INNOVATIVE TECHNOLOGY
Summary Report

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In-Tank Waste Retrieval—Vehicle Based Systems

Tanks Focus Area

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INNOVATIVE TECHNOLOGY
Summary Report

In-Tank Waste Retrieval—Vehicle Based Systems

Tech ID 2012

Tanks Focus Area

Demonstrated at
Hanford Site
Richland, Washington

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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 prospective users consider a technology.

Each report describes a technology, system, or process that has been developed and tested with funding from U.S. Department of Energy's Office of Science and Technology. A report presents the full range of problems that a technology, system, or process will address and its advantages to the Department of Energy 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, worker safety, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the Office of Science and Technology Web site at www.em.doe.gov/ost under "Publications."

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SECTION 1
SUMMARY

Technology Summary

Problem
Baseline methods for dislodging and mobilizing radioactive waste solids on the floor of underground storage tanks are effective for limited distances and use a large volume of water. The baseline methods for dislodging and mobilizing tank waste are high-volume/low-pressure water sluicing or jet mixer pumps (Bailey 2000; Hamel, McMahon, and Meess 2000). The effectiveness of these mixing systems diminishes as the distance to the tank waste increases and as harder residual solids are encountered. In addition, jet mixer pumps and transfer pumps associated with sluicing need a minimum liquid level in the tank to be effective (Hamel, McMahon, and Meess 2000). There is a need to minimize the liquid level during waste retrieval from tanks with potential leaks in the side walls.

Solution
Two vehicle-based retrieval systems can dislodge and transfer wet sludge, hardpan/dried sludge, and the type of saltcake predicted to be remaining in Hanford Tank C-106 following past-practice sluicing. The remotely operated vehicles can deploy high-pressure water sluicers within inches of the solids layer at any point on a tank floor. This tactic is more effective than a baseline water sluicer positioned at one riser 20–70 feet from the waste or a fixed-position mixer located a foot or two above a solid layer. The vehicle-based systems use less water than fixed-position systems and, coupled with a low-suction-head liquid scavenging system, minimize the need for a standing liquid in the tank.

How It Works
Two remotely operated vehicles have been designed to fit through tank risers 24–36 inches in diameter. Each vehicle holds hydraulically operated tools to dislodge hard solids on the floor of waste tanks. The tools include a high-pressure water sluicer that can be positioned within inches of the waste solids on the floor of the tank. With the sluicer so close to the solids, only small volumes of water are needed to dislodge the solids and create a slurry. Transfer pumps remove the slurry before the solids settle out. The pumps are either located on the vehicles or positioned nearby. The Big Wheels vehicle demonstrated by ARD Environmental is shown in Figure 1. The TracPump™ vehicle demonstrated by Environmental Specialties Group (ESG) is shown in Figure 2.

Figure 1. ARD Big Wheels with sluicer.

Potential Markets
Retrieval systems for tank heels are needed at the Hanford and Savannah River Sites.

Advantages over Baseline
Remotely operated vehicles can move sluicers to within inches of solids on the tank floor, where high-pressure/low-volume water is very effective at dislodging solids. The vehicle-mounted pumps (or other suction system) immediately pump dislodged solid slurry to minimize buildup of water in the tank.

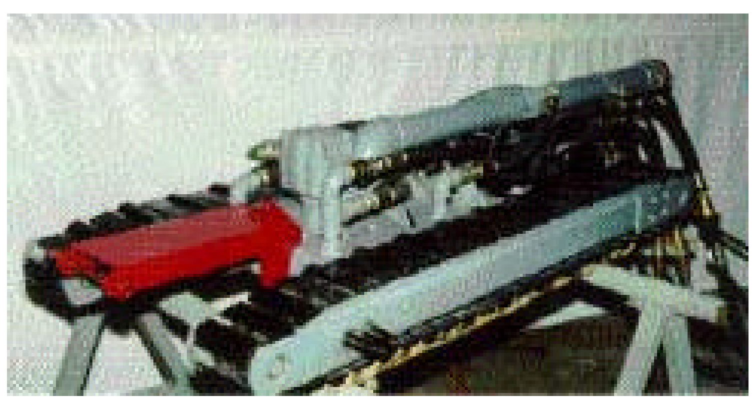

Figure 2. ESG TracPump™ platform.

Demonstration Summary

Demonstrations were conducted in 1997 to generate performance data for each of the vehicles using simulated Hanford waste. Waste simulants were prepared following documented procedures (Powell 1996). Waste simulants were classified as wet sludge, hardpan/dried sludge, and saltcake.

Key Results

ARD Environmental performed a series of tests at its Laurel, Maryland site in April and May of 1997. The ARD Environmental Big Wheels was successfully lowered through a 36-inch-diameter mock riser into a tank with 3 feet of layered, simulated Hanford solid waste. The vehicle was powerful and maneuverable. When operated in opposite directions, the wheels broke up layers of hard solids. Simulant was successfully conveyed from the tank with the integrated pump. The Big Wheels vehicle was successfully retrieved and decontaminated at the conclusion of the demonstration.

Between February and June 1997, ESG performed a series of tests using the TracPump™ at its Holden, Louisiana facility. The equipment was successfully lowered through a riser mockup with a 24-inch-diameter opening. Simulated in-tank obstacles did not impede the vehicle. Each of the different forms of simulant waste was broken up and pumped out of the mock tank. Following the demonstration, the equipment was successfully retrieved from the tank, but water spray in the decontamination chamber could not remove all solids in the tracks.

Parties Involved in the Demonstration

- ARD Environmental Inc. (team included Scientific Applications International Corporation)
- Environmental Specialties Group, LLC (formed with the support of Numanco, LLC and H&H Pump and Dredge Company)

Commercial Availability and Readiness

Commercially available and full-scale equipment was used by ARD Environmental and the ESG team for the demonstrations. Both ARD Environmental and the ESG team can design and fabricate vehicle-based waste retrieval systems to meet tank-specific requirements.

Contacts

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Other

Innovative Technology Summary Reports are available on the Office of Science and Technology Web site at www.em.doe.gov/ost under “Publications.” The Technology Management System, available at the same Web site, provides information about remediation technologies. The Tech ID for the In-Tank Waste Retrieval—Vehicle Based System technology is 2012.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

The ARD Environmental and ESG waste retrieval systems demonstrated in 1997 have similar features. To illustrate the similarities and differences between the two systems, the following description of each team's waste retrieval system has been divided in terms of function: vehicle, waste dislodging and conveyance, and other support systems.

Vehicle

Figure 3 shows a schematic of the ARD Environmental Big Wheels vehicle that was designed specifically for Hanford applications (figure taken from ARD Environmental 1997b). The Big Wheels vehicle has four balloon tires 24 inches in diameter. The vehicle is equipped with hydraulic actuators to permit positioning of the sluicer in a wide range, as shown in the figure.

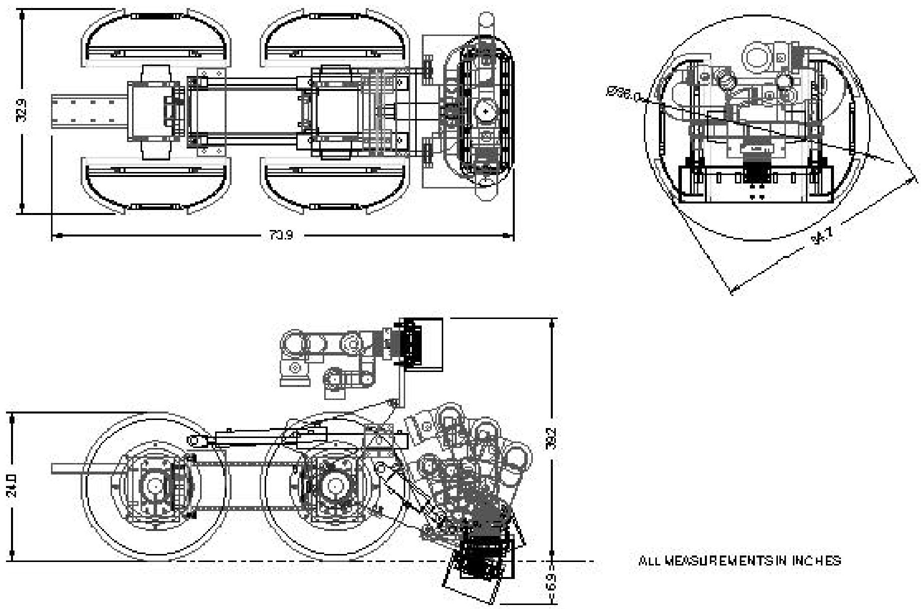

Figure 3. Schematic of Big Wheels vehicle with sluicer.

The ESG TracPump™ is a remotely controlled pumping system that excavates or dislodges waste and pumps sludges and slurries from tanks, basins, lagoons, cisterns, or sewers. The system consists of a motorized, track-driven carriage with a submersible hydraulic pump sized for the specific application (see Figure 4, adapted from ESG 1997); a base unit manufactured to fit through a 36-inch-diameter port; track pontoons hydraulically linked to the carriage platform where the pontoons can be folded underneath the unit to allow access into 24-inch-diameter risers; a pump platform supporting a variable-speed sludge pump; and carriage pontoons housing the track drive assemblies.

