Closure of the Idaho National Laboratory Advanced Test Reactor Complex Catch Tank and Hot Waste Tank Systems – 10240

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ABSTRACT

Legacy tank system components located at the Idaho National Laboratory's Advanced Test Reactor Complex (formerly Test Reactor Area) are being closed in accordance with the Resource Conservation and Recovery Act under the provisions of the Voluntary Consent Order. The tank system components consist of buried waste tanks, direct-buried piping, and pump/valve vaults. Closure activities consist primarily of removal of the mixed (hazardous and radioactive) debris for disposition. The specific tank subsystems currently undergoing closure include the TRA-630 Catch Tank System and the TRA-004 Hot Waste Storage Tank System.

Each of these systems presents significant challenges to successful closure. The Advanced Test Reactor Complex is an operational nuclear reactor testing facility, so protection of co-located laboratory personnel is of paramount importance during closure operations. The radiological contamination contained within these tank systems includes alpha-emitting transuranic isotopes and europium isotopes, which due to their flighty nature, makes contamination control very difficult. There may be issues with the integrity of certain tank system components. Direct-gamma radiation resulting from cobalt and cesium present in the waste necessitates remote operations in many cases. As the components are either direct-buried or located in vaults, access for operations is limited or nonexistent.

Due to the presence of significant buildup (as much as 50% in some instances) of solids and sludge in the system piping, a wax fixative (Waxfix™ from Carter Technologies) was selected to lock-down contamination and fix solid waste remaining inside the piping. The wax fixative was selected primarily for its ability to permeate and fix waste residuals. Other products were tested; however, everything else tested floated on top of the waste residual (which, in many cases, occludes the pipe by 50% or more), and did not penetrate and fix the dry, powdery material. The wax had proven during mockup testing to be very effective at complete permeation and penetration of the residuals to mitigate contamination spread. It was determined during integrated mockup testing that to effectively use the wax fixative, free liquid must be removed from the piping system prior to wax introduction.

To address the need for remote-handling of waste, a Brokk 330 demolition robot was selected. The Brokk has proven to be an effective tool for sizing and removing tank system components while allowing for separation of workers from direct-radiation exposure. Custom end effectors were developed in conjunction with Brokk AB of Sweden to meet specific project needs.

Previous years' activities included technology development and integrated mockup testing. During 2009, field operations commenced for the TRA-613A vault, the TRA-630 vault, and various direct-buried pipe lines. The project successfully performed internal pipe drying of the TRA-613A vault during spring 2009 by using high-efficiency particulate air filtered vacuums to pull air through various valve lineups, while heating the vault to 60°C. Following completion of drying operations, the vault piping internals were waxed by pumping liquefied wax into low points in the piping network and using high-point, high-efficiency particulate air filtered vents to vent displaced air and monitor wax injection. The Brokk

330 with a shear end effector was used to size-reduce and package piping, valves, and pumps. The wax proved highly effective as a contamination control fixative. A direct-buried Duriron pipe (4" HDC-632) was successfully filled with Waxfix during summer 2009. The TRA-630 vault piping will be dried and waxed in December 2009.

INTRODUCTION

Since the early 1950s, the U.S. Department of Energy has operated three test reactors at the Advanced Test Reactor (ATR) Complex (formerly the Test Reactor Area [TRA]) at the Idaho National Laboratory (INL).

The Materials Test Reactor (MTR) was the first reactor constructed with the purpose of producing neutrons for use in various experimental programs, testing reactor components, and studying radiation damage to materials. Completed in 1952, MTR was "the first reactor to be built solely for testing materials to be used in other reactors" [1]. In the 1950s, the usefulness of the MTR was demonstrated and a demand arose for more testing facilities with higher neutron fluxes and space for larger samples. To meet this demand, the Engineering Test Reactor (ETR) was constructed, and in 1957, construction was completed [2]. The ATR was designed and built in the 1960s. The ATR first went critical in 1967 and began full-power operations in 1969. For 40 years, the ATR has provided an overall capability for irradiation testing of nuclear fuels and materials that is unmatched in the world.

