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Pacific Northwest National Laboratory
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Technical Review of Retrieval and Closure Plans for the INEEL INTEC Tank Farm Facility

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September 2001

Prepared for the U.S. Department of Energy
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Acknowledgments

The technical review of the retrieval and closure plans for the Idaho National Engineering and Environmental Laboratory (INEEL) Idaho Nuclear Technology and Engineering Center (INTEC) tank farm facility is a part of the Retrieval Process Development and Enhancements (RPD&E) Project under direction of the US Department of Energy Office of Science and Technology Tanks Focus Area. Funding for this investigation was provided to Pacific Northwest National Laboratory (PNNL) through the Tanks Focus Area and to Oak Ridge National Laboratory (ORNL) through the Robotics Crosscutting Program and the Tanks Focus Area. This work was conducted in collaboration with Keith Quigley and Steve Butterworth, INEEL at the Idaho Nuclear Technology and Engineering Center.

Summary

The purpose of this report is to document the conclusions of a technical review of retrieval and closure plans for the Idaho National Energy and Environmental Laboratory (INEEL) Idaho Nuclear Technology and Engineering Center (INTEC) Tank Farm Facility. In addition to reviewing retrieval and closure plans for these tanks, the review process served as an information exchange mechanism so that staff in the INEEL High Level Waste (HLW) Program could become more familiar with retrieval and closure approaches that have been completed or are planned for underground storage tanks at the Oak Ridge National Laboratory (ORNL) and Hanford sites. This review focused not only on evaluation of the technical feasibility and appropriateness of the approach selected by INEEL but also on technology gaps that could be addressed through utilization of technologies or performance data available at other DOE sites and in the private sector. The reviewers, Judith Bamberger of Pacific Northwest National Laboratory (PNNL) and Dr. Barry Burks of The Providence Group Applied Technology, have extensive experience in the development and application of tank waste retrieval technologies for nuclear waste remediation.

This report summarizes INEEL plans for retrieval and closure as of March 2001 and relevant work performed at the ORNL and Hanford sites. As part of the review process, staff from the INEEL HLW Program visited ORNL and Hanford for information exchange briefings and tours. The briefing at ORNL included presentations and discussions of retrieval and closure activities for the Gunite and Associated Tanks, Old Hydrofracture Facility Tanks, and Federal Facility Agreement Tanks. Retrieval activities were discussed for the Bethel Valley Evaporator Service Tanks and Melton Valley Storage Tanks. The ORNL site visit included tours of several tank farm facilities and the Tanks Technology Cold Test Facility. The Hanford site visit focused on waste dislodging and retrieval technology development and testing. Discussions included: waste retrieval end effectors, Fernald silo remediation equipment, Pit Viper, jet dislodging including the West Valley spray ball, Hanford tank U-107 water-spray system, borehole miner extendible nozzle, leak detection, monitoring, and mitigation, characterization of slurries, and slurry transport in partially filled horizontal pipes.

The reviews showed that the INEEL selected technical approach of using a wash ball for removal of residual waste from tank walls and internal structures with addition of directional nozzles for targeted cleaning and solids resuspension is both feasible and appropriate given the physical property data available for the waste heel, properties of the residual waste on the walls and internal structures and performance data from cold tests performed to date. The grout pouring approach appears to be an effective means of accomplishing a final heel retrieval while grouting the tank floor.

It is extremely important to fully characterize the cleaning effectiveness of the selected approach during the first deployment. Sufficient sampling and inspection should be performed after retrieval is completed to determine whether more aggressive techniques will be required. It is also important to determine whether the retrieval process can be modified to reduce overall water usage, reduce cleaning time, or improve cleaning effectiveness. Attention to the effects of varying flow rates, pressures, traverse rates, etc. during the first deployment could result in much more efficient and effective cleaning in subsequent deployments.

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Acronyms

ASME	The American Society of Mechanical Engineers
BOP	balance of plant
CB	confinement box
CSEE	confined sluicing end effector
DOE	US Department of Energy
DOF	degrees-of-freedom
DSR	decontamination spray ring
ECN	engineering change notice
ER	Environmental restoration
FCE	flow control equipment
FFA	Federal Facilities Agreement
GAAT	Gunite and Associated Tanks
GSEE	Gunite scarifying end effector
GUI	graphical user interface
HAZWOPER	Hazardous Waste Operations and Emergency Response
HEPA	High-efficiency particulate air
HMA	hose management arm
HLW	high-level waste
IGAT	intermediate grout addition tank
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
LDUA	light duty utility arm
LLLW	low-level liquid waste
MET	mast elevation table
MLDUA	modified light duty utility arm
MST	mast storage tube
NEC	National Electric Code
NTF	north tank farm
ORNL	Oak Ridge National Laboratory
PMP	pulsating mixer pump
PNNL	Pacific Northwest National Laboratory
RCRA	Resource Conservation and Recovery Act
ROV	remote operated vehicle
SREE	sludge retrieval end effector
SRI	Southwest Research Institute
SRS	Savannah River Site
STF	south tank farm
TFA	Tanks Focus Area
THS	tether handling system
TPG	The Providence Group
UST	underground storage tank
WD&C	waste dislodging and conveyance
WM	waste management
WRSS	waste retrieval sluicing system
WTI	Waterjet Technology, Inc.

1.0 Introduction

1.1 Background

The Department of Energy (DOE) weapons complex is transitioning from production to environmental restoration (ER). In this process DOE has identified contaminated facilities that are surplus and need to be decommissioned. These activities must be completed safely, timely, and cost effectively. In this context, the tank farm at Idaho Nuclear Technology and Engineering Center (INTEC) has been targeted for closure. The INTEC closure is a high-level waste project that is to be closed in accordance with DOE Order 435.1 and the Resource Conservation and Recovery Act (RCRA) closure plan.

The main focus of the closure is the safe and efficient removal of contamination inside the tanks before closure. To ensure that this closure is completed safely and efficiently, a proof of process is underway at Idaho National Engineering and Environmental Laboratory (INEEL). To provide additional insight into the retrieval aspects of INTEC tank closure, the US DOE EM-50 Tanks Focus Area (TFA) is providing support to INEEL staff to demonstrate and provide a more complete characterization of the performance of proposed remediation concepts so that the information can be shared with others facing similar remediation projects.

To further support successful remediation, staff at Pacific Northwest National Laboratory and Oak Ridge National Laboratory were requested to assess the proposed remediation plan being employed at INTEC to determine whether prior and ongoing research and demonstrations at other DOE sites could be used as supporting technologies if the proposed plan for INTEC needed to employ more aggressive remediation techniques.

1.2 Scope

The project scope is to

- Evaluate the path proposed for remediation of INTEC WM (waste management) tanks
- Provide insight and information about more aggressive tank remediation approaches that could be applied at INTEC
- Provide lessons learned from prior demonstrations and deployments that can be applied to INTEC tank remediation
- Summarize the results in a report to provide access to others wishing to consider these types of remediation.

2.0 Conclusions and Recommendations

To support INEEL remediation of the INTEC WM tanks, the US DOE Tanks Focus funded collaboration between staff at INEEL, PNNL, and ORNL to assess the retrieval and closure technologies being implemented by INEEL to validate the proposed plan and to provide information about technology alternatives that could be implemented if retrieval and closure activities uncover unanticipated results.

To facilitate this activity staff from PNNL and ORNL visited INEEL to review the results of activities and testing to date and proposed activities. To provide increased understanding about retrieval and closure development, demonstrations, and deployments at PNNL and ORNL, technical exchanges at each site were also conducted.

This report summarizes evaluation of INEEL concepts by staff from PNNL and ORNL and technology exchanges between PNNL and INEEL staff that visited PNNL and ORNL in April 2001. Based on these interactions the following observations, conclusions, and recommendations are presented.

2.1 Technology Synopsis

- **Wash Ball.** The wash ball is the primary remediation technology selected for tank cleaning. The wash ball nozzles operate at relatively low pressure (0.69 MPa [100 psi]) and a relatively high flow rate [0.0047 m^3/s (75 gpm)]. In the tank, the nozzle maximum stand-off distance is ~ 10.7 m (35 ft). The nozzle spray pattern requires ~ 14 min to wet the entire tank. Adequate water must be added to the tank to increase the pH to > 2 to facilitate disposal. Water volume added that increases pH to > than pH 2 will potentially be evaporated prior to disposal. So methods that clean the tanks adequately while limiting water use may increase the cost effectiveness of the remediation. Spray techniques that could limit water use by increasing effectiveness of removal of solids from tank surfaces include: use of heated water, use of chemically treated water, use of higher pressure and lower flow rate.
- **Directional Nozzle.** The directional nozzle operation will be utilized for two main purposes: 1) to apply selected directed streams of water to the tank walls, steam coils, or floor to dislodge accumulations of tenacious solids and 2) to sweep solids to the entrance to the steam jet. Controlling the operation of the directional nozzle in both of these cases will be done manually with the operator observing nozzle location via the video camera. A method of automation may assist during remediation by providing some pre-programmed jet patterns to sweep across the floor of the tank to push solids to the entrance to the steam jet or to focus or go back and forth across a patch of tank wall. If significant aerosol generation inhibits visualization via the camera, a visualization system may permit longer periods of operation before mist obscures the vision of the camera.
- **Video Camera.** Discussions with the INEEL team revealed that in the past camera components overheated from the proximity of the camera to the lights. Additional shielding between the lights and the camera is being implemented. Staff at ORNL noted that they also experienced problems with cameras overheating and radiation damage. ORNL devised heat shields that were somewhat effective at delaying the heat damage. They also routinely pulled the overview

cameras out of the tank and took them to a glove box where they were able to replace the video camera modules, lights, and other damaged components and repair the heat shields

- **Variable Depth Steam Jet.** Providing an adjustable height steam jet entrance and increasing the steam jet capacity to match or surpass that of the wash ball or the directional nozzles are the goals of the new steam jet installation. Both features should significantly increase the performance of the tank remediation. The ability to lower the steam jet to just above the floor permits removal of much more slurry and reduces the heel remaining in the tank. Subsequent washings further reduce the solids loading through additional dilution and retrieval. The ability to retrieve at a rate equal to or faster than achieved by washing permits retrieval of the agitated solids prior to the onset of gravitational settling.
- **Pipeline Transport.** Visual observation of slurry transport transients, through review of a video of the transport, was very revealing. These tests showed that air remained in the lines for a significant time after initiation of transport. Pulsating, two-phase (fluid and air) flow persisted through most of the transport. These details showed that use of a coriolus mass flow meter to quantify the amount and density of the fluid transferred would not be reliable. These types of flow meters operate accurately when the pipeline is full of fluid.
- **Mockup Tests.** The tests were conducted to provide both qualitative and quantitative results of equipment performance. Successes included: visualization of the wash ball spray pattern and observation that additional directed jets were required to move solids from the sides of the tank to the steam jet inlet, incorporation and testing of directional nozzles that were able to mobilize and direct sludge from the tank edges to the steam jet inlet and visualization of the erratic two phase flow during slurry transport through the pipeline model.

Based on these results opportunities exist to: develop an application strategy for deploying the directional nozzles to mobilize and move the solids to the steam jet, develop an application strategy for integration of water injection via either wash ball or directional nozzle with slurry removal via steam jet operation, develop criteria, based on measurements of water usage, fluid density, and radiation levels to determine when to continue water addition for tank washing and solids movement and when to cease tank washing and when to cease steam jet retrieval.

