ENGINEERING CHANGE NOTICE

Page 1 of 2 ^{KW}

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Proj.
ECN

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13a. Description of Change				13b. Design Baseline Document? ☐ Yes ☒ No			
Revises the document "Test Plan for Evaluating the Operational Performance of the Prototype Nested, Fixed-Depth Sampling System" with test activities that will be completed in FY 1999 by AEAT. Rev. 0 identified tests for AEAT which were completed in FY 1998 with a conceptual nested, fixed-depth sampling system. The title of the Rev. 1 document was changed to "Test Plan for Evaluating the In-Tank Fluidic Sampling System" to represent a more generic sampling system approach than that of AEAT's nested, fixed-depth sampling system concept.							
14a. Justification (mark one)		14b. Justification Details					
Criteria Change ☒		This change is being made to include additional proof-of-principle					
Design Improvement ☐		testing with a fluidics based sampling system that are to be completed in					
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SDD/DD	☐	Seismic/Stress Analysis	☐	Tank Calibration Manual	☐
Functional Design Criteria	☐	Stress/Design Report	☐	Health Physics Procedure	☐
Operating Specification	☐	Interface Control Drawing	☐	Spares Multiple Unit Listing	☐
Criticality Specification	☐	Calibration Procedure	☐	Test Procedures/Specification	☐
Conceptual Design Report	☐	Installation Procedure	☐	Component Index	☐
Equipment Spec.	☐	Maintenance Procedure	☐	ASME Coded Item	☐
Const. Spec.	☐	Engineering Procedure	☐	Human Factor Consideration	☐
Procurement Spec.	☐	Operating Instruction	☐	Computer Software	☐
Vendor Information	☐	Operating Procedure	☐	Electric Circuit Schedule	☐
OM Manual	☐	Operational Safety Requirement	☐	ICRS Procedure	☐
FSAR/SAR	☐	IEFD Drawing	☐	Process Control Manual/Plan	☐
Safety Equipment List	☐	Cell Arrangement Drawing	☐	Process Flow Chart	☐
Radiation Work Permit	☐	Essential Material Specification	☐	Purchase Requisition	☐
Environmental Impact Statement	☐	Fac. Proc. Samp. Schedule	☐	Tickler File	☐
Environmental Report	☐	Inspection Plan	☐	None	☒
Environmental Permit	☐	Inventory Adjustment Request	☐		☐

20. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

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DEPARTMENT OF ENERGY

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ADDITIONAL

TEST PLAN FOR EVALUATING THE PERFORMANCE OF THE IN-TANK FLUIDIC SAMPLING SYSTEM

R.M. Boger

Prepared by

Lockheed Martin Hanford Corporation, Richland, WA 99352

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Abstract:

The PHMC will provide Low Activity Wastes (LAW) tank wastes for final treatment by a privatization contractor from double-shell feed tanks, 241-AP-102 and 241-AP-104. Concerns about the inability of the baseline "grab" sampling to provide large volume samples within time constraints has led to the development of a conceptual sampling system that would be deployed in a feed tank riser. This sampling system will provide large volume, representative samples without the environmental, radiation exposure, and sample volume impacts of the current base-line "grab" sampling method. This test plan identifies "proof-of-principle" cold tests for the conceptual sampling system using simulant materials. The need for additional testing was identified as a result of completing tests described in the revision 0 test plan document. Revision 1 outlines tests that will evaluate the performance and ability to provide samples that are representative of a tanks' content within a 95 percent confidence interval, to recovery from plugging, to sample supernatant wastes with over 25 wt% solids content, and to evaluate the impact of sampling at different heights within the feed tank. The test plan also identifies operating parameters that will optimize the performance of the sampling system.

