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Hanford Waste End Effector Prototype Test Plan

Prepared for Washington River Protection Solutions

September 2017

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Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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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' Cold Test Facility (CTF) using a Pacific Northwest National Laboratory (PNNL)-designed testing setup. This effort fulfills 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
CTF	Cold Test Facility
HWEE	Hanford Waste End Effector
kPa	kilopascal
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
psi	pounds per square inch
RPM	revolutions per minute
SREE	Sludge Retrieval End Effector
WREE	Waste Retrieval End Effector
WRPS	Washington River Protection Solutions

Contents

Executive Summary	iii
Acronyms and Abbreviations	iv
1.0 Introduction	1.1
2.0 Specifications and Data Quality Objectives	2.2
2.1 Phase 1 Requirements	2.2
2.2 Prior Testing Results	2.3
2.3 Data Quality Objectives	2.5
3.0 Waste Retrieval End Effector Description	3.1
4.0 Test Approach	4.1
4.1 Test Setup.....	4.1
4.2 Test Equipment and Instrumentation	4.1
4.2.1 Equipment	4.1
4.2.2 Instrumentation.....	4.2
4.2.3 Simulant Development	4.3
5.0 Test Instructions	5.1
5.1 Instrument Verification and Cross-check.....	5.1
5.2 HWEE Retrieval Tests	5.2
5.2.1 Pretest Procedure.....	5.2
5.2.2 Retrieval Startup Test Procedure.....	5.2
5.2.3 Retrieval Test Procedure	5.4
5.2.4 Post-test Procedures	5.7
6.0 Data Evaluation	6.1
6.1 Water Usage of HWEE	6.1
6.2 Retrieval Rates and Slurry Dilution Rates	6.1
6.3 HWEE End Effector Force Loads.....	6.2
7.0 Project Record System.....	7.1
7.1 Software and Control	7.1
7.2 Engineering Records	7.1
7.3 Calibration Records.....	7.1
7.4 Quality Assurance	7.2
8.0 Facility and Safety Considerations	8.1
8.1 Electrical Supply	8.1
8.2 Water	8.1
8.3 Compressed Air.....	8.1
8.4 Safety Precautions.....	8.1
8.5 Training and Qualification Requirements	8.3

8.6 Waste Simulant Minimization and Management	8.3
9.0 References	9.1
Appendix A Measuring and Test Equipment.....	A.1
Appendix B Piping and Instrumentation Diagram.....	B.1

Figures

Figure 2.1. End Effector Final Surface Cleaning.....	2.4
Figure 2.2. Screen Clogging during Prior Tests.....	2.5
Figure 3.1. HWEE Concept	3.1
Figure 4.1. Test Setup	4.1

Tables

Table 2.1. Requirements for HWEE Phase 1 Testing.....	2.2
Table 2.2. HWEE Phase 1 Data Requirements	2.6
Table 4.1. Phase I HWEE Simulants	4.4
Table 4.2. Separate Effects Parameters.....	4.6
Table 5.1. HWEE Prototype Phase 1 Tests.....	5.1
Table 5.2. Instrument Validation Tests	5.1
Table 5.3. Equipment Initial Target* Startup Parameters.....	5.3
Table 5.4. Equipment Initial Target* Retrieval Parameters.....	5.5
Table 8.1. Job Hazards Assessment	8.2

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 effort fulfills the informational needs defined in RPP-PLAN-61227 (Wooley 2016) for initial assessment of the HWEE to support Hanford single-shell tank 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 single-shell tanks.

Phase 1 will install the HWEE on a PNNL-designed robotic gantry system at the CTF to perform effectiveness testing. The 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 (Gauglitz 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 tank retrieval systems that began in the 1990s as the confined sluicing end effector and was 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 waste locally at the point of waste dislodging.

The HWEE used for the Phase I testing was fabricated by HiLine Engineering and Fabrication, Inc. based on the procurement specification RPP-SPEC-61356. Specifications and drawings 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.
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 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 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.
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 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 deployment platforms. The 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 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 screen clogging occurs, the enhanced screen back flushing feature will be used and the amount of water usage for screen clearing will be measured. Because 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. 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 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 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 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 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 pounds per square inch (psi) and used 12.5

gallons/minute of water. The hydraulic motor speed was 300 revolutions per minute (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 (see Figure 2.1); using the skirt may have reduced the splattering and resulted in an even cleaner tank surface.

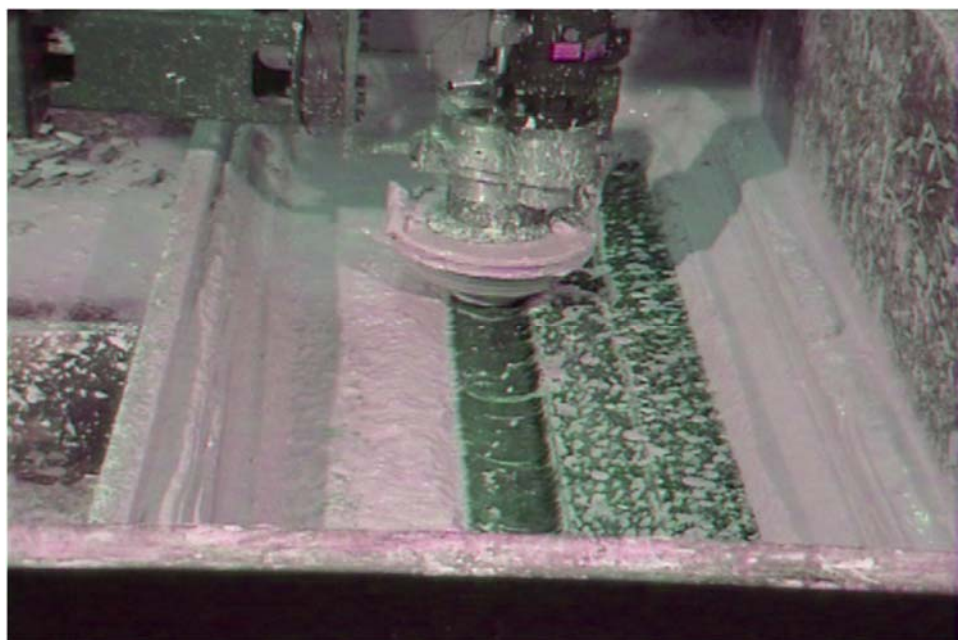


Figure 2.1. End Effector Final Surface Cleaning

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 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 overspray 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 (see 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. 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 requirements 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	Target Accuracy Objective
Retrieval		
Determine slurry output and dilution ratio for different test materials including: Kaolin (Sludge) Kaolin/Plaster (Hardpan) K-Mag (Saltcake)	Test data Video record	±10%
Visually observe slurry product after decant and note presence of large fragments.	Photo record	Qualitative
Measure HWEE tool reaction forces and frequency content during normal operation.	Test data Video record	±5%
Aerosol Generation		
Visually monitor aerosol generation during retrieval tests.	Video record	Qualitative
Screen Plugging		
Determine estimated frequency of screen and shroud plugging during retrieval tests. Evaluate remote flushing techniques to eliminate screen plugging.	Video record	Qualitative
Simulant Production		
Measure density and strength of test simulants to ensure consistency.	Test data	Measurement device Dependent*

*Note: Simulant strength measurements will use a viscometer or penetrometer as applicable to the simulant type. Simulant density measurements will use a gas pycnometer.