- **Grout Placement.** The method of sequentially pouring grout onto the tank floor and cooling coils has shown the usefulness of this method for permitting retrieval of additional slurry from the tank using the installed, variable depth steam jet.

PNNL, Hanford, ORNL, and other DOE sites have developed, demonstrated, and deployed a series of technologies that can be utilized by INEEL to either enhance their current plan for cleaning and remediating the WM tanks or to implement if currently selected technology is subjected to cleaning, dislodging, retrieval, and transport challenges more difficult than currently envisioned. These technologies include: pulsed air, pulsating mixer pump, fluidic pulse-jet mixing, Hanford Tank C-106 sluicer, borehole-miner extendible-nozzle, waste-retrieval end effector, high-pressure scarifier, and Flygt mixers. Four of these techniques the Hanford tank C-106 sluicer, borehole miner, pulsating mixer pump and fluidic pulse-jet mixing will readily fit through a 31-cm- (12-in.-) diameter riser and could be deployed at INEEL if needed.

These developments can provide:

- More aggressive fluid-based techniques for wall cleaning, waste dislodging and mixing
- Additional instrumentation to further quantify the amount of waste retrieved and in-tank methods to measure radioactivity associated with slurry remaining in the tank
- Sampling techniques to measure residual contamination.

In addition, implementation of methods to reduce water usage, such as the use of heated water, chemically treated water, or higher pressure, may reduce costs associated with evaporation

2.2 Conclusions

The technical approach described in section 3 that INEEL plans to utilize was deemed by this review group to be both feasible and appropriate given the physical property data available for the waste heel, properties of the residual waste on the walls and internal structures, and performance data from cold tests performed to date. It is reasonable to expect a sufficient cleaning effectiveness for removing the residual waste from tank walls and internal structures using the wash ball and to expect most of the solids on the tank floor to be mobilized into the steam jet by the rinse water and agitation of the moving nozzles. The addition of the directional nozzle is an inexpensive approach to reduce risk by providing the capability to direct a higher flow of wash water to a specific area if needed. By placing the directional nozzle and wash ball at different locations in the tank the impact of cooling coils and other structures blocking effective cleaning from the wash ball can be overcome. The grout pouring approach that results in residual liquids and solids on the tank floor being concentrated into the region of the tank where the steam jet is located appears to be an effective means of accomplishing a final heel retrieval.

2.3 Recommendations

At this time it appears that the proposed approach will be adequate. INEEL plans a tank cleaning campaign during the latter part of FY 2001 that will provide further performance data on the selected approach. Should that campaign reveal that a more aggressive cleaning will be needed for some parts of the tanks, there are several relatively inexpensive and low risk technologies that could be integrated with the current approach. For now we recommend these technologies be considered only as contingencies and not be pursued further until early field testing of the wash ball is completed. INEEL has previously demonstrated successful deployment of the light duty utility arm (LDUA) system for sampling and inspection tasks. The LDUA could be a very effective tool to assist with cleaning of the tanks if a portion of the walls, floor, or other internal structures turn out to be more difficult to clean. Another option is a simpler articulated mast like the maintenance arm used at Hanford or the Wiedeman arm used at the West Valley Demonstration Project. These are simple devices that can easily fit through the INEEL 31-cm-(12-in.-) diameter risers and can be used to deploy a high pressure lance for more aggressive cleaning. These arms will not be able to reach the entire tank volume from a single access penetration and will be limited in payload capability but they should be considered if unexpected conditions arise.

The cold tests completed to date were found to be extremely useful and cost effective. If the need arises to insert additional technologies for more aggressive cleaning, similar cold tests should be conducted. During the review meetings a number of suggestions were made regarding design and operational details for the cold tests and field work. These detailed suggestions will not be reiterated in this report since the designers have already incorporated those suggestions. The most significant suggestions regarded the selection of instrumentation used for process control and monitoring rather than in the cleaning process per se.

It is extremely important to fully characterize the cleaning effectiveness of the selected approach during the first deployment. Sufficient sampling and inspection should be performed after retrieval is completed to determine whether more aggressive techniques will be required. It is also important to determine whether the retrieval process can be modified to reduce overall water usage, reduce cleaning time, or improve cleaning effectiveness. Attention to the effects of varying flow rates, pressures, traverse rates, etc. during the first deployment could result in much more efficient and effective cleaning in subsequent deployments.

3.0 INTEC Tank Farm Facility Description and Approach to Closure

The purpose of this section is to describe the INTEC tank farm facility and the systems to be deployed to facilitate tank closure. In addition tests to evaluate the performance of these systems using waste simulants and demonstrations in the tank to ensure that the systems are adequate to clean the tanks to achieve tank farm closure are described. Observations associated the sections that address alternatives or areas where improvements could be considered are included.

3.1 Tank Farm Details

The INTEC Tank Farm consists of eleven vaulted 1136 m^3 (300,000-gal.) underground tanks used to store radioactive waste (Palmer et al. 1999). The tank farm was constructed during the 1950s and 1960s and has been in continuous use since 1953. The facility is significantly different from other tank farms in the DOE complex in three respects: 1) the tanks are constructed of stainless (not carbon) steel; 2) the wastes are stored in acidic (not neutralized or alkaline) condition, and 3) the tanks have been repeatedly emptied and refilled over years as liquid wastes were periodically withdrawn to be calcined and as additional new wastes were generated from continued fuel reprocessing.

Each tank is 15 m (50 ft) in diameter with a dome roof. The vertical sidewalls are approximately 6.4 m (21 ft) high. The tanks are constructed from either 0.48- to 0.79-cm- (3/16 to 5/16-in.-) thick stainless steel. Eight of the tanks (WM-180, -182, -183, -185, -187, -188, -189, and -190) were constructed with cooling coils and were used for storing heat generating high-level waste (HLW). Three of the tanks (WM-181, -184, and -186) were constructed without cooling coils for storing non-HLW. Although the tank designs are similar, the tanks were installed in vaults constructed from three different designs. For tanks WM-180 and -181, the first two liquid waste tanks constructed in the early 1950s, the vaults are monolithic, reinforced concrete in an octagonal shape. For tanks WM-182 through -186, constructed from 1954 to 1957, the vaults are octagonal but are constructed using prefabricated pillar and panel construction. For tanks WM-178 through -190, constructed from 1958 to 1964, the tanks are housed in a four-section, reinforced concrete vault. The tank locations and vault types are shown in Figure 3.1.

All of the tanks were designed and constructed to standards in place at the time of construction. However, pillar and panel construction is not as robust as monolithic construction and the unlined concrete in all of the vaults does not meet RCRA secondary containment requirements because concrete is incompatible with acidic waste. Tank WM-190 is maintained as a spare tank that is continuously available to receive contents from any other tank.

The estimated sludge volumes are 39 m^3 (10,200 gal.) in tank WM-183, 20.4 m^3 (5,400 gal.) in tanks WM-180, -181, -182, -184, -185, -186, and 2.3 m^3 (600 gal.) in tanks WM-187, -188, and -189 for a total volume of 168 m^3 (44,400 gal.). Radiochemical analysis of solids from tank WN-182 showed that the TRU nuclide total is 21,640 nCi/g and the total radionuclide activity is 2.6 MCi/g. Since the solid particles exceed the 100 nCi/g TRU limit; the waste must be retrieved.

3.2 Waste Details

To evaluate waste properties, videos of the slurry in the tanks and samples of the slurry have been extracted. Videos show that the waste is light and billowy; when a drop of liquid hits the sludge surface, significant agitation results. The average particle size ranges from 0.1 to 250 μm with the average particle size of 10 μm. The particle size is smaller than gravel [2 to 64 mm (0.079 to 2.5 in.)] and sand [0.5 to 2 mm (0.02 to 0.079 in.)], and approaches the low end of diameters for silt [0.002 to 0.05 mm 0.000079 to 0.002 in.)] and is larger in diameter than clay [<0.002 mm (<0.000079 in.)]. The tank farm sludge is 25 volume % solids particles and 75 volume % interstitial liquid. The particle density is 2000 kg/m^3; the liquid density is 1200 kg/m^3; and the sludge bulk density is 1400 kg/m^3. The bulk density of the sludge is slightly greater than the bulk density of the surrogate sludge simulant. Comparison between the density of INTEC sludge and the densities of other fluids at INEEL are shown in Figure 3.2.

3.3 Tank Closure Process Overview

The tank closure process is shown sequentially in the twelve steps shown in Figure 3.3. Tanks will be closed in phases (groups of two or more tanks) to allow the tank farm to remain operational for management of existing waste until treatment processes are available. This procedure improves logistics associated with operation and is cost effective. Final tank closure and capping will follow closure of all the individual tanks.

- Step 1: Waste is stored in the WM tank farm tanks.
- Step 2: The existing steam jets are used to remove slurry from the tanks. At the end of steam jet operation, a fluid heel remains in the tanks. Current tank transfer equipment leaves a heel approximately 7.6 to 25 cm (3 to 10 in.) in depth.
- Step 3: The tanks are inspected physically and by video. The sampling will consist of representative samples taken throughout the tank farm. Sample analysis may indicate a need for further flushing and waste removal.
- Step 4: The tank and piping are flushed with demineralized water.
- Step 5: The existing steam jets are used to remove slurry from the tanks. At the end of steam jet operation, a fluid heel remains in the tanks. Current tank transfer equipment leaves a heel approximately 7.6 to 25 cm (3 to 10 in.) in depth.
- Step 6: The spray ball and directional nozzles are used to clean the tank with demineralized water. Demineralized water was selected to prevent creation of additional solids. The spray ball provides systematic coverage of the tank to optimize water usage. Approximately 151 to 227 m^3 (40,000 to 60,000 gal.) of water will be used to raise pH to >2 and remove the bulk of the heel sludge. After transfer the water will be evaporated from the sludge. The fixed entrance steam jets are replaced with variable depth steam jets or new fixed height jets 1.3 cm (0.5 in.) above the flow. The new 5-cm- (2-in.-) diameter variable depth steam jet will utilize the existing 3.8 cm (1.5-in.) diameter steam jet steam supply and be installed into the existing 31-cm- (12-in.-) diameter tank riser. A linear actuator is used to adjust the height of the steam jet assembly over the range from 15 to 25 cm (6 to 10 in.).
- Step 7: The tanks are inspected by analyzing physical samples and by video. The sampling will consist of representative samples taken through out the tank farm. Sample analysis may indicate a need for further flushing and waste removal.

- Step 8: The video and physical samples will be evaluated. The waste will be removed from the tank walls, tank bottoms, and piping to meet "risk-based" closure standards. After cleaning the tanks will be visually inspected with a video camera and samples of any residual will be submitted for laboratory analysis. The sampling will consist of representative samples taken through out the tank farm. Sample analysis may indicate a need for further flushing and waste removal.
- Step 9: Using several sequential pours, grout will be used to displace and direct the residual heel to the transfer pump and it will be removed from the tank. The coil piping will be grouted in place during this pour.
- Step 10: The piping lines to the tank will be grouted.
- Step 11: The tank vault will be filled with grout.
- Step 12: The entire tank and vault will be grouted.