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HNF-3042 REVISION 1

**TEST PLAN FOR EVALUATING THE
PERFORMANCE OF THE IN-TANK FLUIDIC
SAMPLING SYSTEM**

**Prepared for
Lockheed Martin Hanford Corporation
Characterization Engineering
by**

**F. R. REICH
J. L. SMALLEY**

COGEMA Engineering Corporation

February 1999

TABLE OF CONTENTS

1.0	INTRODUCTION	1
2.0	SCOPE	2
2.1	SAMPLING SYSTEM TESTING	2
3.0	PURPOSE AND OBJECTIVES	2
4.0	TEST BACKGROUND AND GUIDANCE	4
4.1	TEST SITE DESCRIPTION	4
4.1.1	Conceptual Test System	4
4.1.2	Prototype System Test Site	8
4.2	ANALYSIS AND MEASUREMENT METHODS/TECHNIQUES	8
4.3	VALIDATION OF TEST SIMULANT PROPERTIES	9
4.4	REFERENCE MATERIAL SAMPLING	9
4.5	MEASUREMENT STATISTICS AND ACCURACY/PRECISION	10
5.0	CONCEPTUAL SAMPLING SYSTEM TESTS	11
5.1	OPTIMIZED DESIGN AND OPERATION	12
5.1.1	OPTIMIZED SAMPLING CHANNEL OPERATING PARAMETERS	12
5.1.2	SAMPLING STATION TESTING FOR MATERIAL LOSS AND SAMPLE DELIVERY	14
5.2	REPRESENTATIVE WASTE SAMPLING	16
5.3	PLUGGED SAMPLE SYSTEM RECOVERY	19
5.4	TANK HEAD-SPACE GAS INJECTION	22
6.0	FUTURE SAMPLING SYSTEM TESTING	23
7.0	DOCUMENTATION	25
8.0	ORGANIZATIONAL RESPONSIBILITIES	25
9.0	QUALITY ASSURANCE	26
10.0	REFERENCES	26

LIST OF TABLES

Table 1. Particle Size Range For Test Simulants	18
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LIST OF FIGURES

Figure 1. Single Fluidic Sampling Channel with Bottle Sampling Station Shown Deployed in a Tank.	7
Figure A-1. Schematic Showing the Main Elements of a Fluidic RFD Based Pump.	A-3
Figure A-2. Three Phases of Pump Operation; Top to Bottom, Refill, Drive, and Vent	A-4
Figure A-3. Reverse Flow Diverter, RFD, Element	A-5
Figure A-4. Drive Phase	A-6
Figure A-5. Refill Phase.	A-6
Figure A-6. Jet Pump Pair Used to Produce Drives for the Three Modes of Operation for the Three Phases of the Pump's Cycle	A-7
Figure A.7. Cycle Control with Timer and Pressure Control Systems	A-10

APPENDIX

APPENDIX A - FLUIDIC BASED SAMPLING SYSTEM COMPONENT DESCRIPTION	A-2
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TEST PLAN FOR EVALUATING THE PERFORMANCE OF THE IN-TANK FLUIDIC SAMPLING SYSTEM

1.0 INTRODUCTION

The final treatment of Hanford's Low Activity Waste (LAW) tank wastes will be completed through a vitrification contract with British Nuclear Fuels Ltd. (BNFL). The Project Hanford Management Contract (PHMC) will supply supernatant waste materials from two Hanford Site double-shell staging/feed tanks. Currently 241-AP-102 and 241-AP-104 are planned to be used as the staging tanks. Prior to transfer to BNFL, the waste must conform to the envelope A, B, and C specifications (DOE 1997a and DOE 1997b) that have been negotiated in the BNFL vitrification contract. These feed envelopes are currently targeted to be dilute slurry/supernatant solutions with a maximum of two percent solids by weight.

The PHMC Team has identified critical risks that may result in the PHMC Team paying for idle facility time (HNF-2019, Rev. 0, 1998):

- Facility Processing Rates: BNFL may expect a higher rate of feed than the PHMC Team can initially deliver.
- Waste Feed is Out of Specification: Waste feed may not meet Phase 1 specifications and will require unplanned adjustments.
- Waste Certification Strategy Not Yet Defined: Analytical results may not be available in time to meet schedules."
- Waste Feed Specification Disputes: Waste feed, which the PHMC Team analysis shows as being in specification, may be unacceptable to BNFL based on the results of their analyses, thereby delaying waste feed delivery to the privatization contractors."
- Sample System Downtime: Unable to get the sample system operating due to the sampler being idle for periods of time. Must be able to make necessary repairs with the sampler in place, not having to remove the sampler from the tank riser

The current approved (baseline) for sampling tank liquids is "grab" sampling, which utilizes the "bottle on a string" technique. A major concern is that the length of time required to assure that a tank is well mixed and to extract representative samples may conflict with the schedule needs for staging batches of waste feed. Grab sampling cannot be performed while the mixer pump is operating and when there are adverse (lightning) weather conditions. Other concerns include the potential for non-representative sampling because of a sampling bias with materials from upper tank elevations and the manual operation requiring operator exposure to

radioactive wastes.

In order to address these concerns, a nested, fixed-depth fluidic sampling system is being developed by the AEA Technology Engineering Services Corporation (AEA) for the U.S. Department of Energy (DOE). The tasks to complete the nested, fixed-depth fluidic sampling system are in an Engineering Task Plan (Reich and Smalley 1998). This sampling system will quickly provide representative waste tank samples that can be used for laboratory analysis and/or be used to support an at-tank analysis system.

2.0 SCOPE

This test plan provides the guidance for the proof-of-principle testing of a conceptual sampling system being developed by AEA. This test plan document does not address the at-tank analysis system or its interface with the nested, fixed-depth sampling system. Tests, measurements, and simulant materials are identified that will be used to evaluate the operation and performance of the nested, fixed-depth sampling systems.