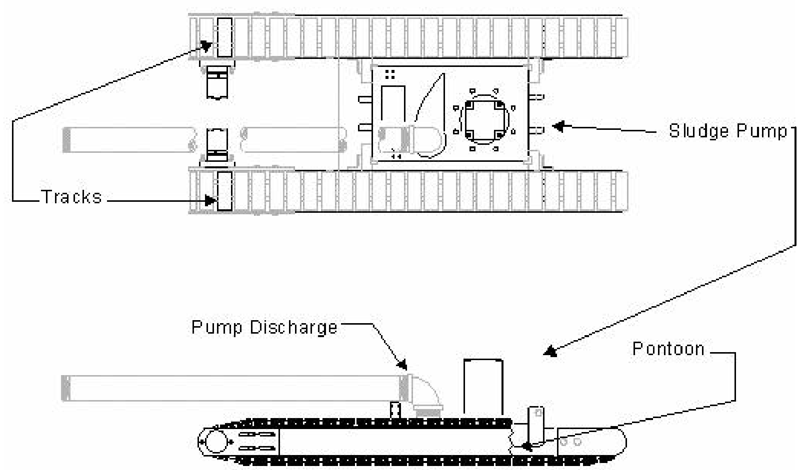

Figure 4. Schematic of ESG TracPump™ unit.

The TracPump™ was equipped with ESG's claw tracks. Claw tracks have replaceable, carbide-tipped spikes attached in a pattern specifically designed for the waste retrieval system application. The motive power for the tracks is provided by hydraulics. The hydraulic power unit is trailer mounted and equipped with all controls necessary to operate the motive system. Adaptation of the power unit system for operation from a remote control room can be readily achieved.

Waste Dislodging and Conveyance

Figure 5 shows a schematic of the ARD Environmental sluicer used for the 1997 demonstration. The sluicer is equipped with 14 sluicing nozzles, each with a nominal diameter of 0.14 inch and a zero-degree spray angle. The nozzles deliver a nominal water flow rate of 110 gallons per minute (gpm) at 400 pounds per square inch (psi). An eductor located in the center of the sluicing nozzles has a suction capacity of 100 gpm. Material collected by the eductor is conveyed out of the tank by an ARD proprietary pumping module. A second proprietary pumping module is located at another location in the tank to convey waste and water that escapes from the eductor located on the sluicer.

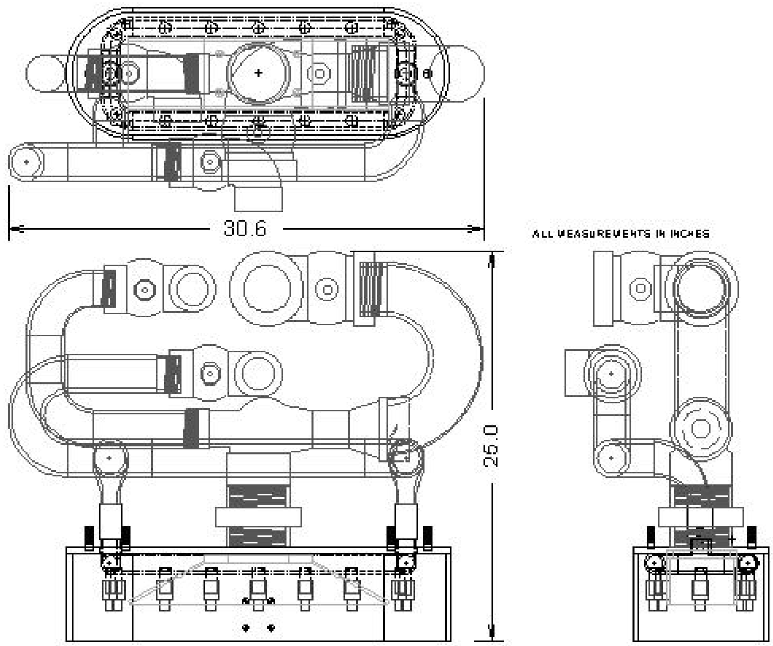

Figure 5. Schematic of ARD sluicer.

The ESG TracPump™ waste conveyance system is a variable-speed, submersible, hydraulic sludge pump, designed to convey slurries with high solids content. The in-tank sludge pump, located on the vehicle platform, is capable of providing a flow rate of 150 gpm to a height greater than 70 feet through 210 linear feet of 3-inch-diameter hose. The unit discharges waste through a flexible discharge hose that is bundled with 14½-inch hydraulic control hoses and a ½-inch water supply hose within a single unit called the "umbilical."

Waste dislodging tools available for the TracPump™ vehicle include HIPRESS, face mill, Smith's auger, and Hougen bit. A description of each tool follows.

- The HIPRESS tool (Figure 6) is a high-pressure water tool package consisting of an oscillating header with various nozzles. Hydraulic motors propel the oscillation of the header, while hydraulic cylinders control positioning of the tool.
- The face mill is a roller with carbide tips propelled at high speed to grind into hard material. Hydraulic cylinders control positioning of the tool. This tool is interchangeable with the HIPRESS tool.
- The Smith's auger is a roller with replaceable carbide tips installed in an auger configuration that grinds hard material and feeds the cuttings to the suction inlet for the pump. The roller is driven by hydraulic motors and positioned by hydraulic cylinders.

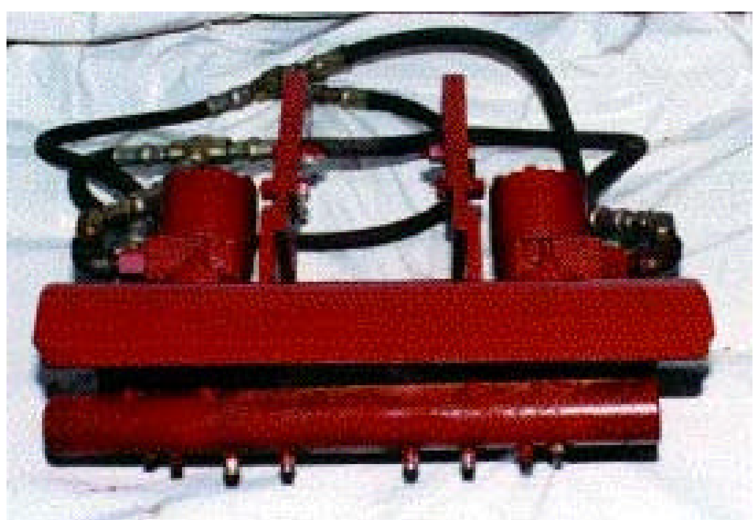

Figure 6. ESG HIPRESS tool.

- The Hougen bit is an impeller-type bit with sharp, hardened tips designed to cut into hard material.

Other Support Systems
For the ESG demonstration, a full-scale containment structure, called a decontamination containment capture vessel (see Figure 7), was constructed to evaluate the procedure for insertion and retraction from an underground storage tank. The decontamination vessel houses the umbilical control system where the umbilical is coiled as it is withdrawn, a complete decontamination wash-down system for use during TracPump™ retrieval, and glove ports for maintenance operations.

The ESG decontamination vessel uses a 0.38-inch-thick stainless steel wall polished to a mirror finish, which is easier to decontaminate than unpolished metal surfaces. Spray nozzles located in the riser provide the bulk decontamination for the inserted vehicle system. Additional nozzles are used for washing residual contamination that enters the decontamination vessel. To minimize worker exposure during placement of the unit over a tank riser pit, the decontamination vessel utilizes a unique air bag seal and an alignment method that does not require personnel to enter the tank riser pit.

For the ARD Environmental demonstration, a full-scale decontamination chamber was constructed and tested. The chamber consisted of a 72-inch-diameter by 84-inch-high aluminum cylinder with an integral flange welded to the bottom. Figure 8 shows the chamber being lifted to the tank riser mock-up platform.

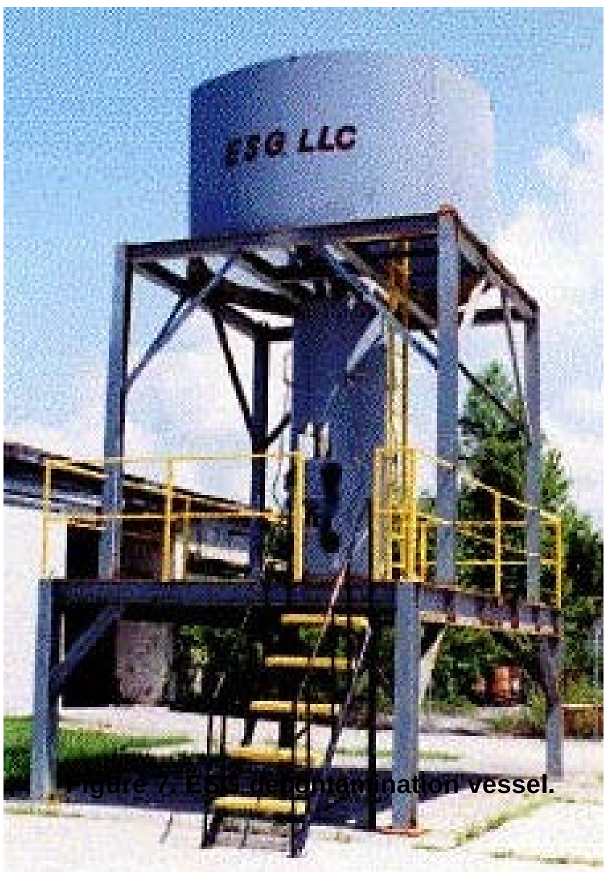

Figure 7. ESG decontamination vessel.


