the construction of an equipment platform and saved two to four relocations of the MLDUA, Houdini ROV, and other equipment. One of the Flygt mixers used in tank W-5 was also used

[13] J. A. Emison, B. B. Spencer, and B. E Lewis, *Gunite™ and Associated Tanks Waste Conditioning System: Description and Operational Summary*, ORNL/TM-2001/149, UT-Battelle, LLC, Oak Ridge National Laboratory, Oak Ridge, Tennessee, February 2002.

in tank W-9 to supplement the mixing performance of the PAMs during the final cleanout of tank W-9. The installation of the Flygt mixer in this tank only slightly improved waste mixing and solids suspension.

Fig. 7-3. Photo of the Flygt mixers prior to their installation in tank W-5.

The Flygt mixers included a mast-mounted 15-hp submersible electric motor with a three-bladed direct-drive axial-flow propeller to agitate the waste in the tank. The submersible motor mixer assemblies had been successfully used in industrial wastewater treatment, paper mills, and the chemical industry applications. Each mixer was attached to a mast assembly that supported all mixer loads from a structural steel platform located above the tank. The length of the mast was adjustable to allow the depth of the mixer to be changed according to the sludge depth beneath each mixer. Once lowered into the tank, the mixer was pivoted 90 degrees from its deployment position and locked into the horizontal-axis operating configuration. In this configuration, the mixer was able to develop high axial flows in the surrounding liquid/sludge materials, mobilizing and suspending the tank sludges into readily pumpable slurry.

The Flygt mixer system was generally reliable, requiring little or no maintenance. However, the system operators considered the mixers to be somewhat temperamental in regard to fault trips. Typically, fault trips were caused by an overcurrent to the motor. The system could be reset and restarted fairly quickly at slightly less current and, consequently, a lower operating speed. The Flygt mixers used in the GAATs were also considered slightly underpowered for this application, with motors rated at only 15 hp. More powerful off-the-shelf models that could be deployed through the existing risers were not available at the time of the GAAT Remediation Project.

Hardened aluminum alloy blades were originally installed on the Flygt mixers, based on the expected operating conditions in the gunite tanks. During installation, one of the propeller blades broke from an impact with the tank riser and the propeller on the other mixer broke from an impact with in-tank debris. The broken propellers were replaced with stainless steel units, and no further problems were experienced.

7.3 PULSATING MIXER PUMP (PMP)

The Russian-engineered PMP was deployed in tank TH-4 (Fig. 7-4) to mobilize the 2–3-ft layer of sludge present in the bottom of the tank. This device included a small pressure vessel, which was inserted into the tank (Fig. 7-5). The vessel has a large suction inlet port at the bottom with a ball-check valve, and an opposed pair of smaller discharge jet ports arranged parallel to the tank floor. A pressure/vacuum source, air distributor system, and control system supply cycling pressure and vacuum to the headspace of the pressure vessel, alternately drawing slurry or supernatant in and then discharging it through the discharge jets. The PMP requires no added working fluids unless needed to achieve a specific dilution.

The Russian PMP was operated for the shortest duration of all the components used in conjunction with the WCS. Tank TH-4 was the smallest of the gunite tanks, with a capacity of ~14,000 gal. The actual TH-4 cleanout campaign lasted only 3 days, and the PMP was operational for ~25 h. Additional time should have been allotted for checkout, adjustment, and operation of the PMP. Although the PMP was successfully used to clean out tank TH-4, hot checkout and operation of the system was limited to a 5-day period, due to budget and schedule constraints. Additional operation of the system would have allowed time for troubleshooting and improvement of the understanding of the applicability of the system in radioactive tank waste retrieval operations.

Fig. 7-4. Tank TH-4 waste mixing operations performed by the PMP in January 2001.

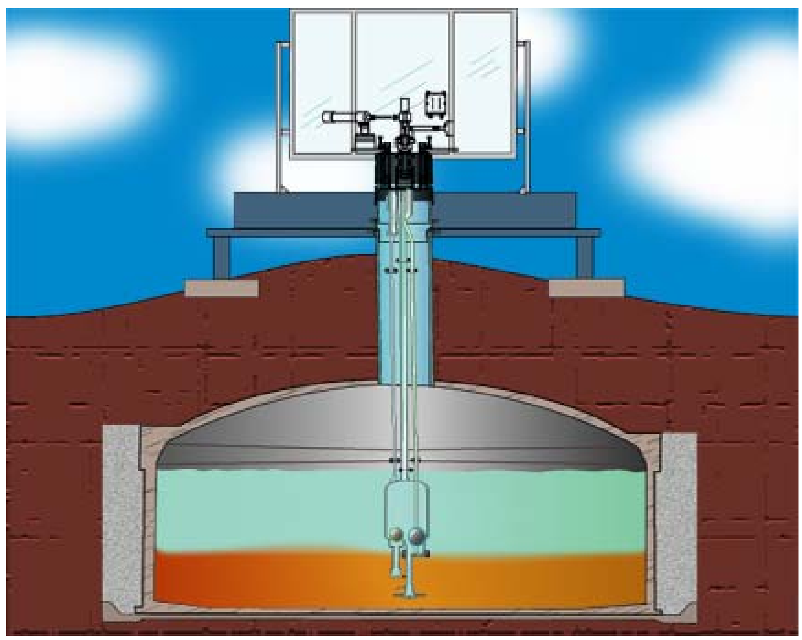


Fig. 7-5. Schematic cross section of the PMP installed in a tank and its containment structure on an equipment platform positioned over an underground storage tank.

8. WASTE-CONDITIONING AND TRANSFER EQUIPMENT

Specialized conditioning and transfer equipment were used to prepare the waste retrieved from the GAATs for safe transfer through the interconnecting pipeline from the STF to the active LLLW system. The interconnecting waste transfer pipeline at ORNL consists of a 2-in.-diam, double-contained underground line connecting the waste-generating and treatment facilities to the MVSTs. The pipeline is over 1 mile long and traverses elevation changes of ~200 ft. Due to the critical role of the waste transfer line in ORNL's operation, the GAAT slurry transfers had to be completed without plugging or damaging the line. Therefore, waste-conditioning and transfer equipment was selected and integrated to ensure the safety and operational integrity of the transfer line. This section provides summary information describing the equipment and systems used to condition and transfer the wastes retrieved from the GAATs. Emison et al. provide a more detailed description of the performance and operation of the waste-conditioning and transfer systems used at the GAATs.[13] Excerpts from Emison et al. are included in this section.

8.1 THE WASTE-CONDITIONING SYSTEM (WCS)

The WCS (sometimes referred to as the SCS) was stationed near the GAAT waste consolidation tank, W-9 (Fig. 8-1). The system was used to mobilize, retrieve, condition, and characterize the waste slurry before it was transferred to the MVSTs. The WCS was composed of two primary equipment enclosures, a submersible waste transfer pump (WTP), a mixing system, and the necessary interconnecting piping and valves. The two equipment enclosures were the PCS enclosure and the SMTL enclosure. Figure 8-2 provides a sketch of the layout of this equipment at the STF.

Fig. 8-1. Components of the WCS, as positioned in the STF near tank W-9 during waste retrieval operations.

The WCS was primarily operated using the PAM system to mobilize the waste in tank W-9. A Flygt mixer was also used in tank W-9 near the end of the waste retrieval operations. Section 7 provides a more complete description of the mixing systems used at the GAATs.

The WCS was operated in a batch mode, with dilute slurry typically maintained in suspension by the PAMs while the WTP circulated the slurry through the PCS, SMTL, and back into tank W-9. In-line slurry-monitoring instrumentation was used to monitor particle size and solids concentration in the slurry downstream of the PCS in the SMTL. After the solids content of the slurry appeared to be stable and consistent with the criteria for transfer to the active waste system, valves were positioned to divert the slurry flow from tank W-9 into the waste transfer line. Batch transfers up to 40,000 gal were made. Upon completion of a batch transfer, the piping was flushed with clean process water introduced at the PCS.

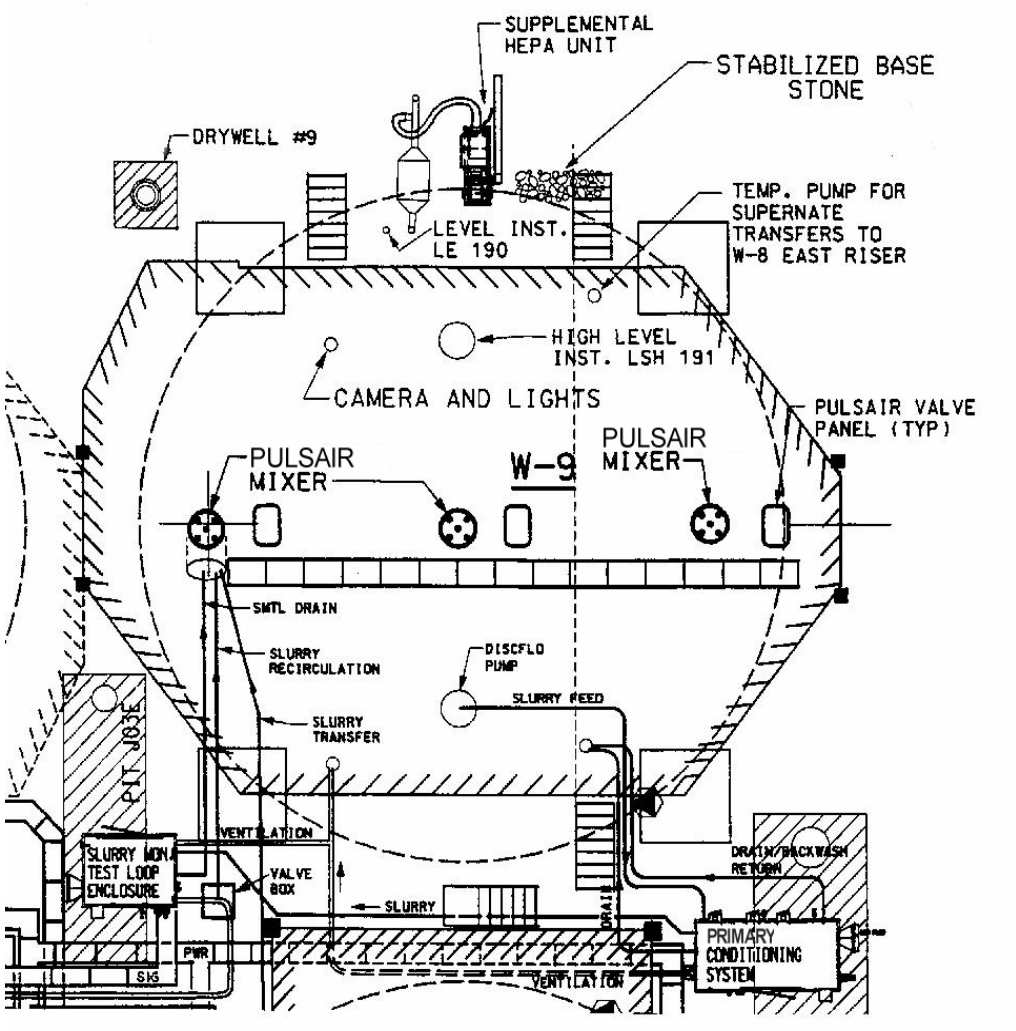


Fig. 8-2. Sketch of the WCS layout at tank W-9.

Double-contained piping was used for all radioactive waste transfer lines. Steel pipe was used for secondary containment for aboveground piping in the WTP piping loop. Polyvinyl chloride (PVC) pipe was used as secondary containment for some underground transfer piping applications (with steel primary piping).

The major components of the WCS are further described in the following sections.

8.1.1 Submersible WTP

The submersible WTP used with the WCS included a 125-hp electric motor with an integrated Discflo™ low-shear pump head. The Discflo pump combined the relatively simple design of a centrifugal pump with the capabilities of a progressive-cavity pump by using a series of rotating disks in place of a typical impeller. This type of equipment was capable of (1) pumping abrasive solids and entrained air with little or no internal wear to the pump head, (2) handling large solid particles, (3) exhibiting little or no increase in the discharge pressure even when the output line is blocked, and (4) generating discharge pressures in excess of 300 psig. The pump was equipped with a variable-frequency drive to control the pump speed and thus the desired discharge flow.

The WTP was mounted on a mast that could be raised or lowered in the tank. The steel deployment mast was attached to a structural platform located above the tank. The mast enabled the pump elevation to be adjusted over a range of ~20–26 ft below the riser in 1-ft increments. The WTP assembly was deployed through a 30-in.-diam riser on the south side of tank W-9. The pump was successfully used to transfer waste slurry through the 1-mile-long 2-in.-diam double-contained stainless steel waste transfer line.

After minor technical problems at the startup of operations in tank W-9, the WTP performed reliably. During the initial testing and installation in tank W-9, an electrical breaker on the 480-V power supply to the pump tripped open after a few hours of operation and could not be reset. Troubleshooting revealed a problem with the variable-frequency drive, which was determined to be caused by extremely low line impedance and a current imbalance across the phases on the ORNL power system. Installation of an isolation transformer and line reactor corrected the situation.

The WTP was observed to overheat when liquid levels in the tank were below the elevation of the motor housing. Because the pump was designed to operate submerged, air cooling was inadequate and an external supernatant flow of ~5 gal/min over the pump housing was subsequently used for cooling.

The WTP operated ~180 h in various recirculation and transfer modes. The total amount of waste transferred was ~483,300 gal, of which ~60,500 gal was wet sludge. Waste transfer operations were intermittent, based on available capacity in the LLLW system.

8.1.2 The PCS Enclosure

The PCS consisted of an enclosure (Fig. 8-3) that contained two parallel roughing filters, three sample ports, a pressure transmitter, a process water flush connection, and the associated valves and piping. The enclosure also included a high-efficiency particulate air (HEPA)-filtered air inlet and a ventilation connection with a back-draft damper that was used to maintain a negative pressure on the enclosure through a connection to the off-gas system for tank W-9. The PCS used a sump to collect any leakage that occurred from the process piping and a drain line that was routed back to tank W-9. A wash-down capability was installed to remove gross contamination inside the enclosure in the event of a catastrophic leak from the primary piping. A sludge grinder was also originally planned for the PCS but was omitted based on sludge characterization data that showed the solids retrieved from the GAATs were primarily <100-μm-diam particles, which met the acceptance criteria for the transfer to the MVSTs.

Fig. 8-3. PCS enclosure at GAAT W-9.

Waste was pumped from tank W-9 to the PCS using the WTP. The waste was then filtered and could be sampled prior to transfer to the SMTL. Samples of the flowing waste stream were taken throughout the mixing process and during batch transfer operations. To ensure compliance with the waste transfer line acceptance criteria, the roughing filters in the PCS were designed to remove solids that exceeded a diameter of 100 μm. Particles that collected on the filters were automatically backflushed to tank W-9, based on either an operator-selected time interval or a preset pressure drop. The roughing filters were used only during the initial transfer of material to the MVSTs. The filters frequently clogged and reduced the downstream pressure, which triggered the automatic backflush cycle, making it virtually impossible to maintain the pressure and flow needed for the transfer. It appeared that the sticky, cohesive nature of the sludge particles contributed to the blockage of the filters. For these reasons, use of the filters was discontinued. Data from the particle size analyzer in the SMTL as well as laboratory analytical data supported the fact that virtually no solids >100 μm were present in the slurry, which led to the conclusion that the classifiers were no longer required.

The PCS was used primarily to collect slurry samples during waste transfer operations. During the final cleanout of tank W-9 (WaRTS operation), and during the waste transfers from tank TH-4 (PMP operation), the PCS enclosure was used as secondary containment for the diaphragm pump used to transfer slurries from tank W-9 to BVEST W-23. The diaphragm pump was installed in the location that had originally been reserved for a grinder.

8.1.3 The SMTL

The SMTL included in-line instrumentation for measuring the solids content and particle-size distribution for the waste slurry. The criteria for transfer of waste slurries through the waste transfer line to the MVSTs require the concentration of suspended solids to be <5 wt % and the maximum particle size to be 100 μm.[14] The SMTL was designed to provide real-time monitoring of the radioactive slurry conditions before and during waste transfers to the MVSTs. Instrumentation monitored the slurry particle size, density, suspended solids concentration, viscosity, temperature, and flow. These monitoring capabilities were designed to operate remotely to minimize radiation dose to workers. The SMTL also included a sample port and HEPA filter air inlet (similar to the PCS), which were incorporated into a containment box that was located in the STF (Fig. 8-2).

The SMTL was designed for operation with pressures up to 300 psig, which was consistent with the maximum operating pressure of the Discflo pump and the ORNL waste transfer line. The system was designed so that any or all of the slurry-monitoring instruments could be used or bypassed as operating conditions required. The SMTL was housed in a steel enclosure, which served as secondary containment for the system components. Figure 8-4 shows the SMTL module in the midground and the air injection hoses attached to one of the three PAM assemblies, which is shown in a riser on tank W-9.

The SMTL provided measurements of particle-size distribution during all three phases of the slurry transfer campaign in the STF and in tank TH-4. The SMTL

Fig. 8-4. SMTL enclosure with top of PAM system in foreground at GAAT W-9.

[14] T. D. Hylton and C. K. Bayne, *Testing of In-Line Slurry Monitors and Pulsair Mixers with Radioactive Slurries,* ORNL/TM-1999/111, Oak Ridge National Laboratory, Oak Ridge, Tennessee, July 1999.

was operated continuously while slurry was being transferred from either tank W-9 or TH-4 to either destination (the MVSTs or BVEST W-23) in the ORNL active LLLW system. The operating times included ~180 h during WTP operations, ~88.5 h during WaRTS operation, and ~30 h during the Russian PMP operation in tank TH-4.

Project operators and management relied on the SMTL as real-time evidence that the waste slurry met the ORNL LLLW system waste acceptance criteria (WAC) with respect to the 100-µm particle-size limit. The SMTL also provided data on the solids content of the slurry. These data were important because the *STF Safety Analysis Report*[15] established limits on the activity (^{90}Sr equivalent) of the slurry that could be pumped through the system and the activity was related to solids content. While the SMTL provided a useful trend in total solids content (i.e., change in value), the actual percentage of solids was not a reliable measurement (i.e., absolute value). Project operators and managers chose instead to rely on analytical laboratory data for solids content. Therefore, laboratory analysis of slurry samples was used to estimate the quantity of solids transferred and the amount of residual material in the tanks following the final batch transfers. In addition to analytical data, operators also relied on radiation readings from a gamma radiation detector that was mounted on the waste transfer line from the SMTL. The detector provided reliable feedback on the radioactive material content of the waste slurry being transferred from the GAATs.

8.2 DIAPHRAGM PUMPS

Commercially available positive-displacement diaphragm pumps were routinely used to transfer wastes and fluids between the gunite tanks and the BVESTs and in the transfer of waste from tank W-5 to tank W-9. Permanent below-grade transfer lines and temporary above-grade transfer lines were connected to these pumps and used to convey the waste slurry.

8.3 WASTE RETRIEVAL AND TRANSFER SYSTEM (WaRTS)

The WaRTS was a key component of the Heavy Waste Retrieval System (HWRS), which was used to remove the sludge remaining in tank W-9 after the lightweight sludge had been mobilized and removed. It was installed on June 22, 2000, after the PAMs, Flygt mixers, and WTP were removed from the tank.

WaRTS was comprised of a Waste Stream Consolidation System (WSCS), a Supernatant-Pumping System (SPS), an air diaphragm pump, and a stand-alone control system for these components. The WSCS included a small accumulation tank and confinement box that was installed on and within a riser on tank W-9 (Fig. 8-5). It interfaced with the WD&CS, which was used to mobilize and transfer material from tank W-9 into the accumulation tank for subsequent transfer to the active system. A positive-displacement air-operated, double-diaphragm pump was added to the PCS enclosure to provide the necessary discharge pressure to overcome the combination of distance, elevation gain, and WCS roughing-filter differential pressure[16] and to satisfy the requirement to maintain uninterrupted turbulent flow through the transfer line. The WD&CS jet pump alone could not meet all the requirements for making the transfer from tank W-9 to BVEST W-23. As long as sufficient supply was available at the inlet to the diaphragm pump, it was capable of maintaining the required flow rate through the transfer line to tank W-23.

[15] L. Holder, Jr., *Phase 1—Safety Analysis Report (SAR) Update Program Hazard Screening–-South Tank Farm Facility 3507,* ORNL/M-2578, Oak Ridge National Laboratory, Oak Ridge, Tennessee, January 1993.
[16] The roughing filters are part of the WCS and were installed in the PCS enclosure.

Operators managed the waste level in the WaRTS accumulation tank to ensure a steady supply and flow to the underground pipeline to BVEST W-23. Operators also ensured that larger particles, which were initially mobilized by the jet pump and subsequently settled out in the accumulation tank, were returned to tank W-9. They also adjusted the water content as necessary to achieve the proper concentration of solids.

The WaRTS was designed to receive recycled supernatant from either tank W-8 or an auxiliary holding tank and also to receive waste from tank TH-4 through an aboveground doubly contained pipeline. "Recycled" supernatant and/or process water were added to the WaRTS accumulation tank to smooth the flow and to reduce the concentration of solids as required.

The secondary containment system for portions of the WaRTS was positioned on the W-9 work platform above a 34-in.-diam riser. The secondary containment system provided containment for the surge tank and the associated piping and valving. Any leakage drained back into tank W-9.

Fig. 8-5. WaRTS accumulation tank and confinement box assembly as it is lifted onto a riser of tank W-9.

Three remote-controlled, air-operated, solenoid-activated valves and a check valve were housed in the WaRTS secondary containment system. These valves controlled the flow of supernatant and could be positioned such that the supernatant was recirculated to the supernatant supply tank, added to the waste stream, or added directly to the holding tank. Check valves were included to prevent any slurry from entering the supernatant supply. Provisions for a clean process water flush of the system and decontamination of the containment system were also provided.

The WaRTS accumulation tank was designed for installation on an existing 24-in.-diam riser. The accumulation tank provided a surge volume between the WD&CS jet pump and the WaRTS transfer pump. It provided a working volume of ~200 gal, a settling volume of ~75 gal, and a ~50 gal capacity above the working high level. The tank assembly features included

- a remotely controlled drain valve in the bottom of the tank, which was designed to fail open, connected with a 4-in.-diam drain line that empties back into the source tank;
- level instruments that provided process information and signals used by either the control system to automatically control the process or the operator to manually control the process;
- a camera system with a remotely controllable variable light source and a remote capability to wash and rinse the camera lens to remove any material splashed during the pumping and waste transfer process;

- a remotely operable air and water sparger in the bottom of the tank; and
- a 4-in.-diam overflow or vent, which prevented overfilling or pressurization of the tank.

Because of the configuration of the waste transfer line between tanks W-9 and W-23, it was necessary to ensure a full pipeline and reasonably constant flow to prevent solids buildup in the transfer line. To ensure that these requirements were met, a makeup supply was added to the accumulation tank to maintain an adequate supply during slurry transfer operations.[17]

The heavier particles of sludge in the accumulation tank were allowed to settle out before transfer to BVEST W-23. Settling was an important operation since subsequent processing facilities limited the acceptable particle size and density of the sludge. However, since the objective of the cleanup operation was to remove the waste as efficiently as possible, settling had to be limited when the particle size and density were below the maximum threshold. In addition, the dense and adhesive nature of the sludge suggested the likelihood of blockages at the accumulation tank drain valve if too much settling was allowed to occur. An air and water sparger in the bottom of the surge tank was provided to permit agitation and mixing of the tank contents, thus controlling settling and limiting the likelihood of valve blockage. Another method to preclude blockage of the drain valve was to periodically drain the accumulation tank by opening the drain valve. Although effective, this second method reduced the efficiency of the waste transfer process, and it was not used as long as the sparger was operational and effective in preventing blockages.

In addition to settling, a second and equally important function of the accumulation tank was to provide a surge volume between the WD&CS jet pump and the WaRTS transfer pump. During sludge-removal operations, the MLDUA or the Houdini was used to move the CSEE over and through sludge piles on the bottom of tank W-9. The cutting jets on the CSEE dislodged the waste and created a slurry, which was vacuumed up by the jet pump and delivered to the accumulation tank inlet. Past experience with the CSEE suggested that as long as the sludge piles and slurry were easily mobilized, the jet pump was capable of delivering ~70 gal/min, which was a rate well above the minimum required flow rate for the WaRTS discharger pump (40 gal/min).[18] At other times, when the sludge piles and slurry become more difficult to mobilize, the flow rate into the accumulation tank could drop to as low as 10 gal/min. The accumulation tank provided a total surge capacity of ~250 gal, which could be used to give the WD&CS operators an opportunity to "catch up."

Past experience with the WD&CS suggested that the surge volume provided by the accumulation tank would be inadequate during certain portions of the waste removal. Depending on the nature of the sludge, delivery from the WD&CS jet pump can be extremely intermittent (e.g., when cleaning the final few inches of sludge from the tank floor). As a result, an SPS (Fig. 8-6) was added to provide makeup supply to the discharge pump when the level in the accumulation tank reached a preset value. The supernatant supply pump was identical to the discharge pump, but the discharge pump was independently controlled. During transfer operations, the supernatant supply pump was started and left running with remotely controlled valves positioned so that the supernatant recirculated to tank W-8, which was used as the supernatant reservoir. The operation of these valves was interlocked with the level instruments in the accumulation tank so that supernatant was delivered to the discharge pump when the level in the accumulation tank fell below a preset level. Unless reset by the operator, the position of the valves remained unchanged until a second, higher, preset level was reached. At that point the supernatant was again recirculated. A remote manual control capability was added to the control system so that the

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[17] U.S. Department of Energy, *Innovative Technology Summary Report: Heavy Waste Retrieval System*, DOE/EM-0595, July 2001.
[18] A 40-gal/min flow rate ensures turbulent flow through the 2-in.-diam transfer line, thus reducing the likelihood of settling.

operators could dilute the slurry in the event that the solids content was above the WAC for the destination tank.

The positive-displacement nature of the diaphragm pumps used in the WaRTS suggested a risk of significant pressures in the event of a deadheaded line downstream from the pumps. However, the downstream pressure from the air diaphragm pumps selected for this application was limited to the air pressure in the supply air line (in this case, <120 psi).

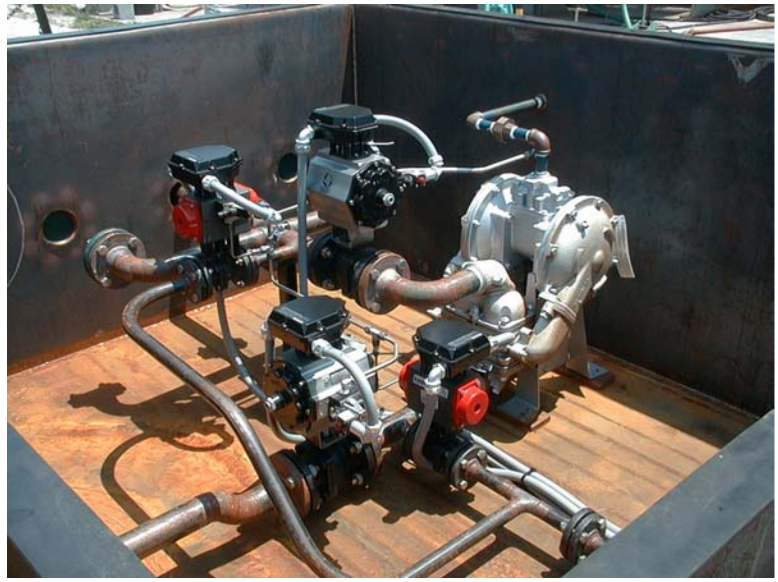

Fig. 8-6. SPS inside the containment box.

8.4 THE HWRS

The HWRS was the designation used for the assemblage of components that were selected and integrated for use in retrieval and transfer of the residual wastes from tank W-9 to the BVEST W-23. The residual waste in tank W-9 included debris and sludge that was not previously mobilized and transferred using the PAM, Flygt mixer, and WTP. A variety of options were considered by Lewis et al. during the conceptual design of the HWRS for GAAT W-9.[19] The resulting HWRS took maximum advantage of the waste retrieval and transfer equipment that was previously developed and used in the GAAT OU. This system consisted principally of the MLDUA, Houdini II, WaRTS, WD&C system, and WCS. During operations, waste was retrieved from tank W-9 using the MLDUA, CSEE, WD&CS, and Houdini II ROV. The jet pump associated with the WD&CS was used to create the vacuum needed for the CSEE to retrieve sludge from the floor of the tank and also to provide the downstream motivating force to transfer the waste slurry to the WaRTS accumulation tank. The screen on the CSEE intake limited the diameter of objects transferred out of tank W-9 to ~0.5-in. diam. The previously described features of the WaRTS controlled the concentration of solids in the discharge stream to tank W-23.

The HWRS generally performed as intended during final cleanup of GAAT W-9. As with the deployment of any new system, however, there was an opportunity to note deficiencies and make recommendations for improvements. These recommendations are presented in Sect. 8.5.

8.5 OPERATIONAL SUMMARY FOR THE GAAT WASTE-CONDITIONING AND TRANSFER EQUIPMENT

During the GAAT Remediation Project, the WCS succeeded in transferring ~654,000 gal of waste (total of solids, recycled liquids, in-leakage, and original supernatant) from the STF. These transfers included transfers from tank W-9 to the MVSTs (~483,000 gal) and to the BVESTs (~147,000 gal) and from tank TH-4 to the BVESTs (~24,000 gal). In addition to the solid and liquid wastes, a total of ~420,500 gal of fresh water (used in sluicing operations) was transferred. Including the sluice water, the total volume of

[19] B. E. Lewis, P. D. Lloyd, S. M. Killough, R. F. Lind, D. E. Rice, M. A. Johnson, and O. D. Mullen, *Basis for Selection of a Residual Waste Retrieval System for Gunite and Associated Tank W-9 at the Oak Ridge National Laboratory*, ORNL/TM-2000/251, UT-Battelle LLC, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September 2000.

material transferred using the WCS was ~1,074,500 gal.[20] The solids (sludge) portion of that total was ~94,000 gal. The transfers were accomplished without significant modification, maintenance, or change in operation of any of the WCS system components, with the following three exceptions: (1) the perceived reliability of the slurry density measurements from instruments in the SMTL (and the utility of temperature, viscosity, etc.); (2) the bypassing of the roughing filters in the PCS, in part because the data on particle sizes from the in-line particle size analyzer indicated they were not needed; and (3) the initial difficulties in getting the Discflo pump on-line.

[20] Transfer volumes were taken from Emison et al., ORNL/TM-2001/149 (ref. 13). Emison's estimates were based on logbook entries. These estimates differ from those reported in DOE/OR/01-1955&D1 (ref. 21, complete citation provided in Sect. 9). DOE/OR/01-1955&D1 does not include the waste transfers from TH-4, and Emison's estimates appear to include some recycled supernate in the waste transfer volume.