Figure 3.1 INTEC tank farm overview showing the 1136-m^3 (300,000-gal.) tanks and vault types

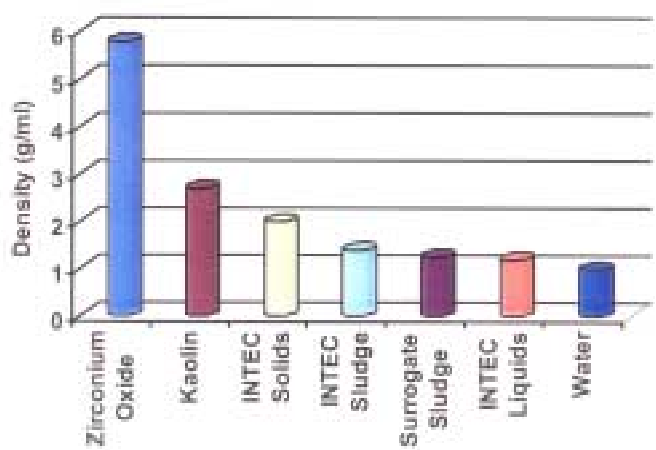

Figure 3.2 Comparison between INTEC sludge and other fluid densities at INEEL

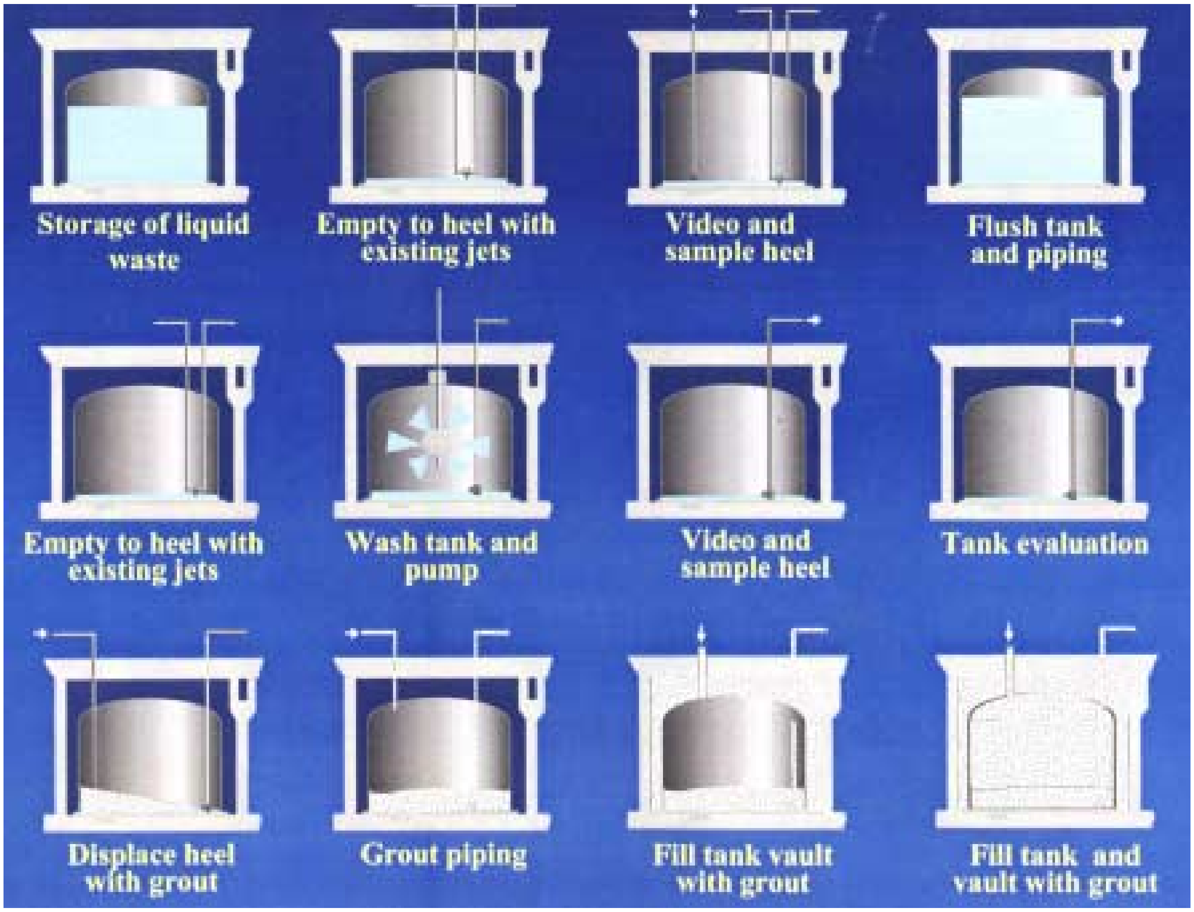

Figure 3.3 Overview of the tank closure sequence

3.4 Wash Ball and Directional Nozzle Operation

The wash ball and directional nozzle were selected to clean the tank walls and tank bottom.

3.4.1 Wash Ball

The wash ball, shown in Figure 3.4, is a commercial grade, off-the-shelf tank cleaning system supplied by Lechler Tank Cleaning Systems.[a] The wash ball is stainless steel and weighs approximately 71 N (16 lbf). The unit selected to decontaminate tanks WM-182 and -183 contains two opposed 10-mm-(0.4-in-) diameter nozzles. The wash ball operates using demineralized water supplied from the pump skid and operates over the pressure range from 0.41 to 0.69 MPa (60 to 100 psi) and flow rates from 0.0038 to 0.0047 m3/s (60 to 75 gpm), respectively. In the tank, the maximum distance of impact from the wash ball nozzle is estimated to be 10.7 m (35 ft) at 100 psi at a flow rate of 0.0047 m^3/s (75 gpm). The unit is supported by the supply piping from the riser interface adapter mounting flange. The wash ball rotation is powered by the water flow and the time to complete one wash cycle is 14 min. Wash ball

[a] Lechler, Inc., 445-T Kautz Rd., St. Charles, IL 60174 USA, Tel: 800-777-2926, http://www.lechler.com/us/

controls provide rotational movement of the wash ball assembly and remotely controlled on/off ball valve for supply wash water. The wash water pressure is measured.

The water supply system will deliver demineralized water to both the nozzles and spray rings. The maximum output capacity of demineralized water is 0.0050 m^3/s (80 gpm) at 0.83 MPa (120 psi). The average planned output capacity is 0.0037 m^3/s (60 gpm) for 12 hrs. Measurements will be made of the total system water usage and the overall instantaneous flow rate. The water supply system does not include freeze protection. All systems will be drained annually when the temperature is <-1 C (30 F); for temperatures between -1 to 4 C (30 and 40 F) all piping including the supply line will be drained; however, water will remain in the supply tank.

Figure 3.4 Wash ball showing the dual opposed nozzles.

3.4.1.1 Observations

The wash ball nozzles operate at relatively low pressure (0.69 MPa [100 psi]) and a relatively high flow rate [0.0047 m^3/s (75 gpm)]. In the tank, the nozzle stand-off distance was estimated to be ~ 10.7 m (35 ft). The nozzle spray pattern requires ~ 14 min to wet the entire tank. Adequate water must be added to the tank to increase the pH to > 2 to facilitate disposal. Water volume added that increases pH to > than pH 2 will potentially be evaporated prior to disposal. So methods that clean the tanks adequately while limiting water use may reduce the cost of the remediation. Spray techniques that could limit water use by increasing effectiveness of dissolution and removal of solids from tank surfaces include: use of heated water, use of chemically treated water, use of higher pressure and lower flow rate.

3.4.2 Directional Nozzle

The full-scale half-tank wash ball tests demonstrated the need for directional nozzles that can be oriented to wash selected sections of the tank that require additional coverage. These two nozzles will be placed 180 degrees apart in the outer risers, 0.9 m (3 ft) from the tank wall, and approximately 4.6 m (15 ft) above the bottom of the tank. The 10-mm- (0.4-in.-) diameter nozzles will operate at 0.83 MPa (120 psi) and provide 0.0025 m^3/s (40 gpm) per nozzle. Each nozzle will have 350 deg horizontal rotation and 120 deg vertical rotation and be capable of directing water to the bottom and walls of the tanks. The nozzles will be controlled remotely; the operators will be in a trailer outside of the tank farm. The directional nozzles will not be operated simultaneously with the wash ball. A camera and light, shown in Figure 3.5, are located adjacent to each directional nozzle and will follow the nozzle motion. An air lance will be used to clean the camera lens. The directional nozzle assemblies have rotational and up/down control and remotely controlled on/off ball valve for supply wash water. The wash water pressure is measured.

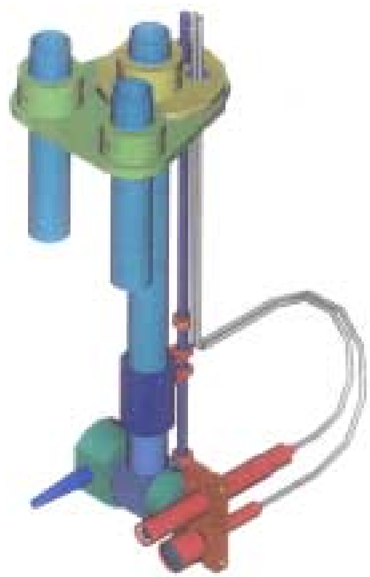

Figure 3.5 Directional nozzle, light, and camera configuration

Figure 3.6 Video camera showing lights and purge air ring

3.4.2.1 Observations

The directional nozzle operation will be utilized for two main purposes: 1) to apply concentrated streams of water to the tank walls, steam coils, or floor to dislodge accumulations of tenacious solids and 2) to sweep solids to the entrance to the steam jet. Controlling the operation of the directional nozzle in both of these cases will be done manually with the operator observing nozzle location via the video camera. A method of automation may assist during remediation by providing some pre-programmed jet patterns to sweep across the floor of the tank to push solids to the entrance to the steam jet or to focus or go back and forth across a patch of tank wall. If significant aerosol generation inhibits visualization via the camera, a visualization system may permit longer periods of operation before mist obscures the vision of the camera. A virtual visualization system such as the one developed to enhance borehole miner operation during remediation of the Old Hydrofracture Tanks at Oak Ridge or an infrared system to permit vision through the mist are potential approaches.

3.4.3 Video Camera

The video camera selected is a commercial grade color unit manufactured by Everest/VIT[a] with integrated lights and a self-contained control system. The unit weighs about 58 N (13 lbf) and is finished in polished stainless steel to facilitate decontamination. The lens is a Ca-Zoom model PZT 4.2 with 18:1 optical zoom and 4:1 digital zoom for a total of 72:1 zoom. The camera is waterproof to a depth of 46 m (150 ft) and the camera head is pressurized at 69 kPa (10 psi). The camera, lights, and control system operate at 120 VAC at 10 amps that is supplied by a vendor furnished dedicated cable from the control trailer to the camera. The camera is supported by pipe from the riser interface adapter mounting flange that has been modified with an additional ring of jets for directing purge air across the lens (Figure 3.6). The video camera has lights and it is controlled and recorded at the control trailer. Instrument air at 69 kPa (10 psi) and 0.028 to 0.57 m^3/s (1 to 2 cfm) supplied from the pump skid is provided to clean the camera lens. The instrument air pressure is regulated locally and the pressure is verified with a pressure switch. A liner actuator on the spray ball/video camera mounting flange operates using 120 VAC at 2 amps.

