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Hanford Waste End Effector Prototype Test Plan

Prepared for Washington River Protection Solutions

June 2017

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Executive Summary

This test plan describes the Phase 1 testing program of the Hanford Waste End Effector (HWEE) at the Washington River Protection Solutions (WRPS) Cold Test Facility (CTF) using a Pacific Northwest National Laboratory (PNNL)-designed testing setup. This task supports Phase 1 development testing of the HWEE to support the informational needs for initial assessment of the HWEE to support Hanford single shell tank A-105 retrieval. This task will install the HWEE on a PNNL-designed robotic gantry system at CTF, install and calibrate instrumentation to measure reaction forces and process parameters, prepare and characterize simulant materials, and implement the test program. The tests will involve retrieval of water, sludge, and hardpan simulants to determine pumping rate, dilution factors, and screen fouling rate.

Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
CLMS	Conveyance Line Management System
CSEE	Confined Sluicing End Effector
CTF	Cold Test Facility
DOE	U.S. Department of Energy
HWEE	Hanford Waste End Effector
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
SREE	Sludge Retrieval End Effector
SST	Single shell tank
WREE	Waste Retrieval End Effector
WRPS	Washington River Protection Solutions

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1.0 Introduction

This test plan describes the Phase 1 testing program of the Hanford Waste End Effector (HWEE) at the Washington River Protection Solutions (WRPS) Cold Test Facility (CTF) using a Pacific Northwest National Laboratory (PNNL)-designed testing setup. This task supports Phase 1 development testing of the HWEE to support the informational needs defined in RPP-PLAN-61227 (Wooley 2016) for initial assessment of the HWEE to support Hanford single shell tank (SST) A-105 retrieval. Note that although the program plan specifies 241-A-105 as a potential target tank, HWEE concept has since been expanded to potentially address all leaking SSTs. Phase 1 will install the HWEE on a PNNL-designed robotic gantry system at the CTF to perform effectiveness testing. The Phase I test platform will include calibrated instrumentation to measure reaction forces and process parameters. Testing will employ benign simulant materials, prepared and characterized by PNNL, as recommended in PNNL-26206 (Gaughlitz et al. 2017). The tests will involve retrieval of water, sludge, and hardpan simulants to determine pumping rate, dilution factors, and screen fouling rate.

The HWEE is a water-based scarifier originally developed by PNNL for U.S. Department of Energy (DOE) tank retrieval systems starting back in the 1990s as the confined sluicing end effector (CSEE) and later used with additional development in the waste retrieval of tanks at Oak Ridge National Laboratory (ORNL), specifically, the Gunite and Associated Tanks as described in PNNL-26037 (Hatchell et al. 2016). The HWEE is being assessed for potential use in A-105 tank retrieval because it is expected to use less water during waste retrieval compared to other water-based methods (e.g., sluicing) previously used in Hanford tanks. This is primarily because the HWEE uses three rotating high-pressure jets rather than non-rotating fan jets for dislodging the waste and a high-velocity conveyance system to retrieve the water and the waste locally at the point of waste dislodging.

The HWEE used for the Phase I testing was fabricated by HiLine Engineering & Fabrication, Inc. based on the procurement specification RPP-SPEC-61356. Specifications and drawings provided by the specification were pulled from the previous design efforts discussed above.

2.0 Specifications and Data Quality Objectives

This section describes the requirements for Phase 1 HWEE testing, provides the results of previous testing, and presents the data quality objectives of the testing. Previous test information is being provided to help guide Phase I testing.

2.1 Phase 1 Requirements

Requirements related to Phase 1 HWEE testing and application to A-105 waste retrieval are listed in Table 2.1. These requirements are the primary drivers for HWEE Phase 1 testing and are based on the WRPS Program Plan (Wooley 2016).

Table 2.1. Requirements for HWEE Phase 1 Testing

Item	Source	Description	Impact to HWEE Testing Requirement
A	7.1.1 Simulant Selection	Select waste form physical properties important to A-105 retrieval methodology	Simulant selection was assessed in PNNL-26206 (Gauglitz et al. 2017). Simulants representing three waste forms (sludge, saltcake, and hardpan) have been selected for Phase 1 testing based on previous testing efforts.
B	7.1.2 Test Facility	Select Phase 1 Test Facility appropriate to assess HWEE performance characteristics	The WRPS CTF has been selected as the location to perform testing. PNNL is providing the associated test equipment for Phase 1 testing of the HWEE.
C	7.1.3 Design and Fabrication	Design/fabricate the HWEE	The HWEE design has been accepted by WRPS based on PNNL's most recent confined sluicer design drawings that include lessons learned from ORNL retrieval and later design upgrades. WRPS has initiated HWEE fabrication and PNNL is providing technical oversight as required.
D	Test Objectives	See subsections below	See subsections below.
D.1	7.1.4, Bullet 1	Determine water usage/water remaining	Water remaining depends on the ability of the HWEE to access and retrieve the water used during waste retrieval operations. The water used by the HWEE waterjets during retrieval simulations and the water remaining in the retrieval tank will be measured by mass and/or volume. The water used by jet pump is measured but not included in water usage for the HWEE.
D.2	7.1.4, Bullet 2	Determine waste dilution ratio (gallons of water vs. gallons of simulant removed)	Dilution rate depends on retrieval efficiency. The water used by the HWEE waterjets for simulant retrieved will be measured by mass and/or volume. Dilution ratio will be converted to volumetric basis as required. The water used by the jet pump is measured but not included in the waste (simulant) dilution ratio.

Item	Source	Description	Impact to HWEE Testing Requirement
D.3	7.1.4, Bullet 3	Determine reaction forces (standoff distance, traverse velocity, high-pressure water flow)	Reaction forces on the HWEE are important for determining future HWEE deployment platforms. The HWEE reaction forces will be measured along with standoff distance, traverse velocity, and water flow/pressure as appropriate. Standoff distance will be initial location of HWEE above the simulant plane in a test run and will not include simulant removed from that plane during the test run.
D.4	7.1.4, Bullet 4	Determine frequency of back flushing or cleaning and associated water usage	Dislodged simulant will likely clog the HWEE 0.375-inch hexagonal openings in the inlet screen based on past usage and testing. When HWEE screen clogging occurs, the HWEE enhanced screen back flushing feature will be used and the amount of water usage for screen clearing will be measured. Because the HWEE screen clearing success may not be assessed until retrieval operations resume, multiple back-flushing attempts may be required to fully assess water usage.
D.5	7.1.4, Bullet 5	Determine aerosol generation and effect on visibility	Aerosol generation by the HWEE will be assessed visually (i.e., camera recordings) during testing operations. The HWEE testing conditions likely will not be fully prototypic of A-105 conditions (enclosed tank) but will give a general assessment of the degree (low, medium, high) of aerosol being generated.

2.2 Prior Testing Results

The conceptual design of the HWEE was based in large part on the Sludge Retrieval End Effector (SREE), which was derived from the Confined Sluicing End Effector (CSEE) developed for ORNL. The HWEE's performance should be equal to or better than the SREE due to refinements in screen design and conveyance inlet geometry, which are design changes based on lessons learned at ORNL. Mullen (1997a and 1997b) documented the performance of the SREE during cold testing and field operation.

Testing was conducted on a SREE variant called the Waste Retrieval End Effector (WREE) in 1998. The WREE is identical to the HWEE design except that the HWEE includes a high-pressure screen-cleaning nozzle and an optional waterjet mole located inside the retrieval inlet. A summary of test results for the WREE is provided below (Hatchell et al. 2016).

Prior retrieval tests focused on measuring retrieval performance during sludge and hardpan retrieval. For these tests, the size of the field was approximately 5-6 inches deep, 2 feet wide, and 8 feet long. The WREE was generally used to remove thin layers of material (1-3 inches). Testing with the WREE was conducted with a serpentine path in which the end effector was swept over the waste surface in a regular pattern, removing waste in horizontal planes. In hardpan retrieval, the waterjets cut channels in the material approximately 4.3 inches wide, which dictated a distance between adjacent passes of 4.3 inches. During the tests, the jet pump was operated continuously at approximately 7000 psi and used 12.5 gallons/minute of water. The hydraulic motor speed was 300 RPM for these tests.