3.0 Waste Retrieval End Effector Description

The HWEE will be used to fragment and dislodge waste and introduce 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 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 glovebox. The HWEE's performance should be somewhat better than the SREE's due to refinements in screen design and conveyance inlet geometry, which were changes based on lessons learned at ORNL. The design of the HWEE is captured in Mullen et al. (1998).

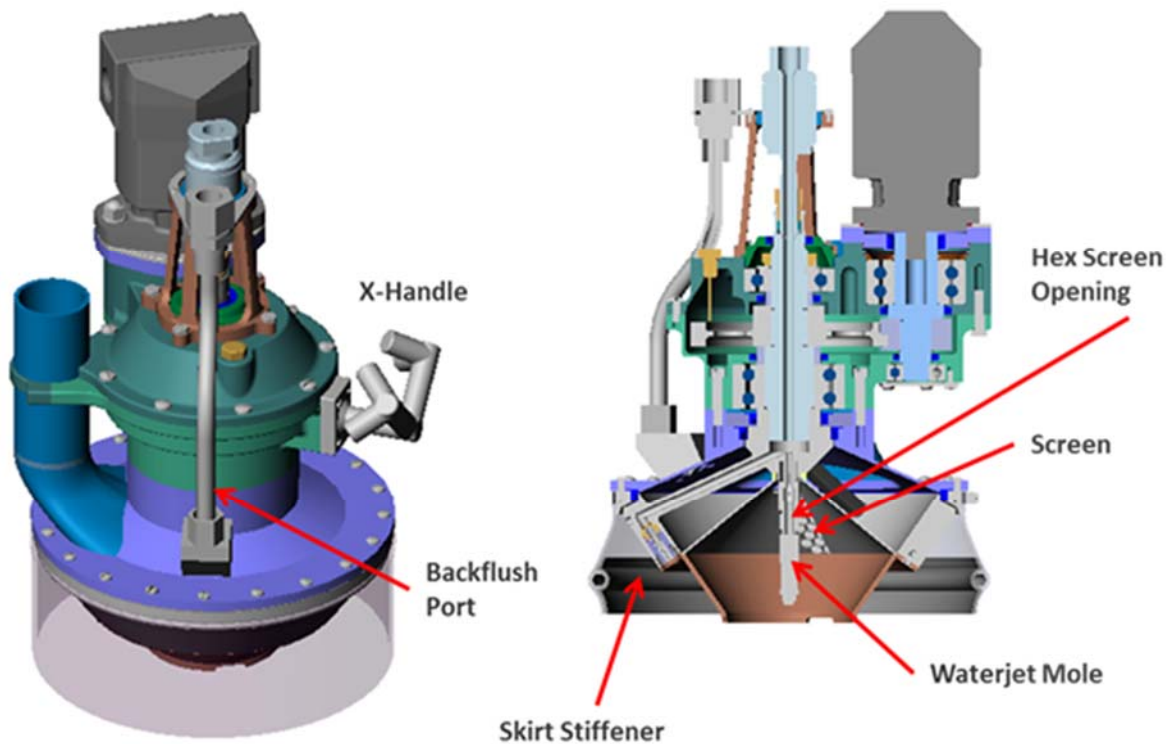


Figure 3.1. HWEE Concept

The following retrieval descriptions are those expected from prior testing. Actual results obtained during this testing sequence using this HWEE scarifier with enhanced capabilities from previous testing may modify some of the operating parameters and results listed below.

Sludge (Kaolin) Retrieval: Sludge will be retrieved by operating the HWEE in the range of 1000 psi and 300 RPM. The pressure, rotation speed, and traverse speed should be adjusted to achieve a 1-inch depth of cut and very small fragments of dislodged material. 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 1 to 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 (Kaolin/Plaster) Retrieval: Hardpan will be retrieved by operating the HWEE starting at 1000 psi and 300 RPM. The pressure, rotation speed, and traverse speed should be adjusted to achieve a 1-inch depth of cut and very small fragments of dislodged material. Retrieval will be similar to sludge retrieval. At higher waterjet pressures, the aerosol generation rate will increase. The hardpan material will not break 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 (K-Mag) Retrieval: Saltcake will be retrieved by operating the HWEE at a maximum pressure of 10,000 psi. The pressure, rotation speed, and traverse speed should 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 into minute particles as the sludge will, so solids are expected to fall out of suspension. A reduction in pumping rate or 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 the WRPS CTF. The test setup, equipment, instrumentation, and simulants are discussed in this section.

4.1 Test Setup

An overview of the test setup is provided in Figure 4.1. The setup consists of a gantry, conveyance line management arm, jet pump, and ancillary equipment. Most of the equipment, including the gantry and HWEE, will be enclosed in a large tent. A high-pressure pump will be positioned nearby. A material receipt tank (denoted the retrieval tank) is located close to the tank where retrieval will occur (denoted the simulant tank) to minimize pumping distance. Hoses will connect the pump to the HWEE, jet pump, and jet pump outlet to the retrieval tank. Instrumentation will be installed to measure process parameters, reaction forces, and retrieval performance.