3.4.3.1 Observations

Discussions with the INEEL team revealed that in the past camera components overheated from the proximity of the camera to the lights. Additional shielding between the lights and the camera were being implemented. Staff at ORNL noted that they also experienced problems with cameras overheating and radiation damage. ORNL devised heat shields that were somewhat effective at delaying the heat damage. They also routinely pulled the overview cameras out of the tank and took them to a glove box where they were able to replace the video camera modules, lights, and other damaged components and repair the heat shields.

The location of the camera can also significantly influence camera performance. During periods of operation when there is a dense aerosolization of water vapor, the view from a camera located near or at the directional nozzle or spray ball will be particularly hampered by the fog. A much clearer view could be attained from a video camera located closer to the water impact zone or located so that the impact zone is viewed from the side rather than in line with the nozzle.

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[a] Everest VIT, Inc., 199 Highway 206, Flanders, NJ 07836 4500 USA, Tel: 888-332-EVIT (3848), http://www.v-i-t.com/ptz/cazoom.html

3.4.4 Riser Interface Adapter

The riser interface adapter is the mounting point for the spray ball/video camera system support flange. The adapter connects to the tank central riser using an existing "swing bolt" design configuration. The adapter includes a spray ring section for decontamination of the adapter when it is removed from the tank. The spray ring operates using either plant water supply or demineralized water supplied from the pump skid at 69 to 414 kPa (10 to 60 psi) and flow rates from 0.00012 to 0.00032 m^3/s (2 to 5 gpm), respectively. The spray ring pressure is regulated locally and monitored remotely for signs of nozzle plugging. The weight of the stainless steel adapter and associated spray ball and video camera systems are supported by an "A" frame support system between the riser interface adapter and the exposed concrete bunker top surface located above the tank and not by the tank riser.

3.4.5 Installation and Operation Sequences

The installation sequence includes:

- Position the "A" frame support system on the bunker and remove the cross frame brace.
- Position the interface spool piece over the riser swing bolt flange.
- Align the "A" frame lip of the spray ring assembly, attach the cross frame brace, and transfer the load to the support system.
- Secure the swing bolt flange interface.
- Lower the upper flange assembly with the spray ball and video camera system onto the riser adapter flange and secure.
- Connect the camera cable, spray ball supply hose, linear actuator power/control cable, camera lens window air purge supply hose, and spray ring demineralized water supply hose to the appropriate bulkhead connectors on the enclosure wall.

The operational sequence includes:

- Turn on the video cameral control consol and video recording equipment in the control trailer.
- Ensure that the camera lens window air purge supply is on.
- Perform a visual inspection of the tank wall, all cooling coils, tank heel level, and the overall condition of the tank interior.
- Verify that the camera splash shield is in place.
- Power up the wash pump and perform decontamination operations; record all operations in the VCR.
- Power up the steam jet and remove the tank heel contents as necessary to achieve optimal solids removal.

To control contamination during operations procedures are developed based on the following assumptions:

- The interior of the tank and risers are the primary sources of contamination.
- The area around the vault openings is contaminated.
- During insertion or removal of equipment, the tank entry enclosure will be open to atmosphere.

Spread of contamination will be reduced by the use of controlled air flow, physical barriers, and a demineralized wash down system. During any time that the 31-cm- (12-in.-) diameter riser is open, an air flow of 0.64 m/s (125 ft/min) will be maintained into the tank. This same airflow will be maintained at the top of the riser vault openings. To meet this demand, the existing vessel off-gas system will be modified. Equipment removed from a riser will be bagged during withdrawal.

3.5 Retrieval and Transport

Waste suspended by the wash ball and directional nozzles will be pumped from the tank using the variable depth steam jet and transported through piping to another tank, such as tank WM-189, for storage.

3.5.1 Variable Depth Steam Jet Pump

The new 5-cm- (2-in.-) diameter variable depth steam jet pump will utilize the existing 3.8-cm- (1.5-in.-) diameter steam jet steam supply and be installed into the existing 31-cm- (12-in.-) diameter tank riser. A linear actuator is used to adjust the height of the steam jet assembly over the range from 15 to 25 cm (6 to 10 in.). The steam line is instrumented with a pressure transmitter. Valves for the wash water to rinse out the ejection pipe and to isolate the waste ejection line are remotely controlled. The following ejected waste water parameters are to be measured: mass flow rate, density and total flow of ejected waste water, and gamma radiation of the ejected waste water. A model of the steam jet used during the retrieval tests is shown in Figure 3.7.

Figure 3.7 Model of steam jet used during retrieval tests

3.5.1.1 Observations

Providing an adjustable height steam jet inlet and increasing the steam jet pumping capacity to match or surpass the water utilization rate of the wash ball or the directional nozzles are the goals of the new jet pump installation. Both features should significantly increase the performance of the tank remediation.

The ability to lower the jet pump to just above the floor permits removal of much more slurry and reduces the heel remaining in the tank. Subsequent washings further reduce the solids loading through additional dilution and retrieval. The ability to retrieve at a rate equal to or faster than achieved by washing permits retrieval of the agitated solids prior to the onset of gravitational settling.

3.5.2 Pipeline

Transport of slurry from the tank being washed and remediated to the storage tank makes use of existing piping. This piping includes bends, elbows, changes in elevation, and passage through valves. To determine whether solids would accumulate in places such as elbows, dead ends, or contractions or expansions in the line, a clear plastic model of the pipeline was constructed. The entire length of this line is shown in Figures 3.8 and 3.9. Tests were conducted to evaluate transport of slurry provided by the steam jet and the solids concentration that could be successfully transported without plugging any lines.

Figure 3.8 View of the entire above ground piping model

Figure 3.9 Close up of piping model showing valve contractions in black.

3.5.2.1 Observations

Visual observation of slurry transport start up transients, through review of a video of the transport, were very revealing. These tests showed that air entering the lines prior to operation and air introduced by a partially submerged inlet remained in the lines for a significant time after initiation of transport. Pulsating, stratified two-layer (fluid and air) flow persisted through most of the transport. These details showed that use of a coriolus mass flow meter to quantify the amount and density of the fluid transferred would not be reliable. These types of flow meters operate accurately when the pipeline is full of fluid.

3.6 Evaluation of Equipment Performance during Mockup Tests

Tests of equipment performance with simulants were conducted to ensure that the approach and equipment selected for waste retrieval perform as anticipated. The spray ball and the auxiliary jet operation were evaluated during tests conducted in a half-circumference, full-diameter tank. These tests are described in the report *INTEC Tank Farm Facility Closure Mockup Test Report Project File No. 015722* (INEEL 2001). Information from the tests, pertinent to this evaluation is presented here.

Tests were conducted in a half-circumference, full-diameter tank, shown in Figure 3.10. The plywood tank included a stainless-steel wall section with stainless steel tubes that simulated cooling coils attached to the wall. Cooling coils were also located on the floor to simulate the physical coils in the actual tanks. To model the waste, simulant was applied to the walls of the tank and on the tank floor to an initial depth of 20 cm (8 in.), covering the cooling coils as shown in Figure 3.10 a. The stimulant was selected to match physical characteristics such as solids settling rate, density, and viscosity of sludge and included kaolin clay, iron oxide and aluminum sulfate. Two recipes for surrogate solids were prepared: one thick recipe [1112 N (250 lbf)] for trowel application to the stainless steel walls and pipes and one thinner consistency for application to the tank floor to cover the cooling coils. The spray ball and steam jet were installed in the tank in prototypic locations. In addition operation of a video camera was evaluated. The test also included using directional nozzles to remove the simulated waste.

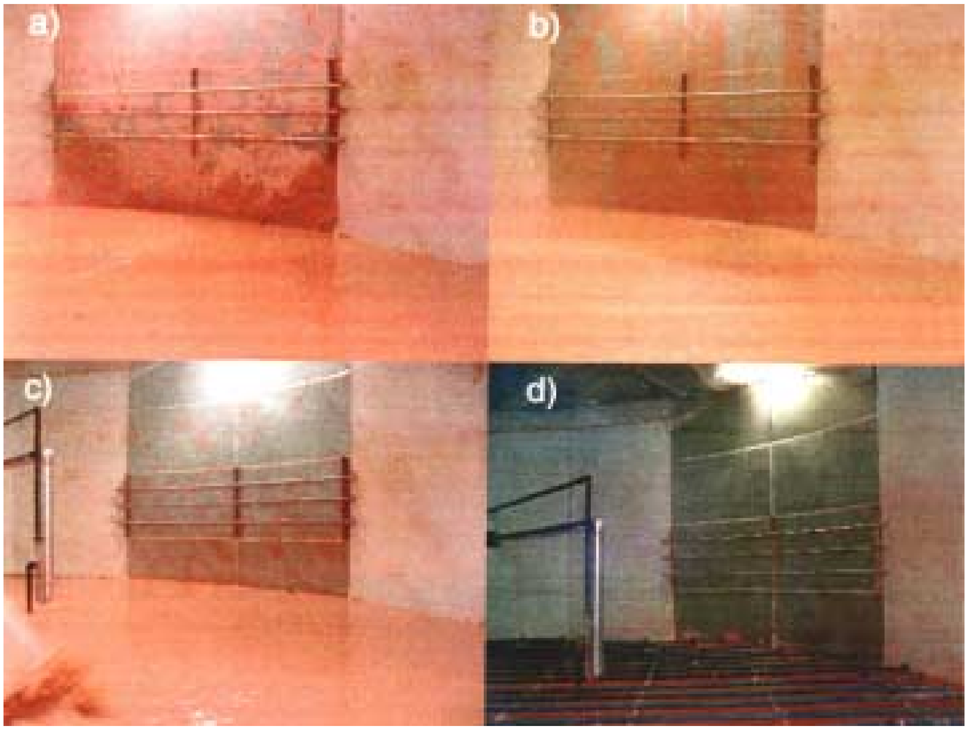

Figure 3.10 Test sequence during tests with wash ball in the test tank.
a) initial condition with surrogate waste covering tank wall,
b) initial washing of the tank, c) subsequent washing of the tank,
d) final washing of the tank.

During the tests nozzle bore diameters ranging from 7 to 12 mm (0.28 to 0.47 in.) were tested. Based on the results of these tests a 10-mm- (0.4-in.-) diameter bore was selected for installation in the wash ball for cleaning of tank WM-182. To further enhance the performance of these nozzles, the bore was machined and polished to a constant 10-mm- (0.4-in.-) diameter throughout the entire length.

3.6.1 Evaluation Summary

- Video camera equipment and systems testing demonstrated the effectiveness of the remote camera operations, camera mounted lights, and an air lance for keeping the lens dry during tank retrieval procedures.
- Tank washing and mixing of surrogate solids determined the efficiency of the washing system and the functional performance of the support systems. The wash ball nozzle size was selected and the need for directional spray nozzles to wash the floor and walls was determined and tested.
- Steam jet testing evaluated the transfer of surrogate solids from the tank and established improved coordination between washing and mixing systems.
- Slurry pipe flow testing permitted observation of removed pumped solids moving through clear piping with bends and simulated valves. No blocking in the discharge lines was observed.

3.6.2 Observations

The tests were conducted to provide both qualitative and quantitative results of equipment performance. Successes included:

- Visualization of the wash ball spray pattern and observation that additional directed jets were required to move solids from the sides of the tank to the steam jet inlet
- Incorporation and testing of directional nozzles that were able to mobilize and direct sludge from the tank edges to the steam jet inlet
- Visualization of the erratic two-phase flow during slurry transport through the pipeline model.