The three reactors were built with common infrastructure that included the radioactive wastewater management systems. Since the shutdown of the MTR and the ETR, the ATR wastewater management systems have been systematically isolated from the legacy wastewater management infrastructure that historically supported all three reactors. The isolated, legacy radioactive wastewater management systems are being removed and disposed of as part of the Voluntary Consent Order (VCO) Project work for the Idaho Cleanup Project at the INL.

REGULATORY AND OPERATIONAL BACKGROUND

The legacy radioactive wastewater systems at the ATR Complex are being addressed under the VCO [3], which implements certain tank system closure activities being conducted at the INL under the Resource Conservation and Recovery Act (RCRA) [4]. The VCO required system identification submittals to the State of Idaho Department of Environmental Quality, followed by characterization documentation, to determine if closure under RCRA was required. Two subsystems, which comprise the balance of the ATR Complex legacy wastewater systems, are currently undergoing closure and remediation: (1) the TRA-630 Catch Tank System (CTS) and (2) the TRA-004 Hot Waste Storage Tank System.

TRA-630 Catch Tank System

The TRA-630 CTS was constructed and operated as MTR's primary radioactive liquid waste collection system. The system is comprised of four 5,678-L storage tanks (known as the catch tanks) located in a belowgrade tank vault, a pump vault, and a myriad of underground direct-buried piping. The tank system was used to collect radioactive wastewater from a variety of MTR sources, including reactor in-pile tube coolant, reactor primary coolant, hot cells, and radiochemistry laboratories. Discharge from the catch tanks was through one of three lines, depending on whether the contents were classified as hot or warm waste. Hot waste was discharged to the TRA-004 Hot Waste Storage Tank System; warm waste was discharged to downstream warm waste management facilities.

In February 2007, field activities associated with the first phase of the TRA-630 CTS closure were completed. This phase included closure of tanks TRA-730-1, -2, -3, and -4; the TRA 730 tank vault; and associated piping. The components were closed to closure performance standards for hazardous constituents specified in the TRA-630 CTS closure plan [5]. The scope of work currently being addressed includes removal and disposition of the TRA-630 pump vault and associated direct-buried piping.

The TRA-630 pump vault was constructed in 1951–1952 as part of the original CTS. The internal dimensions of the pump vault are approximately 6 × 5 m, with a height of 2 m. The walls are high-density concrete and vary from 25 to 30 cm thick [6, 7]. The vault houses the pumps and valves used to transfer waste into and out of the four catch tanks. The direct-buried piping that is most problematic includes gravity-drain lines from radiochemistry laboratories and hot cells.

The radiochemistry laboratory drain line (4” HDC-604-B) was constructed in the early 1950s and used between 1952 and 1986. The approximately 20-m-long pipe line is made of Duriron, a brittle, highly corrosion-resistant, and durable cast alloy. Located below grade in the courtyard south of TRA-604 and east of TRA-661, the approximately 20-m-long 4” HDC-604-B pipe line was designed and installed to transfer radioactive wastewater from the individual laboratory drains in TRA-604 and TRA-661 to the inlet headers for TRA-730-3 and -4. In 1986, the line was cut and capped at the upstream end of the line in the south side of the MTR Wing (TRA-604) basement and is now out of service. The line remains connected to the inlet headers of tanks TRA-730-3 and -4 [8]. The line does not have secondary containment.

The 55-m-long hot cell drain line (4” HDC-632) was constructed in 1952 and is made of 10-cm Duriron. The line is located on the north side of the TRA-632 building and connects to the 4” HDC-604-B line at a mechanical joint, which was installed at the connection of the two lines. On the south end of the line, 4” HDC-632 is connected to the TRA-632 hot floor drain piping network. A portion of the line was located beneath the southeast quadrant of the Alpha Wing Extension (TRA-661E) [8], which has been removed. The line does not have secondary containment.

