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**COORDINATION BETWEEN THE U. S. DEPARTMENT OF ENERGY AND CONTRACTORS
TO DEPLOY INNOVATIVE TECHNOLOGY FOR REMEDIATION
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ABSTRACT

Integration of government and private industry resources resulted in a successful remediation of five inactive liquid low-level waste (LLLW) tanks at the Oak Ridge National Laboratory (ORNL), a U. S. Department of Energy (DOE) facility in Oak Ridge, Tennessee. A Project Team consisting of personnel representing DOE, DOE contractors, and private industry worked together to develop a method to remove approximately 200,000 L of radioactive, highly contaminated liquid and sludge from the five inactive LLLW tanks. To successfully complete the task, the team deployed equipment developed by DOE's Office of Science and Technology that would remotely mobilize the sludge. This equipment was a modification of technology originally developed by private industry for use in downhole mining operations.

The five inactive underground LLLW tanks were up to 40 years old and were beyond their intended service life for storage of LLLW. The inventory of radioactive material in the tanks was approximately 30,000 curies. Because of the age of the tanks, uncertainty regarding their structural integrity, and a lack of secondary containment, the potential for an uncontrolled release of the tanks' contents posed an unacceptable risk to the environment. Therefore, DOE and the regulatory community decided the tanks' contents had to be removed as a non-time critical removal action.

Because of the radioactivity of the sludge in the tanks, the task of safely removing the tanks' contents required careful planning and development of a remotely operated system to protect the workers and environment. After evaluating commercial tank-cleaning methods and equipment, the Project Team selected the use of a single point sluicer for the remedial action. Waterjet Technologies, Inc. (under a contract to Pacific Northwest National Laboratory) modified a Borehole Miner, an extendable-nozzle sluicer used in commercial mining. After modification, the Borehole Miner was integrated into a sluicing and pumping system designed and fabricated by CDM Federal Programs Corporation. Cold testing of the system was performed to ensure proper function, develop operational procedures, and train personnel. In summer 1998, the tanks' contents were successfully removed and transferred to safe storage.

This paper presents how the challenges of designing, building, testing, and implementing a complex mechanical and electronic system were overcome to successfully remediate the tanks, despite the complicated logistics of coordinating the numerous entities involved and having the design and fabrication performed at private industry facilities across the country. The successful modification and implementation of private sector technology demonstrates the feasibility of applying off-the-shelf technology and utilizing diverse resources within private industry for expertise and equipment to perform remedial actions at radioactively contaminated DOE facilities.

INTRODUCTION

Summary

This paper presents an example of a successful integration of government and private industry resources to deploy innovative technology to successfully conduct a remedial action at the Department of Energy (DOE) Old Hydrofracture Facility (OHF) site at the Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee. The OHF was an experimental underground injection waste disposal site at ORNL, in operation until 1981 when injections ceased. Among the facilities at OHF were five underground storage tanks that contained approximately 200,000 L of hazardous and radioactive liquid and sludge wastes. In 1995, a risk assessment indicated that an uncontrolled release of the tanks' contents into a nearby watershed would pose unacceptably high environmental risks. Based on this, DOE received permission from the regulatory community to proceed with a removal action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to transfer the tanks' contents to safe storage.

Lockheed Martin Energy Systems, Inc (Energy Systems), the Management and Operations Contractor for the DOE Oak Ridge Reservation (ORR) facilities, was tasked with implementing the removal action. Energy Systems assembled a project team, consisting of DOE, Energy Systems (contract later changed to Bechtel Jacobs Company LLC), and other contractor personnel to design an approach to accomplish the removal action. Commercial technology, viewed as the quickest and most cost effective way to conduct the removal action, was evaluated for reliability, effectiveness, cost, and other criteria. Based on this evaluation, the Project Team recommended a remote-operation pumping and sluicing system consisting of a single point sluicer, in-tank pumps, and above ground pumps. A commercial technology (the Borehole Miner) previously identified by the Tanks Focus Area (TFA) as a technology that could be adapted for DOE tank remediation, was selected as the single point sluicer. CDM Federal Programs Corporation (CDM) was subcontracted to design and build the pumping and sluicing system. Another subcontractor, Waterjet Technologies, Inc. (Waterjet) -- under contract to Pacific Northwest National Laboratory (PNNL) -- was tasked with modifying a Borehole Miner for use in the OHF tanks.

System components were designed in Oak Ridge; Dallas, Texas; Seattle, Washington; and Long Beach, California. The equipment was fabricated at contractor facilities in Long Beach and Seattle. Extensive planning and communication among the various government and private entities was required to ensure that all components met project specifications when they were assembled at the cold test site in Oak Ridge. After a successful cold test, the equipment was assembled at the OHF site in May 1998. Removal activities commenced in June 1998, and the tanks' contents were safely and successfully transferred to safe storage in July 1998. Project goals for worker safety, total quantity of tanks' contents removed and transferred, and waste-minimization were exceeded, highlighting the success of this project.

