PRELIMINARY LESSONS LEARNED FROM THE GUNITE AND ASSOCIATED TANKS (GAAT) REMEDIATION PROJECT AT OAK RIDGE NATIONAL LABORATORY

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ABSTRACT

The Gunite and Associated Tanks (GAAT) Remediation Project is being conducted at Oak Ridge National Laboratory (ORNL) and has been noted as one of the most highly successful tank remediation projects conducted within the U.S. Department of Energy. The GAAT Remediation Project has successfully integrated robotic, remotely operated, and other equipment, and several contractors to achieve measurable results. With the project under cost and ahead of schedule and tank waste removal activities on track for a September 2000 completion, the GAAT team has begun the effort to capture the lessons learned from this extremely successful project. This paper is a preliminary compilation of the lessons learned during the project, with a complete compilation scheduled for the end of the project.

PROJECT HISTORY

The Gunite and Associated Tanks (GAAT) Remediation Project at Oak Ridge National Laboratory (ORNL) was initiated in 1992 under the Federal Facility Agreement (FFA) between the U.S. Department of Energy (DOE), U.S. Environmental Protection Agency-Region IV (EPA), and the Tennessee Department of Environment and Conservation (TDEC). Under the FFA, a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Remedial Investigation/Feasibility Study (RI/FS) document was to be issued to the EPA and TDEC for review by May 1994. In April 1994 the DOE, the EPA, and TDEC agreed that a CERCLA Treatability Study was required to resolve significant technical and cost uncertainties associated with the remedial alternatives defined in the RI/FS. The RI/FS identified the primary selected alternative as remote tank cleaning due to the high levels of radiation found in the tank waste and the associated risks.

The GAAT Remediation Project conducted the CERCLA Treatability Study to reduce uncertainties in the potential cost and effectiveness of remote tank cleaning equipment using equipment produced jointly with the DOE Tanks Focus Area and the Robotics Program. In the fall of 1996, the GAAT team began "cold tests" of the equipment at the ORNL Tanks Technology Cold Test Facility. The purpose of the cold testing was to take the equipment, operators, and procedures through an initial shakedown prior to the equipment becoming contaminated. Following the completion of the cold tests, the equipment was moved to the ORNL North Tank Farm for use in tanks W-3 and W-4 in the spring of 1997. This move signaled the beginning of the "hot tests" of the Treatability Study. These tanks were selected for the hot tests based on their lower hazard levels compared to the remainder of the gunite tanks. This was also in keeping with the GAAT team's strategy of progressing from lower to higher risk situations to maximize the experience of the operation and maintenance personnel.

Upon completion of the hot tests in early1998, the GAAT team moved the tank cleaning equipment to the South Tank Farm (STF) for waste removal operations in the higher risk tanks (W-5, W-6, W-7, W-8, W-9, and W-10). This move signaled the end of the Treatability Study and the beginning of the Interim Record of Decision that called for waste removal from the tanks located in the South Tank Farm.

CURRENT ACTIONS

STF waste removal operations have successfully cleaned tanks W-5, -6, -7, -8, and -10 and transferred most of the material out of the STF. The Tennessee Department of Environment and Conservation (TDEC) and Environmental Protection Agency (EPA) regulators have approved completion of waste removal operations in these tanks and transfer of sludge removal systems to tank W-9.

FACILITY DESCRIPTION

The GAAT Project consists of eight (8) inactive liquid low level waste (LLLW) storage tanks and associated equipment (piping, valve boxes, pump pits, HEPA filters, etc.) located within or near the North and South Tank Farms in the main plant area of the Oak Ridge National Laboratory (ORNL). Figure 1 shows the location of the site relative to Central Avenue in what is known as “downtown” ORNL. Tanks W-3 and W-4 in the NTF have a capacity of 42,500 gallons, while the STF tanks (W-5 through W-10) have a capacity of 170,000 gallons each.