TRA-004 Hot Waste Storage Tank System

The TRA-004 Hot Waste Storage Tank System collected and stored hot (radioactive) waste from numerous sources within the ATR Complex facility, including the aforementioned CTS. The hot waste management system, operational in 1952, consists of three hot waste storage tanks, two pump vaults (TRA-613-A and TRA-613-B) located adjacent to the hot waste storage tanks, and the associated ancillary equipment and piping. One of the tanks is 34,069-L, glass-lined carbon steel while two of the tanks are 34,069-L stainless steel. All three tanks are direct-buried. The two pump vaults are each somewhat smaller than the TRA-630 vault, measuring on average 3 × 4 m and 2 m in height. Problematic piping included in the TRA-004 tank system includes multiple pipe runs of approximately 198 m consisting of stainless steel direct-buried piping.

TECHNICAL ISSUES AND RESOLUTIONS

The regulatory documentation primarily requires removal of tank system components and disposition. The project faced a variety of technical challenges when planning removal of the tanks, vaults, piping, and associated equipment.

Characterization

Adequate characterization information is essential for successful planning of tank system component retrieval. A variety of methods were used in completing characterization of the components. Direct-buried tank characterization was completed by augering down to the top of the tank and through the tank. Temporary risers were installed that allowed insertion of sampling tools, video cameras, and small robots.

Although the vaults are designed for manned entry, high-beta/gamma radiation fields preclude long stay-times. Entries were made into each of the vaults to collect survey information.

Pipe lines proved to be the most challenging to characterize. Internal radiation measurements were collected by accessing the piping at periodic intervals (which many times required excavation) and pushing a rate meter (AMP-100 or similar) into the piping using a push rod. In other cases, pipes were characterized by inserting thermoluminescent detectors (finger rings) into the pipe for a set period of time and then counting the detectors. Video of piping was also completed, using both wheeled robots and push rods. An example of the piping challenges faced by the project can be seen from a resultant video capture as presented in Figure 1.