OHF Background

The OHF was the site of an experimental facility in the 1960s and 1970s to test the feasibility of deep underground injections of hazardous and mixed waste as a method for permanent waste disposal. Liquid wastes from ORNL were piped to the site, mixed with grout in above ground silos, then pumped downhole and injected into shale formations at depths of approximately 1,000 ft below ground surface. In the early 1980s, injections were discontinued and the site infrastructure was shut down and left in place.

Among the facilities at the OHF site were five underground storage tanks that were used for temporary storage of waste during the injections. When operations were suspended, these tanks were left in place and liquid wastes at

the site were consolidated in the tanks. By 1995, approximately 200,000 L of supernate and sludge hazardous and mixed wastes were stored in the tanks.

A risk evaluation conducted in 1995 (1) indicated that a potential uncontrolled release of the tanks' contents into a nearby watershed posed unacceptably high environmental risks (on the order of 10^{-1}). There was no secondary containment around the tanks and the structural integrity of the tanks' hulls was questionable. Based on these considerations, DOE, the Tennessee Department of Environment and Conservation (TDEC), and the Environmental Protection Agency (EPA), Region IV office agreed to remediate the five tanks under a CERCLA non-time critical removal action. The intent of this removal action was to remove and transfer to safe storage the tanks' contents.

OHF SITE CHARACTERIZATION

Site characterization activities included record searches and sampling and analysis of the tanks' contents. The characterization activities established some facts regarding the tanks and their contents (i.e., the chemical and isotopic composition of the tanks' contents) but were unable to address some uncertainties (i.e., tank hull integrity). The results of these characterization activities are summarized in the following sections.

Waste Characteristics

Sampling campaigns in 1988 and 1995 (1,2) consisted of grab samples of the tanks' contents collected with pumps and sludge coring and collection tubes lowered into the tanks through the tank risers. The analytical data derived from these sampling episodes indicated that the sludge and supernate were hazardous (as defined by the Resource Conservation and Recovery Act) because of elevated levels of heavy metals. Radiological contamination of the sludge included nuclides of cesium, cobalt, strontium, technetium, europium, uranium, neptunium, plutonium, americium, and curium. The wastes were further characterized as transuranic (TRU) waste because of the inventory of alpha-emitting transuranic nuclides. The estimated total radiological inventory of the tanks' contents was approximately 30,000 curies. The tanks also potentially contained a quantity of fissile material sufficient to achieve criticality if consolidated into the proper size and geometric shape. The specific gravity of the sludge was slightly greater than water (~ 1.1). Visual inspections of the sludge collected in the sample tubes did not indicate any evidence of hardened deposits.

Tank Characteristics

Three carbon steel storage tanks were installed in 1963, and two carbon steel, rubber-lined storage tanks were installed in 1966. The tanks were installed on concrete saddles with gravel drain fields around the pads (2). At least two of these tanks had been used previously at another DOE site at Oak Ridge, and all five of the tanks were at least 32 years old in 1995. The tanks ranged in length from 7.3 m to 13.4 m and in diameter from 2.4 to 3.0 m. The capacities of the tanks ranged from 49,210 L to 94,640 L. All five of the tanks were single-hulled steel tanks set in pits approximately 5 m below ground surface. Backfill material around the tanks consisted of gravel and soil fill. Each tank had risers in the center and at each end that extended above grade and were typically capped with a bolted-on steel flange. The center risers were part of the original tank configuration. The end risers were installed in 1995 to support the subsequent remedial action. Cathodic protection was installed in 1968, but was found to be nonfunctional in 1993. Two of the tanks were completely lined with a rubber coating.

OHF Special Site Conditions

Unique or uncertain aspects of the wastes and the tanks made the removal action especially challenging and influenced the evaluation and selection of the appropriate technical approach to accomplish the removal action. These aspects are described in the following paragraphs and summarized in Table I.

The locations within the tanks where analytical samples were collected were limited to the tank centers and ends immediately below the risers. Through mixing and diffusion, the chemical and radiological constituents of the tank contents were potentially homogenized within the supernate and sludge layers. However, the limited data were insufficient to support this assumption with certainty. In addition, the sampling method employed to collect the samples was incapable of collecting any hardened sludge. Therefore, no assessment of the potential or actual quantity of hardened sludge could be made.

Because of the age of the tanks, the duration of burial, and the absence of cathodic protection, no assumptions regarding structural integrity of the tanks could be made, other than to conservatively conclude for planning purposes that the structural integrity was weakened due to corrosion and pitting from rusting. The consistent liquid level readings in each of the five tanks precluded the probability that significant tank hull failure had already occurred, but the potential existed for weak spots in the tank hulls that could fail under aggressive sludge mobilization activities. The condition of the rubber liner in the tanks was also unknown, and could potentially strip off the tank hulls in sheets under aggressive removal techniques, clogging pumping equipment.

The sludge emitted high radiation fields, raising concerns that workers would receive excessive radiation doses during sluicing and pumping operations. DOE orders restrict worker radiation exposure on both a daily and an annual basis. Preliminary dose calculations indicated that any workers within a few meters of the equipment during pumping and sluicing activities would receive exposures in excess of these limits during the removal action operations.

