INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0539

Heel Sampling End Effector

Tanks Focus Area

Prepared for
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INNOVATIVE TECHNOLOGY

Summary Report

Heel Sampling End Effector

OST/TMS ID 2386

Tanks Focus Area

Demonstrated at
Idaho National Engineering and Environmental Laboratory
Idaho Falls, Idaho

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

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SECTION 1
SUMMARY

Technology Summary

Eleven tanks are located at the Idaho National Engineering and Environmental Laboratory (INEEL) Idaho Nuclear Technology and Engineering Center (INTEC). The single-shell, stainless steel tanks—contained in concrete vaults buried 10–15 ft below grade—do not meet the necessary requirements for secondary containment and therefore need to be removed from service by the end of 2015. The Heel Sampling End Effector is being used at INTEC to sample tank residues so that the tanks can be removed from service and permanently sealed. The Heel Sampling End Effector attaches to the Light Duty Utility Arm (LDUA), which enables the end effector to obtain samples of the heel over a large area of the tank bottom.

A closure demonstration of two of these tanks is planned in 2003 by grouting tank residues in place. Developers need heel samples to characterize residues for composition and physical state to develop a grout that will mix with the heel, solidify, and remain stable. The liquids in the tanks are known to be acidic and high in nitrates, conditions detrimental to grout chemistry. Other anions that have been specifically identified by vendors as potentially causing problems with grouting low-level waste are borates, phosphates, permanganates, and sulfates. Additionally, heel samples are required for formulation of waste processing flow sheets, risk modeling, and support of the “waste incidental to reprocessing” (WIR) determination. The WIR determination is a regulatory decision to establish whether the existing tank farm inventory of liquid waste, referred to as “sodium-bearing waste,” will be managed as high-level waste or as mixed low-level waste.

The baseline method for estimating tank heel composition at INEEL was to use prior data obtained from historical process knowledge, sampling of waste sent to the tanks, and sampling of waste transferred from the tanks to the calciner for processing into a solid waste form. Representative heel samples were not available because the baseline (“bottle on a string”) method of sampling tank waste supernatant could not take samples of the soft solids on the tank floor and was restricted to sampling directly under the riser.

At INEEL, the Heel Sampling End Effector was developed to address sampling shallow heels containing soft solids and to provide access to hard-to-reach areas within the tanks, especially in areas not directly below the riser and around cooling coils and steam jets. The LDUA provides the ability to access off-riser locations over a large area of the tank bottom, while the Heel Sampling End Effector provides the ability to obtain representative heel samples up to 800 mL in volume.

How It Works

The Heel Sampling End Effector (see Figure 1) developed at INEEL contains a light source, a camera with a viewing range of 0–50 ft, and a radiation detector with a range of 0–1000 rad/h. The Heel Sampling End Effector is made of stainless steel and weighs about 67 pounds. The sample chamber is remotely detachable for subsequent transport to a laboratory. A 2-inch-diameter capture tube can be immersed in up to 15 inches of liquid or soft slurry waste to pull up to 800 mL of sample into the evacuated sample chamber. The sample chamber contains two septum ports for laboratory sampling in the headspace or liquid in the chamber before breaking the seal on the sample chamber.

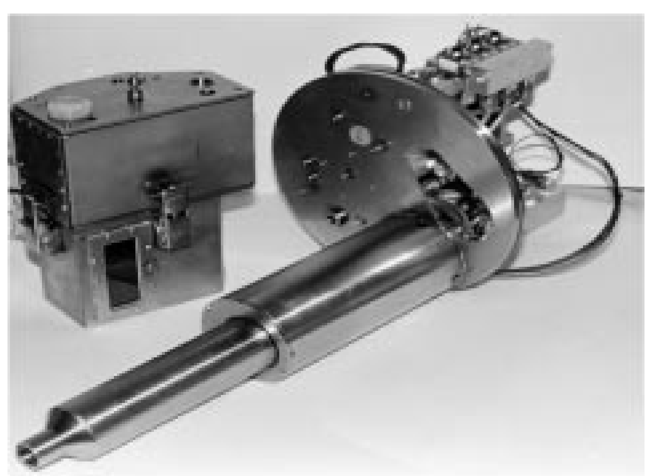

Figure 1. The Heel Sampling End Effector.

The LDUA gives operators remote-controlled access to areas of the tank that cannot be reached by any other means. By using a sampler attached to LDUA, operators can obtain a sample from a greater floor area and deposit it in an enclosed chamber, reducing risks to operators. Heel samples can be analyzed to confirm historical data presently used to estimate the chemical and corrosive characteristics of the tank heel and to support grout formulation development for eventual closure of INTEC tanks.

Advantages over Baseline
Remote use of the Heel Sampling End Effector offers several advantages over baseline sampling techniques:

- Greatly reduces risk from exposure to workers.
- Provides remote-controlled access to samples not reachable by other methods.
- Improves statistical confidence in data because samples are collected from multiple positions within the tanks.
- Obtains sample size adequate for waste analysis characterization, through multiple sampling if needed. The sampler can collect volumes ranging 0–800 mL.
- Obtains a mixed solid/liquid sample.
- Seals samples internally, providing adequate containment during removal to transfer system.
- Radiation detector provides data points for determining radiation levels of the sample.