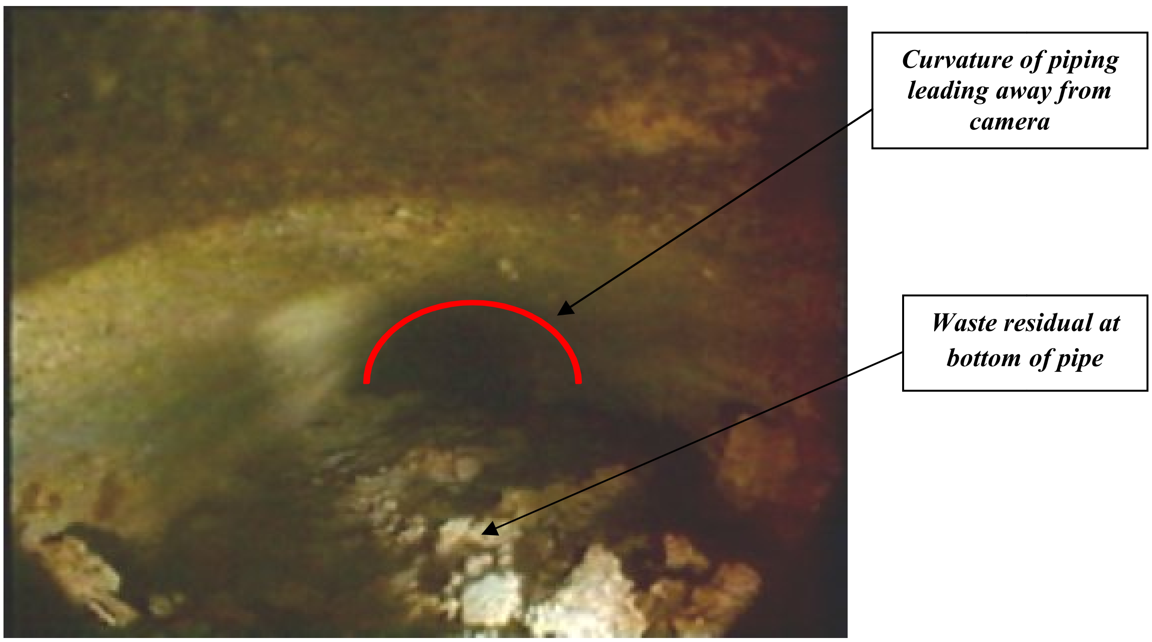

Fig. 1. Hot Cell #1 Drain Header during April 1, 1998, Video Inspection.

Contamination Control

Piping within the vaults and outside the vaults buried in soil contains significant hold-up or residue as can be seen in Figure 1. Sampling and radiological analyses of these residuals indicates the presence of significant quantities of gamma- and alpha-emitting isotopes. A typical sample result is presented in Table I.

Table I. Gamma-Emitting Isotopic Results for Sample Collected from 4” HDC-632 Cleanout.

Isotope	Analytical Result (Bq/g)
Co-60	1.62E+5
Cs-137	5.03E+5
Eu-152	9.58E+4
Eu-154	9.58E+4
Eu-155	1.74E+4

The presence of europium, in particular, is of great concern due to the fact that it is very easily dispersed. Contamination control measures are of particular concern at the ATR Complex given the presence of co-located workers and facilities that are not directly involved in remediation/closure of the tank system components. Continuously occupied buildings are located within 30 m of some pipe removal operations.

While contamination external to piping and components is relatively easily addressed using traditional paints or lock-down materials, determining an effective internal fixative for piping proved to be problematic. The project attempted mockups with a variety of materials and solicited input from a variety of vendors in attempting to identify an appropriate fixative. Various formulations tested included grout, foam, and pourable epoxies or urethanes. In every instance, the fixative did not penetrate or permeate the waste residual, but rather floated over the top of the waste residual. When these pipes were cut, loose material could be freely disbursed, making these ineffective fixatives. In instances in which the pipe is 50% or greater full of dry powdery waste residual, these materials did not prove to be effective fixatives for contamination control.

The VCO Project evaluated Carter Technologies’ molten wax product, Waxfix™. This molten wax can permeate soil, rock, and other material to render the material waterproof and non-dusty. The evaluation included jar tests; a transparent model test (small-scale mockup using 3 m of 8-cm inside-diameter borosilicate glass tube with a 90-degree-long radius upward sweep on each end); a limited-scale mockup (one 2-m-long, 10-cm Duriron pipe with 90-degree bends on each end); and one full-scale mockup (loop of six Duriron pipe segments, two half segments, and six bends). Six types of surrogate materials were used in the full-scale mock-up: (1) bentonite powder with a concrete cap; (2) dry lime with a sodium silicate hard cap; (3) dry mixture of cement, sulfur, plaster, and flyash with a sodium silicate hard cap; (4) dry cement with a sodium silicate hard cap; (5) dry cement, bentonite, and slag with a sodium silicate hard cap; and (6) high-strength concrete made with sand cement bentonite grout. The molten wax permeated all of the surrogate materials in each of the pipes, except for a portion near the end of the pipe that contained the high-strength concrete surrogate. The blue dye in the wax penetrated only a short distance compared to the base wax, which is transparent. This testing indicated that molten wax would be effective for stabilizing the waste inside the piping [9]. The project selected the wax fixative as an appropriate technology for integrated testing (see Figure 2).

The selection of wax as the appropriate fixative brings with it a new set of operational challenges. The wax permeates through the smallest of leaks and sometimes seeps through gaskets in the piping system. In some cases, it is necessary to place a sealant on the outside of flange seals.