Waste storage limitations at the Melton Valley Storage Tanks (MVST) site (the intended destination for the tanks' contents after removal) restricted the amount of additional water that could be added to the waste stream. Water would be needed as the source for the jet spray to dislodge the sludge and slurry the tanks' contents into a mixture with the appropriate solids content for successful transfer through a 50 cm underground line without bridging or clogging. However, adding a significant quantity of water to the waste stream would prematurely fill the MVST, forcing a suspension of the removal action before all of the tanks had been emptied.

Table I. OHF Special Conditions

Certainties	Uncertainties	Project Impacts
<i>Waste Characteristics</i>		
Sludge densities at measured points slightly greater than water	Potential for hardened deposits of sludge	Unsolidified sludge would be easy to slurry and pump. Hardened deposits would be hard to dislodge, and conglomerates of hardened sludge could interfere with sluicing and pumping actions
Chemical and radiological characterization	Potential for criticality based on measured quantities of fissile material in sludge and supernate	A critical mass of fissile material could potentially be achieved through the process of sluicing and pumping through small-diameter pipe
<i>Tank Conditions</i>		
Cathodic protection had expired Tank age ranged from 32-40 years	Structural integrity Thickness of tank walls	Thin or corroded tank walls could fail from aggressive sludge mobilization activities, resulting in an uncontrolled release
Two tanks had rubber liners	Integrity of rubber lining	Aggressive sludge mobilization techniques could strip off the rubber liner, clogging pumps
<i>Other Considerations</i>		
Radiation dose off the sludge were high (5 R on contact)	Radiation dose of the slurry through pipe	High radiation limited worker exposure and proximity to equipment during removal operations
Supernate must be used as a water supply to minimize waste generation	Quantity of coarse material that would be entrained and recycled	Large particles could clog the equipment or the sluicer nozzle

TECHNOLOGY EVALUATION AND SELECTION

With the information gained from the site characterization, the Project Team proceeded with an evaluation of the available technologies. The OHF site conditions, especially the uncertainties, dictated the evaluation and ultimate selection of the tanks' contents removal system.

System Requirements

The conditions described in the preceding section greatly influenced the removal action evaluation and selection decisions. Because of the potential for exposure to radiation for the onsite workers, the removal action had to be performed remotely, necessitating reliable equipment and a sophisticated programmable network that could electronically control the operations of various pumps and valves while monitoring system parameters for problems. The uncertainty of the structural integrity of the tank hulls required that the jet spray be adjustable so hardened deposits of sludge could be targeted and dislodged with greater pressure than required for unconsolidated sludge. Operational flexibility and reliability were key. The equipment needed to be readily retrievable from the tanks if repairs were needed. Reliability was important for several reasons. The pumping and

sluicing system specified in the Preliminary Engineering Report (3) used pumps in sequence. Equipment failure or line blockage at any point would create problems that would cascade through the system (a concern partly alleviated by the inclusion of automatic system shutdowns and various pressure-relief mechanisms). A failure of equipment in the tank would require retrieval and either repair (a hazardous proposition to the onsite workers due to the radiological contamination and exposure concerns) or replacement (an expensive and time-consuming problem). Because of the potential for a release if the tank hulls failed, a timely removal of the tank's content became increasingly important, discouraging the time and expense that would be required to design and build specialized equipment specifically for use in the OHF tanks.

With all of these considerations and restrictions, the Project Team initiated an evaluation of commercially available options that could accomplish the task of removing the sludge and supernate from the OHF tanks. The goals of the project were to identify and deploy existing, commercially available sluicing technologies that would be capable of mobilizing and transferring to safe storage 95 percent of the tanks' contents.

Technology Evaluations

In 1995, the Project Team conducted an extensive survey of commercial tank cleaning services and equipment. The intent of this survey was to identify the range of options available in the commercial industry for cleaning underground tanks. Seventeen companies that perform tank cleaning or manufactured tank cleaning equipment were contacted for information. The various technologies for performing tank cleaning identified and evaluated included robotic tank crawlers, slurry pumps, and spray nozzles. After the potential vendors and technologies were identified, the Project Team evaluated the technologies using subjective weighting criteria that assigned numerical values to various components of the task. The weighting factors assigned the highest importance to cleaning effectiveness, operational flexibility, minimizing worker exposure (as low as reasonably achievable or ALARA) considerations, and cost. The criteria with the lowest weighting factor were the ability to dislodge hardened sludge (based on the available data that suggested the sludge was still largely in a liquid phase) and a broad category of undesired results broadly grouped into "unacceptable side effects". Applying these criteria to the eight potential technologies, single point sluicing (referred to in the matrix as past practice sluicing) was determined to be most appropriate technology for removing the contents of the OHF tanks (based on it receiving the highest score in the evaluation). In the ranking matrix, this method scored 8 or 9 out of 10 in all but one of the criteria. (The one relatively low score of 6 -- for unacceptable side effects, reflected the Project Team's concerns that a directed stream of water could penetrate a weak point in the tank walls, and also the concern for stripping the rubber lining from the interior tank walls.) The results of the technological evaluation are shown in Table II.