Based on these results opportunities exist to:

- Develop an application strategy for deploying the directional nozzles to mobilize and move the solids to the steam jet
- Develop an application strategy for integration of water injection via either wash ball or directional nozzle with slurry removal via steam jet operation. This strategy should address when to operate concurrently, when to operate sequentially, and how to set the flow rates of each device to determine whether fluid will accumulate, stay constant, or decrease when the equipment is operating
- Develop criteria, based on measurements of water usage, fluid density, and radiation levels addressing when to continue water addition for tank washing and solids movement, when to cease tank washing, and when to cease steam jet retrieval.

3.7 Tank Containment

The differential pressure of each enclosure is monitored with respect to the internal tank pressure. HEPA filter differential pressure is measured to detect air flow and clogging of the filter. Also the ventilation fan speed is monitored and speed is controlled using a variable frequency drive.

3.8 Closure

To simulate closure activities, a heel displacement test was conducted in a 0.9-m- (3-ft-) high, full-diameter tank. The tank included simulated steam coils. The purpose of the test was to use grout placements to move the residual heel to the retrieval pump. Figure 3.11 shows the basin and steam coils, while Figure 3.12 shows one of the grout pours into the basin to cover the coils.

The grout pour evaluation was quite successful. By adding the grout in series of five pours, each focusing on separate areas of the tank, a method was developed to channel the remaining slurry to the entrance to the steam jet to permit additional slurry retrieval. The pattern described used a series of five pours that formed a star pattern. Consider the five points of a star with the steam jet located at the intersection between points 3 and 4. Pours one and two occurred on either side of the tank at points 2 and 5. After these pours, a channel exists between point 1 and the steam jet inlet. Pour three occurred at point 1, forcing fluid through the channel to the steam jet inlet. Pours four and five occurred at points 3 and 4, completing transfer of fluid from the tank floor to the steam jet. The final pour submerges the inlet of the steam jet. These grout pours are accomplished using either one or both of the tanks two risers.

Figure 3.11 Tank basin showing location of cooling coils

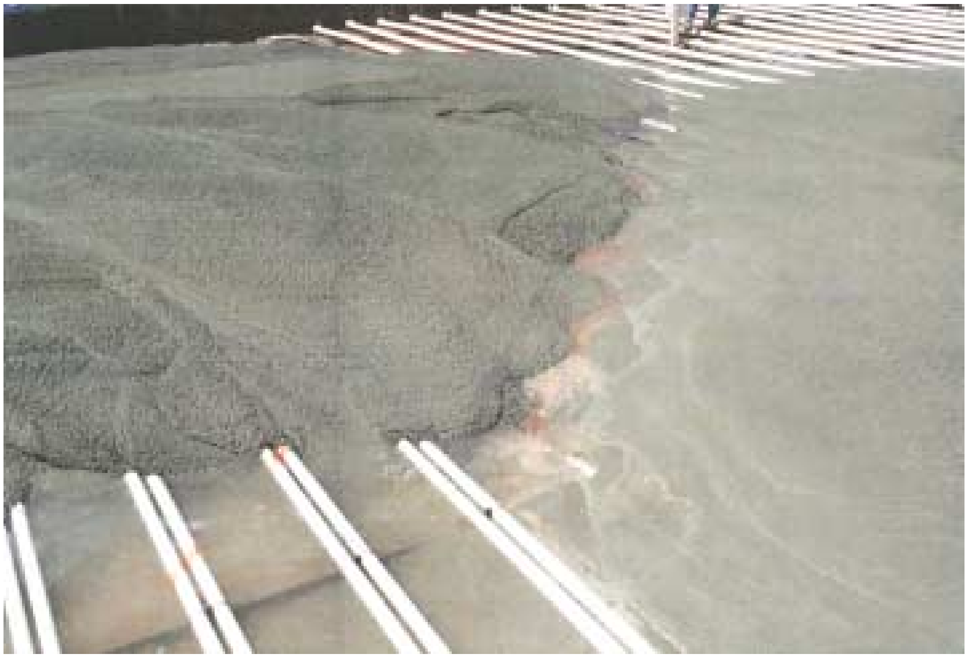

Figure 3.12 Pouring grout over the tank bottom to direct fluid to the steam jet entrance

3.8.1 Observations

The method of sequentially pouring grout onto the tank floor and cooling coils has shown the usefulness of this method for permitting retrieval of additional slurry from the tank using the installed, variable depth steam jet.

4.0 PNNL and ORNL Technology Exchanges with INEEL

Through the US DOE Tanks Focus Area and through collaboration with Hanford via US DOE EM-30 and EM-40 funding, staff at PNNL and Hanford are developing and deploying technologies for waste retrieval from tanks, waste treatment, and tank closure. Many of the systems developed and tested by PNNL have been deployed successfully at ORNL, Savannah River Site (SRS), and West Valley Nuclear Services Corporation. These systems have been designed for operation retrieving waste types that differ from the light, billowy solids observed at INEEL in the WM tanks. This broader technology base may be useful for consideration by staff at INEEL if problems develop during remediation that cannot be solved using existing equipment by changes in operating procedures and different technologies must be considered.

To start this dialog, program staff Keith Quigley and Steve Butterworth from INEEL visited ORNL and PNNL in April, 2001 to meet with technology developers.

4.1 INEEL Meeting at ORNL

The briefing at ORNL included presentations and discussions of retrieval and closure activities for the Gunite and Associated Tanks, Old Hydrofracture Facility Tanks, and Federal Facility Agreement Tanks. Retrieval activities were discussed for the Bethel Valley Evaporator Service Tanks and Melton Valley Storage Tanks. The ORNL site visit included tours of several tank farm facilities and the Tanks Technology Cold Test Facility.

4.2 INEEL Meeting at PNNL

The agenda for the INEEL meeting at PNNL and a synopsis of the interactions follows.

4.2.1 Agenda

Wednesday April 25, 2001

Hanford Training Facility Multnomah Falls Room

7:15	Meet at Hanford Training Facility Multnomah Falls Room
7:30 – 9:30	**Cold Test, Training And Mockup Facility Priority Lessons Learned Workshop,** *Greg McLellan* Welcome/Purpose, Introductions, and Success Criteria Key Drivers, Project Overview and Status Conduct Cold Facility Lessons Learned, Identify what has "Worked Well", Determine impact items and why

2400 Stevens Saddle Room,

9:50	**End Effector Development** - *Brian Hatchell*
10:10	**West Valley Spray Ball** – *Dave Jackson*
10:30	**Jet Cleaning – Borehole Miner -** *Judith Bamberger*

10:50 **Pulse-Air Mixing and Pneumatic Conveyance** –*Judith Bamberger*
11:10 **Ultrasonic Characterization of Slurries -** *Dick Pappas, Judith Bamberger*
11:30 Leave for lunch

Hammer Facility

1:00 **Tour of Pit Viper** facility at Hammer **-** *Sharon Bailey*

338 Building

1:45 **Tour of 338 Building test facility**
End Effector Test Facility – *Brian Hatchell*
Pipe Loop and Mixing Test Facility – *Dennis Mullen*

336 Building

2:15 **Tour of 336 Building test facility**
Mixing, mobilization and scaled tanks (1/25, 1/12, ¼-scale) – *Judith Bamberger*
Pulse-jet mixer tests – *Jagan Bontha (Judith Bamberger)*
Pipe loop and Instrument Validation Test Facility – *Judith Bamberger*
Pneumatic Conveyance Test facility – *Judith Bamberger*

2400 Stevens Saddle Room 1265, PNNL

3:00 **INEEL HLW Tank Closures -** *Keith Quigley*
Development, Evaluation, and Deployment of Directional Nozzle and Wash Ball System
Steam-jet Transfer of Slurries through Pipelines
Tank Farm – Interactive Tank Farm Visualization System
3:45 **Tank U-107 water-spray system to dissolve and remove salt cake -** *Dan Baide*
4:15 Wrap Up Discussions
4:30 pm Adjourn

Thursday April 26, 2001

Conference Room G108B Bldg 2704 200 E

7:30 –8:30 **INEEL HLW Tank Closures -** *Keith Quigley*
Development, Evaluation, and Deployment of Directional Nozzle and Wash Ball System
Steam-jet Transfer of Slurries through Pipelines
Tank Farm – Interactive Tank Farm Visualization System

Conference Room G110 Bldg 2704 200 E

8:30 **Sulzer (Bingham) Pumps, Inc. from Portland, Oregon** will be in the Tri-Cities to discuss pump technology for the radioactive waste environment. In response to the needs of our industry, Sulzer will be presenting several innovative pump designs specifically for handling radioactive slurries along with reviewing their background in the nuclear industry. *Contacts Marshall Hauck or Greg Leshikar.*

Conference Room G108B Bldg 2704 200 E

11:00 **Leak Detection Monitoring Mitigation -** *Jerry Cammann* – presentation and tour of the LDMM site

12:00 Leave for lunch

ISB1-White Bluffs Room 105, PNNL

1:30 **Flygt Mixer Development for Waste Mixing and Mobilization -** *Carl Enderlin*

1:50 **CFD Modeling of Hanford Tanks – TEMPEST** – *Yasuo Onishi*

2:10 **Fernald Silo Cleanout** – *Todd Samuel*

2:30 Slurry transport and measurement in partially filled horizontal transfer lines – *Discussion with Keith Quigley Carl Enderlin, Jim Bates, Judith Bamberger, Chuck Stewart, Yasuo Onishi*

4:00 Adjourn

4.2.2 Synopsis of Meetings

Keith Quigley and Steve Butterworth of the INEEL High Level Waste Program visited Hanford April 24-26 to discuss recent retrieval technology developments with staff at Hanford involved in retrieval programs. This meeting was coordinated by Judith Bamberger of PNNL as part of the TFA support to INEEL HLW Heel Retrieval. The meeting included presentations of the following technologies by PNNL and CHG Staff.

- Waste Retrieval End Effectors
- West Valley Spray Ball
- Borehole Miner
- Fernald Silo Remediation Equipment
- Tank U-107 water-spray system to dissolve and remove salt cake
- Leak Detection Monitoring Mitigation Developments
- Flygt Mixer Development for Waste Mixing and Mobilization
- CFD Modeling of Hanford Tanks – TEMPEST
- Pneumatic Conveyance Testing
- Ultrasonic Characterization of Slurries
- Slurry transport and measurement in partially filled horizontal transfer lines

Keith Quigley and Steve Butterworth also participated in the Cold Test, Training and Mockup Facility Priority Lessons Learned Workshop coordinated by Greg McLellan of CHG. Sharon Bailey provided a technical tour of Pit Viper facility at Hammer. PNNL Staff provided tours of test-beds available to evaluate waste retrieval technologies, including the Hydraulic Test Bed, Critical Velocity Pipe Loop, Mixer Pump Test Facility, Scaled Tank Test Facility (1/25, 1/12, and 1 /4-scale models of Hanford double-shell tanks), Pipe loop and Instrument Validation Test Facility, and the Pneumatic Conveyance Test facility.

During the meeting, Keith Quigley provided a briefing of the development and testing of a directional nozzle and wash ball system for heel retrieval. In addition, Keith described an Interactive Tank Farm

Visualization System developed at INEEL to provide accurate 3-D component information to facilitate the design of future retrieval systems. The meeting concluded with an open discussion regarding slurry transport and measurement in partially-filled transport lines between INEEL, PNNL, and site staff.