Even though the wax is somewhat miscible with water, it is still lighter than water and will separate and float on standing water. Mockup testing indicated that the presence of liquid water within the piping prior to waxing could block the wax and render it ineffective as a permeating fixative. The lower-density wax could simply float over the wet area and not penetrate. Thus, the piping is preferably dried prior to wax insertion. Furthermore, the wax must be kept in a molten state as it is pumped into the piping to ensure all piping fills with wax. The wax can only permeate materials while it is molten, so preheating the pipe helps to keep the wax in a molten state long enough to fully permeate the waste.

Fig. 2. Waxfix Penetrated through the Dry Cement to Fix the Bottom Layer of Dusting Sulfur.

Direct Radiation

Due to the presence of europium, cesium, and cobalt isotopes, direct-gamma and -beta radiation dose rates result in the need for remote operations in some cases. On August 8, 2005, dose rates were measured on the drain line section exterior in the TRA-632 drain line pipe pit inside the north man door to TRA-632. Several layers of lead brick shielded the drain line in the pipe pit. An unshielded on-contact dose rate on the exterior of the drain line measured 75 mGy/hr. On November 7, 2005, dose rate measurements from inside the entire primary length of the Hot Cell #1 drain line outside the cell were attempted. However, the measurement telemetry became stuck in the piping after being lowered approximately 1 m and traversing horizontally about 3 m. The highest dose rate of 2.2 Gy/hr was measured at the 3-m (approximately) point. Potholes dug to access piping associated with the system have yielded external dose rates as high as 120 mGy/hr on contact.

Beta/gamma general body field radiation levels in the TRA-630 pump vault range from 1.5 to 25 mGy/hr, with an average dose rate of about 2.5 mGy/hr. The TRA-613B vault general body field ranges from 1.1 to 11.5 mGy/hr, with an average of about 3.0 mGy/hr. The TRA-613A vault is the most innocuous of the three vaults, with general body fields averaging about 100 µGy/hr.

Many of the tank system components contain radionuclides at levels that may require closure operations to be performed remotely. Compounding this complexity is the need to stabilize the waste within the piping before cutting to maintain contamination control. The VCO Project researched technologies for removing both stainless steel and Duriron piping remotely. Although the focus of these investigations was Duriron piping, the remote-handling technologies will be used with other transuranic-contaminated components, as appropriate, to ensure that radiation dose is maintained as low as reasonably achievable.

The VCO Project investigated remote-demolition tools manufactured by Brokk AB of Sweden. For closing the transuranic-contaminated CTS components, the remote-demolition tools must have the capability to cut Duriron as well as stainless steel pipe, lift cut pipe into waste drums, demolish concrete poured around pipe joints, and demolish concrete walls. The VCO Project evaluated several Brokk remote-demolition tools using the Brokk 330 platform. These tools included a hydraulic shear, grapple, hydraulic bandsaw, rotary saw, drum handler, concrete crusher, and concrete scabbler. Also tested was a chain snap cutter that Brokk engineers developed specifically to cut Duriron piping. All of the testing indicated that the Brokk 330 and associated tools meet the needs of the closure operations. The VCO Project provided Duriron piping filled with a urethane fixative, an agent considered for stabilizing waste inside piping, for testing. Tests showed the chain snap cutter to be very effective for cutting Duriron piping; however, the tests also revealed that the urethane fixative did not crush or shear easily, so the fixative would not be appropriate for the piping. Operators also tested the machine's operational boundaries by tipping the machine, balancing the machine on front skids, and operating the machine on rough terrain. The VCO Project has determined that the Brokk 330 is appropriate for the clean closure of the transuranic-contaminated CTS.

MOCKUP TESTING

An integrated mockup was performed to validate the selection of the individual methodologies/technologies selected. The integrated mockup was further designed to test the selected technologies together to make sure the project plan was appropriate and protective of workers and the public. The integrated mockup was performed in accordance with the integrated mockup plan [10]. The integrated mockup exercise was also used to train operators and gain experience prior to hot deployment. The integrated mockup was successfully conducted at the Mike Mansfield Technology Center operated by MSE in Butte, Montana.