The three technologies that ranked next most effective were similar in design. The mixer pump (ranked 2nd) and the submerged jet (ranked 3rd) both employed a combination jetting and pumping action to slurry and pump the tanks' contents. The submerged jet/elevated sluicer (ranked 4th) incorporated the use of a sluicer nozzle above the water line to facilitate agitation and mixing. All three of these technologies offered a reasonable mix of effectiveness in achieving the removal action, although they all scored low in dislodging hardened sludge. The remaining four technologies scored lowest and were deemed unsuitable for use in the OHF tanks.

PLANNING AND DESIGN

After tabulation of the technology evaluation results in early 1996 the Project Team made a recommendation to proceed with the design of a system that would employ a single point sluicing nozzle combined with in-tank pumps to perform the removal action. This recommendation was summarized in a Preliminary Engineering

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Report (3), which presented a conceptual pumping and sluicing system design. This report identified "...hydraulic sluicing as the technical approach to remove the sludge from the OHF tanks...based on achieving the project mission goal of 95 percent removal via utilization of commercially available proven technologies." Based on this report, a decision was made by Energy Systems to authorize a subcontractor (CDM) to proceed with the design and fabrication of a system that would mobilize and remove the tanks' contents utilizing the Bristol Sluicer as the single point sluicer nozzle.

Pumping and Sluicing System

As conceptualized in the Preliminary Engineering Report (3) and later defined in the 100% Configuration (4), the pumping system consisted of the following:

- Sluicer nozzle
- In-tank submersible pumps (to pump the tanks contents out of the tanks)
- Above ground, high-speed pumps (to provide a continuous water supply to the sluicer nozzle and to pump the tanks' contents to MVST when the desired percent solids mixture was achieved)
- Valves and piping
- A programmable logic controller to control the remote operations

All of this equipment was available from commercial vendors and could be fabricated into a pumping and sluicing system at commercial fabrication facilities.

Table II. OHF Tank Sludge Removal Technology Scoring Matrix

Ranking Factor (Weight Factor)									
Evaluated Technology	Cleaning Effectiveness (10)	Hard-sludge Capability (3)	Operational Complexity and Reliability (6)	Operational Flexibility (10)	ALARA (10)	Unacceptable Side Effects (5)	Cost (10)	Schedule Length (9)	Total Score
Past Practice Sluicing	8	8	8	9	9	6	8	8	514
Mixer Pump	5	3	10	6	4	5	9	9	415
Sub. Jet External Pump	5	3	9	6	6	5	10	10	448
Sub. Jet/Elevated Sluicer	5	3	8	6	4	6	7	7	370
Tank Car Agitator	4	1	2	2	2	5	5	2	188
Toftejorg (manufacturer of in- tank cleaning nozzles)	1	10	4	10	10	1	5	2	337
Sugino (manufacturer of in- tank cleaning systems)	9	9	2	1	2	5	5	1	243
Vehicles	10	9	1	2	1	10	1	2	241

HOW TO INTERPRET THE TABLE: Each of the eight Ranking Factors (Cleaning Effectiveness through Schedule Length) are assigned a relative value of importance (between one and ten). Each of the eight Evaluated Technologies (from past-practice sluicing to vehicles) are ranked for their relative effectiveness in each of the ranking factor categories (also by assigning values from one to ten). For example, for the ranking factor “Cleaning Effectiveness”, vehicles were evaluated to be the most effective of the evaluated technologies in cleaning the tanks and thus scored “10” in this category. By contrast, the Toftejorg was determined to be the least effective of the evaluated technologies in cleaning the tanks and received a “1”. After the matrix was completed, each technologies’ Total Score (far right column) was tallied by multiplying each weight factor by the ranking, then summing the total. For instance, Past-practice sluicing scored “80” for cleaning effectiveness (a rank of “8” multiplied by the weight factor of “10”), “24” for Hard Sludge Capability (8 X 3), and so on.

To minimize waste production, the system design called for the supernate already in the tanks to be used as the water supply for the sluicer nozzle. The supernate would be circulated and pumped to the nozzle to slurry the sludge into a homogenous mixture that could be pumped to the MVST. One tank was designated as the recirculation tank through which each batch was pumped until the desired consistency was achieved.

Borehole Miner

During the period that the pumping and sluicing system was being developed, DOE members of the Project Team learned of the Borehole Miner technology and its capabilities while participating in a TFA meeting. The DOE Office of the Assistant Manager established the TFA Program for Science and Technology as a forum for evaluating and accomplishing the goal of tank waste remediation across the DOE complex. TFA's mission is to bring together users and technical experts to deliver and deploy technical solutions for tank remediation. One aspect of this is the development and use of innovative technology. In keeping with this mission, the TFA suggested to the Project Team that the Borehole Miner be evaluated for deployment in the OHF tanks.

The Borehole Miner was initially identified by the TFA in 1995 as a potential commercial technology that could be deployed for tank remediation (5). The Borehole Miner was developed in the 1960s as a collaborative effort between the U. S. Bureau of Mines and the oil and gas industry for use in downhole mining. The device, which consists of an extendible nozzle housed in a rigid frame body, was lowered downhole to the target zone. The nozzle was then extended out to the borehole wall and a water jet of up to 6,000 psi was used to excavate the borehole. As the borehole wall face was eroded, the extendible nozzle could be extended further to continue delivering constant pressure against the borehole face (Fig 1).