Sludge retrieval was accomplished using 0.054-inch diameter waterjet nozzles operated at 150-1020 psi and a traverse speed of 300 inches/minute. The waterjet pressure was set to 1000 psi for the initial pass, but as successive layers were removed and the sludge became diluted, the waterjet pressure was reduced to approximately 200 psi. The WREE was lowered 1 inch before each pass was initiated, which resulted in a retrieval rate of approximately 7 gallons/minute. The test was conducted without a skirt installed on the WREE; using the skirt may have reduced the splattering and resulted in an even cleaner tank surface.

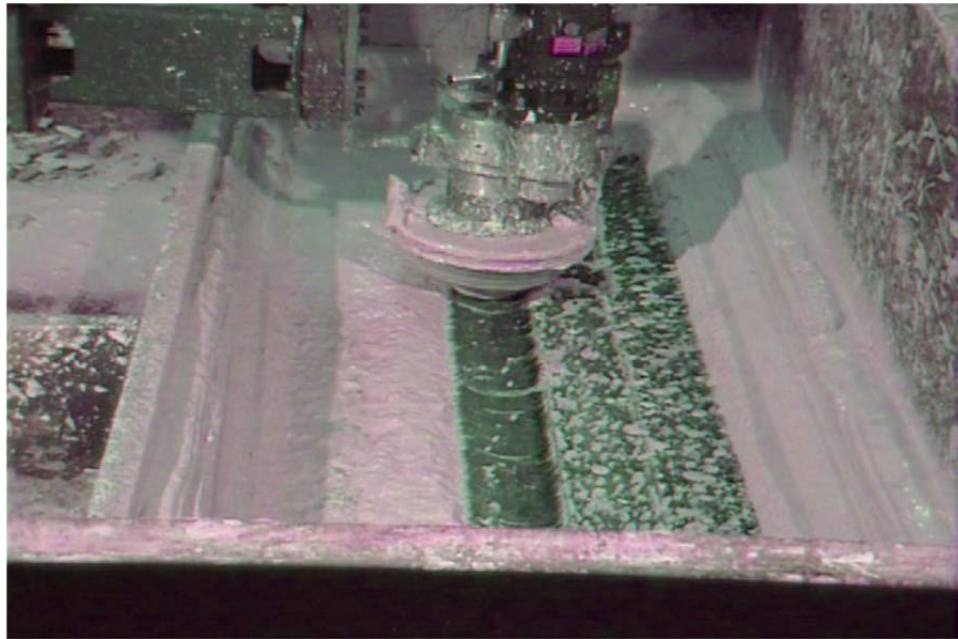


Figure 2.1. End Effector Final Surface Cleaning

Hardpan retrieval was accomplished using 0.038-inch diameter waterjet nozzles and a traverse speed of 225 inches/minute. Initial runs were conducted to determine the relationship between waterjet penetration depth and waterjet pressure. Waterjet pressure of 2000, 2200, 2600, and 3200 psi resulted in cutting depths of 1.7, 1.9, 2.1, and 2.6 inches, respectively. Because we wanted to achieve a relatively shallow depth of cut using as low a pressure as possible (to avoid splatter), a reasonable operating pressure was 2250 psi for a traverse speed of 225 inches/minute. Hardpan retrieval rates ranged from 8.9-14.0 gallons/minute. This rate does not account for the time required to clean the inlet shroud, which will reduce efficiency. The WREE skirt was installed during the hardpan tests and reduced the amount of over-spray considerably.

During hardpan retrieval, the screen became plugged with clumps of dislodged material that were too large to pass through the 0.25-inch opening in the screen (Figure 2.2). Using a combination of back flushing with water and mechanical brushing, the screen was successfully cleaned remotely. Flushing with water alone did not clean the screen completely, especially in the upper recesses of the conical cone. The screen plugged after retrieving approximately 1.0 cubic feet.



Figure 2.2. Screen Clogging during Prior Tests

Reaction forces from the WREE were measured during the tests. Reaction forces were low during sludge retrieval (<20 lbs), moderate during hardpan retrieval (<90 lbs), and highest during sludge retrieval with debris (<200 lbs). Higher forces are attributed to collisions with the simulant surface or debris. However, the tests have shown that the WREE is a robust device capable of withstanding moderately high forces without failure.

The WREE was not used to retrieve saltcake-based simulant. However, an ultra-high-pressure retrieval end effector called the Lightweight Scarifier was used to break up saltcake using 50,000 psi waterjets, which are considerably higher pressure than the maximum pressure of the HWEE, which is 10,000 psi. For this reason, saltcake retrieval using the HWEE is expected to be less effective than sludge or hardpan retrieval.

2.3 Data Quality Objectives

HWEE specifications that require testing to verify compliance were presented in Section 2.1.

Table 2.2 summarizes the objectives of the tests in terms of data requirement that will be fulfilled, the type of data that will be collected, and the desired accuracy. The desired accuracy is based on qualitative judgment on accuracy required to determine if the end effector performs adequately or requires design modifications.

Table 2.2. HWEE Phase 1 Data Requirements

Data Requirement	Data Type	Accuracy Objective
Retrieval		
Determine slurry output, dilution rates, and residual water remaining for different test materials, including: Sludge Saltcake Hardpan Water (flooded suction)	Test data Operator logs Video record	+/- 5%
Characterize the slurry product, including qualitative particle size and density, during sludge and hardpan retrieval tests.	Test data Operator logs Video record	+/- 20%
Measure HWEE tool reaction forces and frequency content during normal operation.	Test data Operator logs Video record	+/- 5%
Aerosol Generation		
Visually monitor aerosol generation during retrieval tests	Operator logs Video record	Qualitative
Screen Plugging		
Determine frequency of screen and shroud plugging during retrieval tests. Evaluate remote flushing techniques to eliminate screen plugging.	Operator logs Video record	+/- 20%
Simulant Production		
Measure density and strength of test simulants to ensure consistency.	Test data	+/- 5%

3.0 Waste Retrieval End Effector Description

The HWEE will be used to fragment and dislodge waste and introduce the slurried waste into the inlet of a conveyance system. Conceptually, the HWEE is an array of small waterjets rotating around a central conveyance inlet (see Figure 3.1). The HWEE's design was based in large part on the SREE developed for ORNL. The fundamental goal was to produce a highly reliable, compact, and lightweight end effector that could be decontaminated and maintained inside a glove box. The HWEE's performance should be somewhat better than the SREE's due to refinements in screen design and conveyance inlet geometry, which were design changes based on lessons learned at ORNL. The design of the HWEE is captured in Mullen et al. (1998).