2.1 SAMPLING SYSTEM TESTING

The testing of a conceptual sampling system will be completed by AEA at their North Carolina facility using a single sampling channel that is constructed with representative materials, dimensions, piping runs, and bend radii that are expected to be used in the prototype nested, fixed-depth sampling system. The testing of a future prototype system will be completed at Hanford. Descriptions of "proof-of-principle" testing for the conceptual system tests are included in this document. The testing for the prototype system, which will include formal Acceptance Testing, will be defined in a future revisions of this test document and in the Acceptance Test document. This test plan will be revised subsequent to the final definition of the prototype system and prior to prototype testing.

3.0 PURPOSE AND OBJECTIVES

The purpose of these tests is to evaluate and demonstrate the proof-of-principle of the sampling system that is being developed for deployment in the PHMC Team's 241-AP-102 and 241-AP-104 waste staging tanks. The object of the testing is to:

- demonstrate that the sampling system can extract waste material that is representative of the waste material within the feed tank. This testing will evaluate the sampling performance with simulants that represent chemical and

physical properties of the supernatant tank waste material anticipated in the Phase 1B privatization contract. The tests address waste materials, waste levels, system dimensional impacts, and sample container filling hardware. (Note: this testing will not address the radiological aspects of the proposed sampling technique.)

- identify and verify the potential impacts of other in-tank systems, such as the mixer pump.
- show that the nested, fixed-depth sampling system can provide representative, large volumes (10-15 liters) of waste samples within a time frame that supports the sample information and waste sample volume needs of the Privatization Contract.

The waste sampling objectives to support the vitrification contract include the following:

- Extract waste samples that are representative of the waste material in the PHMC Team's feed source and/or staging tanks (it is desired that these samples be representative of the tanks content as required in the BNFL privatization contract).
- Obtain representative waste samples from full and partially full tanks.
- Quickly providing relatively large volumes (two to 15 liters within an 8 hour time period) of sample waste material, with minimal impact from weather conditions.
- Sample while other in-tank hardware is operating, including mixer pumps, decanting operations, etc., without impact to the sampling performance.
- Allow safe deployment in a tank riser and meeting tank interface (dimensions, loading, etc.), environmental, safety, and regulatory criteria.
- Have an expected operational longevity that approaches the anticipated 20-year time span of the privatization contract.
- Use a 500-ml sampling bottle as the sampling container.
- Interface with the Site's cask shipping systems (Steel Pig and/or "Safe-Send"TM* cask systems).
- Ability to make necessary repairs to the sampler and make it operational without having to remove it from the tank riser.
- The purge gas exhausted from the sampler into the tank dome space will not affect the existing tank exhaust system.
- The material of construction for all sampler system components shall be compatible with the tank waste and not interfere with the sample analysis.

*Safe-Send is a trademark of 3M Company

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4.0 TEST BACKGROUND AND GUIDANCE

Appendix A provides a description of the basic principles and components for the current sampling system concept being developed by AEAT. This description is representative, for the most part, of the sampling system used by AEAT during conceptual testing. However, conceptual testing may also employ other sample bottle filling techniques differing from that described in Appendix A, sections A.3.6 and shown in Figure A-8.

The test system and tests described below shall comply with the criteria in the Level 2 Component Specification document *Preliminary Level-2 Specification for the Nested, Fixed-Depth Sampling System*, HNF-3483, Rev. 0.

4.1 TEST SITE DESCRIPTION

The testing of the conceptual single channel, sampling system will be completed at AEA Technology's Charlotte, North Carolina, facility.

The initial acceptance testing of the prototype system will be completed at the vendor's site prior to shipment to Hanford. A cold test facility will be set up at Hanford that can support the testing of a full-scale/length sampling system, the development of operating procedures, and operator training. After the system is received and installed at the Hanford site cold test facility, performance and Acceptance Testing will be completed.

4.1.1 Conceptual Test System

Testing will be completed with sampling hardware whose design has been optimized for use with Hanford's tanks and tank waste. The sampling channels used in this testing will be representative of the sampling channel design that will be in the prototype nested, fixed-depth sampling system. This will include, but not be limited to:

- representative surface roughness on all surfaces making contact with the simulant material, including the inside of the piping, charge vessel, and reverse flow diverter (RFD) components
- representative internal dimensions (and shapes) for all components, including inside diameters of all piping, internal orifices of the RFD, volume and dimensions of the charge vessel, the shape, size (dimensions) of the pneumatic driver and its connection to the charge vessel, and the configuration and dimensional parameters of the sample bottle filling station, including the sample container filling hardware,.
- representative piping bend radii and lengths for all piping bends and straight piping runs.