5.0 PNNL and Hanford Retrieval Technology Development

Advances in jet-based waste dislodging, mixing, and instrumentation and control strategies developed at Hanford are described in the following sections. Gibbons (2001) provides an excellent overview of retrieval technologies under development by the Tanks Focus Area.

5.1 Applicable Jet-Based Waste Dislodging and Mixing Technologies

PNNL has investigated, modified, and demonstrated a range of fluid-based technologies for dislodging, mixing, and retrieval of waste from underground storage tanks across the US DOE complex. These technologies include: pulsed air, pulsating mixer pump, fluidic pulse-jet mixing, Hanford Tank C-106 sluicer, borehole-miner extendible-nozzle, waste-retrieval end effector, high-pressure scarifier, and Flygt mixers. The applicability, performance, and useful deployment ranges have been summarized in several papers and reports (Bamberger, Wise, and Miller 1992 and Bamberger 2000).

All of the technologies with the exception of Flygt mixers are based on jet mixing. The jet fluid is either air, slurry, or water. The operating parameters, jet pressure, duration and pulse rate, vary, based on the technology. Several of the technologies are very similar. The pulsating mixer pump and fluidic pulse-jet mixing both create jets by using suction to draw slurry from the tank into a tubefollowed by pressure to expel the fluid jet back through the tube into the vessel. The Hanford Tank C-106 sluicer and the borehole-miner extendible-nozzle are both based on sluicing; however, the borehole miner operates at a higher pressure and has an increased range-of-influence from its extendible arm extension. The waste-retrieval end effector and the high-pressure scarifier are both based on scarification, with the high-pressure scarifier operating at significantly higher pressure than the waste-retrieval end effector. In contrast, the Flygt mixer uses an electrically-powered propeller surrounded by a close-fitting shroud. The propeller creates a turbulent fluid jet.

The performance of these technologies to mobilize or dislodge a specific type of simulated waste such as sludge, hard pan, or salt cake has been evaluated. Other technologies have been identified as promising based on industrial application in another tank cleaning environment. These waste types are more difficult to dislodge and mobilize than the WM tank waste; however, if more aggressive cleaning, mobilization, and mixing is required, these candidate technologies have been demonstrated and deployed for radioactive waste retrieval.

5.1.1 Pulsed-Air Mixer

The pulsed-air mixing technique utilizes short, discrete pulses of air or inert gas to produce large bubbles near the tank floor. Air pulses injected beneath horizontal circular plates positioned just above the tank floor produce the bubbles. These bubbles rise toward the liquid surface and induce mixing; the pulse frequency, duration, gas pressure, and plate sequencing are controlled to create a well-mixed condition within the tank. In 1999, Oak Ridge National Laboratory (ORNL) deployed a pulsed-air mixer in Tank W-9 to mix waste solids and accelerate settling of >100-μm-diameter particles.

5.1.2 Pulsating Mixer Pump

Pulsating mixer pump technology, consisting of a jet mixer powered by a reciprocating air supply has been successfully deployed at ORNL to mobilize settled solids. The PMP is comprised of a pump chamber, check valve, a working gas supply pipe, a discharge manifold, and four jet nozzles. The pump uses two distinct cycles, fill and discharge, to perform its mixing action. During the fill cycle, vacuum is applied to the pump chamber by an eductor, which draws liquid through a small pipe and into the pump. When the liquid level inside the chamber reaches a certain level, the chamber is pressurized with compressed air to discharge the liquid through jet nozzles and back into the tank to mobilize sludge and settled solids. A check-valve is used at the pump chamber inlet to control the direction of flow. Operating frequency and other parameters can be adjusted, depending on the liquid being mixed. The jets are rotated during the discharge cycle to effectively suspend solids on the entire tank floor.. In 2001, pulsating mixer pump technology was deployed in ORNL Tank TH-4 to successfully mobilize settled solids (Hatchell 2001).

5.1.3 Fluidic Pulse-Jet Mixing

Fluidic pulse-jet mixing utilizes pulse-jet agitation to mix sludge with liquid supernatant. The system mixes the sludge and supernatant via a three-phase mixing process: a suction phase, a drive phase, and a vent phase. This approach has been deployed at Oak Ridge National Laboratory to mobilize and retrieve waste from five horizontal storage tanks (W21, W22, W23, C1, and C2).

5.1.4 C-106 Sluicer

The Hanford Project W-320 installed the waste retrieval sluicing system (WRSS) in Tank 106-C to mobilize sludge in Tank 106-C to transfer it to Tank 102-AY. The sluicer has a 2.54-cm- (1-in.-) diameter nozzle with two degrees of motion control: rotation (194 degrees) and nozzle elevation (130 degrees). The nozzle pivots and rotates at a fixed elevation in the tank and can be aimed with a dedicated hydraulic system. The sluicer controls can be operated in manual or semi-automatic mode. The sluicer is approximately 29.2 cm (11.5 in.) diameter and is installed in a 30.5-cm- (12-in.-) diameter riser.

5.1.5 Borehole-Miner Extendible-Nozzle

The borehole-miner extendible-nozzle sluicer uses a semi-flexible, extendible, erectable arm to direct a high-pressure sluicer jet. The arm extension and position are controlled remotely from a control console. This system was deployed in 1998 at Oak Ridge National Laboratory to dislodge and remediate four horizontal underground radioactive waste tanks.

5.1.6 Waste-Retrieval End Effector

In 1997, ORNL selected a lightweight scarifying end effector, a jet-pump conveyance system, and two deployment systems: the light duty utility arm (LDUA) and the Houdini remotely operated vehicle (ROV) to perform the Gunite and Associated Tanks (GAAT) treatability study. Two scarifier end effectors were evaluated: the sludge retrieval end effector (SREE) optimized for sludge retrieval and the gunite scarifying end effector (GSEE) optimized for scarification of gunite surfaces.

5.1.7 High-Pressure Scarifier

A high-pressure scarifier rated to remove 0.0009 m^3/s (2 ft^3/min) of waste was initially developed for dislodging and retrieval of single-shell tank waste. This system used high-pressure [379 MPa (55,000 psi)] jets to dislodge and air conveyance to retrieve waste. During evaluation the system performed well; however, site needs changed and a lightweight version of the scarifier rated to remove 0.0005 m^3/s (1 ft^3/min) of waste was designed and tested. No radioactive deployments have been identified for this system.

5.1.8 Flygt Mixers

Shrouded axial-propeller mixers have been deployed in Savannah River Site Tank 19 to mobilize sludge, zeolite, and salt that remain in the tank after a retrieval campaign conducted in the 1980s. The 37-kW (50-hp) mixers selected for use in Tank 19 have a propeller diameter of 51 cm (20 in.) and operate at 860 rotations per minute (rpm). The spinning propeller creates a turbulent fluid jet with an average exit velocity approaching 5.4 m/s (17.7 ft/s).

5.1.9 Technology Comparisons and Recommendations

To permit comparison between the technologies, their physical and operating characteristics have been summarized in Table 5.1. Items addressed include the operating principal, ability to dislodge waste forms, and other operating characteristics. The technologies are ordered by jet pressure from low to high pressure; the Flygt mixer is listed after the fluid-jet technologies. The results in this table also evaluate the ability of the system to operate using recycled supernatant to reduce water usage. If supernatant recycle is not considered, each technique will generate slurry at the device operating flow rate.

Four of these techniques: the Hanford tank C-106 sluicer, borehole miner, pulsating mixer pump and fluidic pulse-jet mixing, will readily fit through a 31-cm- (12-in.-) diameter riser. The borehole-miner extendible-nozzle can clean walls, embedded piping, and mobilize extremely hard waste throughout the tank. The arm extension of 3 m (10 ft), and its ability to move back and forth can be used to sweep waste from collection piles deposited by the mixer pump back into the mixer pump path or toward the retrieval pump inlet. The pulsating mixer pump and fluidic pulse-jet mixing can provide slurry mobilization; however they are not acceptable for wall cleaning.

Table 5.1 Comparison of the waste mobilization technologies

Criteria	Pulsed Air	Pulsating Mixer Pump	Fluidic Pulse-Jet Mixing	C-106 Sluicer	Borehole-Miner Extendible-Nozzle	Waste-Retrieval End Effector	High-Pressure Scarifier	Flygt Mixer	Mixer Pump
Technique	compressed air pulses	compressed air propels slurry jet	compressed air propels slurry jet	water or fluid jet	water or fluid jet	water jet	water jet	propeller creates a fluid jet	high-volume oscillatory fluid jets
Jet pressure	0.35 to 0.69 MPa (5 to 100 psi) air	0 to 0.69 MPa (0 to 100 psi)	0 to 0.69 MPa (0 to 100 psi)	to 2.07 MPa (300 psi)	0 to 20.7 MPa (0 to 3000 psi)	0 to 69 or 207 MPa (0 to 10,000 or 30,000 psi)	379 MPa (55,000 psi)		up to 2.8 MPa (400 psi)liquid
Flow rate	0.005 standard m^3/s (10 scfm) air per plate	tbd	tbd	0.022 m^3/s (350 gal/min)	0 to 0.0095 m^3/s (0 to 150 gal/min)	0.0063 m^3/s (10 gal/min) /jet	0.00038 m^3/s (6 gal/min) /jet	1.1 m^3/s (17,500 gal/min)	up to 0.315 m^3/s (5000 gal/min) /jet
Enhances dissolution	tbd	yes	yes	yes	yes	yes	yes	yes	yes
Mixes viscous liquids	yes	yes	yes	yes	yes	yes	yes	yes	yes
Mixes slurries	yes	yes	yes	yes	yes	yes	yes	yes	yes
Mobilizes settled solids	to some extent	to some extent	to some extent	to some extent	yes	yes	yes	to some extent	yes
Dislodges solid heels	no	no	no	perhaps	yes	yes	yes	no	if close to mixer pump
Power	7.5 to 15 kW (10 to 20 hp)	tbd	tbd	186 kW (250 hp)	149 kW (200 hp)	tbd	tbd	37 kW (50 hp)	224 kW (300 hp)

Criteria	Pulsed Air	Pulsating Mixer Pump	Fluidic Pulse-Jet Mixing	C-106 Sluicer	Borehole-Miner Extendible-Nozzle	Waste-Retrieval End Effector	High-Pressure Scarifier	Flygt Mixer	Mixer Pump
Operating limits	functions at all liquid levels, plates located <2.54 cm (1 in.) above the tank floor	functions at all liquid levels, nozzle located <15.2 cm (6 in.) from floor	functions at all liquid levels, nozzle located <15.2 cm (6 in.) from floor	functions at all liquid levels	functions at all liquid levels	functions at all liquid levels	functions at all liquid levels	functions when submerged. Mixer is 51 cm (20 in.) in diameter and was installed 20.5 cm (8 in.) above tank floor. Minimum fluid depth is 51 cm (20 in.)	~1.2 m (4 ft) head required for maximum power. Nozzle centerline ~0.3 to 0.46 m (1 to 1.5 ft) from tank bottom
Percent secondary waste generated using supernatant recycle	0%	0%	0%	0%	0%	0%	0.00038 m^3/s (6 gal/min) /jet	0%	>0% (some seal lubrication water added)
Deploy-ment	riser mast, system unfolds	riser mast	riser mast	riser mast	riser arm	arm or remote vehicle	arm or remote vehicle	riser mast, system unfolds	riser mast, system remains under riser
Remotely deployed	yes	yes	yes	yes	yes	yes	yes	yes	yes