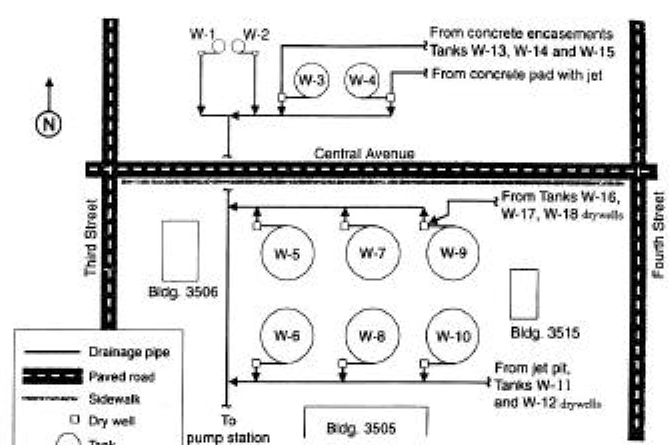

Figure 1

Prior to waste removal operations, the GAAT tanks generally contained supernate liquid, a layer of sludge at the bottom, various forms of solid debris and equipment, and contaminated Gunite in the walls and floors. Supernate volumes varied from unmeasurable in some tanks to levels approaching the operating capacity in others. Sludge residuals varied from 8 inches to several feet deep.

Data generated in support of the remedial investigation (RI) and during early phases of the treatability study (TS) identified various chemical and radionuclide contaminants. Based on laboratory analysis, many of the tanks contained material that exhibited characteristics of hazardous waste as defined and regulated under the Resource Conservation and Recovery Act (RCRA). Since the tanks also contained radioactive materials regulated under the Atomic Energy Act, the waste was classified as a mixed or mixed-transuranic waste.

The North and South Tank Farms are located near the center of the heavily developed industrial, laboratory, and office complex of ORNL. The project was, therefore, limited primarily to use of the tank farm areas on either side of Central Avenue, between Third Street to the East and Fourth Street to the West. Portions of these streets, plus a small lay-down area with lower background radiation levels located directly south of Building 3515, were utilized for certain project activities. An existing building located in the southeast corner of the STF was upgraded to serve as an on-site maintenance and operations facility. An existing prefabricated structure obtained from the Waste Evaporator Facility Decommissioning and Decontamination Project is located at the Northwest corner of the site and used as storage for both uncontaminated and potentially contaminated equipment, supplies, and tools.

ORNL plant utilities (electricity, water, etc.) were available at multiple locations near the project area. Other than utilities, the major interface with ORNL facilities was the active LLLW system. Valve Box 2, located along Central Avenue in the STF, had an existing liquid waste receiving station that was utilized for the transfer of liquid waste from the GAAT tanks. The W-6 Valve Box is located in the southwest corner of the STF and was used as a pipeline interface for both liquid and slurry waste.

DISCUSSION OF ACTIVITIES

The equipment used to conduct the treatability study and the ultimate remediation consisted of a remotely controlled robotic arm known as the Modified Light Duty Utility Arm (MLDUA), a remotely controlled tracked vehicle known as Houdini™, and a Waste Dislodging and Conveyance (WD&C) System that included a Confined Sluicing End-Effector (CSEE), Gunite Scarifying End-Effector (GSEE), and sampling system. Using a technique known as confined sluicing which uses high pressure, low volume water jets integrated with a jet pump, the MLDUA can position the CSEE for sludge removal while Houdini™ plows sludge to the end-effector. The MLDUA can also use preprogrammed paths to clean the tank walls with the CSEE. Houdini™ can also grasp the CSEE and operate independently for sludge removal.

Operating in concert the equipment transferred the sludge as slurry out of the operating tank to tank W-9, which was used as a consolidation tank. In the consolidation tank PulsAir Mixers and a Flygt Mixer were used to mix the consolidated sludge to achieve a slurry that was then pumped using a

DiscFlo pump through the Sludge Conditioning System (SCS) and Slurry Monitor Test Loop (SMTL) to the Melton Valley Storage Tanks (MVST). The SCS consisted of two filters in parallel, three automatic sample points, and space for the future inclusion of a grinder. The SMTL consisted of an automatic sampler, a Lasentec particle size analyzer, a Coriolis flow meter, and an online suspended solids analyzer.