Figure 8. ARD decontamination chamber.

The ARD decontamination chamber contains three spray rings around its inner circumference, located near the bottom of the chamber. Each ring has eight spray nozzles, equally spaced around it, spraying in towards the center axis of the cylinder. In addition to the fixed spray rings, the chamber has two rings of eight equally spaced holes around its perimeter to allow the use of manually operated spray wands. Two sets of four observation windows are also provided on the chamber.

System Operation

The vehicle-based waste retrieval systems designed and tested by the ARD Environmental and ESG project teams are based on retrieval functions and requirements developed for application in Hanford single-shell tanks. The retrieval functions were developed using a systems engineering approach and can be categorized into the following elements: access the tank; deploy tools; dislodge waste; mobilize waste for subsequent conveyance; convey waste out of the tank; preprocess the waste, if required, for transport; transport the waste to a double-shell tank; verify waste retrieval is complete; control and monitor the operations; contain the waste; and monitor and maintain the tank environment.

Special Operational Parameters

Because the ARD Environmental and ESG retrieval systems are both vehicle-based, they have similar operational parameters. Parameters that should be considered for application of either technology for retrieval operations in a tank include compatibility of components with waste; ability of components to operate while submerged; impact from aboveground components on tank infrastructure; and water usage. Tank and site specific requirements may result in modifications to specific pieces of equipment, deployment tools, or operating procedures.

Materials, Energy, and Other Expendable Items

Because the two systems developed by ARD Environmental and ESG are both vehicle-based and were designed to perform the same retrieval functions, the materials, energy, and other expendable items are similar for both systems. Both systems use hydraulics for the vehicles and for positioning tools. The ESG system uses hydraulic tools. Both systems require a water supply and pumps to provide the appropriate flow rate and pressure for the specific system. Both systems use an umbilical containing hydraulic lines, water lines, and pump discharge lines. The ESG system uses an in-tank sludge pump to convey the waste, while the ARD Environmental system uses a water-powered eductor (located in the sluicer unit) and two transfer pumps. Expendable materials were not identified during the demonstrations.

Personnel Requirements

Installation of either system in an underground storage tank will use many of the same skills as for the placement of common in-tank equipment, such as jet mixer pumps and transfer pumps. Decontamination of the equipment for movement to different tanks is envisioned to use the same skills as those currently required for the removal of in-tank components. Some specialized training will be required for operation of the remote systems and for maintenance of the equipment.

Secondary Waste Stream

Operation of either vehicle-based system is not anticipated to create a significant secondary waste stream. Water used for the decontamination of in-tank systems and for the interior of the decontamination chambers is returned to the tank in the current system designs. Decontamination of aboveground equipment may generate secondary liquid and solid waste. Solid secondary waste may also be generated from the maintenance of equipment.

Potential Operational Concerns and Risks

One primary operational concern is the ability to retrieve the vehicle and waste retrieval tools from a tank in the event of equipment failure. Testing performed by ARD Environmental showed that the tether connected to the vehicle could be used to pull the vehicle out through a riser mock-up. ESG did not perform similar failure mode testing. An operational concern is the need to keep the suction pump inlet under water or slurry. During testing, the ARD Environmental pump would cavitate and lose prime when the inlet was not kept under water.

On the other hand, water accumulation protected residual solids from the pressure effect of the sluicer (Bailey 2000). In terms of water flow rates, the demonstrated systems use one third less than the Tank C-106 sluicing nozzle (i.e., the ARD Environmental sluicer used 110 gpm at 400 psi, the ESG HIPRESS tool used 65 gpm at 15,000 psi, and the C-106 sluicing nozzle used 350 gpm at 300 psi). The most important aspect is the much lower operating liquid levels from a tank leak standpoint—1 inch or less versus 5 feet or more of water.

SECTION 3
PERFORMANCE

Demonstration Plan

The objective for the ARD Environmental and ESG demonstrations was to evaluate capabilities of prototype, vehicle-based waste retrieval systems using a mock tank with different Hanford waste simulants. Table 1 lists the waste simulants, components, and physical properties (Powell 1996).

Table 1. Waste simulant composition and physical properties

Simulant	Component (weight %)	Compressive or shear strength (psi)	Bulk density (g/cc)
Wet sludge	EPK pulverized kaolin clay (66) Water (34)	Shear – 0.5	1.65
Hardpan/dried sludge #1	Plaster of Paris (30) EPK pulverized kaolin clay (27.5) Water (42.5)	Shear – 5	1.48
Hardpan/dried sludge #2	Plaster of Paris (40) EPK pulverized kaolin clay (22.5) Water (37.5)	Shear – 22	1.65
Saltcake #1	Dynamate[a] fertilizer (84) Water (16)	Compressive – 3,000	2.25
Saltcake #2	Dynamate fertilizer (88) Water (12)	Compressive – 1,500	1.94
Saltcake #3	Dynamate fertilizer (75) Water (25)	Compressive – 1,500	2.27
Saltcake #4	Sodium chloride rock salt (86) Plaster of Paris (9.33) Water (4.67)	Compressive – 8	1.2
Saltcake #5	Sodium chloride rock salt (95) Plaster of Paris (3.33) Water (1.67)	Compressive – 1.5	1.2

[a]Potassium magnesium sulfate.

The simulant wet sludge made with kaolin had properties close to Hanford wet sludge, i.e., shear strength of 0.5 psi and density of 1.6 g/cc (Daymo 1997). No physical measurements were available for actual Hanford hardpan; however, calculations estimate the shear strength to be 3 psi or higher (Powell 1996). Actual Hanford saltcake varies in compressive strength from “snow-cone” consistency of under 10 psi to as hard as concrete with 2,000–7,000 psi.

ARD Environmental Testing

In April and May of 1997, ARD Environmental performed a demonstration at its Laurel, Maryland site incorporating lessons learned from exploratory work conducted in 1996 (ARD Environmental 1997a). Testing was performed using the Big Wheels vehicle equipped with a sluicing system, manipulator, umbilical, tether cable, control unit, and power unit. Two separate, stand-alone, proprietary scavenger modules were inserted through the mock riser/decontamination chamber by a crane and set on the test bed. The “free water scavenger” module was located away from the Big Wheels operation to capture excess water. Testing was performed using a test bed created by layering six different waste simulants as described in Table 2.

Table 2. Test bed for Big Wheels demonstration

Layer placement	Layer depth (in)	Layer title	Layer volume (ft^3)	Solids (pounds)	Water (gal)	Strength after curing (psi)	Bulk density (gm/cc)
Top	1.1	Saltcake #4	30	Plaster (262) Rock salt (2,400)	16	Compressive – 8	1.2
Layer 2	7.3	Saltcake #3	190	K-Mag[a] (20,080)	803	Compressive – 1,500	2.27
Layer 3	7.3	Saltcake #1	190	K-Mag (22,400)	1,513	Compressive – 3,000	2.25
Layer 4	7.3	Hardpan #2	190	Kaolin (4,300) Plaster (7,625)	859	Shear – 22	1.65
Layer 5	4	Hardpan #1	100 poured (90 left in mixer)	Kaolin (4,950) Plaster (5,375)	914	Shear – 5	1.48
Bottom	4	Wet sludge	100	Kaolin (7,000)	433	Shear – 0.5	1.65

[a]Potassium magnesium sulfate fertilizer (Dynamate).

Figure 9 shows a block diagram of the test layout used for the ARD demonstration (ARD Environmental 1997b). The steel test tank was 5 feet deep with a 20-foot diameter and contained 31 inches of waste simulant, as shown in Table 2. The test tank was enclosed in a scaffolding and truss structure, decked over to provide a simulated tank top 20 feet above the tank bottom. A mock riser, 36 inches in diameter and 6 feet long, was installed extending from the deck downward. The decontamination chamber was placed over the riser. The vehicle operator used video cameras to guide the equipment. The instruments shown in Figure 9 are liquid level (L), pressure sensors (P), and flow rate (Q).