Criteria	Pulsed Air	Pulsating Mixer Pump	Fluidic Pulse-Jet Mixing	C-106 Sluicer	Borehole-Miner Extendible-Nozzle	Waste-Retrieval End Effector	High-Pressure Scarifier	Flygt Mixer	Mixer Pump
Maintain-ability	compressor located outside the tank, plates submerged in waste	valves and compressor located outside tank	valves and compressor located outside tank	pump located outside of tank, pump may be contaminated based on source of fluid	pump located outside of tank, pump may be contaminated based on source of fluid	pump located outside of tank, arm or vehicle inside tank, pump may be contaminated based on source of fluid	pump located outside of tank arm or vehicle inside tank	entire mixer including motor is submerged	pump motor located above the tank riser, pump internals submerged in waste
Removal	system must be collapsed prior to removal	system removed through riser	system removed through riser	system removed through riser	system removed through riser	system removed through riser	system removed through riser	system must be collapsed prior to removal	system removed through riser

5.2 Instrumentation and Measurements

Quantifying the amount of solids removed from the tank is complicated because transport demonstrations using a clear pipe showed that significant amounts of air are present during start up transients. The air persists in the horizontal transfer line for periods greater than 30 min. Therefore, use of a coriolus type mass flow meter will be compromised. Staff at PNNL brainstormed with INEEL to offer alternatives that could provide a more reliable measure of quantification. Marsh McBirney provides a flowmeter used for measurement of open channel flow that may be applicable. In addition, the densimeter, developed by PNNL (Bamberger et al 2001) can be configured to measure the density of slurries. The sensor, embedded in the probe wall, interrogates the fluid that flows past it. By installing the sensor toward the bottom of the horizontal line, fluid properties can be measured even though the upper portion of the pipe contains air.

Radiation detection is another method for quantifying the amount of radioactive solids remaining in the tank and being transported from the tank. PNNL has developed a methodology for estimating the inventory based on sensors scans for West Valley Nuclear Services (O’Brien et al 2001).

In addition, the TFA developed tank mapping system can be used to estimate residual remaining in the tanks and the burnishing tool designed by ORNL for West Valley can be deployed to sample the tank walls and floor to determine residual contamination levels.

5.3 Recommendations

PNNL, Hanford, ORNL and other DOE sites have developed, demonstrated, and deployed a series of technologies that can be utilized by INEEL to either enhance their current plan for cleaning and remediating the WM tanks or to implement if currently selected technology is subjected to cleaning, dislodging, retrieval, and transport challenges more difficult than currently envisioned. These technologies include:

- More aggressive fluid-based techniques for wall cleaning, waste dislodging and mixing
- Additional instrumentation to further quantify the amount of waste retrieved and in-tank methods to measure radioactivity associated with slurry remaining in the tank
- Sampling techniques to measure residual contamination.

In addition implementation of methods to reduce water usage may reduce energy costs associated with evaporation

6.0 ORNL Retrieval Technology Development

Development of equipment for remediation of the Gunite and Associated Tanks (GAAT) and the Federal Facility Agreement (FFA) Remaining Tanks Project present the opposite ends of the spectrum for tank remediation. At GAAT equipment was developed specifically for the specialized dislodging and retrieval of the tanks. At the FFA existing equipment was modified for use in a series of difficult to retrieve tanks with varied access and waste loadings. These approaches are described below.

6.1 Gunite and Associated Tanks

The Gunite and Associated Tanks (GAAT) are a group of eight underground gunite storage tanks associated with two tank farms located in the center of the Oak Ridge National Laboratory (ORNL) main plant. Tanks W-3 and W-4 are in the North Tank Farm (NTF), and Tanks W-5 through W-10 are located in the South Tank Farm (STF). The first two tanks listed each have a capacity of 161 m^3 (42,500 gal.), while the STF tanks each have a capacity of 643 m^3 (170,000 gal.). These inactive tanks were built in the 1940s and were used as the main holding tanks for the Low Level Liquid Waste (LLLW) system at ORNL. The bulk of the waste was removed from the STF tanks in the 1980s using standard hydraulic sluicing techniques. However, this sluicing technique left behind a hard waste heel of up to 0.9 m (3 ft) in depth in each of these tanks; the NTF tanks were never sluiced at all. Radiation levels of up to 200 R/hr were associated with the waste material.

6.1.1 Waste Dislodging & Conveyance System

The remaining waste heel was removed from the gunite tanks in the late 1990s using a suite of complementary remote retrieval technologies (Burks et al 1997, Falter et al 1995, Killough et al 1996, USDOE 2001). The heart of the sludge removal system was the Waste Dislodging and Conveyance System (WD&C) (Lloyd et al 2001). The WD&C system addressed the need for removal of hazardous wastes from underground storage tanks in which radiation levels and access limitations made traditional waste retrieval methods impractical. The system was not a stand-alone unit; rather, it was designed for deployment with either a long-reach manipulator, known as the Modified Light Duty Utility Arm (MLDUA) or a remotely operated vehicle system call the Houdini™ (Falter et al 1999, Falter and Burks 1998, Slifko et al 1999, USDOE 1999).

The WD&C system was comprised of several different components including the confined sluicing end-effector (CSEE), hose management arm (HMA), jet pump, confinement box (CB), mast storage tube (MST), mast elevation table (MET), flow control equipment box (FCE), decontamination spray ring (DSR), and graphical user interface (GUI).

The CSEE was designed by Pacific Northwest National Laboratory, Oak Ridge National Laboratory, and Waterjet Technology Inc. (WTI) and built by WTI. The CSEE is a sluicing end effector equipped with three rotating cutting jets mounted 120 degrees apart. The jets, which are capable of delivering water at pressures of up to 69 MPa (10,000 psi), nearly converge at a point about 5 cm (2 in.) below the conveyance line intake on the end effector. As the jets rotate, hard waste is dislodged, vacuumed up through the center of the CSEE, and into a 5-cm- (2 in.-) ID hose under the motive force provided by a jet pump mounted upstream in the mast of the HMA.

The HMA was designed to act both as a pipeline for the transfer of dislodged waste, and as a hose-positioning system. ORNL and staff from The Providence Group (TPG) Applied Technologies designed the HMA to provide access to all points within a 15-m (50-ft) or smaller diameter tank. The arm has four degrees-of-freedom (DOF): mast vertical travel, mast rotation, shoulder pitch, and elbow yaw. The mast is constructed of a half section of 51-cm- (20-in.-) diameter, carbon steel pipe with a flat plate welded across the half section as a seal. The mast houses a variety of pipes and instrument cables, the CSEE and jet pump's motive water supply lines, the jet pump, and the waste conveyance line. The arm links of the HMA are constructed from Schedule 80 carbon steel pipe; the inner link is connected to the mast via an elbow swivel joint, while an in-line swivel between two 90-degree elbows connects the inner and outer links. A plate at the top of the mast interfaces with the MET. The MET provides support to the mast and is equipped with drive systems to control elevation and rotation of the HMA.

The CB provides secondary containment for the waste piping on the HMA and also allows access via gloveports for operational and maintenance activities on the HMA and CSEE. The MST contains a 1.5-ton hoist for retracting the HMA and is used to store the arm during relocation operations. The FCE is equipped with sluicing discharge piping, including valves for flow control, flushing, and automatic sampling of the waste being retrieved. Instrumentation in the FCE allows discharge flow rate and density to be measured as well.

The DSR contains a ring of spray nozzles that are used to wash down the HMA and CSEE as they are retracted from the tank. The DSR, designed by Southwest Research Institute (SRI), is located between the CB and the tank riser. The GUI links to the low level control systems of the CSEE, HMA, and FCE and to the associated valves, water supplies, and high-pressure pumps that form the Balance-of-Plant (BOP) for the WD&C system. The GUI allows an operator in the control room to monitor and control sluicing and decontamination activities.

Remediation plans for the GAAT project called for a thin layer of gunite to be scoured from the tank walls as a final step in the cleaning process. Initial testing with the CSEE indicated that an insufficient amount of gunite would be removed given the operating pressures available on that end-effector. Therefore, a second end-effector, known as the Gunite Scarifying End-Effector (GSEE) was designed and built to operate at pressures of up to 30 ksi. This scarifying tool was used to clean walls, but not to vacuum waste from the tanks (Fitzgerald et al 2001). Therefore, no HMA was required. Rather the GSEE was designed to be grasped by the MLDUA and deployed down the same riser as the long-reach arm. A portable tether handling system (THS) containing the GSEE was attached to a port on the containment structure for the MLDUA whenever sluicing operations were required. The THS was used to feed the GSEE tether in and out of the tank riser as the MLDUA maneuvered around the tank to clean the walls. High-pressure water was supplied to the end-effector by a separate ultrahigh-pressure water pump.

The WD&C system was most efficient at removing sludge when the waste material was deep enough to partially submerge the CSEE, thereby avoiding three-phase (solid, liquid, gas) pumping. When down to the last 2.5 to 7.6 cm (1 to 3 in.) of tank waste, the most productive method of operation was to use the

Houdini to collect and plow “waves” of waste to the end effector as it was held by the MLDUA. Generally, once sluicing operations were completed, wall scarifying was initiated. In tanks W-3 and W-4, the CSEE was used to scarify the tank walls at pressures of ~45 MPa (6500 psi). The GSEE was used in the remaining tanks once an ultrahigh pressure water pump became available. Although pressures of up to 36 ksi were possible with the new pump, the MLDUA was unable to handle the reaction forces at pressures of greater than 20 ksi.

6.1.2 Fluidic Pulse Jet and Flygt Mixers

Two systems were used to keep the solids suspended in the W-9 receiving tank until the material could be transferred to the Melton Valley Storage Tanks. The first technology was the AEA Fluidic Pulse Jet Mixer. This system used jet nozzles in the tank coupled to a charge vessel. A jet pump created a partial vacuum in the charge vessel, allowing it to be filled with waste. Then air pressure was applied to the charge vessel to force sludge back into the tank and mix it with the supernate. The second technology, known as the Flygt Mixer, was a submersible mixer technology designed specifically to mix large quantities of tank waste. The unit used an open propeller to move waste within the tank and was capable of mixing over 1.3 m^3/s (20,000 gal./min). This system was also used in lieu of the remote retrieval system in tank W-5. Two Flygt Mixer propellers were used to stir the waste before it was pumped out by conventional means.

6.2 Federal Facilities Agreement Remaining Tanks Project

The scope of the Federal Facilities Agreement (FFA) Remaining Tanks Project was to remove the contents from 14 out-of-service liquid low-level waste (LLLW) tanks located at the ORNL and to remediate by removal or grouting these 14 small diameter tanks along with an additional 3 tanks, which did not contain any sludge.

This work was performed under a fixed price subcontract, therefore, the amount of cold testing conducted and the level of technology implemented were much more limited than on the GAAT project. One other significant difference was that each of the remaining FFA tanks was unique—construction materials, interfaces, obstructions, sludge volume and constituents varied and each tank required a slightly different set-up for remediation. This necessitated the implementation of low-cost, portable, and modular equipment.

Activities on each tank are performed in two phases: Phase I includes preparation of all project control documentation including Job Hazard Analyses, Environmental, Safety & Health and Radiation Safety Plans, Safety Authorization Basis, training requirements and qualification matrices. A detailed work plan is also prepared to describe process flow equipment and the methodology to be used for removal of sludge from the tanks, stabilizing the tanks and secondary waste handling and disposition.