The following potential disadvantages may affect the selection of the Heel Sampling End Effector for use in tank waste operations:

- Specially trained personnel are required to operate the LDUA and the associated end effectors, including the Heel Sampling End Effector.
- A large amount of support equipment is necessary to perform operations, mostly associated with the requisite LDUA system, but also for the end effectors.
- It is not designed to sample hard sludges or saltcake.
- It is not designed to be immersed under the waste and is limited to sampling less than 15 inches in waste depth.

Potential Markets
This technology has the potential for use at other sites for in-tank activities. The Heel Sampling End Effector may be used as is or with enhanced modifications in tanks of different size and type.

Demonstration Summary

All documentation and reviews required for the LDUA and Heel Sampling End Effector deployment in Idaho were completed in December 1998. Idaho winters are very severe, with snow, heavy winds, and temperatures well below zero. The LDUA deployment was planned for spring 1999, but because of upcoming commitments and milestones, the Department of Energy (DOE) decided to attempt deploying the LDUA system in February. This decision required that all systems and equipment supporting the LDUA deployment be evaluated for the severe conditions. Designs were completed, and equipment was fabricated and installed to minimize the impact of the weather. This effort was initiated in early January, and equipment began moving to the tank farm on February 8.

Key Results

The LDUA was deployed into Tank WM-188 on February 12, 1999, with samples pulled on February 15, 16, and 18, 1999. Homogeneous characteristics of the WM-188 heel were established from the four samples collected, with outside sample chamber readings ranging 0.4–1.2 rad/h. To establish the accuracy of current waste models, the actual heel samples collected were analyzed and compared against heel composition estimates based on process data and waste history.

Participants

The following parties contributed to successful demonstration and deployment of the Heel Sampling End Effector:

- Tanks Focus Area (TFA)
- DOE Office of Science and Technology (OST)
- DOE Office of Environmental Restoration (ER)
- Idaho National Engineering and Environmental Laboratory
- Lockheed Martin Idaho Technologies Company
- Lockheed Martin Energy Systems

Commercial Availability

The Heel Sampling End Effector is not currently commercially available.

Future Plans

INTEC is continuing to use the Heel Sampling End Effector. Tank WM-182 was sampled in November 1999, and WM-183 was sampled during January 2000. Both heels were very different from that of WM-188, and the radiation level in WM-182 was as high as 26 rad/h. Use of the LDUA and the Heel Sampling End Effector will continue through fiscal year 2012 at INEEL to assist in the inspection and sampling of tanks at the INTEC facility.

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Other

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under “Publications.” The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST/TMS ID for the Heel Sampling End Effector is 2386.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

Deployed by the LDUA, the Heel Sampling End Effector is used to collect heel samples within waste tanks. It can be applied throughout the DOE complex in all types of tanks. Sample data collected can then be analyzed to confirm historical data used for estimation of the chemical and corrosive characteristics of tank heels, development of grout formulations for stabilizing heels prior to tank closure, flow sheet development, risk analysis, WIR determination, and process and closure equipment design.

The LDUA was designed for positioning tools in underground storage tanks that have limited access and high radioactivity. Access is usually through a 12-inch-diameter riser. An LDUA is typically deployed with an end effector tool uniquely designed for performing a specific task. Specialized end effector tools can perform tasks such as inspection, characterization, monitoring, and retrieval. The Heel Sampling End Effector was developed specifically for deployment by the LDUA and is not designed for use by any other enabling technology at this time. For further detail, see the LDUA Innovative Technology Summary Report (EM/DOE-0406).

Description of the Technology
Table 1 lists the sampling components of the Heel Sampling End Effector.

Table 1. Key components of the Heel Sampling End Effector

Component	Function
Camera and lighting system	Enables operators to verify (through sight window in sample chamber) that sample has been successfully retrieved Also aids in guiding LDUA into sampling location
Capture tube	Submerges into waste heel
Sample tube	Collects sample from capture tube up to 800 mL
Diaphragm sample valve	Opens to allow sample collection once proper vacuum level is reached
Geiger-Müller tube radiation detector	Provides reading of radiation level within tank and inside housing with range up to 1000 rad/h Mounted in pocket machined out of front housing Sensor can be changed (finer sensor scale is available)
Vacuum pump	Creates vacuum on sample chamber to draw up sample
Sight window	Enables verification of presence of sample
Solenoid valves	Seals vacuum pump from sample chamber, actuates air supply, and operates decontamination water flow Used for sample sealing and control of compressed air and decontamination water
Septum ports	Enables needle to be inserted into sealed sample chamber Samples waste or gases within chamber without opening the chamber

Figure 2 shows the design of the Heel Sampling End Effector system. The capture tube is shown in both the relaxed and compressed positions. The main sections of the Heel Sampling End Effector are described in more detail below.