The test hardware that makes contact with the simulants and has critical features that impact waste flow, shall be fabricated from stainless steel or of materials that are representative of the material anticipated to be used in the prototype nested, fixed-depth sampling system. The test hardware will also be fabricated with representative dimensions (internal and external), volumes, bends, and piping runs of that are expected to be used in the nested, fixed-depth sampling system design.

The initial tests will identify a range of optimum operating parameters for the eight sampling channels planned with the nested, fixed-depth sampling system. This will include, but not be limited to:

- drive pressures
- refill vacuum levels
- operational cycle (drive time, refill time, etc.).

These optimized parameters will be identified for each test setup and will be used to complete the testing.

One example of a sampling channel for a nested, fixed-depth sampling system with reverse flow diverter (RFD), charge vessel, bottle sampling station, and jet pump is shown in Figure 1 (Note: This shows the bottle filling configuration depicted in Figure A-8). This shows a single sampling channel as it might be installed in a large waste tank. In the setup of the mockup test channels, the use of short (approximately 10 ft long) sections of pipe with bolt flanges on their ends is recommended for the piping runs between the RFD and the sampling station. To change the sample "lift" height (24 and 57 ft heights are expected in this testing, as a minimum), the number of tubing sections in the mockup will be changed, but all the other sampling channel hardware will remain unchanged. The lift height is the distance between the RFD inlet and the highest simulant position in the sampling station. The vacuum and air pressure needed to operate the sampling channel will be supplied by the jet pump (pneumatic driver), shown above the charge vessel. The length of piping between the jet pump and the charge vessel will also be changed for each "lift" height.

The sampling channel will be mounted in a supply tank that has sufficient simulant volume such that the simulant parameters (solids content and particulate distribution) will not be significantly changed during sampling (depth of the simulant will not be significantly changed during sampling). A supply tank capacity of approximately 50-gallon capacity is recommended to ensure that sampling does not deplete tank volume by more than 5-10 percent. For future system testing, under multiple waste depth conditions, the supply tank dimensions may have to be changed. The tank will also include a mechanism to keep the simulant mixed during testing (mixing with no impact to the performance of the sampling system) and ensure simulant homogeneity during testing. An impeller mixer may work with a short tank, but a closed loop pumping system may be needed for the larger supply tank. The completeness of mixing in the

supply tank should be verified by taking replicate grab samples.

The supply tanks, used in the testing, will be designed to allow grab samples to be taken at approximately the same time that a bottle sample is taken. The grab samples will provide the reference materials for assessing the performance of the sampling channel. In addition the simulant effluent stream that is being returned to the supply tank, after passing through the sampling station, will also be “grab” sampled. These “grab” samples will be used to separate the pumping performance of the sampling channel separate from the sampling performance of the sample bottle filling system.

Figure 1. Single Fluidic Sampling Channel with Bottle Sampling Station Shown Deployed in a Tank.

4.1.2 Prototype System Test Site

Details of the test site for the cold testing of the full-scale/length prototype sampling system at Hanford have not been developed. Work in FY 1999 will identify facility features, required to complete testing and potential locations at Hanford that can support these features. The test facility will be designed to support the completion of all the testing, including needed life-time and operational performance tests described below.

4.2 ANALYSIS AND MEASUREMENT METHODS/TECHNIQUES

All measurements will be made using calibrated sensors and instrumentation. The calibration data for the sensor and/or measurement systems will be included with the measurement data. If calibration data is not available, then additional testing that establishes the performance will be completed. This additional testing must be completed such that the resulting data satisfies rule-of-thumb accuracy criteria for measurement systems which is that the accuracy of the measurement system must be at least an order of magnitude better than that required by a test measurement. In addition, sensors and measurement systems shall be selected such that the expected or anticipated measurement value will fall within the central 75% of the sensor or measurement systems sensing/readout range.

The measurement of references, standards, or "blanks" will be used to establish measurement performance before and after completing a measurement campaign. It is recommended that measurements made on the materials in the grab samples and bottle samples be completed using the following:

Particle size distribution -	This will be measured by microscopic examination as per ASTM F312 or by sieve based particle size analysis as per ASTM C92-95. (See also ASTM E276-93 and ASTM D4513-97 for additional information on sieve based particle sizing. In addition, ASTM E1638-94 provides a summary of terminology for sieve based analysis.)
Solids wt% content -	This will be measured by filtration and evaporation at 105 °C per EPA 160.3.
Viscosity -	Viscosity will be measured using rotating bobbin and cup apparatus. Contraves, Haake, or Brookfield apparatus may be used dependent upon shear range.