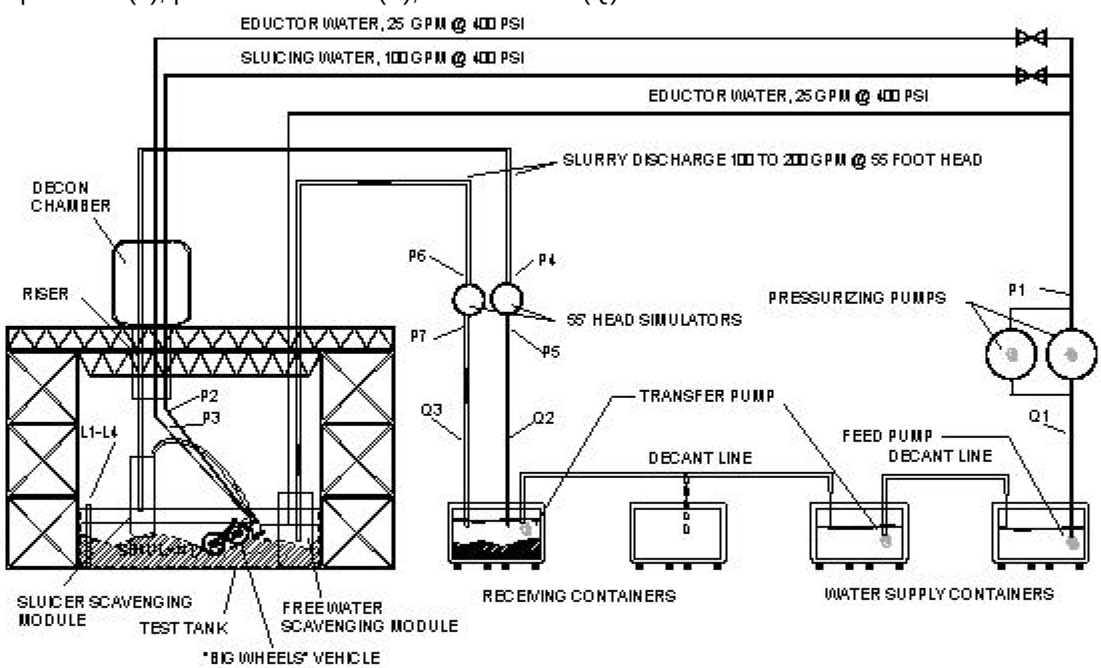

Figure 9. ARD test system block diagram (ARD Environmental 1997b).

Equipment Ingress and Egress

The Big Wheels with attached sluicer was lowered into the riser using a winch mounted to a forklift. The sluicer tilt arm had to be adjusted once for clearance. The vehicle unit was then lowered to the surface of the waste simulant (Figure 10) without incident. Insertion of the vehicle unit was performed using only video feedback. The end of the sluicer eductor discharge hose was retained at the top of the decontamination chamber for connection to the vehicle's water-scavenging module, which was separately lowered into the tank.

Figure 10. Big Wheels vehicle and sluicer landing on waste simulant surface.

The vehicle's water-scavenging module was lowered into the decontamination chamber and then into the riser. The vehicle umbilical and hoses in the riser did not interfere with the insertion of the module. While still in the decontamination chamber, the sluicer eductor hose was connected to the module. This step was performed manually for the demonstration; a remote method would be needed for future applications. Prior to the module being lowered completely to the tank floor, the vehicle operator moved the vehicle forward to make room. No problems were identified for normal ingress and egress of the vehicle and water-scavenging module. Tests for recovery from a failure mode in which the vehicle could not be positioned beneath the riser showed that the vehicle could be easily pulled using the cable tether to a point beneath the riser and then removed from the tank. Independent motors for each wheel reduce the probability that complete failure of all four wheels would occur in an actual tank.

The Big Wheels was connected to an umbilical sheath containing eight 3/8-inch hydraulic hoses, eight ¼-inch hydraulic hoses, one 3-inch suction/discharge hose, and two 1-inch water supply hoses. The diameter of the umbilical bundle was about 6 inches. The sluicer was operated with water supplied at 100 gpm and 400 psi. Eductors on the two waste scavengers were operated at 25 gpm and 400 psi.

Waste Removal Rate

Waste removal rates varied considerably between hard and soft test materials. Relatively soft materials included the wet sludge, hardpan/dried sludge, and saltcake #4 with a low compressive strength. Saltcakes #1 and #3, made with high-compressive-strength material, were considered hard material. The average time to recover a cubic foot of soft and hard material was 2 minutes and 14 minutes, respectively. The solids content of the recovered waste streams, for both hard and soft materials, was consistent with ARD experience at industrial sites and nuclear power plants. Figure 11 shows the Big Wheels vehicle in the test tank.

Figure 11. Waste removal in ARD test tank.

Decontamination

The use of fixed spray rings and a manually operated spray wand in the decontamination chamber was effective at removing waste simulant from the umbilical and vehicle. Some residual was found where tie-wraps bundled the umbilical, in a vehicle motor mount box, and in the sluicer shroud.

ESG Testing

The ESG 1997 demonstration was conducted at its Holden, Louisiana plant. Nine tests were performed to evaluate full-scale equipment, but not in a single full-scale mock-up. For example, waste simulant was placed into plywood forms instead of a test tank to evaluate the waste dislodging tools. The evaluation of the vehicle's maneuverability was performed in a full-scale mock-up of a Hanford tank.

Ingress/Egress Test

Testing was performed to demonstrate the ability of the TracPump™ assembly to ingress/egress a tank using the umbilical control system and the TracPump™ assembly retrieval winch. The TracPump™ assembly was equipped with the HIPRESS tool, sludge pump, simulated umbilical, claw tracks, and folding mechanism. To simulate a tank riser, a 24-inch-diameter, 10-foot-long pipe was placed underneath the decontamination vessel. Figure 12 shows the unit being inserted into the pipe. Although the TracPump™ assembly was able to pass through the pipe, more clearance should be provided to allow for movement of equipment. This accommodation can be achieved in either of two ways:

- Decrease each pontoon width by 2 inches.
- Make the pump base portion of the TracPump™ 2 inches narrower by integrating the pump base and casing.

Figure 12. TracPump™ inserted into pipe.

Waste Retrieval Test

Four test beds were constructed of plywood and filled with different simulants to a depth of about 9 inches. Three of the test beds contained either wet sludge, hardpan/dried sludge #2 or saltcake #1 (described in Table 1), while the fourth bed consisted of a mixture of all three simulant types. The TracPump™ assembly consisted of a sludge pump, claw tracks, hydraulic lines for all hydraulic motors and cylinders, and a 4-inch-diameter discharge hose.

Four tools were evaluated during testing: HIPRESS, face mill, Smith's auger, and Hougen bit. Figure 13 shows the TracPump™ assembly, equipped with the HIPRESS tool, dislodging and pumping wet sludge from a test bed. The high-pressure-water tool was the only tool that was effective at dislodging all of the waste simulants tested. The average time to dislodge and retrieve a cubic foot of waste simulant was 0.9 minutes for wet sludge, 1.8 minutes for hardpan/dried sludge, and 3.8 minutes for saltcake. The other tools were ineffective on the waste simulants, with the exception that the face mill was able to dislodge saltcake for removal.

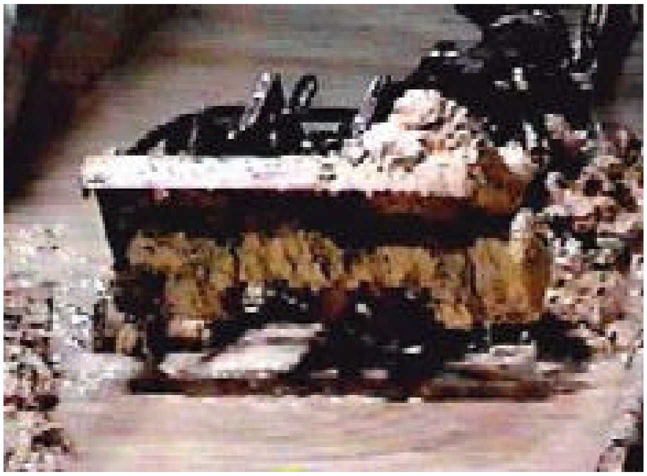

Figure 13. TracPump™ assembly with attached HIPRESS tool in wet sludge.

Table 3 summarizes the test results and lessons learned (ESG 1997).