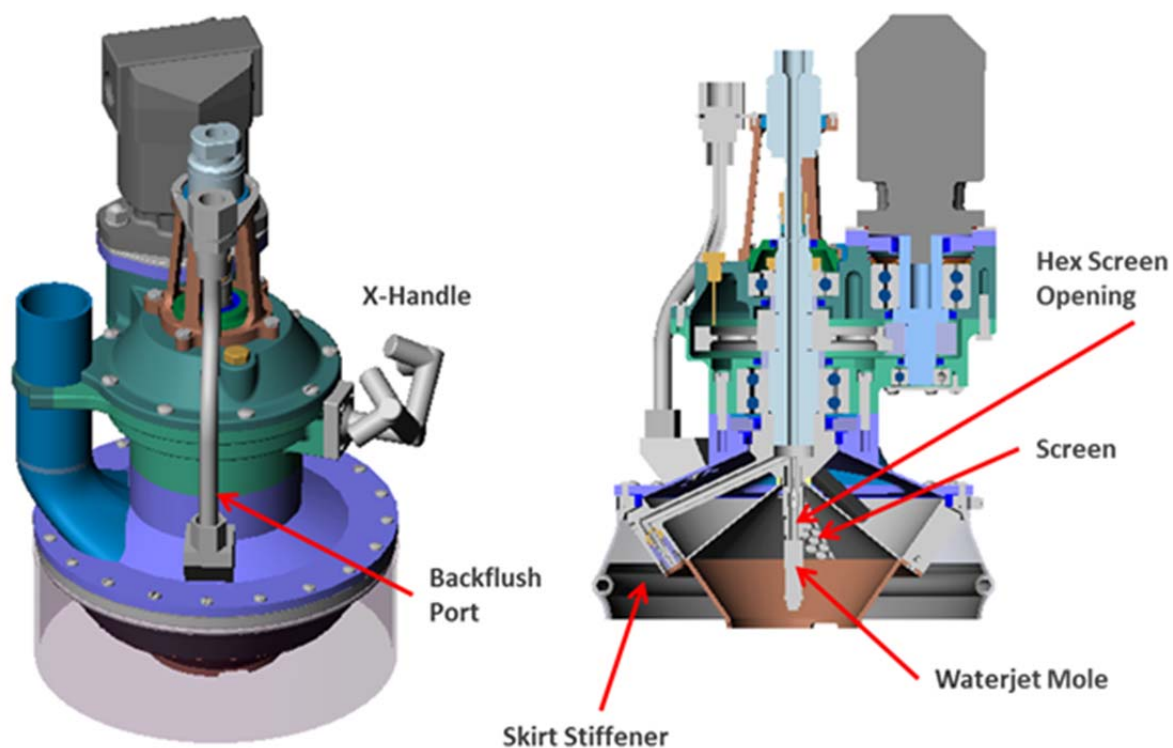


Figure 3.1. Hanford Waste End Effector Concept

Sludge Retrieval: Sludge will be retrieved by operating the HWEE at 1000 psi and 300 RPM. The speed of the HWEE should be maintained at 2-5 inches/sec. This velocity will achieve jet penetration of 1-2 inches, based on prior testing. By using a horizontal trajectory, the amount of sludge that is forced into the inlet can be controlled. The inlet shroud should be extended 1-2 inches into the waste (up to the top of the skirt) to limit aerosol generation, and the waterjets will cut clearance for the HWEE. After a pass is complete, the HWEE is lowered 2 inches, and a return arc is started. A reduction in pumping rate will indicate the need to clear the screen by back-flushing.

Hardpan Retrieval: Sludge will be retrieved by operating the HWEE at 3000-7000 psi and 300 RPM. The parameters should be adjusted to achieve a 1-inch depth of cut and very small fragments of dislodged

material. Retrieval will be very similar to sludge retrieval. At higher waterjet pressures, the aerosol generation rate will increase. The hardpan material will not break up into minute particles as the sludge will, so solids are expected to fall out of suspension. A reduction in pumping rate or an accumulation of water near the conveyance inlet will indicate the need to clear the screen by back-flushing.

Saltcake Retrieval: Saltcake will be retrieved by operating the HWEE at a maximum pressure of 10,000 psi and a nominal rotation speed of 300 RPM. If jet penetration is greater than an inch, then the pressure will be adjusted to achieve a 1-inch depth of cut and very small fragments of dislodged material. Retrieval rate is expected to be lower than during hardpan retrieval due to the hardness of the saltcake simulant. At higher waterjet pressures, the aerosol generation rate will increase. The saltcake material may not break up into minute particles as the sludge will, so solids are expected to fall out of suspension. A reduction in pumping rate or an accumulation of water near the conveyance inlet will indicate the need to clear the screen by back-flushing.

4.0 Test Approach

The HWEE will be installed in the PNNL testing location at WRPS's CTF. The test setup, equipment, instrumentation, and simulants are discussed in this section.

4.1 Test Setup

Before starting retrieval testing, the HWEE will be static and operationally pressure tested by HiLine Engineering per the requirements of ASME B31.3-2014 (ASME 2014) will be stamped with the maximum operating pressure. This associated conveyance jet pump will also undergo similar pressure testing and be similarly stamped by the supplier KMT Aqua-Dyne. Testing will only proceed when the high-pressure system is approved for operation by the appropriate safety authorities at PNNL and WRPS.

The HWEE will then be installed on the PNNL-designed gantry system. An overview of the test setup is provided in Figure 4.1. The gantry, conveyance line management arm, jet pump, and ancillary equipment near the HWEE are enclosed in a large tent. A high-pressure pump is available nearby. A material receipt tank is located close to the test bed to minimize pumping distance. Hoses connect the pump to the HWEE, jet pump, and from the jet pump outlet to the material receipt tank. Instrumentation will be installed to measure process parameters, reaction forces, and retrieval performance. Simulant materials will be prepared and characterized.

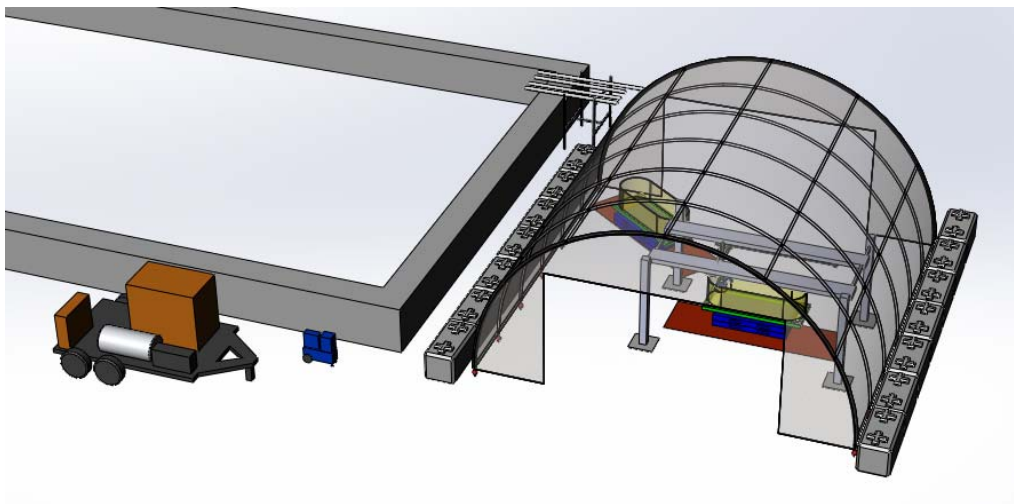


Figure 4.1. Test Setup

4.2 Test Equipment and Instrumentation

The following sections provide a description of the test equipment and instrumentation.

4.2.1 Equipment

Test equipment required for HWEE prototype testing is listed below.

- **PNNL Gantry.** The gantry system provides a horizontal work space of 8 feet by 3 feet at speeds up to 300 in/min.

- **High-pressure Pump.** A high-pressure pump will be used to supply high-pressure water to the jet pump and HWEE. The capacity of the pump is 25 gallons/minute at 10,000 psi.
- **High-pressure Hose.** Two high-pressure hoses will be routed from the high-pressure pump to the HWEE and jet pump. The pressure and flow rate will be regulated in each line independently.
- **Pressure Regulator.** A secondary pressure regulator will be installed in the high-pressure line connected to the HWEE to allow the pressure to be reduced below the pump pressure, if desired.
- **Conveyance Line Management System (CLMS).** A passive two-link CLMS arm will be used to support the conveyance line and high-pressure hoses in the vicinity of the HWEE. Two-inch diameter opaque flexible hose will be used to connect the end of the CLMS to the HWEE and the CLMS to the jet pump.
- **Jet Pump.** The jet pump that will be used for testing is Aquidyne model 61102958 Dyna-vac with 2" FNPT and 6 nozzle ports.
- **Conveyance Hose.** Two-inch diameter hose will connect the jet pump discharge to a receipt tank. The length of line from the end of the jet pump to the receipt tank is less than 20 feet and includes minimal lift (< 12 feet).
- **Hydraulic Power Unit.** A small hydraulic power unit will be acquired to operate the HWEE hydraulic motor. The flow requirement for the motor is 3 gallons/minute at 3000 psi. A hydraulic hoses will be routed from the hydraulic power unit to the HWEE using the CLMS.
- **Simulant Tank.** Simulant will be placed in a steel tank with dimensions 8 feet by 3 feet deep.
- **Test Enclosure.** The gantry and CLMS will be enclosed in a tent enclosure. The top of the tent is open to allow the mast to reach maximum extension; this opening will be covered with a tarp to prevent aerosols from escaping.

4.2.2 Instrumentation

A measurement and test equipment list is provided in Appendix A, and a piping and instrumentation diagram is provided in Appendix B. The instrumentation is briefly described below.