DRAFT LESSONS LEARNED

Incorporating As Low As Reasonably Achievable (ALARA) Contamination Practices

Proven Successes

1. Cold testing prior to operations significantly reduced the radiation exposure. Cold testing was performed in a radiologically clean test facility. This enabled the operators to become familiar with the equipment and procedures, which enhanced their system knowledge and resulted in decreased exposure time during maintenance and operations when hot operations began. Cold testing also allowed operators and craft to develop specialized tools, techniques, and instructions that also decreased their exposure during hot operations.
2. Water was used to fill the tank and cover the sludge, or residual sludge where the tank had been cleaned, to provide shielding and reduce the radiation field.
3. The waste slurry transfer line was shielded at the location where operators worked using lead blankets to reduce the radiation field.
4. Work instructions and pre-job briefings were required before all work was performed to ensure that project and craft personnel had a clear understanding of the task and had the necessary tools prior to entering the radiological areas.
5. Access to radiological areas was limited to only the required personnel.
6. Maintenance procedures were developed and performed with the consideration that the equipment was being used to remove radioactive material and that exposure levels should be kept to a minimum. Using remotely operated equipment to reduce radiation exposure is of limited benefit if maintaining the equipment requires workers to receive high doses.
7. An effort was made to spread the radiation exposure evenly among the operations crew to prevent personnel from receiving higher than necessary exposures.
8. Some activities inside the tank (i.e., wall washing) caused excessive water mist. This mist would build up in the HEPA filter and clog the filter, which prevented adequate flow. This moisture problem was alleviated by drain lines installed in the bottom of the duct leading to the HEPA unit. The moisture would condense in the duct and drain back into the tank, thus extending the life of the HEPA filter and reducing exposure.
9. If full dress-out with a respirator is required in containment structures during hot summer months, plan work early in the morning to prevent errors caused by fatigue and heat stress.
10. Get Health Physics personnel involved early in the design phase of equipment to voice concerns such as containment of equipment when removed from the tank; hoisting and rigging contaminated equipment; washing the equipment before removal; dismantling and sizing the equipment for disposal; packaging for reuse (i.e., stands, cribbing).
11. To reduce radiological waste, consider using personal protective equipment (PPE) that can be washed and reused when not working in areas of high contamination.
12. Do not use cloth or paper shoe covers when walking on wet surfaces in a contaminated area.
13. If working in an area where there is a good chance of encountering contaminated liquid, do not use cloth or Tyvek (paper) PPE.
14. Add absorbent material in the bottom of equipment containment structures when removing equipment from the tank for any period of time. Apply another layer of secondary containment around the bottom of each break. Closed containment systems will have moisture condense and pose a contamination problem when moved.
15. Have plenty of shielding blankets on hand for frisking booths, shielding pipe, etc.
16. If practical, consider laying sheet metal covered with heavy plastic on the platform around equipment. This will help the Radiological Health Physics technician identify contamination problems in the work area.

Future Opportunities

1. Communicate upcoming system changes that may affect radiation fields to all operators in the field before they occur. The GAAT team maintained good group communications. However, in limited instances, changes were communicated as they happened, which did not allow time for operators to move prior to minor changes in exposure level.

Maintenance/Containment

Proven Successes

1. Tool bins, pass-through ports, bag-in/bag-out ports, decontamination spray wands, and other tools that were grasped were placed within easy reach of gloveport locations (about 16 inches axial displacement and 6 inches radial displacement).
2. A preventive maintenance schedule was developed for all systems. Preventive maintenance was scheduled to coincide with the moves between the tanks. This limited

the downtime during operations and identified any components that required replacement prior to failure.

3. Where possible, transparent panels were used to facilitate viewing equipment internals without breaking containment.
4. Gloveports were added to facilitate minor maintenance or repairs without breaking containment. These were typically special purpose gloveports separate from the gloveports used during routine operations and maintenance, and therefore some were in locations that were ergonomically less than optimal.
5. Tether reels have a tendency to foul if tethers get crossed over or unwanted slack develops. Provide a view and gloveport access for tether reels whenever possible to aid in maintenance.
6. Enclosures with lexan panels can build up high heat from solar loading. These panels were covered whenever possible, with a removable reflective cover, to reduce solar heating.
7. Clear plastic equipment boots were used to protect equipment and facilitate viewing of the equipment during waste removal operations.
8. When inserting or removing larger items, the team used a large bag-in/bag-out port to facilitate transfers. Operations should be planned so that the bag-in/bag-out of large items is an infrequent requirement. Avoid single-door approaches when transferring equipment in or out of containment, because of the difficulty in controlling contamination spread. Door openings should be reserved for infrequent operations, such as periodic major system maintenance.
9. Where maintenance and repairs were performed in containment structures, a means of stabilizing the equipment in place was provided. Workers had both hands free to manipulate tools rather than using one hand to hold a piece of equipment in place.
10. The use of tape, hose clamps, and tie wraps for securing hoses and cables was minimized. Use of hose clamps and tie wraps results in localized rub or wear points that cut hoses and cables.
11. Wherever watertight seals were needed, a hard rubber seal was used that retained flexibility and resisted absorbing liquid contaminants better than the foam textured sealing materials. This requires use of rigid panel frame designs.
12. Operating scenarios that require workers to lift more than 20 pounds while using gloveports were avoided. A hoist in the containment structure was used for heavier lifts.
13. Use of any materials with sharp edges/burrs that would potentially tear gloves, damage equipment, or become a sludge trap was avoided.
14. Gloves made of materials compatible with the tank contents and other known items that the gloves would come in contact with, especially oils, solvents, and lubricants, were used.
15. Hoses and cables were consolidated into bundles and secured within 6 to 12 inches of termination points and periodically elsewhere to prevent occurrence of unwanted slack that could catch on something and potentially damage a cable or hose.
16. A safety chain was provided so that workers were not required to place their hands under a suspended load.
17. A method of adjusting tank vacuum was used. At times, such as bag-in/bag-out operations, a strong vacuum pulled bags into the tank making the operator’s task more difficult unless the vacuum was adjusted.
18. Tape for sealing gloves, bags, boots, etc. was kept warm during cold temperatures.

