DOCUMENT RELEASE AND CHANGE FORM

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By Washington River Protection Solutions, LLC., PO Box 850, Richland, WA 99352
Contractor For U.S. Department of Energy, Office of River Protection, under Contract DE-AC27-08RV14800

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RPP-PLAN-62256
Revision 1

Alternative Retrieval System Program Plan

Prepared by

Ted Wooley
Doug Reid
Thom Myer

Washington River Protection Solutions, LLC

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EXECUTIVE SUMMARY

The Washington River Protection Solutions, LLC (WRPS) Chief Technology Office (CTO) is chartered with advancing technologies within the Hanford Site tank farms and integrating with other Hanford Contractors as necessary. The objective of technology development is to achieve Hanford mission goals efficiently, safely, and within budgetary constraints. The CTO Alternative Retrieval System Program is devoted to developing and implementing alternative retrieval technologies to support the following efforts:

- Retrieve waste from single-shell tanks and transfer the waste to double-shell tanks or treatment facilities
- Retrieve waste from double-shell tanks to deliver waste feed to waste treatment facilities.

This program plan defines the current retrieval-based technologies that are either being considered for development or are under development by CTO or WRPS Retrieval organization with the help of subcontractors.

Technology needs are identified through project planning and consolidated within the Technology and Innovation Roadmap.[1] The Roadmap provides the basis for this program plan and all other plans administered by the CTO. Based upon a broad range of input, the Roadmap categorizes technologies that are either planned (funded and currently in the tank farms baseline) or needed which indicates a technology that could be useful but is not currently being sponsored by the U.S. Department of Energy, Office of River Protection. Ranking and rating (high, medium, and low) of one technology over another is a process defined within the Roadmap that serves to help prioritize technology development activities.

This program plan focuses on upcoming retrieval activities planned in the A and AX Tank Farms.

[1]RPP-PLAN-43988, 2018, *Technology and Innovation Roadmap,* Rev. 4, Washington River Protection Solutions, LLC, Richland, Washington.

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LIST OF TERMS

Abbreviations, Acronyms, and Initialisms

3D	three-dimensional
ART	alternative retrieval technology
ASD	auger sampling device
CCTV	closed-circuit television
CTE	critical technology element
CTF	cold test training and mockup facility
CTO	Chief Technology Office
DOE	U.S. Department of Energy
DST	double-shell tank
EOI	expression of interest
ERSS	extended reach sluicing system
HRHM	high-radiation hose materials
HIHTL	hose-in-hose transfer line
HWEE	Hanford waste end effector
LIDAR	light detection and ranging
MWGS	mechanical waste gathering system
MARS	mobile-arm retrieval system
NRIS	new riser installation system
ORP	Office of River Protection
ORSS	off-riser sampler system
PNNL	Pacific Northwest National Laboratory
QA	quality assurance
R2A2	Roles and Responsibilities, Authorities and Accountabilities
Roadmap	*Technology and Innovation Roadmap* (RPP-PLAN-43988)
ROI	return on investment
ROV	remotely operated vehicle
RPP	River Protection Project
RTW	retrieve tank waste
RVMS	residual volume measuring system
SST	single-shell tank
System Plan	*River Protection Project System Plan* (ORP-11242)
TE	technology element
TEDS	Technology Element Description Summary
TMP	training management plan
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
WRPS	Washington River Protection Solutions, LLC

Units

”	inch
°	degree
°F	degrees Fahrenheit
%	percent
µCi	microcurie
µm	micrometer
cP	centipoise
ft	foot
ft^3	cubic feet
in.	inch
g	gram
gal	gallon
kgal	thousand gallons
Mgal	million gallons
mL	milliliter
mph	miles per hour
Pa	pascal
psi	pounds per square inch
R/hr	Roentgens per hour
rad	radiation absorbed dose

1.0 PURPOSE

The purpose of this program plan is to describe and facilitate the overall approach needed to identify, develop, and allow successful deployment of new or enhanced alternative retrieval technologies (ART) for solids removal from waste tanks at the Hanford Site tank farms. The current near-term program focus is retrieving waste from single-shell tanks (SST) in the A and AX Tank Farms.[2] The longer-term goal of this program is to develop the technology necessary to support retrieving all of the remaining tank waste solids in a safe and efficient manner. Tank retrieval activities are governed by ORP-11242, *River Protection Project System Plan*, herein after referred to as the System Plan.

This program plan addresses baseline need and mission risk as identified in the Enterprise Risk and Opportunities Management System as RPP-006. This River Protection Project (RPP) mission-wide risk is titled "SST retrieval system performance does not meet requirements due to controllable causes." The U.S. Department of Energy (DOE), Office of River Protection (ORP) owns this risk. The Washington River Protection Solutions, LLC (WRPS) Retrieval and Chief Technology Office (CTO) organizations handle associated risk mitigation.

1.1 TECHNOLOGY DEVELOPMENT

Technology development is a defined process that includes identifying components or technology elements (TE) needed to advance the technology. This process originated from DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*. Tank farms implementing documents include TFC-PLN-90, *Technology Maturation Management Plan*, and TFC-ENG-TD-C-01, *Technology Maturation Management*. Individual related TEs are typically part of a bigger system.

A TE is "critical" if the system being acquired depends on the TE to meet operational requirements (with acceptable development cost and schedule, and with acceptable production and operations costs) and if the TE or its application is either new or novel. Appendix A provides the critical technology element (CTE) determination process, identified in Tank Farm Contractor procedures.

Technology Readiness Level (TRL) is a metric used for describing the level of technological maturity. U.S. government agencies use this measurement to assess the maturity of evolving technologies (e.g., materials, components, devices) prior to incorporating that technology into a system or subsystem. The TRL scale ranges from 1 (basic principles observed) through 9 (a total system used successfully in project operations). TRL is not an indication of the quality of technology implementation in the design; however, technology testing results are critical in determining the TRL.

At Hanford, a TRL <6 can be generally applied to those WRPS technologies that are under the scope of the CTO. A TRL of 6 is considered the point at which a technology is transitioning into full-scale operations (see Figure 1). TRL 6 is the point at which technology development ends and technology deployment begins; however, TRL 6 could require further refinement including redesign and testing prior to actual deployment. Figure 1 shows the commonly used terms to

[2] All Hanford Site tank farm and tank designations begin with prefix '241-' which is not used for this report to aid readability.

describe the level of maturity associated with each TRL. Table 1 lists TRLs and associated testing configuration and the test environment.

Figure 1. Technology Readiness Levels.

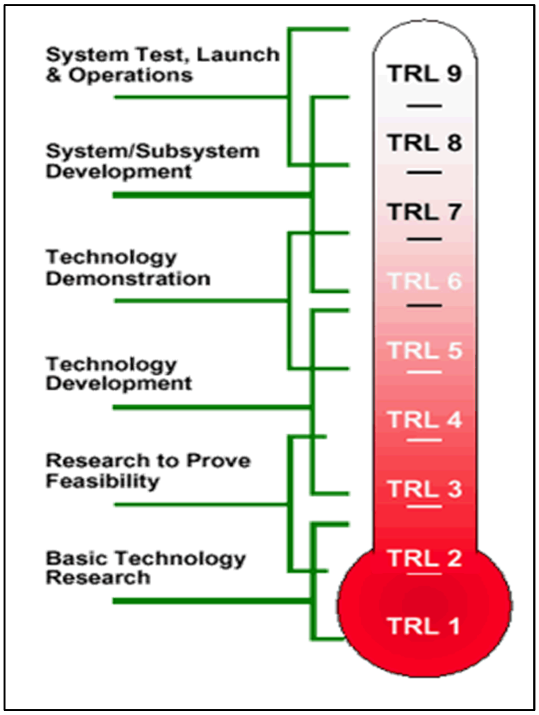


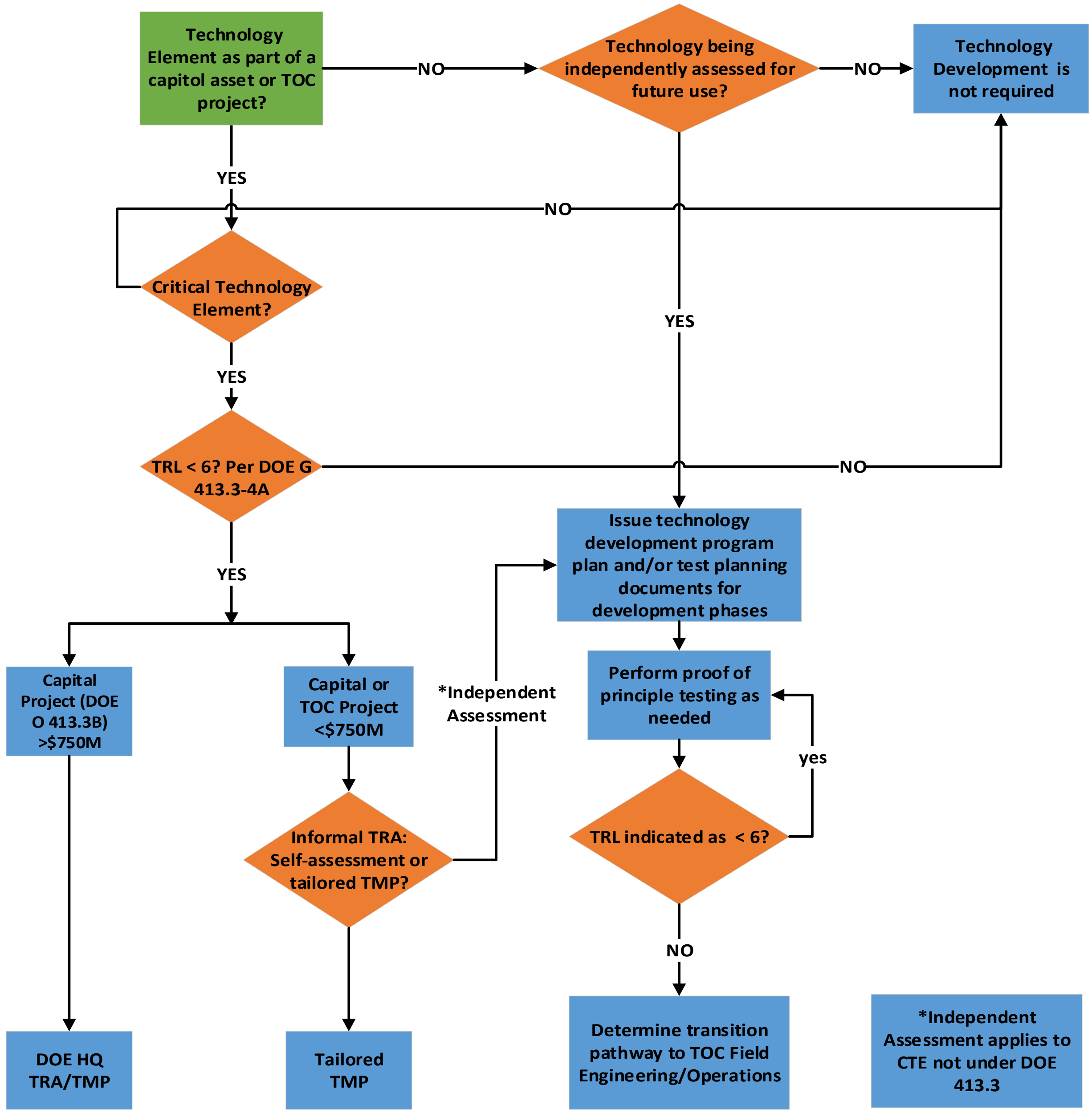
Table 1. Technology Readiness Level vs. Testing.

TRL Level	Scale of Testing	Configuration	Environment
9	Full	Identical	Operational (full range)
8	Full	Identical	Operational (limited range)
7	Full	Similar	Relevant
6	Engineering/Pilot Scale	Similar	Relevant
5	Lab/Bench	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2	N/A	Paper	N/A
1	N/A	Paper	N/A

It should be noted that a single system can have several CTEs at different TRLs. For example, a system could be comprised of one CTE that is at TRL 5 and have other CTEs at lower or higher TRLs. Appendix B includes a TRL assessment for all technologies included in this document.

Figure 2 is used to determine whether technology development is relevant and, if so, which pathway it should take. Note that a TE does not have to be a CTE to undergo technology development. CTEs are typically tied to a project and have a need date. Non-project TEs that have a legitimate future-use may be independently assessed and developed for incorporation into a future retrieval effort.

Figure 2. Technology Maturation Decision Flowchart.



DOE	=	U.S. Department of Energy.	TMP	=	training management plan.
TOC	=	Tank Operations Contractor.	TRL	=	Technology Readiness Level.
TRA	=	Technology Readiness Assessment.			

1.2 TECHNOLOGY DEVELOPMENT PRIORITIZATION

Technology development priority is assigned based on whether a technology is considered a ORP strategic need and when it is needed for use. A "high" priority is assigned to a technology needed with 1 to 4 years, addressing a near-term mission need. A "medium" priority technology is needed with the next 10 years and should begin development within the next 5 years. A "low" priority technology is not needed within the next 10 years nor requires development within the next 5 years.[3] All high-priority technologies are further ranked to determine their relative importance. For example, a high priority technology with a number 2 ranking should take precedent over a high priority technology with a number 3 ranking.

1.3 TANK RETRIEVAL NEAR-TERM MISSION NEED

An ART and/or improvement to previous waste retrieval techniques are needed to meet a 2016 Consent Decree milestone to retrieve the next nine tanks by 2024. WRPS has determined the best approach to meet this decree is to retrieve waste from the A and AX Tank Farms. Thus, the ARTs must improve the removal of hard-packed wastes in leaking SSTs and provide efficiency improvements over previous retrieval techniques (i.e., improved retrieval rates and dilution ratios) for softer solids in non-leaking tanks. Along with development of retrieval technologies, better access to tank bottoms and more accurate waste volume measurement techniques must also be developed.

ARTs developed under this program will support waste retrieval not only from A and AX Tank Farms, but all other future retrievals as well. Targeted development includes retrieval technologies, better access to tank bottoms, and more accurate waste volume measurement.

Initial deployment of the mechanical waste gathering system (MWGS) targets retrieval of tank A-104, a known leaking tank (HNF-EP-0182, *Waste Tank Summary Report for Month Ending February 28, 2018*). Tank A-104 has hard heel material. Deployment will be dependent upon the technology readiness level with respect to the retrieval schedule and specific need dates. There would be an improvement of retrieval by using this technology over other wet retrieval technologies (i.e., sluicing technologies). MWGS is considered a CTE because there are no known dry retrieval technologies available for Hanford use at this time.

Retrieval of tank A-106 is targeted deployment of the Hanford waste end effector (HWEE). Tank A-106 has saltcake and sludge, which requires sluicing. Deployment will be dependent upon the technology readiness level with respect to the retrieval schedule and specific need dates. The HWEE could be an improvement over previous sluicing technologies because of its improved retrieval rates and dilution ratios (see Section 5.3.6) based on early testing results. The HWEE is not considered a CTE because there are available sluicing systems previously used for Hanford tank retrievals.

1.4 EXTENDED MISSION NEED

The extended RPP mission need is discussed in the System Plan (Rev. 8). The timeline for retrieval of the nine remaining SST farms and closure of the double-shell tank (DST) farms is outlined following the retrieval of the A and AX Tank Farms. The system plan identifies the

[3] See RPP-PLAN-43988 Rev. 3 for further detail.

retrieval of all SSTs by 2058 and closure of the DSTs by 2063. Retrieval of waste from these tanks may use many of the same systems used to retrieve waste from C, A, and AX Tank Farms. The development of more efficient salt cake recovery equipment, transfer systems to and amongst the DSTs, and to the Waste Treatment and Immobilization Plant may necessitate additional enhancements.

Future revisions of this program plan will integrate identified program needs and retrieval technologies for removal of contact-handled transuranic waste to be developed. Additionally, as activities associated with the scenarios/opportunities of the System Plan (Rev. 8) are advanced, TEs may be required to support implementation. Future program plan revisions will include these additional opportunities and TEs when identified.