- **Data Acquisition System.** The sensors will be connected to a TBD data conditioning module, which will convert the sensor signals to packets for transmission over Ethernet. This module also provides electrical isolation between the data acquisition computer and the sensors, which reduces the risk of electrical overload at the computer. The computer platform will be a laptop running Windows 7, which will allow rapid sampling (up to 1000 Hz) of instrumentation and process control signals.
- **Waterjet Pressure Transducers.** A visual pressure gauge is included in the high-pressure pump. The gauge is downstream of the pressure-reducing valve, so that the gauge can be used to set the discharge pressure.
- **Force-Torque Sensor.** To measure dynamic forces due to suction, inertia, and waterjet reaction, a sensor that measures forces and torques along three axes is attached to the HWEE mounting beam. At the beginning of each test, the sensor will be "zeroed" to eliminate steady state offset due to the weight of the end effector and loading from the hoses.
- **HWEE Speed Sensor.** A tachometer will be installed on the HWEE to calibrate the hydraulic pump flow rate and valve position with manifold speed.
- **Tank Load Cells.** Load cells will be installed on both the simulant tank and receipt tank to measure the weight of water/simulant transferred during retrieval simulations.

4.2.3 Simulant Development

Simulants have previously been designed to represent the characteristics of hard saltcake and sludges expected in Hanford waste tanks (Powell 1996). The sludge recipes contain a water/kaolin mixture, while hardpan recipes include kaolin and plaster of Paris. In PNNL's review of simulant materials to represent A-105 tank waste (Gauglitz et al. 2017), for use in the Phase I testing of the HWEE, the simulant recipes listed in Table 4.1 were selected. The previous simulants generally span the expected range of strength for hardpan/dried sludge, but there is no information on the erosion rate of the simulants and A-105 waste for this key waste property for confined sluicing.

To meet the objectives of Phase I testing, the simulants are prepared as specified in the prior work (e.g., Powell 1996). Bench-scale simulant samples will be prepared and characterized for yield stress in shear (shear strength) or compressive strength as appropriate from the original work (see Gauglitz et al. 2016). Strength characterization of the prepared simulants will be performed onsite using a Geotest E-280 pocket penetrometer or similar as applicable. Direct comparison of pocket penetrometer and shear strength measurements has previously been performed (Onishi et al. 2011). Gauglitz et al. (2017) noted that if Phase I effectiveness testing proves promising, then new simulants should be considered for the next phase of testing to represent key waste properties for A-105 that are bounded by simulants developed in previous simulant studies. The preparation methodologies provided below are from Powell et al. (1997).

Table 4.1. Phase I HWEE Simulants

Simulant	Solid Simulant Mass for 1.5 Batches at Half Test Vessel Volume (lbs)	Material Strength
Kaolin: 63 wt.% EPK Pulverized Kaolin Clay 37 wt.% Richland City Water	EPK Pulverized Kaolin Clay: 3,350 lbs.	Shear Strength ~ 3,500 Pa
Kaolin/Plaster: 22.5 wt.% DAP Plaster Wall Patch, Plaster of Paris 40.0 wt.% EPK Pulverized Kaolin Clay 37.5 wt.% Richland City Water	DAP Plaster Wall Patch, Plaster of Paris: 1,700 lbs.	Shear Strength ~ 150,000 Pa
K-Mag: 80 wt % Dynamate (potassium magnesium sulfate) 20 wt% Richland City Water	Dynamate: 4,100 lbs.	Compressive Strength ~ 15,000,000 Pa

4.2.3.1 Simulant Preparation, Kaolin

66% wt EPK Pulverized Kaolin Clay

34% wt Water

Supplier: EPK Pulverized Kaolin clay can be obtained from Feldspar Corporation (Edgar, Florida).

Preparation: Mix the water and kaolin using any means that will result in a uniform product. If hand-mixing is not used, special mixing equipment designed for mixing pastes is required, as typical impeller-based mixers will not be adequate. Mixing should continue until a smooth consistency is obtained.

Properties: The mixed paste is very sticky and has a shear strength of approximately 3.5 kPa (0.51 psi). For comparison, creamy peanut butter has a shear strength of about 2.0 kPa (0.3 psi). The physical properties of the mixed kaolin clay are largely independent of temperature over the range of 15° to 80°C (59° to 176°F), but freezing temperatures must be avoided, and care must be taken to prevent evaporation. No cure time is associated with this material, and it may be used immediately after preparation. For the current testing, this simulant is intended to be prepared approximately two days before testing.

4.2.3.2 Simulant Preparation, Kaolin/Plaster

22.5% wt DAP Plaster Wall Patch, Plaster of Paris

40.0% wt EPK Pulverized Kaolin Clay

37.5% wt Water

Suppliers: EPK Pulverized Kaolin clay can be obtained from Feldspar Corporation (Edgar, Florida). DAP Plaster Wall Patch, Plaster of Paris is produced by DAP (Baltimore, Maryland) and is available from The Home Depot.

The plaster of Paris used for this recipe is manufactured by DAP, Inc. and sold in 25-pound bags, Model # 10304.

Preparation: The kaolin/plaster simulant must not be mixed any longer than necessary after addition of the plaster of Paris. Once the plaster of Paris comes in contact with the water, the hydration reaction begins. Prolonged mixing can hinder the growth of the gypsum crystals, which will decrease the cured strength of the simulant. High-shear mixers should not be used for preparing these simulants. A mortar mixer will be used for the current work.

The required quantities of kaolin and water are first mixed to form a uniform slurry. If large quantities are being prepared or if the ambient temperature exceeds about 20 °C, it is advisable to substitute ice for a portion of the water in the mix. Using ice will ensure that the kaolin/water slurry is cold before the plaster of Paris is added. The plaster of Paris hydration reaction is greatly accelerated by elevated temperature, so premature curing of the simulant can occur if the slurry temperature is too high. This is especially problematic when large quantities of hardpan are being prepared. Once the kaolin/water slurry is uniform, the plaster of Paris should be added as rapidly as possible while continuing to mix. Mixing for longer periods can result in markedly lower strengths for the cured simulant. Batches should be sized so that the plaster of Paris is uniformly mixed into the slurry and the slurry is placed into its curing mold no more

than about 10 minutes after the plaster of Paris is added at approximately 20°C. At higher temperatures, even less time is available.

Properties: At room temperature, the kaolin/plaster simulant reaches a peak shear strength of about 200 kPa in about 2–3 hours and a stable shear strength of about 150 kPa after approximately 2–3 hours. Heat is released by the plaster of Paris hydration reaction. Long-term storage of these materials has not yet been evaluated, but the ~ 150 kPa shear strength has been shown stable for 72 hours. As with the kaolin simulant, water evaporation and freezing should be avoided. For the current testing, this simulant is intended to be prepared approximately 2 days prior to testing.

4.2.3.3 Simulant Preparation, K-Mag

80 wt % Dynamate (potassium magnesium sulfate)

20 wt% Richland City Water

Suppliers: The Dynamate feed-grade potassium and magnesium sulfate is produced by Mosaic, Lithia, Florida, and is available for purchase in 50-pound bags from Phibro Animal Health Corporation, Quincy, Illinois.

Preparation: The K-Mag simulant is prepared by mixing the components together until uniform and then placing the resulting slurry in the test vessel to cure. A mortar mixer will be used for the current work. The simulant must be covered to prevent water loss during curing.

Properties: The target compressive strength for the K-Mag simulant recipe was achieved at four days. For the current testing, this simulant is intended to be prepared approximately four days prior to testing.

4.2.3.4 Separate Effects Testing

The American Society for Testing and Materials (ASTM) Method C1750-11 provides general considerations for the development, verification, validation, and documentation of high-level radioactive waste tank simulants. As described by that standard, the first step is to determine the performance characteristic of the simulant. For sediment mobilization or erosion with the fluid jets, Gauglitz et al. (2017) specified the critical shear stress, the applied shear stress for which greater values result in the onset of erosion at a certain rate, as a key processing property. A material's critical shear stress for surface erosion provides a lower bound for the applied shear stress required to initiate erosion at a minimum rate. Higher applied stress values are required for a range of erosion rates, and critical shear stress values can be defined for each rate.

However, there is no information on the erosion rate of the simulants and A-105 waste for this key waste property (Gauglitz et al. 2017). The use of a simulant's shear strength relative to the shear strength of a simulant with a different composition can be misleading with respect to the erosion rate at a given applied stress. Therefore, data useful to describe erosion rate characteristics for each of the three simulants will be collected during startup testing.