A concrete structure of similar dimensions to the CTS pump vault was utilized at MSE for the vault mockup. This structure had three 1.5-m-high concrete walls. The walls were extended to 2 m to support a flat wood frame and sheathing roof to replicate the 2-m-high ceiling of the CTS pump vault. A piping configuration was installed in the concrete structure with one piping section filled with Waxfix.

The trench mockup was located in an undisturbed field at MSE, where a 9-m-long trench was dug, 1.5 m wide and 1 m deep to replicate the CTS buried piping configuration. Cast iron and Duriron piping were placed in the trench. Waxfix-filled Duriron piping was also installed in the trench. Some piping contained concrete around joints, similar to conditions at the CTS.

The Brokk 330 was deployed to MSE in Butte, Montana, for use in the mockup. Operators ran exercises to cut and remove piping from both the vault mockup and the trench. The mockup testing revealed several lessons learned. It was discovered that the shear attachment was the most useful tool in that it allowed both sizing of the piping in the vault mockup but could also be used to grasp and remove debris for placement into waste containers. The portable bandsaw attachment proved to be inadequate for use at the end of the arm. The remote snap cutter worked very well in sizing brittle Duriron piping. Finally, it was discovered that working through a wall in the vault mockup was difficult operationally, which led to a change to removing the roof for hot deployment.

TRA-613A VAULT DEPLOYMENT

The lessons learned from technology development and integrated mockup testing were moved to hot operations beginning with the TRA-613A vault. Roadbase was moved into the area and graded to bring the surrounding terrain up to the level of the top of the vault roof. A 24-m-wide × 35-m-long weather enclosure was erected over the area of both TRA-613 vaults.

Standpipes were placed on piping inlets and outlets based on an engineered plan for vault drying and waxing. To facilitate liquid removal and pipe drying, the vault was heated to heat the piping components and liquid to a temperature around 60°C to vaporize any liquids present in the piping. After the vault was sufficiently heated, a vacuum created by a high-efficiency particulate air filtered vacuum system was used to draw any moisture out of the piping into a waste container. Moisture indicators near the outlet were used to monitor the liquid levels in the air exiting the pipe. Step-by-step procedures and drawings [11] were prepared to detail the valve alignment and equipment setup to ensure as much liquid as possible would be removed from the piping. Three-dimensional drawings were also used to account for any low points. These procedures were used in the field to accomplish safe and effective liquid removal.

Prior to fixative insertion, the vault was heated to a temperature of around 60°C to heat the piping components, and the Waxfix was heated to a temperature of 82–93°C to assist in the proper flow and penetration of the fixative. Thus, Waxfix flowed through the piping as a liquid. A hand pump was then used to pump the Waxfix through the lower-elevation piping to upper elevations until the fixative was present at all outlet standpipes. Total elevation change from low-point insertion locations to high-point vents was approximately 3 m. Once waxing operations commenced, the insertion process took less than 2 hours. To ensure enough wax was present to completely fill all piping, four 208-L drums were heated and prepared for use. All outlets and the vent location were fitted with high-efficiency particulate air filters and standpipes above ground to monitor the outlets for fixative. The outlets and vent location were left open to allow the air in the pipes to escape as the Waxfix filled the pipes until it was evident that the fixative reached all piping necessary. Vault heaters were shut off once Waxfix was present at all outlet standpipes. As the Waxfix cooled, it solidified to its final wax consistency prior to pipe removal. Step-by-step procedures and drawings [12] were prepared to detail the points of insertion, required vent locations, and equipment setup associated with inserting the Waxfix, and to ensure that Waxfix would fill all necessary piping. These procedures were used in the field to ensure the wax fixative was inserted to the extent practical. Figure 3 provides an example of one intermediate wax insertion step for the TRA-613A vault. This figure shows the anticipated flow of fixative through the piping based on elevation differences and pipe location. Green indicates components currently receiving fixative; blue indicates components in which fixative has already been inserted; and brown indicates components that have not yet received fixative.