In early 1996, the DOE Savannah River Site Tank 19 was identified as an initial application candidate for deployment of a modified Borehole Miner. The intent of this deployment was to dislodge and mix a hardened zeolite mass in a tank bottom. A prototype Borehole Miner was taken through a 90 percent design when Savannah River Site priorities changed, suspending the deployment of the Borehole Miner. During routine meetings of the TFA Group, discussions between DOE Oak Ridge personnel and Pacific Northwest National Laboratory (PNNL) personnel lead to the decision to evaluate deployment of a Borehole Miner in the OHF tanks.

The Project Team initiated a review of the Borehole Miner and ultimately determined that, due to its similarity to the Bristol Sluicer (i.e., a nozzle capable of delivering a water jet to spray the tank interior surfaces), it was suitable for use in the OHF tanks. In addition, the Borehole Miner offered performance capabilities beyond that of the Bristol Sluicer. The Bristol Sluicer was rated to operate at a maximum nozzle pressure of 200 psi, whereas the Borehole Miner could operate at a range of pressures up to 6,000 psi. Also, the Bristol Sluicer nozzle was suspended from a fixed frame seated on a riser and hung immediately below the bottom of the riser at the top interior of the tank. Due to the longer frame of the Borehole Miner, the nozzle was suspended further into the tank (closer to the supernate and sludge). The extendible arm added another 3 m to the nozzle's reach, delivering the jet spray much closer to the sludge. For these reasons, the Borehole Miner was viewed as a superior alternative. A Value Engineering Study conducted in October 1996 (6) confirmed the applicability of the Borehole Miner as the appropriate single point sluicer for the removal action. However, because the Borehole Miner had been originally designed for use in boreholes, an application and setting significantly different than underground tanks, modifications were required to make it work for the OHF tanks removal action.