ASTM D5852-00 provides a standard method of expressing erosion resistance. In general, the method relies on providing an applied stress via a fluid jet to a sediment surface for finite test periods and measuring the resultant scour depth. A modification of this technique was applied in Meacham et al. (2012) using erosion depth or distance at different applied stresses to estimate a critical stress for erosion of waste and simulants.

Using a similar approach, data will be taken using the HWEE for each of the three simulants at the completion of start-up testing:

1. Select a flat region of undisturbed simulant surface.
2. Fix the HWEE jet at a constant position at a stand-off of 0.25 inches.
3. Equipment parameters:

Kaolin:	Rotation Speed	0 RPM
	Traverse Speed	0 inches/minute
	Waterjet pressure, location 1	1200 psi
	Waterjet pressure, location 2	3000 psi
	Operation Time	TBD during start-up testing*
Kaolin/Plaster:	Rotation Speed	0 RPM
	Traverse Speed	0 inches/minute
	Waterjet pressure, location 1	1200 psi
	Waterjet pressure, location 2	3000 psi
	Operation Time	TBD during start-up testing*
K-Mag:	Rotation Speed	0 RPM
	Traverse Speed	0 inches/minute
	Waterjet pressure, location 1	3000 psi
	Waterjet pressure, location 2	10,000 psi
	Operation Time	TBD during start-up testing*

* The same operation times are to be used for each simulant

4. Measure characteristic jet penetration depth into simulant for each location.

Steps 1 through 4 follow step 3, Section 5.2.2, during startup testing.

5.0 Test Instructions

This section includes the test phases and individual test instructions. Changes to this test plan will be documented on the “work place” record copy and approved by the program manager as indicated by initial and date. The following table describes the various tests that will be undertaken.

Table 5.1. HWEE Prototype Phase 1 Tests

Test Phase	Test Focus	Test Parameter	Key Data Expected
Instrumentation Verification and Check-out Tests	Controls and Instrumentation Calibration	• Calibrate sensors with known weights, pressures, etc. • Verify controls operation and back flush capability with water	• Calibration of sensors in the installed condition
HWEE Retrieval Tests	Sludge, Saltcake and Hardpan Retrieval Tests	• Tests with sludge, saltcake and hardpan • Flat topography	• Verify basic operating parameters • Identify plugging problems • Water usage • Slurry density • Slurry output rate • Aerosol generation

5.1 Instrument Verification and Cross-check

The following table describes the tests that will be conducted to cross-check and validate the instrument measurements. The tests are intended to augment the calibration of the sensors as provided by the vendor.

Table 5.2. Instrument Validation Tests

Instrument	Method of Measurement Cross-Check
Force/torque sensor	Apply loads of known magnitude to the end effector at points selected to produce readily calculable forces and moments.
Tank load cells	Verify calibration by adding a weight of known magnitude and comparing with output from the sensor.
High-pressure sensor	With the pressure-reducing valve in the open position (so that the jet pump and waterjet lines are at the same pressure), compare the output of the sensors with the pressure at the pump provided by the visual gauge.
Controls Tests	Verify operation of the HWEE gantry E-stop, high-pressure control valves, pump on/off, and compliant joint.

Instrument	Method of Measurement Cross-Check
High-pressure water flow	Allow the HWEE jets and the jet pump water to accumulate in the tanks for a known amount of time (> 10 minutes). Compare flow into each line with nozzle output from flow tables for the appropriate pressure. Flow will be derived from the load cell measurements.

5.2 HWEE Retrieval Tests

Retrieval tests will focus on measuring the HWEE performance during hardpan, saltcake, and sludge retrieval. Associated retrieval operations will also be assessed during retrieval, including scavenging characteristics of the jet pump and assessing aerosol generation during retrieval operations.

5.2.1 Pre-test Procedure

1. Check that cleanup equipment is available.
2. Any additional products used to lubricate or maintain equipment will need to have an approved Material Safety Data Sheet in the WRPS Level 1 Work Package for executing the test.
3. Check oil lubrication level in high-pressure pump. Pump lubrication oil is Mobile 1 Advanced Full Synthetic 10W-30.
4. Check that inlet water pressure is approximately 90 psi.
5. Clear the HWEE gantry workspace area and secure electrical interlock.
6. Initiate ancillary equipment, including cameras, data acquisition, and motor control. Insure the data acquisition and cameras are recording data.
7. To start pump, push Start button. The output from the pump will dump to the recirculation tank for about 10 seconds. This delay can be adjusted inside control panel.
8. Adjust the pump output pressure by turning the main bypass valve to achieve the desired pressure. Note that the rupture disk will fail at 10,000 psi.
9. Turn the pump off.
10. Cover the tent opening with tarps to contain aerosols generated during tests.

5.2.2 Retrieval Startup Test Procedure

The objective of startup testing is to verify proper operation of the test equipment and to ascertain HWEE performance. It is expected that sludge retrieval will be very effective using parameters used in prior testing. It is expected that saltcake retrieval will be marginally effective using parameters used in prior testing, and the frequency of screen cleaning and depth of cut will have to be determined. It is expected that hardpan retrieval will be very effective using parameters used in prior testing, but the frequency of screen cleaning will have to be determined.

1. Fill the tank with simulant to be tested. For startup testing, simulant in the tank will be approximately 4 inches deep, 3 feet wide, and 5 feet long. Divide the tank into 3 long partitions, and place the kaolin sludge into the center partition. Take samples of the simulant during preparation, cover sample to prevent evaporation, and send the samples to the simulant lab for characterization.
2. Program the gantry to make one pass over the simulant field at a stand-off of 0.25 inches using a serpentine mining path. For sludge, the offset between paths should be the width of the waterjets.

Equipment parameters:

Sludge:	Rotation Speed	300 RPM
	Traverse Speed	300 inches/minute
	Waterjet pressure	1200 psi
	Depth of cut	1 inch
Saltcake:	Rotation Speed	300 RPM
	Traverse Speed	300 inches/minute
	Waterjet pressure	3000 psi
	Depth of cut	1 inch
Hardpan:	Rotation Speed	300 RPM
	Traverse Speed	300 inches/minute
	Waterjet pressure	10,000 psi
	Depth of cut	¼ to 1 inch

3. Before the sludge retrieval test, submerge the HWEE in undisturbed sludge and test hydraulic motor rotation. Note maximum rotational speed and force/torque readings.

Motor speed: _____ RPM

Motor torque: _____ foot-pounds

4. Open the jet pump control valve.
5. Turn on the pump and adjust the pump outlet pressure to desired pump pressure.
6. Open the HWEE waterjet control valve.
7. Adjust the HWEE waterjet pressure using the pressure regulator.
8. Close the HWEE waterjet control valve.
9. Position the HWEE in a safe starting position using the control pad to a point immediately above the point where retrieval will start.
10. Open the HWEE waterjet control valve.
11. Activate the hydraulic power unit and adjust manifold speed.
12. After steady state conditions are reached, initiate the mining path. During hardpan and saltcake retrieval, operate the back-flush nozzle for 10 seconds after every 8-foot pass. If the sludge retrieval rate drops appreciably, increase the frequency of back-flushing.
13. Modify the gantry mining path to lower the head 1 inch and repeat step 12.

14. After retrieval is complete, operate the HWEE at higher pressure (5000 psi and 7000 psi) for 2 minutes and visually assess aerosol level. Close the HWEE waterjet control valve.
15. Raise the HWEE at least 6 inches above the waste and allow jet pump to operate for 2–3 minutes to flush the line.
16. Turn off the high-pressure pump.
17. Position the HWEE over a small tank to collect waterjet discharge.
18. Close the jet pump control valve.
19. Store and archive the data acquisition and cameras data files.
20. Repeat steps 1– 19 for saltcake simulant.
21. Repeat steps 1–19 for hardpan simulant.

5.2.3 Retrieval Test Procedure

1. Fill the tank with simulant to be tested. For startup testing, simulant in the tank will be approximately 4 inches deep, 3 feet wide, and 5 feet long. For effectiveness testing, simulant in tank should be approximately 8 inches deep, 3 feet wide, and 5 feet long. Take samples of the simulant during preparation, cover sample to prevent evaporation, and send the samples to the simulant lab for characterization.
2. Program the gantry to make one pass over the simulant field at a stand-off of 0.25 inches using a serpentine mining path. For sludge, the offset between paths should be the width of the waterjets.