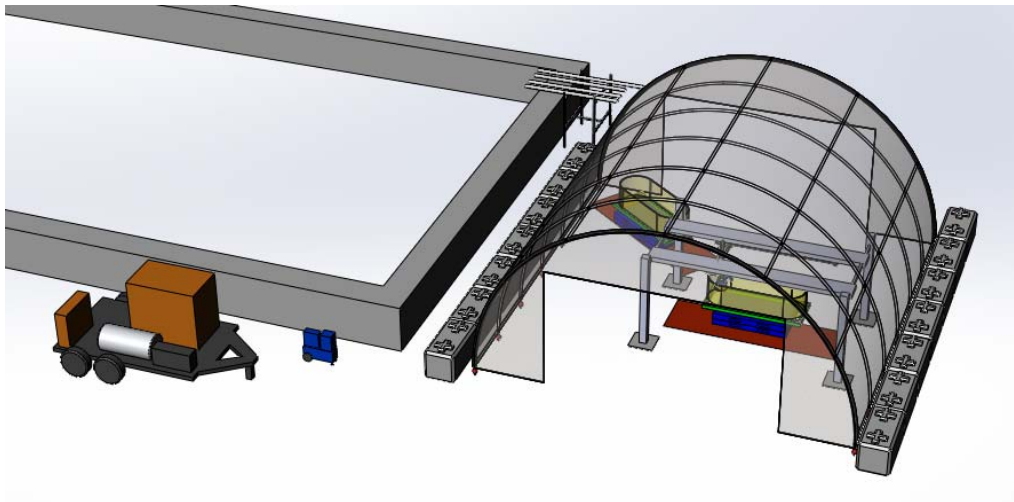


Figure 4.1. Test Setup

Before starting retrieval testing, the HWEE high-pressure manifold will be pressure tested by HiLine Engineering per the requirements of American Society of Mechanical Engineers B31.3-2014 (ASME 2014) and will be stamped with the maximum operating pressure. Once the HWEE is delivered to CTF, it will be installed on the PNNL-designed gantry system. Testing will only proceed when the high-pressure system, including the HWEE, high-pressure pump, and hoses, is approved for operation by the appropriate safety authorities at PNNL and WRPS.

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 consists of a two-dimensional scanner mounted to a four-post automobile lift. The scanner provides a horizontal work space of 8 by 3 feet at speeds up to 300 inches per minute and can be operated manually or programmed for an operating path. The scanner system is attached to a manual automobile lift to provide up to 80 inches of vertical movement.
- **High-pressure pump.** A high-pressure pump will be used to supply water to the jet pump and HWEE. The minimum requirement capacity of the pump is 25 gallons per minute at 10,000 psi. A foot pedal will start and stop high-pressure operations as applicable.
- **High-pressure hose.** 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 by the high-pressure pump and/or pressure reducing manifold.
- **Pressure reducing manifold.** The pressure reducing manifold is a secondary pressure regulator that can be installed in the high-pressure line connected to the HWEE to allow pressure to be reduced below pump pressure, if desired.
- **Hose management system.** A hose management system will be used to support the conveyance line, high-pressure water jet hoses, and hydraulic rotary motor hoses attached to the HWEE as it moves over the test bed (simulant tank).
- **Jet pump.** The jet pump that will be used for testing is AquaDyne model 61102958 Dyna-vac with 2-inch FNPT (Female National Pipe Thread) and six nozzle ports.
- **Conveyance hose.** Two-inch diameter opaque flexible hose will connect from the HWEE to the jet pump supported by the hose management system. A two-inch diameter pipe will connect the jet pump discharge to a retrieval 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 per minute at 3000 psi. Hydraulic hoses will be routed from the hydraulic power unit to the HWEE using the hose management system.
- **Simulant tank.** Simulant will be placed in a steel tank with nominal dimensions of 8 feet long, 2 feet wide, and 3 feet deep.
- **Retrieval tank.** Simulant will be retrieved in a poly tank with nominal dimensions of 73.5 inches long, 36.5 inches wide, and 36 inches deep.
- **Test enclosure.** The gantry with associated HWEE/jet pump and hose management system, simulant, and retrieval tanks will be enclosed in a large tent enclosure.

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 data acquisition system. 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 hertz) 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. A second visual pressure gauge is included on the pressure reducing manifold that can be used to set lower discharge pressures to the HWEE than the jet pump.
- **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.
- **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 and receipt tanks to measure the weight of water/simulant transferred during retrieval simulations.
- **Position (X, Y, Z axis).** Position of the HWEE in 3D space will be monitored using a “Home” position (X, Y axis horizontal plane) from which all movements will be relative and a scale/linear plot that will be used to read the height of the lift relative to a starting point. Limit switches are provided in the X, Y horizontal plane to keep the HWEE within the “safe” confines of the movement operation being attempted (e.g., tank walls, mining inside a wood frame structure).

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 and 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 prior work (e.g., Powell 1996). Bench-scale simulant samples will be prepared and characterized for yield stress in shear 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 studies. The preparation methodologies provided below are from Powell et al. (1997).

Note: From this point on, sludge, hardpan, and saltcake will be referred to in more common simulant terms as kaolin, kaolin/plaster, and K-Mag respectively.

Table 4.1. Phase I HWEE Simulants

Simulant	Solid Simulant Mass for 1.5 Batches at Half Test Vessel Volume (lbs)	Material Strength
Kaolin (Sludge): 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 (Hardpan): 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 (Saltcake): 80 wt % Dynamate (potassium magnesium sulfate) 20 wt% Richland City Water	Dynamate: 4,100 lbs.	Compressive Strength ~ 15,000,000 Pa

All simulant characterization performed by the PNNL HWEE test team will be done using PNNL standard procedures and calibrated equipment as applicable. All simulant characterization is considered confirmatory in nature.

4.2.3.1 Simulant Preparation, Kaolin (Sludge)

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 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 kilopascal (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.

4.2.3.2 Simulant Preparation, Kaolin/Plaster (Hardpan)

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 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 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.

4.2.3.3 Simulant Preparation, K-Mag (Saltcake)

80 wt % Dynamate (potassium magnesium sulfate, K-Mag)

20 wt% Richland City Water

Suppliers: The Dynamate feed-grade potassium and magnesium sulfate is produced by the Mosaic Company (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 at least 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 the 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 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 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 startup testing:

1. Select a flat region of undisturbed simulant surface.
2. Fix the HWEE metal shroud at a constant position at an initial standoff of 0.25 inches (± 0.25 inches).
3. Equipment parameters (see Table 4.2).

Table 4.2. Separate Effects Parameters

Kaolin	Rotation Speed	0 RPM
	Traverse Speed	0 inches/minute
	Waterjet pressure, location 1	1000 psi (target)
	Waterjet pressure, additional location(s)	TBD during testing*
	Operation Time	TBD during testing*

Kaolin/Plaster	Rotation Speed	0 RPM
	Traverse Speed	0 inches/minute
	Waterjet pressure, location 1	1000 psi (target)
	Waterjet pressure, additional location(s)	TBD during testing*
	Operation Time	TBD during testing*
K-Mag	Rotation Speed	0 RPM
	Traverse Speed	0 inches/minute
	Waterjet pressure, location 1	1000 psi (target)
	Waterjet pressure, additional location(s)	Up to 10,000 psi
	Operation Time	TBD during testing*

* Operation times \ waterjet pressure may be varied to gauge waterjet performance in simulant.

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

(Note: Similar steps 1–4 above are used during startup testing in Section 5.2.2 following Step 3.)