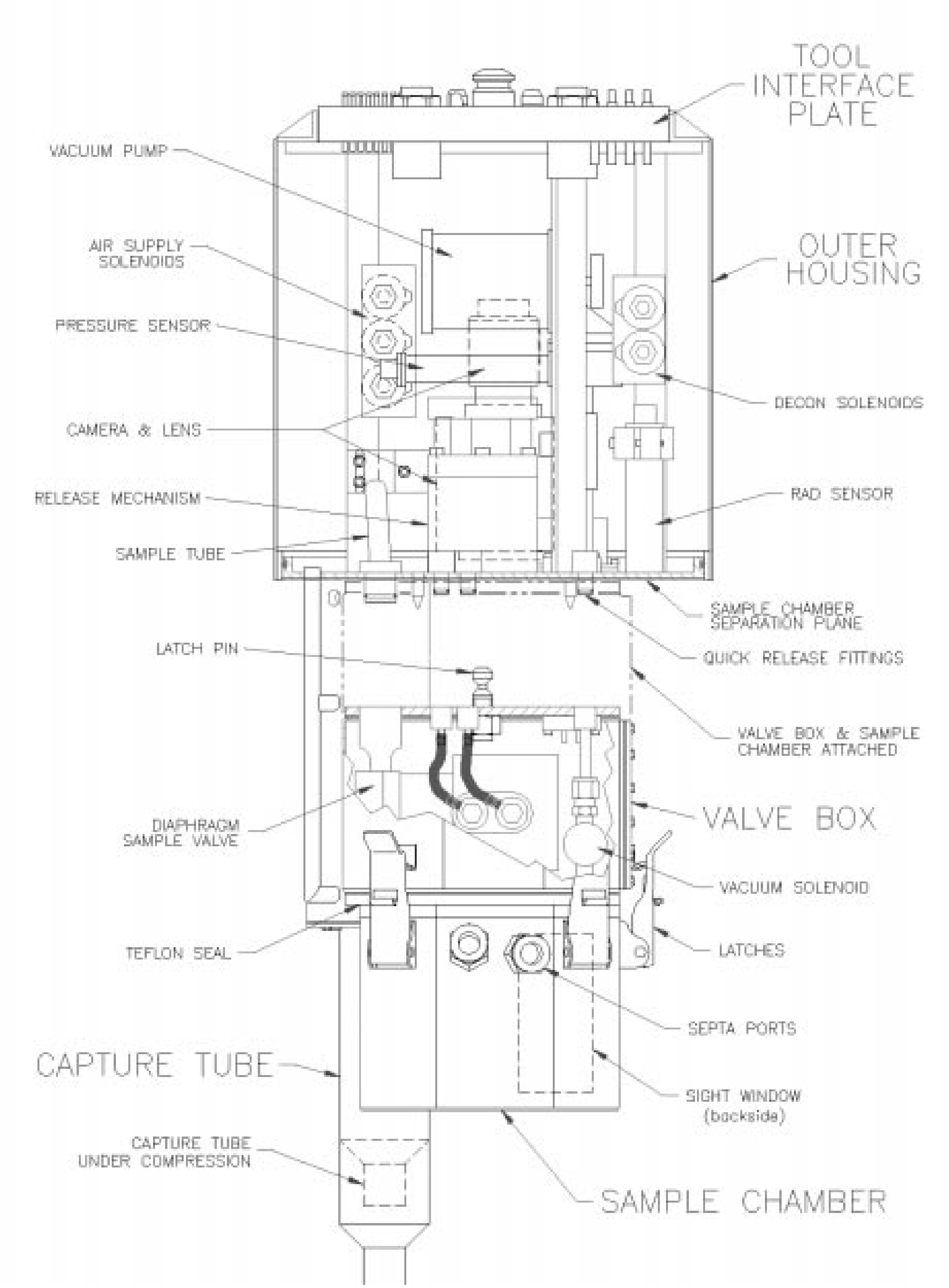

Figure 2. Final design schematic of the Heel Sampling End Effector.

- The **Capture Tube** is a column with a funnel shape on the end to limit the amount of solids retrieved because of their potential high radioactivity. The tube is 14.5 inches long and 2 inches in diameter. To ensure that the capture tube is not damaged during seating against the bottom of the tank, a compliance joint provides the "soft touch" needed to enable the rigid LDUA arm to place the end effector into contact with the tank floor without damaging it. The joint contains two limit switches that provide feedback on the state of the joint's compression.

- The **Sample Chamber** is an odd-shaped box built to contain the sample. It is sealed to the bottom of the valve box with four latches that squeeze a Teflon® gasket at the interface. The chamber contains the sight window and two septum ports. The sample chamber maintains the seal after the chamber is detached from the end effector until it is opened for laboratory analysis.

- The **Valve Box** sits atop the sample chamber and contains two valves. During sampling, the solenoid vacuum valve is opened to allow the pump to create a vacuum within the chamber. Once the vacuum is established, the solenoid valve is closed to protect the pump from the waste, and the diaphragm sample valve is opened to retrieve a sample. Both valves are closed after waste is retrieved to seal the sample safely in the sample chamber.

- The **Outer Housing** encloses a camera and lighting system, sample-release mechanism, the vacuum pump, and a pressure transducer. The release mechanism enables the sample to be remotely released from the housing for transfer to the laboratory. The release mechanism uses an air cylinder to trap the latch pin attached to the valve box. The cylinder is simply retracted to release the sample chamber. For safety, the latching cylinder contains a fail-safe spring to ensure that the sample chamber is not released in the event of a utility failure.

- The **Tool Interface Plate** enables the Heel Sampling End Effector to attach to the LDUA and the End Effector Exchange System. The Remote End Effector Exchange System (not shown) is used to detach the sample chamber and place it into the shielded sample transfer cart.