Table 3. Summary of ESG tests

Test objective	Test results	Lessons learned
Determine the waste retrieval rates and level of processing for a variety of TracPump™ tools.	HIPRESS tool effectively dislodged the three waste simulants.	Mills and grinders were ineffective in dislodging waste simulants.
Evaluate available materials, hose construction, surface finish, chemical resistance, strength, and flexibility (bend radius) of the umbilical design. Perform review of umbilical control system design.	Reviewed the design of the umbilical and umbilical control system.	
Test the maneuverability of the TracPump™ assembly in a simulated tank environment.	Demonstrated the TracPump™ assembly's ability to traverse fields of waste simulants while pulling umbilical. Demonstrated operation of the umbilical control system in coordination with the TracPump™ assembly.	Umbilical rubbed against umbilical control system chain drive. ACTION: Reposition sprockets or install chain guard. Umbilical occasionally adhered to decontamination vessel shell. ACTION: Further testing required.
Assess the components, materials, and fabrication of a decontamination vessel prototype.	Reviewed design of the decontamination vessel.	
Analyze the requirements of remote surveillance equipment for the tank environment.	Reviewed availability and potential designs for remote surveillance equipment.	
Verify the efficacy of a high-pressure water lance to backflush system for unclogging the pump discharge hose.	Demonstrated the ability of the high-pressure water lance to clear a pump discharge hose with waste simulant.	Locate the insertion point for the water lance in the discharge line. Add a pressure relief line to allow water to flow back into a waste tank.
Confirm the minimum riser penetration size for ingress/egress of the TracPump™ assembly.	Demonstrated ingress and egress through a 24-inch riser.	Modify TracPump™ to provide more clearance.
Determine conveyance rates of TracPump™ assembly with dislodged waste simulants.	Demonstrated pumping rates of 140 gpm to 70-foot height through 210 feet of 3-inch hose.	Recirculation of discharge slurry to increase solids content could reduce water usage.
Establish a schedule of expected maintenance for TracPump™ assembly components.	Demonstrated that maintenance could be performed inside the decontamination vessel. Schedule established.	Identified equipment modifications to simplify maintenance operations.

Maneuverability Test
A full-scale mock-up of Hanford Tank AY-104 was constructed. The test material replicated worst-case conditions for maneuverability in a tank. A portion of the mock-up tank was filled with a random mixture of saltcake and hardpan/dried sludge waste simulants. The TracPump™ assembly, equipped with claw tracks, was placed in the tank with 100 feet of 5-inch-diameter tank car hose attached to the pump discharge and four hydraulic lines attached for operation of the tracks. The HIPRESS tool was mounted to the front of the vehicle and raised in its near-vertical orientation with spray nozzles aimed forward.

Figure 14 illustrates the path the TracPump™ assembly was maneuvered along for the test. The vehicle easily moved around the simulated obstacles placed in the mock-up tank while pulling 100 feet of umbilical. This task was achieved on both the flat portion of the mock-up tank not covered by waste simulant and on the portion filled with waste simulant resulting in an increasing slope from the center to the tank edge.

To determine the stability of the vehicle, it was driven with one set of tracks climbing a ramp. The vehicle climbed the ramp until an angle of 65 degrees from horizontal was reached. The vehicle did not tip over but ceased to climb because of the lack of contact between the tracks and either the ramp or the ground.

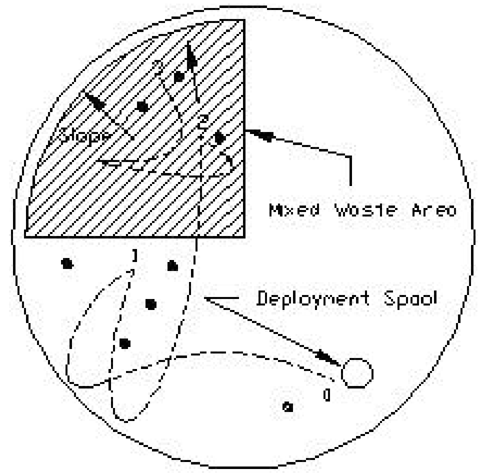

Figure 14. TracPump™ maneuverability test.

To test the control of the umbilical handling system, 55 feet of 5-inch-diameter tank car hose was inserted into the umbilical control system. The system was then operated remotely using the hydraulic power unit. The hose was reeled out and in a number of times to test the umbilical control system and the umbilical apron. This test was then repeated with the TracPump™ assembly retrieval winch connected to the umbilical. The TracPump™ assembly was reeled out and in a number of times using the winch, while the umbilical was controlled by the umbilical control system. No problems were identified. Some sticking of the umbilical to the decontamination vessel was observed during the tests but is not anticipated to be an issue for a tank application because the umbilical used for testing had a rougher jacket material than the urethane jacket proposed for tank applications.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Technology Applicability

Table 4 summarizes waste retrieval elements that were addressed by the ARD Environmental and ESG demonstrations. These elements address application considerations such as riser size required for inserting equipment, waste type, reach, water usage, liquid level required, and liquid level during retrieval operations. Applications that fall outside the parameters evaluated in the demonstrations require further evaluation and discussions with the specific vendor.

Table 4. Summary of waste retrieval elements addressed by demonstrations

Element	ARD Environmental	ESG
Riser diameter	36 inches	24 inches
Waste (based on simulants)	Wet sludge, hardpan/dried sludge, saltcake	Wet sludge, hardpan/dried sludge, saltcake
Reach	Vehicle successfully pulled 50 feet of umbilical	Vehicle successfully pulled 100 feet of umbilical
Water usage	Sluicer: 110 gpm at 400 psi	HIPRESS water-jet: 65 gpm at 15,000 psi
Liquid level in tank required for operation	None: vehicle-based retrieval system tested on simulants with no supernatant layer present	None: vehicle-based retrieval system tested on simulants with no supernatant layer present
Liquid level in tank during retrieval operations	Maximum level observed was 4 inches	Maximum level observed was 4 inches

Baseline Technologies

Past-Practice Sluicing
The commonly used arrangement for a sluicer-based system involves two sluicing nozzles positioned diametrically opposite just inside the tank wall (Erian, Mahoney, and Terrones 1997). A slurry pump is positioned at one side of the tank to retrieve accumulated waste slurry, A heel pump, located near the tank center, is used to dewater the tank. The height of the nozzles above the waste surface is usually fixed, but their orientation (pitch and yaw) relative to the initial horizontal direction along a tank diameter is variable.

For the Hanford Tank C-106 retrieval operation performed between November 1998 and October 1999, a sluicing nozzle and slurry pump were positioned at diametrically opposed locations just inside the tank wall (Bamberger 2000). Sixty-five feet separated the sluicing nozzle and slurry pump. The nominal sluicer flow rate was 350 gpm, with a maximum operating pressure of 300 psi. A video inspection of the tank in July 2000 showed that about 45,000 gallons of waste remained in the tank, made up of mostly liquid, with about 4,500 gallons of coarse rubble in several piles around the tank wall. Due to a decision to forego installation of a heel pump, the remaining solids were not amenable to further sluicing (Cuta et al. 2000).

Jet Mixer Pumps
Jet mixer pumps are sometimes referred to as “long-shaft centrifugal mobilization” or “mechanical mixer” pumps. In a jet mixer pump, waste enters a submerged inlet and passes through an impeller, then out through a pair of jet nozzles (Meyer, Stewart, and Brennen 1999). Two tangentially opposed jet nozzles are located at the end of a jet mixer pump column. The nozzles are opposed to create a net zero force on the pump column. The entire pump-motor assembly rotates so that the two discharge jets sweep the tank bottom. At the West Valley Demonstration Project near Buffalo, New York, 1.5-inch-diameter nozzles discharge liquid at an elevation about 10 inches above the tank bottom (Erian 1999). Each nozzle discharges 600 gpm at the 100% rated centrifugal pump speed of 1800 revolutions per minute. Operational experience at West Valley shows the six jet mixer pumps operate most efficiently with a 14-inch tank liquid

level (Hamel, McMahon, and Meess 2000). Each jet mixer pump has a radius of influence between 13 and 33 feet.

Transfer Pumps
A number of different transfer pumps have been used throughout the DOE complex. For waste retrieval activities, a transfer pump is selected to meet requirements such as retrieval flow rate, compatibility with waste chemistry, and compatibility with slurry properties (e.g., density, viscosity, particle size). At the West Valley Demonstration Project, one long-shafted vertical turbine transfer pump was installed in Tank 8D-2 (Hamel, McMahon, and Meess 2000). This pump is about 40 feet long with the inlet suction about 1.4 inches above the tank bottom. A 20-horsepower motor drives the pump, with a variable flow device for flow control. The pump operates at a typical flow rate of 100 gpm.

Comparison of Vehicle-Based Waste Retrieval System with Baseline
Further evaluation is needed to determine whether the vehicle-based retrieval systems demonstrated could be used in lieu of the baseline retrieval method for future applications similar to those in Hanford Tank C-106, Savannah River Site Tank 19, and West Valley Demonstration Project Tank 8D-2. The demonstrations did result in sufficient information for a general comparison of the ability of the vehicle-based systems to address some of the limitations faced by the baseline retrieval method.

- Effective cleaning radius—The effectiveness of sluicing nozzles and jet mixer pumps to dislodge and mobilize waste decreases as a function of distance from the unit. Multiple jet mixers were needed for applications at West Valley Demonstration Project and the Savannah River Site. A second sluicing nozzle was recommended in the lessons learned document for Hanford C-106 (Bailey 2000). The effective cleaning radius for a vehicle-based system is limited only to those areas accessible by the vehicle. For a tank with no internal obstructions, a vehicle-based system can theoretically clean the entire floor of a tank from a deployment through a single riser.

- Tank liquid level—Jet mixer pumps, and to some extent transfer pumps, are most efficient with a standing liquid level in the tank. This condition may not be acceptable in a potentially leaking tank. The vehicle-based waste retrieval systems demonstrated did not require a liquid level on the waste simulant except for a minimal liquid level in the localized area around the waste conveyance system to cover the suction inlet. The maximum liquid level in the tank during the two demonstrations was 4 inches and may be reduced by improved waste conveyance methods.