Future Opportunities

1. Design tether reels and stow positions so that the major pieces of equipment inside containment can be positioned near standing gloveports for maintenance and routine operations, i.e., let the ergonomics of gloveport location drive equipment positioning for gloveport operations rather than having equipment stow position determine gloveport location. If necessary, some gloveports can be placed at heights that dictate use of a kneeling position, but avoid heights that dictate use of a crouching position.
2. Pass-through ports and bag-in/bag-out ports should be accompanied by a sliding table that can move transferred items from the edge of the port to within easy reach of gloveports.
3. Design equipment for subassembly replacement instead of repair in order to reduce time spent working in a radiological exposure field.
4. Design for reliability. Cheap parts and less than quality workmanship cost many times more in the long run than quality.

Modified Light Duty Utility Arm (MLDUA)

Proven Successes

1. The MLDUA was ideal for scarifying the tank walls since the scarifying paths could be preprogrammed. Wall scarifying generated a mist in the tanks, which reduced visibility to near-zero, so the ability to preprogram the MLDUA to maintain an even standoff distance from the walls increases safety during this operation
2. The Gripper End Effector (GEE), original handling equipment supplied with the Tank Riser Interface Confinement (TRIC), was replaced during the equipment cold tests with a system that reduced the amount of time containment was breached, thus addressing some operator safety concerns. A cart that travels on the TRIC floor was used in the removal/attachment of the GEE.
3. A small hydraulic pump, with a motor and controls, was installed to supply hydraulic pressure to the GEE gripper. Before this change, the MLDUA computers and main

hydraulic pump had to operate continuously to maintain a hold with the GEE gripper. After the change, the GEE could hold equipment (e.g., CSEE) overnight in its gripper, while the rest of the MLDUA system was shut down. This change saved many hours of unnecessary operations of the MLDUA system when grasping the CSEE and other tools.

Future Opportunities

1. Limit the number of robotic/computer-controlled actions to those only requiring such precision/control to increase flexibility and reduce cost. MLDUA operations that should have been controlled manually include the Mobile Deployment System (MDS) X, Y, and Roll adjustment; Vertical Positioning Mast (VPM) Housing gate valve operations; raising and lowering the VPM Housing; and MDS outrigger operations.
2. Locate routine maintenance equipment within the VPM housing for ease of maintenance. Consider placing the VPM Housing angle and purge pressure sensors along with the lubrication oil drain and fill ports for the VPM Tube winches outside the contaminated VPM Housing. The umbilical tethers should have been mounted in cable carriers than could take the strain of tether motion and tension rather that placing the signal carrying cables under tension.
3. Make the GEE gripper controls position adjustable instead of just open or close operations.
4. Plan display screens carefully to provide needed control information in a single area. The MLDUA Human Machine Interface (HMI) information was spread across many HMI displays.
5. Provide a method to prevent the same warning from producing a continuing warning alert until the warning condition clears.
6. Install a winch inside the TRIC with a 150-pound capacity.
7. The GEE camera was contained inside the gripper; suggest increased accessibility.