During waxing operations, remote-video cameras were placed in-vault to monitor for wax leakage. Due to the exceptional permeating ability of the wax, it was expected that flanges with missing or badly damaged gaskets would leak. The remote-video cameras did indeed show leakage from several damaged gaskets. In two instances, the leakage was bad enough that it would have prevented filling the pipe network had it continued. As a result, several valves were closed isolating the leaking section of lines, resulting in a small portion of the piping network that remained being un-waxed.

A key lesson learned from integrated mockup testing was the difficulties associated with operation of the Brokk 330 through the sidewall of the vault. Due to the challenges of the low ceiling when operating through a demolished wall, it was decided to cut off the roof of the vaults.

Once the roof was removed, a radiological containment 12 × 12 × 4 m was erected. The Brokk 330 with a shear attachment was moved into the radiological containment. The operator position was established on a scissor lift so that the platform could be elevated to allow the operator to see not only the video screens, but also the tool within the vault. Three remote-video cameras were placed within the containment to allow perspective views of the shear in relation to vault piping and obstructions. Once operations were initiated, the vault piping removal was accomplished in a single day of operations.

The wax coupled with 3M Firedam external fixative proved to be very effective contamination control. Smearable contamination within the vault prior to fixative application was as high as 300 μGy/hr [13]. Smearable beta/gamma contamination on jaws of the shear after completion of piping removal averaged 37 Bq/100 cm^2. Smearable beta/gamma contamination within the enclosure following pipe removal averaged 65 Bq/100 cm^2 [14]. Brokk operations are illustrated in Figure 4.

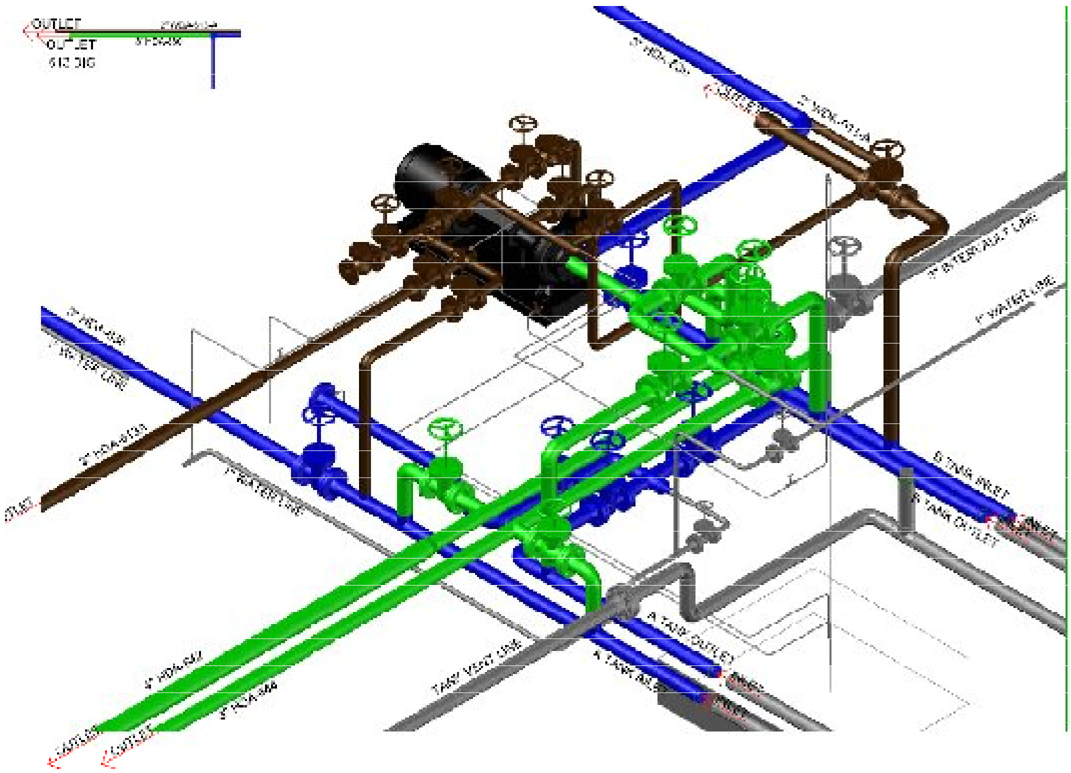

Fig. 3. Isometric View of Vault during Waxing.