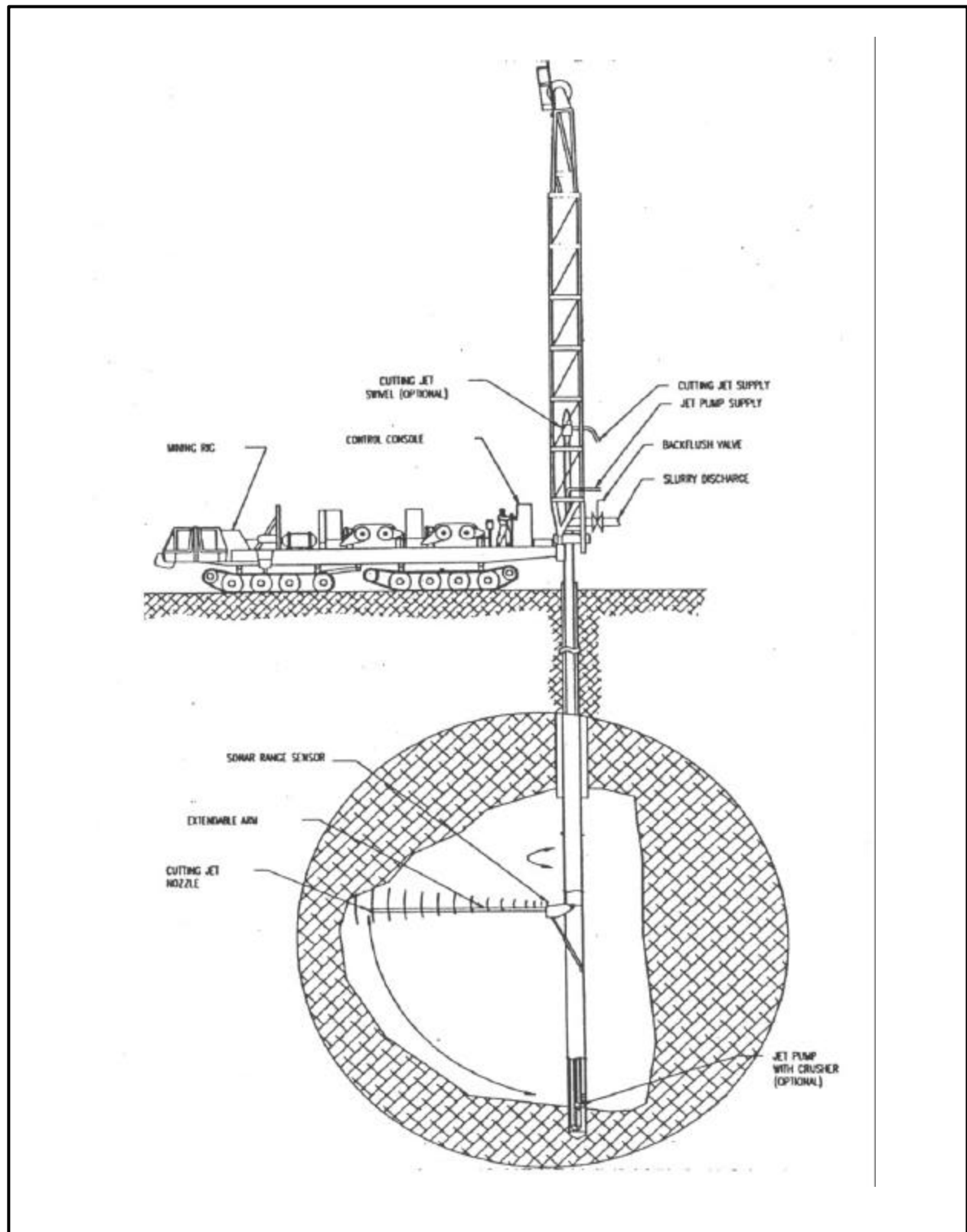


Fig. 1. Borehole Miner Configured for Borehole Mining and Excavation

Modification of Borehole Miner Design

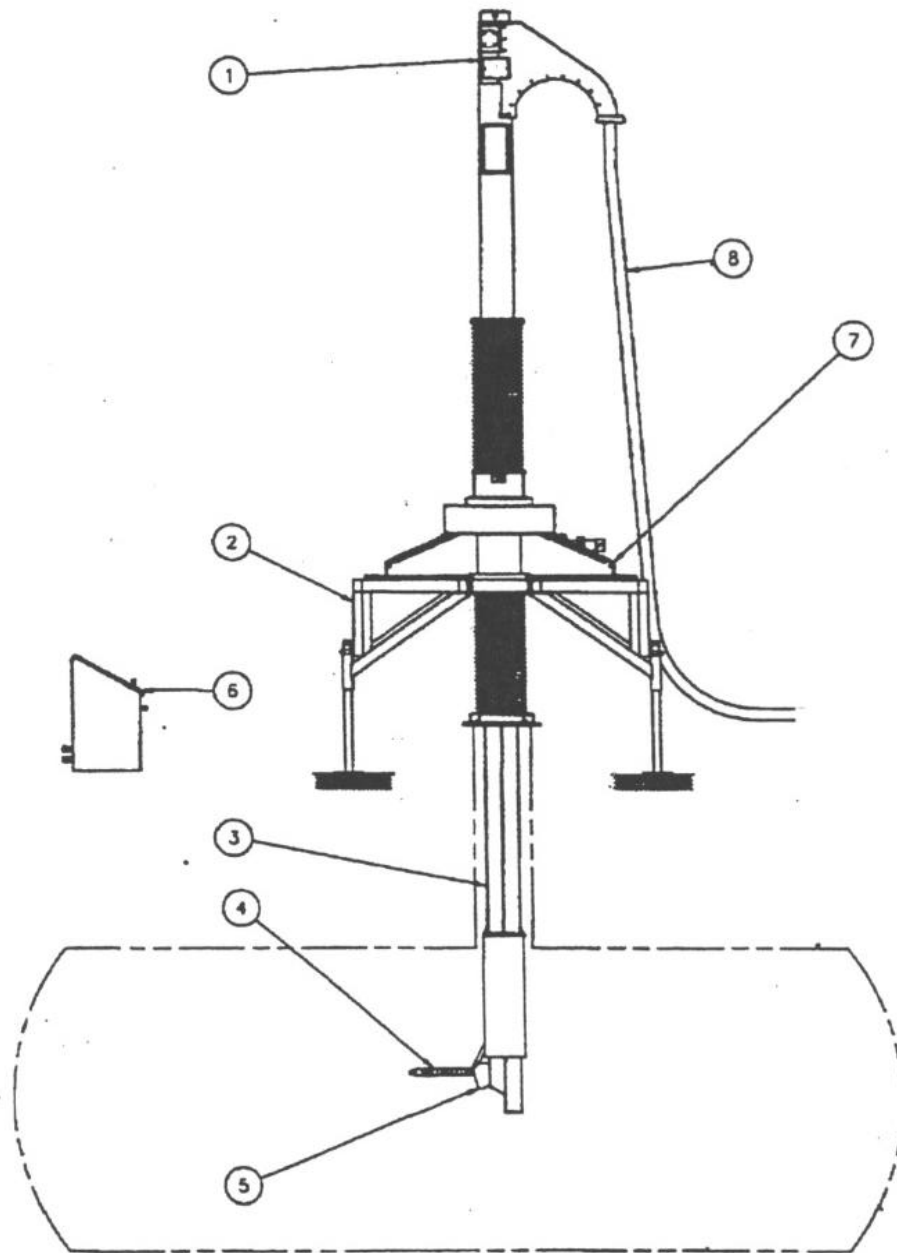
The Borehole Miner is a nozzle on an extendible arm housed in a long, rectangular frame (also referred to as a mast). The extendible arm is capable of extending out from the frame to a maximum distance of slightly more than 3 meters. The extendible arm consists of a series of rigid metal boxes in sequence that allows the arm to bend through 90 degrees as it exits the frame (which is suspended vertically in the borehole) and then extend horizontally. The frame is approximately 12 meters long and houses the extendible arm and the hose that supplies water to the nozzle on the end of the arm. The frame is small in cross-section for ease of entry into relatively narrow boreholes. The Borehole Miner is suspended from a drill rig and is lowered into the borehole via wire line. Because of the narrow space in the borehole, the nozzle is able to apply high pressure to the borehole face with very little displacement of the frame in the opposite direction. Water for the jet spray is provided by an above ground source and supplied continuously as the nozzle sprays and erodes the borehole face. After the borehole face is excavated, the Borehole Miner is retrieved and the excavated material is pumped to the surface.