4.3 VALIDATION OF TEST SIMULANT PROPERTIES

The properties of the simulants will be measured (characterized) and validated for each of the system tests using two independent methods.

- Accurate measurements (to 0.1 percent) shall be made for the simulant's constituents (volume or weight of each constituent, particulate distributions, etc.) during the makeup of a simulant. This simulant makeup data will be used to assess the potential presence and impact of other, non-sampling system, error sources (non-sampling system error sources, such as incomplete mixing in the simulant vessels). The simulant makeup and the reference sample data sets will provide validation data that the test simulant properties are in conformance with the simulant specification (Rinker 1998a).
- Samples taken at the inlet of the sampling channel during operation of the sampling system will be used as simulant property references to compare with samples taken from the sampling station and samples from the effluent exiting the sampling station. The grab samples at the inlet of the sampling channel will be considered the baseline or reference for assessing the sampling performance of the sampling system. The reference samples shall be taken very close to the inlet of the RFD and within the same time interval that a bottle sampling is being taken in the sampling station. This should minimize the potential for interfering errors from other non-sampling system sources (e.g., lack of homogenous mixing in the vessels holding the simulants).

The performance of the sampling system will be made comparing the bottle samples and the sampling station effluent samples with the simulant reference samples. The same analyses methods and techniques will be used for all samples. The required measurements in this test plan specifically identify particulate size distribution and wt% solids as the two main parameters for measuring the performance of the sampling system. Other physical property measurements may be necessary to ensure that a simulant meets specifications.

4.4 REFERENCE MATERIAL SAMPLING

Reference samples, when required, will be obtained using a grab sampling process. The ASTM standard, *Standard Practice for Sampling Industrial Chemicals (ASTM E300-92)*, provides guidance for this grab sampling, which is the current Hanford baseline method for obtaining liquid and slurry tank waste samples. Care and diligence should be used in the acquisition of the grab samples. Section 10.0 of the ASTM standard covers the sampling of "Simple Liquids" while Section 35.0 covers "Slurry Sampling." The practices, procedures, limitations and cautions, etc., described in these sections should be used as guidance in the planning and execution of grab sampling. The grab sampling should use a 100-500-ml size

sample bottle/flask with other recommendations and physical characteristics as described in ASTM E300-92 (mouth size, total sample volume, etc.).

4.5 MEASUREMENT STATISTICS AND ACCURACY/PRECISION

The performance objective of the sampling system is to provide samples that have chemical and physical properties that are within $\pm 5.0\%$ of the tank waste, with a 95 percent confidence level. The sampled waste reference will be the material directly adjacent to a sampling channel inlet (this reference material will be obtained by careful grab sampling).

The following definitions will apply in this testing work:

- **Sensitivity:** This is the relationship between an instrument's output and the parameter it is responding to. It is used to specify the minimum detectable change in a parameter that the instrument will respond to (most often this is the signal-to-noise ratio of the instrument).
- **Accuracy:** This is an indication of how close a measured value (or a group of measured values) is to the "true" value or an accepted standard. How close together the group of measurements are with respect to each other is not an issue. With a group of repeated measurements, there is high accuracy if the mean value of the measurement group is very close to the "true" value. However, there can be a significant span (see definition below) between the individual measurement values.
- **Precision:** This is an indication of how repeatable a measurement is (the spread of the grouping of repeated measurements). Precision is different from accuracy in that it is defined without reference to what the "true" value or accepted standard value may be. For a group of repeated measurements, if the span of the measured values is relatively small (tightly grouped measurements), the measurements would have high precision. If there is a wide span between the values, the precision will be low. Precision can be expressed in a number of ways. One of the most common is the Standard Deviation from the mean value.
- **Selectivity:** This is the ability to discriminate between a parameter of interest and possible interferences. Selectivity usually has meaning in the sensing of chemical species where there can be interferences from other chemicals.
- **Range:** This is defined as the interval over which a parameter is measured--the lowest and highest values of the parameter.

- **Span:** This the width of the range; the difference between the upper- and lower-range values.
- **95% Confidence Interval:** This is the measurement interval (or delta), usually on either side of the sample mean, within which we will find 95% of the members of the sample. In other terms, this is the interval around the sample mean in which there is a 95% probability that a member of a sample will be found.

In comparing the mean values of two sets of measurements, such as the grab samples with the bottle samples, there are two factors that impact the comparison; the standard deviation of the two populations and the number of samples in each population. The FY 1998 AEA test data indicated that both the “grab” and bottle samples had a standard deviation of around 10%. The Student’s t-distribution indicates that if we have two sample populations or measurements that have been both sampled 18 times and each has a standard deviation of 10%, then statistically the mean values of the two populations or measurements can be considered to be indistinguishable, within a 95% confidence level, if the mean values are within +/- 10% of each other. Another explanation of this is that if the tails of the two sampled population distributions overlap, such that their means are within 10% of each other, then we are unable to statistically differentiate between the two populations with a 95% confidence level. Therefore, if we wish to show that the means of the “grab” reference samples and the bottle samples (or the effluent samples) are within +/- 10% of each other, with a 95% confidence level, we must take at least 18 individual samples of each population where each population has a standard deviation of 10%.