HoudiniÔ Remotely Operated Vehicle

Proven Successes

1. The Houdini™ remotely operated vehicle and the MLDUA worked well together. Sluicing operations were most efficient when the plow on Houdini™ pushed sludge toward the MLDUA. The MLDUA worked best for bulk sludge retrieval and wall cleaning, while the Houdini™ was better at plowing the residual sludge (< 8 in.) to the CSEE while it was held by the MLDUA.
2. Shell Tellus 32, a mineral-oil-based fluid, replaced a water/glycol fluid initially used for the hydraulic system. The water/glycol fluid was found to cause an inordinate number of failures in the valves located on the vehicle and in the TMADS. The electrically conductive water/glycol fluid also caused electrical short circuits on the manipulator when a failed servo valve allowed the fluid to flood the arm's housing.
3. The Schilling Titan-II manipulator arm was replaced with a Titan-III arm with a housing that was sealed at the shoulder. The housing on the original Titan-II was open at the shoulder and allowed handfuls of sludge to collect inside the arm during mock retrieval and decontamination operations. These pockets of sludge could be removed only by disassembling the arm.
4. The electrical cables that were damaged on Houdini I during deployments and retractions were difficult to change. These cables had to be spliced and soldered inside the TMADS to be replaced. The new tether design on Houdini II had the connectors installed in the vehicle termination, which proved to be field-serviceable and did not require re-soldering in the field.
5. Caution was used when driving the Houdini™ or manipulating the Schilling manipulator arm. Administrative controls in the form of slower travel speeds were employed to prevent collisions between the Houdini™/CSEE/other tools and objects within the tank, including the tank wall.
6. Vehicle vibrations produced by the lugs on the tracks produced more vibrations than anticipated. Locking bolts and other fasteners failed the conventional locking methods. Nord-loc lock washers proved to be successful at eliminating the loosening effects of the vibrations.
7. Changing the center of gravity of the vehicle to hang straight during deployments and retractions reduced riser interference and self-inflicted damage to the vehicle.
8. The new tether design with the connectors installed in the vehicle termination end proved to be field-serviceable by eliminating the need for field-soldering repaired electrical connections.
9. The current design of the Houdini™ Tether Management and Deployment System (TMADS) although improved over Houdini™ I design, still offers limitations and inherent problems with the system ergonomics. The maintenance doors on the TMADS had full-length hinges that did not seal very well. New doors with positive compressive seals were used, and all full-length hinges were removed. The maintenance door side was reduced in size and hinged along the bottom edge to create a ramp to facilitate vehicle removal.
10. Design the vehicle to limit connector and hose stress during folding for deployment and retraction of the vehicle. Many of the connectors were subject to damage or loosening when the vehicle was folded. The most common failure point was at the elbow fittings to the track drive manifolds. It was also during these operations that the hoses sometimes pinched. Project fixes on the original system were limited to controlling hose routing with wire ties, daily inspections of all hoses, and weekly tightening of all connectors.

11. Redesign camera attachment. Mounting screws on the body camera loosened frequently even when a thread-locking compound was applied.

Future Opportunities

1. Although the maintenance tent was an extremely helpful tool for the Houdini™ maintenance, it was also cost and schedule prohibitive at times. The maintenance tent and major systems could be designed for quicker connection and disconnection.
2. Maintaining tolerable working conditions in the maintenance tent during the summer months proved to be challenging. Heat loading from the sun during the summer made the containment area of the tent very uncomfortable and introduced heat stress limitations that affected the duration of the work activities.

Waste Transfer System

Proven Successes

1. The nozzles of the CSEE were kept submerged whenever possible while using the cutting jets to minimize creating aerosol and splattering of waste.
2. Minimal water flow was maintained through the cutting jets any time the end-effector nozzles were submerged to prevent clogging of the nozzles.
3. Three PulsAir mixers were installed in the consolidation tank (W-9) to suspend the waste to be transferred out of the tank farm. Observations indicated the PulsAir should be operated continuously to improve results. The best results were achieved when the system was operated during waste consolidation and transfers completed near the end of consolidation (i.e., maintain waste in suspension versus resuspending settled solids).
4. Two Flygt mixers were added to tank W5 as an alternative to the full remote robotic system. The mixers were successful in cleaning this tank, saving two to four relocations of the MLDUA, Houdini™, and associated equipment. A single Flygt mixer was used as an additional mixing aid in the consolidation tank with some measurable success.
5. The Sludge Conditioning System was designed to include a grinder that was never installed. This connection was later identified as the best possible location for an additional transfer system pump. Reuse of the existing connection enhanced installation of the pump.
6. Hardened alloy blades were initially installed on the Flygt Mixers based on expected operating conditions. During operation, two blades broke: one during installation and the other by in-tank debris. The blades were replaced with stainless steel props with no further problems.
7. The DiscFlo pump motor controller, when placed in a weatherproof enclosure, was subject to its own heat generation and solar heating on the enclosure. A separate air conditioning unit was installed to reduce the heat load on the motor controller.