9. TREATABILITY STUDY PHASE 2—WASTE RETRIEVAL OPERATIONS AND SYSTEM PERFORMANCE IN THE NORTH TANK FARM

The waste retrieval operations in tanks W-3 and W-4 in the NTF were considered hot tests, which were performed as the second phase of the GAAT Treatability Study. The hot tests were conducted to determine the efficiency and performance of the RTCS and supporting equipment during operations in a radioactive environment. The NTF was used for hot testing due to the relatively low levels of radioactivity present in the wastes in these tanks. This section includes summary information on the waste retrieval operations conducted in tanks W-3 and W-4 and presents the performance results of the waste retrieval equipment in these tanks. More detailed information on the operations in the NTF and performance of the RTCS is provided by Rule et al. (1998).[7] A summary of the amount of waste transferred from the NTF is given in Table 9-1.[21]

Table 9-1. NTF waste removal performance summary

Condition	W-3	W-4	Total
Starting liquid volume, gal	15,688	29,754	45,442
Starting sludge volume, gal	5,500	13,500	19,000
Ending sludge/liquid volume, gal	100	100	200
Starting contamination, Ci	356	987	1,343
Ending contamination, Ci	12	11	23
Water used, gal	41,800	92,300	134,100
Waste removal % (volume basis)	99.7	99.7	
Waste removal % (Ci basis)	96.5	98.9	

9.1 WASTE RETRIEVAL OPERATIONS IN TANK W-3

Fig. 9-1. The RTCS equipment set up on the equipment platform constructed over tanks W-3 and W-4 in the NTF.

Tank characterization activities in tank W-3 began in April 1997. By this time the equipment platform had been constructed over tanks W-3 and W-4, so it was fairly easy to access the tank interiors (Fig. 9-1). A remote video camera was installed in tank W-3, and a tank inspection was performed on April 21, 1997. During the inspection the tank wall was scraped with a sampling device so that scale from the tank wall could be collected and analyzed to determine the type and amount of contamination present on the tank walls. The GIMP was installed in this tank so that the isotopic

[21] Bechtel Jacobs Company LLC (BJC). *Remedial Action Report on the Gunite and Associated Tanks Interim Remedial Action Project at the Oak Ridge National Laboratory Oak Ridge, Tennessee*, DOE/OR/01-1955&D1, Oak Ridge National Laboratory, Oak Ridge, Tennessee, June 2001

composition of the tank walls could be assessed. This tank characterization effort was conducted from April 21 through May 13, 1997. Waste characterization results in tank W-3 indicated that the sludge depth was ~24 in. and that the sludge was generally fluid in nature.

During May and June of 1997, the RTCS components were installed on the equipment platform over tank W-3. A readiness review was conducted from June 12 through June 24 to check out the waste retrieval systems and operating procedures. Operations began in tank W-3 on June 25, 1997, with the deployment of the Houdini I ROV. Primary operations in tank W-3 are described in the following sections.

9.1.1 Houdini I ROV Operations and Performance

On June 25, 1997, the Houdini I ROV was the first component of the RTCS to be deployed in Tank W-3. The ROV was deployed and retracted a total of 24 times during operations in tank W-3. Initially, the Houdini I ROV was used to determine the strength and flexibility of some small metal pipes that were obstructing its landing area. These pipes were suspended from the top of the tank dome and were no longer in use. The Houdini I was suspended above the floor of the tank and used to deploy a hydraulic shear to cut the pipes (Fig. 9-2). The pipes were later retrieved by the ROV and placed in a wire mesh bucket that served as a debris basket, removed from the tank, and packaged for disposal (Fig. 9-3).

Fig. 9-2. The Houdini I ROV preparing to cut piping obstructions in its landing area inside tank W-3.

The plow blade on the front of the ROV was used to break down sludge banks and push waste (plowing) toward the MLDUA and CSEE (Fig. 9-4). The onboard cameras, mounted on the wrist and body of the ROV, assisted with remote visual observations. The Houdini ROV was also useful in assisting with deployment of the HMA.

Fig. 9-3. Houdini I ROV holding debris basket inside tank W-3.

In general, the Houdini I ROV performed a wide variety of operations very well. However, the ROV routinely suffered from hydraulic fluid leaks from the numerous fittings and hose connections on the system. This problem area was successfully addressed in the improved Houdini II, which was deployed in the STF (see Sect. 6.4.2).

9.1.2 MLDUA Operations and Performance

Fig. 9-4. Houdini I ROV plowing sludge inside tank W-3.

The MLDUA was deployed in tank W-3 on June 26, 1997. The initial deployment was made to check out the system and to deploy the CEE, which was used to perform additional wall characterization. The MLDUA was deployed a total of 20 times in tank W-3. It was primarily used to position the CSEE during confined sluicing operations and to deploy the CEE during wall characterization. The repeatability and accuracy of the MLDUA's positioning system made it the ideal system to deploy the CEE for wall characterizations. Set standoff distances from the tank wall could be programmed into the MLDUA, which was helpful not only in maintaining the standoff distance between the CEE and tank wall but also for the CSEE during tank wall-cleaning operations. The MLDUA proved to be rugged enough to handle the reactive forces of the CSEE during sluicing operations at pressures <7100 psig. However, the dynamics of the DSR impinging on the MLDUA mast as it was withdrawn through the tank riser were such that decontamination operations had to be conducted at a pressure of ~500 psig, which was well below the 2100 psig maximum available pressure from the DSR. This lower operating pressure was found to be adequate for gross decontamination of the MLDUA.

9.1.3 WD&CS Operations and Performance

The WD&CS was deployed in tank W-3 on June 30, 1997. It was initially used to perform wall-cleaning operations, which occurred on July 1, 1997. The initial wall-cleaning efforts proved that the CSEE could effectively clean the aluminum hydroxide scale from the tank walls. The WD&CS was operated at a pressure of 6000 to 7000 psig, with a traverse rate of 0.25-0.5 in./s and a wall standoff distance of 4–18 in. Wall-cleaning operations used about 19.1 gal of water per square foot of wall.

Visibility was significantly impaired inside the tank during wall-cleaning operations because of the water vapor generated by the water jets impacting the tank walls. Therefore, the MLDUA was initially operated in a dry-run mode (i.e., without water feed to the CSEE) so that the arm movement/position could be programmed to avoid collisions with the tank wall during the wall-cleaning operations. Figure 9-5 shows the MLDUA holding the CSEE during wall-cleaning operations. The HMA is on the right side of the figure.

The WD&CS was also used to perform confined sluicing operations. Twenty-five separate sluicing events were conducted in tank W-3, with the resulting waste slurry transferred to tank W-4. Two of the sluicing events were performed to retrieve the supernatant. The vacuum power provided by the WD&CS jet pump was very effective for retrieving supernatant. Retrieval rates from 70 to 110 gal/min were recorded. The maximum signal from Coriolis flow meter registered at 110 gal/min. These rates include motive water rates of 9.5–10.5 gal/min, at supply pressures of 6000 to 7000 psig. Sludge washed from the tank wall during wall-cleaning operations was retrieved during five of the sluicing events. The remaining 18 sluicing events were either for sludge retrieval or for flush and decontamination water retrieval.

The sludge retrieval strategy included clearing an ~6- by 6-ft area down to the floor of the tank using the CSEE held by the MLDUA (Fig. 9-6). The cleared area served as a landing zone for the Houdini I ROV. After the area was cleared, the Houdini I ROV was deployed and used to manipulate the CSEE for additional sludge retrieval. Equipment operators performed sludge-mining operations to break up and slurry the thick and deep banks of sludge on the bottom of the tank. The CSEE was positioned along the side of a sludge bank so that its water jets could effectively cut through the sludge. The combined action of the water jets and the vacuum power of the CSEE would cause portions of the sludge wall to break away and slide into the cleared area on the tank floor. The Houdini effectively used the CSEE to clear away sludge banks at the tank wall and floor junction. After a sufficiently large area was cleared in the tank, the sludge-mining operations were conducted with the combined efforts of the MLDUA, Houdini I ROV, and the CSEE. While the MLDUA used the CSEE in a specific area of a tank, and the Houdini would drive up to sludge banks and use its plow to cut down the bank and then plow the sludge toward the CSEE. This combined effort proved highly effective in accelerating sludge-mining operations.

Fig. 9-5. Wall cleaning using the MLDUA and CSEE in tank W-3.

Fig. 9-6. Sluicing operations using the MLDUA, CSEE, and HMA in tank W-3.

Tank W-3 waste retrieval operations were completed on September 27, 1997. A tank inspection at the end of sludge-mining operations indicated that less than 1 in. of waste slurry remained in this tank (Fig. 9-7). The RTCS equipment was removed from tank W-3, and necessary maintenance and repairs were performed before the equipment was installed on the platform over tank W-4.

Fig. 9-7. Tank W-3 near the end of waste retrieval operations.

9.1.4 Waste Retrieval Performance in Tank W-3

Waste retrieval operations in tank W-3 resulted in the removal of ~96.5% of the contamination originally present. The retrieval rates and amount of process water used during sludge retrieval operations were dependent on the type of operations being performed and the characteristics of the sludge. The average combined waste retrieval rate from tanks W-3 and W-4 was

37.4 gal/min, including all the water added. The average amount of water added for the confined sluicing operations in W-3 was 4.44 gal of water per gallon of sludge pumped. It is estimated that if the sludge is relatively fluid and does not require additional mobilization and dilution by the CSEE, the water addition ratio could be reduced to 3.89 gal of water per gallon of sludge retrieved.

To ensure that objects would not become lodged in the throat of the jet pump in the WD&CS or the waste transfer lines, a screen was attached to the CSEE inlet to reject objects larger than 0.5 in. Plugging of this screen with debris and/or sludge occurred frequently, but was easily cleared by back-flushing with water. The back-flush system proved to be invaluable and provided the ability to dislodge blocked lines during operation and to clean the process lines at the end of each sluicing operation.

DSRs mounted to the top of the tank risers were used to decontaminate the MLDUA, Houdini I, and HMA as they were retracted from the tank. Decontamination of the MLDUA required ~17 gal of water per decontamination event, at supply pressures of 200–500 psig. Decontamination of the Houdini I ROV required an average of 45 gal of water per decontamination event at pressures of 500–2000 psig. Decontamination of the HMA required an average of 35 gal of water per decontamination event at supply pressures ranging from 1000 to 2000 psig.

9.2 WASTE RETRIEVAL OPERATIONS IN TANK W-4

The waste in tank W-4 was sampled on August 11, 1997, while waste retrieval operations were being performed in tank W-3. Tank W-4 served as a temporary waste holding tank for the waste retrieved from tank W-3. On August 16, 1997, about 14,500 gal of LLLW was transferred from tank W-4 to tank W-9 in the STF. A temporary aboveground transfer line (Fig. 9-8) was installed between these tanks. The transfer line ran across Central Avenue, so the road was blocked off and waste transfers were made after regular plant operating hours. An additional transfer of 10,500 gal was made to tank W-9 in September.

Fig. 9-8. Central Avenue with the temporary aboveground waste transfer line connecting the NTF to the STF.

Operations began in tank W-4 in early October 1997. The waste retrieval operations in tank W-4 were similar to those conducted in tank W-3 and began with tank wall characterization activities. The MLDUA was deployed in tank W-4 in the first week of October 1997. System checks were performed for the MLDUA, and autosequences for the deployment and retraction of the arm were defined. The reach of the arm inside the tank was also defined at this time. On October 22, 1997, the MLDUA deployed the CEE to determine the baseline radiation levels on the tank walls. Average radiation readings of 330–570 mR/h were measured at elevations of ~7 and 6 ft from the floor of the tank.

On October 23, 1997, a modified steel wrecking ball was deployed in tank W-4 to compact the sludge beneath one of the tank risers. The wrecking ball was equipped with an attached steel skirt on its bottom hemisphere, which formed a flat bottom, and was deployed from an overhead crane to compact the sludge under the riser where the HMA would be deployed. These operations were performed to ensure that there was sufficient headspace to deploy the HMA. Tank W-4 contained two very hard layers of sludge, which resulted in false depth readings when the sonar mapping was performed. The hard sludge layers acted like false tank bottoms, making the amount of sludge appear to be only inches deep when in fact it was several feet deep.

After the sufficiency of the headspace was verified, the HMA was installed and deployed the CSEE to remove ~18,800 gal of LLLW and 92,337 gal of additional process water over a 54-day operating period. The HMA was also used with FCEE to successfully retrieve heel material from the floor of tank W-4.

9.2.1 Wall-Cleaning Operations in Tank W-4

The MLDUA used the CSEE to clean the walls of tank W-4 to a height of ~10 ft from the tank floor at operating pressures up to 7000 psig. Wall-cleaning operations with the MLDUA were performed at an average pressure range of 5980 to 6020 psig and a rate of 0.25 in./s. Wall-cleaning operations successfully removed the aluminum hydroxide scale containing an estimated 3.7 Ci of radioactive material. Figure 9-9 shows a section of the wall in tank W-4 after cleaning. Approximately 15 gal of water per square foot of wall area was used in wall-cleaning operations in tank W-4. Trial scarification activities were performed on January 27, 1998, using the GSEE with the CSEE high-pressure water pump at a supply pressure of 6000 psig and 265-rpm rotational speed. True scarification (i.e., removal of a layer of gunite) of the tank wall was not possible at this supply pressure.

Fig. 9-9. Walls of tank W-4 after cleaning.

9.2.2 Sludge Retrieval Operations in Tank W-4

Sludge retrieval operations in W-4 were significantly more difficult than those in W-3 because of the existence of hard sludge material beneath the soft sludge in parts of the tank. Waste retrieval operations were performed at an average rate of 3.4 gal of sludge per minute using the CSEE. Water addition for the CSEE to fluidize the sludge, motive water for the jet pump, and flush water totaled 4.0 gal per gallon of sludge pumped. Sludge retrieval operations began on November 18, 1997, using the HMA and MLDUA with the CSEE. After clearing a landing area for the Houdini I, the vehicle was deployed on December 9, 1997, to assist with the sluicing activities by plowing sludge toward the CSEE and to maneuver the CSEE for sluicing operations. Problems with a broken wire in a servo valve delayed full deployment operation of the Houdini I until December 16, 1997, at which point the vehicle was used to break up and move around the hard sludge in the bottom of the tank. Since the weight of the Houdini I was in excess of 1000 lb, it was used to roll over the hard sludge material to break it into smaller more manageable pieces.

The Houdini I was also used in conjunction with the "Jaws-of-Life" hydraulic shear to cut the numerous floor-to-ceiling pipes left over from previous tank operations. Pipes were also discovered tangled up in the sludge beneath the riser openings. On one occasion, the pipes were cut into 1-ft sections starting at the floor of the tank. When the manipulator arm on the Houdini I could no longer reach the vertical pipes, the vehicle was suspended in midair to continue cutting the upper sections of the pipe. The remaining pipes were cut near the roof of the tank. The short pipe sections and other debris were later loaded into a debris bucket and transferred out of the tank. Typical debris found in W-4 included tape, steep pipes and cords, assorted hand tools, plastic bags, and bottles. The longer pipe sections were removed using a "nut hanger." Problems with the Houdini I during operations in W-4 included erratic behavior of the Schilling manipulator wrist because of a damaged slave controller cable and a damaged plow-lift mechanism. Repairs to the vehicle were made during movement of the equipment to the STF.

Once the majority of the waste had been removed from tank W-4, heel material was removed from the floor of the tank using the FCEE. The FCEE was deployed and held by the HMA to retrieve residual material from the floor of tank W-4 in the range of 1- to 0.5-in. depth. These operations resulted in the removal of ~98.9% of the contamination originally present in tank W-4.

Decontamination of the MLDUA, Houdini I, and HMA were accomplished using DSRs mounted to the tops of the tank risers. The systems were decontaminated using both the DSR and a handheld spray wand. Water usage was recorded only for the DSR. The average water usage per decontamination event was 32 gal for the MLDUA, 47 gal for the Houdini I, and 61 gal for the HMA.

10. WASTE RETRIEVAL OPERATIONS IN THE STF

This section describes waste retrieval operations in the STF. Rather than presenting the information in numerical order based on the tank numbers, the information is presented in the chronological order for tank waste retrieval operations. All tanks in the STF were 50-ft diam, with 12-ft-high vertical walls, and a domed roof with a 6-ft vertical rise at its highest point. These tanks had a capacity of 170,000 gal and showed varying degrees of contamination and interior deterioration. At the beginning of the waste retrieval operations, tank W-9 was designated as the consolidation tank for the waste retrieved from the other gunite tanks in the North and South Tank Farms. Tank W-8 also served as a supernatant consolidation and holding tank for the operations in the North and South Tank Farms during the GAAT remediation. A summary of the amount of waste transferred from the STF is given in Table 10-1.[21] The starting quantities given in Table 10-1 are based on best estimates and take precedence over the approximate starting volumes shown in the chronological plots for each tank in this section.

Table 10-1. STF waste removal performance summary

Condition	W-5	W-6	W-7	W-10	W-8	W-9	Total
Starting liquid volume, gal	27,964	41,479	3,565	105,860	64,581	45,616	289,065
Starting sludge volume, gal	6,600	12,880	10,100	28,100	10,400	9,300	77,380
Ending sludge/liquid volume, gal	2,610	1,567	476	786	544	1,398	7,381
Starting contamination, Ci	261	4,433	4,819	60,165	8,111	6,242	84,031
Ending contamination, Ci	83	564	208	1,064	844	1,148	3,911
Water used, gal	0	52,000	62,000	65,280	42,153	65,000	286,433
Waste removal % (volume basis)	98.5	99.1	99.7	99.7	99.7	99.3	
Waste removal % (Ci basis)	68.2	87.3	95.6	98.2	89.6	82.2	

10.1 TANK W-6 OPERATIONS

Tank W-6 is located in the southwest corner of the STF. Operations to support the cleanout and closure of tank W-6 began on March 19, 1998, with brief training periods on the use of the MLDUA and WD&CS equipment to familiarize the equipment operators with the operation of the equipment in the larger tanks. Tests were also performed to ensure the functionality of the equipment and/or the operation of the GSEE. Several types of operations were performed in tank W-6, which are described in the following sections. Other operations included equipment decontamination, repositioning equipment in order to accommodate waste retrieval, equipment handoff between the MLDUA and Houdini I, and standby time to investigate unusual circumstances, make minor repairs, and to adjust system operating parameters.

10.1.1 Initial Characterization Activities in Tank W-6

The initial characterization efforts in tank W-6 included tank inspection and sampling activities. The tank walls were scraped and the sludge was probed with hand tools to provide information on the condition of the tank walls and characteristics of the sludge in the bottom of the tank. Prior to these operations, in February 1997, the walls of tanks W-6 and W-5 were inspected using the TMS.[22] The TMS was used to measure the extent and depth of damage to the tank walls. A subsequent video inspection of tank W-6 revealed several areas on the tank walls where the gunite had dislocated from the wall, revealing the underlayer of wire mesh, which made the integrity of the tank walls questionable. Similar, but significantly greater, deterioration was observed in tank W-5, which is shown in Fig. 1-10. These observations raised a question and concern over the depth of the wall deterioration and whether the wall could withstand a high-pressure cleaning. The MLDUA was initially deployed in tank W-6 on April 20, 1998, and was used in conjunction with the CEE on April 21 to assess the contamination levels in the tank walls. The MLDUA also deployed scraping and pricking tools to obtain wall samples for chemical analysis. After informing the regulators of the conditions in tank W-6 and discussing the operations for wall cleaning, it was mutually agreed that a low-pressure spray would be used to rinse the walls of tank W-6.

10.1.2 Wall-Cleaning and Tank-Modification Operations in Tank W-6

Low-pressure testing of the GSEE as it was held by the MLDUA was conducted in tank W-6 beginning on May 4, 1998. The GSEE was initially deployed in NTF tank W-4 for a very brief test under low-pressure operation (<7000 psig). Testing in tank W-6 was initiated to further assess the performance of the wall scarification system at various water supply pressures and standoff distances from the tank wall. The GSEE was deployed in the tank using the HMA of the WD&CS. Testing and wall-cleaning operations with the GSEE held by the MLDUA continued through May 21, 1998. The tank wall in the north half of tank W-6 was rinsed at low pressure for a total of ~15 h, including ~6 h of testing.

The pipe-plugging tool was deployed by the MLDUA for the first time on May 27, 1998, to plug a leaky 3-in.-diam horizontal overflow pipe in the north quadrant of tank W-6. The pipe-plugging tool was one of three separate tools developed for use in remotely cutting and sealing piping inside the gunite tanks, the other two being the pipe-cutting tool and the pipe-cleaning tool. Beginning in tank W-7, the pipe-cutting tool was the primary tool used to clear piping from the gunite tanks. The pipe-cleaning tool was not required but was deployed in tank W-7 to validate the electrical operation of the tool. The pipe-plugging tool was used on three occasions—once in W-6, once in W-8, and once in W-9. The pipe plug used an epoxy sealant with a mechanical alignment/holding device to plug either horizontal or vertical pipes. The plugged pipe in tank W-7 was monitored through the end of 1998 and continued to show no signs of leakage. Prior to plugging, this pipe would routinely discharge groundwater into the tank. Moreover, the tank vacuum increased immediately from 1- to 2-in. of water after the pipe was plugged. Thus, the effects of isolating this pipe not only produced favorable results on groundwater in-leakage into the tank but also reduced the air in-leakage into the tank. The time required from plug preparation until the plug was installed onto the pipe was about 2 h.

Wall-cleaning operations in the southern half of tank W-6 were conducted using the CSEE as it was held by the MLDUA. These operations were conducted over ~9.5 h on August 5 and 7, 1998. All wall-cleaning operations in tank W-6 were performed at pressures less than ~7000 psig.

10.1.3 Waste Retrieval Operations in Tank W-6

The WD&CS HMA was first deployed in W-6 on May 5, 1998, to exercise the system after the move from the NTF. Operator training was also conducted at this time to practice grasping and handoff of the

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[22] G. A. Armstrong, B. L. Burks, and S. D. Van Hoesen, *South Tank Farm Underground Storage Tank Inspection Using the Topographical Mapping System for Radiological and Hazardous Environments*, ORNL/TM-13437, Lockheed Martin Energy Research Corp., Oak Ridge National Laboratory, Oak Ridge, Tennessee, July 1997.

CSEE and GSEE. The HMA was exclusively used to deploy the CSEE and GSEE into the waste tanks. Once inside the tank the CSEE and/or GSEE were handed off to either the MLDUA or Houdini ROV. The GSEE was eventually deployed by attaching a THS to the TRIC and placing the GSEE into the MLDUA gripper prior to deployment of the MLDUA. The GSEE THS was designed with hoses and couplings that could handle the high pressures of the UHPP, which was deployed during operations in tank W-7.

Sluicing operations to remove excess supernatant from tank W-6 were conducted on June 17 and July 16, 1998. Bulk sludge removal operations were performed using the CSEE and MLDUA from June 18 through July 15, 1998. These operations cleared a landing area for deployment of Houdini I ROV.

The Houdini I ROV was first deployed in tank W-6 on July 17, 1998. Sludge-mining operations were conducted from July 17, 1998, through August 4, 1998. Operations were conducted with the MLDUA grasping the CSEE and the Houdini I ROV breaking down banks of sludge and pushing them toward the CSEE with its plow blade. Sludge removal operations were continued on August 10 after minor equipment repairs were performed and the removal of a rag that became caught in the CSEE on August 7. After the rag was removed, the system did not immediately rotate properly. Problems with the HMA cable bundle delayed completion of sluicing operations until August 12, 1998.

After the waste retrieval and wall-cleaning operations were completed, the Houdini I ROV deployed the core-sampling tool to collect wall core samples. Surveys were also performed with the CEE. These surveys were used to determine the amount of wall contaminations that was removed during the wall-cleaning operations. These activities were conducted August 13 through 18, 1998.

A brief test of the GSEE held by the Houdini I ROV was conducted on August 19, 1998, prior to decontamination and removal of the equipment and tools from tank W-6.

10.1.4 Waste Retrieval Performance in Tank W-6

Waste retrieval was completed in tank W-6 on August 13, 1998. More than 87.3% of the contamination present in tank W-6 was successfully removed. The retrieval equipment was moved from tank W-6 to W-7 during the period August 25 through September 2, 1998. The total approximate operating times and tank operations conducted with the major equipment systems used in tank W-6 are given in Table 10-2.

Table 10-2. Operating times and tasks for the major equipment systems used in tank W-6

Description of operation	MLDUA	Houdini I	HMA	Cameras W-6	Cameras W-9
Characterization	26.5			26.5	
Sluicing and transfer	68.5	28	77	75	74
Plowing		6.5		1	
Wall cleaning	23	2.5	19.5	25.5	
Wall coring	5	4.5		8	
Training	5		5	5	
Equipment tests	7	3	4	7	
Miscellaneous	35	5.5	21	35	
Total (h)	**170**	**50**	**126.5**	**183**	**74**

A chronological plot of the waste retrieval operations in tank W-6 is provided in Fig. 10-1. This figure also indicates the approximate amount of water that was added to the tank during tank W-6 operations.

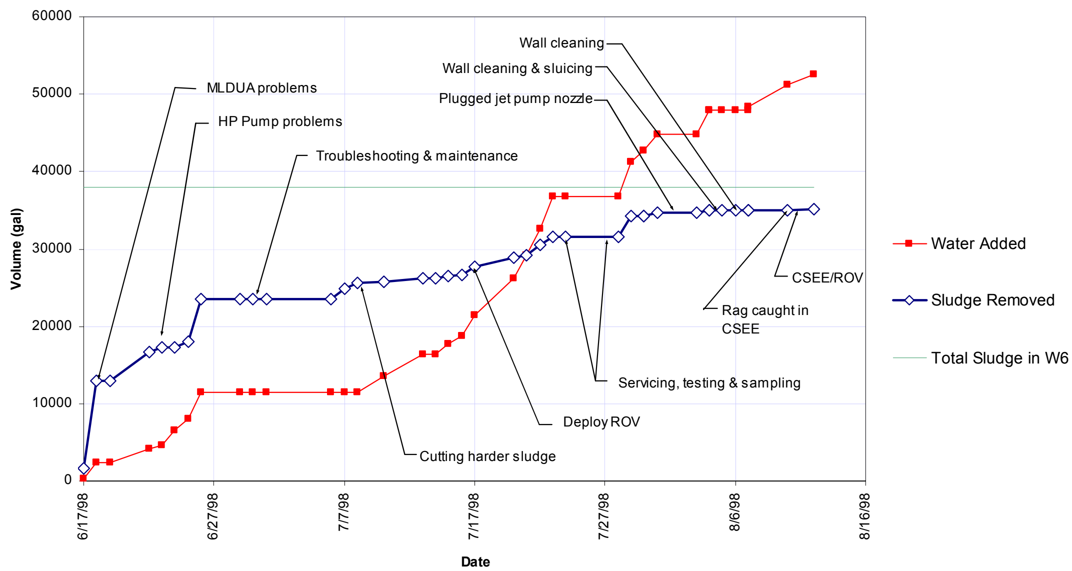

Fig. 10-1. Chronological plot of W-6 retrieval operations.

Confined sluicing operations were generally most productive in the deep, softer sludge encountered at the beginning of the waste retrieval operations, as is evident from the specific efficiency plots (Fig. 10-2). The initial day of sluicing operations resulted in an average retrieval rate of 7 gal of sludge per gallon of water used. As the level of waste in the tank was reduced, it became more difficult to maintain ideal pumping conditions (a flooded suction inlet and low-viscosity slurry), which resulted in a reduction in the retrieval efficiency. The retrieval efficiency continued to decrease as the depth of the remaining sludge decreased; the sludge density and overall hardness of the waste increased; and more buried debris was exposed. The instantaneous efficiency typically dropped off quickly to about 4–5 gal of water per gallon of waste. The cumulative retrieval efficiency shown in Fig. 10-2 and throughout Sect. 10 is the quotient of the cumulative waste retrieved divided by the cumulative water usage, asymptotic to the heel retrieval efficiency. The average heel retrieval efficiency reported is the amount of waste retrieved over water used for the portion of the campaign where the instantaneous efficiency has more or less stabilized at a low value. The average instantaneous sludge heel removal efficiency for tank W-9 operations was 0.39. The extrapolated values in Fig. 10-2 are the estimates to correct for missing water usage data (i.e., waste retrieved with no water used was assumed to have a water usage of 11,500 gal). The extrapolated corrections interpolate the water usage calculated from the waste retrieved data using (1) the last prior instantaneous efficiency value and (2) the average of 12 instantaneous values in the "typical" rate period between 15,000 and 40,000 gal of cumulative water use. The “Extrapolated Cumulative Efficiency” curve uses correction two as a basis.

The reduction in transfer efficiency from tank W-6 can be partially attributed to the presence of a mound of solidified sand that was sampled and found to have a very low radioactive material content. Review of the waste disposal records for the GAATs determined that this material had been excavated from the Nevada Test Site for experiments at ORNL. Since the material was extremely hard packed and of low radioactive material content, the majority of it was left in the tank.

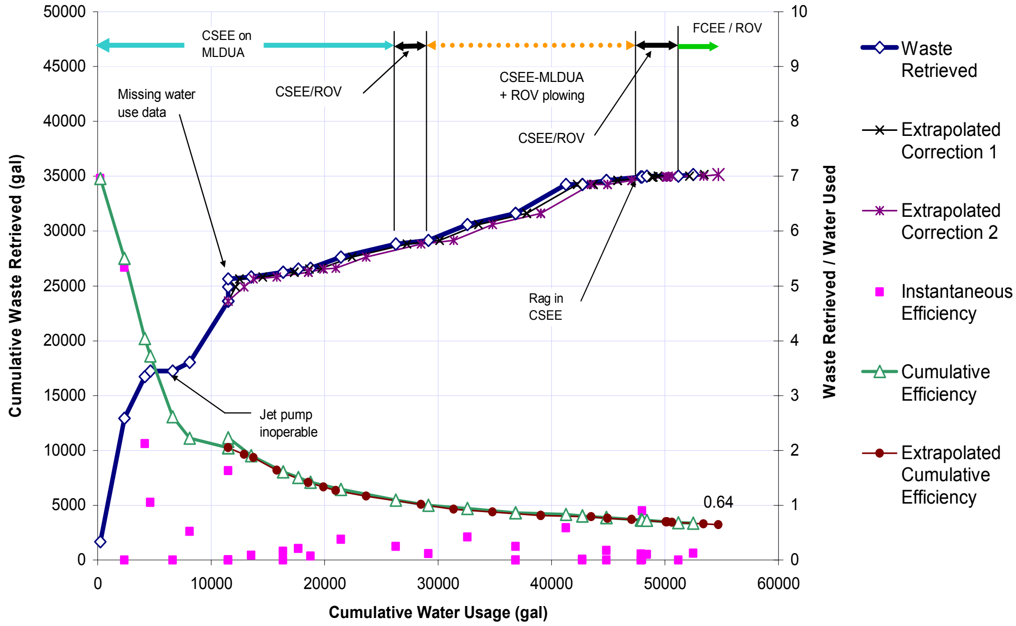

Fig. 10-2. Waste retrieval efficiency for operations in tank W-6.

10.1.5 Summary of Problems during Waste Retrieval Operations in Tank W-6

The following problems were noted by logbook entries during waste retrieval operations in tank W-6:

- A software problem with HMA control system caused erratic movement of the arm.
- Hydraulic fluid leaks on the track drive motor for Houdini I ROV occurred. The leaks were repaired and the Houdini I returned to service after 3 days of downtime.
- A jet nozzle on the CSEE became clogged. The jet was unclogged and operations continued after 1 day of downtime.
- A rag became caught in the rotating head of CSEE on August 7, 1998. After the rag was removed, the system did not immediately rotate properly.
- Problems with the HMA cable bundle delayed completion of sluicing operations until August 12, 1998.