1.5 TECHNOLOGY AND INNOVATION ROADMAP

RPP-PLAN-43988, *Technology and Innovation Roadmap,* hereinafter referred to as the Roadmap, focuses on identifying and connecting technology needs to high-priority, near-term RPP cleanup mission objectives. The Roadmap considers longer-term gaps and pending programmatic decisions that require technology support. The Roadmap is updated annually to incorporate changing RPP technology needs and to status ongoing technology development activities.

All of the known technology needs are identified by the appropriate subject matter experts and summarized via individual Technology Element Description Summary (TEDS) sheets. The Roadmap Rev. 4 currently identifies a total of 33 technologies to support both retrieval and closure activities. These activities are grouped under the retrieve tank waste (RTW) functional group as defined in the Roadmap. Twenty-seven are in the needed category (currently non-funded) and six are planned (identified in the baseline and currently funded). Each category is further prioritized as high, medium, and low based on a ranking process defined in the Roadmap (Section 1.2 above). This plan addresses only retrieval-based technologies that facilitate tank cleanout and monitoring before, during, and after retrieval (i.e., verifying residual tank volumes). Eight of the 33 provided in the Roadmap directly support retrieval activities (see Sections 4.2.1 and 4.2.2 of the Roadmap).

The following TEDS are currently funded or planned TEs and CTEs that are being addressed under this program plan as part of the RTW functional group as defined in the Roadmap.

- **RTW-01** – Development of next generation retrieval waste sampling tools (auger sampling device [ASD]). (Ranked High)
- **RTW-02** – Residual volume measuring system (RVMS) to improve the ability to determine the amount of waste in a tank during and after retrieval operations. (Ranked High)
- **RTW-34** – Extended reach sluicing system (ERSS) modifications to improve the efficiency of waste removal as compared to modified sluicing. (Ranked Medium)
- **RTW-08** – In-tank MWGS to improve the retrieval of hardpan material. (Ranked High)
- **RTW-55** – HWEE to improve retrieval rates and reduce the amount of water added to the tanks. (Ranked High)

The following TEs addressed under this program plan are categorized as needed to enhance mission completion capability. These proposed technologies are currently non-funded:

- **RTW-53** – Three-dimensional (3D) flash light detection and ranging (LIDAR) technology to map waste tanks. (Ranked High)
- **RTW-10** – Development testing of high-radiation hose materials (HRHM). (Ranked Low)
- **RTW-12** – Development of a new riser installation system (NRIS) to improve access inside the tanks. (Ranked Medium)

Section 10.0 of this document addresses those technologies that are known to support Scenario 5 of the System Plan.

1.6 TECHNOLOGY BENCHMARKING

One of the primary goals of the WRPS CTO is to develop working relationships with offsite entities concerning technology development. These relationships facilitate a more efficient process for identifying, developing, and deploying the necessary technology to close hazardous facilities throughout the world. Key relationships are fostered through benchmarking.

Benchmarking compares technology development of other nuclear sites via informational exchange. This can be done via video teleconferences or knowledge/technology exchanges. A retrieval technology video teleconference was held in June 2018 that included presentations from the Sellafield (UK), Hanford, and Savannah River Sites. The three sites shared information on site-specific radioactive sludge removal challenges and proposed solutions.

Over the past several years, WRPS has hosted an annual National Technology Workshop involving collaboration between academia, National Laboratories, and industry vendors. These workshops are key to establishing and maintaining a comprehensive technology maturation baseline for the Hanford Site.

Over the past several years, WRPS has participated and presented technologies such as the HWEE and MWGS at the Waste Management Symposia.

2.0 BACKGROUND

The Tank Operations Contractor has retrieved waste from tank S-112 (Saltcake Demonstration Project) and all C Tank Farm tanks (except tank C-301 and the CR vaults which are part of future closure activities). In support of these operations, the Tank Operations Contractor has used modified sluicing, salt mantis, enhanced sluicing using the ERSS, salt cake dissolution, foldtrack, chemical dissolution, high-pressure water, and the mobile-arm retrieval systems (MARS-S and MARS-V) for tank waste retrieval. Each process required addition of liquids to the SSTs for heavy sludge and hard cake removal. The remaining materials can be granular like sand, hardened rock-like materials (chunks), or a mixture of sandy material with clay and the hardened chunks. As such, the efficiency of retrievals has not met expectations, led to longer retrieval durations, and the need to use multiple technologies to retrieve from an SST.

The aforementioned retrieval systems have all been deployed through risers (pipe openings) in the top of each tank. These systems have been successful at retrieving the liquid, salt cake, and sludge waste. Although these systems have retrieved waste from 18 tanks, some have performed at a somewhat lower retrieval rate than desired. That is, retrieving the solid hard heel or salt cake material (generally the bottom layer) without introducing large amounts of additional liquid and chemicals. Using large volumes of water promotes undesirable system impacts, which is the motivation for developing more efficient solutions. The following are some key examples:

- A Tank Farm includes two tanks, A-104 and A-105, which are known to have leaked. The carbon steel liner of tank A-105 was ruptured lifting it up from the tank foundation. Although the liquid portion of the waste (supernate/slurry) is no longer present in A-104, this tank has heavy sludge, hard cake, or salt cake to be retrieved. Tank A-105 has a similar processing history, but the waste volume is currently being evaluated for retrievability and closure options. Re-introduction of liquids into the leaking or suspected leaking SSTs for retrieval presents environmental issues. The in-tank MWGS (see Section 5.2) does not require liquid (as a motive force) to erode solids from a tank bottom; however it requires liquid to slurry up the waste for conveyance out of the tank. This system allows for the controlled removal of tank waste that will control liquid leaking from the tanks during retrieval.
- Sluicing is still a viable option for retrieving solids from the next series of sound, or non-leaking, tanks. Plans to utilize the ERSS for upcoming A and AX Tank Farm retrievals are underway. Increased retrieval efficiency is under consideration for the ERSS (see Section 5.5).
- WRPS CTO, in cooperation with WRPS Retrieval engineering, is developing a confined sluicing system. This system could potentially optimize waste removal capability (i.e., better retrieval rates and lower dilution ratios) for potential use in non-leaking A Tank Farm tanks. Confined sluicing is considered another potential tool to complement existing sluicing devices. The HWEE (see Section 5.1) is a confined sluicer, intended to minimize water usage and increase retrieval rates during solids retrieval.

Though the short-term goals for tank waste retrieval operations are limited to the A and AX Tank Farms, WPRS has the mission to retrieve waste from all of the SSTs and DSTs. Program Plan updates will address technology needs for additional tank farms.

2.1 SINGLE-SHELL TANK FARMS

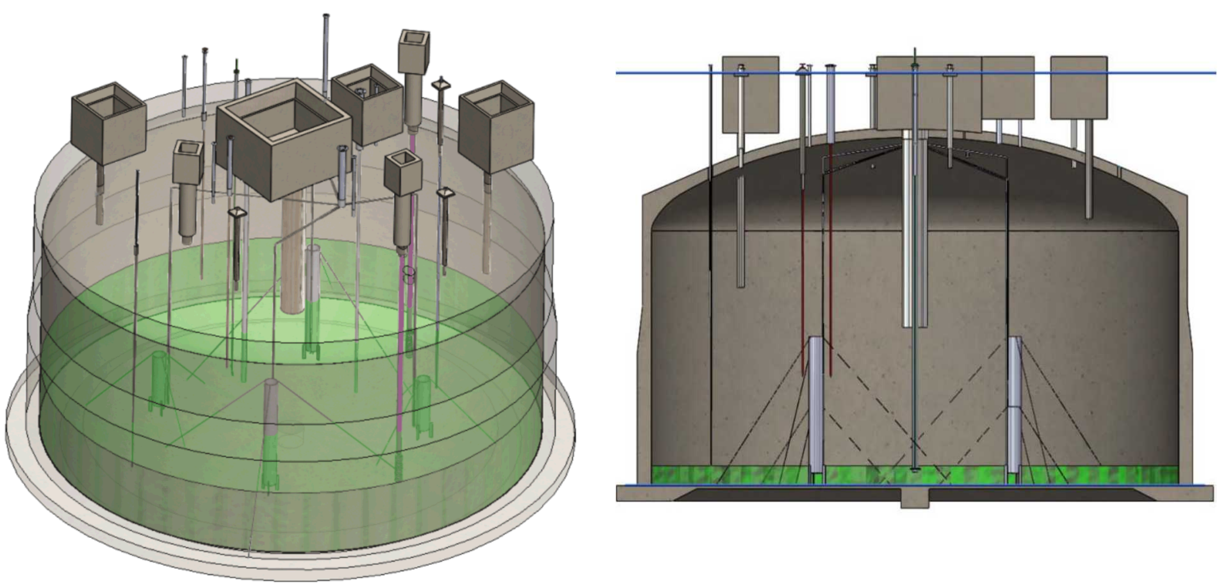
Of the 18 Hanford Site tank farms, 12 are SST farms that contain 149 of the 177 tanks. The SST farms, constructed between 1943 and 1964, are in groups of 4 to 18 tanks and divided equally between the 200 East Area and the 200 West Area. The original SST design was a reinforced-concrete shell and dome with an internal liner (structurally independent from the reinforced-concrete tank) of mild carbon steel covering the bottom and sidewalls.

The first SSTs were designed with operating volumes of 530,000 gal. The succeeding generations of SSTs were built with operating volumes of 758,000 gal and 1 Mgal. Included among the 149 SSTs are 16 smaller tanks that share the same design as the larger tanks but have operating volumes of only 55,000 gal. Tank surveillance data indicates that a number of SSTs have leaked waste (i.e., waste has leaked through the carbon-steel liner and concrete shell and has entered the surrounding soil). To reduce the potential for additional leakage, free liquids were removed from the SSTs and pumped to DSTs via a process referred to as interim stabilization. The current mission includes retrieval of the remaining wastes from the SSTs. The next two SST farms on the tank retrieval schedule, A and AX Tank Farms, are briefly described in the following sections.

2.1.1 A Tank Farm

The A Tank Farm includes six 75-ft diameter SSTs (see Figure 3). The six A Tank Farm tanks were constructed during 1953 and 1955 with a nominal capacity of 1 Mgal each. These tanks are underground and are constructed as a cylindrical, reinforced-concrete shell with a domed roof and a flat bottom. The interior of the tanks contains a 75-ft diameter liner constructed of mild steel, extending up the tank wall to a height of 32.5 ft. The concrete shells of these tanks maintain the structural integrity of the steel liner by protecting it from soil loads.

Figure 3. Three-Dimensional Model of an A Tank Farm Tank.

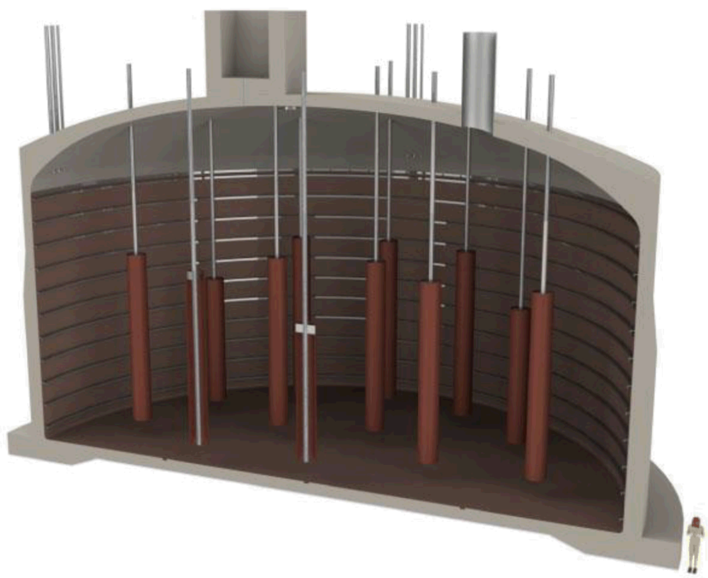


Access to the tank interior for installing various process equipment and instrumentation is provided by vertical risers that penetrate the tank dome. The A Tank Farm tanks contain covered pits, which provide surface access to the process piping and some of the tank risers. Pit structures also provide the locations where jumpers (temporary piping connections), pumps, and other equipment are typically installed to establish waste transfer routing. The existing pits are constructed of reinforced concrete. Their walls and floors are located below grade and provided with removable reinforced-concrete cover blocks or steel cover plates located just above grade level.

2.1.2 AX Tank Farm

The AX Tank Farm contains four 1-Mgal capacity SSTs. These tanks consist of a 75-ft-diameter carbon steel liner inside a concrete tank. The tank steel bottoms intersect the sidewalls orthogonally (similar to A and SX Tank Farm tanks), rather than the dished bottoms of earlier designed tank farms. The concrete thickness is 1.5 ft on the tank bottom, 1.25 to 2 ft on the side walls, and 1.25 ft at the tank dome. The concrete tank dome thickness increases to approximately 5 ft along the sidewalls. Each tank was originally equipped with numerous risers ranging in size with a maximum diameter of 42 in. (see Table 2). that penetrated the tank dome. In addition, each tank was equipped with 22 air lift circulators operated to suspend solids, mix the tank contents, and dissipate heat (see Figure 4).

Figure 4. Air Lift Circulators in AX Tank Farm Tanks.



Source: RPP-RPT-58352, 2015, *Retrieval Technology Selection for AX Farm*, Rev. 0.

2.2 A AND AX TANK CONFIGURATION AND RISERS

Table 2 provides an overview of the current configuration and types of solids stored in the tanks to be retrieved in A and AX Tank Farms.

Table 2. Tank Configuration and Risers.

Tank	No. of 2.5 – 4" Risers	No. of 6 – 8" Risers	No. of 10 – 12" Risers	No. of 14" Risers	No. of 18 – 20" Risers	No. of 34 – 36" Risers	No. of 42" Risers	Flat Bottom	Primary Waste Type	Highly Congested (yes/no)	Leak Status
A-101	11	1	5	0	3	0	1	Yes	Saltcake	No	Sound
A-102	7	2	6	0	1	0	1	Yes	Saltcake	No	Sound
A-103	8	2	4	0	1	0	1	Yes	Saltcake	No	Sound
A-104	12	3	5	0	1	0	1	Yes	Sludge	No	Assumed Leaker
A-105	13	5	5	0	1	0	1	Yes	Sludge	No	Assumed Leaker
A-106	6	7	5	0	1	0	1	Yes	Sludge	No	Sound
AX-101	11	15	4	1	1	2	1	Yes	Saltcake	Yes	Sound
AX-102	11	15	2	1	1	2	1	Yes	Saltcake	Yes	Sound
AX-103	14	15	2	1	1	2	1	Yes	Saltcake	Yes	Sound
AX-104	11	15	3	1	1	2	1	Yes	Sludge	Yes	Sound

Source: RPP-RPT-44139, 2014, *Nuclear Waste Tank Retrieval Technology Review and Road Map*, Rev. 4.

2.2.1 Other Tank Farm Retrievals

Technologies addressed in this program plan are adaptable for all Hanford waste tanks. Updates to this plan will include identification of tank retrievals and planned for waste retrieval.

2.2.2 Catch Tanks, Double-Contained Receiver Tanks, and Inactive Miscellaneous Underground Storage Tanks

Catch tanks and double-contained receiver tanks have been removed from service (i.e., no further waste additions are allowed) and are stabilized and isolated in accordance with environmental management program requirements. Inactive miscellaneous underground storage tanks are radioactively contaminated, inactive, and abandoned underground storage tanks. Catch tanks, double-contained receiver tanks, and inactive miscellaneous underground storage tanks are small tanks (up to 50,000 gal), and the remaining waste volumes in these tanks are typically much less than the operating volumes.

Retrieval technologies for removing residual waste volume could be needed for these tanks depending on the closure standards. There might be a greater need for sample collection for establishing closure standards.

2.3 DOUBLE-SHELL TANK FARMS

To provide additional storage capacity, 28 DSTs were built in six tank farms between 1968 and 1986. Five of these tank farms are located in the 200 East Area and one is located in the 200 West Area. All DSTs are similar in design and are designed to minimize the potential for leaks of radioactive liquids to the environment. Each DST consists of a carbon-steel primary tank and a carbon-steel secondary tank within a protective reinforced-concrete shell. The primary tank contains waste, is freestanding, and rests on an insulating concrete pad. The insulating pad rests on the secondary tank and was cast with air distribution and drain grids to

(1) provide for leak detection, (2) maintain a uniform tank bottom temperature, (3) facilitate heat removal, and (4) eliminate pockets of water condensation.