The total number of samples at three sample points, identified above, will be 48 samples. Each of the 48 samples must be individually analyzed to provide the measurement data to support a statistically based analysis. If the standard deviation is less than 10% for each sample population (“grab”, bottle, and effluent samples), then the number of samples needed to statistically compare the sampling performance can be reduced. The Student’s t-distribution shall be used to identify the reduced number of samples.

5.0 CONCEPTUAL SAMPLING SYSTEM TESTS

The test descriptions below address the testing of a conceptual sampling system that is being designed by AEAT. Additional testing that will be required, such as the testing of the prototype system, will be addressed in future revisions of this test plan. The test system and tests described below shall comply with the criteria in the Level 2 Component Specification document *Preliminary Level-2 Specification for the Nested, Fixed-Depth Sampling System* (HNF-3483, Rev. 0).

Prior to beginning the conceptual system testing, it is expected that work to optimize the components of the conceptual sampling system shall have been completed. This optimized design data will then be used to construct the conceptual sampling system and test setups. The conceptual sampling system test results will be used to:

- validate the sampling performance of the RFD based sampling concept and
- provide data that can be used in the design of the prototype full-scale nested, fixed-depth sampling system.

Testing will be completed that identifies the optimized operating parameters for each of the sample lift heights (24 and 57 ft lift heights) and that provides data for validating the performance of the conceptual system with various simulants and under various operating conditions. Lift height is the distance between the RFD inlet and highest simulant point in the sampling station.

5.1 OPTIMIZED DESIGN AND OPERATION

The test system, used for testing in FY 1998 by AEA, used some components and hardware that would not be used in a prototype (full-scale) sampling system. As indicated in section 4.1.1 above, there are major design issues that concern the internal and external dimensions, materials (surface roughness), and shapes of piping and components, as well as issues with the technique and configuration of a satisfactory bottle filling technique. The conceptual system, used to complete the testing below, will be as close to a final sampling channel design expected for a prototype system as permissible at this time, with the possible exception of the sample bottle filling hardware.

5.1.1 OPTIMIZED SAMPLING CHANNEL OPERATING PARAMETERS

These tests identify and demonstrate the optimum operating parameters for the conceptual sampling system. The tests are to be completed with setups for 24 ft and 57 ft sample height lifts.

Test Objective:

Determine and demonstrate optimized pumping cycle parameters for the conceptual sampling system for 24 and 57 ft height sample lifts. The goal is to deliver the required sample volume within the shortest time period, using a minimum of pneumatic drive pressures, flow, and volume. Using these optimized parameters, the sampling performance then will be demonstrated and the operating parameters documented. The optimized sampling parameters must be within performance limits established by other optimization tests (less than the pressure levels required to produce sampler material

escaping within the bottle sampling station when no bottle is present).

Test Setup:

The setup of the sampling channel will be according to the description in Section 4.1.1 and based on the FY 1998 tests completed by AEA. The sampling channel for these tests shall use optimized components and modules, including pneumatic drive, sampling channel, and sampling station hardware, that will be the basis for the prototype sampling system design. The sampling channel shall have components constructed with representative materials (stainless steel) having representative surface roughness, representative dimensions (internal and external), volumes, bends, and piping runs of that expected to be used in the prototype sampling system design. The test setup, at a minimum, will provide for testing with lift heights of 24 and 57 ft.

The supply tank will be setup according to the description in Section 4.1.1. Specifically, the supply tank will be large enough so that sampling will not adversely impact the simulant solids content and particulate homogeneity and will have a method to maintain the homogeneity of the simulant. The tank shall be large enough so that the extraction of samples will not deplete the simulant volume (and/or height of the simulant in the tank) by more than 5-10%. The supply tank will include a method (mechanical) to mix the simulant during testing (no impact to the sampling system) and ensure material homogeneity during the testing. The supply tank will also support the acquisition of grab, reference samples directly adjacent to the sampling system RFD inlet during sample acquisition.