5.0 Test Instructions

This section includes 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. Table 5.1 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	- Performance check sensors with known weights, pressures, etc. - Verify controls operation and back-flush capability with water	Performance check of sensors in the installed condition
HWEE Retrieval Tests	Sludge, Saltcake, and Hardpan Retrieval Tests	- Tests with sludge, saltcake, and hardpan - Flat topography	- Verified basic operating parameters - Plugging problems - Water usage - Slurry density - Slurry output rate - Aerosol generation

5.1 Instrument Verification and Cross-check

Table 5.2 describes the tests that will be conducted to cross-check and validate the instrument measurements. The tests are intended to augment calibration of the sensors as provided by the vendor.

Table 5.2. Instrument Validation Tests

Instrument	Method of Measurement Cross-Check or Performance Check
Force/torque sensor	Apply a force/torque load to the HWEE and note response of calibrated force/torque sensor.
Tank load cells	Apply a load (i.e., adding weight) to the HWEE simulant and retrieval tanks and note response of calibrated load cells.
High-pressure sensor	With the high-pressure pump pressure reducing valve in open position, compare output pressure of high-pressure pump visual gauge with downstream visual gauge on pressure reducing manifold as applicable.
Controls	Verify operation of HWEE gantry E-stop, high-pressure control valves, and pump on/off.
High-pressure water flow	Allow various combinations of HWEE jets and jet pump water to accumulate in tanks for a known amount of time (target >1 minute). Flow will be derived from load cell measurements.

5.2 HWEE Retrieval Tests

Retrieval tests will focus on measuring HWEE performance during kaolin (sludge), kaolin/plaster (hardpan), and K-Mag (saltcake) retrieval. Associated operations will also be assessed during retrieval, including scavenging characteristics of the jet pump and assessing aerosol generation.

The following procedures are a general guide for retrieval testing and may be adjusted in the field as necessary to achieve HWEE retrieval performance objectives and changing field conditions. Operational sequencing steps for this testing are defined in general terms to portray how HWEE equipment is setup and operated during the retrieval process. The order of retrieval of the three different simulants can be varied as necessary.

5.2.1 Pretest Procedure

The pretest procedure below is a general framework for pretest startup.

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 that inlet water pressure is on.
4. Check that inlet air pressure is on (i.e., to operate diaphragm pump).
5. Clear the HWEE gantry workspace area and secure electrical interlock.
6. Initiate ancillary equipment, including cameras, data acquisition, and motor control. Insure data acquisition and cameras are recording data.
7. Perform high-pressure pump prestart checks and then start pump. Check for leaks in high-pressure lines. Check that high-pressure dump water is being collected and not dumped to the ground.
8. Adjust the pump output to the desired pressure. Pump maximum allowable operating pressure is 10,000 psi. The pump is protected by a rupture disk that will fail at a pressure just above 10,000 psi.

5.2.2 Retrieval Startup Test Procedure

The objective of startup testing is to verify proper operation of the test equipment and ascertain HWEE performance. The key goal is to check the HWEE retrieval operating parameters (nozzle size, water pressure, and traverse speed) are adequately cutting into the simulant material (target depth is 1 inch) and observe any HWEE screen inlet plugging and subsequent clearing by flushing. This test is not intended to optimize parameters but to determine viable HWEE retrieval parameters to be used in the following larger single-simulant retrieval tests.

During this testing it is expected that kaolin (sludge) retrieval will be very effective using parameters from prior testing. It is expected that kaolin/plaster (hardpan) retrieval will be very effective using parameters from prior testing, but the frequency of screen cleaning will have to be determined. It is

expected that K-Mag (saltcake) retrieval will be marginally effective using parameters from prior testing, and the frequency of screen cleaning and depth of cut 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 three long partitions and place the kaolin sludge into the center partition. Take samples of the simulant during preparation and/or in the field as appropriate. Collect sample to prevent evaporation and send samples to the PNNL simulant lab for characterization.
2. Program the gantry to make one pass over the simulant field being tested at a standoff of approximately 0.25 inches (± 0.25 inch) using a serpentine mining path. For kaolin/plaster (hardpan) and K-Mag (saltcake), the offset between paths should be the width of the waterjets. Initial target parameters are provided in Table 5.3.

Table 5.3. Equipment Initial Target* Startup Parameters

Kaolin (Sludge)	Rotation Speed	300 RPM
	Traverse Speed	300 inches/minute
	Waterjet pressure	1000 psi
	HWEE vertical stepping	1 inch
Kaolin/Plaster (Hardpan)	Rotation Speed	300 RPM
	Traverse Speed	300 inches/minute
	Waterjet pressure	3000 psi
	HWEE vertical stepping	1 inch
K-Mag (Saltcake)	Rotation Speed	75–300 RPM
	Traverse Speed	300 inches/minute
	Waterjet pressure	Up to 10,000 psi
	HWEE vertical stepping	¼ to 1 inch

* Target parameters are estimated from past testing and may be adjusted as necessary to achieve desired HWEE performance characteristics in the various simulant materials. Results from separate effects testing (see Section 4.2.3.4) may be used to adjust these initial target parameters.

3. Ensure the retrieval tank is configured to accept retrieved simulant and load cells are operational. Depending on time and fluid volume of retrieval operations, the retrieval tank may need to be periodically emptied. If emptying is required during a retrieval operation, operations should be placed in a holding condition and tank liquid pumped down to decant the liquid only if possible while keeping track of beginning and ending tank loads. At the end of each retrieval operation, a tally of total weight retrieved is determined, residual simulant material collected should be assessed as applicable, and then disposed into the CTF slurry receipt pit.
4. Ensure the simulant tank is configured for retrieval operations and load cells are operational. The HWEE jet pump is used to collect and transport the retrieved simulant to the retrieval tank. During some operations when simulant retrieval is not being done (e.g., configuring the HWEE system pressures), alternate means can be used to collect water (e.g., separate tank or volume in simulant with no simulant) and to remove water (e.g., pumping to CTF slurry receipt pit directly using a diaphragm pump) not associated with retrieval activities.

5. Open the jet pump control valve.
6. Turn on the pump and adjust the pump outlet to desired pressure.
7. Open the HWEE waterjet control valve.
8. Adjust the HWEE waterjet pressure using the regulator on the pressure reducing manifold.
9. Turn on diaphragm pump to remove excess water used to adjust HWEE jet pressure.
10. Close the HWEE waterjet control valve.
11. Position the HWEE in a safe starting position close to the point where retrieval will start.
12. Open the HWEE waterjet control valve.
13. Activate the hydraulic power unit and verify/adjust HWEE rotational speed.
14. Turn off diaphragm pump
15. After steady-state conditions are reached, initiate the mining path. During kaolin/plaster (hardpan) and K-Mag (saltcake) retrieval, operate the HWEE flush system(s) in the configuration and frequency necessary to clear HWEE inlet screen. If the retrieval rate drops appreciably during mining operations, increase the frequency of flushing. Alternate flushing methods may be employed to determine flush frequency such as stopping retrieval operations periodically to look at debris buildup on HWEE screen and then activating flush to clear the screen.
16. Modify the gantry mining path to lower the head approximately 1 inch and repeat the previous step until simulant depth is reached or adequate retrieval data is collected.
17. Raise the HWEE at least 6 inches above the waste and allow jet pump to operate for a period of time (e.g., 2–3 minutes) as necessary to flush the line of simulant material.
18. Turn off the high-pressure pump.
19. Position the HWEE over a tank to collect waterjet discharge (as applicable).
20. Close the jet pump control valve.
21. Store and archive the data acquisition and camera data files.
22. Repeat steps 1– 21 for second simulant.
23. Repeat steps 1– 21 for third simulant.