The secondary tank is 5 ft larger in diameter than the primary tank, providing an air space (annulus) that separates the two steel tank walls. The secondary tank serves as a barrier to the environment in case the primary tank leaks.

DST AY-102 was determined to be a leaking tank in October 2012, requiring it to be retrieved. This was a significant effort that utilized both standard sluicers and ERSS to remove the sludge. Future sludge removal from DSTs may require improved techniques.

3.0 ORGANIZATIONAL ROLES AND RESPONSIBILITIES

Table 3 identifies the Roles and Responsibilities, Authorities and Accountabilities (R2A2) for each organization or contractor anticipated to be involved with the currently identified ART throughout the technology development phases (through TRL 6).

Table 3. Organizational R2A2.

Organization	Phase 1 (TRL 1-3)*	Phase II (TRL 3-5)*	Phase III (TRL 5-6)*
Washington River Protection Solutions, LLC			
Chief Technology Office/Technology Management and Field Solutions	- Perform overall project management. - Conduct subcontractor oversight. - Review vendor technology entries and data. - Approve testing equipment design and technology selection.	- Perform overall project management. - Conduct subcontractor oversight. - Approve technology design, deployment system selection and testing equipment design.	- Perform overall project management. - Conduct subcontractor oversight. - Review testing data. - Approve testing facility, integrated system design. - Transition to Retrieval Organization for future deployment.
Retrieval Organization	- Review vendor technology entries and data. - Approve testing equipment design and technology selection.	- Review and approve technology design, deployment system selection and testing equipment design.	- Review testing data. - Approve testing facility, integrated system design. - Integrate with CTO to transition for future deployment.
Tank and Pipeline Integrity	- Provide input to program planning, testing equipment design and technology selection. - Review vendor technology entries and data.	- Provide input to program planning, sensor technology design, deployment system selection and testing equipment design. - Review testing data.	- Provide input to program planning, testing facility, and integrated system design. - Review testing data.
U.S. Department of Energy, Office of River Protection			
Tank Farms Programs Division	- Provide approval on the selection of technology.	- Provide approval on the modification/design of the technology and selection of deployment system.	- Provide approval on the testing facility and the final integrated system design.
Subcontractor			
National Laboratory, Academia, Industry	- Prepare test plan and test protocol for the vendor technology selection. - Prepare testing equipment. - Gather vendor data and prepares report.	- Prepare test plan and test protocol for technology design modification and deployment system selection. - Gather testing data and prepares report.	- Prepare test plan and test protocol for full-scale testing of the integrated non-destructive examination system. - Gather testing data and prepares report.

*TRLs associated with each phase are provided as a range due to their variability from project to project.
TRL = Technology Readiness Level.

4.0 FUNCTIONS AND REQUIREMENTS

The tank waste retrieval program is currently focused on removing waste from the tanks in A and AX Tank Farms by 2026. As such, the near-term retrieval functions and requirements need to be tailored for the conditions in those two tank farms. Additional functions and requirements may be necessary to retrieve waste from the nine remaining tank farms.

4.1 NEAR-TERM FUNCTIONS AND REQUIREMENTS

Efficient development of retrieval equipment prototypes requires an established list of functions and requirements to generate the appropriate basis for design and fabrication. Ultimately, the detailed requirements for any system deployed in the tank farms is documented within the procurement process. The following sections list the basic requirements for retrieval equipment to be used in the A and AX Tank Farms.

4.1.1 A and AX Tank Farm Requirements

Based on A and AX Tank Farms field conditions and current waste inventory, a field-deployed ART or new system would generally require the following attributes:

- Retrieves solid waste
- Fits through a maximum 42-in. inner-diameter pipe[4] (riser at the top of the tank) or fits through a 12-in. riser for either ERSS or HWEE
- Reaches waste spread across the entire 75-ft diameter of the tank
- Access is through multiple risers
- Reaches the bottom of the tank approximately 60 ft below grade
- Moves or rotates to reach waste around the perimeter of the tank
- Moves or rotates around potential in tank obstructions (air lift circulators, thermocouple trees, liquid level indicators, and uneven surfaces)
- Tolerates radiation to approximately 1,000 rad/hour (gamma) 50,000 rad/hour (beta)
- Operates between 50 to 200 °F
- Operates within pH levels of 7 to 15
- Operates in humid environments up to 100% relative humidity
- Manages the amount of liquid needed to mobilize and retrieve waste in order to minimize the resulting volume of supernatant
- Minimizes the amount of free-standing liquid in a tank during waste retrieval.

[4] Removal of the 42-in. inner diameter down comer that extends to within 20 ft. of the bottom of the tank may need enlargement for ART system deployment (original construction, see Figure 3).

4.2 ADDITIONAL REQUIREMENTS

The waste retrieval components on the tank exterior shall be designed for use and storage in an unprotected outdoor environment with the following conditions per TFC-ENG-STD-02, *Environmental/Seasonal Requirements for TOC Systems, Structures, and Components*, and TFC-ENG-STD-06, *Design Loads for Tank Farm Facilities*:

- Equipment will be exposed to ambient temperatures ranging from -25 to 115 °F
- Relative humidity up to 100%
- Frequent blowing sand and dust
- Three second gusts of wind with velocities up to 91 mph
- Rainfall up to 2.5-in. in 6 hours
- Full solar exposure up to 900 Langley.[5]

[5] 41,840 J/m² (joules per square meter).

5.0 TECHNOLOGY DESCRIPTIONS

The following sections provide an overview of the wet and dry retrieval technologies being considered for technology development or currently under development by the CTO and/or by the Retrieval organization. Technology needs and priorities will drive the scope and timing of the phased approach for technology development (see Appendix A). Therefore, technologies will not necessarily progress through the phases in the same timeframe.

5.1 DEVELOPMENT OF NEXT GENERATION RETRIEVAL WASTE SAMPLING TOOLS –AUGER SAMPLING DEVICE (RTW-01)

Tank retrieval and closure requires sampling of residual tank waste. Currently none of the existing sampling methods are able to reliably collect hard heel material that is not directly under the tank riser. The current off-riser sampler system (ORSS) is a General Electric Inspection Technology crawler and sample scoop (Figure 5). The sample scoop (clamshell) design is not strong enough to break off a piece of hard heel for sampling without additional mechanical support from the sample crusher (tenderizer).

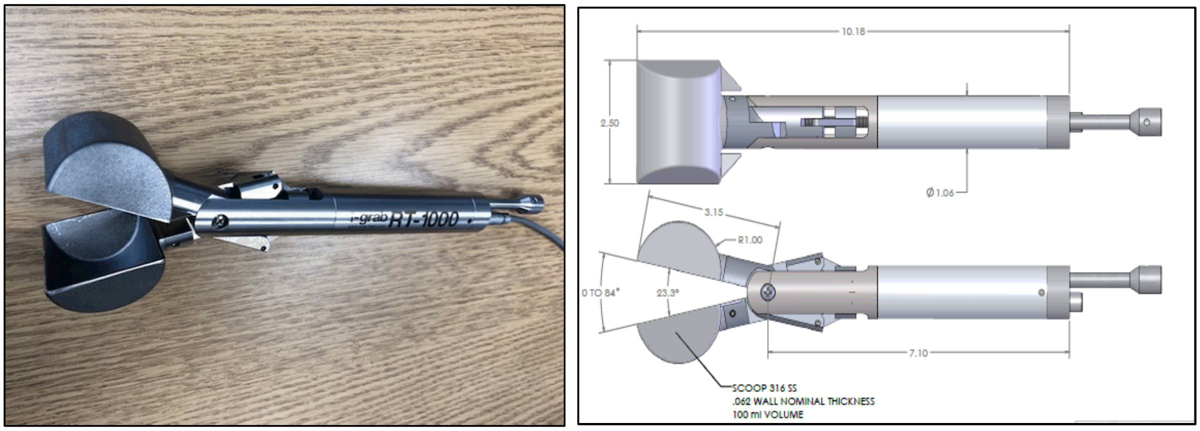
A next generation retrieval waste sampling tool the ASD (Figure 6) with an ORSS would allow collection of hard-heel samples away from the tank riser. Retrieval of homogenous samples from tank waste requires development, design, and fabrication of a new auger device. The sampling tools used in the tank farms cannot extract subsurface tank waste samples.

5.1.1 Mission Driver

Residual tank waste sampling is necessary for establishing tank closure standards but also for developing effective retrieval processes. Simulants used for cold testing prototype retrieval systems must be based upon the physical characteristics of actual tanks waste. Accurately determining physical characteristics requires representative tank waste solids samples.

Figure 5. Current Crawler and Sample Scoop Device.

Figure 6. New Sampling Scoop.



5.1.2 Risk, Opportunity, and Return on Investment

Successful deployment of next-generation retrieval waste sampling tools would help mitigate the following risk while providing opportunities and return on investment (ROI).

5.1.2.1 Risk

A next-generation ASD addresses the following risks associated with retrieval of tank waste:

- **Risk number RPP-006** – SST retrieval system performance does not meet requirements due to controllable causes.
- **Risk number RPP-054** – Facility closure costs are not fully evaluated.
- **Risk number A/AX-11** – Waste not as expected (different than characterized); takes longer or cannot be retrieved.

5.1.2.2 Opportunity

Opportunities associated with this technology are:

- Successful implementation of an ORSS would allow for statistical sampling away from tank risers.
- The ORSS has application for all future tank farm closure requirements.
- Successful implementation of an ORSS would allow completion of regulatory required statistical sampling of remaining tank waste, to support tank closure.

5.1.2.3 Return on Investment

A quantitative ROI has not been determined at this time.

5.1.3 Next Generation ASD Down Selection

In order to select the appropriate next generation ASD, WRPS issued an expression of interest (EOI) in May 2015, with proposals for new-generation ORSSs (2DB00-MWV-015-002, *Expression of Interest*; RPP-RPT-58752, *Off-Riser Sampling System Report*). Nine companies responded to the EOI. Successful tank waste sampling away from the tank risers involves completion of a workshop, down-selection of the companies, prototype fabrication, and cold testing, per RTW-1. Figure 7 shows a new hard heel sampler. Hard heel samples are required to define realistic simulants for developing and testing retrieval tools and systems for efficiency and deployability.

5.1.4 CTE Determination

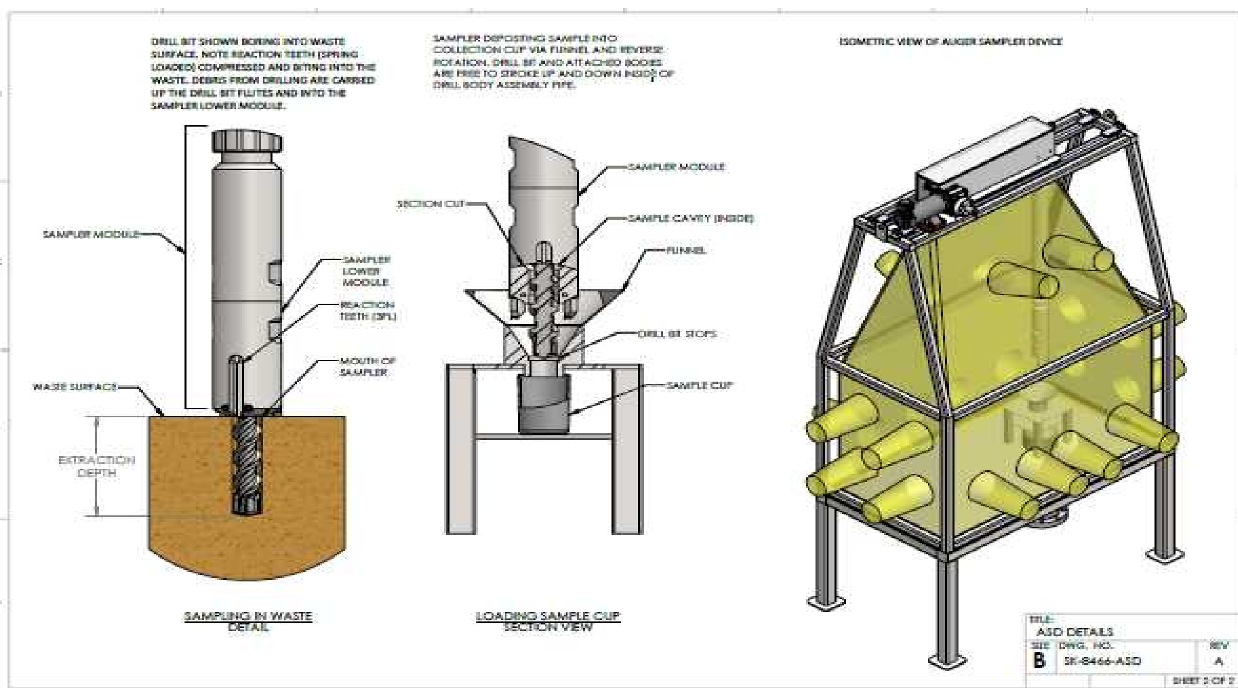
CTEs are at-risk technologies essential to the successful operation of the facility. CTEs are new or applied in new or novel ways or environment. DOE G 413.3-4A, *Technology Readiness Assessment Guide*, provides the following approach to determining if a technology is a CTE (Appendix A). Qualification of a technology as a CTE requires a "Yes" response to one question in each question set. This technology is not a CTE after answering the questions provided in Appendix A.

A graded approach may allow development of non-critical technologies (see Figure 2). The following section describe phases of technology development per the graded approach.

5.1.5 Technology Development Phases for the ASD

Generally, the ASD path forward includes: (1) conducting a vendor workshop with the nine companies that submitted proposals to the ORSS EOI, (2) reviewing proposals and down-selecting an option or options for cold testing, (3) characterizing the tank hard heel composition, and (4) specifying an applicable simulant to enable better cold testing.

Figure 7. New Hard Heel Sampler Concept.



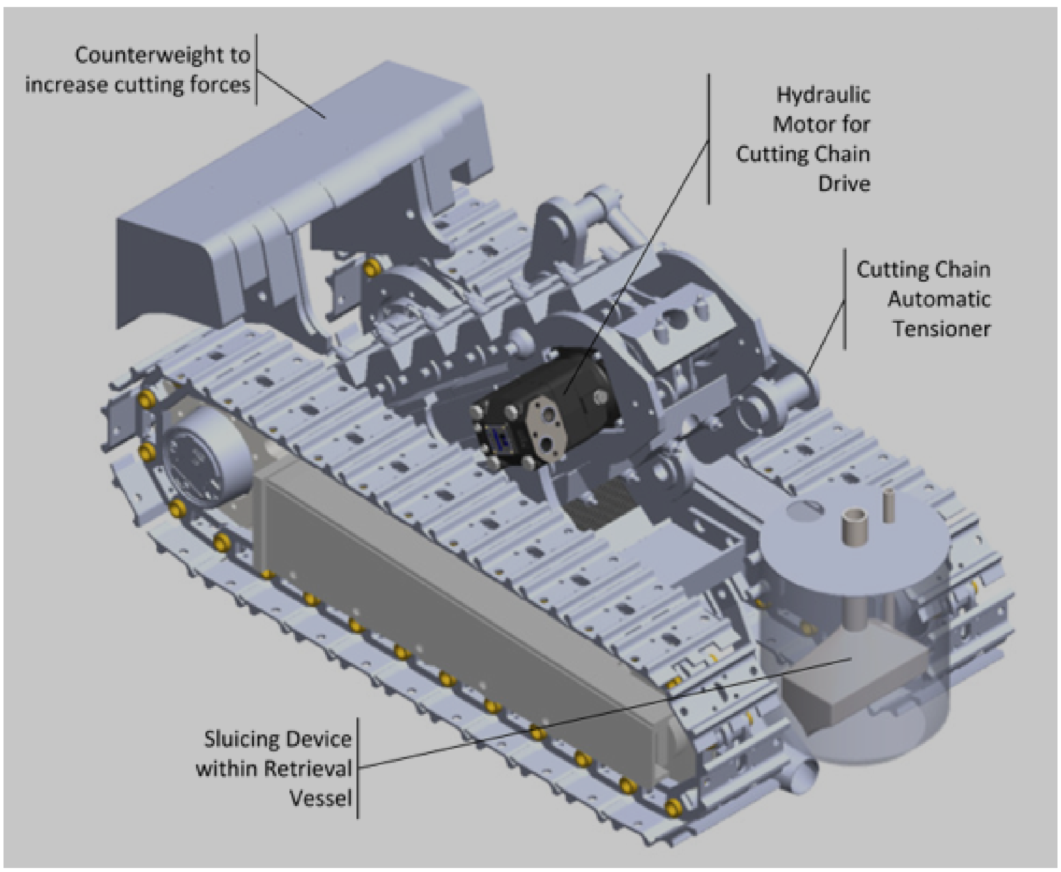
5.2 MECHANICAL WASTE GATHERING SYSTEM (RTW-08)

The MWGS is a dry retrieval system being developed as an ART to the MARS-V. The current practice for sludge and solids retrieval from the SSTs involves sluicing with either large volumes of supernatant or water. This approach is ineffective for tanks with hardpan coated bottoms; and is not allowed for leaking tanks, as the addition of large volumes of liquid to leaking tanks has the potential to lead to an environmental release.