- Bulk suspension of solid waste—The baseline retrieval method operates either by pushing waste towards the transfer pump (sluicing-based system) or by suspending and mixing waste solids into solution for retrieval by a transfer pump (jet mixer pump–based system). The vehicle-based waste retrieval systems demonstrated showed that waste dislodging and conveyance can be performed in localized areas and not require bulk movement of the waste.

Patents/Commercialization/Sponsor

The Tanks Focus Area and Hanford Tank Waste Remediation System (now the River Protection Project) funded the two demonstrations. The two demonstrations utilized full-scale prototypical and commercially available equipment. System components are commercially available from the two demonstration project teams.

SECTION 5
COST

Methodology

The evaluation of cost for a vehicle-based, waste retrieval system is influenced by waste properties, tank configuration, and site cleanup requirements. There are no historical costs for application to large (75- to 85-foot-diameter) underground radioactive waste tanks. Proposed project costs to retrieve waste from four large tanks in Hanford's AX tank farm were used to illustrate costs of both baseline past-practice sluicing and a vehicle-based retrieval system (Krieg 1998).

Description of Tanks in Hanford AX Tank Farm
The four single-shell tanks in the AX tank farm are AX-101, -102, -103, and -104. Each tank has a capacity of 1,000,000 gallons, a diameter of 75 feet, and a flat tank floor that is 50 feet below surface grade. All four tanks are made of concrete with an inner steel liner.

Assumptions for Cost Estimate
Table 5 shows 1998 waste volumes used for the cost estimate. The table also contains tank waste volumes as of May 31, 2001 and proposed end-point volumes to be reached by past-practice sluicing and/or vehicle-based sluicing. An assumption was made that vehicle-based sluicing could yield an end-point volume of 2,700 gallons per tank. For the tanks in the AX tank farm, 2,700 gallons is equivalent to a layer of residual waste 1.3 inches deep, assuming a perfectly flat tank floor. The floors of AX tanks are likely to be somewhat uneven.

Table 5. AX tank farm waste volumes and proposed end-point volumes

Tank	Waste volume[a] (gal)	Waste volume[b] (gal)	Proposed end-point volume (gal)
AX-101	750,000	662,000	Sluicing down to 17,000, followed by vehicle sluicing to 2,700
AX-102	33,000	30,000	Vehicle sluicing to 2,700
AX-103	112,000	112,000	Sluicing down to 17,000, followed by vehicle sluicing to 2,700
AX-104	7,000	8,000	Vehicle sluicing to 2,700

[a] Krieg 1998.
[b] May 31, 2001.

The baseline sluicing system envisioned for the AX tank farm project was based on past-practice sluicing operations in Hanford Tank C-106. Because of numerous internal structures inside the AX tanks, one sluicing stream would have limited access to residual waste. Therefore, the cost estimate for AX sluicing assumed that two sluicing nozzles would be positioned at opposite sides of the tank. The C-106 sluicing system used a single nozzle. The vehicle-based system envisioned for the AX tank farm project was to be a second-generation system based on lessons learned from the ARD Environmental and ESG demonstrations. Cost risks and cost uncertainties identified for the AX tank farm project are summarized below. Many of the cost uncertainties deal with the undemonstrated ability to retrieve waste down to a residual volume of 2,700 gallons.

- Technical capability—The effectiveness of a vehicle-based retrieval system in removing waste to less than a 1.3-inch depth across the entire tank floor has yet to be demonstrated in a Hanford tank.

- Maneuverability—The assumption was made that the vehicles can maneuver around in-tank obstacles pulling the umbilical forward and then retreat as the umbilical is pulled back. There are considerable uncertainties. Backtracking the vehicle through a maze of obstacles requires the ability to steer the vehicle and simultaneously coordinate umbilical withdrawal. Potential entanglement of the umbilical remains a concern to be addressed in hot demonstrations.

- In-Tank Equipment—The AX tanks contain a maze of equipment extending down to the floor of the tank or near the bottom of the tank. There are 22 air-lift circulators, 30 inches in diameter, which reach down to within 2 feet of the tank bottom. Saltwell screens typically extend within 2–5 inches from the bottom of the tank. Equipment extending into the tank at various levels include thermowells, thermocouple trees, drywells, and miscellaneous instruments. The spacing of in-tank equipment must be analyzed before a vehicle-based system can be deployed.

- Air-lift circulators—The ability of a vehicle to remove waste from the interior of the 30-inch-diameter circulator pipe is not known. To achieve a total tank residual waste volume of 2,700 gallons, waste may have to be removed from the interior and exterior of the air-lift circulators as well as the interior and exteriors of salt wells.

- Operational time—The assumed retrieval rates for past-practice sluicing and vehicle-based sluicing are based on discussions with personnel familiar with the C-106 retrieval project at Hanford and personnel with experience with in-tank vehicles used at the Oak Ridge Reservation. The retrieval time will be different for each tank depending on unique internal obstructions and different degrees of difficulty in dislodging residual waste.

- Saltcake sluicing—Past-practice sluicing experience at Hanford has been with sludge. The assumption that past-practice sluicing will dislodge the majority of the saltcake from Tanks AX-101 and AX-103 is not based on actual experience. This lack of experience, combined with lack of data on the waste properties, results in significant uncertainties for the cost of sluicing these tanks.

Cost Analysis

The estimated project cost to retrieve waste from four Hanford AX tanks is shown in Table 6 (Krieg 1998). The assumed end-point volume in each tank was 2,700 gallons (360 cubic feet) of residual waste.

Table 6. Cost estimate to retrieve waste from four Hanford AX tanks

Task Element	Cost ($)	Comment
Remove long-length contamination equipment	2,818,000	Includes $600,000 to remove new sluicer from AX-101 and AX-103 to allow for vehicle insertion.
Procure and install sluicing system for AX-101 and AX-102	22,446,000	Based on Tank C-106 waste retrieval project estimated costs with addition of second nozzle.
Control room for sluicing system	204,000	One-time, up-front cost.
Procure and install vehicle-based system for all tanks	11,442,000	Equipment $5,500,000; installation $842,500 per tank; contract and other cost $2,572,000.
HVAC system for all tanks	1,082,000	One-time, up-front cost.
Transfer line to Tank 241-AY-102	980,000	One-time, up-front cost.
New jumper pit	334,000	One-time, up-front cost.
Decontaminate and clean 11 pits in AX and AY Tank Farms	16,500,000	Estimated as one-time cost; may need to be repeated.
Balance of plant modifications and installations	5,343,000	Examples: waste line jumpers; cover block removal, fabrication, disposal; and new concrete pads.
Safety and permitting	1,393,000	One-time, up-front cost; assumes no unusual event.
Sluicing operational costs	2,470,000	24.3 weeks for AX-101 and 8.2 weeks for AX-103. Round-the-clock operation. Five-person crews, four shifts. Site personnel operate sluicing system.
Vehicle system operational costs	3,699,000	AX-101 (19.9 days), AX-102 (21.4 days), AX-103 (19.9 days), AX-104 (6.0 days). Round-the-clock operation. Four weeks to move system between tanks. Four weeks to dismantle system. Vendor crew operates. Dedicated site support crew.
TOTAL	**68,711,000**	

Table 6 provides a cost estimate for a retrieval project of an entire tank farm. Table 7 separates the project costs into three separate categories: costs to prepare the tank farm for retrieval, past-practice sluicing costs, and costs for the vehicle-based retrieval system.

Table 7. Cost of sluicing technologies, in dollars

Task element from Table 6	Cost from Table 6	Tank farm preparation	Past-practice sluicing	Vehicle-based retrieval
Remove long-length contamination equipment	2,818,000	2,818,000		
Procure and install sluicing system for AX-101 and AX-102	22,446,000		22,446,000	
Control room for sluicing system	204,000		204,000	
Procure and install vehicle-based system for all tanks	11,442,000			11,442,000
HVAC system for all tanks	1,082,000	1,082,000		
Transfer line to Tank 241-AY-102	980,000	980,000		
New jumper pit	334,000	334,000		
Decontaminate and clean 11 pits in AX and AY Tank Farms	16,500,000	16,500,000		
Balance of plant modifications and installations	5,343,000	5,343,000		
Safety and permitting	1,393,000	1,393,000		
Sluicing operational costs	2,470,000		2,470,000	
Vehicle system operational costs	3,699,000			3,699,000
TOTAL	**68,711,000**	27,470,000	25,120,000	15,141,000

Table 7 shows that the cost estimated to prepare the four AX tanks for retrieval was $27,470,000. These preparatory costs are likely to be the same regardless of which final retrieval technology is deployed. The estimated cost of past-practice sluicing technology for two tanks was $25,120,000. The estimated cost of deploying the vehicle-based retrieval system was $15,141,000 for four tanks, or about $4 million per tank.