Basic Principle of the Technology

The Heel Sampling End Effector design uses negative pressure to collect samples from the tank waste heel. Figure 3A shows a simplified sampling system positioned to collect a sample. The capture tube is positioned against the tank bottom within the solids layer, and the vacuum pump creates a vacuum on the sample chamber. Once the proper vacuum level is established, the sample valve is opened and the sample is collected. Figure 3B shows the system the instant after a sample is collected. The contents captured within the capture tube have been sucked out of the tube and into the sample chamber. With sufficient vacuum and some amount of solids around the bottom of the capture tube to help it seal, the vacuum can evacuate the interior of the capture tube before more waste can seep in around the bottom. By evacuating the entire capture tube, a representative waste column or "core" sample is retrieved. After a sample has been transferred from the capture tube into the sample chamber, the valves are closed to seal the sample chamber. The LDUA is then brought out of the tank and positioned to release the sample chamber into a transport system.

If the sample has radiation levels too high to be handled, it must be returned to the tank. The arm is deployed down the riser and back into the tank. The end effector is positioned horizontally just above the waste surface to drain the chamber. Once drained, the end effector is repositioned vertically, and the sample chamber is filled with decontamination water supplied through the LDUA. The water level is observed through the sight window to fill the sample chamber 3/4 full. The sample chamber is then moved back into the horizontal orientation and drained. This fill-and-drain process is repeated to ensure the maximum amount of sample has been flushed out of the sample chamber.

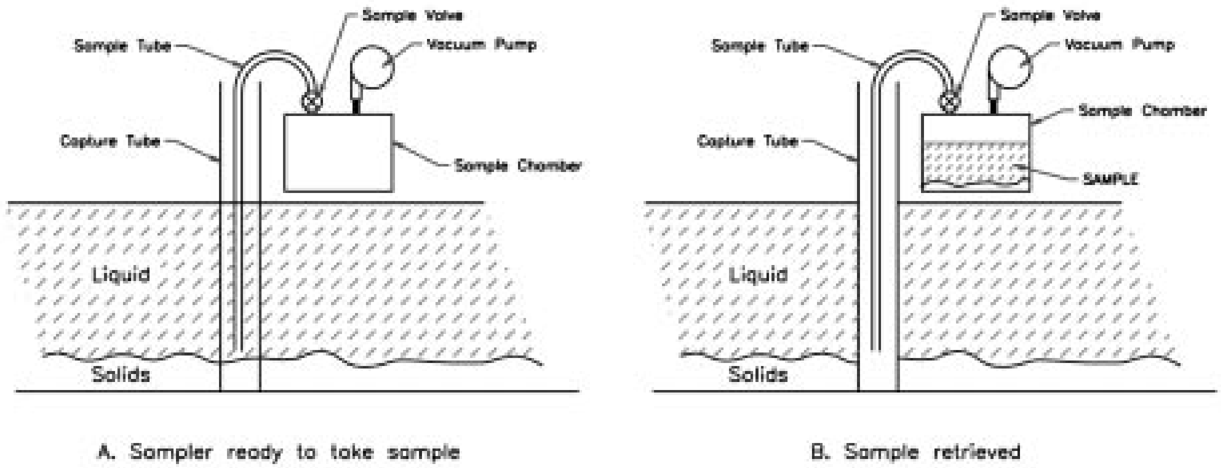

Figure 3. Sample collection schematic.

Supporting Equipment

The major support systems include the decontamination system and the sampler end effector control system. These systems are described below.

Decontamination System

The design uses demineralized water supplied through the arm to rinse off the interior surfaces of the system that contact the waste. Two nozzles are mounted in the capture tube to rinse its interior, and another is attached to the sample tube to flush it clean.

Sampler End Effector Control System

The LabVIEW control screen used by the operator manipulating the Heel Sampling End Effector is divided into a single status frame and several control frames. The status frame provides a quick view of the current state of the end effector. The status of all the valves, the current readings for the radiation sensor and vacuum pressure, the status of the pump (on/off), and the condition of the two compliance joint travel indicators are all shown. The control frames divide the control functions into three separate groups, camera functions, light functions, and sampler actions, as follows:

- Camera Controls—The top right control frame contains all of the camera controls. There are controls for each camera function (zoom, iris, and focus) to be operated in both directions of travel. In addition to these controls, there is a separate travel speed control that enables the user to fine-tune the speed of each camera function. The user can set the individual function speeds to the appropriate value for the viewing situation to minimize overshoot caused by an extremely fast motion or the extended pause caused by a very slow motion.

- Light Controls—The middle right control frame provides control over the lighting for the end effector. The light can be turned on and off and the light intensity controlled to accommodate the viewing situation.

- Sampler Actions—The bottom right control frame contains the set of actions used to retrieve a sample. Each action actuates the required valves and devices in the proper sequence and timing to correctly accomplish the given task. The actions are arranged in Table 2 in operational order for a typical sample retrieval campaign.

Advanced Control—To provide additional flexibility in controlling the end effector, an advanced control frame is provided. This screen contains camera and light control frames identical to those on the previous screen. A control screen very similar to the previous status screen provides control for all valves and devices individually. All controls act as toggles and must be selected once to open them and then again to close them. This control frame provides the operator the ability to operate any device in any order.