A retrieval system capable of removing hardpan waste without the addition of liquid to the tanks is needed whether they are leaking or not. The MWGS is being developed for this purpose. In addition, the removal of soft waste from leaking tanks is being developed in another ART project (the HWEE, see Section 5.3).

The goal of the MWGS is to improve the retrieval of resilient hard-packed wastes in both leaking and non-leaking tanks. The MWGS is a robust tracked device (remotely operated vehicle that fits through a 42-in. diameter riser). A rotating cutting chain with tungsten carbide teeth is used to break up the waste material. The debris is then vacuumed into a waste receiving vessel. The Barrnon Ltd proprietary Bladecutter technology further size reduces and slurries up the waste where it is then pumped out of the tank. Figure 8 illustrates the configuration and main components comprising the MWGS.

Figure 8. MWGS Prototype Schematic Showing Major Components.



Engineering design is underway to tie the MWGS conveyance line to the transfer system via a hose-in-hose transfer line (HIHTL). The above surface system should use existing transfer equipment with little if any development required. As this equipment becomes specified, it will allow for additional information about the interface with MWGS to be developed.

Atkins and Barrnon Ltd. developed and tested an initial prototype, the Rotocutter. The Rotocutter efficiently cut asphalt and concrete substrates (see Figure 9). The cutting rate for asphalt was 21.9 ft^3 an hour. Further technology development will include the following:

- Build a full system to cut, gather, and dispatch substrates from a mockup tank, including closed-circuit television (CCTV) and control desk
- Incorporate and evaluate tank floor and wall protection devices
- Conduct sufficient testing to evaluate material removal rates and equipment life relative to the tank farm application.

Figure 9. Robotic Crawler with Rotocutter and Retrieved Simulant.

During system installation testing, commissioning, and grooming (preliminary testing), all opportunities will be taken to increase the robustness or functionality of the system. Note that by initially using bounding simulants, it is hoped to demonstrate said operational life will be a conservative estimate. All testing performed on this program will be at full scale. At this stage, ambient environment trials will be conducted. Equipment will be highly tolerant to radiation, moisture, high pH, and high temperature.[6] Of these environmental challenges, the potential radiation levels will be the most onerous.

5.2.1 Mission Driver

A technology is needed for retrieving solids from Hanford tanks that contain primarily solids (sludge, salt cake, and hard pan). An ART to the MARS-V is needed to meet a 2016 Amended Consent Decree milestone to complete A and AX Tank Farms retrievals by September 30, 2026.

[6] For cost-benefit reasons, items where radiation tolerant equivalent equipment are proven and available but expensive, such as CCTV cameras, are substituted substitute with low-cost commercial alternatives of generally similar performance.

5.2.2 Risk, Opportunity, and Return on Investment

Successful deployment of MWGS would help mitigate the following risk while providing opportunities and ROI.

5.2.2.1 Risk

An MWGS would be addressing the following identifiable risk associated with retrieval of waste tanks:

- **Risk number RPP-006** – SST retrieval system performance does not meet requirements due to controllable causes, such as technology limitations, equipment availability, retrieval rate, vapor issues, etc.
- **Risk number A/AX-11** – Waste not as expected; hard to remove.

5.2.2.2 Opportunity

Opportunities associated with this technology are:

- An in-tank MWGS would prevent leaking tank waste to the environmental.
- Tank liquids were previously removed due to environmental impacts; an in-tank MWGS would prevent reintroduction of liquids to the leaking tanks.
- An in-tank MWGS would prevent reintroduction of liquids to the leaking tanks.

5.2.2.3 Return on Investment

A quantitative ROI has not been determined at this time.

5.2.3 MWGS Down Selection

The MWGS dry retrieval down selection included assessing current industrial practices. Table 4 shows the down-selection assessment criteria.

Table 4. MWGS Down Select.

		Does system avoid water introduction?		Can system withstand large reaction forces?		Is system robust?		Is system compact (fits through a 42-in. riser)?	
End Effector Type	Deployment Configuration	Yes	No	Yes	No	Yes	No	Yes	No
Mechanical Cutting		✓		✓		✓		✓	
Tool Kit (Brokk)		✓		✓		✓			✓
Sluicing			✓	✓		✓		✓	
	Compact ROV	n/a	n/a	✓		✓		✓	
	Large ROV	n/a	n/a	✓		✓			✓
	Mast System	n/a	n/a		✓	*	*	✓	
	Folding ROV	n/a	n/a	✓			✓	✓	

*A mast system of this size capable of supporting large cutting forces has not been tested.
ROV = remotely operated vehicle.

5.2.4 CTE Determination

CTEs are the at-risk technologies that are essential to the successful operation of the facility and are new or are being applied in new or novel ways or environment. DOE G 413.3-4A provides the following approach to determining if a technology is a CTE. A yes response must be given to one question in each question set to qualify a technology as a CTE. A yes to question 2 of Set 1 and a yes to question 2 of Set 2. The evaluation is summarized in Table 5.

Table 5. MWGS CTE Determination.

Set 1 - Criteria	Yes	No
1. Does the technology directly impact a functional requirement of the process or facility?		X
2. Do limitations in the understanding of the technology result in a potential schedule risk (i.e., the technology may not be ready for insertion when required)?	X	
3. Do limitations in the understanding of the technology result in a potential cost risk (i.e., the technology may cause significant cost overruns)?		X
4. Do limitations in the understanding of the technology impact the safety of the design?		X
5. Are there uncertainties in the definition of the end state requirements for this technology?		X
Set 2 - Criteria	**Yes**	**No**
1. Is the technology new or novel?	X	
2. Is the technology modified?		X
3. Have the potential hazards of the technology been assessed?		X
4. Has the technology been repackaged so a new relevant environment is realized?		X
5. Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		X

5.2.5 MWGS Development Phase I

During MWGS development Phase I, a working prototype system was developed. It successfully demonstrated breaking up tough asphalt and unreinforced concrete substrates that generally bounds the hardness of hardpan tank waste. In addition it was able to gather the broken-up material into a nearby vessel for further particle size reduction (in-vessel sluicing).[7] Phase I was a proof-of-principle demonstration independently funded by Atkins and Barrnon Ltd. Another challenging simulant (sandstone, 60 MPa compressive strength) was also successfully mobilized. The demonstration included lowering the system through a simulated 42-in. riser (see Figure 10) as identified in the functions and requirements in Section 4.1.1.

5.2.5.1 Phase I Test Simulant

Simulant for MWGS development Phase I included asphalt and unreinforced-concrete substrates.

[7] Water will be added to the sealed retrieval vessel only and not directly into the simulated SST.

Figure 10. MWGS Deployed through a 42-in. Opening.

5.2.6 MWGS Development Phase II

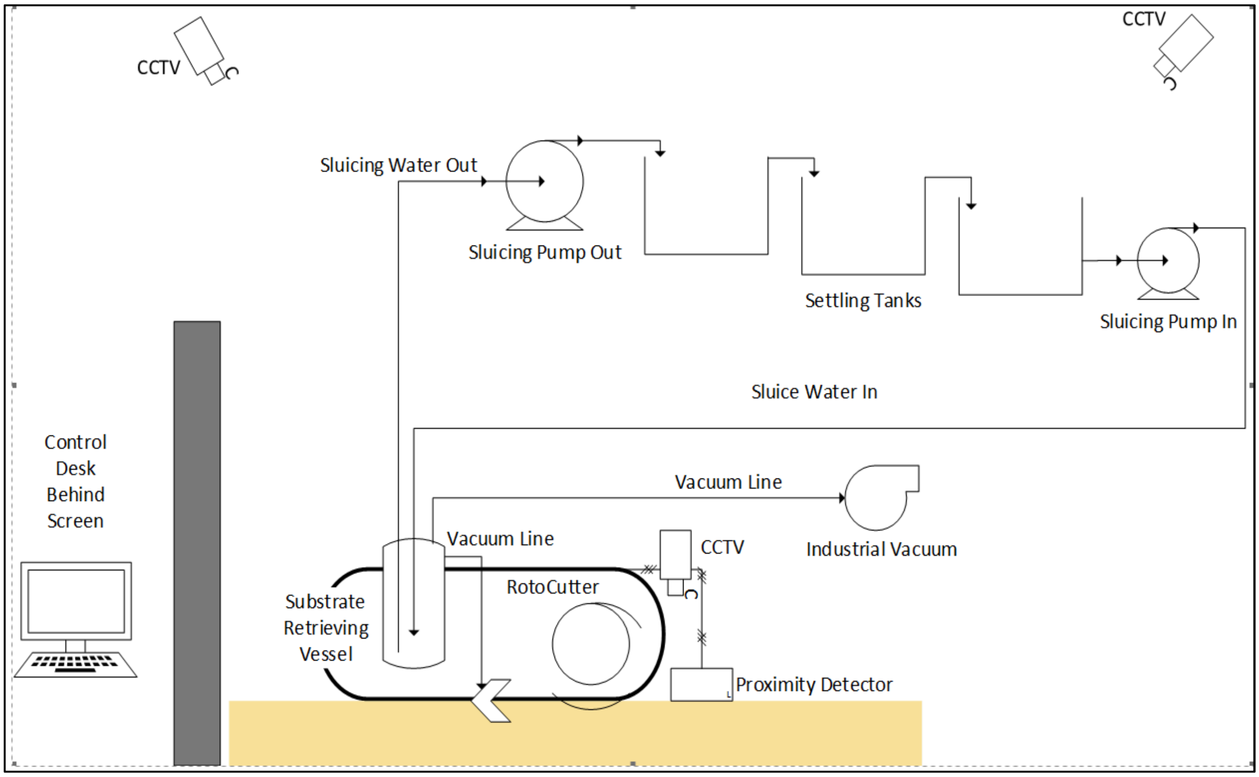
Phase II goals were to incorporate lessons learned from Phase I and focus on refining the design of CTEs, including the waste collection system, the sluicing/retrieval vessel, the remote viewing system, the tank floor protection sensors, and the overall control system. A key decision made during this phase was to decouple the two functions – the Rotocutter and the retrieval (vacuum/sluicing) system – to allow optimization of each without compromising the other. In particular, this allowed a compliant vacuum crevice tool optimization in an open framework without obstruction by the Rotocutter. The aspects of the CTEs developed were:

- Establish Rotocutter tool life (endurance test)
- Improve vacuum collection system pickup efficiency
- Evaluate the capability of MWGS to break up representative substrate simulants
- Test dual metal detecting sensors to ensure the tank floor is not damaged during operation
- Develop the control system
- Develop a PID loop to control water level in the substrate collection vessel

- Demonstrate the ability to remotely operate MWGS via a range of CCTV cameras and remote controls
- Modify the human-machine interface to display when either sensor detected metal.

Figure 11 shows the Phase II test configuration. The water recycle system (sluicing pumps and settling tanks) used for testing will not be deployed as depicted. This configuration simplified testing for water reuse.

Figure 11. MWGS Phase II Test Configuration.



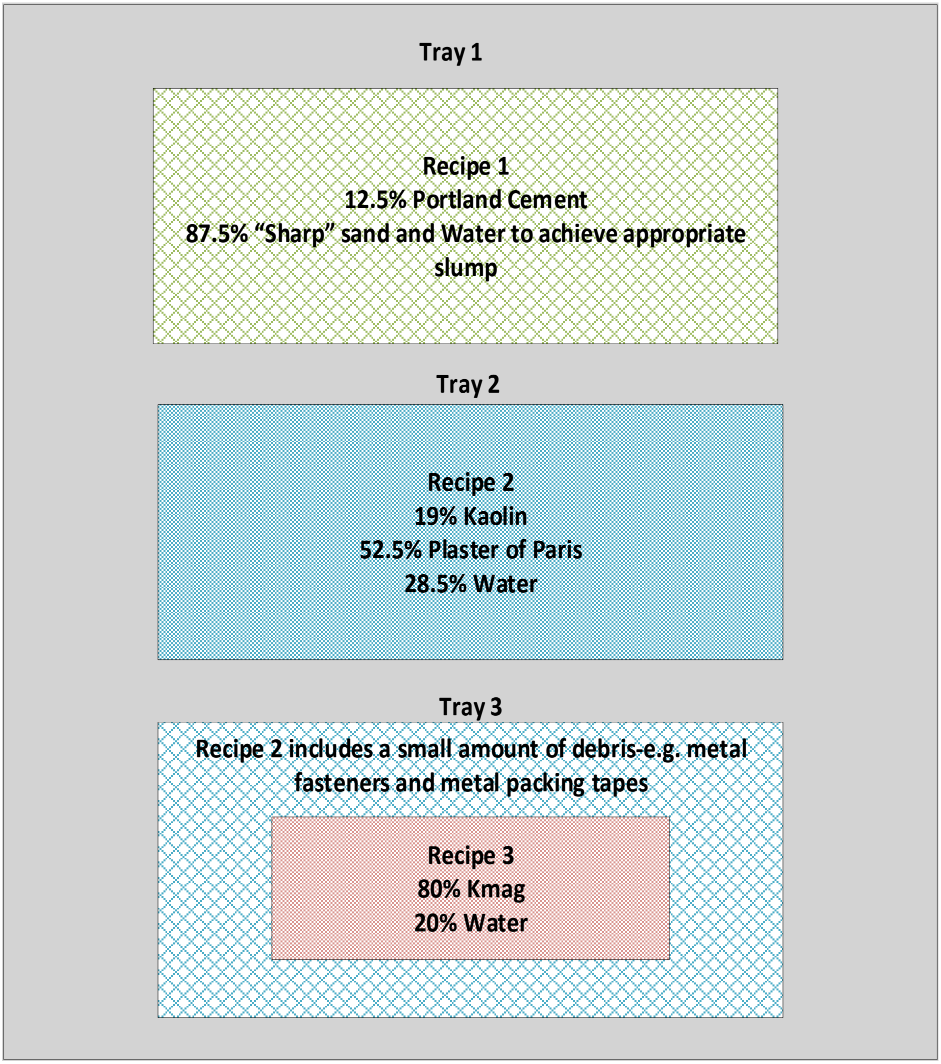
5.2.6.1 Phase II Test Simulant

Three test bed trays were used for the MWGS Phase II test:

- Tray 1 is a single monolith comprised of a 7:1 sand to cement mix, 8.8-in. deep used for endurance testing.
- Tray 2 is a single monolith comprised of a mix of Plaster of Paris and Kaolin, approximately 4.9-in. deep.
- Tray 3 is a combination of two monoliths. The outer monolith is comprised of a mix of Plaster of Paris and Kaolin, approximately 4.9-in. deep. The inner monolith is a 6.6 × 3.3 ft island of potassium magnesium sulfate (KMag). In addition, a mixture of miscellaneous debris (e.g., metal tapes) was added to the plaster/Kaolin mix for this tray.

Figure 12 shows the key simulants. All simulant and chemicals will be handled and kept by the affiliate and will not be considered government property.

Figure 12. MWGS Phase II Test Simulant Recipes.