Equipment parameters:

Sludge:	Rotation Speed	300 RPM
	Traverse Speed	300 inches/minute
	Waterjet pressure	1200 psi
	Depth of cut	1 inch
Saltcake:	Rotation Speed	300 RPM
	Traverse Speed	300 inches/minute
	Waterjet pressure	3000 psi
	Depth of cut	1 inch
Hardpan:	Rotation Speed	300 RPM
	Traverse Speed	300 inches/minute
	Waterjet pressure	10,000 psi
	Depth of cut	¼ to 1 inch

3. Before the sludge retrieval test, submerge the HWEE in undisturbed sludge and test hydraulic motor rotation. Note maximum rotational speed and force/torque readings.

Motor speed: _____ rpm

Motor torque: _____ foot-pounds

4. Open the jet pump control valve.
5. Turn on the pump. Adjust the pump outlet pressure to desired pump pressure.
6. Open the HWEE waterjet control valve.
7. Adjust the HWEE waterjet pressure using the pressure regulator.
8. Close the HWEE waterjet control valve.
9. Position the HWEE in a safe starting position using the control pad to a point immediately above the point where retrieval will start.
10. Open the HWEE waterjet control valve.
11. Activate the hydraulic power unit and adjust manifold speed.
12. After steady state conditions are reached, initiate the mining path. During hardpan and saltcake retrieval, operate the back-flush nozzle using the frequency determined in startup testing. If the sludge retrieval rate drops appreciably, increase the frequency of back-flushing.
13. Modify the gantry mining path to lower the head 1 inch and repeat step 12.
14. After retrieval is complete, operate the HWEE at higher pressure (5000 psi and 7000 psi) for 2 minutes and visually assess aerosol level. Close the HWEE waterjet control valve.
15. Raise the HWEE at least 6 inches above the waste and allow jet pump to operate for 2–3 minutes to flush the line.
16. Turn off the high-pressure pump.
17. Position the HWEE over a small tank to collect waterjet discharge.
18. Close the jet pump control valve.
19. Store and archive the data acquisition and cameras data files.
20. Repeat steps 1–19 for saltcake simulant.
21. Repeat steps 1–19 for hardpan simulant.

5.2.4 Post-test Procedures

1. Empty hopper into interim storage tanks outside. Record in laboratory record book general impression of the test slurry (e.g., dilute water with hardpan fragments).
2. Place simulant tank or catch drum under end effector.
3. Disconnect pump from power supply by turning the switch on pump to the off position.
4. Cover the simulant with plastic to prevent evaporation.
5. Inspect test bed floor for standing water and remove it with the wet/dry pump, squeegees, and wet vacuums.
6. Clean up general area as needed for continued safe operations.

6.0 Data Evaluation

All data records, calculations, and analyses reported from this test will be documented sufficiently to be traceable from the primary data and the methods and equipment used, through the assumptions and/or interpretations made, to the corresponding reported results. This section outlines planned analysis and a preferred system of units for reported values.

6.1 Planned Analyses

The first step in the data evaluation process will be to convert the raw data to engineering units for graphical display. Where applicable, instantaneous data and average results will be analyzed and compared. Analyses of test data will be conducted to obtain the following derived results:

- End effector maximum reaction forces and moments
- Simulant volume
- Retrieval rates and slurry dilution ratio versus simulant type
- HWEE force loads experienced during retrieval operations

To collect derived parameters, a process will be used to collect static measurements. These values will be used to derive critical summary parameters. See below for a description of static and derived parameters. Once this strategy is finalized, steps will be embedded into the test procedure.

Table 6.1. Description of Static and Derived Parameters

Measurement	Abbreviation	Instrument	Units
BASELINE / INITIAL CONDITIONS (STATIC)			
Simulant Container Tare Weight	SCTW	Container Weigh System	KG / LB
Retrieval Container Tare Weight	RCTW	Container Weigh System	KG / LB
Simulant Container Water Level Tare Weight	SCWLTW	Container Weigh System	KG / LB
Retrieval Container Water Level Tare Weight	RCWKTW	Container Weigh System	KG / LB
Initial Simulant Weight	ISW	Container Weigh System	KG / LB
Initial Simulant Volume	ISV	Level In Container OR Water Fill to Level	Liters/Gallons
Initial Simulant Density	ISD	Calculate ISW/ISV OR Measure from Sample	KG/Liter OR LB/gallon
Initial Simulant Container Weight with Simulant	ISCW-S	Simulant Container Weigh System	KG or LB
Initial Retrieval Container Weight Empty	IRCW-E	Retrieval Container Weigh System	KG or LB
RETRIEVAL OPERATIONS (DYNAMIC)			
HWEE Rotary Jet Water Flow	HWF	Low Pressure Flow Meter OR Cash & Weigh	GPM

Measurement	Abbreviation	Instrument	Units
HWEE Flush Water Flow	HFF	Low Pressure Flow Meter OR Cash & Weigh	GPM
Container Weight Simulant	CWS	Simulant Container Weigh System	KG or LB
Video Recording – Simulant Container	VRSC	Digital Video – Simulant Container Liquid Level & Aerosols	
Jet Pump Nozzle Flow	JPWF	Low Pressure Flow Meter OR Cash & Weigh	GPM
Container Weight Retrieval	CWR	Simulant Container Weigh System	KG or LB

1. Baseline both simulant and retrieval containers dry and empty.
 - a. Simulant Container Tare Weight
 - b. Retrieval Container Tare Weight
2. Baseline both simulant and retrieval containers with water to a height at least 2 inches above highest expected simulant level in both containers.
 - a. Simulant Container Water Level Tare Weight
 - b. Retrieval Container Water Level Tare Weight
3. Make-up Simulant in Simulant Container.
4. Baseline Retrieval Operation Conditions.
 - a. HWEE Rotary Nozzle Flow at Pressure (Cash & Weigh)
 - b. HWEE Flush Flow at Pressure (Cash & Weigh)
 - c. Jet Pump Flow at Pressure (Cash & Weigh)
Set pressure of device. Start flow. Move quickly into weigh system and time for several minutes. Repeat measurement two more times. If all measurements are within 5% on weight, average the three measurements. If all measurements are NOT within 5%, repeat measurement.
5. Baseline Retrieval Start Conditions
 - a. Initial Simulant Weight
 - b. Initial Simulant Volume
 - c. Initial Simulant Density
 - d. Initial Container Weight Simulant
 - e. Initial Container Weight Retrieval
6. Take initial measurement above as baseline prior to starting retrieval to establish baseline. Simulant volume is estimated by level in tank and compared against equivalent volume measurements with water. Simulant density is calculated from initial simulant weight/initial simulant volume. This simulant density can alternately be calculated from a sample of the actual material or excess make-up simulant using standard laboratory measurements for density (e.g., water displacement from volume and weighing).

7. Set HWEE into retrieval positions. When positioned, start retrieval operations and clock. Dynamically take the following measurements:
 - a. Time.
 - b. HWEE Rotary Jet Water Flow (if available).
 - c. HWEE Flush Water Flow (if available).
 - d. HWEE Water Flow – Rotary Jet & Flush (if available).

Note: If a & b are available, calculate c. If a & b not available, measure c. If c is not available, go to e.
 - e. Jet Pump Nozzle Flow (if available).

Note: If d. not available, may be included with e.
 - f. Total HWEE & Jet Pump Flow – Water Only

Note: If e. not available, monitor container weight retrieval changes with time.
 - g. Container Weight - Simulant
 - h. Video Recording – Simulant Container

Note: Video recording may be useful in estimating water left simulant water tank by noting the water level in tank and water left in retrieval features (i.e., cuts and depressions from HWEE operations)
 - i. Container Weight Retrieval
8. When retrieval operation is completed, calculate **TOTAL WATER USED** by one of the following methods (depends on data taken)
 - a. Total water flow through HWEE rotary nozzle

Note: Requires HWEE water source separate from the jet pump.