5.2.3 Retrieval Test Procedure

Retrieval testing will test the performance and operating characteristics of the HWEE to retrieve waste simulants kaolin (sludge), kaolin/sludge (hardpan) and K-Mag (saltcake) in a mining operation. Information obtained from retrieval startup testing (see Section 5.2.2) will be used as applicable to set HWEE retrieval operating parameters for this testing. The goal is not to optimize retrieval parameters but to demonstrate the effectiveness of the HWEE to retrieve these waste simulants and obtain information for using and optimizing the HWEE in any follow-on retrieval operations.

The test operation steps for this retrieval testing are nearly identical to retrieval startup testing except simulant bed covers close to three times the horizontal area and two times the depth (except K-Mag) yielding six times the volume of simulant.

1. Fill the tank with simulant to be tested. Simulant should be approximately 8 inches deep (4 inches deep for K-Mag), 3 feet wide, and 5 feet long. Take samples of the simulant during preparation and/or in the field as appropriate. Collect sample in a way to prevent evaporation and send samples to the PNNL simulant lab for characterization.
2. Program the gantry to make one pass over the simulant field at a standoff of approximately 0.25 inches (± 0.25 inch) using a serpentine mining path. The offset between paths should be the width of the waterjets. Initial target parameters are provided in Table 5.4.

Table 5.4. Equipment Initial Target* Retrieval Parameters

Kaolin (Sludge)	Rotation Speed	300 RPM
	Traverse Speed	300 inches/minute
	Waterjet pressure	1000 psi
	HWEE vertical stepping	1 inch
Kaolin/Plaster (Hardpan)	Rotation Speed	300 RPM
	Traverse Speed	300 inches/minute
	Waterjet pressure	3000 psi
	HWEE vertical stepping	1 inch
K-Mag (Saltcake)	Rotation Speed	75 RPM
	Traverse Speed	6–8 inches/minute
	Waterjet pressure	6,600 psi
	HWEE vertical stepping	¼ to 1 inch

* Target parameters are estimated from past testing and may be adjusted as necessary to achieve desired HWEE performance characteristics in the various simulant materials. Results from retrieval startup testing (see Section 5.2.2) may be used to adjust these initial target parameters.

3. For kaolin (sludge) retrieval test only, before retrieval starts submerge the HWEE in undisturbed kaolin and test hydraulic motor rotation. Record rotational speed and force/torque readings to acquire maximum motor speed in this condition. (Note: HWEE has a hydraulic motor that is expected to have better performance than the previous electric motor that stalled under these conditions in kaolin simulant.)
4. Ensure the retrieval tank is configured to accept retrieved simulant and load cells are operational. Depending on time and fluid volume of operations, the retrieval tank may need to be periodically emptied. If emptying is required during a retrieval operation, the operations should be placed in a holding condition and tank liquid pumped down to decant the liquid only if possible while keeping track of beginning and ending tank loads. At the end of each retrieval operation, a tally of total weight retrieved is determined, the residual simulant material collected should be assessed as applicable, and then disposed into the CTF slurry receipt pit.
5. Ensure the simulant tank is configured for retrieval operations and load cells are operational. The HWEE jet pump is used to collect and transport the retrieved simulant to the retrieval tank. During

some operations when simulant retrieval is not being done (e.g., configuring the HWEE system pressures), alternate means can be used to collect water (e.g., separate tank or volume in simulant with no simulant) and remove water (e.g., pumping to CTF slurry receipt pit directly using a diaphragm pump) not associated with retrieval activities.

6. Open the jet pump control valve.
7. Turn on the pump. Adjust the pump outlet to desired pressure.
8. Open the HWEE waterjet control valve.
9. Turn on diaphragm pump to remove excess water used to adjust HWEE jet pressure
10. Adjust the HWEE waterjet pressure using the regulator on the pressure reducing manifold.
11. Close the HWEE waterjet control valve.
12. Position the HWEE in a safe starting position close to the point where retrieval will start.
13. Open the HWEE waterjet control valve.
14. Turn off diaphragm pump
15. Activate the hydraulic power unit and verify/adjust HWEE rotational speed.
16. After steady-state conditions are reached, initiate the mining path. Operate the HWEE flush system(s) using the configuration and frequency determined in startup or subsequent testing. If retrieval rate drops appreciably during mining operations, increase the frequency of flushing. Alternate flushing methods may be employed to determine flush frequency, such as stopping retrieval operations periodically to look at debris buildup on HWEE screen and then activating flush to clear the screen.
17. Modify the gantry mining path to lower the head 1 inch and repeat the previous step until simulant depth is reached or adequate retrieval data are collected.
18. Raise the HWEE at least 6 inches above the waste and allow jet pump to operate for a period of time (e.g., 2-3 minutes) as necessary to flush the line of simulant material.
19. Turn off the high-pressure pump.
20. Position the HWEE over a tank to collect waterjet discharge (as applicable).
21. Close the jet pump control valve.
22. Store and archive the data acquisition and camera data files.
23. Repeat steps 1–22 for second simulant.
24. Repeat steps 1–22 for third simulant.

Aerosol testing is intended to show aerosol generation by the HWEE in the three simulants at two standoff distances and various pressures starting at 1,000 psi. This testing is done after retrieval operations are complete for a simulant and may be performed at any time, in any container, and with a smaller amount of simulant as deemed adequate for aerosol demonstration.

25. Spread first simulant approximately level over a portion of a tank/container floor.

26. Perform initial aerosol test at standoff distances of approximately $\frac{1}{4}$ inch (target tolerance is $\pm\frac{1}{4}$ inch).
27. Operate the HWEE with jet rotating at 1,000 psi and then increase up to maximum available test pressure (~6,600 psi) or until excessive aerosol or splattering is reached; note maximum pressure reached. Run test for approximately 1 minute at each pressure when steady state is reached. Visual recording is used to observe aerosols generated.
28. Move 12 inches up from the $\frac{1}{4}$ -inch position to another position over the simulant bed with similar simulant starting features as the $\frac{1}{4}$ -inch testing under the HWEE. Repeat testing in previous step.
29. Turn off HWEE waterjets when aerosol testing is complete.
30. Repeat steps 25– 29 for second simulant.
31. Repeat steps 25–29 for third simulant.