5.2.7 MWGS Development Phase III

Phase III of MWGS development will include design and manufacture and building. Design will include a sluicing system, a vacuum system, and sensors. Manufacture and building will include an integrated waste gathering system, a vacuum system, a hydraulic power system, a forward pumping system, a basic programmable logic controller, a human-machine interface, and camera systems.

Phase III will also test an integrated crawler with a Rotocutter and vacuum system in a cold test training and mockup facility (CTF) environment emphasizing the following:

- Final development prior to releasing the system to Retrieval
- Cold testing, training, and eventual deployment at tank farms
- Cost and schedule based on performance and lessons learned from Phases I and II.

Documentation will include a formal test plan, a test results report, and delivery inventory.

5.2.7.1 Phase III Test Simulant

Test simulant will be defined at a later date.

5.3 HANFORD WASTE END EFFECTOR (RTW-55)

The primary use of the HWEE will be to supplement existing retrieval technologies, such as the ERSS, which relies on a separate transfer pump to convey waste. Although the ERSS has been used successfully to retrieve SSTs and tank AY-102 the retrieval/closure operations continually works to enhance its performance. Section 5.7 discusses seven other potential enhancements to the ERSS.

The HWEE is currently being assessed for potential use in A Tank Farms tank waste retrieval because it is anticipated to use less water compared to other water-based retrieval methods (e.g., sluicing) previously used in Hanford tanks. This reduction comes primarily from the use of three rotating high-pressure jets rather than non-rotating fan-jets for dislodging the waste and an integrated. The HWEE also has an onboard high-velocity conveyance system to retrieve the water and waste locally at the point of waste dislodging. In cases of non-leaking tanks where solids makeup is primarily hardpan, initial use of the MWGS (Section 5.2) followed by the HWEE might yield the best result. This retrieval logic could apply to tanks with significant in-tank obstructions (e.g., airlift circulators) constraining the movement of the MWGS.

The HWEE is a remote device intended to fragment and dislodge waste and simultaneously introduce slurried waste into the inlet of an onboard conveyance system. The HWEE is a confined sluicer water-based solids erosion/mobilization device. Confined sluicers typically operate at higher pressures (1,000 to 10,000 psig), requiring less liquid (1.5 to 3 gpm per nozzle) than the more conventional Hanford sluicers using supernate such as the ERSS or MARS-V. These sluicers using supernate required nozzle pressures and flows in the range of 100 to 140 psi and 68 to 125 gpm (RPP-SPEC-47739, *Specification for an Extended Reach Sluicing System for C Tank Farm*) respectively. Note that these sluicers sometimes use water for breaking up solids at approximately 2500 psi and 3gpm, then switching to supernate for actual sluicing and retrieval. This approach has required a very high volume of liquid (i.e., up to 250,000 gal to retrieve tank C-105).

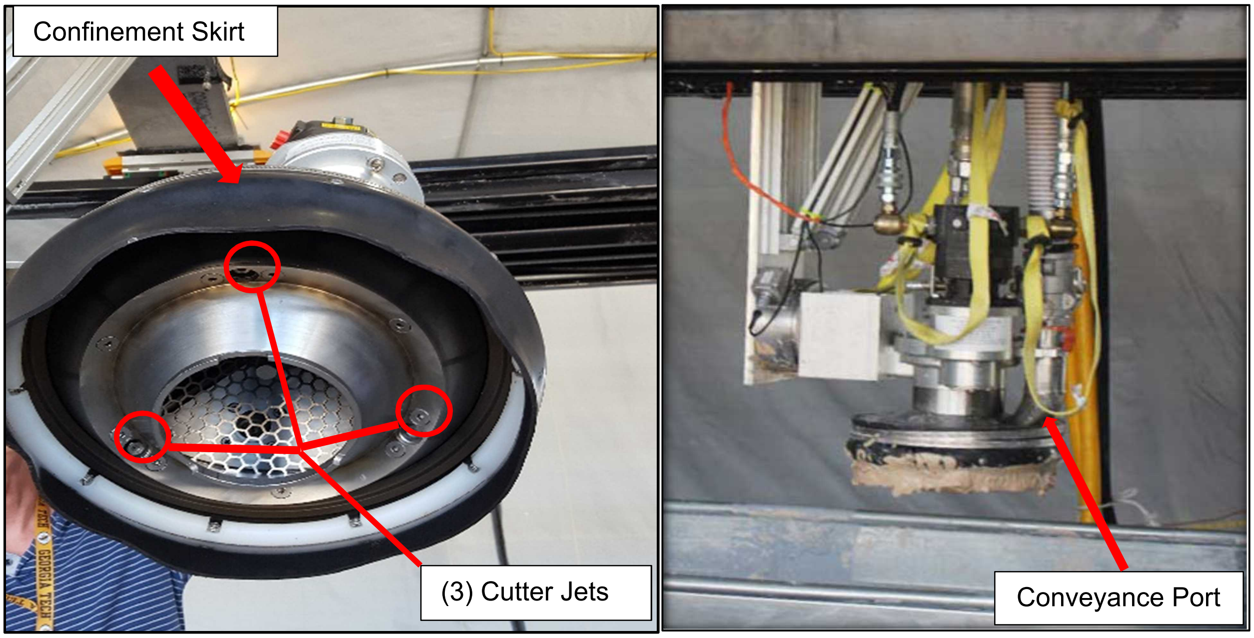
The key difference between the HWEE and previous Hanford sluicers has been in retrieval performance. The HWEE has proven (using equivalent simulant to MARS-V) to achieve a dilution ratio (PNNL-27803, *The Hanford Waste End Effector Phase II Test Report*) that is one order of magnitude greater than what MARS-V could achieve. The dilution ratio is the primary indicator of liquid usage, the closer the ratio is to 0 the greater the amount of liquid is needed to retrieve the solids (see Table 9).

General characteristics of a confined sluicer include the following (see Figure 13):

- Closely coupled with a removal system
- Confinement skirt enhances effectiveness of the three cutter jets, serves as a backstop to the slurried solids
- Short standoff distance resulting in greater control of sluicing operations
- Less water usage to remove the waste

- Waste heels that resist mobilization by long-range sluicing jets have a high potential to be removed.

Figure 13. Hanford Waste End Effector Phase I Configuration.



The HWEE is a water-based scarifier originally developed by PNNL for DOE tank retrieval systems in the 1990s as the confined sluicing end effector and later used with additional development in the waste retrieval of the gunite and associated tanks at Oak Ridge National Laboratory (PNNL-26037, *Alternate Retrieval A-105 Application Assessment Report*). In 1998 as part of the Hanford Tanks Initiative Project, a contractor team led by Foster Wheeler proposed to deploy the technology with a remote crawler to remove sludge and hardpan from tank C-106 during a retrieval demonstration. The prototype was fabricated by Oceaneering International and tested by PNNL.

Robotic operation, decontamination, and effective retrieval of wet sludge and hardpan was demonstrated, but due to the high frequency of screen fouling, a stationary fan-jet aligned with the inlet screen was recommended, which was later incorporated into the design of the HWEE. Retrieval of C Tank Farm tanks (except tank C-301 and the CR vaults which are part of future closure activities) was ultimately conducted in 1999 and 2003 with sluicing and acid dissolution. Later, enhanced sluicing using the ERSS and the MARS-V (RPP-RPT-50506, *MARS-V Technology Phase 11 Qualification Test Report*) have been used to retrieve waste from SSTs.

The HWEE used for Phases I through III testing was fabricated by HiLine Engineering and Fabrication, Inc., based on RPP-SPEC-61356, *Specification for Prototype ERSS with Hanford Waste End Effector (HWEE)*. Previous design efforts provided the specifications and drawings.

Deployment of the HWEE ideally will be through an existing tank riser. The outer diameter of the HWEE is currently 12.7 in., so this design currently excludes using a standard 12-in. riser; however, future redesign of the HWEE to an outer diameter of approximately 10 in. is being considered.

5.3.1 Mission Driver

A technology is needed for retrieving solids from Hanford tanks that contain primarily solids (sludge, salt cake, and hard pan). An ART to the MARS-V is needed to meet a 2016 Amended Consent Decree milestone to complete A and AX Tank Farms retrievals by September 30, 2026.

5.3.2 Risk, Opportunity, and Return on Investment

Successful deployment of HWEE would help mitigate the following risk while providing opportunities and ROI.

5.3.2.1 Risk

An HWEE would be addressing the following identifiable risk associated with retrieval of waste tanks:

- **Risk number A/AX-28** – Cannot retrieve around air lift circulators.
- **Risk number A/AX-11** – Waste not as expected; hard to remove.
- **Risk number RPP-006** – SST retrieval system performance does not meet requirements due to controllable causes.

5.3.2.2 Opportunity

Opportunities associated with this technology are:

- Having more wet retrieval options in support of retrieving SSTs in A and AX Tank Farms.

5.3.2.3 Return on Investment

The anticipated ROI comes from a cost savings that correlates to an improved performance. This performance would result from a 2x to 5x improvement in retrieval rate and 10x improvement in dilution ratio as compared to previous Hanford wet retrieval systems. Therefore, retrieval time and water usage would be significantly reduced.

5.3.3 HWEE Down Selection

The ORP 2015 Grand Challenge Workshop product, "Using a High-Pressure, Low-Flow-Rate Scarifier to Fragment Solids Coupled with Pneumatic Conveyance to Retrieve the Solids and Cutting Fluid Slurry with Reduced Fluid Use and Reduced Solids Dissolution in SST," provided the basis for assessing confined sluicing-type technologies for future tank waste retrievals.
In 2016, PNNL was tasked by WRPS with finding available technologies that meet the intent of this Grand Challenge. A literature search revealed Oak Ridge National Laboratory had previously deployed the best-known version of this type of apparatus.

5.3.4 CTE Determination

After evaluation of this technology against the questions provided in Appendix A it is determined that this technology is not considered a CTE.

5.3.5 HWEE Development Phase I

Phase I HWEE development testing was successfully completed in 2017 and focused on demonstrations in the following four areas:

- An end effector with minimal in-tank water usage that can be used in a leaking tank
- Potentially higher retrieval effectiveness with lower dilution
- An end effector that can be deployed using existing systems
- Aerosol generation from the end effector aerosol generation does not impact visibility.

Phase I installed the HWEE on a PNNL-designed robotic gantry system at the WRPS CTF to perform effectiveness testing. The test platform included calibrated instrumentation to measure reaction forces and process parameters. Testing employed benign simulant materials, prepared and characterized by PNNL, as recommended in PNNL-26206, *Evaluation of A-105 Waste Properties and Potential Simulants for Confined Sluicing Testing*. The tests involved retrieval of water, sludge, and hardpan simulants to determine pumping rate, dilution factors, and screen fouling rate.

HWEE development Phase I testing results are discussed in detail in PNNL-26856, *Hanford Waste End Effector Phase I Test Report.*

5.3.5.1 Phase I Test Simulants

To meet the objectives of Phase I testing, three simulants were prepared as specified in the prior work. See Table 6.

Table 6. Summary of Simulants Developed Previously.

Simulant Type	Simulant Material	Typical Strength (Pa)	Reference
Wet Sludge	Clay (kaolin and/or bentonite)	500 – 10,000[(a)]	PNNL-10582 PNNL-11021 PNNL-11685 PNNL-19094 PNNL-21167
Hardpan/Dried Sludge	Kaolin/Plaster	30,000 to 150,000[(a)]	PNNL-11021 PNNL-20048
Hard Saltcake	K-Mag (K2SO4 2MgSO4)	10,000,000 to 30,000,000[(b)]	PNNL-11021 PNNL-11685 PNNL-11103

Note: Lines for listed references are provided in Section 14.0.
(a) Shear strength.
(b) Compressive strength.

The Phase I simulant materials were thus selected to match the prior products. However, preparation and characterization of bench-scale simulant samples for yield stress in shear (shear strength) demonstrated strength differences, so the recipes were adjusted accordingly. Table 7 lists the HWEE Phase I simulants.

Table 7. HWEE Phase I Test Simulants.

HWEE	Simulant	Material Strength	Reference
Phase I	Kaolin/Water	3500 Pa	PNNL-26206 PNNL-26856
	Kaolin/Plaster/Water	150,000 Pa	PNNL-26206 PNNL-26856
	Potassium-Magnesium Sulfate	12,000,000 Pa	PNNL-26206 PNNL-26856

Note: Lines for listed references are provided in Section 14.0.

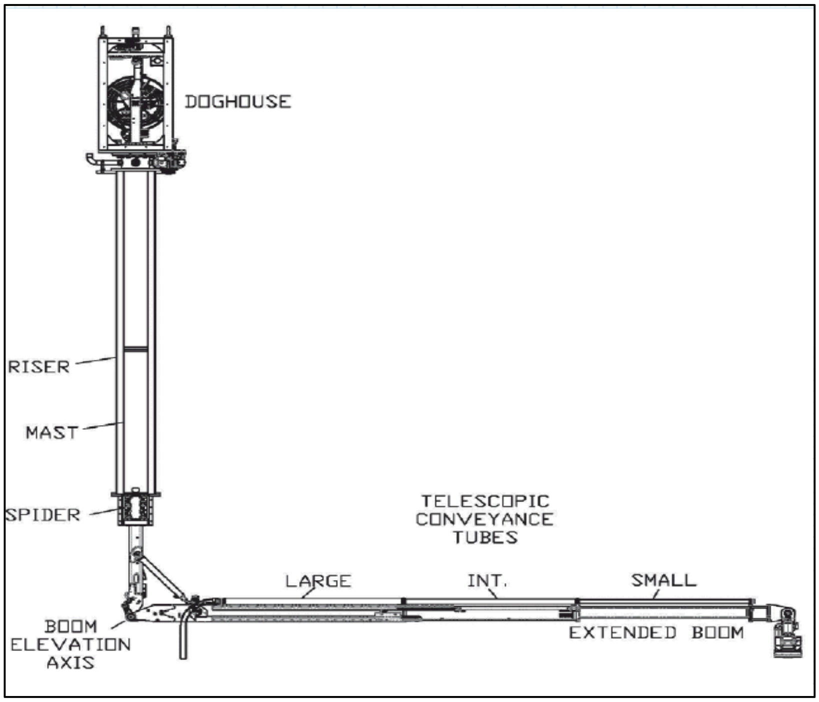
5.3.6 HWEE Development Phase II

Phase II of the HWEE test program addressed two areas of development:

- Additional proof-of-principle testing to address challenges related with stratification in waste hardness; waste surface topography as described in PNNL-27803 (see Figure 14); and vertical conveyance of mobilized solids.
- Conceptual design providing integration of the HWEE with appropriate support systems for future deployment in an actual SST or DST. This includes modification to a spare tank C-105 ERSS arm with attachment of the HWEE for testing at the CTF (see Figure 15).

Figure 14. Hanford Waste End Effector Tilt Mechanism.

Figure 15. Conceptual ERSS with HWEE Adaptation.



The following Phase II program objectives were employed for a successful continued proof-of-principle test program:

- More challenging waste retrieval mining to better mimic actual Hanford tank conditions as follows:
  - Layered waste simulant mining
  - Topography waste simulant mining.
- More challenging waste vertical conveyance of the jet pump to assess if waste can be lifted out of a Hanford waste tank or at least to a higher staging location.
- HWEE mining capabilities made more flexible to meet new mining challenges.
- HWEE inlet screen made more robust.
- HWEE water usage reduced; back flush jet was reduced to decrease water consumption.
- Instrumentation upgrades to improve retrieval and water dilution rate calculations.

A conceptual design for a deployment system (i.e., use of an articulated mast or a remotely operated crawler) and a waste conveyance system was initiated in accordance with RPP-SPEC-62134, *Specification for Prototype ERSS with Hanford Waste End Effector (HWEE)*, to determine the viability of HWEE deployment using an articulated mast. Figure 15 depicts this conceptual design. The amount of the design that is accomplished in Phase II will determine the scope of Phase III that provides for collecting and transferring the retrieved waste out of an SST. Phase I testing was performed with a multiple-scale (small- to full-) retrieval system. At Phase I not all components were required to be full-scale but will focus on system component integration. The ability to achieve the goals of any waste retrieval campaign is highly dependent upon a systems-level approach. A number of systems can enable the HWEE to be successful. Simple categorical areas include (1) how to access the tank (i.e., riser size); (2) how to enter the tank (via a remote arm, a remote vehicle, or another subsystem that deploys the HWEE for use by the arm and the remote vehicle in-tank); (3) how the waste is mobilized and removed locally; (4) how waste is removed from the tank; and (5) how the waste is transferred to its next destination.