During this phase, detailed system designs and tank interface hardware are developed and fabricated based on tank "as-built” drawings as well as on-site walk-downs and interviews with those familiar with the tank history.

Phase II is mobilization. The Providence Group (TPG) is responsible for furnishing or procuring all labor, supplies and services needed to remove the sludge and remediate all 17 tanks. Once TPG has established and posted the site construction and Hazardous Waste Operations and Emergency Response (HAZWOPER) boundaries, mobilized equipment to the site and completed all interface connections, a video survey is normally completed to verify sludge volumes in the tank. Bulk sludge retrieval is performed using both low-pressure and high-pressure nozzles to mobilize the waste before it is removed from the tank using an air diaphragm pump.

Each tank is unique, and the TPG design and operating crews are often forced to redesign and implement field changes "on the fly" when initial inspections of the tank interior differ from archived "as-built" drawings. Flexibility, ingenuity, and in-house fabrication facilities are key to maintaining a smooth flow of operations. Cross-training both design and field crew team members in procurement, fabrication, qualification testing and operation of every component of the waste retrieval and grouting systems was extremely beneficial in ensuring that all team members understood the costs, risks and difficulties associated with field operations. The fact that everyone on the team had an opportunity to introduce and be a part of implementing innovations helped allow TPG to meet project milestones in the safest, most cost-effective and efficient manner possible.

Once waste was pumped out of the tank, the material was transferred to the active Low Level Liquid Waste System. The residual moisture in the tanks was mixed with dry Portland cement or an approved alternative. The tanks were then filled with a flowable fill and the permanent riser cover installed.

7.0 Lessons Learned from Deployments at ORNL

ORNL has completed successful remediations of waste in vertical and horizontal underground storage tanks by deploying a range of waste dislodging and retrieval techniques. Specific project lessons learned and operations lessons learned from these deployments are described.

7.1 General Project Lessons

Periodic reviews on each of the projects conducted at ORNL provided a valuable opportunity to review lessons learned and thereby improve operations. Although many administrative and operational improvements were made as a result of these reviews, only the design and operational issues are discussed in this document.

First and foremost, cold testing is extremely beneficial prior to any first-time field deployment. Not only does this initial testing in a clean environment allow any significant design flaws to be identified and reworked before contamination controls become a significant issue, but it also provides valuable training for the operators and craft personnel by providing them with an opportunity to become familiar with the equipment from the inside out. In addition, integrated cold testing allows development of procedures that reflect how operations are actually conducted and allows multiple operators to receive training under low-pressure conditions rather than "on the front lines". Finally, cold testing can provide important opportunities to demonstrate readiness as part of a phased readiness review process.

Waste storage tanks are generally difficult to fully characterize prior to deployments; therefore, retrieval operations require a significant amount of flexibility and contingency plans for the unexpected. On the FFA project, in particular, a lack of "as-built" drawings and limited sampling resulted in tank risers being several inches to several feet longer or shorter than expected, undocumented obstructions, such as float systems and cooling coils, and occasionally, radiological conditions that were different from historical samples and surveys. The ability to reconfigure the sluicing system "on the fly" kept the job progressing successfully.

Using redundant or at least complementary systems whenever possible can result in significant cost savings and minimize downtime. Both the MLDUA and the Houdini were capable of deploying the sluicing end effector. When one system was down for repair, waste removal operations continued using the other deployment platform. The high-pressure pumps used for the CSEE cutting jets and jet pump were identical. This minimized the critical spare parts that had to be kept on hand, made system operations and repairs easier, and allowed either scarifying or supernate removal to continue by temporarily switching between the pump requiring maintenance and the working pump. Using the same type of overview cameras throughout also afforded a considerable degree of flexibility.

7.2 Equipment Lessons Learned

Equipment lessons learned are presented related to system design, grouting system design and operation, vision systems, containment, maintenance, and operations.

7.2.1 System Design

When designing a waste retrieval system, considerable effort must be made to differentiate between "want" and "must have" design elements. Allow all stakeholders in the retrieval project [i.e., regulatory, operations, and craft personnel; National Electric Code (NEC), American Society of Mechanical Engineers (ASME) and radiological control code inspectors, etc.] to provide input during the design phase, but ensure that features and constraints incorporated into the system are appropriate for the time, conditions and regulatory requirements of the project.

Freeze protection should be provided for any water-based systems during cold weather, but should be disabled when the weather warms. This may sound obvious, but a failure to disable freeze protection was the root cause of steam build-up in a line and the subsequent minor explosion. Operating shifts must also be considered and sufficient lighting provided to illuminate the equipment area if night operations are a possibility.

Wherever watertight seals are needed, a hard rubber seal should be used. Hard rubber retains its flexibility and resists absorbing liquid contaminants better than foam textured sealing materials. Decontamination, in general, needs to be considered for every aspect of the equipment. Sharp edges or catch points should be minimized on all in-tank equipment. Audio feedback of in-tank operations should be available to equipment operators to provide an indication of sluicing performance, equipment failures, and interferences encountered during deployments or retractions.

The tank vacuum or high-efficiency particulate air (HEPA) filter system needs a damper so that negative pressure can be adjusted when necessary for equipment installations and maintenance activities (particularly for bagging parts or tools in or out of the containment structures). Operators have enough to worry about without having their pieces and parts unexpectedly sucked into the void. Operations that generate excessive mist in the tank can cause high humidity or mist to build up on and clog the HEPA filter, preventing adequate flow. To alleviate this moisture problem, drain lines to the tank should be installed in the bottom of the duct leading to the HEPA unit. The moisture will condense in the duct and drain back into the tank, thus extending the life of the filter.

The control system should discriminate carefully between key alarms and warnings and potential nuisance messages. Not every off-normal condition needs to trigger a barrage of verbal complaints or warning bells that the operator can't escape or legally disable. A primary example from the WD&C system GUI was the "low tank vacuum warning". Designed to warn the operator in the event of a HEPA failure on the slurry receiving tank, the warning retriggered and a bell pinged every thirty seconds during operations whenever the pulse air mixer was blowing bubbles to help keep the tank solids suspended. Although the initial warning was appreciated, investigated and found not to be a containment threat, the almost constant warning bell was an unnecessary distraction for the operators and may even have qualified as cruel and inhumane treatment.

Field check all critical dimensions before installing equipment at the site. Discovering that a tank interface is not quite as depicted on a drawing from the 1950s is much more difficult to recover from if the discrepancy is not detected until the equipment is suspended from a crane over the riser.

Once the system has been installed at the deployment site, have a knowledgeable person (preferably one who is unfamiliar with the system) walk down the as-built drawings prior to the start of operations. Verify that all changes to the system have been captured on the drawings and documented in Engineering Change Notices (ECNs).

7.2.2 Grouting System Design and Operation

Airspace should be maintained between the end of the fill hose and the tank whenever a contaminated tank is being filled with grout. Upon completion of operations, the end of the grout hose should be removed from the tank prior to “blowing down” the grout hose. Blowing down the hose involves using air pressure to force a sponge through the fill hose in order to clean any residual grout from the interior walls. Removing the end of the hose from the tank avoids over pressurizing the tank HEPA system when the sponge is blown out of the end of the hose. On the FFA project, both of these items were addressed through the use of an Intermediate Grout Addition Tank (IGAT). The grout fill hose is secured to an opening in the lid of the IGAT, and grout is allowed to flow into the container. From there, the material gravity-drains to the underground storage tank. A valve on the bottom of the IGAT allows the grout flow into the underground storage tank (UST) to be carefully controlled once the fill level nears the top. The valve on the IGAT is shut during the blow-down, but once complete, the valve can be reopened so that material forced into the IGAT can be used to top off the tank.

7.2.3 Operations

Prepare procedures that are as complete as necessary to address all safety issues, but as general as possible to provide flexibility in dealing with unknown situations.

Designate one point of contact to interface with craft and coordinate craft activities on-site to avoid confusion over priorities and assignments. Minimize nonessential personnel in the control room to avoid distracting the operators. Not all tours can be avoided but either try to schedule them away from critical or first-time operations, or set up a separate view of the operations in another room.

Expect visibility to be limited by aerosol spray during operations when using spray jets that are not submerged. Automating the planned cleaning paths so that operators can “fly blind” will make the most efficient use of this time.

Wash the gloves in the containment structure frequently with detergent and water. Aside from the radiological benefits, this will remove stickiness from any hydraulic fluids or tape adhesive.

Use valves to isolate pumps or other components when not in use to prevent backflow of contaminated liquid.

7.2.4 Vision Systems

Cameras are critical to the success of any remote operations. Sufficient lighting, multiple views, radiation hardness and modularity were the main issues of concern on the GAAT project. Multiple risers were available for the cameras, which had to be waterproof and rad-hard for extended stays in a moist tank environment. High wattage (250 Watt) lighting was required for the 15-m- (50-ft-) diameter tanks, and this resulted in some problems with overheating of the cameras. Overheating was addressed by the addition of high-temperature plastic shielding. For the FFA project, versatility, size and cost-effectiveness were the key to camera operations. Sometimes, only one small riser [only 7.6 or 15 cm (3 or 6 in.) in diameter] was available for installation of all sluicing, grouting and inspection equipment. One "expensive" camera with integral lighting, pan/tilt and zoom was purchased for regulatory inspections. This camera was used sparingly as no comparable backup was available. Inexpensive infrared and color cameras (<$200) were often mounted on extendible poles for inspections during messy sluicing and grouting operations. Fluorescent lighting was used to illuminate the tanks when the disposable color camera was used.

The use of reflective tape and/or contrasting colors on the equipment made it easier for the operators to determine the location and configuration of the systems even in misty, dark conditions. The ability to spray down or otherwise clean the in-tank cameras without retracting them was also a key to more efficient operations.

7.2.5 Containment and Maintenance

Containment structures must be built with equipment maintenance needs and operator ergonomics kept in mind. Sufficient space should be available to stow and stabilize equipment in the containment structure. A large bag-in/bag-out port or double-door transfer chamber should be made available for sending parts and special tools in during maintenance activities. Commonly needed tools should be available inside the structure in a bin or hung from retractable lanyards. Cameras and a microphone installed inside the containment structure provide valuable feedback to control room personnel, allowing them to ensure that field operators or maintenance personnel are clear of the equipment during any necessary repositioning or checkout operations. Glove port positions should allow operators to work without crouching, and should allow easy access to all storage locations, equipment and tools inside the containment structure. A lifting device should be made available for any lifting required over 89 N (20 lbf).

Equipment should be as modular as possible, allowing maintenance personnel to quickly replace subassemblies rather than trying to disassemble tiny pieces and parts while wearing gloves. Critical spares should be identified long before the field deployment, kept on site, and reordered in a timely manner. Camera and pump parts should be included as well as fasteners, special tools and diagnostic equipment.

7.3 Recommendations

All of the items described under lessons learned should be considered at the start of a remediation and implemented as required. Especially pertinent items are summarized in the list of recommendations that follows.

- Verify critical interfaces and tank dimensions prior to equipment construction
- Design equipment to be interchangeable, modular or complementary to reduce down time for repairs
- Plan and conduct cold tests prior to first time deployments to identify the validity of the procedure and to train operations staff.

- Enhance camera vision by using reflective tape and/or contrasting colors to enhance camera visibility during misty and/or dark conditions.

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