 - If HWEE input water is measured with flow meter / totalizer, then determine time periods HWEE rotary nozzle was operating and calculate total flow.
 - b. Total water flow through HWEE flush (if available)

Note: Requires jet pump water source separate from the HWEE

 - If HWEE input water is measured with flow meter / totalizer, then determine time periods HWEE rotary nozzle was operating and calculate total flow.
 - c. Total water flow through HWEE rotary nozzle and flush (if available)

Note: Requires HWEE water source separate from the jet pump.

 - If HWEE input water is measured with flow meter / totalizer, then determine time periods HWEE rotary nozzle was operating and calculate total flow.
 - d. Total water flow through jet pump (if available)

Note: Requires jet pump water source separate from the HWEE.

 - If jet pump input water is measured with flow meter / totalizer, then determine time periods jet pump was operating and calculate total flow.
 - e. Total water flow through HWEE (rotary nozzle & flush) and jet pump

Note: Using only the container weigh scales

- Using container weigh systems for both simulant and retrieval tanks, determine the combined weight increase in both tanks. Dynamic monitoring of the water flow rate by this method will be an estimate because some of the water may be in transport through the jet pump system and not accounted for.
Note: This method requires HWEE and jet pump to have separate or combined water source.
- f. If HWEE and jet pump have separate water sources with flow meter/totalizer, then determine total by adding these together.
 - If HWEE and jet pump have a combined water source with flow meter/totalizer, then determine time periods HWEE and jet pump were operating and calculate total flow.
- 9. When retrieval operation is completed, calculate **TOTAL SIMULANT RETRIEVED** and **TOTAL WATER REMAINING IN SIMULANT TANK**.
Note: Use only the container weigh scales
 - Calculate TOTAL SIMULANT RETRIEVED (TSR): Weigh the simulant container at the end of retrieval (SCER). Fill simulant container tank up to a baseline water level determined in step 2 and weigh (SCER-PWL). From this weight (SCER-PWL), subtract the water level tare weight (SCWL TW) for this container to determine the unretrieved simulant weight (USW). From the initial simulant weight (ISW), subtract the unretrieved simulant weight (USW) to determine the TOTAL SIMULANT RETRIEVED weight (TSRW).
 - Calculated TOTAL WATER REMAINING IN SIMULANT TANK (RWRST): Take the simulant container weight at the end of retrieval (SCER) and subtract the unretrieved simulant weight (USW) to determine TOTAL WATER REMAINING IN SIMULANT TANK (RWRST)

6.2 Preferred Units

The following table provides the preferred units for all expected reported values.

Table 6.2. Expected Reported Values and Their Preferred Units of Measurement

Measurement	Preferred Unit
High Pressure	ksi
Low Pressure (water, air)	psi
Volumetric Flow Rate	gpm
Mass Flow Rate	lb _m /s
Particle Size	mm
Pipe Diameter	inch
Pipe Length	ft
Stand-off Distance	inch

Measurement	Preferred Unit
Density	g/cm ³
Air velocity	ft/s
Mass	lb _m
Force	lb _f
Shear Strength	MPa

7.0 Project Record System

This section describes how testing data and results will be documented and maintained.

7.1 Software and Control

The majority of the data will be collected with the computer data acquisition equipment and saved to hard disk. Portions of this data will be converted to Microsoft Excel spreadsheet format for data manipulation and display. Other data, such as current atmospheric data, will be taken manually and recorded in the laboratory record book.

A test summary database will be maintained to capture the essential aspects of each test. This database will, at a minimum, record the following information:

- Date
- Start Time
- End Time
- Test Description (including test parameters if part of a test matrix)
- Reference Test Instruction of Procedure
- Laboratory Record Book Page (starting)
- Excel Data File Name(s)
- Excel Data File Archive Name and Location
- Raw Data File Name(s)
- Raw Data File Archive Name and Location
- Notes

Data files will be double archived to optical disk. Copies of the archive disks will be stored in remote locations. Test data archives will be included in the project Record Inventory and Disposition Schedule as set forth in PNNL's "Plan for Managing Project Records" workflow in the How Do I? system.

7.2 Use of Engineering Notebooks

All laboratory data, general observations, and details of the activities performed per this test plan will be documented in an engineering notebook. For each test, the following information will be recorded: date, time, procedure number, procedure parameters, data file, and observations.

7.3 Calibration Records

Quality Assurance Engineering will approve the measurement and test equipment list before test initiation. Calibration records of all instruments used to generate reported data will be maintained in the project files. Instrumentation that has not been calibrated within the approved interval will be recalibrated before testing.

7.4 Quality Assurance

This test program shall follow the guidelines of DOE Order 5700.6C implemented through the Quality Management System Description within PNNL's How Do I? system. All requirements are implemented through manuals, work controls, and workflow procedures. Quality Assurance personnel shall assist in data verification, calibration, inspection, and other activities as required. Staff from the WRPS contract team are invited to witness all aspects of testing.

8.0 Facility and Safety Considerations

The HWEE will be installed in the PNNL test bed, located at WRPS's CTF. This section provides an overview of the CTF systems that will be used in the tests and reviews safety and personnel training considerations.

8.1 Electrical Supply

The HWEE does not require any electrical power. However, electrical power will be required for the following:

- HWEE and jet pump hydraulic power unit(s) and the high-pressure pump(s) may require facility electrical power if an electric motor is used (gasoline or diesel generation is expected).
- PNNL test bed gantry system.
- Control and data acquisition trailer located nearby.

A service request will be submitted to connect these pieces of equipment before operation as applicable.

8.2 Water

Water will be required for the following:

- Supply for the high-pressure pump(s).
- A hose for wash-down.

All water used in the facility must be confined and controlled. Cleanup equipment for excess water cleanup will be available.

8.3 Compressed Air

The diaphragm pump and pressure regulator require compressed air at 80 psi for operation.

8.4 Safety Precautions

Battelle's Industrial Hygiene, Occupational Safety, and Fire Protection Manual (PNNL-MA-43) and How Do I? system workflows and work controls provide the minimum requirements for routine operations. Table 8.1 summarized potential hazards that may be encountered during the test program. Steps to mitigate or eliminate hazards are also provided. This table is consistent with the WPRS Job Hazard Analysis Checklist and the PNNL Off-site Risk Management Plan that has been approved for this activity.

The most serious hazards associated with test bed operations are listed below.

- There is a serious hazard to personnel involved with the motion of the gantry in the PNNL test bed. Personnel cannot be allowed into the working envelope of the gantry during operation except under the very controlled conditions described in PNNL-MA-43 and ANSI 15.06 American National Safety Standard for Industrial Robots and Robot Systems (ANSI/RIA 1992).

- There is a serious hazard to personnel from high-pressure waterjets due to their ability to penetrate and damage human skin. This hazard will be managed by preventing personnel from entering the tent containment during pump operation.

Table 8.1. Job Hazards Assessment

Sequence of Basic Job Steps or Work Activity	Hazards Present	How to Eliminate Hazards
Operation of low-pressure water system	Water leakage	Isolate water sources when not in use. Monitor water and discontinue operation if significant uncontrolled water is generated.
Testing and operation of high-pressure water system	Hazardous Energy (air, steam, fluid, pressurized)	Continuous burst-shielded hose from valves at high-pressure water source to test bed.
	High noise levels during operation (>85 dBA)	Whip checks to secure quick disconnect fittings. Piping protected by rupture disk discharging into safe area.
	Heat Stress due to localized heat source or special PPE use	End effector nozzles will be operated within personnel barrier/shield (e.g., tent)
		Hearing protection for personnel exposed to greater than 85 decibels. Warning signs. Strobe light indicates system operation with time delay.
		Apply heat stress mitigation checklist
Assembly and operation of compressed air hoses	Hazardous Energy (air, steam, fluid, pressurized)	Secure hoses at appropriate points and intervals. Compressed air is not to be used for housekeeping.
HWEE gantry	Rotating, Moving Equipment or Pinch Points	Work zone to be established and interior cleared of personnel prior to operation.
		Personnel barrier (e.g., tent enclosure) with interlock to E-stop control will prevent access to the work space of the gantry. Warning signs will be placed on the personnel barrier to warn personnel of the hazard of entering the working envelope.