10.2 TANK W-5 WASTE RETRIEVAL OPERATIONS

Tank W-5 is located in the northwest corner of the STF. Historically, this tank was used as a precipitation and holding tank for various types of LLLW resulting from ORNL operations. Acidic wastes from fuel reprocessing operations were typically neutralized before transfer to the gunite tanks. However, tank inspections conducted inside tank W-5 showed significant wall deterioration (Fig. 1-10), which indicated that the wastes transferred into tank W-5 may not have always been completely neutralized before transfer. The initial inspections of tanks W-5 and W-6 were conducted in February 1997 using the TMS to measure the extent and depth of damage to the tank walls. A video camera and lighting system were subsequently installed in the northeast riser of the tank. Detailed inspections of the tank walls indicated that the wall damage was primarily limited to the inner gunite layer with little or no damage to the primary outer gunite wall. Generally speaking, it was found that the inner 2–3 in.-thick layer of gunite had been removed over an area ~4-ft high that spanned the entire circumference of the tank walls.

As a result of the deteriorated condition of the walls in tank W-5, the decision was made not to deploy the RTCS components in this tank. It was thought that disturbing the walls from the actions of confined sluicing and wall cleaning might cause portions of the inner tank walls to fall and possibly harm the retrieval equipment. Instead of using the RTCS to retrieve the wastes from tank W-5, two Flygt mixers and a positive-displacement pump were used to mobilize and transfer the waste to the GAAT waste consolidation tank.

10.2.1 Initial LLLW Transfer from Tank W-5

A positive-displacement air-diaphragm pump was installed in the center riser of tank W-5 to transfer waste to tank W-9. The diaphragm pump was mounted inside the center riser and included a flexible suction hose. The flexible suction hose could be positioned at various depths in the tank by raising and lowering suction leg foot piece, which was attached to a steel cable that was secured to the tank riser.

The supernatant in the tank was transferred to tank W-9 to allow visual inspection of the sludge remaining on the bottom of the tank. During the tank inspection, the depth of the sludge was estimated and the locations of sludge mounds were noted. The inspection also revealed that debris (rubber bladders, concrete plugs, and steel cables) was lying near the intakes to the Flygt mixers. The steel cables presented a potentially significant operational problem for the mixers. The mixers utilize a propeller shroud configured for minimum flow restriction while affording protection from large objects known to be in the tank. This design is, however, potentially vulnerable to wire and small-diameter steel objects such as tubing and rods. Therefore, the decision was made to remove the mixers and relocate the interfering cables.

A novel method of capturing the cables was attempted that used a small remotely controlled boat equipped with a hook to catch the cables. Unfortunately the boat did not have sufficient power to pull the cables from the sludge in the bottom of the tank. More traditional means using long-handled tools were able to move the cables out of the way of the inlets to the mixers. Once the debris was relocated, the mixers were reinstalled in the tank.

After the tank inspection, supernatant from tank W-8 was pumped into tank W-5 to reduce the dose rate and also to reduce the likelihood of the formation of a sludge aerosol during subsequent equipment installation and mixing operations.

10.2.2 Waste Mixing Operations in Tank W-5

In July 1998, two Flygt mixers (Fig. 7-3) were installed in the east and west risers of tank W-5. During the installation the aluminum propeller on one mixer was broken after coming into contact with the tank dome as it was being lowered into the tank. There appeared to be no visible damage to the motor shaft or seals. Following replacement with a stainless steel propeller, the two mixers were reinstalled in tank W-5 and operated briefly while suspended over the LLLW to verify proper motor rotation direction.

Once the Flygt mixers were installed in the tank, they were pitched up 90 degrees from the vertical stowed position and locked into place with the axis of the motor in the horizontal plane. This configuration allowed the mixers to develop high axial flows in the surrounding liquid/sludge materials. The axial flow mobilizes and suspends the sludge in the supernatant to produce a pumpable slurry.

The direction of outflow from the mixers was set by manually rotating the support mast around the vertical axis and locking it into place prior to operating the system. This positioned the mixers to maximize the mobilization of the sludge mounds observed and noted during the initial tank inspection. Additional supernatant from tank W-8 was transferred into tank W-5 to establish a predetermined level and optimize the mixing performance of the Flygt mixers. The depth of each mixer was verified using the in-tank video camera system.

Visual observation of initial mixer operation indicated that significant turbulence was created in the tank contents, freeing several old floats (used in past tank-level measurements) from the surrounding sludge. During one of the slurry transfers to tank W-9, it was found that a piece of tubing from one of the floats was wrapped around one of the mixers, causing damage to a propeller blade. The mixer was removed from the tank and the propeller was replaced with a stainless steel unit before the mixer was reinstalled in the tank.

During the initial waste mixing operations in tank W-5, the mixer operating times were restricted to about 4 h. The mixers were initially shut down while the waste slurry was transferred to tank W-9. As operators gained more experience with the mixing system, the mixers were run for much longer periods of time. Typically, the Flygt mixers were operated for one or more 12-h shifts. A sample was taken to determine the amount of suspended solids in the waste slurry. The Flygt mixers were operated around the clock during batch transfers of the waste slurry, which typically lasted 2–3 days.

The transfer pump installed in the center riser successfully transferred the slurry to tank W-9. Each transfer lasted a few hours, and the liquid level in tank W-5 was reduced by 1–3 ft.

A waste inventory log was maintained throughout the transfer operation. The in-tank video system was used to monitor the mixing process, and an operator would stop the slurry transfer from tank W-5 at the start of cavitation. Cavitation occurred when the slurry level in tank W-5 dropped to the point that allowed the mixers to entrain a significant amount of air into the slurry and to begin to minimize the mixing intensity from the Flygt mixers. Once cavitation was noted, the ORNL Waste Operations Control Center would be notified that a chemical operator should be dispatched to transfer supernatant from tank W-8 to tank W-5. Job jurisdictional union issues required that a chemical operator perform this task and operate the supernatant pumps. The operation of any systems including pumps needed to mobilize and transfer waste slurry was the responsibility of GAAT project personnel. Supernatant was transferred for a few hours to raise the waste level in the tank back to the level before the slurry transfer was initiated.

Following each transfer from tank W-5, visual observations were used to change the mixer orientation to direct the discharge (and associated maximum turbulence and mixing intensity) toward areas with the most sludge. Operation of the mixers was continuous during slurry and supernatant transfers. When a sufficient amount of supernatant was returned to tank W-5 to achieve an appropriate waste level, the process was started over with another slurry transfer to tank W-9.

After a series of around-the-clock transfers for 2–3 days, another slurry sample was taken to compare the percent of suspended solids to the previous sample. The change in suspended solids supported a material balance and provided a basis to project the progress of the sludge removal process. Mixing operations would be interrupted and the tank pumped down again to detect any changes in the position and size of sludge mounds. The Flygt mixers were repositioned as necessary to apply the maximum mixing effect on the remaining sludge. At various times both directional and vertical repositioning of the Flygt mixers was undertaken.

This entire process was repeated several times until the effectiveness of the mixing and waste transfer operation diminished to the point that the suspended solids content of the supernatant in W-5 was less than 0.10 wt %, which occurred following the fifth mixing campaign, in November 1998.

10.2.3 Waste Retrieval Performance Summary for Tank W-5

During the September–November 1998 sludge retrieval activities in tank W-5, each Flygt mixer logged a total operating time of ~250 h. Table 10-3 summarizes the operating times for the major pieces of equipment used in tank W-5.

Table 10-3. Operating times for the major equipment used in tank W-5

Description of operation	Air diaphragm pump	Flygt mixers (ea)	Cameras W-5	Cameras W-9
Sluicing and transfer	84	69	86	86.5
Sludge suspension		181	18	
Total (h)	**84**	**250**	**104**	**86.5**

The Flygt mixers were easy to operate and proved to be quite reliable over the course of bulk sludge retrieval work in tank W-5. During waste-mixing and retrieval operations in tank W-5, about 3990 gal of sludge was transferred, leaving about 2610 gal of sludge out of the original 6600 gal contained in the tank. It is estimated that the radioactive contamination was reduced from about 261 to ~83 Ci (68.2% removal) as a result of sludge-mixing and retrieval operations. Based on contamination data from other gunite tanks, ~84% of the residual activity probably exists in and on the tank walls.

Regulators from the Tennessee Department of Environment and Conservation (TDEC) were present during a video inspection of tank W-5 following the final mixing campaign. They agreed that no further sludge retrieval from this tank was needed. DOE concurred with this assessment.

A key benefit of using the Flygt mixers for bulk sludge retrieval at W-5 was the ability to use existing supernatant liquids during mixing and solids suspension. While an estimated 250,000 gal of liquid was circulated through the tank in support of bulk sludge retrieval, 100% of this amount was recycled material. No additional process water was required, thereby minimizing the amount of LLLW requiring eventual treatment.

10.2.4 Summary of Problems from Waste-Mixing Operations in Tank W-5

The following problems were observed during the operation of the Flygt mixers in tank W-5:

- The only maintenance issue encountered was the durability of the original aluminum propellers. Both of the original propellers were replaced with stainless steel units.
- The Flygt mixer located in the east tank riser could not be run at full rotation speed due to a high current draw. It was theorized that this might have been associated with the incident in which the propeller was damaged during mixer installation. Even though the cause of the anomaly was not determined, the mixer operated reliably at a somewhat reduced speed for the duration of the tank W-5 operation.
- With only two mixers, the ability to fully mix the contents of the waste tank was somewhat limited, because a region of low turbulence (and associated settling) always existed somewhere in the tank. Potential remedies include using an automatic oscillating mixer mast to sweep the tank

periodically. Also the simultaneous use of three or more mixers in a tank would likely improve the performance of the system.

- Another limitation of the Flygt mixer configuration in tank W-5 was that the mixers could not be positioned any closer than 1 ft above the tank floor. This configuration has a compound effect of focusing the mixing energy directly in front of the propeller above the sludge layer and requiring a greater liquid depth/volume to operate the mixers. The additional liquid depth/volume requires additional energy to achieve a given mixing intensity or velocity relative to what would be required for a lower liquid level/volume.

10.3 TANK W-7 OPERATIONS

Tank W-7 is located between tanks W-5 and W-9 in the north side of the STF. Inspections of tank W-7 indicated that this tank contained hardly any supernatant and showed that the sludge waste contained large chunks of material, which posed a concern for waste retrieval operations in this tank. The sludge in tank W-7, as well as that in tanks W-8, W-9, and W-10, was a result of past collection and treatment (precipitation) of metal-bearing waste streams at ORNL. Operations to support the cleanout of wastes from tank W-7 began on September 30, 1998, and were completed on April 5, 1999. The general approach for this work was as follows:

- sluice loose sludge from the tank,
- scrape or scarify the tank walls or sludge surface to loosen additional sludge,
- sluice the loosened material from the tank,
- characterize the walls by sample analysis or probing, and
- repeat the scraping or scarifying operation as required.

Sludge removal operations started at the south quadrant of the tank, moving to the west, north, and east quadrants until the tank contents were removed to an acceptable level as measured by percentage of sludge volume or curie content removed. Tank W-7 was one of two gunite tanks in which the MLDUA was sequentially moved to each quadrant to facilitate the removal of waste.

The RTCS was moved from tank W-6 to tank W-7 between August 25, 1998, and September 3, 1998. The ensuing operations included setup of the DSR and TRIC on the tank W-7 risers, followed by placing the WD&CS HMA and MLDUA on the W-7 support platform. The MLDUA was first deployed in tank W-7 on September 28, 1998, to inspect and characterize the walls in the south quadrant of tank W-7 using the CEE. Piping hanging from the ceiling of the tank initially restricted the overall movement and operation of the MLDUA. The newly developed pipe-cutting tool was deployed in this tank to remove the obstructions. Wall-scraping samples were obtained in three campaigns beginning on September 30, 1998, and continuing throughout the remainder of the week.

10.3.1 South Quadrant Operations in Tank W-7

After some initial problems and learning experiences with a newly developed band-saw-type pipe-cutting tool, pipe-cutting operations were successfully performed in the south quadrant of tank W-7 on October 7, 1998. The pipe-cutting tool was deployed by the MLDUA to clear the way for unrestricted operation of the RTCS. The initial pipe-cutting effort was performed on a vertical 2-in.-diam pipe that unknowingly was not well attached to the ceiling of the tank. The pipe was cut successfully; however, as the lower pipe section fell to the tank floor, the pipe remaining in the ceiling also fell to the floor. This falling length of pipe was long enough to reach the floor and still remain in the ceiling of the tank. The falling section of pipe trapped the cutting tool and the MLDUA in the tank for a short period of time. The MLDUA was used to break the saw blade on the pipe-cutting tool and free the system. No damage to the pipe-cutting tool or MLDUA was incurred. The remaining piping in the south quadrant of the tank was cut the next day without incident. Further pipe-cutting operations were not needed again until November 19, 1998.

The GSEE was initially deployed by the HMA and handed off to the MLDUA in the south quadrant of tank W-7 on October 19, 1998, to scarify the tank walls. The GSEE was operated for ~7 h over a 2-day period at pressures <7000 psig. The GSEE was eventually attached to the THS and deployed in the grasp of the MLDUA GEE.

Sluicing and transfer of the sludge to tank W-9 was halted after 1 h of operation to replace the W-9 camera lights that had failed. After allowing the solids to settle over the weekend, the supernatant in W-7 was pumped to W-9 over a 4.5-h period. Again the GSEE was used for scarifying the walls in the south quadrant of the tank for a period of 5 h. A sludge depth probe (typically a metal rule) was grasped by the MLDUA GEE and used to measure the sludge depth. The sludge depth in the south quadrant was determined to be ~7 in.

When resumption of sluicing operations was attempted, the rotation of the CSEE nozzles was impaired. Inspection revealed that sludge was caked onto the CSEE and wedged between the rotating and stationary components. Removal of the caked-on sludge did not completely alleviate the rotational problems for the CSEE but did allow continued operation and the completion of sludge removal operations in the south quadrant of tank W-7. Sludge decontamination was accomplished using hands-on operations with high-pressure water spray tools inside the HMA glove box after gross decontamination during retraction through the DSR. The rotational problems with the CSEE were initially related to the use of plastic bushings between rotating and stationary components. The plastic bushings were easily deteriorated by grit in the sludge, which resulted in less efficient operation of the CSEE. Brass bushings were also used, but these resulted in seizing of the rotating nozzles when grit lodged between the stationary and rotary components. It was thought that a more powerful motor to turn the CSEE nozzles may have allowed the use of brass bushings on the CSEE.

Prior to moving the MLDUA to the west quadrant, the CEE was deployed to characterize the tank wall. When the need for additional wall cleaning was indicated, the tank wall was scraped with a tool affixed to the MLDUA. Operations in the south quadrant of the tank were completed on November 4, 1998.

10.3.2 West Quadrant Operations in Tank W-7

The MLDUA was moved to the west quadrant of tank W-7, and the initial characterization of the tank wall in this quadrant using the CEE began on November 18, 1998. The initial characterization of the west quadrant required ~3 h to complete.

Sludge removal operations continued in a similar manner as before. Using a scraping tool in the GEE of the MLDUA, scraping of the west quadrant tank wall required ~2.5 h to complete. The GSEE was then deployed to scarify the tank walls, but after ~1 h of operation, a leak occurred in one of the high-pressure fittings associated with the GSEE. The leak was repaired and, over the succeeding 2 days, the GSEE was used for an additional ~8 h to scarify the tank walls in the west quadrant.

The CEE was deployed on November 25, 1998, to characterize the tank wall over a 3-h period. Following this characterization operation, another 3 h of scraping using the MLDUA was needed to remove additional contamination from the tank walls in this quadrant. The CEE was deployed again on December 3, 1998, to survey the tank walls. This operation took ~3 h and was the last operation in the west quadrant of tank W-7.

10.3.3 North Quadrant Operations in Tank W-7

The MLDUA was next moved to the north quadrant of the tank. Sludge removal operations began in this quadrant on December 15, 1998. The wall was scraped, followed by characterization using the CEE. The pipe-cutting tool was then deployed by the MLDUA and used to cut three pipes in only 1 h of sawing operation.

Testing of the UHPP with the GSEE began on January 12, 1999, in the north quadrant of tank W-7. In the initial tests, a nozzle failure and a rotational problem with the GSEE caused an imbalance for which the MLDUA could not compensate. The problems with the GSEE were corrected, and wall-scarifying operations continued the following day. At a UHPP operating pressure of 25,000 psig, the MLDUA shoulder yaw joint faulted. Scarifying operations at various UHPP operating pressures between 7000 and 20,000 psig were successful, and qualitative tests were made at various standoff distances (distance between nozzle and working surface). Over a 4-day period, 14 h of scarifying operations was accumulated using the UHPP and GSEE. The 4-day scarifying period was necessary because of the low visibility caused by the mist from the scarifier operation. Although the operators utilized the robotic control mode of the MLDUA to operate even when visibility was zero, they also allowed the mist to clear from time to time to inspect the cleaned walls. The tank wall was then surveyed using the CEE, and samples were scraped from the wall using the MLDUA. Sludge removal operations using the CSEE were resumed and conducted over a 7-h period.

On January 28, 1999, the Houdini II was first deployed in the GAATs to measure the sludge depth and to plow the sludge toward the CSEE. Over 4 days of operation, the Houdini II accumulated 13 h of operating time before developing a hydraulic system leak. The leak was corrected, and sluicing and plowing operations continued until February 11, 1999. Another problem with the Houdini II during its use in tank W-7 was the loosening of frame bolts and manifold plugs, which periodically had to be inspected and tightened.

On February 17, 1999, the pipe-cutting tool was used with the MLDUA to cut several pipes in the north quadrant of tank W-7. The Houdini II was then used to move the cut pipes to a safe position. Core drilling of the tank wall in the north quadrant was attempted on February 18, 1999, but problems with the equipment caused the task to be temporarily abandoned.

10.3.4 East Quadrant Operations in Tank W-7

On February 25, 1999, the MLDUA was moved to the east quadrant of tank W-7. Operations similar to those used in the previous quadrants were used to characterize and scarify the tank walls and to plow and sluice sludge from the tank. Wall-scarifying operations using the GSEE and MLDUA were conducted from March 4–8, 1999. Core-drilling operations in this quadrant were successfully completed using the Houdini II on March 9, 1999. On March 10, 1999, the manipulator arm on the Houdini II failed and had to be placed in a stowed position and deactivated. The problem was later found to be caused by water leakage into the tether termination on the Houdini II, which required the replacement of the tether. Completion of the cleanout of tank W-7 using the CSEE held by the MLDUA and the Houdini II to plow wastes toward the CSEE was accomplished on March 16, 1999. Final sludge depth measurements were made using a rule attached to the MLDUA GEE on March 17, 1999.

10.3.5 Waste Retrieval Performance in Tank W-7

Sludge retrieval operations in tank W-7 were completed on March 18, 1999. More than 95.6% of the curie content of the waste in tank W-7 was successfully removed. The estimated total operating times for the major equipment components used in tank W-7 are summarized in Table 10-4. A chronological plot of the waste retrieval operations in tank W-7 is provided in Fig. 10-3. This figure also indicates the approximate amount of water added and sludge removed during tank W-7 operations. Figure 10-4 shows the specific waste retrieval efficiency of the various operations in tank W-7.

Table 10-4. Operating times and tasks for the major equipment systems used in tank W-7

Description of operation	MLDUA	Houdini II	HMA	UHPP	Cameras W-7	Cameras W-9
Characterization	44.5	1			44.5	
Sluicing and transfer	84		84		83.5	83.5
Plowing		40				
Wall cleaning	65		4	10.5	65	
Wall coring	3	6			7	
Training						
Equipment tests	3		1		3	
Miscellaneous	27	2	2		27	
Total (h)	**226.5**	**49**	**91**	**10.5**	**230**	**83.5**

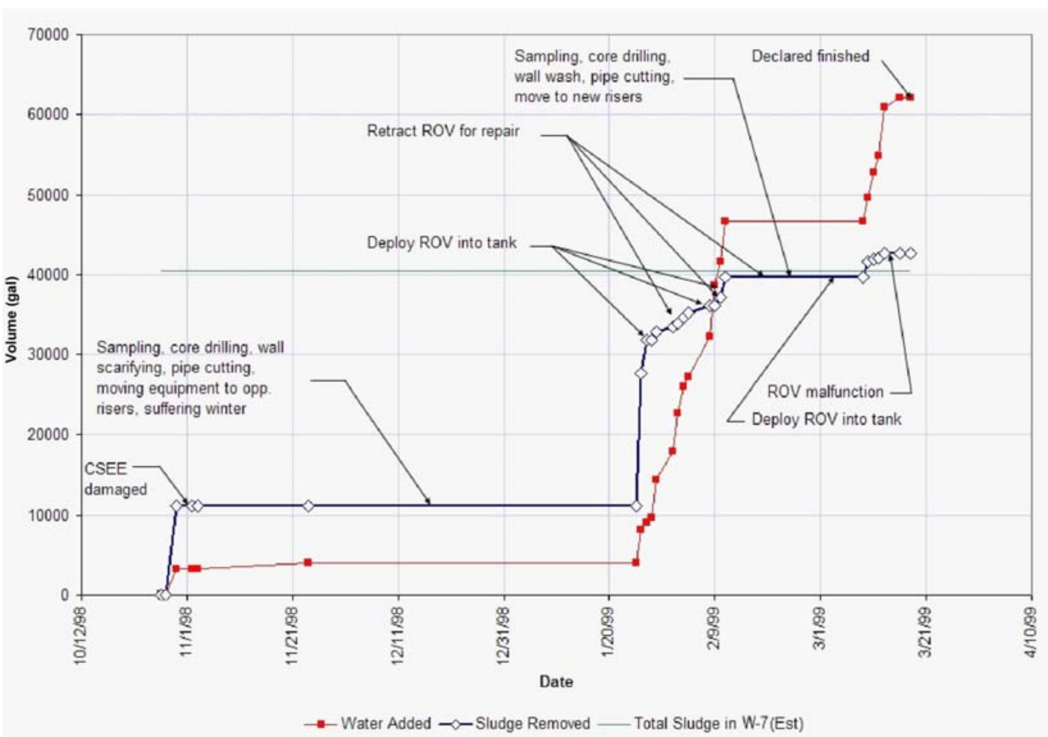

Fig. 10-3. Chronological plot of tank W-7 waste retrieval operations.

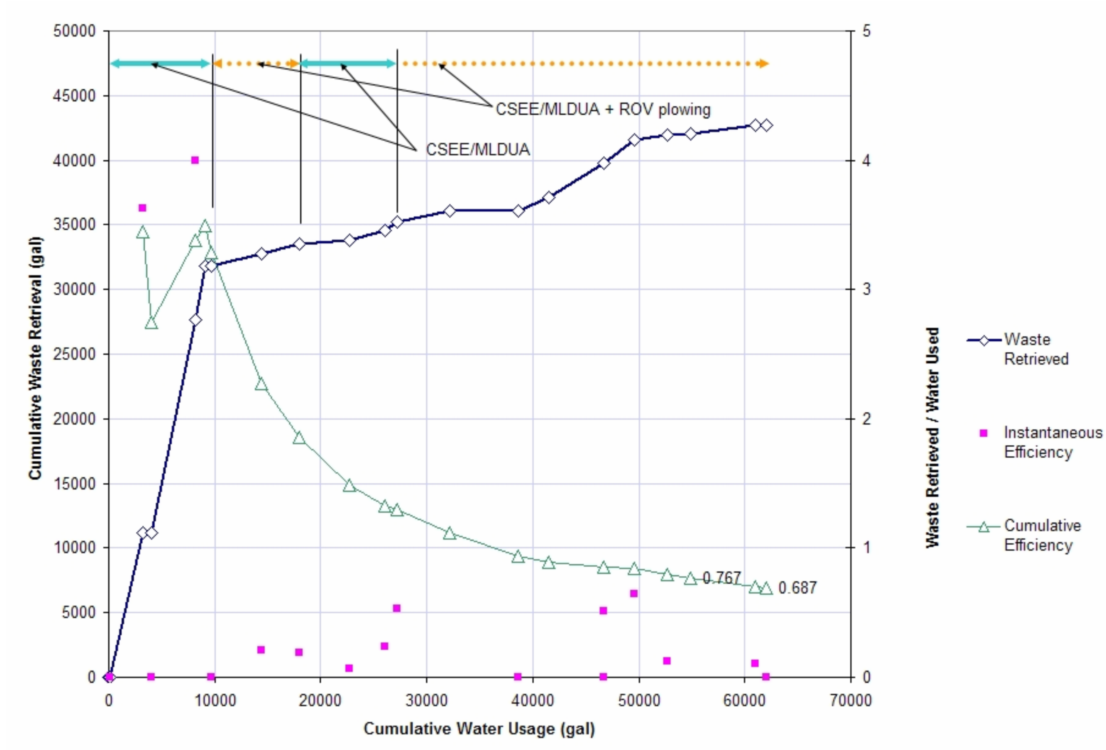

Fig. 10-4. Waste retrieval efficiency for operations in tank W-7.

10.3.6 Summary of Problems from Waste Retrieval Operations in Tank W-7

The following problems were observed during waste retrieval operations in tank W-7:

- A band-saw-type pipe-cutting tool was successfully used to remove piping obstructions from the inside of the tank; however, improvements to allow the release of the band-saw blade when the saw is trapped are needed to improve the utility of the tool.
- Sludge caked onto the CSEE and wedged between the rotating and stationary components. Removal of the caked-on sludge did not completely alleviate the rotational problems for the CSEE but did allow continued operation and the completion of sludge removal operations.
- The manipulator arm on the Houdini II failed as a result of a water leakage into the tether termination on the Houdini II. The tether could not be repaired and had to be replaced. An improved sealing and termination system is needed.
- During the initial deployment of the Houdini II, several minor hydraulic system leaks developed. These leaks were relatively easy to repair and less problematic than those observed with Houdini I.
- Frame bolts and manifold plugs on the Houdini II periodically had to be inspected and tightened.
- At a UHPP operating pressure of 25,000 psig, the MLDUA shoulder yaw joint faulted, necessitating operations of the GSEE at pressures <20,000 psig. Lateral force limitations must be considered when designing and operating high-pressure scarification equipment. Operating limits for the MLDUA design were calculated and verified during use of the GSEE with the UHPP.

10.4 WASTE RETRIEVAL OPERATIONS IN TANK W-10

Tank W-10 is located in the southeast corner of the STF. Waste removal operations in tank W-10 began on May 25, 1999, and were successfully completed on October 26, 1999. Tank W-10 was one of the two gunite tanks in which the MLDUA was sequentially moved from quadrant to quadrant as waste was retrieved. The MLDUA was initially installed in the northwest quadrant of the tank and was moved to the northeast, southeast, and southwest quadrants to complete the sludge removal operations. The general approach was to break up the sludge with the GSEE, sluice the material from the tank with the CSEE, and characterize the wall surfaces through either sampling or use of the CEE to ascertain the extent of sludge removal. The Houdini II vehicle was deployed in tank W-10 after about half of the waste had been retrieved and a clear landing area was provided.

10.4.1 Northwest Quadrant Operations in Tank W-10

Preparations for installation of the MLDUA at the northwest riser of tank W-10 were initiated on April 7, 1999. The HMA was placed in the center riser of the tank followed by the first deployment of the MLDUA in tank W-10 on May 20, 1999. The following day the pipe-cutting tool was deployed, but the task was delayed when the saw blade broke. While repairs were being made to the pipe-cutting tool, the CEE was deployed by the MLDUA for ~4.5 h of operation to characterize the internal tank surfaces. Deployment of the repaired pipe-cutting tool took place on May 24, 1999. About 3.5 h of pipe-cutting operations were conducted over a 2-day period to clear the piping from this quadrant of the tank.

The GSEE was first deployed in tank W-10 on May 27, 1999. After checkout, it was used for a 2.5-h period on June 2, 1999, to map the tank for subsequent automated scarifying operations. Automated operation of the GSEE was used to improve operational efficiency when the visibility inside the tank was decreased by the dense fog produced during scarification. During scarification, the GSEE was positioned by the MLDUA at ~10–12 in. from the tank wall and moved across the wall at a traverse speed of ~0.5 in./s to remove the scale layer from all accessible wall areas inside the tank.[23]

During the period June 4–16, 1999, the CSEE was used for 26 h to sluice waste from the northwest quadrant of the tank. On June 17, 1999, the northwest quadrant of the tank was scarified for 8 h using the GSEE. Characterization of the northwest quadrant of tank W-10 was completed the following day by using the MLDUA to obtain wall-scraping samples.

Near the end of the waste retrieval operations in the southwest quadrant of the tank, the Houdini II vehicle and TMADS were installed in northwest quadrant to facilitate final cleanout and characterization of the tank. These operations are further described in Sect. 10.4.4.

10.4.2 Northeast Quadrant Operations in Tank W-10

Work to move the MLDUA to the northeast quadrant of tank W-10 was initiated on June 23, 1999. Severe weather delayed the completion of the move until July 8, 1999. Operations including ~4.5 h of pipe cutting, 11 h of sluicing with the CSEE, and 5 h of scarifying with the GSEE proceeded without incidence and were completed on July 27, 1999. Wall-cleaning/scarifying operations were primarily conducted with the UHPP operated at pressures ranging from 6000 to 10,000 psig. Installation of the Houdini II vehicle at the northeast quadrant of the tank began on August 4, 1999. The Houdini II vehicle was then used in conjunction with the MLDUA and CSEE to retrieve the wastes from tank W-10.

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[23]U.S. Department of Energy, *Innovative Technology Summary Report: Gunite Scarifying End Effector*, DOE/EM-0610, September 2001.

10.4.3 Southeast Quadrant Operations in Tank W-10

Moving the MLDUA to the southeast quadrant of tank W-10 began on July 30, 1999. Pipe-cutting operations using the pipe-cutting tool and MLDUA were performed in this quadrant on August 11, 1999. With the piping obstructions cleared from the quadrant, sluicing operations began the following day and continued through August 16, 1999. The actual sluicing time during this period was ~9.5 h. Scarifying operations using the GSEE with feed from the UHPP were completed over the succeeding 2-day period with an accumulated 5.5 h of operation. Operations in the southeast quadrant of tank W-10 were completed August 19, 1999.

10.4.4 Southwest Quadrant Operations in Tank W-10

Moving the MLDUA to the southwest riser took place August 20–26, 1999. Pipe-cutting operations on September 1, 1999, required only 1.5 h to complete and clear the way for unrestricted operation of the MLDUA and CSEE. Over a 2-day period, September 7–8, 1999, the CSEE was used for ~10 h to sluice the wastes from this quadrant of the tank. The CEE was then deployed by the MLDUA to characterize the tank walls. Scarifying operations using the GSEE and UHPP were conducted on September 13–14, 1999, for ~6.5 h of accumulated scarifying time. Another 3 h of operation of the CEE to characterize the tank surfaces took place on September 17, 1999. Because of wear and tear, new nozzles were installed on the GSEE and on October 1, 1999, these nozzles were checked in a 1.5-h test.

Preparations to move the Houdini II/TMADS began on October 5, 1999. The TMADS was placed at the northwest riser of the tank on October 13, 1999. On October 15, 1999, sluicing operations with the CSEE resumed. The Houdini II was deployed in the tank on October 18, 1999. Both the MLDUA and Houdini II were used with the CSEE for sluicing and wall-washing operations. On October 20, 1999, problems with the articulated arm on the Houdini II slowed work. No problems were reported the following day. The core-drilling tool was deployed using the Houdini II on October 22, 1999. Although problems with the arm were again encountered, three core samples were obtained in 4 h of operation. Waste retrieval operations in tank W-10 were considered complete on October 26, 1999.

10.4.5 Waste Retrieval Performance in Tank W-10

More than 98.2% of the curie content of the waste in W-10 was successfully removed. The ROV was used only for washing the walls and knuckle of tank W-10 and bulldozing during the last half of the waste retrieval efforts in the tank. The total estimated operating times for the major equipment components used to remove sludge and supernate wastes from tank W-10 are summarized in Table 10-5.