Table 2. Bottom right control frame set of actions used to control sampler actions and retrieve a sample

Prior state of sampler	Selected action	Sampler response
All devices off prior to retrieving sample.	Release sample chamber	Opens mechanism to receive assembly.
Sample chamber assembly is aligned and inserted onto end effector.	Latch sample chamber	Secures sample chamber assembly to end effector.
LDUA arm is used to position end effector into waste heel and seat capture tube against tank bottom. Travel indicators on status frame indicate when end effector has been adequately seated.	Establish vacuum	Turns on vacuum pump until vacuum pressure reaches desired level.
Desired vacuum pressure level is observed on status frame pressure readout.	Retrieve sample	Turns off pump and draws waste contained in capture tube into sample chamber above waste surface; vacuum level is sufficient to drain capture tube contents.
Sample chamber is filled.	Pump off	Turns off vacuum pump. With vacuum pump off, vacuum pressure slowly leaks down.
After waiting several minutes to ensure retrieval is complete, LDUA arm is used to remove end effector from waste, allowing sample tube to drain. Once bottom of capture tube is above waste surface, “seal sample” action is selected.	Seal sample	Closes diaphragm sample valve and seals sample in sample chamber.
Sample chamber is safely sealed. LDUA arm is used to orient end effector into horizontal position with sample tube below sample chamber.	Flush sample tube	Sample tube is rinsed with decontamination water; horizontal position enables sample tube to fully drain, minimizing any trapped contamination.
Sample tube has been flushed, and end effector is repositioned to vertical.	Flush capture tube	Opens capture tube solenoid valve and rinses interior of capture tube with decontamination water.
If retrieved sample proves to be too radioactive to handle and must be returned to tank, arm is used to position end effector into horizontal pouring position with capture tube below sample chamber.	Drain/vent sample chamber	Opens sample solenoid valve, enabling sample to drain back into tank through sample tube.
LDUA positions sample chamber vertically.	Fill sample chamber	Opens sample tube decontamination valve; in vertical orientation with sample valve open, decontamination water can flow into sample chamber.
After sample chamber is filled with decontamination water.	Drain sample chamber	Drains decontamination water from sample chamber.

Prior state of sampler	Selected action	Sampler response
If retrieved sample's radiation levels are low enough to be handled, LDUA is used remove end effector from tank and position it in transport system. Containment camera system is used to help guide end effector into position.	Release sample chamber	Releases sample chamber assembly from end effector for transportation to analytical laboratory; after release, arm must raise end effector out of the way.

While the Advanced Control feature provides great flexibility, it also allows the end effector to be damaged. Care must be taken to examine what will happen before changing a device's state using the Advanced Control frame. For example, the vacuum pump should not be turned on with a retrieved sample already in the sample chamber because doing so would allow the sample to be drawn into the pump, damaging it and contaminating interior tubing that cannot be flushed.

System Operation

Operation of the Heel Sampling End Effector is performed remotely from a control trailer outside the tank radiation area. The end effector can be operated from the control trailer with assistance from several in-tank video cameras not located on the LDUA and deployed through other tank risers. Important operational considerations are discussed below.

Operational Parameters and Conditions

- Predeployment setup and testing are recommended prior to deploying the sampler. The camera and lighting system, release mechanism, compliance joints, and the ability of the sampler to pull adequate vacuum should be tested. The viewing windows should be cleaned, O-rings inspected and greased, sampler port septa replaced, and the Teflon sample chamber gasket replaced.

- An in-tank camera should be used prior to deployment to verify that no cooling coils will interfere with the sampling operation.

- After the LDUA is deployed down the riser and into the tank and the end effector is positioned in the appropriate area, the sampler is lowered into the waste. Horizontal movement as the end effector is moving into the waste is avoided when obtaining a core sample. Unique conditions within a tank may require sampling at other than a 90^{o} angle.

- Once within the tank, the sampler camera system is used to aid in positioning the end effector directly over the predetermined sampling location in a vertical orientation.

- Once the capture tube comes into contact with the tank bottom, the compression joint begins to compress, tripping the lower-limit switch and lighting the "Travel Start" indicator on the LabVIEW control screen. The vertical height of the arm should be noted at the point where the indicator turns on. The end effector should then be lowered an additional inch to fully seat the capture tube against the tank bottom.

- The arm should not be lowered beyond the 2 inches of joint travel. If the "Travel Limit" indicator lights, the joint has reached its hard stop, and all downward motion should stop. Further downward force could damage the capture tube assembly.

- Once the sample has been removed, a new sample can be taken in a different location, or the sample chamber can be replaced with a clean one for another retrieval.

- Sample coordinates should be recorded in the computer control system so that the sample position can be duplicated.

Volume Sampling

The end effector can be used to retrieve a given volume of sample. To do this, the sampler is deployed into the tank, positioned over a sampling location, and slowly lowered into the waste to the desired depth. In this method, the capture tube is not seated against the bottom of the tank to seal it. Thus, the sample is collected from the area surrounding the end of the sample tube.

Materials and Labor

Two operators are needed to operate the LDUA system from within the operations control center. One operator controls the LDUA, and the other controls the installed end effector and the video displays and recorders. Two additional operators are needed to perform end effector changes and to decontaminate the LDUA and end effectors during removal from the tank.

Technical Skills/Training

Because the Heel Sampling End Effector and the LDUA system are unique and somewhat complex, special training is required to ensure safe operation. The system operators developed, verified, and practiced using operating procedures in cold-test facilities, as shown in Figure 4. The training took place in the Fuel Processing Restoration facility at INTEC. The utility arm was extended into one of the large basement chambers for operators to practice using the arm and the end effectors. While two of the operators were at the controls, the others were in the basement chamber watching the arm move. This procedure helped all operators get a feel for how the arm worked and how to control it. The training began in April 1998 and ended in November 1998, when the operators were certified. During this time, key craft personnel were also trained to support setup, takedown, and maintenance of the equipment.