Sequence of Basic Job Steps or Work Activity	Hazards Present	How to Eliminate Hazards
HWEE gantry (continued)		Mechanical stops on the gantry have been provided by the vendor to define the gantry operating envelope. In addition, software limits the travel of the individual degrees of freedom. Operators will be instructed on the proper use of gantry and location of E-stops. A list of personnel qualified to operate the system will be posted at the system control station. Emergency stops (or E-stops) for the gantry are provided at the drive cabinet. When this switch is activated, all brakes are applied, power is cut to the gantry drive, and the system is disarmed. While the gantry is operating, one person will be designated system operator. The system operator will be the only person to command the gantry to move. The operator must be within arm's reach of an E-stop button and will be responsible for activating the E-stop if it is deemed necessary.
Simulant equipment cleaning	Hazardous Energy (air, steam, fluid, pressurized)	Wear rubber gloves, boots, overalls or rainsuit, eye and face protection.
Simulant preparation	Inhalation of nuisance dusts	Use dust mitigation procedure to reduce dust, such as HEPA vacuum. Wear respirators when handling dry materials. Wear eye protection, gloves, and coveralls when handling simulant materials. Respirators will include HEPA cartridges with pre-filters.
	Manual lifting	Use proper lifting procedures and material handling equipment.
Simulant disposal	Vehicular Traffic, Equipment, and/or Forklift	Post observer as required to guide forklift or truck operator and keep personnel clear.
HWEE operation	Rotating, Moving Equipment or Pinch Points	Pre-job briefing. Hydraulic motor to be deactivated prior to personnel entering tent.

8.5 Training and Qualification Requirements

Personnel training for the operation of test equipment will be done using a combination of briefings, equipment walk-throughs, site hazard orientation, and on-the-job training in accordance with the Identify, Schedule, and Complete Training workflow (see <https://hdi.pnl.gov/hdi>). Briefings of operational and test procedures will be conducted by the author of the procedure being discussed. Equipment walk-through and on-the-job training shall be conducted by experienced operations personnel. Attendance for all

training activities will be documented using training attendance forms. Training on equipment use will be based on vendor-supplied documentation.

8.6 Waste Simulant Minimization and Management

Waste disposal procedures have been developed with the cooperation of the PNNL Environment, Health, Safety and Security organization for all materials that will be used in this test program. Simulants will be deposited into the CTF slurry receipt pit. Waste simulant disposal must also be in accordance with the Hanford Waste End-Effector Cold Test Facility Memorandum of Understanding Section 5.5.

9.0 References

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Appendix A

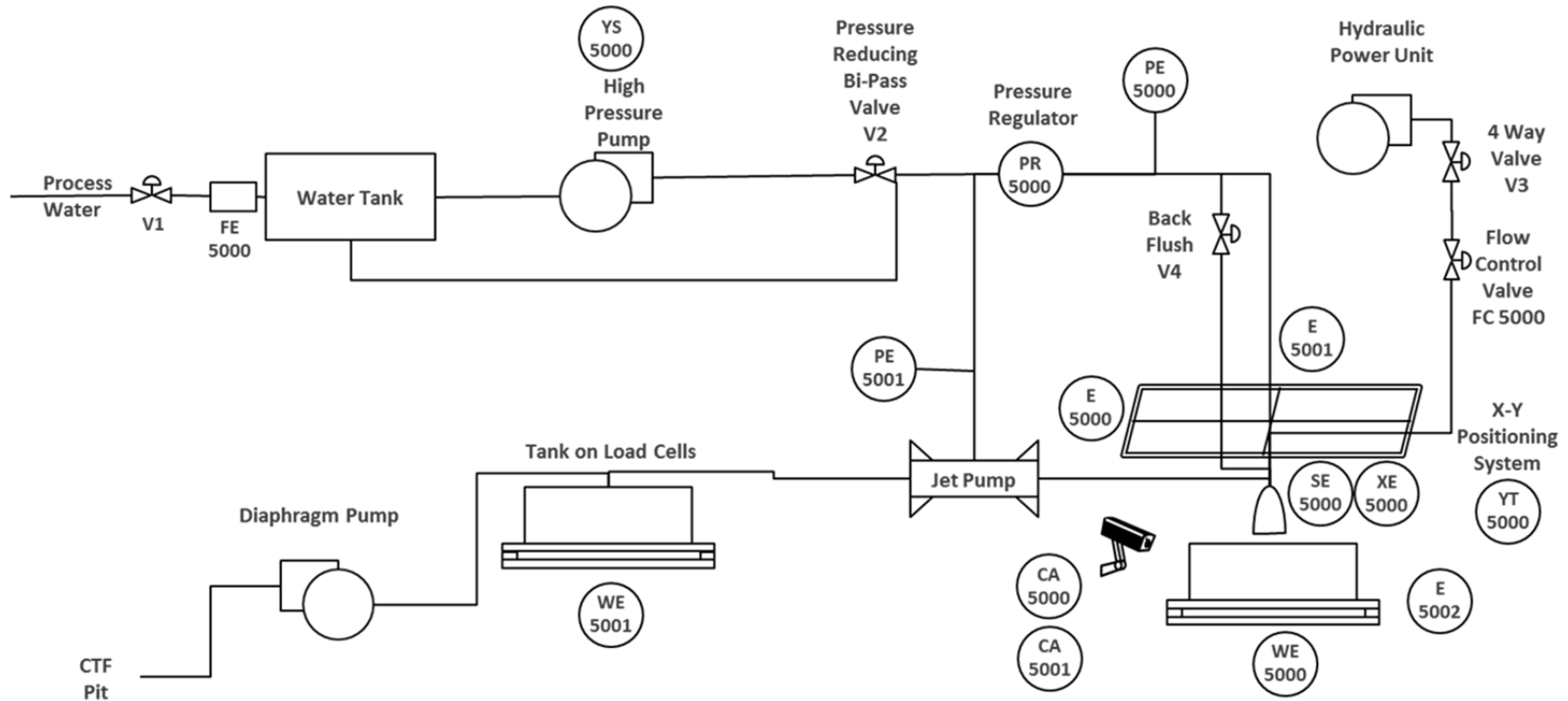
Measuring and Test Equipment

Measured Parameter	Range, Units	Tag #	Sensor / Control Element	Signal Conditioning
Process Water Control Valve	On, Off	V1	TBD	Manual
Pressure Reducing Bi-pass Valve	0-10,000 psi	V2	TBD	Manual
Pressure Regulator	0-10,000 psi	PR 5000	TBD	Manual
Pressure, HWEE Waterjet	0-10,000 psi	PE 5000	TBD	Sight glass
Pressure, Jet Pump	0-10,000 psi	PE 5001	TBD	Sight glass
HPU Control Valve	On, Off	V3	TBD	Manual
Hydraulic Fluid Flow Control	0-3 gpm	FC 5000	TBD	Manual
Scanner Position, X	0-2450 mm	E 5000	QR12-1000-6-A-B-L-C-A	0.001024 inch/count
Scanner Position, Y	0-920 mm	E 5001	QR12-1000-6-A-B-L-C-A	0.001024 inch/count
HWEE Rotation	0-1000 RPM	SE 5000	MCS-655M Photo-Reflective Speed Sensor	DT-5TXR Panel Tachometer
			ZZEL0021 (50 ft cable)	DOP-FVTR Analog output module (4-20mA & 0-1, 0-10, 1-5 VDC)
Retrieval Tank Weight	0-10000 lbs	WE 5000	SPWE-SR-2.5K	IPE50
Slurry Receipt Tank Weight	0-10000 lbs	WE 5001	SPWE-SR-2.5K	IPE50
Scanner Position, Z	0-80 inches	E 5002	JX-EP-80-N11-110-15N Linear Position Transducer	Visual

Measured Parameter	Range, Units	Tag #	Sensor / Control Element	Signal Conditioning
High Pressure Pump	On, Off	YS 5000	TBD	Manual
Scanner E-Stop	On, Off	YT 5000	TBD	Manual
Camera, Overview		CA 5000	TBD	
Camera, Close-up		CA 5001	TBD	
Force/Torque Sensor (forces and torques in three directions)	Fx, Fy: +/-300 lbf Fz: +/-875 lbf Tx, Ty, Tz: +/- 1800 in-lbf	XE-5000	9105-T-OMEGA160-IP65 US-300-1800	ATI F/T Controller
HWEE Back Flush Valve	On, Off	V4	TBD	Manual

Appendix B

Piping and Instrumentation Diagram



Appendix C

Test Data Sheets



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