Using the UHPP with the GSEE proved to be highly effective in reducing the radiation levels in the tank wall.[23] Wall-cleaning/scarifying operations were successfully conducted at pressures primarily in the range of 6000 to 10,000 psig. After scarification, radiation levels in the tank wall were reduced by approximately 50–60% of their initial values. A chronological plot of the waste retrieval operations in tank W-10 is provided in Fig. 10-5. This figure also indicates the approximate amount of water added and sludge removed during tank operations. Figure 10-6 shows the specific efficiency of the various waste retrieval operation in tank W-10.

Table 10-5. Operating times by task for major equipment systems used in tank W-10

Description of operation	MLDUA	Houdini II	HMA	UHPP	Cameras W-10	Cameras W-9
Characterization	11				11	
Sluicing and transfer	66.5	4	66.5		66.5	66.5
Plowing						
Wall cleaning	27.5	4.5		25.5	30.5	
Wall coring		4			4	
Training						
Equipment tests	1.5			1.5	1.5	
Miscellaneous	22	1			23	
Total (h)	**128.5**	**13.5**	**66.5**	**27**	**136.5**	**66.5**

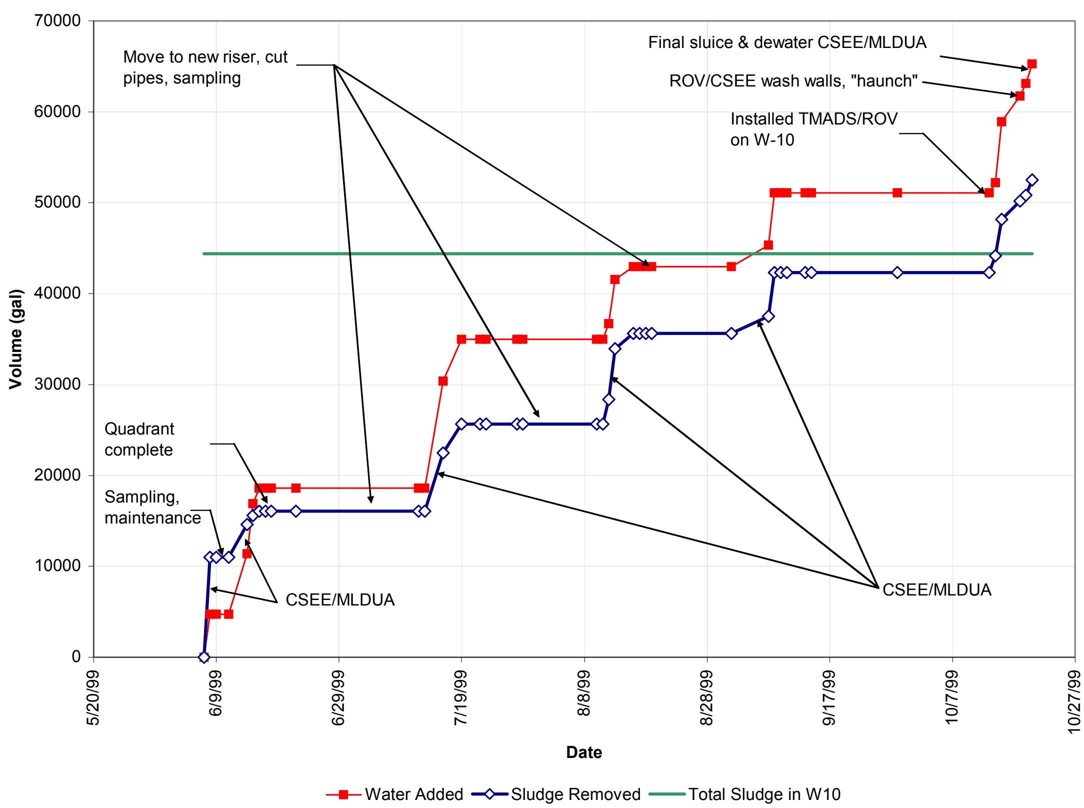

Fig. 10-5. Chronological plot of tank W-10 waste retrieval operations.

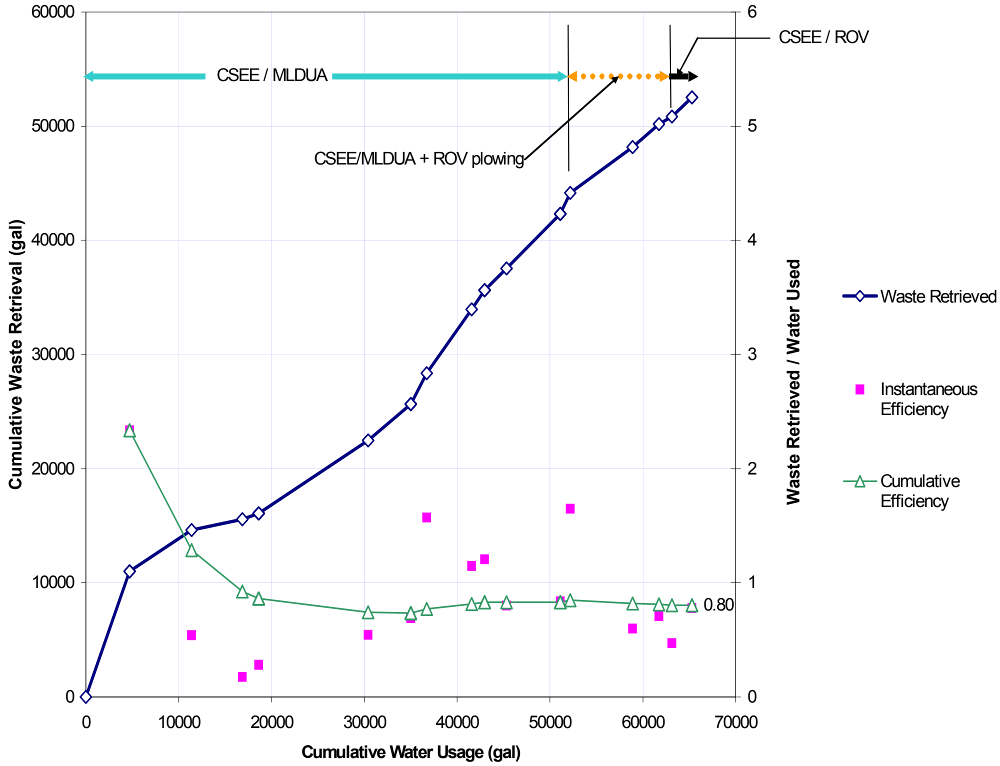

Fig. 10-6. Waste retrieval efficiency for operations in tank W-10.

10.4.6 Summary of Problems from Waste Retrieval Operations in Tank W-10

The following problem was observed during waste retrieval operations in tank W-10:

- Substantial misting and reduction in visibility occurred while operating the GSEE near the tank walls. Computer-programmed operation of the MLDUA was required to maintain a constant distance from the tank wall and to ensure safe and efficient operations.

10.5 WASTE RETRIEVAL OPERATIONS IN TANK W-8

Tank W-8 is located between tanks W-6 and W-10 in the south side of the STF. Operations began in tank W-8 on December 11, 1997, when the decision was made to use this tank as the supernatant holding tank for the operations in the North and South Tank Farms during the GAAT remediation.

Waste retrieval operations began in tank W-8 on November 29, 1999. The waste from tank W-8 was transferred to tank W-9, where the sludge was allowed to settle. After 3 or more days of settling, supernatant was pumped from the top of tank W-9 back to tank W-8, where it was either used in continuing STF operations or transferred to the ORNL active waste system. Since most of the waste in tank W-8 was relatively fluid and easily suspended,[3] the overall removal efficiency was higher than that for the previous tanks.

As the GAAT Remediation Project progressed into its third year of field operations, significant wear and tear on some of the equipment systems became apparent. The MLDUA began experiencing signal problems in its main cable bundles, which eventually led to the partial loss of movement in 1 DOF. Stopping the project for a protracted maintenance period for the MLDUA was not practical as long as the system remained functional. The decision was made to keep the MLDUA in service with the system lead working around the signal problems to the greatest extent possible. In order to reduce unnecessary wear and tear on the MLDUA and to avoid likely downtime, another decision was made to eliminate high-pressure wall-scarifying operations in tanks W-8 and W-9 using the MLDUA and GSEE. Waste retrieval operations in tank W-8 were completed on March 28, 2000.[21]

10.5.1 Operations in the South Half of Tank W-8

In-tank operations in W-8 were initiated on November 18, 1999, when the pipe-cutting tool was deployed by the MLDUA through the tank's south riser. Pipe-cutting operations were conducted to remove in-tank obstructions prior to deployment of the MLDUA and Houdini II for use in waste retrieval operations. The initial pipe-cutting operations were completed over a 2-day operating period with an accumulated cutting time of ~3 h. The CEE was deployed and the tank wall was characterized in 1 h of operation. A scraping tool was deployed using the GEE on the MLDUA to obtain three wall-scraping samples.

The CSEE was initially deployed by the HMA in tank W-8 for waste retrieval operations on November 29, 1999. After 1 h of operation, work was halted to make repairs and adjustments to the HMA. Other maintenance, including replacing a clogged HEPA filter on the off-gas system was completed the following day. Sluicing operations using the CSEE with the MLDUA progressed smoothly during the remainder of the week and into the following week. Scrape samples were obtained using a scraping tool that was held by the MLDUA GEE. The tank walls were also characterized using the CEE before moving the MLDUA to the north half of the tank.

10.5.2 Operations in the North Half of Tank W-8

Efforts to move the MLDUA to the north riser of tank W-8 took place during the last 2 weeks of 1999. Before sludge removal operations resumed, tank W-8 was used as a holding tank for supernatant from tank W-9 while the topography of the sludge in W-9 was examined. The supernatant was pumped from tank W-9 to tank W-8 on January 4, 2000, and returned on January 6, 2000.

Characterization of the walls around the north riser of tank W-8 using the CEE and MLDUA was completed on January 10, 2000, after ~1.5 h of operation. The CSEE was then deployed by the HMA and handed off to the MLDUA to begin the retrieval of wastes from the north half of tank W-8. By the end of the day on January 11, 2000, ~7 h of sluicing operations had been completed with the CSEE. Operations were halted when a hydraulic fluid leak developed at the base of the Vertical Positioning Mast (VPM) for the MLDUA. The leak was repaired by January 27, 2000, and waste retrieval operations using the CSEE and MLDUA resumed on January 31, 2000.

On February 1, 2000, the CSEE nozzles became plugged. It was thought that the nozzles had been inadvertently inserted into the sludge during deployment when the water feed to the nozzles was turned off. Manipulating or pulsing the water pressure and cleaning with the DSR were used to free the obstruction from the CSEE nozzles. Such trial-and-error methods were often used to clear plugs or free the rotation. Direct hands-on repair of problems in which the precise cause could be identified was the method of last resort because of the cost, time, and potential radiation exposure to personnel. By February 3, 2000, the nozzles were cleared and sluicing continued.

On February 8, 2000, the CSEE was deployed by the HMA and handed off to the Houdini II ROV to accomplish ~6 h of sludge mobilization and sluicing operations. The following day, the CSEE was used with the MLDUA for another 5 h of sludge removal. On February 10, 2000, the CSEE was again used with the Houdini II for ~5 h of sludge mobilization and sluicing operations.

The pipe-plugging tool was deployed by the MLDUA on February 14, 2000, to plug an overflow pipe that connected tank W-7 to tank W-8. This task required 1.5 h to complete.

The LSEE was first deployed in tank W-8 on February 28, 2000, for wall-washing tests. About 6.5 h of operation was completed the first day. Problems with the LSEE developed the following day. Loops in the hoses of the LSEE jammed the MLDUA when attempts were made to retract the LSEE from the tank. The limited size of the riser would not permit both the MLDUA and LSEE hose loops to pass unless the hose loops could be compressed. However, the hose loops were sufficiently rigid that the force used to pull the hose also pulled the MLDUA off the vertical before the hoses would yield. The consequence of tilting the MLDUA mast caused the cables in the retrieval mechanism to slip off the guide grooves; thus, attempts to forcibly remove the hose had to be discontinued. No quick repair for the LSEE could be identified, so it was abandoned in place on March 2, 2000, to avoid adversely affecting the remediation schedule.

Wall-washing and sludge transfer operations resumed March 3, 2000, using the CSEE and Houdini II. The Houdini II was also used for pushing (plowing) sludge toward the CSEE. Sludge removal operations were completed on March 9, 2000. The Houdini II was used on March 13, 2000, to obtain five wall core samples, which required ~4 h of operating time. A final 1-h sluicing operation was used to remove the remaining water–supernate mixture from the floor of tank W-8. On March 15–16, 2000, the HMA and Houdini II were removed from the tank and decontaminated in preparation for moving the equipment to tank W-9. The remaining in-tank systems were demobilized by March 28, 2000.

10.5.3 Waste Retrieval Performance in Tank W-8

During the waste retrieval operations in W-8, more than 89.6% of the radioactive contamination was successfully removed from the tank. As a result of the decision to eliminate the use of high-pressure scarification in tank W-8, less than half of the contamination in the tank walls was removed. The contamination in the tank walls was the most significant contribution to the contamination remaining in the tank. The total estimated operating time for the major equipment components used to remove sludge and supernate wastes from tank W-8 is summarized in Table 10-6.

Table 10-6. Operating times by task for major equipment systems used in tank W-8

Description of operation	MLDUA	Houdini II	HMA	Cameras W-8	Cameras W-9
Characterization	9			9	
Sluicing and transfer	50	1	21.5	59.5	59.5
Plowing		4			
Wall cleaning	2	15	6.5	15	
Wall coring	4			4	
Training					
Equipment tests					
Miscellaneous	6.5	5.5	5.5	9.5	
Total (h)	**71.5**	**25.5**	**33.5**	**97**	**59.5**

A chronological plot of the waste retrieval operations in tank W-8 is provided in Fig. 10-7. This figure also indicates the approximate amount of water added and sludge removed during tank W-8 operations. Figure 10-8 shows the specific efficiency of the various waste retrieval operations in tank W-8. The average heel retrieval efficiency for this tank was 0.51.

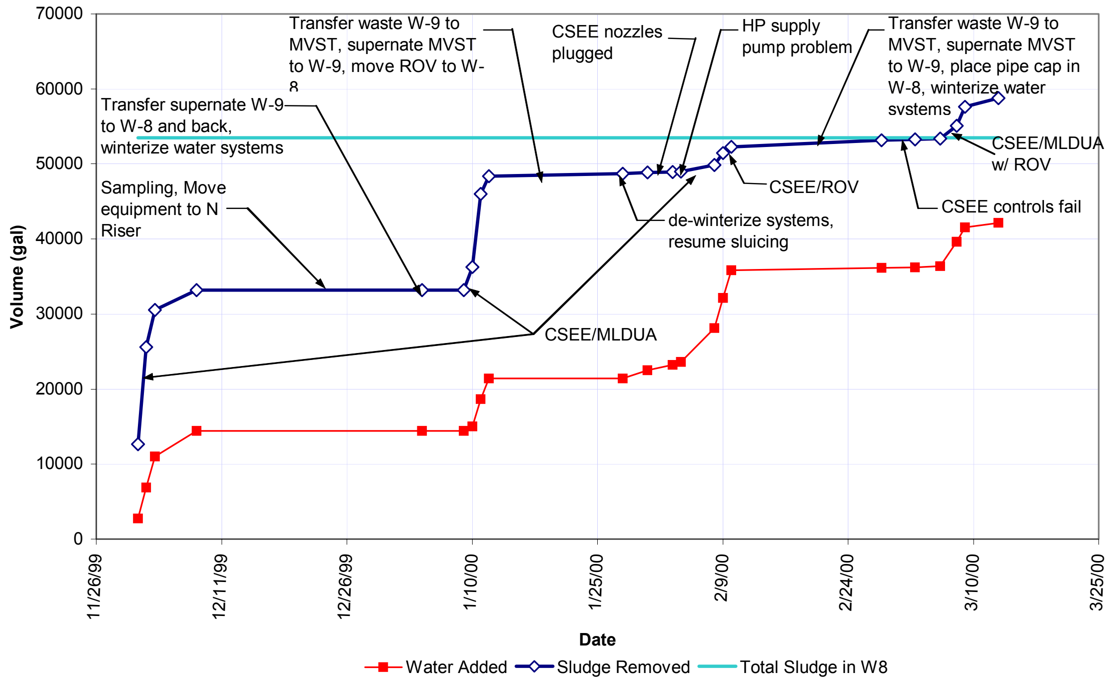

Fig. 10-7. Chronological plot of tank W-8 waste retrieval operations.

10.5.4 Summary of Problems from Waste Retrieval Operations in Tank W-8

The following problems were observed during waste retrieval operations in tank W-8:

- The MLDUA began experiencing signal problems in its main cable bundles, which eventually led to the partial loss of movement in 1 DOF. The system lead worked around the signal problems to the greatest extent possible to keep the system operational.
- In order to reduce unnecessary wear and tear on the MLDUA and to avoid likely downtime, high-pressure wall-scarifying operations were discontinued.
- Operations were temporarily halted when a hydraulic fluid leak developed at the base of the VPM for the MLDUA.
- When attempts were made to retract the LSEE from the tank, loops in the supply hoses for the LSEE jammed the MLDUA. The limited size of the riser would not permit both the MLDUA and LSEE hose loops to pass. No quick repair for the LSEE could be identified, so it was abandoned in place to avoid adversely affecting the remediation schedule.
- The CSEE nozzles were inadvertently plugged with sludge during deployment when the water feed to the nozzles was turned off. Manipulating or pulsing the water pressure and cleaning with the DSR were used to clear the obstruction. Such trial-and-error methods were often used to clear plugs or free the rotation. Direct hands-on repair of problems in which the precise cause could be

identified, was the method of last resort because of the cost, time, and potential radiation exposure to personnel.

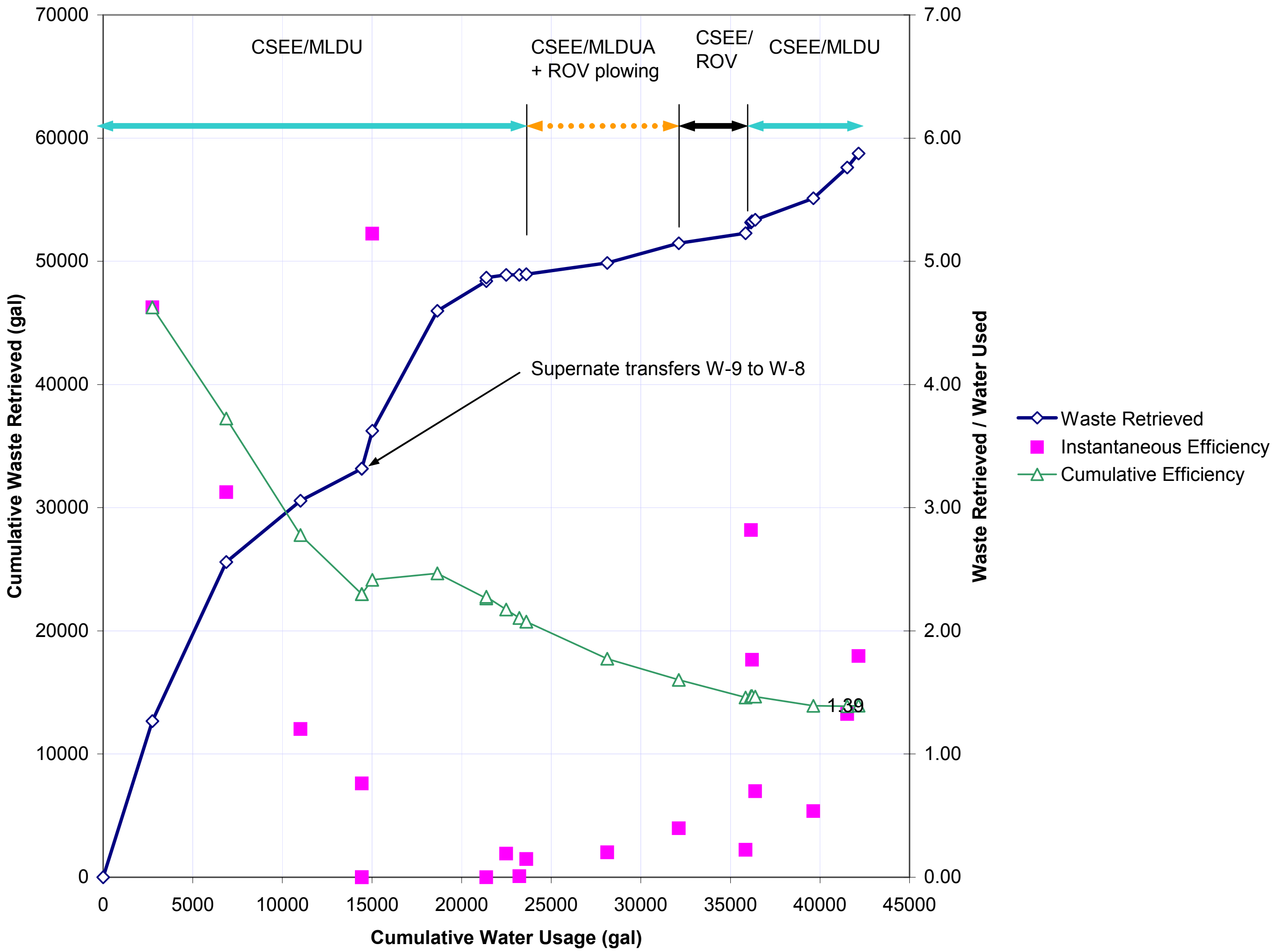

Fig. 10-8. Specific efficiency of W-8 retrieval operations.

10.6 OPERATIONS IN TANK W-9

Tank W-9 is located in the northeast corner of the STF at ORNL. Operations in tank W-9 began on November 24, 1997, and were completed on September 13, 2000. The early start of operations reflects the fact that tank W-9 was used as a sludge consolidation tank for the NTF operations following the transfer of wastes from tank W-3 to tank W-4 and later for the STF operations. Operations in tank W-9 were conducted in the following two phases:

1. Consolidation and transfer to the MVSTs. This phase included a total of 18 waste transfer operations.
2. Final waste retrieval and transfer to the BVESTs. This phase began on July 13, 2000, and included a total of 14 slurry transfers.

10.6.1 Tank W-9 Waste Consolidation and Transfer to the MVSTs

Tank W-9 operations to support the consolidation of wastes retrieved from tanks W-3, W-4, W-5, W-6, W-7, W-8, and W-10 began on May 8, 1998, and ended April 26, 2000. The primary function of tank W-9 during waste consolidation was to receive wastes from the other tanks in the GAAT OU and to act as a batch feed tank for waste transfer operations to the MVSTs. All waste transfer operations from tank W-9 used the WCS to mix, mobilize, sample, and characterize the wastes. The WCS was composed of in-tank mixing systems, WTPs, classifiers (filters), samplers, and in-line instrumentation to measure various characteristics of the waste slurry prior to and during transfer. The equipment was either installed directly inside the tank or contained in equipment enclosures near the tank. The WCS enclosures included the PCS and SMTL.

A PCS enclosure was used to house three samplers, two solids classifiers, a pressure sensor and transmitter, and ancillary piping and valves. The SMTL enclosure contained the necessary in-line slurry-monitoring equipment for determination of particle sizes, solids content, viscosity, temperature, and density.

The PAM system was installed in tank W-9 on June 12, 1998, to support sludge suspension, sluicing, and pumping operations. On August 13, 1999, one of the Flygt mixers previously used in tank W-5 was installed in tank W-9 to assist the PAMs in mobilizing and mixing the contents of the tank. The Flygt mixer was operated a total of ~322.5 h from September 1999 to the end of March 2000. The system was reliable and required little or no maintenance. However, the system operators considered the Flygt mixers to be somewhat temperamental concerning fault trips. Typically, fault trips were caused by an overcurrent condition to the motor. The system could be reset and restarted fairly quickly at slightly less current and consequently a lower operating speed. The 15-hp Flygt mixers used in the GAATs were also considered slightly underpowered for the application. More powerful off-the-shelf models that could be deployed through the existing risers were not available at the time of the GAAT Remediation Project.

Slurries transferred from tank W-9 were transferred using a 125-hp Discflo™ WTP that was installed and initially tested on April 12, 1999. This WTP was used to recirculate supernatant and/or fluidized sludge in tank W-9, transfer sludge and supernatant slurries through the WCS to the MVSTs, and transfer supernatant to other STF tanks. The WTP was operated for ~180 h in recirculation and transfer modes. The Discflo pump was observed to overheat when liquid levels in the tank were below the elevation of the motor housing. Because the pump was designed to operate submerged, air cooling alone was insufficient to maintain the proper operating temperature for the pump. Therefore, an external pump was used to provide a flow of ~5 gal/min of supernatant over the pump motor housing for cooling. The liquid was delivered through a wash-down pipe installed as an integral part of the Discflo pump's support mast. Supernatant was used for cooling to avoid the addition of clean water to the tank, which would then require subsequent treatment.[13]

Eighteen slurry transfers to the MVSTs were conducted during consolidation of the wastes in tank W-9. The total amount of waste transferred to the MVST was ~483,300 gal, of which ~60,500 gal was wet sludge. Waste transfer operations were intermittent, based on the available capacity in the ORNL LLLW system. Table 10-7 provides a summary of the WTP transfers to the MVSTs. The particle-size information in Table 10-7 was obtained from a Lasentec™ in-line particle-size analyzer, which was part of the WCS SMTL.

Table 10-7. Operating summary of WTP transfers to the MVST

Transfer number	Transfer date	Slurry density (g/mL)	Slurry volume (gal)	Sludge transferred (gal)[a]	Total activity transferred (Ci)[b]	Particle size <105 μm (%)[c]
1	5-25-99	1.024	10,435	753	395	Not available
2	6-11-99	1.037	25,704	2,501	3,074	Not available
3	6-22-99	1.044	23,795	3,381	2,845	99.953
4	7-22-99	1.044	27,220	3,868	5,703	99.955
5	7-28-99	1.058	26,144	3,521	5,210	99.976
6	8-17-99	1.050	41,860	5,316	5,562	99.945
7	9-09-99	1.023	37,570	5,396	6,374	99.964
8	9-28-99	1.047	29,813	3,694	2,803	99.972
9	10-26-99	1.055	25,100	4,395	3,591	99.978
10	11-17-99	1.028	25,330	3,657	2,382	99.963
11	12-07-99	1.024	36,659	4,833	2,810	99.982
12	1-13-00	1.045	23,048	3,434	2,308	Not available
13	1-20-00	1.042	24,300	2,520	1,813	Not available
14	2-11-00	1.043	21,000	3,000	2,039	99.944
15	2-18-00	1.042	24,027	2,756	1,842	99.926
16	3-09-00	1.029	27,120	2,222	1,330	Not available
17	3-23-00	1.039	25,066	2,233	1,460	99.976
18	3-30-00	1.049	29,086	2,971	2,021	99.958
Total			**483,277**	**60,451**	**53,562**	

[a]Volume of sludge transferred is an estimate of the amount removed from the GAATs. It is based on an initial estimate of 88,000 gal of wet sludge stored in the GAATs. Based on the remedial investigation data, the sludge had an average bulk density of 1.26 g/mL and a solids content of 31% by weight.

[b]Total activity transferred to the MVST is an estimate in curies. Calculations are based on the total activity in Bq/mL × 103 mL/L × 3.875 L/gal × volume transferred in gal × 2.7×10^{-11} Ci/Bq.

[c]Percentage by number, from Lasentec measurements.

An in-tank camera was used to monitor the operations inside tank W-9. The original camera had to be replaced with a refurbished unit on August 6, 1999, as a result of the harsh environmental conditions in the tank. The refurbished camera was used through the end of the project.

The operating times for the major equipment systems used to support other tank operations are included in the totals listed in Sect. 10.6.3. However, to avoid double accounting of the W-9 camera time, the operating times listed in Sect. 10.6.3 do not include those durations reported previously in Tables 10.1–10.5.

The PAM system proved to be the most reliable of all the components used at tank W-9. It operated for 15 months starting in January 1999 and was removed from the tank on April 3, 2000. The system was effective in suspending sludge in the vicinity of each mixer accumulator plate but was not effective in preventing larger particles from settling to the bottom of the tank away from the influence of the accumulator plates. The only problem with the system occurred when one of the air supply pipes became plugged with sludge during installation. At that time, the sludge was probably >2-ft deep and would eventually accumulate to a depth of >4 ft as sludge was transferred into W-9. The system was forced down into the sludge and was not operated for several months between the initial testing phase in June and regular operation beginning in December. It was thought that sludge hardened in the air supply pipe to one of the accumulator plates and blocked the air supply. The air supply line to the plugged accumulator plate was temporarily refitted for a process water supply, and the line was cleared using hydrostatic pressure.

On April 26, 2000, the Flygt mixer was removed from tank W-9 and disconnection of the Discflo pump was started. Demobilization of this equipment prepared the tank for final waste removal operations using the HWRS.

10.6.2 Tank W-9 Waste Transfers to the BVESTs

The HWRS was installed in tank W-9 after removal of the PAM, WTP, and Flygt mixer. The HWRS maximized the use of existing equipment (MLDUA, WD&CS, Houdini II, and parts of the WCS) in conjunction with the new WaRTS. The HWRS was assembled to facilitate the removal of the more difficult-to-retrieve waste from tank W-9. Previous waste transfer operations in tank W-9 had removed the lighterweight solid material from the tank.

The MLDUA was installed in the south riser of tank W-9 on May 9, 2000. During the period between June 9, 2000, and June 15, 2000, over 23,000 gal of supernate was pumped from tank W-9 to W-8. On June 16, 2000, the CEE was deployed via the MLDUA for tank wall characterization and to obtain wall scrapings.

The WaRTS was installed in the east riser of tank W-9 on June 22, 2000, and operational tests began. The WaRTS included a small surge tank that received waste from the WD&CS jet pump operating in tank W-9. Operators managed the waste level in the WaRTS surge tank to ensure a steady supply and flow to the underground pipeline to the BVESTs. A positive-displacement diaphragm pump installed in the PCS enclosure was connected to the WaRTS surge tank and used to transfer waste the short distance from tank W-9 to BVEST W-23. Operators also ensured that larger particles that were initially mobilized by the jet pump and subsequently settled out in the surge tank were returned to tank W-9. They also adjusted the water content as necessary using either recycled supernatant from tank W-8 or process water from an auxiliary holding tank to achieve the proper concentration of solids. The transfer of supernate from tank W-9 to BVEST W-23 using the WaRTS was initiated July 13, 2000.

On July 19, 2000, a yardstick that was held by the MLDUA GEE was used to determine the sludge depth in tank W-9. Sludge depth in the southern half of the tank was determined to be ~23 in. Over 9 operating days, through the period ending August 2, 2000, the CSEE was used in conjunction with the MLDUA and WaRTS to sluice and transfer supernate and sludge to BVEST W-23. Only one minor problem with the HMA elbow resolver and one CSEE nozzle rotation problem occurred at the start of the initial sluicing operation. These problems were quickly resolved, and waste retrieval operations continued.

The MLDUA was used on one occasion to retrieve a glove that had fallen into the tank. On August 3, 2000, in 3 h of operation, the hard material in the tank was sampled with the MLDUA scraping tool, and an overflow pipe leading to tank W-10 was successfully plugged using the pipe-plugging tool.

The MLDUA was moved to the north riser of tank W-9 on August 8, 2000, and the Houdini II ROV was deployed through the south riser the following day. On August 11, 2000, the pipe-cutting tool was deployed with the MLDUA to cut two pipes. The sludge depth under the north riser was determined to be 26 in. using a yardstick in the grasp of the MLDUA GEE.