Test Simulant:

The simulants that will be used in this testing will be a EPK Pulverized Kaolin clay (from Feldspar Corporation, Edgar, Florida) and water slurry with a specific gravity greater than or equal to 1.4. The testing, completed in FY 1998, indicated that this simulant required higher drive pressures than pure water for optimum sampling performance. The Kaolin content to achieve a 1.4 specific gravity is expected to range from a 25 wt% to 35 wt% mixture. As an example, a 25 wt% Kaolin/water slurry will have a density of about 1.18 g/mL and a yield stress of about 2.0 Pa. Although this is a relatively small yield stress, the tank waste materials are likely to have even smaller yield stresses. The 1.4 specific gravity Kaolin/water slurry is expected to represent a worst-case scenario due to its material adherence to the surfaces of the sampling system hardware, high specific gravity, and high viscosity. The solids concentration and yield stress of an actual tank waste sludge layer are expected to be much greater than those offered by this 25 wt% water/Kaolin slurry simulant. A 45 wt% water/Kaolin slurry will have a yield stress of approximately 60 Pa (in the range of a concrete slurry), which is similar to that measured in tank sludge samples that have been recently disturbed (such as the sluicing/pumping actions). More details on Kaolin/water slurries can be found in

Powell and Rinker 1998a and 1998b.

After completing the setup of the system and the filling of the sample vessel, the system should be operated until steady-state conditions are reached prior to initiating testing.

Test Measurements:

The pneumatic drive parameters for the “optimum” sampling system will be determined and measured. These include, for a typical drive cycle:

- drive pressure
- suction pressure
- drive time
- suction time

These parameters shall be optimized around the two goals of delivering a maximum amount of representative sample material to the sample bottle in the shortest time period for lift heights of 24 and 57 ft. The optimum pumping cycle parameters will then be used to demonstrate the filling of a 500 ml sample bottle, recording the number of cycles required to fill the bottle to 95% of its fill capacity. It is also desired that the approximate rate of filling be measured as the bottle is filled. This can be done by using a bottle with volume graduations and recording the number of pump cycles to fill to each of these levels (this can be a single, continuous test). These volumes will then be plotted against the number of pumping cycles.

Performance Criteria:

Demonstrate that a 500 ml sample bottle can be filled to 95% of capacity (to the needle level in the bottle) in 30 minutes or less time. The jet pump flow requirements to achieve this performance level shall not exceed the following upper limits:

- Peak flow rate into the tank exhaust system of less than 100 SCFM (Standard Cubic Feet per Minute)
- An average flow rate less than 40 SCFM under all sampling system operating conditions.

5.1.2 SAMPLING STATION TESTING FOR MATERIAL LOSS AND SAMPLE DELIVERY

The design of the sampling station and the bottle filling hardware are some of the critical parameters for an optimized sampling channel design. This test evaluates the performance of the sampling station hardware, which normally fills a sample bottle, when no bottle is present and the channel is being driven with the “wrong” (higher) drive parameters. The sampling channel will be the optimized sampling channel discussed in Section 4.1.1 above. The test conditions

will be based on the operating conditions that were identified in Section 5.11 above for producing an optimized sampling performance. .

Test Objectives:

Demonstrate that there is no material escaping from the bottling filling hardware when there is no sample bottle present. The drive conditions of this test shall cover the full range of drive pressures expected to be used for any of the sampling heights that will be used in the feed tank (elevation of the inlet within the feed tank). Currently these range from 24 to 57 ft lifts. This test assures that there will be no material escape in the sampling station if "wrong" drive pressures (pressures may be allowed for other channels or other purposes, such as unplugging) are used inadvertently on a sampling channel when no sample bottle is present.

Test Setup:

The setup of the sampling channel and the drive system shall be according to the test setup criteria in Section 4.1.1 above. The system operation shall use the operating results from the system optimization tests in Section 5.1. above. The test setup, at a minimum, will provide for testing with sample channel lift heights of 24 and 57 ft. The sampling channel will have components constructed with representative materials (stainless steel) having representative surface roughness, representative dimensions (internal and external), volumes, bends, and piping runs of what is currently expected for the prototype sampling system. The sampling station hardware will be based on the optimized fluidic design that produces an optimum sampling performance with no material escape/loss when no sample bottle is present.

The supply tank will also be setup according to the description in Section 4.1.1. Specifically, the supply tank will be large enough so that sampling will not impact the homogeneity of the simulant and will not deplete the total volume (and/or simulant level) by more than 5-10%. The tank will include a method (mechanical) to mix the simulant during testing (no impact to the sampling system) and ensure material homogeneity during the testing. The supply tank will also support the acquisition of grab, reference samples directly adjacent to the sampling system RFD inlet during sample acquisition.

Test Simulant:

The simulant for this test will be water with no solid or chemical additives present. Water should be a "worst case" simulant in that its viscosity and density are less than that for the Kaolin/water clay slurry used to establish the optimized, sampling system operating parameters. The water simulant should be more prone to material escape with the application of the wrong drive parameters.