Figure 4. System operators training with the LDUA in a cold-test facility.

Secondary Waste Considerations

Most of the secondary waste is wastewater derived from decontamination of the equipment; however, the interior parts of the sampler are rinsed while the sampler is still in the tank. The sampler is then removed from the tank, and the arm is retracted out of the tank. The wash-down system at the top of the riser is used to thoroughly wash the exterior of the end effector as the arm is retracted. At the top of the riser, radiation sensors are used to check the radiation levels of the sample.

Concerns/Risks

The risk from the decontamination water is negligible (it drains into the tank), as are any other risks associated with this technology because using this remote-controlled system reduces direct contact with the tank and its contents. Some tasks, such as end effector exchange, require operator activities above the tank but do not pose significant risks to workers. The alternative of placing personnel in the position to extract the waste from the tank and exposing the waste to the environment is of much greater risk.

SECTION 3
PERFORMANCE

Demonstration Plan

The LDUA and a variety of other end effectors were demonstrated at the Hanford Site in September 1996 and at Oak Ridge Reservation in July through September 1997. The LDUA was deployed at INTEC using various end effectors in February 1999, November 1999, and January 2000. These deployments demonstrate the use of the LDUA for in-tank inspections and heel sampling.

Major Objectives
The demonstrations at the Hanford Site and Oak Ridge Reservation focused on improving the LDUA performance in underground radioactive waste storage tanks. The objective of the deployment at INEEL was to retrieve actual waste heel samples for characterization in support of future tank closure activities. Table 3 lists the Heel Sampling End Effector performance objectives of the INTEC deployment.

Table 3. Performance objectives for INTEC deployment

Component	Requirements
In-tank end effector equipment	• Operates under extreme environmental conditions with continuous use for up to 8 h without degradation or damage to the underground storage tank • Withstands in-tank temperatures up to 100ºF and radiation fields up to 500 rad/h with an accumulated dose of 1×10^8 • Load-bearing components operate with sufficient factor of safety • Withstands acidic chemical environment with high levels of sodium and chloride • Maximum weight of 75 pounds • Fluids added to the tank during operation approved by tank farm operations • Exposed surfaces easy to decontaminate and withstand repeated decontamination with high-pressure fluids • Does not hang up or become trapped inside the tank during postfailure retrieval • Suitable for Class 1, Division 1, Group B environments as defined by National Fire Protection Association • Able to reach between cooling coils to obtain waste heel samples
Sampler system	• Obtains a mixed solid/liquid sample within 30 minutes • Adequately contains sample during removal and transfer
Software	• Adequately and correctly performs all required functions with supporting user documentation
Control system	• Interfaces with the LDUA Supervisory Data Acquisition and Control System to control camera and lighting system • Uses Tool Interface Plate (TIP) and LDUA cables to supply services and communication to end effector • Uses two cables (up to 900 ft) for control and communication with control trailer

Major Elements
The Heel Sampling End Effector testing includes the actual sampler end effector at the end of the robotic arm; the at-tank support systems for utilities; and the display, data processing, and control systems located in the control trailer. The Heel Sampling End Effector is used to obtain a sample of waste from the bottom of the tank and place the sample chamber in a transfer system. The sample is then transported to a laboratory for analysis.

Results

The Heel Sampling End Effector was deployed to inspect and sample underground highly radioactive waste storage tanks using the LDUA. All the performance objectives listed in Table 3 were met. This section presents an overall discussion of the Heel Sampling End Effector performance.

On February 12, 1999, the Heel Sampling End Effector was deployed through a 12-inch riser into Tank WM-188 at INTEC, as depicted in Figure 5. Tank WM-188 as a 300,000-gallon, underground, stainless steel tank approximately 50 ft in diameter and 45 ft from riser top to tank bottom, containing a residual slurry heel of high-level radioactive liquid waste about 10 inches deep. The deployment occurred under winter conditions with an outside air temperature of 10ºF, snow cover, and occasional wind and precipitation. Operations staff devised an enclosed tent to protect the riser area where the end effectors were changed out and heel samples could be packaged for transport to the laboratory. The heel samples gathered through this deployment were analyzed to confirm historical data used to estimate chemical and corrosive characteristics of the tank heel and to support closure strategies and equipment design for eventual closure of INTEC tanks.

Figure 5. Deploying the LDUA into an underground liquid radioactive waste storage tank at the INTEC tank

The LDUA and various end effectors were redeployed in Tank WM-182 from October 25 to November 11, 1999. Site personnel expected the heel to be about ¼- to ½-inch thick. Instead, a 4-inch-thick heel composed of flocculent material was retrieved. Four heel samples were obtained with volumes ranging 480–830 mL and contact gamma fields of 9–24 rad/h. In addition, Tank WM-183 was sampled from December 1999 through January 2000, and the heel contained up to 11 inches of viscous solids, plugging the sampling end effector before it could be filled completely. To acquire enough solids to make one composite sample for hot-cell tests, seven heel samples were taken between December 8, 1999 and January 20, 2000. In the prior two deployments, very little solids were observed or obtained in the heel sample solutions. The presence of viscous solids refutes the long-standing belief that INTEC tanks contain only liquids. Rheological properties of the solid fraction will be measured so that a simulant can be formulated. Changes to some design attributes of the sampling end effector will be tested with the simulant in an effort to avoid future plugging.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

Samples of the waste at the bottom of INTEC tanks had never been taken directly. Instead, samples were pulled from calciner process lines after waste had been removed from the tanks using steam jets. Direct in-tank sampling was considered necessary to obtain samples for analysis and comparison to estimates of composition from process history.