However, fundamental differences between a borehole and the OHF tanks required certain modifications to the Borehole Miner. Safety considerations (specifically related to the radiological contamination and to DOE prohibitions on hoisted loads being energized) necessitated other modifications to the Borehole Miner's design. The major design modifications are summarized below. The modified Borehole Miner is shown in Fig. 2.

Support During Sluicing. The Borehole Miner was designed to be suspended vertically in a shaft and, because of the confining nature of the borehole, was allowed to hang freely during borehole facewall excavation. However, DOE safety protocols do not allow for suspended equipment to be energized while working. In addition, the tanks interiors were less confining than a narrow borehole. With the nozzle extended and jetting, the opposing pressure would displace the Borehole Miner from vertical, and in the roomier space of the tanks, extensive displacement of the mast would effect performance of the jet spray and potentially damage the equipment. To address these concerns, the Project Team designed a four-legged stand that would sit over a tank riser and support the Borehole Miner. The Borehole Miner could be lifted with a crane and seated in the stand, with the nozzle end of the miner suspended inside the tank. Once seated, the Borehole Miner could be disconnected from the overhead crane. The stand held the frame rigid, preventing movement of the frame in the direction opposite the spray.

Nozzle Spray Angle. The original frame configuration was enclosed at the lower end, limiting the nozzle's ability to spray directly beneath the frame. Because the nozzle was intended to spray and excavate borehole faces that were horizontal to the frame, this was not a problem in the original configuration. However, an inability to deliver a spray beneath the frame could potentially leave areas of radioactive sludge that would not be sluiced and pumped from the tanks. Due to the highly radioactive character of the sludge, leaving a significant quantity immediately under the frame was unacceptable. To address this concern, the lower end of the frame was shortened and left open so that the nozzle could spray straight down.

Hose Reel. The original design for the Borehole Miner used a supply hose from the water source into the frame and connected to the nozzle. Operational conditions at the surface were such that personnel could work near the point of entry of the Borehole Miner into the borehole and guide the hose as the Borehole Miner was raised, lowered, or rotated. However, due to the high radiation fields generated by the tank



Legend: (1) top mast frame assembly, (2) platform assembly, (3) lower mast frame assembly, (4) arm assembly, (5) launch assembly, (6) control console, (7) bridge mount, and (8) containment hose, reel assembly.

Fig. 2. Borehole Miner Modified for OHF Tank Use

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wastes, remote operation during sluicing was required. To eliminate the direct involvement of personnel, a hose reel was installed at the top of the mast. This allowed the hose to retract, extend, or rotate in an orderly manner as the Borehole Miner was deployed and actuated in each tank.

In addition to a modified Borehole Miner design, PNNL also provided a high-pressure pump to supply water to the Borehole Miner at pressures up to 1,500 psi. A visualization system, developed by personnel at Sandia Laboratories, was also designed and built. This visualization system was an operator aid that tracked nozzle extension and position in a tank and displayed the data on a computer screen in an animated graphic of the tank. This system gave the operators real time information regarding arm status as the system was operated during tank sluicing operations.

PROJECT COORDINATION

The coordination of this complex project was challenging throughout its duration. The work was conducted as a design/build project, with various aspects of the system being designed discretely at various Project Team offices. While the pumping and sluicing system design and fabrication continued, work also proceeded at the cold test site and at the OHF site. These various activities required careful coordination to ensure that specific project milestones were met on schedule, and that critical path activities were not held up awaiting completion of other activities.

Pumping and Sluicing System

When the decision was made to use the Borehole Miner, representatives from PNNL and Waterjet Technologies were incorporated into the Project Team. Already underway was the preparation of a 50 percent configuration for the sluicing and pumping system, with the design and planning being conducted in several different locations. CDM personnel were primarily responsible for designing the mechanical and electrical systems and for programming the programmable logic controller (PLC) for the remote operation. In 1997, Waterjet personnel initiated the design of a modified Borehole Miner, working with the Project Team members to coordinate the specifications and ensure all requirements were incorporated into the final design.

The need for close, detailed communication became essential. The Project Team in Oak Ridge met weekly to update the status of the project. Weekly teleconferences between the design teams in Hanford, Seattle, Dallas, and Long Beach were also conducted to ensure that the various components of the system came together.