5.2.4 Post-test Procedures

1. Empty retrieval tank(s) with retrieved simulant into the CTF slurry receipt pit or other approved designated area. Record general impression of the test slurry (e.g., dilute water with hardpan fragments).
2. Empty simulant tanks of any remaining simulant and fluids into the CTF slurry receipt pit.
3. Place simulant tank or other container under HWEE when not in use to catch fluid leaks as applicable.
4. When testing is complete, demobilize from the CTF as directed by the client.

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.

The first step in the data evaluation process will be to convert 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 requirements listed in Table 2.2 that must be derived from test data as follows:

- Water usage of HWEE components
- Retrieval rates and slurry dilution rates versus simulant type
- HWEE force loads experienced during retrieval operations.

6.1 Water Usage of HWEE

Water usage of the various HWEE water jetting components is derived by using a cash-and-weigh system for collected water out of the HWEE device water jet(s) operating at steady-state conditions for a collection time, typically at least 1 minute. Data will be collected at a range of operating pressures, typically from 1000 to 10,000 psi.

$$\text{Water Weight Collected (steady state) / Collection Time} = \text{Water Usage Rate}$$

Water usage is collected dynamically from HWEE load cells under the simulant and retrieval tanks. Prior to data collection, the weight of the tank is typically zeroed and the weight in the tank increases as the device runs.

6.2 Retrieval Rates and Slurry Dilution Rates

Two methods are identified for calculating retrieval rates and slurry dilution rates.

A. Match Previous Work

Retrieval rate is derived by estimating the mining path width and depth, and mining path speed.

$$\text{Mining Path Width} \times \text{Mining Depth} \times \text{Mining Path Speed} = \text{Retrieval Rate}$$

Dilution ratio is the simulant retrieval rate divided by the water usage rate of the HWEE (flushing contribution may need to be estimated).

$$\text{Retrieval Rate} / \text{Water Usage Rate by HWEE} = \text{Dilution Ratio (no units)}$$

B. Weight Transfers

Retrieval rate is derived by monitoring simulant and retrieval tank load changes and accounting for the water from all the HWEE components. This will be evaluated at steady-state conditions for given time period(s).

Dilution ratio is the simulant retrieval rate divided by the water usage rate of the HWEE (flushing contribution may need to be estimated).

$$\text{Retrieval Rate} / \text{Water Usage Rate by HWEE} = \text{Dilution Ratio (no units)}$$

6.3 HWEE End Effector Force Loads

HWEE force and torque data will be evaluated for a representative period of time during retrieval of each simulant type. HWEE reaction forces will also be evaluated versus cutting jet and flush jet operating pressure. Finally, HWEE reaction forces and torque will be evaluated during startup of the hydraulic motor after the inlet shroud is submerged in kaolin sludge. This data will be used to develop requirements for potential deployment platforms.

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 these data will be converted to Microsoft Excel spreadsheet format for data manipulation and display. Other data, such as observed test conditions, will be collected manually in an electronic repository or notebook.

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
- 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 and associated records

Data files will be archived to optical disk and 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 Engineering Records

All laboratory data, general observations, and details of the activities performed per this test plan will be documented electronically. Hardcopy documents, datasheets, observations, etc. will be scanned as applicable for data retention. For each test, the following minimum information will be recorded: date, time, procedure number, procedure parameters, data file, and observations.

7.3 Calibration Records

Quality Assurance Engineering will review the measurement and test equipment list before test initiation. Calibration records of 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. Instrumentation used that is not calibrated can be post calibrated with the condition that no issues were found at the time of calibration and calibration information will be submitted to WRPS Quality Assurance for review. Equipment calibrated by vendors to national standards is acceptable for this testing.

7.4 Quality Assurance

This test program shall follow the guidelines of U.S. Department of Energy 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 the 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, but electrical power will be required for the following:

- HWEE and jet pump hydraulic power unit(s) and the high-pressure pump(s) 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)
- 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 summarizes 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 WRPS Job Hazard Analysis Checklist and the PNNL Offsite Risk Management Plan that has been approved for this activity.

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) High noise levels during operation (>85 dBA) Heat stress due to localized heat source or use of special personal protective equipment	Continuous burst-shielded hose from valves at high-pressure water source to test bed. Whip checks to secure quick disconnect fittings. Piping protected by rupture disk discharging into safe area. 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 Bump potential due to low overhead structure	Work zone to be established and interior cleared of personnel prior to operation. Personnel barrier (e.g., tent enclosure) with interlock to emergency stop (or E-stop) control will prevent access to the work space of the gantry. Warning signs will be placed on the personnel barrier to warn of the hazard of entering the working envelope. Mechanical stops on the gantry have been provided by the vendor to define the gantry operating envelope. 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. 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, who 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. Hardhats or bump caps will be required when working under the lift envelope of the gantry.
Simulant equipment cleaning	Hazardous energy (air, steam, fluid, pressurized)	Wear rubber gloves, boots, overalls or rainsuit, eye and face protection.

Sequence of Basic Job Steps or Work Activity		
Activity	Hazards Present	How to Eliminate Hazards
Simulant preparation	Inhalation of nuisance dusts Manual lifting	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 prefilters. 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	Prejob briefing. Hydraulic motor to be deactivated prior to personnel entering tent.

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

- 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, *Standard for Industrial Robots and Robot Systems* (ANSI/RIA 1992).
- High-pressure waterjets may penetrate and damage human skin. This hazard will be managed by preventing personnel from entering the tent containment during pump operation.