Sluicing and transfer of sludge from the northern half of the tank, using the CSEE with the MLDUA and WaRTS, began August 15, 2000. Sludge was plowed away from the tank wall using the Houdini II ROV on August 19, 2000. The Houdini II continued to be used to plow sludge toward the CSEE for several days.

The core-drilling tool was deployed using the Houdini II ROV on September 1, 2000, and two wall-core samples were obtained during 4 h of operation. The core drill was deployed again on September 5, 2000, and two more wall-core samples were obtained in another 4 h of operation. Sluicing and transfer of sludge continued September 6–7, 2000, using the CSEE (held by the MLDUA) and the Houdini II ROV to plow waste toward the CSEE. The HMA jet pump provided the suction to the CSEE and the power to transfer wastes to the WaRTS. Wall-scrape samples were obtained with the MLDUA on September 12, 2000. The following day, attempts to characterize the wall using the CEE were halted due to failure of the range finder (a device used to gage the distance between the wall and the CEE). However, based on the analysis of the samples, tank retrieval was considered complete.

A total of 14 separate transfers were made to BVEST W-23 using the HWRS during waste transfer operations in tank W-9. These batch transfers were always significantly smaller than the Discflo batch transfers to the MVSTs because the WaRTS was not designed for the flow rates produced by the Discflo pump and the WaRTS was operated only while the in-tank robotic systems were actively sluicing. Table 10-8 provides summary information on the wastes transferred from the tank W-9 using the HWRS. More than one transfer operation was made during some of the time periods listed in Table 10-8.

Table 10-8. Operating summary of HWRS transfers to tank W-23

Transfer		Volume	Est. sludge volume	Particles of size <105 μm
no.	date(s)	(gal)	(gal)[a]	(%)[b]
1	07/13/00	8,850	1,372	Not available
2	07/18/00	10,500	1,550	99.970
3	07/22/00	17,450	2,514	99.963
4	07/26–27/00	24,100	5,297	99.933
5	08/01–02/00	18,900	3,293	99.892
6	08/15–16/00	19,450	5,425	99.827
7	08/19–21/00	19,200	5,208	99.735
8	08/29–30/00	17,950	2,816	99.842
9	09/06–07/00	10,500	787	99.881
Totals		146,900	28,262	

[a]The initial total activity in both sludge and supernatant was estimated at 85×10^3 Ci. Approximately 7×10^3 to 1×10^4 Ci contributed by residual sludge and contamination trapped in the tank walls was estimated to remain in the tank. Thus, $\geq 75 \times 10^3$ Ci was removed from the tank.

[b]Percent by count, from Lasentec measurements.

10.6.3 Waste Retrieval Performance in Tank W-9

More than 82.2% of the radioactive material present in tank W-9 was successfully removed. Although only a small amount of material remained in tank W-9, there was a significant amount of radioactivity in the gravel-like and gunite material that was left behind by the HWRS and in the walls of the tank.[21] The total estimated operating time for the major equipment components used to remove sludge and supernate wastes from tank W-9 is summarized in Table 10-9.

A chronological plot of the waste retrieval operations in tank W-9 is provided in Fig. 10-9. This figure also indicates the approximate amount of water added and sludge removed during tank W-9 operations. Figure 10-10 shows the specific efficiency of the various waste retrieval operation in this tank.

Table 10-9. Operating times by task for major equipment systems used in tank W-9

Description of operation	MLDUA	Houdini II	HMA	Pulsair mixer	Discflo pump	Flygt mixer[a]	Cameras W-9[b]
Characterization	10						10
Sluicing and transfer	94		94		123.5		94
Mixing/recirculation				2386	56.5	321.5	
Plowing		35					
Wall cleaning		6					6
Wall coring		4					8
Training							
Equipment tests	2	1	2	4.5		1	7.5
Miscellaneous	4						4
Total (h)	**110**	**46**	**96**	**2390.5**	**180**	**322.5**	**129.5**

[a] One of the two Flygt mixers from tank W-5 was moved to and used in tank W-9.
[b] Time for operations in conjunction with other tanks is not included here.

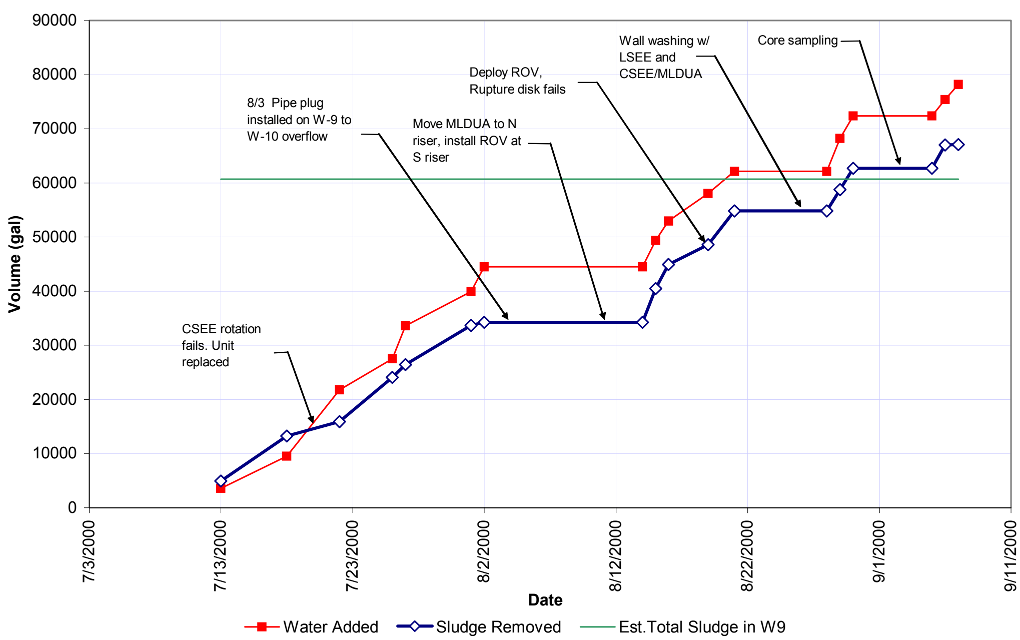

Fig. 10-9. Chronological plot of tank W-9 waste retrieval operations.

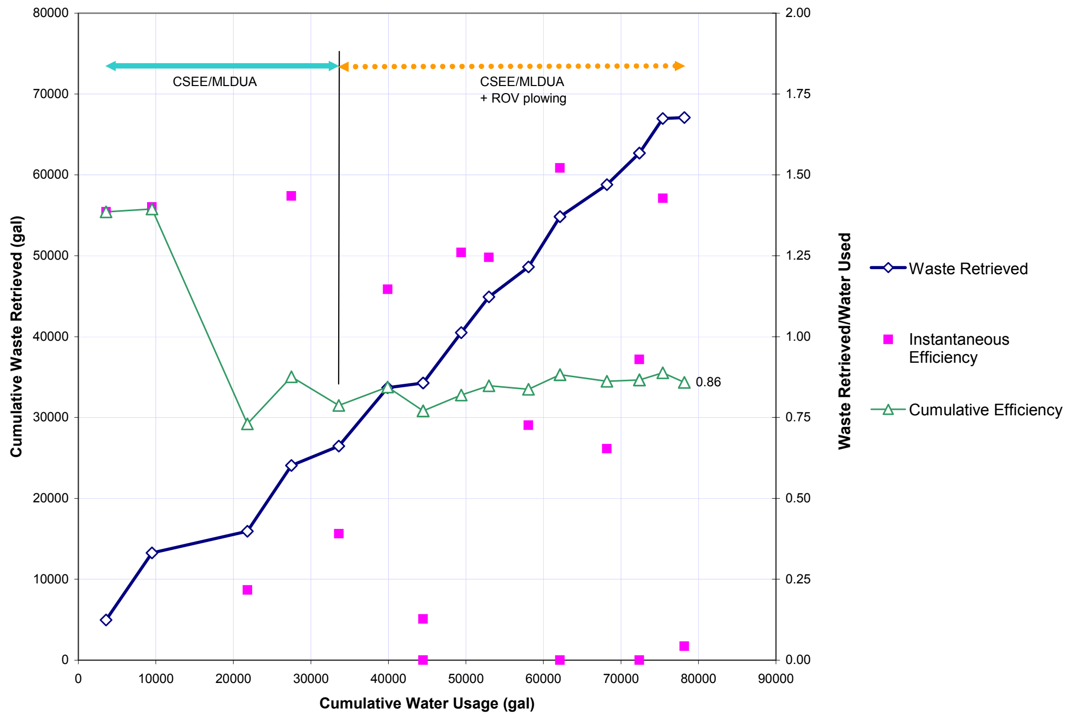

Fig. 10-10. Specific efficiency of W-9 retrieval operations.

10.6.4 Summary of Problems from Waste Retrieval Operations in Tank W-9

The following problems were observed during waste retrieval operations in tank W-9:

The PAM system was the most reliable of all the components used at tank W-9. The system was effective in suspending sludge near each mixer accumulator plate but was not effective in preventing larger particles from settling to the bottom of the tank away from the influence of the accumulator plates.

- One of the air supply pipes for the PAM became plugged with sludge during installation as a result of being forced down into the sludge and not operated for several months. The line was subsequently cleared using hydrostatic pressure.
- Lightning was also suspected of disrupting the PAM system by causing the control system to stop functioning. This situation was observed several times during inclement weather, but it was never precisely determined how the system was disrupted. After each outage, the controls were reset and the system restarted.
- The Discflo pump was observed to overheat when liquid levels in the tank were below the elevation of the motor housing. A supplemental pump was used to pump supernatant over the motor for cooling to avoid the addition of clean water to the tank.
- Operators considered the Flygt mixers to be somewhat temperamental concerning fault trips. The system could be reset and restarted fairly quickly at slightly less current and consequently a lower operating speed.
- Although reliable and relatively trouble free, the 15-hp Flygt mixers used in the GAATs were also considered slightly underpowered for this application.
- A minor problem with the HMA elbow resolver was quickly resolved during final waste retrieval operation in tank W-9.

- A minor problem with the CSEE nozzle rotation mechanism occurred at the start of the initial sluicing operation in tank W-9.
- Attempts to characterize the wall in tank W-9 using the CEE were halted due to failure of the range finder used to gage the distance between the wall and the CEE.

10.7 SUMMARY OF OPERATING TIMES BY TASK

The estimated operating times by task for each of the major equipment systems used in the removal of wastes from the STF gunite tanks are summarized in Table 10-10. Those data are the sum of the operating times listed in Tables 10-1–10-8, which were obtained from notes in the project's operating logs. The equipment that accumulated the most operating hours were the in-tank mixers (Pulsair and Flygt mixers), the MLDUA, and the HMA. Operating time of the viewing systems was closely tied to the operation of the MLDUA and HMA. The reason that camera time appears low for the Houdini plowing operations is that the in-tank camera was often used to concurrently view both the MLDUA and Houdini operations. Logging the camera time as the view switched between tasks was not practical, so it was associated more strongly with the MLDUA operation.

Table 10-10. Operating times by task for major equipment systems used in waste retrieval from the STF gunite tanks

Description of operation	MLDUA	Houdini I	Houdini II	HMA	UHPP	Air diaphragm pump	Pulsair mixer	Discflo pump	Flygt mixer	Cameras
Characterization	101		1							101
Sluicing and transfer	363	28	5	343		84		123.5	69	834.5
Mixing/recirculation							2386	56.5	321.5	
Sludge suspension									181	18
Plowing		6.5	79							1
Wall cleaning	117.5	2.5	25.5	30	36					142
Wall coring	12	4.5	14							31
Training	5			5						5
Equipment tests	13.5	3	1	5	1.5		4.5		1	19
Miscellaneous	94.5	5.5	8.5	30.5						98.5
Total (h)	**706.5**	**50**	**134**	**413.5**	**37.5**	**84**	**2390.5**	**180**	**572.5**	**1250**

11. WASTE RETRIEVAL OPERATIONS IN TANK TH-4

Waste retrieval operations in tank TH-4 were conducted separately from waste retrieval operations in the North and South Tank Farms. Tank TH-4 is located southeast of the STF. Characterization information and the risk assessment performed during the RI/FS determined that this tank had risks similar to those associated with tanks W-3 and W-4 located in the NTF.[24] A Russian-fabricated PMP was used to mobilize the settled waste in tank TH-4, permitting the waste to be retrieved as a slurry. The deployment of the PMP at ORNL marked the first deployment of Russian-developed technology in the U.S. radioactive tanks remediation program.

11.1 PMP DESCRIPTION

The PMP assembly is shown schematically in Fig. 11-1. The PMP is comprised of a pressure vessel, check valve, working gas supply pipe, discharge manifold, and four discharge nozzles (jets). The pump uses two distinct cycles, fill and discharge, to perform its mixing action. During the fill cycle, vacuum is applied to the pressure vessel by an eductor located inside the UST to draw liquid into the pressure vessel. When the liquid level inside the pressure vessel reaches a predetermined level, the chamber is pressurized with compressed air to discharge the liquid through the jets and back into the tank to mobilize sludge and settled solids. The maximum design working pressure of the PMP is 230 psi (1586 kPa). A large-diameter spherical check valve located at the pressure-vessel inlet controls the direction of flow. The PMP can be rotated, using a pneumatic cylinder, through a 90º arc in alternating clockwise and counterclockwise directions to sweep the entire bottom of the tank. Figure 11-2 is a photograph of the lower end of the PMP, which shows the mixing nozzles (four tapered pipes near floor of tank) and intake for the PMP (perforated cylinder). On the top of the PMP (not shown), various shut-

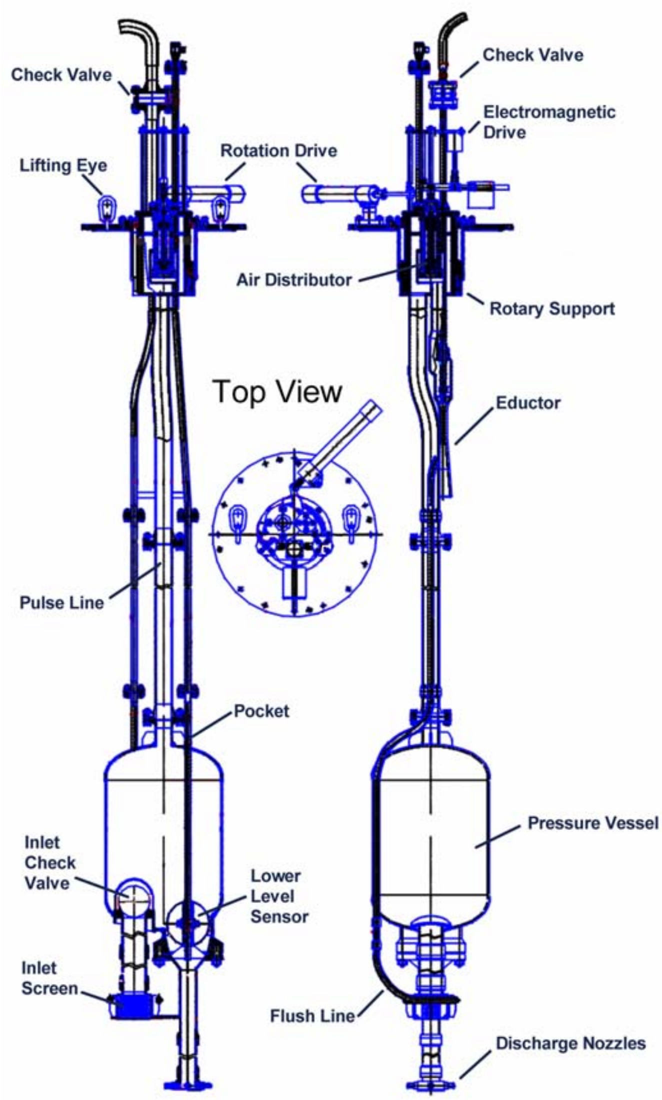

Fig. 11-1. Schematic of the PMP.

[24] U.S. Department of Energy, *Addendum to the Remedial Investigation/ Baseline Risk Assessment for the Gunite and Associated Tanks Operable Unit at Waste Area Grouping 1 at the Oak Ridge National Laboratory, Oak Ridge, Tennessee*, DOE/OR/02-1593&D3, Oak Ridge, Tennessee, 1996.

off valves are operated in conjunction with an electromechanical air-distribution valve to direct either compressed air or vacuum to the pressure vessel. LLLW from the waste tank is drawn into the pressure vessel through a coarse screen and check-valve assembly connected to the bottom of the vessel. In the event of a plug in the inlet screen, wash water can be used to rinse the screen. A level sensor located inside the vessel is used to control the vacuum and discharge cycles, with cycle duration dependent on the time required for filling and discharge. Operating frequency and other parameters can be adjusted to generally accommodate the properties of the liquid being mixed. The entire system was remotely controlled and monitored by a laptop computer using Labview™ software.

Fig. 11-2. PMP intake and discharge nozzles.

11.2 COLD TESTING OF THE PMP AND PREPARATION FOR WASTE RETRIEVAL

The PMP and associated equipment were assembled at the ORNL TTCTF in the summer of 1999. The system consists of the following three subsystems

1. the PMP assembly and control system,
2. the Tank Riser Interface (TRI), and
3. the DSR.

Cold tests of the equipment commenced immediately upon installation of the system and continued until October 2000. Cold testing consisted of a pretest inspection, functionality tests, and performance tests. The pretest inspections included a review of fabrication documentation (e.g., quality assurance records, weld inspection reports, and as-built drawings), visual and ultrasonic inspection of the equipment, analysis of materials composition, and hydrostatic tests. Operational tests were conducted to assess the functionality of the TRI, DSR, control system components, transport cradle, support fixtures, and contamination control devices. Performance tests were conducted in a simulated waste tank environment. These tests were focused on evaluating the mixing efficiency, estimating the effectiveness of decontamination, measuring the effective cleaning radius (ECR), and evaluating tolerance to debris. The PMP equipment and enclosure were moved from the cold test facility for installation at tank TH-4 on October 13, 2000 (Fig. 11-3). The equipment was installed on a platform constructed over tank TH-4. Before the platform was

Fig. 11-3. The PMP enclosure installed on the equipment platform constructed over tank TH-4.

constructed, the tank had been modified by the addition of tank access risers to allow the deployment of the PMP in the tank. During the construction of the equipment platform, a temporary 2-in.-diam double-contained, aboveground transfer line was installed to carry waste slurry from tank TH-4 to the tank W-6 valve box in the STF. The waste slurry was directed from the valve box, through the existing SCS, and then transferred to BVEST W-23. A SandPIPER™, air-powered double-diaphragm pump (Model SB1-1/2-A) was used to propel the waste slurry through these systems. After the installation of the PMP and ancillary equipment was completed, DOE concluded an operational readiness review on January 11, 2001. Based on the results of that review, authorization to commence operations was received and retrieval of waste started that day.

11.3 WASTE RETRIEVAL OPERATIONS IN TANK TH-4

Waste retrieval operations began in tank TH-4 on January 11, 2001, and were completed on January 15, 2001. The PMP was successfully operated in the tank, and the majority of the waste was transferred to tank W-23. At the beginning of the waste retrieval operations, the tank was at full capacity due to the in-leakage of groundwater. Excess liquid was removed from the tank until the initial operating level for the PMP was reached (~5.6 ft from the bottom of the tank). The project safety documentation required that a layer of supernatant be maintained in the tank that was equal to the depth of the sludge present in the tank (initially estimated to be 2.5-ft deep). The PMP was operated over a holiday weekend for several periods ranging from 1 h to more than 10 h. The total accumulated operating time was ~24.5 h. The mixing operations effectively agitated the sludge and mixed it with the remaining LLLW supernatant. The waste slurry resulting from the mixing operations in tank TH-4 was transferred through the temporary transfer line to the SCS in the STF and then on to tank W-23 as planned. Initially, the inlet to the transfer pump was located on a mound of sludge estimated to be ~1 ft deep. This limited the lowest level to which waste could be removed from the tank. The inlet was later repositioned to within ~1 in. of the floor of the tank for the final waste transfers.

11.4 WASTE RETRIEVAL PERFORMANCE IN TANK TH-4

At the beginning of the waste mixing and retrieval operations, the estimated sludge depth in the bottom of tank TH-4 was ~2.5 ft. After the last pump-implemented waste transfer, only an outer band of sludge remained in the tank. This band of sludge ranged from about 1 ft to slightly over 2 ft wide. The depth of the band was ~1.25 ft. These observations indicated that the PMP had an ECR of ~8.5 ft. After the completion of the waste transfer operations, the outer band of watery sludge slumped and spread toward the center of the tank as shown in Fig. 11-4. The initial sludge content of tank TH-4 was estimated at 6266 gal.[25] Supernatant was recycled from tank W-8 to provide

Fig. 11-4. Tank TH-4 at the end of waste retrieval operations with the PMP.

[25] J. W. Autry, D. A. Costanzo, W. H. Griest, L. L. Kaiser, J. M. Keller, C. E. Nix, and B. A. Tomkins, *Sampling and Analysis of the Inactive Waste Storage Tank Contents at ORNL*, ORNL/ER-13, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, Oak Ridge, Tennessee, May 1990.

a mixing medium. During mixing and sludge removal operations, a total of over 24,000 gal of slurry was transferred from tank TH-4 to tank W-23. The residual sludge was estimated at a volume of ~1098 gal, which indicated that ~82% of the sludge had been removed. The total activity of waste remaining in the tank was reduced from ~3.37 to ~0.59 Ci. It is believed that continued recycling of supernatant and operation of the PMP would have likely resulted in the removal of additional sludge. However, the DOE and TDEC regulators inspected the tank on January 18, 2001, and determined that additional sludge removal was not required.

11.5 SUMMARY OF PROBLEMS FROM WASTE RETRIEVAL OPERATIONS IN TANK TH-4

The PMP was used successfully to mix the sludge and supernatant in tank TH-4. However, difficulties were experienced during the initial operation of the PMP, which are described in the following sections.

11.5.1 Excessive Friction in the Air Distributor Valve

During the initial operations of the PMP at tank TH-4, the air distributor valve would not reliably seat. This problem resulted in a partial loss of vacuum as the pumping chamber refilled. It also caused frequent shutdowns by the control system. The waste retrieval operations in tank TH-4 were performed in the middle of winter under relatively cold environmental conditions. It was observed that the performance of the valve (and, consequently, the PMP) significantly improved as the temperature increased above freezing. Subsequent correspondence with the Russian designers indicated that a minor design change made to PMP units 2 and 3 should have been made to unit 1 prior to deployment. It was the designer's opinion that this modification, adding a small vacuum relief port to prevent the accumulation of moisture and subsequent freezing inside the air distributor valve, could have prevented the difficulties that occurred during operations in tank TH-4. However, similar problems were observed with the air distributor valve during follow-on cold testing of PMP unit 2.[26]

11.5.2 Erratic Rotation of the PMP

In its rotating mode, the PMP typically moves through an arc of about 90º. Erratic motion was observed near the end of the 90º arc during waste retrieval operations. It was suspected that the air pressure supplied to the PMP was too low to permit complete movement in one smooth motion.[27]

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[26] B. E Lewis, *Extended Cold Testing of a Russian Pulsating Mixer Pump at the Oak Ridge National Laboratory, Oak Ridge, Tennessee*, ORNL/TM-2002/241, Oak Ridge National Laboratory, Oak Ridge, Tennessee, December 2002.

[27] B. K. Hatchell, B. E Lewis, J. D. Randolph, and M. A. Johnson, *Russian Pulsating Mixer Pump Deployment in the Gunite and Associated Tanks at ORNL*, PNNL-SA- 34056, Pacific Northwest National Laboratory, Richland, Washington, March 2001.

12. GAAT REMEDIATION PROJECT SCHEDULE, COSTS, AND FUNDING ORGANIZATIONS

This section presents a summary-level description of the schedule and costs for the GAAT Remediation Project and a listing of the responsible funding organizations. Several management and organizational changes took place during the course of the project. As a result of the changes in project leadership, it is difficult to break out detailed subtask costs because of the various cost structures used to track and control the project. The GAAT remediation effort was conducted over an 8-year period. The schedule for the major field operations for the project is presented in Fig. 12-1 along with the fraction of waste removed from each storage tank.

This schedule, in addition to the monthly cost breakdowns for the project, served as the basis for estimating the costs for startup, waste retrieval operations by tank, and demobilization and documentation activities. Estimates for these cost elements are presented in Table 12-1. The initial costs for start up of the project include a variety of elements such as

- the initial project management,
- alternative studies,
- design and procurement of equipment,
- cold testing,
- tank waste characterization,
- operator training,
- CERCLA documentation,
- safety assessments,
- procedure preparation, and
- site preparation of the NTF site.

Set-up and maintenance costs include primarily movement of the waste retrieval systems and work platforms in addition to the required maintenance on the retrieval equipment. The waste retrieval costs listed in Table 12-1 include primarily the estimated costs for operations, maintenance, and management support during the period when waste retrieval operations were conducted.

Cost data for all the phases of the GAAT Remediation Project, beginning in FY 1993, before the GAAT Treatability Study began, and including information pertaining to project planning and organization, are presented in Table 12-2. Table 12-2 also lists the responsible prime contractors, the annual costs associated with project operations, and a breakout of the approximate costs for broad elements of the project. The cost information presented in Table 12-2 does not include the costs for design, development, and procurement of the systems provided under the DOE Office of Science and Technology (EM-50).

ID	Task Name	Duration	Start
1	**GAAT Treatability Study**	**177 days**	**Fri 6/13/97**
2	W-3 Waste Retrieval	93 days	Fri 6/13/97
3	W-4 Waste Retrieval	66 days	Mon 11/17/97
4	**GAAT Remediation**	**838 days**	**Tue 11/4/97**
5	W-6 Waste Retrieval	106 days	Thu 3/19/98
6	W-5 Waste Retrieval	45 days	Thu 9/17/98
7	W-7 Waste Retrieval	134 days	Wed 9/30/98
8	W-10 Waste Retrieval	111 days	Tue 5/25/99
9	W-8 Initial Supernate Collection	523 days	Thu 12/11/97
10	W-8 Waste Retrieval	78 days	Sat 12/11/99
11	W-8 Final Supernate Collection	211 days	Wed 3/29/00
12	W-9 Waste Consolidation and Transfer	627 days	Tue 11/4/97
13	W-9 Final Waste Retrieval	45 days	Thu 7/13/00
14	TH-4 Waste Retrieval	5 days	Thu 1/11/01

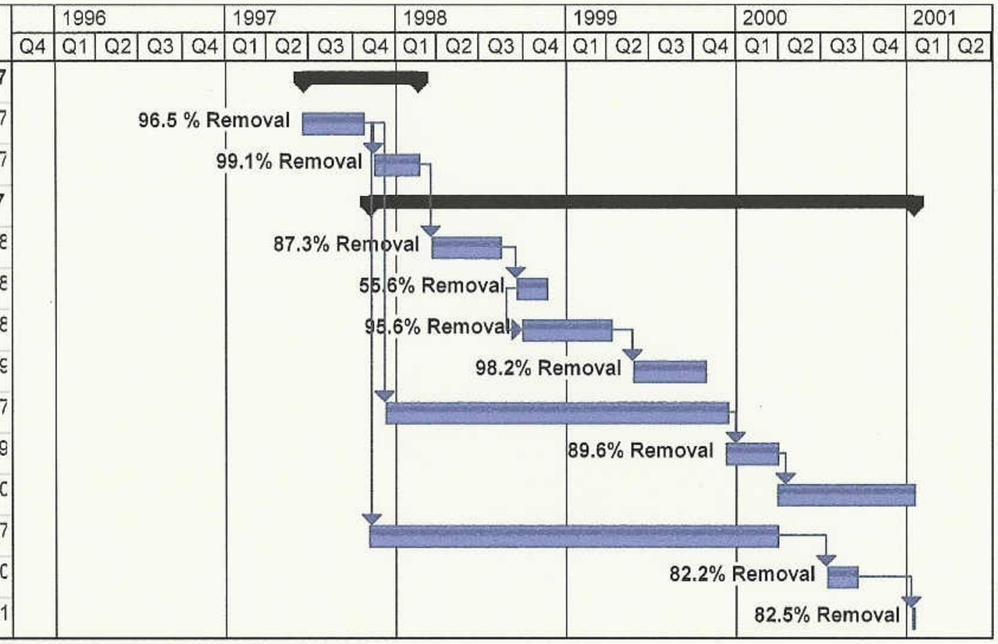

Fig. 12-1. GAAT Treatability Study and Remediation Project schedule.

Table 12-1. Estimated costs for the GAAT remediation by tank

Operation	Schedule	Start-up costs ($K)	Set-up/ maintenance costs ($K)	Waste retrieval costs ($K)
Start-up	November 1993 – June 12, 1997	30,124		
W-3 waste retrieval	June 13, 1997 – October 21, 1997		3,752[a]	4,856
W-4 waste retrieval	November 17, 1997 – February 16, 1998		795	3,275
W-5 waste retrieval	September 17, 1998 – November 18, 1998		415	535
W-6 waste retrieval	March 19, 1998 – August 13, 1998		1,364	3,762
W-7 waste retrieval	September 30, 1998 – April 5, 1999		590	4,104
W-8 waste retrieval	December 11, 1999 – March 28, 2000		991	2,490
W-9 waste retrieval	July 13, 2000 – September 13, 2000		2,981	1,568
W-10 waste retrieval	May 25, 1999 – October 26, 1999		1,893	4,542
TH-4 waste retrieval	January 11, 2001 – January 17, 2001		1,848	17
Demobilization/documentation	January 18, 2001 – September 30, 2001		357	
Total		30,124	11,221	25,184

[a] Estimated based on costs for previous 3 months.

Table 12-2. Waste retrieval cost summary and responsible contractors for final cleanout of the GAATs

	Responsible prime contractors										
	MMES[a]	LMES[b]	LMER[c]			BJC/LMER[d]		BJC/UTB[e]			
	Fiscal Year										
	1993	1994	1995	1996	1997	1998	1999	2000	2001		
Cost Category	Cost ($K)									Total	%
Project management	530	132	635	673	804	800	632	767	134	5,107	7.3
Preliminary design and technology selection	535	1,385	2,169	1,809	6,496	414				12,808	18.2
Final design		237	987	1,461	1,285	243	435	293		4,941	7.0
Materials			50	3,256	1,141	90				4,537	6.5
Site preparation		152	1,827	3,749	1,511	1,397	947	1,962		11,545	16.4
Operations		338	3,294	2,695	1,036	7,977	8,365	5,826	1,222	30,753	43.8
Closure							56	363	149	568	0.8
Annual cost	1,065	2,244	8,962	13,644	12,273	10,921	10,435	9,211	1,505		
Cumulative cost	1,065	3,308	12,270	25,914	38,187	49,108	59,543	68,754	70,259		

[a] April 1, 1984, through March 31, 1994.
[b] April 1, 1994, through December 31, 1995.
[c] January 1, 1996, through March 31, 1998.
[d] LMER continued as the M&O contractor from April 1, 1998, through March 31, 2000, with BJC as the M&I contractor beginning April 1, 1998.
[e] UT-Battelle began as the M&O contractor on April 1, 2000, with BJC continuing as the M&I contractor.