Future Opportunities

1. Locate equipment control panels away from present and anticipated future radiation fields and equipment interference. The PulsAir and Flygt mixer panels on the consolidation tank became more difficult to use after structures for robotic equipment were relocated over them.
2. Include carrier fluid density measurements to improve information from the Slurry Monitor Test Loop. The suspended solids concentration in the slurries was reasonably estimated from the slurry density measurement obtained with the in-line Coriolis meter; however, the suspended solids concentration measurement could be improved by also simultaneously monitoring the density of the carrier fluid.
3. Facilities with floor grating should include an access to the sump to aid in removal of items that fall into the sump.
4. The classifiers/filters located in the Sludge Conditioning System were installed to ensure that the slurry particle size was less than 100μm. The frequency at which the filters needed back flushing indicated blinding of the filter by particles less than 100μm, which reduced the efficiency of the transfers. The classifiers eventually had to be bypassed and the particle size determined by sampling.
5. The air volume allowed for operation of the PulsAir mixers was limited to prevent requiring the tank off-gas system being designated a safety-related system. Trade-off between greater flexibility in mixing and expensive off-gas system upgrades is an area for further study.

Remote Cameras

Proven Successes

1. One 250-watt light bulb was attached to each camera to provide better lighting (although a mirrored reflector shield would have been better than polished aluminum). The factory standard two 35-watt lights initially used were not sufficient lighting for the tanks.
2. A heat shield was inserted between the light and the camera because the 250-watt bulb provided more light but it also caused a heat problem. Initially, the heat shield was aluminum with fiberglass taped around it, but due to continued camera problems, this was replaced with a high temperature plastic shield.
3. The camera systems came with a pole that was in 6-foot sections. This allowed for a fixed position of the camera with an adjustable depth in the tank. A separate camera cable was factory-installed inside the camera pole for convenience and contamination control. A waterproof box with a connector was attached at the top of the camera pole so the main camera cable could be connected without going inside the tank. This worked well but a plastic bag covering

the top of the pole and riser was still necessary to keep water out of the box and vinyl boot inside the tank.

4. A 2" to 3" rubber PVC pipe coupler was hose-clamped to the pole above the camera head. The coupler was used as a securing point for a vinyl boot. The vinyl boot was taped at the coupler and at the top edge of the aluminum adapter to keep contamination from getting on the pole. When a camera was removed from the tank, the boot was peeled inside out and the excess cut off. A new boot and coupler were taped on before the camera was placed back into the tank. This worked well.
5. A glovebox with all necessary tools was provided for camera repairs along with a designated maintenance area. These proved essential for efficient operation.
6. During operations that generate a fog/mist, visibility is limited but can be improved by using indirect lighting.

Future Opportunities

1. Provide at least two camera views and lights for any in-tank task.
2. Cool cameras with internal purges, internal fans, heat shields, or other means to dissipate heat from high wattage lights. When cameras are not in use, turn off or reduce the lighting.
3. Use paint colors for equipment that provide high visibility and good contrast between the equipment and tank environment.
4. Provide lights and cameras inside containment structures to monitor critical operations or equipment components. For example, a camera in the containment structure could provide visual feedback if a leak was to occur in the waste transfer line.
5. Use cameras for monitoring the inside tank operations that are easy to replace and inexpensive. The performance of cameras used inside the GAAT tanks for operations suffered cumulative damage from overheating and radiation exposure resulting in frequent replacements.

Leak Detection

Proven Successes

1. Internal tank liquid level data and external dry well groundwater conductivity data were successfully used to evaluate the integrity of the tanks.
2. The internal and external methods determined that the tanks were not leaking and were able to identify potential liquid releases at a threshold of 0.5 gallons/hr.
3. Use of the external dry well monitoring proved to be a robust and cost-effective technique that allowed the use of the tanks for temporary transfer and storage operations and helped shorten the schedule and reduce overall project costs.