Several site visits were conducted during the design and fabrication stage. In December 1996, PNNL and Waterjet personnel traveled to Oak Ridge to redline a preliminary design for the modified Borehole Miner. In February 1997, Project Team members from Oak Ridge traveled to PNNL to review specifications, and then traveled to Waterjet to tour the facility. In March 1997, the 50 percent design review was conducted at PNNL. In April 1997 in Oak Ridge, reviews were conducted of the 90 percent design for the Borehole Miner and the 50 percent design of the balance of plant for the sluicing and pumping system. In August 1997, Project Team members traveled to Waterjet and witnessed the final acceptance testing for the Borehole Miner. On August 11, 1997, the Borehole Miner was delivered to ORNL. In September 1997, Project Team personnel traveled to Long Beach to review status of the balance of the pumping and sluicing system being assembled at a CDM fabrication shop. In November 1997, Project Team personnel witnessed an acceptance test for the pumping and sluicing equipment, and on November 21, 1997, the pumping and sluicing system was delivered to ORNL for assembly and testing at the cold test site.

Cold Test Site Preparation

Simultaneously with the design and fabrication of the sluicing and pumping system, the cold test site was being prepared and preliminary work was also being performed at the OHF site. The cold test site was at the Robotics Division at ORNL. Two tanks (approximately one-half the size of the OHF tanks) were equipped with risers and placed in an underground vault. The two tanks simulated a recycle tank and a sluice tank. A surrogate sludge consisting of kaolin clay was placed in one of the tanks, and water was added to both tanks. A control room was established in an adjoining building to house the PLC and the operational controls.

OHF Site Preparation

At the OHF site, preparations were underway for delivery and deployment of the equipment. A thick pad of gravel was laid over the entire site to level it and prepare a stable base for the large equipment skids. The sluicing and pumping system had significant electrical demands, so a 600-volt transformer was installed at the site. Large bulk storage bins supported by steel stanchions that stood approximately 18 m above ground surface were part of the original OHF injection facilities. Because of their deteriorated condition, these bins had to be removed before the sluicing and pumping equipment could be brought in. A control trailer was relocated onsite and modified to accept the PLC and the Borehole Miner hydraulic control unit. In-tank pumps not used for the cold tests were installed in the OHF tanks. A high efficiency particulate air (HEPA) ventilation system was installed. A lead-lined frisk shack used as the ingress and egress point for radiological contamination control was set in place.

SYSTEM IMPLEMENTATION

Cold Test

Cold test operations were conducted in early 1998 after assembly of the equipment was completed in January 1998. OHF project personnel tested the equipment, developed operating procedures, and demonstrated the feasibility of mixing and sluicing the sludge and supernate within the tanks using the Borehole Miner. An open tank served as a transfer point, and during cold test operations, the tanks' contents were successfully sluiced and transferred to the open tank on several occasions. In April 1998, a DOE Readiness Review Board granted approval to relocate the system to OHF and initiate set-up.

OHF Tanks Contents Removal Action

After completion of the cold test, the remaining equipment was transferred to the OHF site in April 1998 and assembly was completed in June 1998. Final approval to initiate sluicing and pumping actions was held until the entire system was assembled, structural containment integrity of all piping and fittings was established, and all equipment was demonstrated to be functioning. In June 1998, DOE granted approval to proceed with the removal action.

Waste removal operations were initiated on June 26, 1998 with the transfer of supernate between tanks to balance the water content for purposes of achieving the 10 percent solids mixture required for safe transfer to MVST. The contents of the recycle tank and one of the sluice tanks were transferred initially. Various mechanical problems were encountered during the sluicing operations, including failure of one of the Moyno pumps, failure of an in-tank pump in the recycle tank, and other electrical and mechanical problems. As the last tank was being cleaned, the hydraulic control unit for the Borehole Miner shut down (likely due to low fluid pressure). However, at this point the final tank had been emptied, and the removal action completed. TDEC personnel reviewed each

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tank after the contents were removed (via cameras placed in each tank to visually observe sluicing operations), approved the level of cleaning in each tank, and granted approval to proceed with sluicing the next tank. On July 18, 1998, the final tank was emptied, and on August 31, 1998, the equipment was disassembled and the removal action was completed.

Over 98 percent of the tanks' contents were removed and transferred to the MVST tanks. The work was performed safely, with no injuries or lost workdays incurred. The actual radiation exposures received by the site workers were well below DOE limits, and below the ALARA projections established at the beginning of the work.

Make-up water was minimized, with less than 25,000 L added to the system, primarily as decontamination water used to remove contamination from the Borehole Miner before transfer from one tank to another.

CONCLUSION

The OHF Tanks' Contents Removal Action represents a successful integration of government and private industry resources and expertise to safely accomplish a removal action. A significant measure of this success was that the project exceeded projected goals for worker safety, quantity removal (98 percent actual contents removed vs. 95 percent planned), and waste minimization. Through careful coordination and extensive communication, a sophisticated sluicing and pumping system was designed and fabricated at private industry facilities across the country. This system was then successfully assembled and deployed, first at a cold test site to check equipment operation, develop procedures, and train workers, then at the OHF site. The innovative modification and use of the Borehole Miner, incorporated into a system comprised of commercial pumping and sluicing equipment, demonstrates the feasibility of adapting and using commercial technology to safely and successfully remediate nuclear waste legacy sites at DOE facilities.

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