8.5 Training and Qualification Requirements

Personnel training for the operation of test equipment will include 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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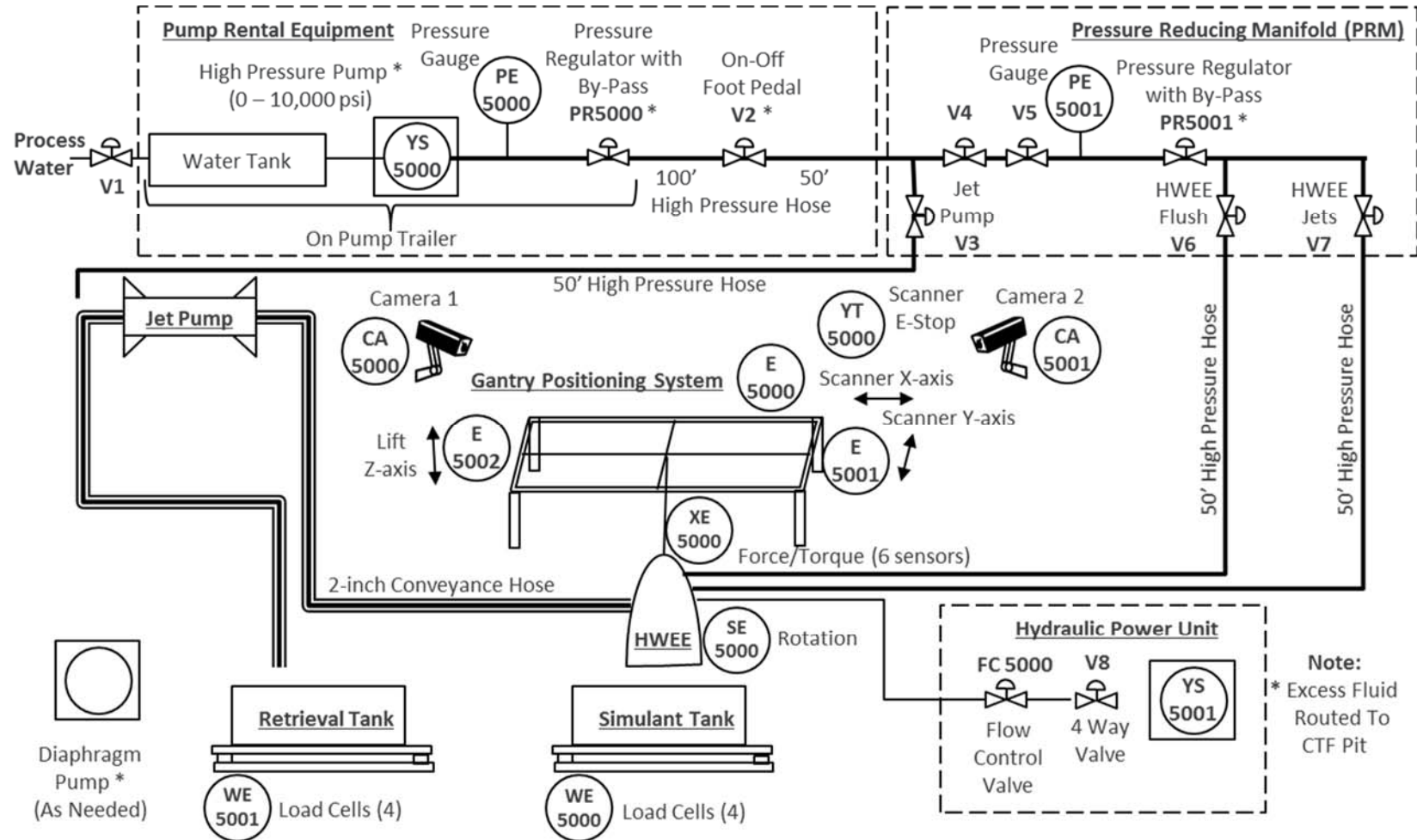
Appendix A

Measuring and Test Equipment

Measured Parameter	Range, Units	Tag #	Sensor / Control Element	Serial Number	Manufacturer	Signal Conditioning	Serial Number	Manufacturer	Accuracy	Calculated Error (+/-)	Calibration Date	Calibration Due Date	Reference
Camera, Overview	N/A	CA 5000	RJ45	N/A	Security Camera Warehouse Inc.	N/A	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
Camera, Close-up	N/A	CA 5001	RJ45	N/A	Security Camera Warehouse Inc.	N/A	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
Stepper Motor, X-Axis	0-2450 mm	E 5000	CP*HV343-02-10-EC	N/A	Compumotor	0.001024 inch/step	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	DT-5TS_and_DT-5TX_manual.pdf page 19
Stepper Motor, Y-Axis	0-920 mm	E 5001	CP*HV343-02-10-EC	N/A	Compumotor	0.001024 inch/step	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	DT-5TS_and_DT-5TX_manual.pdf page 19
Lift Position, Z-Axis	0-25 inches	E 5002	SP1-25	1815	Government Scientific Source, Inc.	N/A	N/A	N/A	Control Element, Indication Only	0.075 inches	N/A	N/A	SP1 Installation Guide (SP1-MANUAL) (full scale = 25 inches)
Hydraulic Fluid Flow Control	0-3 gpm	FC 5000	HPU 13-1-3GC	N/A	Foster MFG Corp	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
Pressure, Main Pump (HWEE Jet Pump)	0-10,000 psi	PE 5000	4008 Pressure Gauge	PNL-13-01-003	NLB Corporation	Sight glass	N/A	N/A	see cert	see cert	7/28/2017	7/27/2018	Cert PNL-13-01-003:1501169614
Pressure, HWEE Components	0-10,000 psi	PE 5001	3008 Pressure Gauge	PNL-13-01-002	NLB Corporation	Sight glass	N/A	N/A	see cert	see cert	7/28/2017	7/27/2018	Cert PNL-13-01-002:1501166816
Pressure Regulator with By-Pass	0-10,000 psi	PR 5001	Pressure Reducing Station PRS-270HC	N/A	NLB Corporation	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
Pressure Regulator with By-Pass	0-10,000 psi	PR5000	Model #10305 Pump	N/A	NLB Corporation	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
HWEE Jet Rotation	0-1000 RPM	SE 5000	MCS-655M Optical Receiver	N/A	Electromatic Eq. Company	DT-5TXR Panel Tachometer DOP-FVTR Analog output module	P16710090	Electromatic Eq. Company	+/- 0.008% +/- 1 digit	1 RPM	N/A	N/A	N/A
Process Water Control Valve	On, Off	V1	Model #10305 Pump	N/A	NLB Corporation	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
High Pressure Foot Valve	On/Off	V2	N/A	N/A	NLB Rental Supply	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
HWEE Jet Pump Valve	0-10000 psi	V3	Pressure Reducing Station PRS-270HC	N/A	SAMI	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
PRM Isolation (Spare)	0-10000 psi	V4	Pressure Reducing Station PRS-270HC	N/A	SAMI	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
PRM Isolation	0-10000 psi	V5	Pressure Reducing Station PRS-270HC	N/A	SAMI	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
HWEE Flush Valve	0-10000 psi	V6	Pressure Reducing Station PRS-270HC	N/A	SAMI	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
HWEE Jet Valve	0-10000 psi	V7	Pressure Reducing Station PRS-270HC	N/A	SAMI	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
HPU Control Valve	On, Off	V8	HPU 13-1-3GC	N/A	Foster MFG Corp	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
Simulant Tank Weight	0-10000 lbs	WE 5000	See Cell	See Cell	See Cell	IPE50	496308	Load Cell Central	See Cell	N/A	4/25/2017	4/24/2018	See Cell
Cell 1	Function as unit	WE 5000 (Cell 1 of 4)	SPWE-SR-2.5K	80162	Load Cell Central	See Main Unit	See Main Unit	See Main Unit	zero bal. 1.0% fs, linearity 0.25%, hysteresis 0.3%	N/A	4/25/2017	4/24/2018	Calibration Certificate
Cell 2	Function as unit	WE 5000 (Cell 2 of 4)	SPWE-SR-2.5K	80041	Load Cell Central	See Main Unit	See Main Unit	See Main Unit	zero bal. 1.0% fs, linearity 0.05%, hysteresis 0.03%	N/A	4/25/2017	4/24/2018	Calibration Certificate
Cell 3	Function as unit	WE 5000 (Cell 3 of 4)	SPWE-SR-2.5K	80028	Load Cell Central	See Main Unit	See Main Unit	See Main Unit	zero bal. 1.0% fs, linearity 0.05%, hysteresis 0.03%	N/A	4/25/2017	4/24/2018	Calibration Certificate
Cell 4	Function as unit	WE 5000 (Cell 4 of 4)	SPWE-SR-2.5K	80062	Load Cell Central	See Main Unit	See Main Unit	See Main Unit	zero bal. 1.0% fs, linearity 0.05%, hysteresis 0.03%	N/A	4/25/2017	4/24/2018	Calibration Certificate
Retrieval Tank Weight	0-10000 lbs	WE 5001	See Cell	See Cell	See Cell	IPE50	496300	Load Cell Central	See Cell	N/A	6/7/2017	6/6/2018	See Cell