Overall Lessons Learned

Proven Successes

1. The GAAT team approach of moving from low risk to high risk activities (i.e., cold testing to hot testing to hot operations) had many significant benefits:
   - Modifications/repairs to equipment identified during development, and performed during cold testing, resulted in lower employee exposure and project cost.
   - The move from lower to higher risk activities provided a firm basis of experience for successively more rigorous operational readiness evaluations.
   - The move from lower to higher risk activities lowered the overall risk to employees and the environment with a “ learn as you progress approach” by allowing procedures, equipment, and the project experience to mature before higher risk activities were undertaken.
2. Significant efforts were required early in the project and through out to ensure that all stakeholders (DOE, regulators, public, and ORNL employees) were in agreement with project plans. Early involvement and successful interaction through public meetings, documentary videos, and presentations, etc. created a sense of "ownership" and understanding for everyone involved with the project. This paid huge dividends during the higher cost operations portion of the project by avoiding changes in direction/scope and impacts from co-located employee environmental safety and health concerns.
3. Developing detailed cost and schedule baselines early in the project was challenging (cost, accuracy of information, etc.) but crucial to tracking project progress.
4. This complex, lengthy project was approached as a “marathon” race not a “sprint.” It is easy for project personnel to become physically/mentally rundown under long-term high stress situations, potentially compromising safety. In addition, high stress situations result in significant employee turnover that could be costly when highly skilled employees are involved.
5. Early project successes were consciously identified, pursued, and publicized to provide a basis for funding continuation and employee morale.
6. Early interaction with the Tanks Focus Area, Robotics Program, and others was key to obtaining resources and research and development support for the waste removal technologies that were integrated into a successful waste retrieval system.
7. Initial and ongoing tank and waste characterization (video inspections, wall cores, waste samples, etc.) were key activities that helped in the successful planning of the project, as well as in analyzing the project’s effectiveness and efficiency.
8. The "Plan of the Day" sent to all members of the team via email, kept everyone informed of the daily objectives and near-term goals of the project.

9. Events that required alarms and events that only required warnings were differentiated; thus, the number of alarms that required procedural response was minimized.
10. A break room and meeting room were provided on site where activities that otherwise would interfere with operations were staged.
11. Systems that handled water were designed with freeze protection in mind.
12. Plenty of 120 VAC Ground Fault Current Interrupter receptacles were provided in the vicinity of the on-tank equipment and also near the balance of plant equipment locations.
13. Whenever possible, duplicate equipment was used rather than unique models. For example, the CSEE cutting jets and jet pump could be operated with identical high-pressure pumps. This provides flexibility in operations if one pump failed and also reduced the spare parts inventory.
14. Cold test facilities were used to conservatively mock up the tank conditions as closely as possible, especially all physical interfaces and constraints.
15. Field deployment and field maintenance qualification testing was performed under the same conditions that were encountered in the field. Examples include workers wearing full personnel protective equipment (PPE), representative lighting and viewing, similar communications equipment, identical platform access conditions, and identical procedures.
16. Critical spare parts and consumable items were identified in detail. These items were procured prior to operations and stored in a location convenient to the operations staff.
17. Inspectors for National Electrical Code, ASME, DOE Radiation Control, and other applicable codes were involved early to identify necessary modifications for code compliance.
18. As-built drawings for all major systems, including off-the-shelf items, were walked down so that accurate drawings were available if field modifications or repairs became necessary. Lightweight mock equipment was used to perform fit tests.
19. Commonly used tools were secured in tool bins and/or on lanyards. More than three or four lanyards together were not used because of tangling/clutter. Retractable or stowable lanyards were preferred. Lanyards had rotational freedom for tools such as screwdrivers and hex-head wrenches. Special use tools were kept on hand where they could be inserted when needed.
20. A double-door pass-through port was added for introducing clean supplies, clean tools or clean bags of tools, into containment structures. Gross contamination of the pass-through port was avoided by minimizing the transfer of contaminated items back out through the pass-through port and by precluding the use of the port for temporary storage.
21. Gloves were washed frequently with detergent and water. Aside from the radiological benefits, this removed stickiness from hydraulic fluid and tape adhesive.
22. Removal, or consolidation out of the working area, of in-tank debris, as soon as possible, avoided potential tangles or blockages of retrieval equipment. Cables and wires that could wrap around the CSEE rotating head or become entangled in the Houdini™ tracks were especially watched. Deal with debris early to prevent the need to recover multiple times because of interference with a single piece of debris.
23. Access to the control room by nonessential personnel was minimized. Tours are unavoidable in any high visibility project, but unscheduled drop-ins were controlled.
24. Allowance was made within the operating plan for the development and deployment of new tools. For example, when a piece of debris or waste was discovered that was of interest for lab analysis, a customized tool for grasping it was created.
25. Maintenance activities were performed using graded work instructions that allowed personnel the freedom to respond to unknowns and use their craft skills flexibly while completing the maintenance task.
26. Instruments that were critical were identified and calibrated regularly. Routine calibration was not required for instruments that were used only for non-critical relative measurements.
27. Monitoring requirements were identified and delineation made between those required to meet regulatory or safety requirements and those used for process knowledge. When instrumentation failed, a determination could more quickly be made whether operations could continue or must be suspended for repairs.
28. One point of contact was designated to interface with craft and coordinate craft activities on site to avoid confusion over priorities and assignments.
29. At ORNL, craft resources were frequently in high demand, and craftsmen with all required training to work on equipment at the tank farm were in short supply. Therefore, a detailed plan was prepared for system installation or any other activity that is craft-intensive. This plan was communicated to the craft supervisors early to obtain commitments for key resources required. While developing this plan, a balance in the demand for specific crafts over the duration of the job was a key goal. A smaller crew of semi-dedicated craftsmen provided more ownership, and they functioned as part of the project team.
30. Control documents at the project level. Although the paper system used may seem more cumbersome, the ability to control the whole process allowed for much faster turnaround time. Control within the project, along with a very limited controlled distribution list, ensured a quick turnaround time that allowed the project to maintain deadlines.