The EM-50 programs provided a significant amount of support in developing, procuring, and modifying the RTCS components such as the MLDUA, GEE, CEE, Houdini I and II, WCS, WaRTS, CSEE, GSEE, UHPP, WD&CS, HMA, Flygt mixers, and pipe-plugging/cutting/cleaning system. The EM-50 program also supported the testing and deployment of the Russian PMP. Table 12-3 provides a list of the major EM-50 supported tasks, systems, and equipment and includes the approximate levels of support for each item. Many of the equipment and systems developed and used during the GAAT Remediation Project were either one-of-a-kind or first-of-a-kind systems that required a significant amount of development, testing, and/or modification prior to field deployment. The data in Table 12-3 include development and cold testing costs as well as the capital costs funded by EM-50 in direct support of the GAAT remediation effort.

Table 12-3. GAAT waste retrieval systems and equipment support provided by the DOE Office of Technology Development

EM-50-supported equipment and systems	Approximate EM-50 support ($K)	Initial deployment date
LDUA feasibility study for ORNL application	150	
TTCTF (including vehicle comparison tests)	510	
TMS	1,000	
MLDUA	1,630	June 1997
GEE	225	June 1997
CEE (including THS)	700	June 1997
Houdini I	2,250	June 1997
Houdini II	2,075	January 1999
TRIC	500	June 1997
DSR and riser sleeves	150	June 1997
CSEE (I and II)	650	June 1997
GSEE (including THS)	500	January 1998
Hydraulic shear	35	January 1998
UHPP	275	January 1999
Pipe-Plugging/Cutting/Cleaning System	400	October 1998
WD&CS	75	June 1997
HMA II	175	January 1999[a]
SCS (including remote maintenance assessment and PAMs)	1,100	June 1998
Flygt mixers	65	July 1998
WaRTS	700	July 1999
Russian PMP	1,670	January 2001
Total	14,835	

[a] Available as a backup for the primary HMA.

13. GAAT REMEDIATION PROJECT LESSONS LEARNED

Over the course of a multiyear project such as the GAAT Remediation Project, a variety of situations will arise that are different from the initial expectations. These unexpected situations typically result in lessons learned, which can either be immediately applied to the ongoing project or used to improve performance and simplify the operations in future activities. Lessons learned are either narrowly focused on a specific component or operation or have broad applicability to an entire system or the project in general. Some of the more specific lessons learned for the GAAT Remediation Project were included in the sections of this report that focused on specific operations or components. This section provides a complete summary of the lessons learned for the GAAT Remediation Project. These lessons learned have resulted in various outcomes ranging from minor changes in direction, process changes, and procedure improvements to major equipment modifications and upgrades.

13.1 COMMUNICATIONS AND GENERAL OBSERVATIONS

Frequent open communication with staff and stakeholders was a key ingredient to the overall success of the GAAT Remediation Project. The project conducted several public meetings to solicit stakeholder input and to provide status updates. The project management team also held daily and weekly meetings with key participants to provide direction, obtain status updates, and ensure that roles and responsibilities were well understood. Routine meetings provided a continuous forum for feedback and problem solving.

13.1.1 Communications

Some of the more practical methods of communication used during the GAAT Remediation Project are described in the paragraphs that follow.

Ensure that management, regulators, stakeholders, and support and technical staff are in agreement with project plans. Significant involvement and interactions were required early in the project, and throughout, using public meetings, documentary videos, and presentations, etc., to create a sense of "ownership" and understanding for everyone involved with the project. These efforts paid huge dividends during the higher-cost operations portion of the project by avoiding changes in direction/scope and impacts from environmental safety and health concerns collocated employees.

Work instructions and prejob briefings were essential for effective communications. Maintenance activities were performed using graded work instructions that allowed personnel the freedom to respond to unknowns while completing a maintenance task. Prejob briefings were used to ensure that all personnel performing a specific task thoroughly understood their assignment and the hazards involved. Worker safety was the highest consideration throughout the project.

Hold “Plan of the Day” meetings with key personnel to establish and prioritize daily objectives and near-term goals for the project. The “Plan of the Day” was sent to all members of the team via e-mail to ensure that everyone was well informed.

Designate a single point-of-contact to interface with craft workers and coordinate on-site craft activities. This avoided confusion over priorities and work assignments.

Plan and communicate craft resource needs. At ORNL, craft resources were frequently in high demand and craft workers with the required training to work on equipment at the tank farm were in short supply. Therefore, a detailed plan was prepared for system installation or any other activity that was craft intensive. This plan was communicated to the craft supervisors early on to obtain commitments for the key resources required. While developing this plan, a balance in the demand for specific crafts over the duration of the job was a key goal. A smaller crew of semidedicated craft workers provided more ownership of the project and functioned as an integral part of the project team.

13.1.2 General Observations

The following paragraphs provide a summary of the general considerations and observations relative to items that worked well and items that could have been improved during the GAAT Remediation Project.

Although the GAAT OU was on the National Priorities list of waste sites requiring urgent attention, the situation was such that it was possible for the project to proceed from the lowest-difficulty, lowest-risk activities to higher-difficulty, higher-risk activities. Moving from low-risk to high-risk activities had many significant benefits:

- Lower employee exposures and reduced project cost. Modifications and repairs to equipment and systems identified during development and performed during cold testing resulted in lower employee exposure and project cost.
- Establishing an experience base for successively more rigorous operations. The move from lower- to higher-risk activities provided a firm basis of experience for successively more rigorous operational readiness evaluations.
- Lower overall risk to employees and the environment with a "learn as you progress approach." The move from lower- to higher-risk activities lowered the overall risk to employees and the environment with a "learn as you progress approach" by allowing procedures, equipment, and the project experience to mature before higher-risk activities were undertaken.

Early project successes should be identified, pursued, publicized, and celebrated to provide a basis for funding continuation, to maintain employee morale, and to ensure continued project acceptance and support.

This complex, lengthy project was approached as a "marathon" race, not a "sprint." It is easy for project personnel to become physically and/or mentally run-down under long-term high-stress situations, potentially compromising safety. In addition, high-stress situations result in significant employee turnover, which could be costly when highly skilled employees are involved.

Develop detailed project cost and schedule baseline early in the project. This was a challenging effort because of the cost, accuracy of information, changes in responsible contractors, and changes in organizational structure as described in Sect. 12.

Control documents at the project level. Although the document control system used in the GAAT Remediation Project may have seemed cumbersome, the ability to control the whole process allowed for much faster turnaround time. Control within the project, along with a very limited controlled distribution list, ensured a quick turnaround time that allowed the project to maintain deadlines.

Provide flexibility within the operating plan for the development and deployment of new tools. For example, when a piece of debris or waste was discovered that was of interest for laboratory analysis, the operating plans allowed for the creation and use of a customized tool for grasping the article of interest.

Identify critical instruments early in the project and have them regularly calibrated. Routine calibration was not required for instruments that were used only for relatively noncritical measurements.

Identify all monitoring requirements, and delineate between those required to meet regulatory or safety requirements and those used for process knowledge. Once this delineation was made, when an instrument failed, a determination could be more quickly made whether operations could continue or must be suspended for repair of a critical instrument.

Use a single configuration management system and a single change log for the whole project, instead of one for each system. A baseline status and scope for the GAAT Remediation Project was defined and a straightforward, simple process used to make changes to allow the scope and costs to be controlled as the system continued to evolve throughout the project.

The work-planning process should consider and provide allowance for

- control and capture (absorption) of small amounts of unanticipated contaminated liquid,
- impacts from established weather patterns, and
- the sequence and duration of activities.

Expect, plan for, and manage continuing changes in equipment and processes, even after operations are under way. No matter how thorough the planning phase of a project, situations will arise that were not originally anticipated—especially for tank waste retrieval operations. Change control procedures should be in place to approve and document all process and equipment changes with significant impacts to the project's schedule and/or budget.

Early interactions with the Office of Science and Technology Tanks Focus Area, Robotics Crosscut Program, and other DOE offices were key elements to obtaining vital resources and research and development support for the waste removal technologies that were integrated into the successful remediation of the GAATs.

The initial and ongoing tank and waste characterization efforts (video inspections, wall cores, waste samples, etc.) were key activities that helped in the successful planning of the project, as well as in analyzing the project's effectiveness and efficiency.

Ensure that adequate lighting of the work area is available if other than day-shift operations are anticipated.

To minimize the number of alarms that require a procedural response, differentiate between events that require alarms and those events that require only warnings.

Provide an on-site break room and meeting room where activities that otherwise would interfere with operations can be staged. A separate trailer near the operations trailer served as the GAAT break/meeting room.

Establish the equipment and site drawings as controlled documents early in the project, and maintain a "red-lined" controlled set of documents at the work site for use in maintenance and troubleshooting.

Provide a means of removing in-tank obstructions such as pipes, risers, pumps, gratings, etc., that cannot be maneuvered around. Access to the walls and floor of a tank by the retrieval system is crucial to the successful removal of waste.

13.2 HEALTH AND SAFETY, ALARA, AND CONTAMINATION CONTROL

The health and safety of the personnel involved in the GAAT Remediation Project was of the highest priority throughout the project. Maintaining personnel radiation exposures as low as reasonably achievable (ALARA) and controlling the spread of contamination is directly tied to personnel safety, ensuring personnel availability, and overall project control.

13.2.1 Health and Safety

The following paragraphs describe some of the health and safety lessons learned during the GAAT Remediation Project.

Use skid-proof shoe covers when walking on wet surfaces in contaminated areas. Paper or plastic shoe covers should be avoided when walking on such surfaces.

Plan work to avoid environmental stresses on personnel. Environmental stresses on personnel during hot periods can result in excessive fatigue or heat stress. During the hot summer months, when working in Class C or higher personal protective equipment (PPE), the work should be scheduled for the early morning hours to avoid performing high stress work during the hottest part of the day.

Use safety chains to assist with suspended loads. Safety chains were used to guide suspended loads to prevent workers from placing their hands under the load.

Minimize access to the equipment control room to avoid distractions during operations. The operation of the robotic retrieval and process systems requires concentration and attention to detail by the operators to minimize operational problems and ensure the safety of personnel, the equipment, and the environment. Tours and visits by stakeholders should be scheduled to avoid interference with critical operations.

13.2.2 ALARA

Maintaining contamination and radiation exposure levels for personnel ALARA is essential. ALARA principles must be key considerations during the design and equipment selection phase of the project. The following paragraphs describe some of the lessons learned relative to the ALARA goals of the project.

Involve RP personnel early in the planning stages of the project. Such personnel should be key members of the planning team for the project, review all equipment and process designs, and have a thorough understanding of equipment function and planned operations. RP personnel should provide input on items such as containment of equipment when removed from the tank; hoisting and rigging of contaminated equipment; washing equipment before removal; dismantling and sizing the equipment for disposal; and packaging for reuse (i.e., stands, cribbing).

Locate equipment control panels away from present and anticipated radiation fields and equipment interfaces. Control panels typically require frequent access by personnel and should therefore be located away from radiation fields. Control panels should also be located away from equipment interfaces because of the potential for leakage and the necessity to reorient or relocate the equipment from time to time.

Have a sufficient quantity of shielding blankets on hand for use in frisking booths, shielding pipe, etc. Shielding blankets provide a convenient and relatively inexpensive method of protecting personnel from radiation exposure. More often than not, radioactive materials will accumulate in places that were not initially anticipated. The use of shielding blankets may provide an alternative to expensive modifications or frequent flushing of a system to minimize exposure.

Effectively communicate system changes that may affect radiation fields. RP personnel should be kept apprised of all system changes and be a permanent member of the change control board for the project.

Use inexpensive available materials for shielding wherever possible. Water was used to cover the radioactive sludges and provide shielding to reduce the radiation exposures to operators working with equipment in containment boxes over open tank risers.

Limit and control the access to radiological areas. Access to the GAAT site was limited to those personnel required to perform work. Visitors and guests were required to sign in and out on an access log.

Monitor radiation exposures and balance work activities to prevent personnel from receiving higher-than-necessary exposures.

Use work instructions and prejob briefings to minimize confusion and exposure time and to enhance safety. Work instructions and prejob briefings were required before any work was performed to ensure that both project and craft personnel had a clear understanding of the task and had the necessary tools prior to entering the radiological areas.

Develop and perform maintenance procedures to minimize personnel exposure. Maintenance procedures were developed and performed with the consideration that the equipment was being used to remove radioactive materials and that exposure levels should be kept to a minimum. Using remotely operated equipment to reduce radiation exposure is of limited benefit if maintaining the equipment requires workers to receive high doses.

Where moisture accumulation is possible, use drain lines from HEPA filter systems. Certain activities inside the tanks, such as wall washing and/or scarifying, resulted in a significant amount of mist (water) being drawn into the tank's HEPA filter system. The mist would coalesce and accumulate in the HEPA filters and eventually block and/or restrict the airflow from the tanks. This problem was alleviated by installing drain lines in the bottom of the duct leading to the HEPA unit to allow the moisture in the duct to drain back into the tank. Extending the life of the HEPA filter reduced personnel exposure through reduced maintenance requirements.

Use reusable PPE whenever possible. To reduce radiological wastes, PPE that can be washed and reused should be considered.

Use waterproof PPE in areas where there is a potential for contact with contaminated liquids. Avoid the use of cloth or Tyvek PPE in areas where there is a potential for contact with contaminated liquids.

Add absorbent material in the bottom of equipment containment structures when removing equipment from the tank for any significant period of time. Secondary containment should also be used around the bottom of each piece of equipment removed from the waste tanks. Moisture will condense inside closed containment systems, which will pose a contamination problem when the equipment is moved.

Use sheet metal covered with heavy plastic on work platforms around waste retrieval equipment. This will assist RP technicians in identification of contamination problems in the work area.

Plan operations so that the bag-in/bag-out of large items is an infrequent requirement. When inserting or removing large items, a large bag-in/bag-out port was used to facilitate the transfer. Avoid single-door approaches when transferring equipment in or out of containment, because of the difficulty in controlling the spread of contamination. Small access ports or air locks should be used whenever possible. Door openings should be reserved for infrequent operations, such as periodic major system maintenance.

Use a double-door pass-through port for introducing clean supplies, clean tools, or clean bags of tools into containment structures. Gross contamination of the pass-through port can be avoided by minimizing the transfer of contaminated items back out through the pass-through port and by precluding the use of the port for temporary storage.

Operational efficiency and personnel radiation exposure levels were improved by leaving the MLDUA inside the tank at the end of each shift.

13.2.3 Contamination Control

Controlling the spread of contamination provides the basis for ensuring the health and safety of personnel and protection of the environment. Some of the lessons learned from the GAAT Remediation Project relative to contamination control consideration are described in the following paragraphs.

Wash gloves frequently. Gloves should be changed and washed frequently with detergent and water. Aside from the radiological benefits, this procedure removed stickiness from hydraulic fluid and tape adhesive.

Be vigilant in preventing the accumulation of debris. Debris should be removed as efficiently and as soon as possible to prevent interference with operations both inside and outside the waste tank. Debris should either be removed or consolidated in the work area inside the tanks as soon as possible to avoid potential tangles or blockages of retrieval equipment. Cables and wires that could wrap around rotating equipment such as the CSEE or become entangled in the Houdini tracks were of special concern. Debris accumulation outside the waste tanks on work platforms should be consolidated and managed to ensure personnel safety and protection of the environment.

A spray wand should be assessable in containment structures to aid in decontamination of components and equipment as they are removed from the waste tank.

Internal tank liquid level data and external dry well groundwater conductivity data can be used to successfully evaluate the integrity of the tanks and monitor any further spread of contamination to the environment. The internal and external methods can be used to determine that the tanks are not leaking. These monitoring methods were able to identify potential liquid releases at a threshold of ~0.5 gal/h. Use of the external dry well monitoring proved to be a robust and cost-effective technique that allowed the use of the tanks for temporary transfer and storage operations and helped shorten the schedule and reduce overall project costs.

13.3 EQUIPMENT DESIGN, TESTING, AND MAINTENANCE

Most of the equipment used in the GAAT Remediation Project was a part of either a very specialized unique system or a system or component used in a unique application. Simplified maintenance requirements to minimize downtime and proper containment to prevent environmental releases and personnel contamination are essential to the success of a tank waste remediation project. The lessons learned from the project with potential impacts on future equipment design, testing, and maintenance are as detailed in the following sections.

13.3.1 Design Preparation

Prior to beginning the design process, sufficient information on the characteristics of the tanks and the tank waste must be collected. This effort should include the following.

- Understanding the characteristics of the sludge wastes before selecting classifiers/filters. The classifiers/filters located in the WCS were installed to ensure that the size of the particles entering the waste transfer line was $<100\ \mu m$. The frequency at which the filters automatically back-flushed indicated blinding of the filters by particles $<100\ \mu m$, which resulted in reduced transfer efficiency from frequent back-flushes. The classifiers were eventually bypassed when it was determined by sampling and in-line measurements that the particle sizes were predominantly $<100\ \mu m$.
- Establishing the characteristics of the waste and process chemicals to ensure the proper selection of materials for all gloves and glove ports. The characteristics of the wastes and process chemicals that come in contact with the equipment must be adequately established to ensure the proper selection of materials.
- Ensuring that the tank atmosphere is properly characterized and that any impacts on the design and operation of the in-tank equipment are well understood. This is especially important if flammable gases are present.
- Performing degradation tests using actual waste materials and process chemicals during the selection phase if characterization or resistance data are unavailable.

Involve inspectors early in the design process to identify necessary modifications to ensure code compliance. The GAAT Remediation Project obtained early involvement of inspectors for the National Electric Code, American Society of Mechanical Engineers (ASME) code, DOE radiation control, and other applicable codes during the design and construction process.

When relatively high-pressure gas is used with the PAMs, a considerable shock wave can be produced inside the waste tank. This shock wave may be capable of damaging mechanical and structural elements of the tank. Before Pulsair mixing is used, the structural stability of the tank must be assessed to ensure that it will not be damaged by the anticipated shock waves.

13.3.2 Mechanical Design Considerations

In-tank radioactive waste retrieval operations are highly specialized and unique. The design process should specify the use of proven high-quality equipment whenever possible, rather than one of a kind or cheaply made systems. Design and manufacture the equipment to be as rugged as possible to avoid mechanical problems and to withstand the harsh environment inside the waste tanks and the sometime rough handling during installation, removal, and operation. It was not uncommon for the equipment being inserted or withdrawn from the GAATs to be dragged against the tank risers or to have protrusions hang on entrance or exit from the tanks.

Design the equipment to withstand a harsh environment. Some equipment will be more vulnerable to radiological and chemical damage than others. If a piece of equipment must be deployed and retracted frequently to minimize exposures, incorporate a trade-off evaluation to determine whether it will be more cost-effective to design the equipment for prolonged exposure than to spend the time required for frequent deployments and retractions.

Seals on all equipment contacting the waste should be designed to withstand the harsh chemical and physical characteristics of the wastes. The abrasive nature of the waste caused excessive wear on the seals on the CSEE. As the seal wore, the vacuum at the CSEE inlet was reduced and pumping efficiency decreased.

All systems should be designed for reliability to ensure sufficient availability to meet the project schedule and to avoid costly downtime for repair. Designs should be modular and permit subassembly replacement to reduce the repair time and avoid personnel exposure to contamination or harsh environments. Use redundant systems, when possible, to minimize downtime for repairs. For example, the CSEE and the jet pump could be operated with identical high-pressure pumps. This provided flexibility in operations in the event that one pump failed and also reduced the spare parts inventory.

Consider freeze protection when designing systems that handle water. For long-term projects or short-term projects conducted during the winter months, all piping and equipment systems should be self-draining and have clearly defined procedures for freeze protection. Use hard rubber seals whenever watertight seals are needed. This type of seal necessitates using rigid panel frame designs. Hard rubber seals retain their flexibility and resist absorbing liquid contaminants better than foam sealing or expanded rubber materials.

The containment system should be designed to minimize overspray from decontamination systems. Water spray and splash from the DSR made sealing the 20-in.-diam bag-out port (located in the TMADS containment bezel) very difficult. Because of a poor seal design, the port had to be cleaned and decontaminated before a polycarbonate window could be installed to provide additional light for workers.

Ensure that tank access is sufficient to allow deployment of the selected retrieval system components with relative ease. In waste tank applications, access risers must be large enough to allow easy deployment and maneuverability of equipment. Separate risers are needed for each piece of equipment to be installed inside the tank.

Risers, in-tank equipment, and debris in the tank can hinder the deployment of retrieval system components. Ensure that all in-tank materials and equipment are mapped and their interference with the retrieval system components is well understood prior to operation.

During tank waste retrieval operations, the addition of heavy equipment loading on the tank dome must be considered. A load-bearing platform that bridges the tank may be needed if the tank dome is not capable of supporting the load. Load-bearing platforms were successfully used by the GAAT Remediation Project to transfer the weight of required equipment to the soil around the outside diameter of the tanks.

The inlet screen on the CSEE was easily plugged by waste and debris. Back-flushing was not as effective as originally anticipated. In addition, the back-flush operations added a significant volume of water to the system. An improved method of cleaning this screen is needed.

Rotation of the nozzles on the CSEE was occasionally interrupted by loose debris such as rags, tape, and rope. The design should be improved to either better protect the rotating nozzles or allow for easier debris removal.

Although unlikely, a fine mist of waste supernatant may be generated when the PAM system is operated at high pressures. Ensure that the capacity of the tank ventilation systems is sufficient to handle any increased vapor loads.

Design accessories to ensure that their weight does not exceed the payload limitation for remotely operated systems such as the MLDUA. This restriction requires consideration of the weight of the hose, gripper device, and the accessory (GSEE, CSEE, CEE, etc.).

Design accessories to ensure that their lateral forces do not exceed the design limitations of remotely operated system such as the MLDUA (i.e., 22,000 psi).

Design accessories to operate outside the fundamental frequency of remotely operated systems such as the MLDUA. The first fundamental frequency of the MLDUA is ~1 Hz. Any frequency generated near 1 Hz is likely to result in severe vibration problems for the MLDUA.

13.3.3 Operational Considerations

System designs must consider the consequences of exposure of personnel to radiation and harsh chemicals during equipment maintenance and waste retrieval operations. Contamination scenarios for all systems and equipment must be projected and decontamination facilities provided to ensure that personnel exposure is ALARA. Time, distance, and shielding must be used as appropriate to minimize personnel exposure.

Avoid the use of materials with sharp edges or burrs, which have the potential to tear gloves, damage equipment, or trap contamination.

For glove port use, choose gloves that are compatible with all materials and chemicals that the gloves will contact, including oils, solvents, and lubricants.

Design tether reels and stowage positions so that major pieces of equipment inside a containment structure can be positioned near standing-height glove ports for maintenance and routine operations. Provide sufficient access ports to facilitate the maintenance of tether reels, which have a tendency to foul if the tethers become crossed or if slack develops. Viewing ports and glove ports should be provided to aid in maintenance and troubleshooting. Avoid operating scenarios that require operators to lift more than 20 lb while using the glove ports. Provide a hoist inside the containment structures for items heavier than 20 lb.

The ergonomics of glove-port locations must be considered and should determine the positioning of equipment for routine or maintenance operations. Try to keep stowed equipment at a standing glove-port height. If necessary, some glove ports can be placed at a height that requires a kneeling position. The position of some glove ports in the containment structure for the Houdini ROV required operators to kneel when performing maintenance activities (Fig. 13-1). However, try to avoid glove-port heights that dictate a crouching position. Provide sliding tables that can be used to move items from the edge of bag-in/bag-out ports to within easy reach of the glove ports. Provide access to the sump in facilities that use floor gratings to aid in the removal of items that fall into the sump.

Maximize the visibility of equipment with viewing ports and see-through contamination-control covers. Operators must have good visibility within the containment structure so that they can safely perform required operations, such as attaching end-effectors and performing hands-on tasks without breaking containment. Enclosures with see-through panels can cause the equipment to become overheated due to solar loading, so provide removable reflective covers to reduce solar heating when visibility is not required.

Fig. 13-1. Containment structure for the Houdini ROV showing an operator kneeling to perform a maintenance activity.

Design all equipment interfaces so that they are user-friendly for the operators. Keep in mind the talents, abilities, and background of the operators. Straightforward user interfaces are preferred. Obtain operator input during the interface design to ensure ownership and acceptance of the equipment during field operations. Consider providing audio feedback of in-tank operations to equipment operators. This type of feedback would provide another indication of equipment performance, failures, and interference.

Walk down as-built drawings for all major systems (including off-the-shelf items) with the operators. This ensures that accurate drawings are available if field modifications or repairs are required. It also ensures that the operators understand how the systems are built and intended to operate.

Minimize the use of tape, hose clamps, and tie-wraps for securing hoses and cables. Use of hose clamps and tie wraps results in localized rub and wear points capable of cutting hoses and cables.

Consolidate hoses and cables into bundles and secure them near termination points to prevent occurrence of unwanted slack that could catch on something and potentially damage the equipment.

Use an adjustable tank vacuum source to accommodate variations in operations. A method of adjusting the tank vacuum was used during operations such as bag-in/bag-out of equipment from containment areas. If the vacuum was too strong, bags were pulled into the tank, making the operator's task more difficult.

Consider environmental effects on adhesive sealing equipment. During cold temperatures, the tape used to seal gloves, bags, boots, etc., was kept warm to improve adhesion properties.

Consider providing a temporary in-tank holder or resting place for the CSEE when the MLDUA and/or Houdini is needed for other short-term tasks. The HMA could be used for this service, but a separate stand or holder could provide more flexibility of operations.

Coordinate activities and emphasize water conservation in all aspects of waste retrieval operations.

13.3.4 Equipment Testing

Thorough cold testing of all equipment and checkout of operating procedures must be done before deploying the equipment in a radioactive environment. Cold testing allows the systems to be successfully integrated and provides training opportunities for personnel in a low-risk environment.

Cold testing should be performed under simulated conditions similar to the tank being remediated and with the actual systems that will be deployed in a radioactive environment. Use the same deployment and maintenance requirements, including representative lighting, communications equipment, identical platform access, and identical procedures.

Workers should wear full PPE during portions of the cold testing to ensure that activities can be performed within the confines of the PPE. This process also allows personnel a chance to develop specialized tools and techniques that can decrease their exposure during field operations. It is much easier to develop a solution to an equipment or process problem during cold testing than during field deployment where access is significantly limited.

13.3.5 Maintenance Considerations

Prepare and implement a preventive maintenance (PM) schedule to avoid costly downtime. For a long-term project, PM will ensure the continued reliability of a system. PM schedules should be worked into the project schedule as a key portion of the overall operations plan. PM schedules were developed for all the GAAT waste retrieval systems. PM actions typically coincided with movement of the equipment between tanks, which limited the downtime during operations and identified any components that required replacement prior to failure.

Identify critical spare parts and consumable items in detail. All critical spare parts and consumables must be identified and adequate supplies maintained throughout the duration of a project. Critical spare parts should be identified during the design phase and procured along with the equipment during fabrication. For the GAAT Remediation Project, these items were procured prior to operations and stored in a location convenient to the operations staff.

Secure commonly used tools in tool bins and/or on lanyards. No more than three or four lanyards were used together because of tangling/clutter. Retractable or stowable lanyards were preferred. Lanyards provide rotational freedom for tools such as screwdrivers and hex-head wrenches. Special-use tools were kept in a location where they could be easily accessed when needed.

Place tool bins, pass-through ports, bag-in/bag-out ports, and decontamination spray wands within easy reach of glove ports. Operators must be able to conveniently and safely reach all tool bins, ports, and decontamination equipment within a containment structure. For the GAAT Remediation Project, the equipment was placed within ~16-in. axial displacement and 6-in. radial displacement of glove ports.

Add glove ports as necessary to improve operations and maintenance. Glove ports were added, as necessary, to facilitate minor maintenance or repairs to avoid shutdowns and breaking containment. These were typically special-purpose glove ports, separate from those used during routine operations and maintenance. Since these glove ports were retrofitted to the containment structure, it was necessary to place some in locations that were ergonomically less than optimal.

Provide stabilizing and hold-down systems inside containment structures. When maintenance and repairs were performed inside containment structures, a means of stabilizing the equipment in place was provided. Use of stabilizing and hold-down equipment allowed workers to have both hands free to manipulate tools rather than using one hand to hold a piece of equipment in place.

13.3.6 Utility and Service Systems

Provide sufficient 120-Vac ground fault current interrupter receptacles. This type of electrical power service was provided near the equipment platforms and near the location of the balance of the plant equipment to meet service demands.

Ensure that the capacity of the available off-gas handling systems is adequate to meet process system needs. The permissible air volume for operation of the Pulsair mixers was limited, to prevent the tank off-gas system from being designated as a safety system. Trade-offs between greater flexibility in air-motivated mixing operations and expensive off-gas system upgrades should be assessed early on during system design.

13.4 WASTE RETRIEVAL AND SPECIFICS CONCERNING WASTE RETRIEVAL EQUIPMENT

Waste retrieval systems and equipment must be selected based on the specific tank operating conditions and constraints at each site. The Houdini and the MLDUA worked well together for efficient waste retrieval operations at the GAAT OU. The combination of the Houdini's mobility and ruggedness in operations in the bottom of the tanks with the MLDUA's reach and dexterity in operations in the upper portion of the tanks provided an excellent system for use in tank waste retrieval operations. Sluicing operations were most efficient when the plow on Houdini pushed sludge toward the MLDUA. The MLDUA worked best for bulk sludge retrieval and wall cleaning, while the Houdini was better at plowing the residual sludge (<8 in.) to the CSEE while it was held by the MLDUA.

Visibility in the tanks is a key element to successful waste retrieval operations. Multiple camera views and adequate lighting are needed to enable the operators to adequately see the wastes, obstructions, and retrieval equipment.

Computer control and preprogramming of repetitive events can significantly increase waste retrieval efficiency; however, the operators must have the capability to intervene and take control of the equipment during unusual conditions. If possible, control algorithms should be developed using operator input on preprogrammed operations.

13.4.1 MLDUA

The MLDUA provided the dexterity and reach needed to effectively clean the walls of the GAATs and perform bulk waste retrieval operations. The lessons learned from the operation of the MLDUA in the GAATs are presented in this section.

13.4.1.1 MLDUA User Interface

The MLDUA user interface included system controls and video monitors that displayed the video signals from the integrated MLDUA cameras, as well as the overview cameras in the tank being remediated. The MLDUA information display screens were spread across the MLDUA console (Fig. 13-2), which made it more difficult for operators to monitor the system operation and performance. Future designs for a user interface should consider the positioning of the display screen carefully and provide needed control information in a unified area that is easily visible to the operator.

Future user interface designs should avoid the use of continuous warning alerts and instead check warning status periodically to see if the warning condition clears. Continuous alerts fill the computer log with multiple alerts that are unnecessary, can hider diagnosis and repair of the error, and desensitize operators to more crucial warnings and alerts.

13.4.1.2 Preprogrammed Operations

The MLDUA was ideal for washing and scarifying the tank walls to remove contamination; however, low visibility occurred in the tanks during these operations due to the formation of mist at the higher operating pressures. By preprogramming the MLDUA with the scarifying paths, controlled movement was achieved so that operations could continue in poor visibility.

Fig. 13-2. MLDUA user interface.

Preprogramming the robotic arm worked well and helped to simplify operations. However, it is recommended that the number of robotic/computer-controlled actions be limited to only those actions that require such a degree of precision or control that programming will increase flexibility and reduce cost. Some of the MLDUA operations that should have been manually controlled rather than remotely controlled include the following:

- Mobile Deployment System (MDS) X, Y, and roll adjustment;
- Vertical Positioning Mast (VPM) housing gate valve operations;
- raising and lowering the VPM housing; and
- MDS outrigger operations.

13.4.1.3 Maintenance

In future applications, consideration should be given to the installation of at least a 150-lb-capacity winch inside the MLDUA TRIC structure. A winch with increased capacity would allow the use of a wider range of materials and tools.