Fig. 4. Brokk 330 Demolition Robot in Operation at the TRA-613A Vault.

BURIED DURIRON PIPING DEPLOYMENT

Work has begun on removal of the hottest piping, the Duriron drain piping from a hot cell facility to the TRA-630 vault. This piping is currently slated for removal in spring 2010. Approximately 30 m of this Duriron piping has been successfully waxed. Unlike the vault scenario, in which the ambient temperature was elevated to 60°C, the buried piping was unheated. Integrated mockup testing and engineering calculations had shown that the heat capacity of the wax was such that the wax could be heated to approximately 204°C and injected directly into 12°C piping buried 2–3 m below ground surface. The wax was successfully placed from one end of the piping to the other, demonstrating the ability of performing cold pours for reasonable sections of piping.

PATH FORWARD

Given the successful completion of removal of piping from the TRA-613A vault, the project will complete removal of buried Duriron piping and piping from the TRA-613B and TRA-630 vaults using techniques similar to those demonstrated on the TRA-613A vault.

Drying and waxing of the TRA-613B vault is in process as of November 2009. The TRA-630 vault will be dried and waxed in December 2009. Piping removal operations will commence shortly after waxing and drying.

The operational difficulty of leaking wax from damaged portions of piping or old and damaged flange gaskets has been solved via additional mockup testing, in which external fixative applied to the flanges is capable of sealing the flanges and stopping leakage. This solution will be implemented for waxing of the TRA-613B and TRA-630 vaults.

CONCLUSIONS

It is imperative for any complicated cleanup in a radiological environment to perform adequate characterization. Many legacy facilities are not constructed so as to allow access for characterization. Buried piping, in particular, can prove troublesome. The project overcame these challenges using remote-video cameras, which were used inside tanks, vaults, and pushed into pipe runs. Piping internal radiological assessments were conducted using AMP-50 or AMP-100 GM rate meters pushed into piping using a fiberglass push rod. External characterization of buried pipe was completed by digging potholes to find and survey piping.

Use of wax fixative has proven highly effective as an internal fixative when dealing with easily dispersed radioactive components such as europium isotopes. The wax's permeative ability ensures that occluded pipes are completely fixed prior to cutting. The significant challenge of employing wax as a fixative is the necessity that the pipe be free of liquids, which could pool in low places and cause the low-density wax to float over those areas. This challenge was overcome by drying pipes prior to inserting the wax. Pipe drying was primarily accomplished by drawing air through the piping, with heating, if possible. While the heating of the vaults ensured that the wax stayed molten during insertion, it was also discovered that due to a relatively high heat capacity, the wax can be successfully used in direct-buried applications with no ambient or pipe heating. A section of 10-cm direct-buried Duriron pipe was successfully waxed without heating the pipe, just by placing the pre-heated wax.

The Brokk 330 demolition robot was successfully used to remove piping, pumps, valves, and miscellaneous scrap metal from the TRA-613A vault. The shear attachment proved to be the most useful of the end effectors used by the project. The shear was capable of easily sizing the 5- and 8-cm piping contained within the vault and could also be used to grasp and retrieve cut segments of piping.

The integrated technical solutions identified for the TRA-630 CTS and TRA-004 Hot Waste Storage Tank System have to date proven highly effective. The hot deployment at the TRA-613A vault has shown that the tank system components can be removed while limiting spread of contamination and ensuring worker dose is kept as low as reasonably achievable. Deployment on the more highly radioactive TRA-613B and TRA-630 vaults is ongoing and should be complete in 2010.

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