5.3.6.1 Phase II Test Simulant

Table 8 lists the simulant used in HWEE Phase II testing. HWEE development Phase II testing is discussed in detail in PNNL-27422, *Hanford Waste End Effector Test Plan-Phase II.*

Table 8. HWEE Phase II Simulant.

HWEE	Simulant	Material Strength	Reference
Phase II	Kaolin/Water	Layered simulant 3500/280/3500 Pa	PNNL-27422
	Kaolin/water	"Bath tub ring" Monolith 3500 Pa	PNNL-27422

Note: Lines for listed references are provided in Section 14.0.

5.3.6.2 HWEE Simulant Retrieval Performance Phase I and Phase II Testing

The results of HWEE Phase I and II proof-of-concept testing performed at CTF are shown in Table 9. Results provided in Table 9 for dilution ratio and retrieval rate indicate a higher performance for the HWEE as compared to a previous retrieval system.

5.3.7 HWEE Development Phase III

The Phase III HWEE development program will demonstrate full-scale integrated HWEE system effectiveness in a cold simulated waste environment. Phase III testing will include all components previously developed and tested in Phases I and II but at full scale. Depending on the pedigree of the full-scale system, the primary goal of Phase III testing is to achieve TRL 6 per DOE G 413.3-4A (see Appendix B).

Phase III cold testing will require a full-scale test bed with internal obstructions based upon the A or AX Tank Farm tanks. This phase of testing will demonstrate overall HWEE system effectiveness and deployability. The test bed and process lines will be instrumented (e.g., level monitors, pressure gauges, Coriolis meters) as needed to prove system viability. Although the test vessel may be open top (see Figure 22), all components will be sized to deploy through maximum 42-in. riser that extends approximately 20 ft into the tank head space.

Table 9. HWEE vs MARS-V Performance.

Device	Simulant	Shear Strength (Pa)	Retrieval Rate (gpm)	Dilution Ratio	Comment
MARS-V	Simulant 1M	< 750[a]	4.3	0.05	Simulant 1M "considered to be pumpable"[b]
	Simulants 2	unknown	1.5	0.02	Simulants were non-pumpable prior to jet erosion
	Simulants 3	172,000[c]	0.7	0.01	
HWEE Phase 1	Kaolin	3,700	4.9	0.3	
	Kaolin/Plaster	160,000	3.1	0.19	
HWEE Phase 2	Kaolin (layered)	3,500 /280 /3,500	7.6	0.24	3,5000 Pa simulants were non-pumpable prior to jet erosion
	Kaolin (uneven surface)	3,500	3.1	0.11	

Note: Reference lines for cited sources are provided in Section 14.0.

(a) Reported shear strength for similar simulant to Simulant 1 (see RPP-RPT-51652) from RPP-SPEC-39670. Simulant 1M is Simulant 1 without the Plaster of Paris component RPP-RPT-51652; RPP-SPEC-39670. Decreasing the Plaster of Paris component concentration in a kaolin/Plaster of Paris substantially decreases the shear strength (PNNL-11685; PNNL-24255). Based solely on the Simulant 1M kaolin concentration reported in RPP-RPT-51652, the shear strength can be estimated at approximately 100 – 400 Pa depending on the kaolin, water, and preparation (PNNL-24255). The sand addition, depending on all parameters previously referenced for the kaolin as well as the sand size range and distribution, can increase the shear strength, but not to the magnitudes expected for the Plaster of Paris addition (Ancey and Jorrot 2001, PNNL-11685; PNNL-24255). Thus Simulant 1M is judged to most likely have lower shear strength than that reported Simulant 1, which is in keeping with the "considered to be pumpable" description in RPP-RPT-43107.

(b) Description in RPP-RPT-43107 for a decreased plaster content of Simulant 1.

(c) Reported compressive strength for Simulant 3 from RPP-SPEC-39670, is 50 psi (~345,000 Pa). The shear strength value of 172,000 Pa is estimated from a relation for compressive strength and shear strength which although it has been supported by practice as well as by experimentation and numerical results, it is not universally accepted. See Appendix B of PNNL-17707.

5.4 NEW RISER INSTALLATION SYSTEM

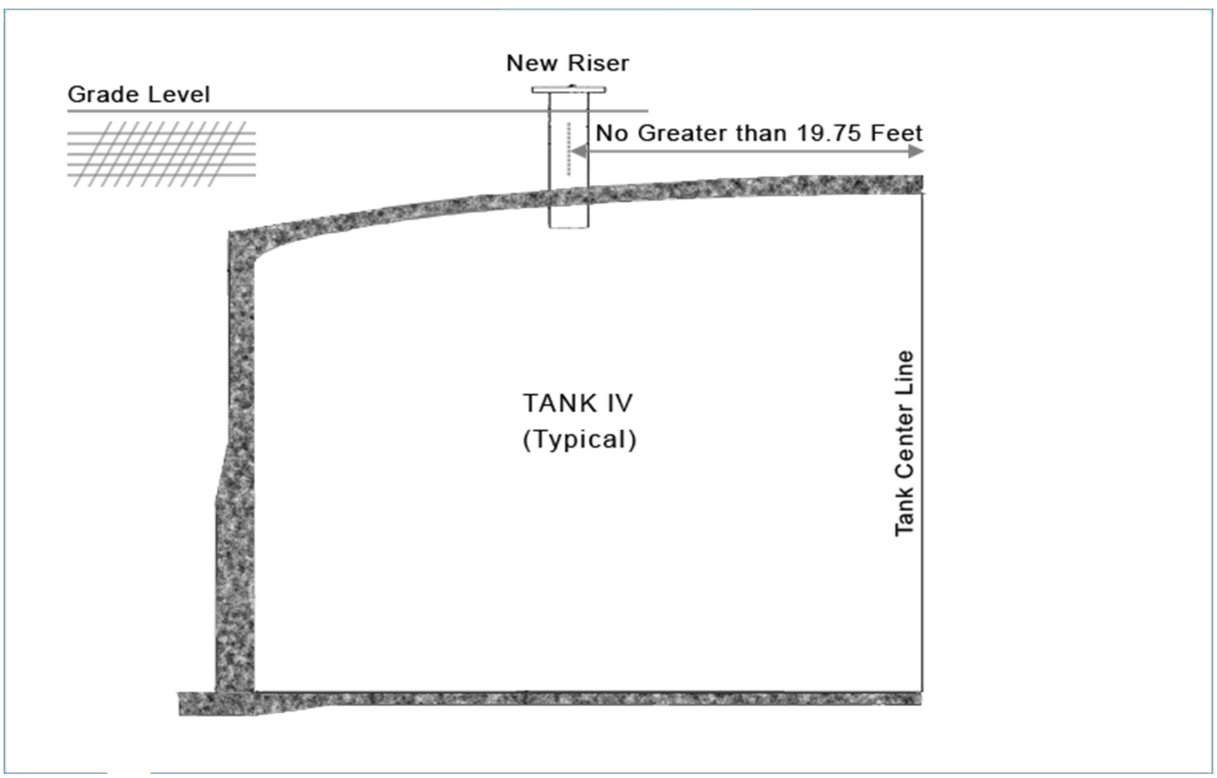
Tank bottom accessibility is a key challenge when attempting to remove solids from a tank. Use of existing tank risers is preferred. In some cases, where there is not the correct number or size of riser available, holes must be cut into the tank domes and new risers installed. Technology for drilling new enlarged tank holes for risers up to 5 ft in diameter is needed.

Figure 16 shows an example rotary core cutter, and Figure 17 shows a proposed location for larger riser installations.

Currently this technology is not being pursued. Additional analysis is being performed this fiscal year to assess risks of encountering potential abandoned transfer lines and/or conduit during removal of overburden soil.

Figure 16. Example Rotary Core Cutter.

Figure 17. Proposed Location for Larger Riser Installation.



5.4.1 Mission Driver

The goal of this work is to develop a method, such as the NRIS, that is safer for tank farm personnel, is more efficient, and is more cost-effective to implement than previous core cutting efforts. The NRIS would allow for a 60-in. cut, creating the largest hole ever made in a Hanford tank dome. In addition, hard-to-access risers and pits will no longer need to be used for retrieval (e.g., tank C-105). The NRIS is based on as low as reasonably achievable (ALARA) principles that will provide a more efficient method to install a riser in support of tank waste retrieval. The installation will minimize the need to remove existing equipment and allow installation of additional access for other new retrieval equipment.

5.4.2 Risk, Opportunity, and Return on Investment

Successful deployment of NRIS would help mitigate the following risk while providing opportunities and ROI.

5.4.2.1 Risk

The RCSS would be addressing the following identifiable risks associated with retrieval of waste tanks:

- **Risk number RPP-006** – SST retrieval system performance does not meet requirements due to controllable causes.
- **Risk number AAXRC-043-R** – Equipment in risers is more difficult to remove than anticipated.
- **Risk number AAXRC-051-R** – Damage to tank/equipment during equipment installation or removal.

5.4.2.2 Opportunity

Opportunities associated with this technology are:

- Decreases time required by reducing the amount of soil removal by hand digging.
- The technology reduces worker exposure to tank hazards.

5.4.2.3 Return on Investment

The anticipated ROI is significant cost and labor savings over the current cutting method because it removes soil without manual labor.

5.4.3 NRIS Down Selection

An NRIS technology is needed that can be used to safely, efficiently, and cost effectively install new tank risers through 8 to 12 ft of soil over-burden and penetrate the 15-in. concrete-reinforced tank dome, for deployment of tank waste retrieval equipment. The selected technology needs to have detection capabilities to avoid damaging buried lines or creating incidental contamination releases while removing soil over-burden. The design should have dust suppression capabilities to be able to maintain contamination control. Additionally, the selected technology may not exceed the prescribed tank load limits for the tanks under consideration. The selected technology should be capable of efficiently removing the soil above the tanks, storing or preparing the soil for disposal, and inserting an approximate 2- to 6-ft (nominal) diameter metal riser through the tank dome. Emphasis will be placed on the cost effectiveness of the technology selected. Final selection will take into account the findings of the recent dome load analysis performed by PNNL (PNNL-28219, *Structural Analysis of Off-Center Penetrations in the A-Farm Tank Domes*).

5.4.4 CTE Determination

After evaluation of this technology against the questions provided in Appendix A, it is determined that this technology is not considered a CTE. Technologies that are not identified as critical may still be developed under this program via a graded approach. Targeted development includes retrieval technologies, better access to tank bottoms, and more accurate waste volume measurement. ARTs developed under this program will support all other future retrievals as well.

5.4.5 NRIS Phase I

NRIS development Phase I activities include conceptual design and procurement of the coring system equipment and materials to develop the conceptual components.

5.4.5.1 Phase I Test Simulant

Simulant is not expected to be needed for development testing.

5.4.6 NRIS Development Phase II

NRIS Development Phase II activities will include design, component fabrication, and component/subsystem factory acceptance testing.

5.4.6.1 Phase II Test Simulant

Simulant is not expected to be needed for development testing.

5.4.7 NRIS Development Phase III

NRIS design and construct system test facility. Perform system testing, training, green tag, and deliver to WRPS for future deployment.

5.4.7.1 Phase III Test Simulant

Simulant is not expected to be needed for development testing.

5.5 RESIDUAL VOLUME MEASUREMENT SYSTEM

Three-dimensional laser scanning has only recently been utilized to determine tank waste volumes. For RVMS down selection, this was accomplished by lowering a 3D laser scanner down a 12-in. tank riser, until it was inside the tank headspace. Although relatively new, the technology proved its value by quickly producing accurate tank volume estimates. Unfortunately, this 3D laser scanning system is too large to fit down risers in tanks that will soon need volume estimates.

5.5.1 Mission Driver

The integrity and shape of the tank walls and floors is important for tank waste retrieval and closure. Bulges and dips in the tank floor impair estimates of remaining tank waste. The ability to survey tank waste levels has been demonstrated with a laser scanner system (RPP-RPT-58401, *Tank 241-C-104 Laser Scanning Equipment Test*); however, the laser scanner cannot penetrate the remaining waste to locate the tank floor.

5.5.2 Risk, Opportunity, and Return on Investment

Successful deployment of RVMS would help mitigate the following risk while providing opportunities and ROI.

5.5.2.1 Risk

The RVMS would be addressing the following identifiable risk associated with retrieval of waste tanks:

- **Risk number RPP-006** – SST retrieval system performance does not meet requirements due to controllable causes.

5.5.2.2 Opportunity

Opportunities associated with this technology are:

- Successful deployment of a waste volume measurement/tank bottom classification technique(s) would allow Tri-Party Agreement (Ecology et al. 1989) compliant closure of AX Tank Farm tanks.
- An efficient means to deploy waste volume measurement/tank bottom classification would reduce the mission risk by accurately measuring residual tank waste and identifying tank bottom abnormalities.

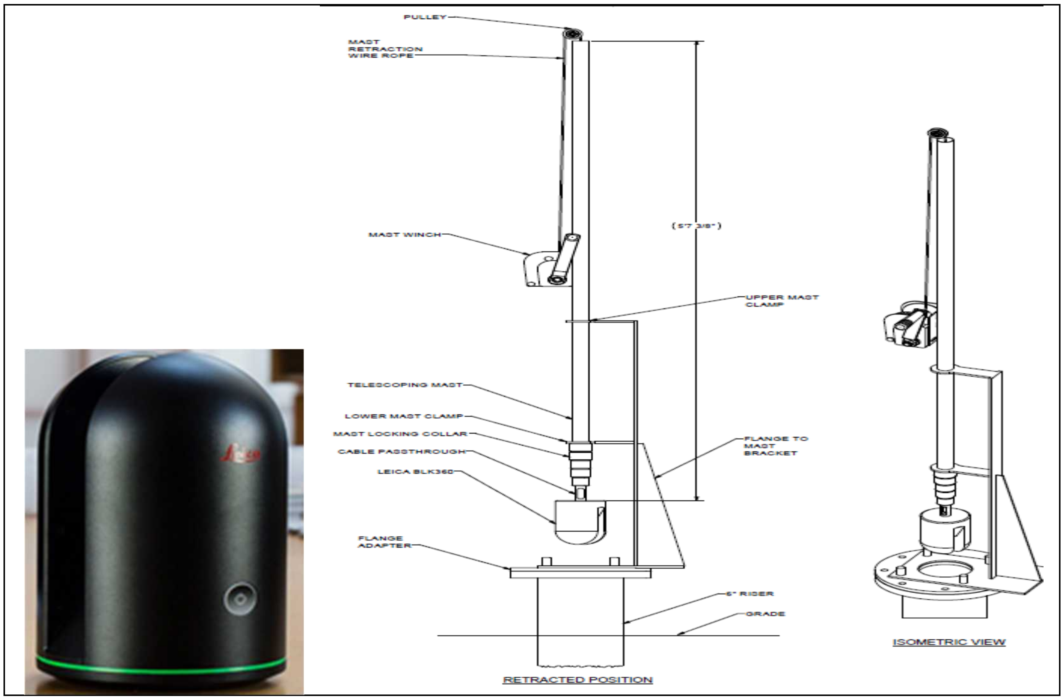
5.5.2.3 Return on Investment

The anticipated ROI is significant cost and labor savings over the current measurement method because it will provide a more accurate assessment of solids volume. The improved accuracy optimizes retrieval operations.

5.5.3 RVMS Down Selection

A market survey and product demonstration resulted in the Leica Geosystems BLK360 as a possible option. The BLK360 (see Figure 18) is a much smaller 3D laser scan than units previously used. It has the potential to allow 3D laser scans to be performed through waste tank risers as small as 4 in.

Figure 18. Laser Scanner.



5.5.4 CTE Determination

After evaluation of this technology against the questions provided in Appendix A, it is determined that this technology is not considered a CTE. Technologies that are not identified as critical may still be developed under this program via a graded approach (see Figure 2).

The phases of technology development per the graded approach are provided in the following sections.