Tables 6 and 7 show a preoperational cost of $11,442, 000 to procure one vehicle-based retrieval system and install it into four tanks (Krieg 1998). Procurement cost is broken down as follows. The vehicle cost was $5,500,000, including vendor design, fabrication, testing, and delivery of a system ready to install in a Hanford tank (see Table 8). A vendor cost of $1,272,000 was estimated for preoperational work, including the operational readiness review, training, and acceptance testing over a 6-month period. The Hanford contractor cost of $1,300,000 included bid and award ($200,000), contract management ($400,000), first readiness review/acceptance test plan ($400,000), and three additional acceptance test plans ($300,000 total). The estimated cost to install a vehicle-based retrieval system into a radioactive waste tank was $842,500 per tank, yielding the total preoperational cost of $11,442,000.

Table 8. Cost of vehicle-based retrieval system

Cost element	Cost ($)	Comments
Vehicle and support equipment	5,500,000	Hardware costs only
Vendor preinstallation expense	1,272,000	Vendor participation in operational readiness review, training, authorization to proceed
Hanford contractor preinstallation expense	1,300,000	Contract management, operational readiness review, authorization to proceed
Subtotal: Preinstallation expense	8,072,000	Subtotal of first three cost elements
Installation into one tank	842,500	Installation costs $842,500/tank

Operational costs per tank	925,000	24-hour operation, vendor operates, dedicated site support crew
Total cost to retrieve first tank	9,839,500	Preinstallation + installation + operational costs
Cost for second tank	1,767,500	Installation and operational costs only
Cost for third tank	1,767,500	Cumulative = $13,374,500, or $4,460,000/tank
Cost for fourth tank	1,767,500	Cumulative = $15,142,000, or $3,788,000/tank

The vehicle-based retrieval system has a preinstallation cost of $8,072,000, with an additional cost of $1,767,500 per tank for installation and operation. Since both vehicles demonstrated were designed to be retrieved from a tank and reused, the overall cost per tank goes down as more tanks are emptied. For example, use of a vehicle-based retrieval system in 10 tanks would incur a one-time cost of $8,072,000 for the initial purchase and training followed by a $1,767,500 cost per tank for installation and operation, yielding a 10-tank total cost of $25,747,000. The average cost per tank would be $2,575,000.

Cost Conclusions

The estimated costs presented in this section are for illustrative purposes only. Each tank will have different internal obstructions and different degrees of difficulty in dislodging residual solids.

The cost analysis illustrates that a one-time application of the vehicle-based retrieval system would cost about $10 million. The cost per tank goes down if the vehicle is used over and over in several tanks. The per-tank cost for 10 tanks would be $2.6 million; for 20 tanks it would be $2.2 million per tank. Additional cost reductions can be realized by replacing the vendor crew with a site crew. Cost reductions can be realized by reducing the hours for the full-time site support crew to vehicle installation and removal. The costs of vehicle installation, operation, and withdrawal are expected to decrease as experience is gained.

SECTION 6
OCCUPATIONAL SAFETY AND HEALTH

The following sections provide an overview of occupational safety and health aspects of the vehicle-based retrieval systems based on information contained in demonstration documents; it is not intended to be a complete safety and health evaluation of the technology.

A Technology Safety Data Sheet is not currently available for either of the vehicle-based retrieval systems demonstrated. When a Technology Safety Data Sheet has been completed, the document will be available via the Office of Science and Technology Web site or from the International Union of Operating Engineers, the organization currently tasked with preparing this information.

Comparison with Baseline Operating Safety

Deployment of a vehicle-based retrieval system will require the use of a crane and at least one dedicated riser. Existing procedures used for the installation of long-length equipment such as mixer pumps and transfer pumps into underground radioactive waste storage tanks will also be applicable for the installation of the vehicle-based retrieval systems. In-tank lighting and video surveillance equipment is needed during deployment and operation of the vehicle-based, in-tank retrieval systems.

Additional requirements for surface support include a means for supplying water to the decontamination chambers, a location for the hydraulic systems, and a location for the control trailer. The pressure required for the ARD Environmental waste dislodging component is 400 psi, which is comparable to the 300 psi for a typical past-practice sluicing nozzle. With the ESG system, the pressure needed for the HIPRESS water-jet tool is 15,000 psi. This higher pressure allows for a lower liquid flow rate for the dislodging operation (e.g., 65 gpm for the ESG system compared to 110 gpm for the ARD Environmental system and 350 gpm for a sluicing nozzle).

Comparison with Baseline Maintenance Safety

The decontamination chambers designed by the ARD Environmental and ESG teams are used for maintenance as well as decontamination. The decontamination/maintenance chamber provides containment and access not typically available to baseline technologies such as mixer pumps and transfer pumps. Because the decontamination/maintenance chamber is attached to the top of the riser, decontamination fluids carrying residual contamination fall into the tank below. After a vehicle used in the tank has been decontaminated, maintenance can be performed within the same containment chamber through access ports in the side of the chamber. Maintenance requirements for the at-tank support systems, such as the hydraulic power supply, control system, and retrieval fluid flow systems, are anticipated to be equivalent to existing systems in use at Department of Energy sites.

Required Safety and Health Measures

Both of the demonstrated vehicle-based retrieval systems use pressurized fluid for dislodging waste. The requirements for the ARD Environmental system are comparable to those of a sluicing nozzle; the requirements for the ESG system are significantly higher. However, because a higher fluid pressure is used by the ESG system, a lower flow rate of water is needed for waste dislodging compared to the other two systems.

Additional precautions associated with mechanical movement of equipment and pressurized hoses on top of the tank should be reflected in operating procedures and operator training. Precautions associated with the transfer of waste material between tanks is site specific and the responsibility of the site contractor.

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SECTION 7
REGULATORY AND POLICY ISSUES

Regulatory Considerations

Regulatory acceptance of a vehicle-based waste retrieval system is not considered a potential issue, based on the extensive commercial use of in-tank vehicles to perform a variety of applications and prior application of in-tank vehicles at the Oak Ridge Reservation (OST 1999, 2001). Results from the two 1997 Oak Ridge demonstrations are most applicable for Hanford but are also useful for the large tanks at the Savannah River Site.

Secondary Wastes
Operation of either of the two vehicle-based systems is not anticipated to create a significant secondary waste stream. Water used for the decontamination of in-tank systems and for the interior of the decontamination chambers is returned to the tank in the current system designs. Decontamination of aboveground equipment may generate secondary liquid and solid waste. Solid secondary waste may also be generated from the maintenance of equipment. The quantity of secondary waste generated from a vehicle-based waste retrieval system is not anticipated to be greater than that generated from other in-tank systems.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Evaluation

This section summarizes how the vehicle-based waste retrieval systems address CERCLA evaluation criteria.

1. *Overall Protection of Human Health and the Environment*
   Use of a vehicle-based waste retrieval system is envisioned to result in a greater percentage of material being retrieved from waste tanks with minimal additional worker exposure.

2. *Compliance with Applicable or Relevant and Appropriate Requirements*
   The vehicle-based waste retrieval systems demonstrated in 1997 were designed to meet Hanford Site requirements. Compliance issues with the deployment of either of the two systems at Hanford are not anticipated. Further evaluation is needed for application of these systems at other Department of Energy sites.

3. *Long-Term Effectiveness and Permanence*
   Use of a vehicle-based waste retrieval system is envisioned to result in a greater percentage of material being retrieved from waste tanks, thus reducing the long-term risk from residual tank waste material by minimizing the quantity of material left in a tank.

4. *Reduction of Toxicity, Mobility, or Volume Through Treatment*
   Use of a vehicle-based waste retrieval system is envisioned to result in a greater percentage of material being retrieved from waste tanks, thus reducing the quantity of residual tank waste material. The reduction of the quantity of residual tank waste material should therefore improve the performance of a tank closure method for reducing toxicity and mobility of residual waste.

5. *Short-Term Effectiveness and Permanence*
   Use of a vehicle-based waste retrieval system is envisioned to result in a greater percentage of material being retrieved from waste tanks, thus reducing risk from residual tank waste material by minimizing the quantity of material left in a tank. One potential short-term operational concern is the vehicles' umbilical cord getting tangled in internal tank obstacles. Future design considerations will be needed for umbilical management in tanks with internal obstructions.

6. *Implementability*
   Full-scale testing of vehicle-based waste retrieval systems has been completed and showed the equipment capable of meeting performance requirements for the Hanford Site. Further evaluation is recommended to ensure the compatibility of equipment with tank-specific requirements and appropriateness of equipment for a specific tank waste.

7. *Cost*
   Relative to the baseline method using jet mixer pumps, transfer pumps, and sluicing wands, a vehicle-based waste retrieval system represents increased capital cost. However, if the use of a vehicle-based system is implemented, it will be because the baseline methods are not capable of meeting cleanup goals or because the baseline methods have reached a point of diminishing return for the amount of waste retrieved per retrieval campaign. Operating costs for a vehicle-based system are estimated to be the same as or lower than those for a sluicing wand because of the remote operation aspect. Waste retrieval efficiency is anticipated to be higher for a vehicle-based system than for the baseline because the suction pickup point can be moved to the location of the waste rather than relying on movement of the waste to the suction points of the transfer pumps fixed in one location.