Locating routine maintenance equipment within the VPM housing would simplify maintenance of the housing in future applications. Another modification would be to locate certain components outside the contaminated VPM housing, including the VPM housing angle and purge/pressure sensors, the lubrication oil drain, and the fill ports for the VPM tube winches.

In the future, it would be better to mount the MLDUA umbilical tethers in cable carriers that could take the strain of the tether motion and tension, rather than placing the signal-carrying cables under tension.

13.4.1.4 Recommendations to Reduce Operating Time

Originally the MLDUA computers and main hydraulic pump had to operate continuously to hold equipment with the GEE. A small continuous-duty hydraulic system was installed to improve the control of the GEE. A small hydraulic pump, with a motor and controls, supplied hydraulic pressure to the MLDUA GEE. After the change, the GEE could hold equipment (e.g., the CSEE) overnight while the rest of the MLDUA system was shut down. This modification saved hours of operating time for the MLDUA by eliminating the need to grasp and stow the tool at the beginning and end of daily operations. Other needed improvements to the GEE include the following:

- making the grasp adjustable, instead of just an open or close position to improve performance and flexibility, and
- increasing the accessibility of the GEE camera (contained inside the GEE) to improve maintenance and adjustment.

13.4.2 Houdini ROV

The Houdini ROV provided the power and mobility to break up wastes and effectively clean the floors of the GAATs. Caution was required when driving the Houdini or manipulating the manipulator arm. Administrative controls in the form of slower travel speeds were employed to prevent collisions between the Houdini, the CSEE, and other tools and objects within the tank, including the tank wall. Problems with the hose routing of the hydraulic transmission lines on the Houdini I ROV, as well as problems with the manipulator arm and umbilical, led to the development and deployment of the Houdini II ROV in the tanks in the STF. Another improvement, which changed the center of gravity of the vehicle to allow it to hang straight during deployments and retractions, reduced tank riser interference and self-inflicted damage to the vehicle. Prior to this improvement, the vehicle was subject to hanging on the edge of the riser sleeve at the dome of the tank during withdrawal.

13.4.2.1 Hydraulic System

Shell Tellus 32, a mineral-oil-based fluid, was used in place of the water/glycol fluid initially used for the vehicle's hydraulic system. The water/glycol fluid was found to cause an inordinate number of failures in the valves located on the vehicle and in the TMADS. The electrically conductive water/glycol fluid also caused electrical short circuits on the manipulator arm when a failed servo valve allowed the fluid to flood the arm's housing.

13.4.2.2 Vehicle Manipulator Arm

The Schilling Titan-II manipulator that was integrated with the Houdini I ROV was replaced with a Titan-III manipulator with a sealed shoulder housing in the design for the Houdini II ROV. The housing on the original Titan-II manipulator arm was open at the shoulder, which allowed sludge to collect inside the arm during mock retrieval and decontamination operations during the cold tests. The sludge could be removed only by disassembling the arm.

13.4.2.3 Connectors, Fasteners, and Hoses

The ROV should be designed to limit connector and hose stress during folding for deployment and retraction. Many of the connectors on Houdini I were subject to damage or loosening when the vehicle was folded. The most common failure point was at the elbow fittings to the track drive manifolds. It was also during these operations that the hoses sometimes pinched. During waste retrieval operations, problems with the original Houdini I system were controlled by routing hoses with wire ties, daily inspections of all hoses, and weekly tightening of all connectors. For Houdini II, hoses and fittings were replaced by manifolds whenever possible to reduce failure points.

Connectors for electrical cable terminations in the Houdini tether should be used to simplify maintenance. The electrical cables that were damaged on Houdini I during deployments and retractions were difficult to change. When replacement was necessary, these cables had to be spliced and soldered inside the

TMADS. The new tether design on Houdini II had the connectors installed in the vehicle termination, which proved to be field serviceable and did not require resoldering in the field.

Use appropriate fasteners for mobile waste retrieval systems. Vehicle vibrations produced by the lugs on the tracks produced more vibrations than originally anticipated. Locking bolts and other fasteners failed to hold. However, Nordloc™ lock washers proved to be successful in eliminating the loosening effects of the vibrations.

Another suggested change would be a redesign of the camera attachment. During Houdini I and Houdini II ROV operations, the mounting screws on the body of the camera were frequently loosened. A thread-locking compound was applied to the mounting screws, but the problem persisted.

13.4.2.4 TMADS

The Houdini II design of the TMADS, although improved over Houdini I design, still had limitations and inherent problems with the system ergonomics. The Houdini II TMADS was improved to replace the maintenance doors, which had full-length hinges that did not seal very well, with new doors with positive compression seals and no full-length hinges. The side maintenance door was reduced in size and hinged along the bottom edge to create a ramp to facilitate vehicle removal.

Use of a separate power supply for TMADS would allow the system to remain energized while the Houdini vehicle was being maintained. The current design uses a single power supply and requires that the TMADS be shut down whenever maintenance and repair operations are conducted on the Houdini.

The hoist inside the TMADS should have a separate power feed to allow continued use during maintenance and repair operations on other parts of the system. Power feeds also need to be accessible from the outside of the containment structures.

13.4.2.5 Cold Testing and Maintenance

Although the Houdini system is not overly complex to operate, it does require some specialized training prior to operations to prevent inexperienced operators from damaging the system. Sufficient lead time and a cold test facility are needed to ensure that operators are properly trained.

The maintenance capabilities of stand-alone systems should be improved. Although the STF maintenance tent was an extremely helpful tool for the Houdini maintenance, it was also cost and schedule prohibitive at times. The maintenance tent and the major equipment systems should be improved to allow for quicker, more efficient connection and disconnection.

It would be beneficial to the workers to improve the environmental controls in maintenance areas. Maintaining tolerable working conditions in the maintenance tent during the summer months proved to be challenging. Heat loading from the sun during the summer made the containment area of the tent very uncomfortable and introduced heat-stress limitations that affected the duration of the work activities.

13.4.3 In-Tank Viewing Systems

Remote camera and lighting systems are crucial to the success of in-tank waste retrieval operations. Without these systems, operators would be unable to safely perform operations. Camera systems with adequate depth-of-field zoom capability and light sensitivity must be selected. Lighting systems must also be compatible with the environment and the selected camera system.

13.4.3.1 Remote Cameras

At least two camera views are needed for in-tank operations. A single camera view does not provide the operator with an adequate depth perception to reliably operate the in-tank systems. Cameras used for monitoring interior tank operations should be equipped with adequate zoom capability to provide detailed close-up views and light sensitivity to provide views with adequate depth of field. The camera systems should be easy to install and replace. Cameras should be relatively inexpensive unless they are proven to be radiation hardened. The cameras used inside the gunite tanks suffered cumulative damage caused by overheating from the lights and radiation exposure. Rather than having a camera fail during waste retrieval operations, problematic cameras were replaced before they were deployed in the next tank undergoing remediation.

Ensure that the camera systems can be easily positioned inside the tanks. Each camera system at the GAATs was mounted on a pole that could be vertically extended by attaching additional 6-ft sections. A separate camera cable was factory installed inside the camera pole for convenience and contamination control.

Ensure that the cameras are waterproof. A waterproof box with a connector was attached at the top of the camera pole so that the main camera cable could be connected from outside the tank. Although this worked well, a plastic bag covering the top of the extension pole and riser was still required to prevent water from entering the connector box and the vinyl boot inside the tank.

Use vinyl boots to protect the camera equipment. A 2- to 3-in. rubber PVC pipe coupler was attached to the vertical extension pole above the camera head using hose clamps. This technique was used to secure a vinyl boot, which was taped at the coupler and at the top edge of the aluminum camera adapter to keep the vertical extension pole from becoming contaminated. When a camera was removed from the tank, the boot was peeled inside out to contain any contamination and the excess cut off and properly disposed of. A new boot and coupler were installed on the vertical extension before the camera was returned to the tank.

Ensure that adequate tools and a maintenance area are available for camera maintenance. A glove box with the necessary tools was provided for camera repairs in a designated maintenance area. These proved essential for efficient maintenance operations.

Use cameras that are easy to replace and inexpensive. The in-tank overview camera systems used in the GAATs were not radiation hardened but were high-quality cameras that cost ~$1K each. The total cost of each overview camera system used in the GAATs was ~$30K, which included the waterproof sealed camera module, lights, pan and tilt, extension poles, cables, and controllers. The cameras used inside the GAAT tanks suffered cumulative damage from overheating and radiation exposure, resulting in frequent repairs and replacements. On average, the camera modules were replaced about once every 6 to 12 months.

13.4.3.2 Remote Lighting

In-tank lighting systems must be compatible with the environment and the selected camera system. The two factory-standard 35-W lamps integrated into the video camera housing were not sufficient to illuminate the 25- to 50-ft-diam tanks. Camera housings were modified to include a single 250-W lamp with a polished stainless steel reflector shield, instead of the two factory-standard 35-W lamps. Heat from the 250-W lamp, plus the position of the housing relative to the camera, caused the camera to frequently overheat. In future applications, consider positioning the lights to the side of the camera and maintain enough distance so that heat generated from the lights does not overheat the camera. Adequate heat dissipation for the lamp housings is needed to extend the life of the cameras. As a result of the overheating problems with the in-tank camera, a heat shield was required between the 250-W lamp and camera. A heat shield was initially constructed of aluminum with fiberglass taped around it; however, because of continuing camera problems, this shield was replaced with a high-temperature plastic shield. Cameras can be cooled using a variety of means, including internal purges, internal fans, heat shields, or other means to dissipate the heat from high-wattage lamps. When cameras are not in use, they should be turned off or operated with reduced lighting.

13.4.3.3 Recommendation to Improve In-Tank Visibility

To increase the visibility of equipment during waste retrieval operations, paint in-tank equipment with bright colors that provide high visibility and contrast in the tanks. Visibility is limited during operations that generate a fog/mist. Reflective tape can also be used to make equipment more visible in high-fog conditions. This was used very successfully with the LSEE so that operators could verify that the nozzles were moving appropriately. In-tank visibility can also be improved by using indirect lighting during high-mist- or fog-generating operations. Additional light sources, installed perpendicular to the camera view, may also be used to provide indirect lighting and cast shadows to aid in depth perception.

Provide lights and cameras inside the equipment containment structures to monitor equipment deployments or retractions and to provide additional views for equipment operators. For example, an additional camera installed in the HMA's containment structure could have provided visual feedback if a leak were to occur in the waste transfer line.

13.5 WASTE-CONDITIONING, MIXING, AND TRANSFER EQUIPMENT

The waste-conditioning, mixing, and transfer systems provided the capabilities to effectively suspend waste solids and transfer material from the GAATs to either the MVSTs or BVESTs. This section describes the lessons learned and observations pertinent to the operation of these systems and components.

13.5.1 WCS

The WCS provided needed flexibility for installation of an alternate transfer pump. The WCS was designed to include a grinder; however, because of the flowable nature of the majority of the waste in the GAATs, the grinder was ultimately not installed. The grinder connection was later identified as the best location for an additional transfer pump for transfer of wastes from the STF to the BVESTs. Redirection and reuse of the existing WCS connections simplified the installation of the pump. Future applications should consider providing extra connections that can be used as they are needed or used later as conditions change. The extra connections improve the flexibility of this type of system and simplify the integration of additional equipment that may be required for successful waste retrieval and transfer.

The motor controller for the Discflo pump was placed in a weatherproof enclosure and subjected to its own heat generation as well as the solar heating on the enclosure. The added environmental heat loads created stability problems for the motor control center, which required using a separate air-conditioning unit to reduce the heat load. In future applications, heat loads on motor control centers should be taken into account during the design and integration of equipment.

The Discflo pump was a vital component in the overall success of the WCS. Regulators with the State of Tennessee and the EPA had made it clear that the removal of waste from the STF to the MVST was the ultimate goal of the entire project. The Discflo pump functioned almost flawlessly after the initial technical problems were resolved. A problem with the electric power feed caused an early failure of the variable frequency drive unit and was easily corrected. The pump was designed to operate while submerged in water, and when the liquid level in the tank dropped below the motor housing, the motor overheated and automatically shut down. Using a secondary pump to transfer a stream of supernatant across the housing solved the cooling problem.

The PCS performed well with two of the four key functions it was designed to do. The Isolok™ samplers and the pressure transmitter were vital in monitoring the transfer of waste from tank W-9 to the MVST or BVEST W-23. The roughing filters in the PCS were used only once because of (1) difficulties with blinding of the filters by the sticky solids and (2) the evidence provided by the Lasentec instrument and sample analysis data that showed that the solid particles were typically <100 μm. The PCS was also designed to accept a solids grinder, but this device was not needed and was not installed. However, that flexibility did permit installation of the air-operated diaphragm pump used by the WaRTS to transfer waste to the BVEST, as previously mentioned.

The SMTL proved to be of critical value to the GAAT project in regard to providing the credible data needed to demonstrate that the waste slurry met the particle size limits of the WAC for the waste transfer line. This capability took on even greater importance when the PCS classifiers were bypassed. However, the inability of the SMTL to provide credible absolute slurry density measurements meant that samples had to be taken during every transfer to verify that nuclear safety limits were met and to maintain a material balance.

Instrumentation in the SMTL provided the operators with information on the instantaneous flow rate. By monitoring the flow rate and estimating the nominal flow rate, the operators could estimate the total volume of waste delivered during a given period of time. The addition of a flow totalizer that is resettable and remotely indicating would be useful in maintaining accurate waste transfer balances.

Include in-line carrier fluid density measurements to improve the quality of the information from the SMTL. The suspended solids concentration in the slurries was reasonably estimated from the slurry density measurement obtained with the in-line Coriolis meter; however, the suspended solids concentration measurement could be improved by also simultaneously monitoring the density of the carrier fluid.

The doubly contained waste pipeline (flexible hose inside a PVC pipe), constructed to temporarily connect tank TH-4 to the WCS enclosure, was adequate for the brief clean-out campaign for that tank.

13.5.2 WaRTS

The WaRTS performed as designed. Its only operational difficulty was that the air sparger in the bottom of the surge tank became plugged. However, this did not have an adverse effect on the tank clean-out process.

The addition of viewing ports or windows in the covers for the WaRTS secondary containment for the accumulation tank and the supernatant pumping system would have been useful in monitoring and troubleshooting the systems.

While no leaks in the WaRTS SPS were experienced, a leak detector in the bottom of the secondary containment would provide valuable advance notification in the event of such a leak.

The installation of the air diaphragm pump used with the WaRTS to draw supernatant out of tank W-8 represented an attempt to take full advantage of the advertised suction lift. When difficulty was experienced in priming and maintaining prime on the suction side of the pump, additional supernatant had to be added to the supernatant reservoir to reduce the suction lift at the pump inlet.

Following deployment in the STF, sludge was suspected to have migrated into the air-water sparge line at the bottom of the WaRTS accumulation tank, causing partial blockage of the sparger. This reduced the effectiveness of the sparger but did not significantly hinder operations. Periodic (approximately once each hour) opening of the accumulation tank drain valve was required to prevent the heavier sludge in the surge tank from clogging the drain. The initial design of the air-water sparge line called for an O-ring seal to prevent the migration of sludge into the sparge line. Subsequent "refinement" of the design eliminated this seal. Cold testing using waste surrogates did not reveal a problem with the refined design.

The volume of the accumulation tank will be bounded by physical limitations, such as installation location, and operational issues, such as shielding and accident analysis. However, as a general rule, larger surge tanks will provide increased operational efficiency and operator flexibility. Batch-type transfers (such as those required during the final portion of the W-9 waste removal campaign) are most efficient with large waste volumes.

13.5.3 PMP

The maximum available operating air pressure for the Russian PMP at the GAAT site was 90 psig. A higher operating pressure would have increased the system's ECR and decreased the amount of residual sludge.

Sufficient air pressure should be supplied to the pneumatic cylinder controlling the rotation of the PMP. Erratic motion was observed near the end of the 90º arc during waste retrieval operations at tank TH-4. It was suspected that the air pressure supplied to the PMP was too low to permit complete movement in one smooth motion.

Additional time should have been allotted for checkout, adjustment, and operation of the Russian PMP. Although the PMP was successfully used to clean out tank TH-4, hot checkout and operation of the system were limited to a 5-day period due to budget and schedule constraints. Additional time for troubleshooting and continued operation to improve the understanding of the operation of the system in a radioactive waste tank was needed.

Additional testing and evaluation of the air distributor valve on the PMP are needed to improve the reliability of the system. Operational difficulties associated with the air distributor valve during cold weather conditions resulted in frequent system restarts.

13.5.4 Flygt Mixers

Flygt mixers were successfully used in cleaning of tanks W-5 and W-9. Two Flygt mixers were added to tank W-5 as an alternative to the RTCS. The mixers were successfully used in cleaning tank W-5, which saved two to four relocations of the MLDUA, Houdini, and associated equipment. However, with only two mixers, the ability to fully mix the contents of the waste tank was somewhat limited, which resulted in a region of low turbulence (and associated settling) in the tank. Potential remedies include using an automatic oscillating mixer mast to sweep the tank periodically. Also, the simultaneous use of three or more mixers in a tank would likely improve the performance of the system. A single Flygt mixer was used as an additional mixing aid in tank W-9 to only slightly improve mixing and solids suspension.

Use ruggedized mixer blades on the Flygt mixers. Although hardened aluminum alloy blades were initially installed on the Flygt mixers (based on the expected operating conditions in the GAATs), two of the blades broke during operation. One of the blades broke during installation and the other by contact with in-tank debris. The blades were replaced with stainless steel props with no further problems.

The Flygt mixer configuration in tank W-5 was such that the mixers could not be positioned any closer than 1 ft above the tank floor. This configuration has a compound effect of focusing the mixing energy directly in front of the propeller above the sludge layer and requiring a greater liquid depth/volume to operate the mixers. The additional liquid depth/volume requires additional energy to achieve a given mixing intensity or velocity relative to what would be required for a lower liquid level/volume. Future designs should provide the flexibility to position the mixers as close to the waste and bottom of the tank as possible.

The in-tank video camera system proved to be essential for positioning the Flygt mixers and monitoring their operation. The camera and lighting system was also found to be essential for inspections of the mixers and the tanks.

13.5.5 PAMs

PAMs should be operated continuously to prevent plugging and to obtain improved results. The initial operation of the PAMs did not maintain positive air pressure on the system at all times, which allowed sludge to backfill and plug one of the mixer pads. This plug was subsequently removed by applying air and water backpressure.

The PAMs were more capable of maintaining solids in suspension than in resuspending settled solids. The best results with the PAM system were observed while the system was operating during waste consolidation operations and during transfers, which were completed near the end of the consolidation operations.

The PAM system does not appear to be suitable for mobilizing stiff, cohesive sludges in large-diameter flat-bottomed tanks.

13.5.6 CSEE

Maintain a minimal water flow through the cutting jets on the CSEE while the exit nozzles are submerged. Maintaining a water flow to the cutting jets will prevent clogging of the nozzles when they are submerged in tank waste.

If possible, to minimize the creation of aerosol and splattering of waste, the nozzles of the CSEE should remain submerged while using the rotating cutting jets. Aerosols reduce visibility and provide a pathway for the spread of contamination. Splattering of waste on the retrieval equipment and around the tank makes waste retrieval and decontamination operations more difficult. Further development is needed to produce an effective skirt to contain spray when washing hard surfaces at high pressure.

14. CONCLUSIONS

After the bulk waste retrieval operations in the GAATs in the early 1980s, final cleanout of the tanks was conducted during a Remediation Project, which was the first of its kind performed in the United States. Robotics and remotely operated equipment were used to successfully transfer over 439,000 gal of radioactive waste slurry from nine large USTs. Almost 94,000 gal of remote-handled transuranic sludge and over 81,000 Ci of radioactive contamination were safely removed from the tanks, which were located in a high-traffic area of ORNL near a main thoroughfare.

A phased and integrated approach to waste retrieval operations was used for the GAAT Remediation Project. The project promoted safety by obtaining experience from lower-risk operations in the NTF before moving to higher-risk operations in the STF. This approach allowed project personnel to become familiar with the tanks and waste, as well as the equipment, processes, procedures, and operations required to perform successful waste retrieval. By using an integrated approach to tank waste retrieval and tank waste management, along with specialized equipment, the project was completed years ahead of the original baseline schedule, which resulted in avoiding millions of dollars in associated costs.

14.1 WASTE RETRIEVAL PERFORMANCE SUMMARY

The initial bulk waste retrieval operations in the ORNL GAATs were conducted in six of the tanks in the STF over an 18-month period from 1982 through January 1984. Single-point sluicing was used in conjunction with a 2.5% bentonite slurry to mobilize and retrieve ~90% of the estimated 400,000 gal of sludge in the six gunite tanks in the STF. At the end of the sluicing operations in 1984, an estimated 2,195,400 lb of sludge had been removed from the STF tanks and was transferred to the MVSTs. The waste remaining in the gunite tanks consisted primarily of materials that could not be readily removed using conventional sluicing and pumping technology.

Beginning in 1993, efforts were initiated to select processes and equipment for use in the removal of the remaining waste in the gunite tanks. After design, construction, and cold testing, residual waste retrieval operations began in the NTF with the deployment of the Houdini I ROV in tank W-3 in 1997. Waste retrieval operations progressed from the NTF to the STF and were concluded with tank TH-4 in January 2001. A summary of the amounts of waste and contamination removed from the GAATs is presented in Table 14-1. A total of 93,967 gal of residual sludge and 439,208 gal of supernatant were removed from the gunite tanks. Approximately 420,533 gal of fresh water was also used during the retrieval of the waste heel material from the GAATs. In addition to the fresh water used in the high-pressure sluicing operations, recycle supernatant was used as needed to facilitate mixing operations in tanks W-5, W-9, and TH-4 and to provide shielding during mixing and retrieval operations. In order to avoid accounting twice for the wastes transferred from the GAATs, retrieval and transfer of the heavy wastes remaining in tank W-9 were not generally included in these totals. Waste retrieval operations for the consolidated wastes in tank W-9 were conducted during nine transfer operations, resulting in the transfer of ~146,900 gal of waste (28,262 gal of sludge and 118,638 gal of supernatant). Considering the transfer of recycled supernatant, over 1M gal of waste was transferred from the GAATs.

14.2 SUMMARY OF EQUIPMENT USAGE

A diverse collection of equipment and components were used during waste retrieval operations at the gunite tanks. Most of the equipment was used intermittently throughout the GAAT Remediation Project, with the majority of the time spent in standby or in transition from one tank to the next. An estimate of the actual operating times, by task, for each of the major equipment systems used in the removal of wastes from the STF gunite tanks is presented in Table 10-10. Operating times during retrieval of waste from the NTF and

Table 14-1. Gunite tank waste removal performance summary[a]

	Tank number									
	W-3	W-4	W-5	W-6	W-7	W-10	W-8	W-9[b]	TH-4	Total
Beginning supernatant volume, gal	15,688	29,754	27,964	41,479	3,565	105,860	64,581	45,616	10,734	345,241
Beginning sludge volume, gal	5,500	13,500	6,600	12,880	10,100	28,100	10,400	9,300	6,400	102,780
Final sludge/supernatant volume, gal	100	100	2,610	1,567	476	786	544	1,398	1,098	8,679
Beginning radioactivity, Ci	356	987	261	4,433	4,819	60,165	8,111	6,242	3.44	85,377
Final radioactivity, Ci	12	11	83	564	208	1,064	844	1,148	0.59	3,935
Water used, gal	41,800	92,300	0	52,000	62,000	65,280	42,153	65,000	0	420,533
Waste removed, %	99.7	99.7	98.5	99.1	99.7	99.7	99.7	99.3	93.5	98.1
Radioactivity removed, %	96.5	98.9	68.2	87.3	95.6	98.2	89.6	82.2	82.5	95.4

[a] Estimates reflect supernatant volumes and curies content based on the RI addendum. Sludge volumes and curie contents for all tanks are based on the best available estimates. Curie values include sludge, supernate, wall scale, and gunite. Information on tanks W-3, W-4, W-5, W-6, W-7, W-8, W-9, and W-10 was taken from DOE/OR/01-1955&D1, *Remedial Action Report on the Gunite and Associated Tanks Interim Remedial Action Project at the Oak Ridge National Laboratory, Oak Ridge, Tennessee*, June 2001.

[b] W-9 values reflect waste at initiation of operations only and do not include “consolidated” waste.

tank TH-4 were not included in this summary table. Information on the specific operations in the NTF is provided elsewhere. Waste retrieval operations in tank TH-4 were conducted over a brief 4-day period in January 2001 and did not result in the accumulation of a significant number of hours of operation on the Russian PMP and associated equipment. The equipment that accumulated the most operating time during the STF operations included Pulsair mixers (2390.5 h), viewing system cameras (1250 h), the MLDUA (706.5 h), Flygt mixers (572.5 h), and the HMA (413.5 h). The operating time for the viewing systems was closely tied to the operation of the MLDUA and HMA. The Houdini I and II vehicles had in-tank operating times of 50 and 134 h, respectively.

A variety of additional information on the usage and operation of the equipment deployed during the remediation of the GAATs is given in Appendix C (Vol. 2). Summary comments on the utility of the equipment are provided in the following sections.

14.2.1 Characterization Tools

The tools described in this section were used for in situ characterization of the tank walls and waste inside the tanks. Each system and/or device served a key function in the collection of data on the condition of the gunite tanks and character of the waste.

Floating Boom, Camera, and Sampling Device—This device was a modified off-the-shelf component that was successfully used during tank and waste characterization operations. The device was manually inserted, operated, and retracted from the tank and was used primarily to deploy the Sludge-Mapping Tool and Ponar Sampler.

TMS—A structured light measurement system that provides three-dimensional mapping capability for the inside of USTs. The system can map any exposed sludge or solid waste but not waste covered with supernatant. The overall reliability of the system was good, but it is a complex system that will require experienced personnel to repair in the event of failure.

Sludge-Mapping Tool—The sonar-based mapping system deployed using a floating boom was used to make initial estimates of sludge volume in each tank. Significant experience is required to interpret the results. This tool had good resolution (+/- 0.2 in.), but the accuracy was highly dependent on the operator's interpretation of the results.

GIMP—This array of columinated beta and gamma radiation detectors was designed for deployment through a tank riser using an overhead crane. The as-received system appears to have limited applicability in waste tanks.

CEE—This multipurpose device provided data on the amount and type of radioactive contamination present in the GAATs. This equipment saw very limited service during GAAT operations, and its use was abandoned in favor of other tools, specifically the CARP and the Wall-Coring Tool.

CARP—This device, which consisted of a single radiation detector and an ultrasonic range sensor, provided good service; however, improvements to the quality of the in-tank display (i.e., larger display) are needed to facilitate remote viewing.

Feeler Gage—This low-tech, highly reliable, off-the-shelf, throw-away item was deployed to determine the consistency and depth of the sludge in the GAATs and the verticality of the tank walls.

14.2.2 Sampling Tools

The tools described in this section were used to remove samples from inside the GAATs. Each device served a unique function in the collection of samples of either the tank walls or the waste present in the tanks.

Ponar Sampler—This low-cost sampling device was successfully used a limited number of times in the GAATs to provide key tank characterization information at multiple locations away from tank risers.

Push Tube Sampler—This commonly used sampling device was reliable during several GAAT sampling efforts. Sample tubes were fabricated on-site at ORNL and were one-time-use items.

In-Line Sampler—These reliable, off-the-shelf, no-maintenance components were successfully incorporated into several GAAT systems.

Wall-Scraping Tool—This simple scraping tool was fabricated from common Unistrut™ stock, a stiff spring, an "X-handle," and a sample collection bag. The tool was successfully deployed by the MLDUA to take scrape samples of the surface of the tank walls.

Wall-Coring Tool—This modified commercially available coring tool was deployed by MLDUA and subsequently "handed-off" to the Houdini for wall-coring operations. Approximately one in three coring attempts failed due to dropped sample or other difficulty.

14.2.3 Remote Cameras and Lights

The equipment described in this section provided views of the inside of the GAATs to facilitate tank waste retrieval operations.

Multicamera Pan, Tilt, and Zoom Controller—This multiplexed pan, tilt, and zoom camera controller provided a simple and convenient method to select and control multiple camera pan/tilt/zoom features from a single control station located in the control room. This device enhanced operational efficiency by increasing the ease with which multiple cameras could be controlled by various operators in the control room.

Overview Cameras—Multiple camera views are crucial to providing operators with the necessary depth-of-field information for remote operation of retrieval systems. Heat from high-intensity lights mounted in close proximity to the camera module must be managed to avoid premature degradation of camera performance. High-quality overview cameras should be used to limit the amount of distortion that occurs when camera views are zoomed to high magnification, as is often required.

MLDUA Mast Cameras—Use of this pair of fixed-focus color cameras and integral lights in the mast of the MLDUA was eventually abandoned due to poor performance and excessive cost/complexity required for repair/replacement. In a deployment in which additional risers are not available for an overview camera, these mast cameras would be very useful. However, the overview cameras used in the GAATs provided much better views than the mast cameras.

MLDUA Wrist Cameras—This single fixed-position color camera in the MLDUA GEE was useful when it worked (~50% of the time). The failure of this camera was suspected to be result of a combination of radiation damage and damage from hydraulic leaks in the MLDUA. The utility of this camera was also somewhat limited by the overspray from the CSEE/GSEE, which clouded the lens opening and reduced visibility. When functioning and clean, this camera was very useful in assisting with grasping operations.

Houdini Cameras—The Houdini system contained a total of four cameras, which significantly enhanced the efficiency of waste retrieval operations by allowing the operators to get a ground-level view of the retrieval progress.

WaRTS Cameras—This simple waterproof security-system-type camera is compact and worked well in this application.

14.2.4 Obstruction Removal Tools

The tools described in this section were used to remove obstructions from inside the GAATs. Each tool served a unique function in clearing a path for subsequent deployment of the waste mobilization and retrieval systems.

Pipe-Cutting Tool—This straightforward modification of a commercially available band saw provided reliable service during several deployments throughout the GAAT Remediation Project. This tool became the principal tool for removal of pipe obstructions inside the tanks.

Hydraulic Shear—This straightforward modification of a readily available small hydraulic shear was used by the Houdini ROV to cut away small (<1-in.-diam) pipe obstructions in the underground tanks.

Modified Wrecking Ball—This modified steel wrecking ball was deployed by a crane through a tank riser and used to compact sludge below the riser in tank W-4 to allow deployment of the HMA. This tool was needed in only one of the gunite tanks.

Pipe-Plugging Tool—The pipe-plugging tool used a metal cup filled with an epoxy sealant to cover and seal the exposed end of a pipe. The device was successfully used to seal three pipes in the GAATs.

Large-Diameter Hole Saw—This device was successfully used to cut holes in the top of the GAATs to allow additional access to accommodate the various pieces of equipment used during the GAAT remediation.

14.2.5 Mixing Equipment

The equipment described in this section was used to mobilize the solids inside the GAATs. Each mixer was deployed to address a unique need during the GAAT remediation.

Pulsair Mixer—This system was used in GAAT W-9 to agitate and suspend solids in the supernatant during all phases of the operation. The system was very reliable and was operated for extended periods of time (continuous operation for week-long periods over 3 years), more than any other GAAT mixing or waste retrieval component. This mixer system primarily facilitated the retrieval of smaller-diameter solids (<100 μm).

Flygt Mixer—These mixers performed well during operations in tank W-5 and subsequent operations in tank W–9.

Russian PMP—This system was used only for a short period of time in tank TH-4 and appears to have high potential for use in low-cost retrieval of bulk sludges. Additional development is needed to resolve issues associated with a sticky air distribution valve and the design of the TRI for future applications.