5.5.5 RVMS Development Phase I

Phase I of RVMS development will include development of a 3D laser scanner deployment tool for use with 12-in., 8-in., and 6-in. risers. This phase will also include a quantitative test of BLK360 volume estimating capabilities in a CTF. Phase I will investigate the possibility of size reducing the BLK360 (less than 4 in.) and/or investigate the availability and functionality of the Transco Business Technologies mini scanner version 2 as an option to replace the BLK360 if necessary.

5.5.5.1 Phase I Test Simulant

No simulant is needed for the technology development.

5.5.6 RVMS Development Phase II

Phase II of RVMS development will deploy the BLK360 using the 3D laser scanner deployment tool into tank C-104 using the same riser as the FARO® unit. This will provide assurance the

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system will work in field conditions and allow comparison to two measurements previously performed. On success of the tank C-104 deployment, the BLK360 will be deployed in other tanks with 12-in., 8-in., or 6-in. risers.

5.5.6.1 Phase II Test Simulant

No simulant is needed for the technology development.

5.5.7 RVMS Development Phase III

Phase III of RVMS deployment will reduce the diameter of the BLK360 (or substitute the Transco unit) and provide modifications to the 3D laser scanner deployment tool for future use in a 4-in. riser.

5.5.7.1 Phase III Test Simulant

No simulant is needed for the technology development.

5.6 THREE-DIMENSIONAL FLASH LIDAR

The flash LIDAR is a 3D imaging camera (see Figure 19) that can be lowered into the tank at several locations to capture 3D images of the solids remaining in the tank. 3D laser scanning has only recently been utilized to determine tank waste volumes. Current methods to measure volumes of residual solids left in the tanks are estimations based on analysis of a series of photographs taken as the residual material dries. This approach is typically labor intensive, time-consuming (dependent on the drying period), and prone to uncertainties associated with interpretation of features captured in the photographs.

Figure 19. 3D Flash LIDAR Camera.

5.6.1 Mission Driver

This concept improves mission efficiency by providing an innovative, accurate tool for measuring the total volume of waste remaining in the tank after retrieval sequences. It can provide feedback regarding the extent of waste still requiring removal, and also provide a defensible method for declaring when a tank is sufficiently retrieved. This system also has the unique capability to differentiate the solid fraction of the waste. The capabilities of the 3D flash LIDAR technology can guide retrieval operations decisions based on residuals volumes and potentially optimize retrieval and subsequent closure.

5.6.2 Risk, Opportunity, and Return on Investment

Successful deployment of 3D flash LIDAR would help mitigate the following risk while providing opportunities and ROI.

5.6.2.1 Risk

The 3D flash LIDAR would be addressing the following identifiable risk associated with retrieval of waste tanks:

- **Risk number RPP-006** – SST retrieval system performance does not meet requirements due to controllable causes.

5.6.2.2 Opportunity

Opportunities associated with this technology are:

- This project is motivated by the need to quantify the inventories of radioactive and stable constituents left in the legacy high-level waste underground storage tanks located at the Hanford Site, after bulk waste removal and subsequent cleaning. The objective is to develop the capability to efficiently and accurately measure the residual solids volumes left in each tank after cleanup, which is to meet site remediation closure agreements by DOE.
- Current methods can estimate volumes of residual solids based on analysis of a series of photographs. Such an approach is labor intensive, time consuming, and sensitive to uncertainties associated with interpretation of features captured in the photographs.
- The proposed mapping approach will combine controlled positioning of 3D imaging sensors with algorithms that compute the volumes of the residual waste. The 3D flash LIDAR uniquely offers the capability to determine the residual solids existing in the presence of residual sluicing liquids, therefore enabling an accurate quantification of the solids. Thus, the residual waste assessment can be conducted as soon as the tank cleaning has reached the maximum extent possible.
- LIDAR would significantly decrease the time for quantification of inventories due to the capability and improved accuracy of 3D imaging of solids (with some or all of the solid phase material covered by liquid). This cost savings would be realized for the period required for the tank closures. The benefit of successfully implementing the flash LIDAR technology for Hanford tank closures could also be realized at the Savannah River Site.

5.6.2.3 Return on Investment

The anticipated ROI is potential savings in excess of $12 million for the time to remove liquids from the solids, and to analyze and quantify the inventories remaining. There are more than 160 waste tanks that require the need to quantify the inventories of radioactive and stable constituents left in the tanks. This estimated savings considers the cost of labor, the time to perform the analysis for quantifying inventories from photographs, and the time for rework due to potential error in two-dimensional interpretation of remaining tank waste (liquid and solids).

5.6.3 3D Flash LIDAR Down Selection

The down selection process will be initiated by releasing an EOI, which will seek input from LIDAR vendors or competing technologies. This event will occur at a future date.

5.6.4 CTE Determination

After evaluation of this technology against the questions provided in Appendix A, it is determined that this technology is not considered a CTE. Technologies that are not identified as critical may still be developed under this program via a graded approach. Targeted development includes retrieval technologies, better access to tank bottoms, and more accurate waste volume measurement. ARTs developed under this program will support all other future retrievals as well.

5.6.5 Technology Development Phases for 3D Flash LIDAR

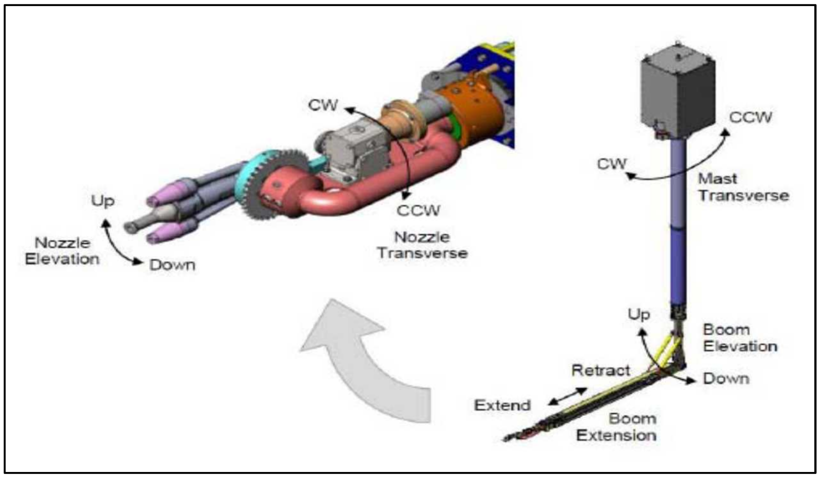
A procurement specification would need to be written to purchase the 3D flash LIDAR system. Testing the LIDAR system in a full-scale tank mockup would need to occur and development of software that takes data from different locations and stitches it together. This will allow the system to be placed in multiple ports and all the data sets can be combined into one 3D tank map.

Testing of the LIDAR system and stitching software with various simulated wastes to determine if it can map contours under water and any other limitations would then need to occur. The system will have to be demonstrated to ensure it is viable in the Hanford Site tank environment. The proposed mapping technology offers the potential of reducing the required labor, reducing the task duration (no waiting for waste to dry), improving mapping accuracy (more quantitative data), and will map solids under water.

5.7 EXTENDED REACH SLUICING SYSTEM AND SLURRY PUMP MODIFICATIONS

The current ERSS has a boom fixed at the bottom of a support mast that extends and retracts to increase the reach of both high and low pressure nozzles, thereby increasing the effectiveness of the sluice stream to break up and mobilize solid waste in the tank (see Figure 20). The ERSS also is a remote and hydraulically controlled, high-volume jetting system, but it is equipped with three fully articulating nozzles that provide elevation and transverse coverage. The combination of the boom extension and the nozzle transverse functions of the ERSS provide a “wristing” function such that it is capable of sluicing behind objects within the reach of the boom. The ERSS boom is designed to extend, retract, elevate approximately 90° along the vertical, and rotate ±180° in its horizontal axis to bring the nozzle as close as possible to the waste in the tank. The nozzle also rotates ±180° and elevates ±140° (VI-50713, *Extended Reach Sluicing System*).

Figure 20. Extended Reach Sluicing System.



The ERSS is designed to be deployed through an outer riser with a sluicer pump installed in a center riser (i.e., central pump pit) and reach the full circumference of the tank.

The need is to develop, design, and fabricate enhancements to modify existing tank retrieval sluicers (ERSS, MARS) that will allow for greater retrieval efficiency. Based on discussions with the Retrieval organization, the following areas were evaluated for enhancement options:

- **Mast Extension** – Considers adding capability of the ERSS mast to extend vertically.
- **Pressure Increase** – Includes enhanced pumping capability as well as increased nozzle pressure for more efficient hard-pan removal.
- **Nozzle Optimization** – Includes material selection, dimensions, and fixed versus rotating configuration for improving nozzle design.
- **Supplemental Track Vehicle** – Considers the addition of a tracked vehicle with a sluicer attached to it, or a track vehicle working in cooperation with the sluicer.
- **Hose Management** – Addresses the methodology of efficient hose and cord routing in tank during operation.
- **Particle Size Management** – Addresses particle size reduction to enhance retrieval efficiency and ease conveyance with existing pumps.
- **In-Tank Particle Size Management Blending Vessel** – Considers receiving retrieved waste that cannot be pumped out of the tank in the current physical state into an intermediate vessel.

5.7.1 Mission Driver

A technology is needed for retrieving solids from Hanford tanks that contain primarily solids (sludge, salt cake, and hard pan). An alternative treatment technology to the current ERSS and sluicer pump is needed to meet a 2016 Amended Consent Decree milestone to complete A and AX Tank Farms retrievals by September 30, 2026.

5.7.2 Risk, Opportunity, and Return on Investment

A successfully modified ERSS would address the following risk while providing ROI.

5.7.2.1 Risk

The ERSS would be addressing the following identifiable risk associated with retrieval of waste tanks:

- **Risk number RPP-006** – SST retrieval system performance does not meet requirements due to controllable causes.

5.7.2.2 Return on Investment

The anticipated ROI comes from a cost savings that correlates to an improved performance. This performance will result from an increased retrieval rate and improved dilution ratio as compared to previous Hanford wet retrieval systems. Therefore, retrieval time and water usage will be significantly reduced.

5.7.3 ERSS Modifications Down Selection

Down selection of enhancements to modify existing tank retrieval sluicers that will allow for greater retrieval efficiency has been performed. Based on discussions with Retrieval organization engineering, the following areas were evaluated for enhancement options. Table 10 shows the results of nine ERSS modification option evaluated.

5.7.4 CTE Determination

After evaluation of this technology against the questions provided in Appendix A, it is determined that this technology is not considered a CTE. Technologies that are not identified as critical may still be developed under this program via a graded approach. Targeted development includes retrieval technologies, better access to tank bottoms, and more accurate waste volume measurement. ARTs developed under this program will support all other future retrievals as well.

5.7.5 ERSS Modification Development Phase I

Based upon the above scoring (Table 10), Phase I of ERSS modification development will include design, evaluation, and prototype component fabrication of ERSS enhancements to modify existing tank retrieval sluicers and pumps that will allow for greater retrieval efficiency. Improvements in this retrieval technology are sought in the following areas:

- **Pump** – Develop back stop and mechanical particle size reducer
- **Pressure increase**
- **Sluicer** – Develop a vertical travel system for the sluicer arm
- **Hose Management**.

Table 10. Evaluated ERSS Modification Options.

Sluicer Enhancement Options		Retrieval Rate Increase	Dilution Ratio (approaches 1)	Ease of Deployment	Capital Asset Reduction	Maintenance & Operation Optimization	Total Score
1	Mechanical Assistance	0	0	0	0	0	0
1A	ERSS Mast Vertical Extension	2	0	2	1	1	6
1B	Pressure Increase	2	2	0	0	2	6
1C	Nozzle Optimization	2	2	0	0	2	6
1D	Hose Management	2	2	0	0	2	6
1E	Pump Back Stop Particle Size Management	2	2	0	0	1	4
1F	In-Tank Particle Size Management Blending Vessel	2	2	0	0	1	5
2	Deploy Multiple Units	2	0	0	0	0	2
3	Training Automation	0	0	2	0	2	4
4	HWEE Deployment	2	2	0	0	1	5

Individual option scores range from 0 through 2 with a possible maximum total score of 6:
0 = no impact or possibly a negative impact to the ranking criteria.
1 = 10% increase to current retrieval capability.
2 = 30% increase to current retrieval capability.

5.7.5.1 Phase I Test Simulant

Simulant not applicable.

5.7.6 ERSS Modification Development Phase II

Based on Phase I results, fabricate prototype pump and sluicer systems that have the modifications listed in Phase I. Perform factory acceptance testing.

5.7.6.1 Phase II Test Simulant

Phase II is not applicable to the sluicer enhancement testing. For the pump, a robust larger particle size simulant must be developed to validate the effective ness of the mechanical size reducing modifications.

5.7.7 ERSS Modification Development Phase III

Incorporate applicable lessons learned from the Phase II factory acceptance testing and complete as-builts. Fabricate the modified sluicer and pump systems to Hanford deployment requirements. Perform cold testing and training at the CTF. Release for future farm deployment.

5.7.7.1 Phase III Test Simulant

Utilize the simulant developed under Phase II for cold testing the pump backstop and mechanical size reducing modifications.

5.8 DEVELOPMENT TESTING OF HIGH-RADIATION HOSE MATERIALS

All WRPS retrieval technologies use in-tank pumps to transfer radioactive tank waste. Waste slurry is pumped from the SSTs through rubber HIHTLs (Figure 21), to valve boxes for re-routing the waste to the DSTs. Several A Tank Farm tanks have highly radioactive waste (~43,000 R/hr total beta and ~365 R/hr gamma at the waste surface) that may compromise the hoses, considerably shortening their life expectancy. Development of HRHM is necessary to increase life expectancy of HIHTL.

Figure 21. Standard HIHTL.

5.8.1 Mission Driver

All WRPS retrieval technologies use in-tank pumps to transfer radioactive tank waste. Waste slurry is pumped from the SSTs through rubber HIHTLs, to valve boxes for re-routing the waste to the DSTs. Several A Tank Farm tanks have highly radioactive waste (~43,000 R/hr total beta and ~365 R/hr gamma at the waste surface) that will compromise the hoses, considerably shortening their life expectancy.

5.8.2 Risk, Opportunity, and Return on Investment

Successful deployment of HRHM would help mitigate the following risk while providing opportunities and ROI.

5.8.2.1 Risk

The HRHM would be addressing the following identifiable risks associated with retrieval of waste tanks:

- **Risk number RPP-006** – SST retrieval system performance does not meet requirements due to controllable causes.
- **Risk number AAXPC-016-R** – Excessive equipment failures (other than pumps).

5.8.2.2 Opportunity

Opportunities associated with the use of a more radiation resistant non-metallic material would eliminate the need for transfer line replacement during a retrieval operation. These replacements are driven by the requirements found in RPP-12711, *Temporary Waste Transfer Line Management Program Plan*.

5.8.2.3 Return on Investment

The anticipated ROI is that development and testing of HRHM has the potential to extend the life of the HIHTLs and improve tank retrieval operations performance. The replacement cost of HIHTLs is significant; life extension through optimizing material of construction would save replacement costs and support.

5.8.3 Down Selection

This section will be developed at a future date.

5.8.4 CTE Determination

After evaluation of this technology against the questions provided in Appendix A, it is determined that this technology is not considered a CTE. Technologies that are not identified as critical may still be developed under this program via a graded approach. Targeted development includes retrieval technologies, better access to tank bottoms, and more accurate waste volume measurement. ARTs developed under this program will support all other future retrievals as well.

5.8.5 Technology Development Phases for HRHM

In general, the development approach for HRHM includes preparation of specifications and a statement of work to award a contract with a commercial vendor(s). The contract will include development and testing of materials for use in hoses for application in high radiation areas. The research likely includes testing to meet the physical requirements (e.g., pressure, flexibility, temperature) of the hoses. Based on successful testing, a prototype hose material is expected to be designed, fabricated, and delivered to the Hanford Site for final testing and deployment.

6.0 SIMULANT DEVELOPMENT

The use of simulants is important for waste retrieval technology development for a wide variety of reasons. Ideally, the physical properties of the target tank waste (e.g., shear strength, compressive strength, and cohesiveness) should be well understood. If those properties are well known and based upon sampling and testing of real waste, then a simulant that closely mimics the key physical properties can be developed and used for testing. However, as in the case with all underground storage wastes, the sampling and testing of real waste materials may be prohibitively expensive or technically difficult. Testing with real waste also involves regulatory constraints that will likely hinder timely development.