Technology Applicability

The Heel Sampling End Effector is applicable to tanks at DOE sites, particularly the Hanford Site and INEEL. Industrial applications may apply as well.

The Heel Sampling End Effector has the following applications:

- sampling of tank waste for laboratory analysis and inventory assessment
- visual inspection and radiation level screening of the tank heel
- support for retrieval and closure operations
- support for risk determination and regulatory closure designs

In determining the applicability of the technology for other tanks, parameters that should be considered include the following:

- Access—Risers must be able to accommodate the equipment's dimensions.
- Height—The mast rises 48 ft.
- In situ operations—Obstructions within the tank may hinder the equipment's ability to access desired locations.
- Hardness of solids in heel—The Heel Sampling End Effector will sample only liquids and soft solids.
- Depth of liquid to sample—The Heel Sampling End Effector will sample up to 15 inches of heel.
- The LDUA and sampling end effector are already designed for flammable/explosive headspace application.
- Tank dome loading—Equipment may require support by a load-bearing platform.

Patents/Commercialization/Sponsor

The Heel Sampling End Effector was developed jointly by Idaho National Engineering and Environmental Laboratory and Lockheed Martin Idaho Technologies Company. DOE OST, ER, and TFA sponsored development and deployment of the Heel Sampling End Effector.

The LDUA, the robotic arm that moves the Heel Sampling End Effector around in the tanks, was manufactured by SPAR Aerospace. The double-door, sealed transfer system for transferring the sample to the laboratory was developed at Central Research Laboratories, a private firm, and adapted for INTEC applications.

SECTION 5
COST

Methodology

Costs for deploying the Heel Sampling End Effector in Tank WM-188 are summarized below. The baseline technology is to rely on process samples and historical data to estimate heel composition. The costs for deploying baseline technologies are likely to be significantly less than for deploying the Heel Sampling End Effector because of the training and deployment costs associated with the LDUA. When the cost of the overall project and the consequences of failure are considered, however, the Heel Sampling End Effector deployment has positive cost impacts.

Cost Analysis

Table 4 reports the costs incurred by the DOE for the Heel Sampler End Effector deployment at INTEC.

Table 4. Heel Sampling End Effector development and deployment costs

Activity	Cost ($K)
Design and prototype testing	120
Fabrication	80
Additional sample chamber fabrication (per chamber)	30
Testing	40
Total	270

Note: Includes funds to perform LDUA tasks required to deploy the Heel Sampling End Effector.

Future costs will vary greatly depending on the deployment site and the equipment used to field the end effector (e.g., LDUA type, support equipment, specialty staff).

Capital and Operating Costs
The cost to develop the Heel Sampling End Effector was $270K, and the cost to deploy it most recently at INEEL is estimated at $400K. A portion of the deployment cost includes some costs required to deploy the LDUA, which was needed to perform the inspection. This cost covers labor for the operating crews, project management, and consumable items.

Cost Benefits
Using the LDUA and Heel Sampling End Effector provides samples that can be used to obtain accurate, quantitative information about the composition of the tank heel. The LDUA and Heel Sampling End Effector are considered an enabling technology since the baseline “bottle-on-a-string” method for in-tank sampling was considered inadequate. Actual data, rather than estimates based on historical records of the tank heel composition, may enable selection of less expensive tank retrieval and closure options. Without this data, regulators may reject closure options, or unnecessary conservatism may be factored into closure options.

Table 5 summarizes estimated costs for the various closure options. The estimates address closing 11 tanks, tank vaults, and ancillary piping located in the tank farm facility at INTEC. In the past, the base requirement was clean closure (Option 2 or 3), which is to remove all waste, leave the tank structures in place, and fill the tank voids. The current plan is to perform a risk-based clean closure, if possible, or a landfill closure, as a contingency, (Option 2 or 4), which includes removing the waste and grouting the remaining heel in place. Clean grout will then be used to fill the rest of the tank above the heel level and fill the surrounding vault. The cost differential between these options is over $50 million.

Table 5. Estimated costs of INEEL high-level waste tank closure options

Closure option	Estimated cost ($ millions)
1. Tank removal and demolition closure	5,330
2. Risk-based clean closure, low-level waste grout fill	205
3. Risk-based clean closure, CERCLA waste fill	238
4. RCRA landfill closure, low-level waste grout fill	185
5. RCRA landfill closure, CERCLA waste fill	220
6. Close to landfill standards, clean fill	135

Source: Spaulding et al. 1998.

Technology Scale-Up

Scale-up is not an issue with the Heel Sampling End Effector. Inspection of large tanks may require multiple deployments of the LDUA into different risers if its reach from a single riser is not sufficient to inspect and sample across the entire tank bottom.