14.2.6 Sludge Heel Retrieval and Wall-Cleaning Equipment

The equipment described in this section was used to facilitate the retrieval of wastes from the GAATs. Each system provided unique capabilities in the manipulation of tools, retrieval of waste, wall cleaning, and facilitating the operation of other equipment.

MLDUA—This complex device was used extensively to deploy and operate a variety of tools and equipment during the GAAT Remediation Project and was one of the cornerstones to the success of the project. The complex nature of the system resulted in a number of corrective maintenance requirements during operations in the GAATs. Most problems were resolved completely; however, some were considered too difficult or too expensive to pursue or not appropriate from an ALARA perspective. Of greatest significance was a cable failure in the mast, which resulted in loss of control for the wrist roll motor. As a result of the extended downtime required to repair the system, the decision was made to proceed without the joint. In order to accomplish required tasks, operators developed procedures to properly align the wrist manually in the TRIC prior to each deployment. This reduced efficiency and limited flexibility but did not prevent operations. Routine maintenance was essential, and the procedures varied from simple daily inspections during operation to more sophisticated and detailed inspections conducted less frequently.

Houdini Vehicles—This unique and complex system required specialized training and skilled operators but was more straightforward to operate than the MLDUA. Periodic preventative maintenance is required. Two vehicles (Houdini I and Houdini II) were deployed in the GAATs. Houdini II was a second-generation vehicle that incorporated lessons learned from its predecessor during early cold testing and deployment in the GAATs. Although the vehicles were one of the cornerstones to the success of the GAAT Remediation Project, they suffered from an assortment of significant maintenance issues that generally required difficult and lengthy repair efforts to correct. This system was operated in concert with the MLDUA to provide an overall efficient waste retrieval system.

WD&CS—This suite of subsystems was designed to dislodge, mobilize, and retrieve waste from USTs to aboveground treatment or storage systems. The system consisted of the CSEE, HMA, jet pump, and FCE&CB. Limited maintenance-related problems occurred during operation in the GAATs. With few exceptions, repairs were made with relative ease and the WD&CS was successfully used during the 3-year waste retrieval effort in removing ~95% of the radiation sources and ~98% of the waste volume from the GAATs.

CSEE—This rotating water-jet cutter and vacuum-head-equipped device was used extensively to dislodge and mobilize sludge and (some) solid waste in the GAATs. Operation of cutting jets can add significant volumes of process water to the waste stream, which, on average, added ~2 gal of process water to each gallon of sludge removed. The CSEE was most efficient when partially submerged, although care was needed to avoid burying the CSEE to the point of clogging the rotating cutting-head seal. The most efficient shallow-sludge (1–3-in.) operation was found to be with the CSEE held stationary near the tank floor while the Houdini ROV plowed sludge toward the CSEE inlet. Toward the end of the GAAT project, clogged nozzles were found to contain what appeared to be rust particles, which were suspected of coming from the few carbon steel components on the high-pressure water supply for the system. Large quantities of in-tank debris have the potential to significantly reduce the efficiency of the CSEE. The CSEE waste inlet was covered with a coarse (~3/8-in. grid) wire mesh screen that was prone to clogging with in-tank debris during sluicing operations. Later in the project, a remote debris removal tool was developed for use by the Houdini (while the MLDUA maintained its grasp of the CSEE). The result was a significant increase in operational efficiency (reduced downtime and reduced fresh water usage). While the CSEE cutting jets added a significant amount of water to the waste stream, they proved to be indispensable by increasing overall waste removal efficiency for the remediation effort.

Axial-Flow Jet Pump—This highly reliable component performed without failure throughout the GAAT Remediation Project. The initial off-the-shelf pump body was modified and constructed of highly erosion resistant material (hardened stainless steel, 17–4PH) that performed well throughout the project.

HMA—The rugged, reliable, and flexible system performed very well during GAAT operations. The 4-DOF teleoperated arm acted both as a pipeline for the transfer of dislodged waste and as a hose-positioning system for the CSEE and other waste dislodging end-effectors. The HMA facilitated access to all points within the 25-ft- and 50-ft-diam GAATs.

FCE&CB—This aboveground process piping, valving, and instrumentation system received the waste stream discharge from the axial-flow jet pump in the HMA. Although the presence of significant air entrainment in waste stream rendered the system's Coriolis flowmeter ineffective for qualitative measurements, the WD&CS delivered consistent and reliable performance throughout the GAAT project.

GSEE—This second-generation version of the CSEE provided the option of increased operating pressures (tested up to 45,000 psi, administratively limited to 30,000 psi) and improved efficiency for wall-washing and scarifying operations. However, experience in the GAATs showed that pressures in excess of ~7000 psi produced little advantage with respect to the amount of waste removed in a single pass and significantly increased the generation of mist during wall washing. Higher pressures also increased the resultant loads on deployment systems such as the MLDUA, which could not tolerate the reaction forces generated at operating pressures above ~20,000 psi.

FCEE—This custom-designed end-effector was used to vacuum shallow layers of water from the tank floor. As the GAAT operational team gained experience, it became the common consensus that efforts spent on removing the final remnants of waste from the tank were of questionable value. Given the fact that in-leakage of groundwater was continuing to occur, that secondary wastes were being added to the waste stream by the WD&CS jet pump, and that nontrivial amounts of water would be added back into the tank by the decontamination systems upon withdrawal from the tank, the incremental cost of removing the final ~0.25 in. of water was not considered warranted.

LSEE—This unique but relatively simple design was deployed in two GAATs to facilitate cleaning of a 10-ft-high by 1-ft-wide section of the tank wall in <1.5 min without repositioning the deployment system. The concept appears to be valid but requires additional design and testing prior to future deployment.

DSR—This custom but very simple design provided highly reliable service throughout the GAAT project. A common design was used for all GAAT DSRs. The current DSR configuration was somewhat difficult to install due to ergonomic and contamination control considerations.

UHPP—This system provided reliable service during limited operations in the GAATs. Routine periodic maintenance is recommended.

Gripper-End Effector Hydraulic Pump—This auxiliary hydraulic pump was added to the MLDUA system to permit "overnight" grasping of the CSEE or other end-effectors independent of the MLDUA Hydraulic Power Unit. This customization provided highly reliable service during extended operations in the GAATs.

14.2.7 Waste-Conditioning and Transfer Equipment

The equipment described in this section was used to condition and transfer the wastes retrieved from the GAATs. Each device or system served a unique function in either the transfer or conditioning of waste slurries from the GAATs.

WCS—This suite of subsystems was designed to mobilize readily suspendible solid waste in the tanks, classify the solids, provide real-time monitoring of the slurry characteristics, and process slurried LLLW in preparation for transfer to a remote processing, treatment, or storage facility. The WCS consists of the PCS, the SMTL, a submersible WTP, a PAM, and the associated piping system. This unique design represents an integration of readily available off-the-shelf process equipment. The system was demonstrated to be reliable over 2 years of intermittent operation during the GAAT remediation.

WTP—The DisFlo pump performed well as the primary WTP for the GAAT Remediation Project. The pump motor was intended for submerged operation. A supernatant flow over the exterior surface of the motor was added to effectively extend the pump-down capability of the system. The pump was designed for no scheduled maintenance during its intended operating life.

PCS—This system was demonstrated to be reliable during intermittent operation throughout the GAAT project. This unique design integrated off-the-shelf components and provided space for future equipment options. Use of the clarifiers was very limited. The initial operations showed that the clarifiers (in-line filters) frequently clogged with fine sludge, which activated the automatic back-flush system and reduced throughput efficiency. Subsequent sample analysis data and information from the in-line particle size analyzer in the SMTL showed that almost all of the solids were <100-μm diam. To improve transfer efficiency, the filters were bypassed for the remaining duration of the GAAT remediation and reliance placed on sample analysis data and information from the particle size analyzer.

SMTL—This system was demonstrated to be reliable during intermittent operation throughout the GAAT project, with little or no required maintenance. This unique design integrated readily available off-the-shelf process equipment and specially designed instrumentation, including a Coriolis flowmeter, a particle size analyzer, an ultrasonic suspended solids monitor, a pump power monitor, an in-line sampler, and pressure and temperature sensors. The information from the in-line particle size analyzer generally did not agree with particle size data from laboratory sample analysis but provided useful information to ensure that waste transfers to the active waste system met the acceptance criteria.

Diaphragm Pumps—Commercially available units were used extensively during the GAAT project to provide robust and reliable operation in a number of configurations. Commercially available electronic leak detection units are recommended when the units are intended for remote operations.

WaRTS—This system was the only new component of the HWRS that was intended for use in the retrieval of the residual heavy dense sludge that remained in the GAAT consolidation tank after removal of the lighter, less dense sludge. WaRTS was comprised of a WSCS, an SPS, an air diaphragm pump, and a stand-alone control system for these components.

WSCS—This system allowed for maximum use of existing equipment during final tank cleaning and minimized the need for new or modified waste retrieval capability. The system provided reliable performance during limited operations in the GAATs. This unique design integrated an assortment of commercially available components. Although the surge tank was installed in a tank riser, the components that are likely to fail (e.g., remotely controlled air-operated valves and viewing camera) were located so that they could be accessed without being removed from the tank riser. One problem encountered was repeated clogging of the sparger assembly, which was located in the settling volume of the surge tank. Several blockages of the sparger were cleared using hydrostatic pressure. Redesign of this feature should be considered in any future applications.

SPS—This system provided reliable performance during limited operations in the GAATs. The unique design integrated an assortment of commercially available components. The system's air diaphragm pump, while self-priming, has a limited suction head (~20 ft of water). Installation in the STF at the GAAT OU resulted in operations near this limit, which caused some difficulties.

HWRS—The HWRS took maximum advantage of the existing waste retrieval equipment by combining existing capabilities with the WaRTS to economically meet performance requirements.

Mobile Modular Power Distribution System—This custom-designed system incorporated commercially available components that provided reliable service throughout the GAAT operations in the STF. Significant cost and schedule savings were realized by use of mobile, connectorized power distribution and temporary cable trays versus a typical fixed power distribution system.

14.3 EQUIPMENT DISPOSITION AND REUSE

The equipment used in waste retrieval and transfer operations at the GAATs included a variety of remotely operated systems and components. Efforts to locate follow-on users for the GAAT equipment have resulted in planned reuse for some of the equipment at ORNL or at other DOE sites. Figure 14-1 presents a view of the GAAT STF at the height of the remediation project during waste retrieval operations in tank W-7. The site has since been cleared and operations to close the GAATs completed. The equipment from the GAAT site has been reused; temporarily held in storage for potential future reuse; or prepared for disposal, as appropriate.

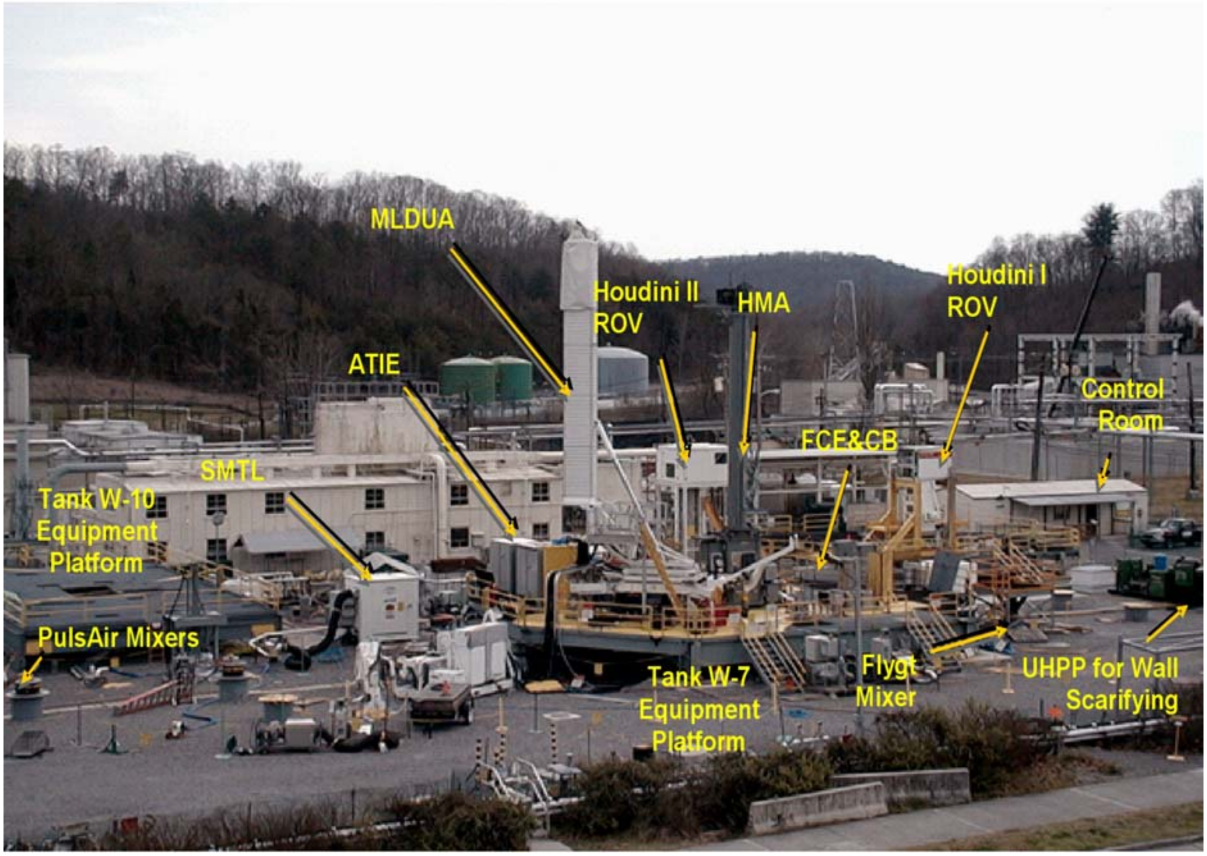

Fig. 14-1. Operations in STF during waste retrieval operations in tank W-7.

In general, the contaminated equipment used during the GAAT remediation has been packaged and placed in interim on-site storage, pending possible reuse or awaiting disposal. The larger equipment items, such as the MLDUA and Houdini ROVs, were placed in sea-land containers and stored on-site following the demobilization of the GAAT site. The in-tank components of the Russian PMP were disposed of inside of tank TH-4 and grouted in place. The external uncontaminated portions of the PMP were reused in follow-on testing of the PMP at higher operating pressures. Uncontaminated pump skids, such as the UHPP, and other minor pieces of equipment were either used on-site in other projects or transferred to other DOE sites for continued use. Table 14-2 provides a brief description of the disposition of the major pieces of equipment used in the retrieval of wastes from the GAATs.

Table 14-2. Summary of GAAT equipment disposition

Item No.	Name	Disposition
Modified Light-Duty Utility Arm		
1	MLDUA	Moved to Solid Waste Storage Area (SWSA)-6 for interim storage, pending reuse or disposal as contaminated material.
2	MLDUA Hydraulic Power Unit	Interim storage at SWSA-6 pending MLDUA decision.
3	MLDUA Control System	Interim storage at GAATs pending MLDUA decision.
4	MLDUA TRIC	Packaged for off-site shipment. Currently in interim storage at SWSA-6 pending MLDUA decision.

Remote Operated Vehicles (ROVs)		
5	Houdini I	Moved to SWSA-6 for interim storage, pending reuse or disposal as contaminated material. PDCU and control console will be disposed of as noncontaminated equipment if a user is not found.
6	Houdini I TRI Components	Packaged and in interim storage at SWSA-6, pending disposal as contaminated metal.
7	Houdini II	Moved to SWSA-6 for interim storage, pending reuse or disposal as contaminated material.
8	Houdini II TRI Components	Packaged and in interim storage at SWSA-6 pending disposal as contaminated metal.
Mixing Equipment		
9	PAMs	Packaged and in interim storage at SWSA-6 awaiting disposal as contaminated metal.
10	PAM Controls	Air surge tank used temporarily with Russian PMP and disposed of as scrap metal. Remainder packaged and in interim storage at SWSA-6 awaiting disposal as contaminated material.
11	Flygt Mixers	Packaged and in interim storage at SWSA-6 waiting disposal as contaminated metal.
12	Russian PMP	Disconnected and grouted in place in tank TH-4. Two clean units awaiting disposal as scrap metal or surplus equipment.
13	Russian PMP TRI	Used at the TTCTF at Oak Ridge in follow-on cold testing of Russian PMP units 2 and 3 and then disposed of as noncontaminated waste.
14	Russian PMP Support Platform	Used at TTCTF at Oak Ridge in follow-on cold testing of Russian PMP units 2 and 3. Presently awaiting disposal as clean metal.
15	Russian PMP Transport Cradle	Moved to SWSA-5 for interim storage awaiting disposal as clean metal.
16	Russian PMP DSR	Packaged and in interim storage at SWSA-6 awaiting disposal as contaminated metal.
Waste-Conditioning Equipment		
17	WCS Primary Enclosure	Interim storage at SWSA-6 pending disposal as contaminated metal.
18	Instrumentation and Controls Hardware for the WCS and WaRTS	Transferred to others for continued use at ORNL in ongoing projects.
19	SMTL	Interim storage at SWSA-6 pending disposal as contaminated metal.
20	Lasentec Particle Size Analyzer	Removed and stored for possible continued use at ORNL in future projects.
21	DiscFlo Pump	Packaged and in interim storage at SWSA-6 awaiting disposal as contaminated metal.
22	Moyno Pump Skid	Transferred to other users for remediation efforts at Oak Ridge.
Additional Waste Retrieval Equipment		
23	HMA I	Packaged and in interim storage at SWSA-6 awaiting

		disposal as contaminated metal.
24	HMA II	Will be moved to SWSA-5 for interim storage. If a viable use is not found prior to the end of FY 2001, the equipment will be disposed of as noncontaminated material.
25	WaRTS	Packaged and in interim storage at SWSA-6 awaiting disposal as contaminated metal.
26	CSEE/GSEE	Packaged and in interim storage at SWSA-6 awaiting disposal as contaminated metal.
Other Equipment		
27	THSs	Packaged and in interim storage at SWSA-6 awaiting disposal as contaminated metal.
28	At-Tank Instrument Enclosure (ATIE)	Select components removed for reuse with other equipment. Remainder in interim storage at SWSA-5 awaiting disposal as clean metal.
29	DSR	Packaged for off-site shipment and in interim storage at SWSA-6 awaiting disposal as contaminated material.
30	Power Supply and Distribution Trailer	Staged at ORNL for transfer to new owner.
31	Process Water Supply Trailer	Transferred to new user for remediation activities at Oak Ridge.
32	UHPP	Transferred to new user at West Valley Demonstration Project.
33	High-Pressure Water Pump Skids	Transferred to new users for remediation efforts at Oak Ridge.
34	Valve Panel	Transferred to new user for remediation activities at Oak Ridge.
35	In-Tank Camera Systems	Packaged for off-site shipment and in interim storage at SWSA-6, pending reuse or disposal as contaminated waste.
36	Camera Controls	Interim Storage at GAATs and SWSA-6 pending camera decision.
37	Spare Parts, Drawings, Documentation	Will be packaged for transfer to new owner with appropriate equipment. Remainder will be disposed of or salvaged as clean material.
38	Miscellaneous Tools, Spare Parts, etc.	Interim storage at SWSA-6 awaiting transfer with associated equipment or disposal as contaminated material, as appropriate.
39	Miscellaneous Hoses and Cables	Interim storage at SWSA-6 awaiting transfer with associated equipment or disposal as contaminated material, as appropriate.
40	Miscellaneous Hoses and Small Items	Some equipment transferred to other users for remediation efforts at Oak Ridge. Remainder packaged and in interim storage awaiting disposal.

14.4 SCHEDULE REDUCTIONS

The initial schedule for completion of the remediation of the GAATs was based on information taken from an internal report on one of the options presented in the feasibility study cost estimate that was prepared by the Radian Corp. in 1993. The feasibility study cost estimate showed the GAAT remediation being completed during the first quarter of FY 2007. As a result of the technological advances employed in the GAAT Remediation Project, the remediation was completed in FY 2001, ~5.5 years ahead of the initial schedule.

14.5 COST AVOIDANCE/COST SAVINGS

The Remedial Action Report for the GAAT project indicates a cost of $70,259K for the GAAT remediation. These costs are consistent with the data presented in Table 12-2. However, the complete cost of the GAAT remediation must also include the costs for the supporting development and purchase of the advanced technology and remotely operated systems provided by the DOE Office of Science and Technology Development Programs (EM-50). The approximate costs for the various systems provided by EM-50 total $14,835K (Table 12-3). Combining the EM-50 costs with the project costs from the Remedial Action Report results in a total remediation cost for the GAATs of $85,094M. The Remedial Action Report further indicates an adjusted cost estimate from the RI/FS as $205,529K. This number was determined by adjusting the RI/FS cost estimate to match the actual scope conducted during the GAAT remediation. Based on the adjusted RI/FS cost estimate and total GAAT remediation costs, the cost savings for project is $120,435K.

14.6 SUMMARY OF MAJOR LESSONS LEARNED

During the GAAT Remediation Project, a variety of situations arose that were different from the initial expectations. These unexpected situations typically result in lessons learned, which were either immediately applied to the project or used to improve performance and simplify the operations in future activities. The lessons learned during the GAAT Remediation Project ranged in scope from items narrowly focused on a specific component or operation to items with broad applicability to an entire system or the project in general. The following sections provide listings of the lessons learned from the GAAT Remediation Project that generally have broad applicability.

14.6.1 Communications and General Observations

Frequent open communication with staff and stakeholders was a key element of the overall success of the GAAT Remediation Project. The GAAT Remediation Project conducted several public meeting to solicit stakeholder input and to provide status updates. The project management team also held daily and weekly meetings with key project participants to provide direction, obtain status updates, and ensure that roles and responsibilities were well understood. Routine project meetings provided a continuous forum for feedback and problem solving. Good communication is needed at all levels to

- ensure continuing cooperation and support;
- ensure that management, regulators, stakeholders, and support and technical staff are in agreement with project plans;
- establish and prioritize daily objectives and near-term goals for the project;
- plan and communicate craft resource needs; and
- maintain a safe working environment.

Although the GAATs were on the National Priorities list of waste sites requiring urgent attention, the situation was such that it was possible to proceed from the lowest-difficulty, lowest-risk activities to higher-difficulty, higher-risk activities. Moving from low-risk to high-risk activities had many significant benefits including

- lower employee exposures and reduced project cost,
- establishing an experience base for successively more rigorous operations, and
- lower overall risk to employees and the environment with a “learn as you progress approach.”

Complex, lengthy projects should be approached as a “marathon,” not a “sprint,” to minimize stress, improve safety, reduce turnover, and ensure physical and mental stamina.

Early project successes should be identified, pursued, publicized, and celebrated to provide a basis for funding continuation and employee morale.

Expect, plan for, and manage continuing changes in equipment and processes even after operations are under way. No matter how thorough the planning phase of a project, situations will arise that were not originally anticipated. Change control procedures should be in place to approve, document, and communicate all process and equipment changes with significant impacts to the project’s schedule and/or budget.

14.6.2 Health and Safety, ALARA, and Contamination Control

The health and safety of the personnel involved in the GAAT Remediation Project was of the highest priority throughout the project. Maintaining personnel radiation exposures ALARA and controlling the spread of contamination is directly tied to personnel safety, personnel availability, and overall project control. The following are some of the key lessons learned that are specific to health, safety, ALARA, and contamination control:

- Plan work to avoid environmental stresses on personnel. Environmental stresses on personnel during hot periods can result in excessive fatigue or heat stress. During the hot summer months, when working in Class C or higher PPE, the work should be scheduled for the early morning hours to avoid performing high-stress work during the hottest part of the day.

- Minimize access to the equipment control room to avoid distractions during operations. The operation of the robotic retrieval and process systems requires concentration and attention to detail by the operators to minimize operational problems and ensure the safety of personnel, the equipment, and the environment. Tours and visits by stakeholders should be scheduled to avoid interference with critical operations.

- Maintaining contamination and radiation exposure levels for personnel ALARA is essential. ALARA principles must be key considerations during the design and equipment selection phase of the project. RP personnel should be key members of the planning team for the project, review all equipment and process designs, and have a thorough understanding of equipment function and planned operations as early in project as possible.

- Effectively communicate system changes that may affect radiation fields. RP personnel should be kept apprised of all system changes and be a permanent member of the change control board for the project.

- Work instructions and prejob briefings are essential to minimize confusion and exposure time and to enhance safety.

- Be vigilant to prevent the accumulation of debris. Debris should be removed as efficiently and as soon as possible to prevent interference with operations both inside and outside the waste tank.

14.6.3 Equipment Design, Testing, and Maintenance

Most of the equipment used in the GAAT Remediation Project was a part of either a very specialized unique system or a system or component used in a unique application. Simplified maintenance requirements to minimize downtime and proper containment to prevent environmental releases and personnel contamination are essential to the success of a tank waste remediation project. The following are some of the key lessons learned that are specific to general equipment design, testing, and maintenance:

- Design equipment for reliability and for subassembly replacement (instead of repair) to avoid lengthy repair times, increased potential for the spread of contamination, and personnel exposure to hazardous and radioactive environments.

- The equipment must be as rugged as possible to withstand the harsh environment inside the waste tanks and the sometime rough handling during installation, removal, and operation.

- Consider personnel exposure consequences when designing systems and determining maintenance and operating procedures.

- Walk down as-built drawings for all major systems, including off-the-shelf items. This ensures that accurate drawings are available if field modifications or repairs are required and that the operations staff is as familiar with the systems as possible prior to startup.

- Cold test the equipment and check out operating procedures prior to hot deployment. Cold testing allows systems to be successfully integrated and provides training opportunities for personnel in a low-risk environment. Cold testing of the actual systems intended for hot deployment is essential to allow the operators hands-on experience with and training on the equipment. Cold testing also allows operators and craft workers to develop specialized tools, techniques, and instructions that decrease exposure during hot operations.

- The equipment interface should be designed with consideration for the talents, abilities, and background of the personnel who will be operating the equipment. User-friendly straightforward equipment interfaces should be used. Operator input should be used during the design to ensure ownership and acceptance of the equipment in the field.

- Maximize equipment visibility with viewing ports and see-through contamination covers. Operators must have good visual access to containment structures to be able to safely attach end-effectors, decontaminate tools, retrieve samples, and perform other hands-on tasks without breaking containment.

14.6.4 Waste Retrieval and Specifics on Waste Retrieval Equipment

Waste retrieval systems and equipment must be selected based on the specific tank operating conditions and constraints at each site. The Houdini and the MLDUA systems worked well together, resulting in efficient waste retrieval operations at the GAATs. The combination of the Houdini's mobility and ruggedness in operations in the bottom of the tanks and the MLDUA's reach and dexterity in operations in the upper portion of the tanks provided an excellent system for use in tank waste retrieval operations. Sluicing operations were most efficient when the plow on Houdini pushed sludge toward the MLDUA. The MLDUA worked best for bulk sludge retrieval and wall cleaning, while the Houdini was better at plowing the residual sludge (<8 in.) to the CSEE while it was held by the MLDUA.

The MLDUA provided the dexterity and reach needed to effectively clean the walls of the GAATs and perform bulk waste retrieval operations. The following lessons learned are specific to the MLDUA:

- Use preprogramming where necessary to simplify operations. The MLDUA was ideal for scarifying the tank walls; however, because of mist formation, low visibility occurred in the tanks during wall scarifying. Preprogramming of the MLDUA with the scarifying paths worked well for controlling the movement of the equipment under poor visibility conditions.

- Use a separate, small continuous-duty hydraulic system for GEE control to avoid unnecessary operation of the MLDUA computers and main hydraulic pump while holding equipment for extended periods of time with the GEE.

- Locate equipment requiring routine maintenance within the VPM housing for ease of maintenance.

The Houdini ROV provided the power and mobility to break up wastes and effectively clean the floors of the GAATs. The following lessons learned are specific to the Houdini vehicle:

- Use appropriate fasteners for mobile waste retrieval systems to ensure that the vibrations produced during operation do not cause locking bolts and other fasteners to fail to hold.

- The Houdini II design of the Houdini TMADS, although improved over Houdini I design, still had limitations and inherent problems with the system ergonomics.

- Design the vehicle to limit connector and hose stress during folding for deployment and retraction of the vehicle.

- Improve maintenance capabilities of stand-alone systems. Although the maintenance tent was an extremely helpful tool for the Houdini maintenance, it was also cost and schedule prohibitive at times. The maintenance tent and major systems should be improved to allow for quicker more efficient connection and disconnection. Attention should also be given to the environmental controls in maintenance areas. Maintaining tolerable working conditions in the maintenance tent during the summer months can be difficult.

- Although the Houdini system does not require complex qualifications, inexperienced operators may be able to damage the system. Sufficient lead time and a cold test facility are needed to ensure that operators are properly trained.

Visual access was crucial to the success of the tank waste retrieval operations during the GAAT Remediation Project. Camera systems with adequate depth-of-field zoom capability and light sensitivity must be selected. Lighting systems must also be compatible with the environment and the selected camera system. The following lessons learned are specific to the camera systems:

- At least two camera views and lights are needed. A single camera view does not provide the operator with an adequate depth of field to reliably operate the in-tank systems.

- Adequate heat dissipation is needed to extend the life of in-tank cameras. Cameras should be cooled using internal purges, internal fans, heat shields, or other means to dissipate heat from high-wattage (250-W) lamps. When cameras are not in use they should be turned off or operated with reduced lighting.

- Ensure that the camera systems can be positioned easily and that they are waterproof.

- Select and use paint colors for the in-tank equipment that provides high visibility and good contrast between the equipment and the tank.

14.6.5 Waste Mixing and Transfer

The waste-mixing and transfer systems used in the GAATs provided the capabilities to effectively suspend waste solids and transfer material to the MVSTs. The following lessons learned are specific to the mixing and transfer systems:

- PAMs should be operated continuously to prevent plugging and to obtain improved results. PAMs were more capable of maintaining solids in suspension than in resuspending settled solids.

- Maintain a minimal water flow through the cutting jets on the CSEE to improve performance and prevent clogging of the exit nozzles when they are submerged in tank waste.

- Operational heat loads on motor control centers should be taken into account. Added environmental heat loads can create problems for the motor control centers and may require the use of a separate air-conditioning unit to manage the heat load.

14.7 TANK STABILIZATIONS

The GAATs were all stabilized in place as part of a subsequent separate project by filling the tanks with a low-strength grout. The basic grout formulation used for this activity is described in Table 14-3. The amount of water was not specified in the recipe and is based on laboratory test data.[28]

Table 14-3. Formula for low-strength grout used to fill the GAATs

Components		Quantity (lb)	% of total (wt%)
Portland cement		1.4	2.2
Sand		48.8	76.5
Water		13.6	21.3
	Total	63.8	

Since no waste retrieval operations were needed for the three stainless steel tanks (W-13, W-14, and W-15) in the NTF, they were stabilized in place in FY 1998. The smaller gunite tanks (W-1 and W-2) in the NTF and tank W-11 (located southeast of the STF) were stabilized in 2000. The next gunite tank to be stabilized in place as part of the GAAT Remediation Project was tank TH-4. Tank TH-4 was stabilized in April 2001, after demobilization of the waste retrieval equipment. The remaining larger-diameter gunite tanks (W-3 through W-10) were stabilized in place, by filling them with grout, as part of a separate CERCLA Removal Action that began in July 2001 and was completed in September 2001.

[28] C. A. Langton, R. D. Spence, and J. Barton, *State of the Art Report on High-Level Waste Tank Closure*, WSRC-TR-2001-00359, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina, July 21, 2001.

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