To reduce the risk of ineffective retrieval performance, a series of simulants needs to be developed that are likely to be bounding of what may be encountered in the tank. While this is not an ideal situation, this approach has been used in the past (PNNL-11685. *Retrieval Process Development and Enhancements Waste Simulant Compositions and Defensibility*; PNNL-11021, *Initial ACTR Retrieval Technology Evaluation Test Material Recommendations*). The other challenge with the development and use of simulants is a practical one. Simulants for bench-scale testing are used in small quantities; however, in full-scale tests, the volume of simulant required is quite large, and cost has to play a key role in the materials that are chosen for simulants. Equally, the ability to easily dispose of spent simulant material is a necessity. Table 11 and Table 12 provide the general tank waste characteristics contained in A and AX Tank Farms, respectively.

Table 11. Physical Properties of A Tank Farm Tank Waste. (3 sheets)

Waste Property	Waste Type	Nominal
Percent by weight	Saltcake Solid	36.4
	Supernatant	46.2
	Sludge	44.2
	Interstitial liquid	46.2
Temperature (°F)	All	83-85
Tank A-101[a]		
Density (SpG)	Saltcake Solid	1.74
	Supernatant	No data available
	Sludge and Liquid	1.61
	Interstitial liquid	1.49
Viscosity (cP)	No data available	
Percent by Weight	Saltcake Solid	29
	Supernatant	No data available
	Sludge	44
	Interstitial liquid	44
Temperature (°F)		90-110
Tank A-102[a]		
Density (SpG)	Saltcake Solid	1.7
	Supernatant	1.57

Table 11. Physical Properties of A Tank Farm Tank Waste. (3 sheets)

Waste Property	Waste Type	Nominal
	Sludge	No data available
	Interstitial liquid	1.57
Viscosity (cP)	No data available	
Percent by Weight	Saltcake Solid	34
	Supernatant	46
	Sludge	No data available
	Interstitial liquid	46
Temperature (°F)	All	85-90
Tank A-103*		
Density (SpG)	Saltcake Solid	1.32
	Supernatant	1.51
	Sludge	1.34
	Interstitial liquid	1.34
Viscosity (cP)	No data available	
Percent by Weight	Saltcake Solid	38
	Supernatant	50
	Sludge	69
	Interstitial liquid	50
Temperature (°F)		80-105
Tank A-104*		
Density (SpG)	Saltcake Solid	No data available
	Supernatant	No data available
	Sludge Solid	0.95
	Interstitial liquid	No data available
Viscosity (cP)	No data available	
Percent by Weight	Saltcake Solid	No data available
	Supernatant	No data available
	Sludge Solid	0
	Interstitial liquid	No data available
Temperature (°F)		140-165
Tank A-105*		
Density (SpG)	Saltcake Solid	No data available
	Supernatant	No data available
	Sludge Solid	1.54
	Interstitial liquid	No data available
Viscosity (cP)	No data available	
Percent by Weight	Saltcake Solid	No data available

Table 11. Physical Properties of A Tank Farm Tank Waste. (3 sheets)

Waste Property	Waste Type	Nominal
	Supernatant	No data available
	Sludge Solid	0
	Interstitial liquid	No data available
Temperature (°F)		120-205
Tank A-106*		
Density (SpG)	Saltcake	1.58
	Sludge	1.51
Viscosity (cP)	No data available	
Percent by Weight	Saltcake	44
	Sludge	46.9
Temperature (°F)	No data available	

*RPP-46690, 2010, *Level 2 Specification for the A Farm Tank Waste Retrieval Systems*, Rev. 0.

Table 12. Physical Properties of AX Tank Farm Tank Waste.

Property	Supernate	Interstitial Liquid	Salt Cake + Liquid	Saltcake solid	Sludge + Liquid	Sludge Solid
Tank AX-101*						
Volume (kgal)	n/a	47	n/a	307	3	n/a
Density	n/a	1.53	n/a	1.73	1.51	n/a
% Water by Weight	n/a	43	n/a	33	62	n/a
Temperature (°F)	n/a	85-105	n/a	85-105	85-105	n/a
Tank AX-102*						
Volume (kgal)	n/a	n/a	24	n/a	6	n/a
Density	n/a	n/a	1.58	n/a	1.57	n/a
% Water by Weight	n/a	n/a	34	n/a	43	n/a
Temperature (°F)	n/a	n/a	70-75	n/a	70-75	n/a
Tank AX-103*						
Volume (kgal)	n/a	20	n/a	79	8	n/a
Density	n/a	1.45	n/a	1.61	1.61	n/a
% Water by Weight	n/a	49	n/a	43	44	n/a
Temperature (°F)	n/a	85-100	n/a	85-100	85-100	n/a
Tank AX-104*						
Volume (kgal)	n/a	n/a	n/a	n/a	n/a	7
Density	n/a	n/a	n/a	n/a	n/a	1.8
% Water by Weight	n/a	n/a	n/a	n/a	n/a	80-90
Temperature (°F)	n/a	n/a	n/a	n/a	n/a	80-90

*RPP-46689, 2010, *Level 2 Specification for the AX Farm Tank Waste Retrieval Systems*. Rev. 0.

7.0 TEST FACILITIES

Development Phases I, II, and III require a CTF to perform test work. The WRPS CTF is the only main facility that is used. Future updates of this program plan will add descriptions of other CTFs as they apply for future program activities.

The WRPS CTF is located just south of the Hanford Site at 2740 Horn Rapids Road in Richland, Washington. It provides a test bed for full-scale testing of tank waste retrieval, transfer, and sampling hardware to be procured by the WRPS SST Closure organization. Tests will be performed in simulated tank and tank waste conditions that are nonradioactive and non-hazardous. In addition to testing, the CTF will allow procedure validation, personnel training, and conducting off-normal and recovery activities. Tests at the CTF will be conducted in accordance with TFC-PLN-151, *Hanford Cold Test Facility Management Plan*.

The CTF consists of an open-top, 75-ft-diameter by 27-ft-high, steel tank that simulates the general geometry of a SST or DST. Coupled with an overhead superstructure, the tank-superstructure combination provides the means to deploy and operate tank-based equipment within an environment that is dimensionally accurate, controlled, contamination free, and functionally equivalent to an actual Hanford waste tank. Figure 22 shows an external overview of the simulated tank and the inside of the simulated tank including the mock air lift circulators.

Figure 22. Cold Test Facility.

7.1 TEST FACILITY REQUIREMENTS

Technology development Phases I, II, and III will require use of test facilities that have the same general attributes. These attributes are based upon the present Hanford tank configuration. The primary difference between the facilities will be the equipment scale. Phase I and Phase II test facilities will be multi-scale facilities as needed to complete test objectives. For example, the HWEE will be functionally and/or geometrically full-scale in all phases, but the balance of the test facility will not be full scale until Phase III. Phase IV, field deployment, is addressed in Section 0.

Overall test bed requirements will vary based on the technology being developed. Table 13 lists common characteristics that may be required for any tank-based technology development.

Table 13. Common Test Bed Characteristics.

Test Platform Characteristic		HWEE	MWGS	ERSS Enhancements	RVMS	NRIS*
Physical Attributes	Partial Tank Bottom	✓	✓	✓	✓	*
	Partial Tank Height	✓		✓		*
	Full Radius Knuckle					*
	Full Lift to Ground Level	✓		✓		*
	Tank Riser	✓		✓	✓	*
	Prototypic Steel Thickness					*
	Prototypic Welds					*
	Similar Refractory (Physical Properties)					*
Functions	In-Tank Obstructions	✓	✓	✓	✓	*
	Hold Simulant (Slurry Containment)	✓	✓	✓		*
	Measure Water Loss	✓		✓	✓	*
	Mobilize and Capture Simulant	✓	✓	✓		*
	Simulant Conveyance (Transfer Out of Tank)	✓	✓	✓		*
	≥10K psi Water Pressure					*
	Material Balance	✓	✓	✓		*
	Water Handling	✓	✓	✓		*
	Video Monitoring	✓	✓	✓		*
	Dark (No Ambient Light)				✓	*

*NRIS test bed requirements are not defined at this time.

ERSS = extended reach sluicing system.
HWEE = Hanford waste end effector.
MWGS = mechanical waste gathering system.
NRIS = new riser installation system.
RVMS = residual volume measuring system.

8.0 PHASE IV FIELD DEPLOYMENT

The primary goal of this program plan is to ensure deployment of necessary retrieval-based technologies. To that end, integrated project teams ensure all aspects of the transition from technology development through field deployment. Integrated project teams generally include representatives from the following organizations: CTO, Operations/Maintenance, Risk management, ORP, Level 1 Sponsor, Engineering, Property Management, Commissioning, and Quality Assurance (QA). Transitioning the prototype technology to a field organization typically includes an enhanced design effort, final fabrication, field construction, commissioning, and final deployment.

9.0 PROPOSED COST AND SCHEDULE ESTIMATES

The following sections provide proposed costs and schedule estimates for the ART development phases described in this program plan.

9.1 NEXT GENERATION ASD ESTIMATE

Project or Activity	FY19				Totals
	Q1	Q2	Q3	Q4	
Prototype design	■	■	□	□	$26
Procurement	□	□	■	□	$44
Testing	□	□	□	■	$56
Funding in thousands (000s)	$126				$126

9.2 IN-TANK MWGS ESTIMATE

Project or Activity	FY18				FY19				FY20				Totals
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
(Phase 1) Prototype development & testing			■	■	■	■	■						$1,920
(Phase 2) Integrated system testing							■	■	■	■	■	■	$2,750
Funding in thousands (000s)	$670				$2,000				$2,000				$4,670

9.3 HWEE ESTIMATE

Project or Activity	FY17				FY18				FY19				FY20				Totals
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
(Phase 1) Build and test HWEE determine efficiency	□	■	■	■													$1,500
(Phase 2) HWEE system development					■	■	■	■									$418
(Phase 3) Full-scale cold testing			■						■	■	■	■					$1,500
(Phase 4) Deployment in SSTs													■	■	■	■	$2,500
Funding in thousands (000s)	$1,500				$418				$1,500				$2,500				$5,918

9.4 NRIS ESTIMATE

Project or Activity	FY20				FY21				Totals
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
Procure equipment/materials	▮	▮	▮						$1,040
Conceptual drawings/calcs		▮							$156
Proof of principle testing			▮						$169
Design and results report			▮						$70
Initial testing				▮	▮				$670
Perform secondary testing					▮				$280
Testing results report						▮			$215
Funding in thousands (000s)	$1,835				$765				$2,600

9.5 RVMS ESTIMATE

Project or Activity	FY19				Totals
	Q1	Q2	Q3	Q4	
Design, procure, fabricate system	☐	▮	▮	☐	$44
Offsite system test	☐	▮	▮	☐	$35
C104 validation test	☐	☐	▮	▮	$164
Funding in thousands (000s)					$243

9.6 3D LIDAR ESTIMATE

This work is estimated to cost less than $1,000,000 and have a duration of 3 to 4 years to achieve TRL 6.

9.7 ERSS MODIFICATIONS ESTIMATE

Project or Activity	FY19				Totals
	Q1	Q2	Q3	Q4	
Design/Fabricate backstop	☐	▮	▮	▮	$126
Design/Fabricate macerator	☐	▮	▮	▮	$130
Design/Fabricate ERSS enhanced vertical reach	☐	▮	▮	▮	$507
Funding in thousands (000s)					$763

9.8 HRHM ESTIMATE

The ROM overall project cost is estimated to be between $1 and $5 million and have a duration of 2 to 3 years.

10.0 QUALITY ASSURANCE PLAN OVERVIEW

Technology development will take place in four phases, each phase becoming progressively more advanced as the technology is matured. Likewise, the applied QA controls will become more rigorous as testing moves through the four phases.

Guidance for applying QA requirements for research and development work is given in ASME NQA-1-2008, *Quality Assurance Requirements for Nuclear Facility Applications* (with NQA-1a-2009 Addenda), Part IV, Subpart 4.2, "Guidance on Graded Application of Quality Assurance (QA) for Nuclear-Related Research and Development." This guidance will be applied in developing the graded approach for each ART development phase, as appropriate.

Specific QA Program requirements will be incorporated into the applicable documentation for each phase of the project.

11.0 PROJECT CLOSE-OUT CONCEPTS

All projects will ensure that decommissioning and/or layup activities are safe, complete, and documented. At a minimal level of close-out, all tanks and piping systems will be flushed and dried out. Simulants and project-related resources will be stored onsite waiting for disposition. All data files and computer systems will be also stored and secured onsite with backups. Further disposition (e.g., transportation, dismantlement, and permanent storage) will be decided by WRPS at the end of testing activities. Note that if any part of the planned testing is not completed, it will be up to WRPS to change the close-out plan based on additional testing needs.

12.0 PROGRAM PLAN UPDATES

As a minimum, this program plan will be reviewed for updates prior to the start of each development phase. If program decisions or strategic changes are made during the active phase, all conflicts with this plan will be corrected, and the plan will be reissued accordingly.

13.0 PROJECT RISK

Although the current ART maturation is focused on minimizing water usage during tank waste retrieval, the technology under consideration is still considered a wet retrieval technique. Using a wet retrieval process in compromised tanks may be prohibited from a regulatory standpoint. There is therefore uncertainty as to whether the selected ART will be approved by the Washington State Department of Ecology. There is no intention to gain regulator acceptance prior to Phase III full-scale cold testing.

14.0 REFERENCES

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APPENDIX A

IDENTIFYING CRITICAL TECHNOLOGY ELEMENTS

IDENTIFYING CRITICAL TECHNOLOGY ELEMENTS

A critical technology element (CTE) is identified if there is at least one positive response for each set of criteria.

Set 1 - Criteria	Yes	No
1. Does the technology directly impact a functional requirement of the process or facility?		
2. Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		
3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		
4. Do limitations in the understanding of the technology impact the safety of the design?		
5. Are there uncertainties in the definition of the end state requirements for this technology?		

Set 2 - Criteria	Yes	No
1. Is the technology new or novel?		
2. Is the technology modified?		
3. Have the potential hazards of the technology been assessed?		
4. Has the technology been repackaged so a new relevant environment is realized?		
5. Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		

APPENDIX B

TECHNOLOGY READINESS LEVEL DETERMINATION

TECHNOLOGY READINESS LEVEL DETERMINATION

The Technology Readiness Levels (TRL) depicted in the following table represent current status of the technologies at the issuance of this document.

Technology	Individual System Components	TRL 1 Have the basic process technology process principles been observed and reported?	TRL 2 Has an equipment and process concept been formulated?	TRL 3 Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?	TRL 4 Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?	TRL 5 Has bench-scale equipment/process testing been demonstrated in a relevant environment?	TRL 6 Has prototypical engineering scale equipment /process testing been demonstrated in a relevant environment; to include testing of the safety function?
ASD	Drive System						
	Auger						
	Deployment System						
HWEE	End effector						
	Deployment arm						
	Conveyance system						
	Process control (HMI)						
MWGS	ROV						
	Umbilical (i.e. hydraulics feed)						
	Rotocutter						
	Vacuum collection system						
	Process control (HMI)						
	Conveyance (blade cutter, aux pump, settling tanks)						
	Tank bottom sensor						
ERSS Modifications	Pressure increase						
	Nozzle optimization						
	Hose management						
	Particle size management						
	Pump enhancements						
RVMS	3D laser scanner (capable of fitting down a 6-in. riser)						
	Deployment tool for 6-in. riser version						
	3D laser scanner (capable of fitting down a 4-in. riser						
	Deployment tool for 4-in. riser version						
3D LIDAR	**Develop image stitching software**						
	Develop deployment methodology						
	Radiation harden camera						

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NRIS	Dome cutting						
	Soil removal						
	Grout deployment system						
	Dome section holder						
HRHM	Hose material development						

TRL = Technology Readiness Level.
ERSS = extended reach sluicing system.
HMI = human-machine interface.
HRHM = high radiation hose materials.
HWEE = Hanford waste end effector.
ROV = remotely operated vehicle.