Cost Conclusions

Using the Heel Sampling End Effector avoids costs when compared to the alternative of relying on process samples and historical information. Using the Heel Sampling End Effector results in cost avoidance from using data obtained to implement less conservative retrieval and closure alternatives.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

In general, waste in storage tanks at DOE sites is subject to a number of different regulations and regulatory authorities, including the following:

- DOE Order 435.1, Radioactive Waste Management, requiring all DOE waste to be managed in a manner that protects the worker, public, and the environment.
- Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA).
- Resource Conservation and Recovery Act of 1976, Public Law 94-580, as amended (RCRA).
- State of Idaho, Settlement Agreement, U.S. District Court of Idaho, Civil No. 91-0054-S-EJL, Oct. 16, 1995.
- State of Idaho, Notice of Noncompliance Consent Order. The consent order, developed by the state, requires DOE's Idaho Operations Office to cease use of the five pillar and panel vault tanks by 2009 and to cease use of the remaining six tanks by 2015. An August 1998 modification to the Consent Order accelerated these dates to 2003 and 2012, respectively.
- INEEL Site Treatment Plan, describing how DOE-Idaho proposes to treat or develop treatment for mixed waste and the schedules to accomplish these tasks.

Waste storage and treatment facilities are also required to meet the Clean Air Act and Clean Water Act requirements for liquid and airborne effluents. Requirements are typically implemented at the state or local levels for these statutes.

Secondary Waste
Most of the secondary waste, which is governed by the U.S. Environmental Protection Agency (EPA), is wastewater derived from decontamination of the equipment. DOE is responsible for safe storage and treatment of the waste.

CERCLA Evaluation
This section summarizes how the Heel Sampling End Effector addresses the nine CERCLA evaluation criteria.

1. Overall Protection of Human Health and the Environment

    - Remote-controlled inspection and monitoring of tanks with hazardous or radioactive components significantly minimizes exposure to workers.
    - Tanks can be isolated faster, with fewer personnel, in much safer surroundings, thus reducing threats to human health and the environment.

2. Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)

    - The Heel Sampling End Effector with the LDUA was designed and deployed according to applicable regulatory requirements.
    - Established procedures and controls are in place to ensure compliance.

3. Long-Term Effectiveness and Permanence

    - This technology can help accelerate tank remediation and closure schedules.
    - The Heel Sampling End Effector is radiation-hardened and was constructed to withstand temperatures 0–50ºC.

4. Reduction of Toxicity, Mobility, or Volume through Treatment

    - This system avoids manual inspection of tank integrity, which generates significant amounts of secondary waste due to exposure of additional tools and clothing to radiation sources.
    - Chemical and physical characterization is essential to treating the waste, whether left in place or retrieved for treatment, storage, and disposal.

5. Short-Term Effectiveness

    Radiation exposure to workers is maintained as low as reasonably achievable (ALARA) through the following measures:

    - Inspection data collection is done away from the tank.
    - Established procedures and controls exist, and workers are thoroughly trained and qualified.

6. Implementability

    - Deploying tools while the LDUA is in a tank for needed retrieval or closure activities optimizes efficiency and cost.
    - Worker exposure is minimized.
    - Worker training and qualification programs and procedures are in place.

7. Cost data are provided in Section 5.
8. State (Support Agency) Acceptance

    - EPA and the State of Idaho have agreements that cover regulatory issues and establish requirements for management of tanks.

9. Community Acceptance is discussed below.

Safety, Risks, Benefits, and Community Reaction

Because the main components of the Heel Sampling End Effector are operated remotely, there are no major worker safety issues posed by using this equipment. The support equipment includes a decontamination system as part of the LDUA. This feature enables remote decontamination of the LDUA and the Heel Sampling End Effector. The other support systems are located above the tank and require hands-on operation; however, the support equipment does not present any special safety concerns for workers.

Public and stakeholder reaction to the successful deployment of the LDUA and Heel Sampling End Effector at INTEC was positive. The technology is viewed as low risk and essential in obtaining data to appropriately close underground tanks as stipulated in the Idaho Settlement Agreement.

DOE issues news releases on upcoming events and announces opportunities for public comment on all key program documents or proposed cleanup plans in area newspapers. Notices are also mailed to stakeholders.

Fact sheets providing technology updates are distributed to the public. Information is available to the public on the Internet on DOE's home page at http://www.doe.gov or at http://techcatalog.inel.gov.

SECTION 7
LESSONS LEARNED

Implementation Considerations

The technology performed well in the field. Issues discovered during the demonstration resulted in several suggestions for future deployments:

- Determine the depth of liquid in the tank before the sampler is landed so that operators will know the volume of a capture sample to expect. The depth may be a factor in determining whether a volume sample or a capture sample is to be pulled.
- Document the time it takes to pull a given vacuum in the chamber. This information will enable operators to estimate the time if the sample chamber pressure indicator should fail.
- Do a detailed time study to determine how many samples can be pulled in a day without requiring overtime.

Technology Limitations and Needs for Future Development

Recommended upgrades (based on lessons learned) are to redesign the capture tube and inner suction tube to better sample soft solids. Some suggestions include broadening the capture tube tip and increasing the diameter of the inner suction tube to the sample chamber.

Technology Selection Considerations

The Heel Sampling End Effector is an option for sampling waste heels in DOE tanks with limited access. Most, if not all, of DOE's tanks have restricted access.

APPENDIX A
REFERENCES

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APPENDIX B
ACRONYMS AND ABBREVIATIONS

ALARA	as low as reasonably achievable
ARARs	applicable or relevant and appropriate requirements
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ER	U.S. Department of Energy Office of Environmental Restoration
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology Engineering Center
LDUA	Light-Duty Utility Arm
OST	Office of Science and Technology
RCRA	Resource Conservation and Recovery Act
TFA	Tanks Focus Area
TIP	Tool Interface Plate
TMS	Technology Management System
WIR	waste incidental to reprocessing