Measured Parameter	Range, Units	Tag #	Sensor / Control Element	Serial Number	Manufacturer	Signal Conditioning	Serial Number	Manufacturer	Accuracy	Calculated Error (+/-)	Calibration Date	Calibration Due Date	Reference
Cell 1	Function as unit	WE 5001 (Cell 1 of 4)	SPWE-SR-2.5K	77380	Load Cell Central	See Main Unit	See Main Unit	See Main Unit	zero bal. 1.0% fs, linearity 0.25%, hysteresis 0.3%	N/A	6/7/2017	6/6/2018	Calibration Certificate
Cell 2	Function as unit	WE 5001 (Cell 2 of 4)	SPWE-SR-2.5K	79970	Load Cell Central	See Main Unit	See Main Unit	See Main Unit	zero bal. 1.0% fs, linearity 0.05%, hysteresis 0.03%	N/A	6/7/2017	6/6/2018	Calibration Certificate
Cell 3	Function as unit	WE 5001 (Cell 3 of 4)	SPWE-SR-2.5K	79966	Load Cell Central	See Main Unit	See Main Unit	See Main Unit	zero bal. 1.0% fs, linearity 0.05%, hysteresis 0.03%	N/A	6/7/2017	6/6/2018	Calibration Certificate
Cell 4	Function as unit	WE 5001 (Cell 4 of 4)	SPWE-SR-2.5K	77156	Load Cell Central	See Main Unit	See Main Unit	See Main Unit	zero bal. 1.0% fs, linearity 0.05%, hysteresis 0.03%	N/A	6/7/2017	6/6/2018	Calibration Certificate
HREE Forces/Torque	See Unit	XE-5000	Omega160 IP65	FT20766	ATI Industrial Automation	FTCTL Controller	FT20766	ATI Industrial Automation	US-300-1800 calibration	See Unit	6/2/2017	6/1/2018	Manual 9620-05-CTL
Fx	+/-300 lbf	XE-5000 Fx	See Main Unit	See Main Unit	See Main Unit	See Main Unit	See Main Unit	See Main Unit	1.50% full scale (300 lbf)	4.5 lbf	6/2/2017	6/1/2018	PO 354110, ATI Quote # 170419-ATI-040
Fy	+/-300 lbf	XE-5000 Fy	See Main Unit	See Main Unit	See Main Unit	See Main Unit	See Main Unit	See Main Unit	1.50% full scale (300 lbf)	4.5 lbf	6/2/2017	6/1/2018	http://www.ati-ia.com/products/ft/ft_models.aspx?id=Omega160
Fz	+/-875 lbf	XE-5000 Fz	See Main Unit	See Main Unit	See Main Unit	See Main Unit	See Main Unit	See Main Unit	1.25% full scale (875 lbf)	13.125 lbf	6/2/2017	6/1/2018	http://www.ati-ia.com/products/ft/ft_models.aspx?id=Omega160
Tx	+/-1800 in-lbf	XE-5000 Tx	See Main Unit	See Main Unit	See Main Unit	See Main Unit	See Main Unit	See Main Unit	1.00% full scale (1800 lbf-in)	18 lbf-in	6/2/2017	6/1/2018	http://www.ati-ia.com/products/ft/ft_models.aspx?id=Omega160
Ty	+/-1800 in-lbf	XE-5000 Ty	See Main Unit	See Main Unit	See Main Unit	See Main Unit	See Main Unit	See Main Unit	1.25% full scale (1800 lbf-in)	22.5 lbf-in	6/2/2017	6/1/2018	http://www.ati-ia.com/products/ft/ft_models.aspx?id=Omega160
Tz	+/-1800 in-lbf	XE-5000 Tz	See Main Unit	See Main Unit	See Main Unit	See Main Unit	See Main Unit	See Main Unit	1.25% full scale (1800 lbf-in)	22.5 lbf-in	6/2/2017	6/1/2018	http://www.ati-ia.com/products/ft/ft_models.aspx?id=Omega160
High Pressure Pump	On, Off	YS 5000	Model #10305 Pump	N/A	NLB Corporation	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
Hydraulic Power Unit	0 - 3 gpm (@ 3000 psi)	YS5001	Model 13-1-3 GC		Foster Manufacturing Corporation	N/A	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
Scanner E-Stop	On, Off	YT 5000	Commercial Vendor	N/A	N/A	Manual	N/A	N/A	Control Element, Indication Only	N/A	N/A	N/A	N/A
Data Acquisition	N/A	N/A	DaqBook/2001	808665	Measurement Computing	N/A	N/A	N/A	0.015 reading + 0.005 range	0.02%	5/30/2017	5/29/2018	DaqBook 2000 Series user manual (967496) page 124, Certificate of Calibration
Field Linear Measurement	0-8 Inches	CALIPER-1000	CD67-S8 IN PS	4937	M1TUTOYO	N/A	N/A	N/A	see cert	see cert	9/5/2017	9/4/2018	Cert PNL-0004937 09052017
Simulant Strength	0-5.25 kg(f)/cm2	POCKPEN-1000	S-170 Pocket Penetrometer	N/A	Durham	N/A	N/A	N/A			8/18/2017	8/17/2018	User calibration data sheet

Appendix B Piping and Instrumentation Diagram





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