8. *State Acceptance*
   No issues are anticipated for state acceptance of a vehicle-based system because similar systems have been used commercially for nonradioactive storage tanks. In addition, the deployment of a vehicle-based waste retrieval system would enable a site to meet tank cleanup criteria, should the baseline methods prove to be inadequate.

9. *Community Acceptance*
   No issues are anticipated for community acceptance of a vehicle-based system because similar systems have been used commercially for nonradioactive storage tanks.

Safety, Risks, Benefits, and Community Reaction

These topics have been addressed above under “Regulatory Considerations” and also in Section 6, “Occupational Safety and Health.” Site and tank-specific requirements will dictate needed modifications to either of the demonstrated vehicle-based waste retrieval systems prior to deployment.

SECTION 8
LESSONS LEARNED

Design and Implementation Considerations

The ARD Environmental and ESG demonstrations provided an opportunity to determine which aspects of each retrieval system required future adjustment. Each demonstration was designed to learn how vehicle-based equipment would perform using Hanford simulated waste.

Ingress/Egress Through Riser
The ARD Environmental Big Wheels was lowered through a 36-inch riser into the test bed without incident. Two water-scavenging modules were also lowered through the riser to remove water that accumulated in the outer edges of the tank floor. Three separate placements of equipment through the 36-inch-diameter riser were required to complete the Big Wheels installation.

In an open tank with no internal obstacles, a test was performed to determine whether a Big Wheels with no power to its wheels could be dragged through the simulated sludge and lifted out of the riser. The Big Wheels weighs about 2,000 pounds, and the tires are 2 feet in diameter. Retrieval was successful, even with the Big Wheels tipped over on its side.

The ESG TracPump™ assembly was lowered through a simulated tank riser 24 inches in diameter and 10 feet long. The TracPump™ assembly was equipped with the HIPRESS tool, sludge pump, simulated umbilical, claw tracks, and folding mechanism. Although the TracPump™ assembly was able to pass through the riser, more clearance should be provided to allow for movement of equipment. This accommodation can be achieved in either of two ways:

- Decrease each pontoon width by 2 inches. This change will provide ample clearance without affecting the performance of the TracPump™ unit.

- Make the pump base portion of the TracPump™ 2 inches narrower by integrating the pump base and casing. This alternative will not affect the performance of the TracPump™ unit.

Umbilical Handling System
The controls for the ARD Environmental Big Wheels contained 19 hoses bundled in an umbilical 6 inches in diameter. The umbilical contained 16 hydraulic hoses, a 3-inch suction/discharge line, and two 1-inch water lines. The system demonstration confirmed the Big Wheels had sufficient power to drag 50 feet of umbilical through a test bed of solids.

The ECG TracPump™ had sufficient power to drag 100 feet of umbilical consisting of a 5-inch tank-car hose (sludge pump discharge hose), four hydraulic fluid supply hoses, and a high-pressure water supply hose. The umbilical control system was located in the decontamination chamber where the umbilical was sprayed down with water and coiled as it was withdrawn. Coiling of the umbilical in the decontamination chamber was an effective way to manage the movement of the umbilical in and out of the tank. Some sticking of the umbilical to the decontamination vessel was observed during the tests but was not anticipated to be an issue for a tank application because the umbilical used for testing had a rougher jacket material than the urethane jacket proposed for tank applications. During testing the umbilical rubbed against umbilical control system chain drive. A future action will be to reposition sprockets or install a chain guard.

Future design considerations will be needed for umbilical management in tanks with internal obstacles. The ability of a 6-inch umbilical to bend and weave around obstacles remains to be demonstrated.

Vehicle Maneuverability
The demonstration showed that the ARD Environmental Big Wheels was a very powerful vehicle that could extricate itself from complete emersion in solids. With motors on each of four wheels, the Big Wheel's mobility was limited only by tire tread. The tread had to be kept open to prevent solids from accumulating in

the tread with a resulting loss of all traction. Tire chains were added to improve traction. Future vehicle designs should incorporate tires with the most aggressive tread design possible.

The Claw Tracks (patent pending) on the ESG TracPump™ enabled it to climb over slippery surfaces without becoming mired. Claw Tracks are tracks with replaceable carbide-tipped spikes attached in a pattern specifically designed for the rough terrain and slipperiness of Hanford waste. The lesson learned was that the TracPump™ tipping angle was greater than 65 degrees. With the umbilical in place, the turning radius was 8 feet. The umbilical limited the maneuverability of the vehicle. Turning the TracPump™ created forces on the umbilical attachments. The cam-lock fitting used to attach the umbilical with the pump discharge failed. A more rugged fitting capable of withstanding the loads encountered needs to be installed for future tests.

Waste Retrieval
The ARD Environmental Big Wheels contained a high-pressure sluicer for breaking up solids; however, the tires on the Big Wheels proved more effective in breaking up solids. By operating the front and back sets of wheels in opposite directions (each wheel has its own motor), the resulting thrashing action and weight of the vehicle was effective in breaking up solids.

During the ARD tests, the suction pump operated only when it was fully submerged. Every time the suction pump was lifted out of the water, it would lose prime and cavitate, and reestablishing prime proved difficult. It was also difficult to maintain the suction pump under water as the Big Wheels was moved. Maneuvering the vehicle invariably broke the suction and lost the prime. When the pump lost its prime, water accumulated and flowed over to the two water-scavenging modules. Over 50% downtime was attributed to priming the pump. Future testing should focus on providing a greater water level to eliminate broken suction at the point of sluicing. Future development efforts should consider a pump that is easier to prime.

The ESG TracPump™ was a moving platform on which different sluicing/cutting/mining tools could be attached. The high-pressure water jet was the most effective in dislodging solids. Mills and grinders were ineffective in dislodging waste simulants because the solids caked on the tools, rendering them useless. Most of the testing was therefore focused on the water jet. A great deal of time was needed to define the best combination of pressure and flow rate through the water jet to achieve optimum waste retrieval rates. A high-pressure water lance backflush system was developed and successfully used to unplug discharge lines purposely plugged with solids. Dislodging pressures up to 3,000 psi were used.

Decontamination
The use of the ARD decontamination chamber with fixed spray rings and a manually operated spray wand was effective at removing waste simulant from the Big Wheels vehicle and its umbilical. The areas that were particularly difficult to clean were the hydraulic hose bundle (umbilical), the region around the sluicer lift arms at the motor shafts (sluicer shroud), and the vehicle motor mount boxes. The residual material between the hoses in the umbilical was found where the hoses were bundled with tie-wraps. Material located in these areas was easily removed. The dye tracer mixed in with the simulant waste was not useful in determining the presence of residue on the equipment. The presence of residue was easily determined visually. Future design of the Big Wheels for a tank application should address the areas of equipment that collected material and should use a continuous sheath around the umbilical.

Decontamination of the umbilical and the ESG TracPump™ was easily performed in the decontamination chamber. The coiling of the umbilical within the decontamination chamber provided containment.

Technology Limitations and Needs for Future Development

Areas that require further evaluation and/or development include the following abilities:

- maneuver in a tank with suspended in-tank equipment such as air-lift circulators,
- decontaminate suspended in-tank components such as air-lift circulators,
- remove the last 1–2 inches of residual waste from the tank floor, and
- deploy a vehicle into residual waste that covers the entire vehicle and all other deployed components.

Technology Selection Considerations

Vehicle-based waste retrieval systems are well suited for applications in potentially leaking tanks. By deploying waste dislodging and conveyance tools directly on the waste instead of requiring bulk movement of waste to a transfer pump, a localized retrieval area is established that minimizes or eliminates the standing liquid level across the entire tank floor during retrieval.

A vehicle-based system is useful for applications with just one tank riser or when riser use is limited to one or two. The ARD Environmental system would require insertion of a vehicle and a slurry scavenging system through one riser and the insertion of another slurry scavenging system through a different riser. The ESG system was designed for deployment through a single riser. For comparison, the baseline retrieval method requires a minimum of two insertions (e.g., one sluicing nozzle and one transfer pump for C-106). More insertions are likely needed for large-diameter tanks because the effective cleaning radius for the baseline dislodging and mobilization methods would not encompass the full area of a large tank from installation through a single riser.

A vehicle-based system has the capability to reach every part of a tank that is open and free of internal obstructions. Tanks with no obstructions are candidates for vehicle-based retrieval systems. The presence of obstructions remains a topic for future development. Obstructions around the entry riser create a question of snagging the umbilical as the vehicle moves off-center. The presence of air-lift circulators extending to within 2 feet of the tank floor creates another question regarding the ability of a vehicle to work under the circulators. Each tank is expected to contain a unique array of internal obstructions that have to be taken into consideration prior to deployment of a vehicle-based system.

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APPENDIX A
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APPENDIX B
ACRONYMS AND ABBREVIATIONS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
ESG	Environmental Specialties Group
gpm	gallons per minute
OST	Office of Science and Technology
psi	pounds per square inch