31. One configuration management system and one change log was used for the whole project instead of one for each system. A starting scope was defined, and a straightforward, simple process was used to make changes to allow the scope to be maintained as the system continued to evolve throughout the project.

Future Opportunities

1. Provide audio feedback of in-tank operations to equipment operators. This gives another indication of sluicing performance, equipment failures, and interference.
2. The work planning process needs to consider control and capture (absorption) of small amounts of unanticipated contaminated liquid, weather, sequence, and duration of activities.
3. If other than dayshift operations are anticipated, ensure adequate lighting is available.
4. Some equipment will be more vulnerable to radiological or chemical damage from in-tank exposures than others. If a piece of equipment must be deployed and retracted frequently to minimize exposures, incorporate a tradeoff evaluation during design to determine whether it will be more cost-effective to design for prolonged exposures rather than spending the time required for frequent deployments and retractions.
5. Establish the equipment and site drawings as controlled documents early in the project and maintain a "red-lined" controlled set of documents at the work site for use in maintenance and troubleshooting.

SUMMARY

Several themes were apparent in the lessons learned on the project. Ideas that have been expressed in the previous pages in a number of different ways include the following:

For Contaminated/Remote Access Locations

- Make equipment as rugged as possible to avoid mechanical problems.
- Consider personnel exposure consequences when designing systems and determining maintenance and procedures.
- Maximize visibility with view ports and contamination covers, cameras, and lighting.
- Design equipment interfaces with operators in mind: ergonomics, lifting wenches.
- Use computer control and preprogramming, but also allow operator input.

All Areas

- Coordinate and get buy-in from management, regulators, support and technical staff.
- Progress from lowest difficulty and risk to higher difficulty and risk activities.
- Expect, plan for, and manage continuing changes in equipment and processes even after operations are underway.
- Celebrate successes to maintain morale, ensure continued project acceptance and support, and provide lessons learned to others facing similar challenges.

The Gunite and Associated Tanks Remediation Project has been successful because a team approach was initiated from the start of the project and carried through to the end. This team consisted of not only the prime contractor, but also the DOE program managers and facility representatives, state and federal environmental regulators, local stakeholders, and a number of subcontractors. Team members were solicited from the beginning for their input, which was evaluated and incorporated into the many different facets of the project, from design to completion.

These lessons learned were derived mostly from many hours of planning; however, in some cases they were the result of oversights. Where the latter were the case, many more hours were expended in finding root causes and correcting the systems to protect and ensure against future recurrence. It is our desire that through the lessons learned program that future projects of this scope can reduce their planning and recovery time by incorporating our lessons learned on their project.

REFERENCES

DOE/EM-0495, *Houdini™ II Remotely Operated Vehicle System Innovative Technology Summary Report*, December 1999.

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