Test Measurements:

In the FY 1998 testing, AEA demonstrated that the larger or higher sample lifts (57 ft lift) would require higher pressures for optimum sample delivery from the sampling station than the lower sample lifts (24 ft lift). The performance of the sampling station will be tested and demonstrated using the following drive pressure and lift height ranges:

- Test for escaping materials in the sampling station with sampling channels setup for lift heights of 24 and 57 ft.
- Drive Pressure Range:
The drive pressure will cover a range defined between a minimum and a maximum level, defined as:
 - Minimum - the minimum drive pressure will be less than or equal to the optimum drive pressure that is needed for sample delivery for the 24ft lift height setup
 - Maximum - the maximum drive pressure will be greater than or equal to 2 times the highest drive pressure required to deliver an optimum sample for the 57 ft lift height setup.

It is recommended that the drive pressure be changed in increments of 10% of this pressure range and the performance of the sampling station recorded. The parameters to be recorded, as a minimum will include:

- drive pressure
- vacuum level
- drive time
- vacuum time
- visual observation of material escaping or not escaping

Performance Criteria:

Minimum performance criteria:

No material escape within the sampling station, with no sample bottle present, when the highest drive pressure is applied to the sample channel.

Desired performance criteria:

No material loss within the sampling station, with no sample bottle present, when 2 times the highest drive pressure is applied to the sample channel.

5.2 REPRESENTATIVE WASTE SAMPLING

The feed tank sampling system is being developed as a replacement sampling method for the current baseline "grab" sampling method. This sampling system will be used to quickly provide waste samples that can be used for laboratory analysis as required by the privatization contract and/or be used to support an at-tank analysis system. The samples must therefore be

representative of the waste in the feed tank.

The tank wastes will contain both liquids and solids. The chemical aspects of the wastes are not expected to have an impact on the performance of this sampling system. However, there will be sampling related impacts from the solids content. Therefore, the waste sampling tests below are concerned with solid bearing simulants having a range of particulate size distributions.

Test Objective:

Verify that the sampling system can extract waste samples that have solids content and particulate distributions that are representative of the waste directly adjacent to the inlet of a sampling channel.

Test Setup:

The sampling system will be an optimized sampling channel setup according to the description in Section 4.1.1 and with the optimized drive parameters as determined from section 5.1.1 testing. The sampling channel will have components constructed with representative materials (stainless steel) having representative surface roughness, representative dimensions (internal and external), volumes, bends, and piping runs of that is currently expected for the final nested, fixed-depth sampling system design. The sampling channel hardware will be the optimized design, with optimized drive parameters, that shall be used in the future prototype sampling system. The test setup, at a minimum, will provide for sample acquisition with the sampling lift heights of 24 and 57 ft.

The supply tank will be setup according to the description in Section 4.1.1. Specifically, the supply tank will be of sufficient size (volume) that the removal of all samples, during a test, will not adversely impact the homogeneity of the simulant remaining in the supply tank. The sampling shall not deplete the total volume (and/or simulant depth) by more than 5-10%. The supply tank will include a mechanical method to mix the simulant during testing (mixing with no impact to the performance of the sampling system) and ensure material homogeneity during the testing. The supply vessel will also be large enough to complete grab sampling (reference material) adjacent to the sample channel inlet without impacting the homogeneity of the simulant or the performance of the sampling channel.

Test Simulants:

Two sand/water slurry simulants will be used in this test; a 1-2 wt% sand/water slurry and a 10-15 wt% sand/water slurry. The particle size distributions of the sand shall be adjusted to be consistent with the high end of that allowed by the expected particle size ranges shown in Table 1. Roughly 1 wt% of the particles will be in the 500 to 4000 μm

range, 5 wt% will be in the 50 to 500 μm range, and 94 wt% will be in the less-than-50 μm range (Rinker 1998a). Since the water will have a lower density and viscosity than the liquid expected in the tank wastes, the sand/water simulants should provide worst case or conservative tests of the performance of the sampling system (the sand will be more susceptible to settling and particulate sifting than the solids in the tank wastes). A more detailed description and justification of these simulants is included in Rinker 1998a and a summary of tank waste chemical and physical properties can be found in Rinker 1998b.

Test Measurements and Analysis:

After completing the system setup and filling the sample vessel with simulant, the sampling system will be operated until a steady-state condition is reached where there is a consistent and homogeneous flow of simulant through the sampling channel hardware, including the sampling station. Grab samples will be taken from two places in the sampling system; adjacent to the sample channel inlet and from the simulant effluent being returned from the sampling station to the supply tank. The samples are not to be blended or combined, but are to be maintained as individual samples and analyzed as individual samples. This means that a new/clean sample bottle is to be used for each grab sample and for each bottle sample. The number of samples needed to support a statistically based performance assessment is identified in Section 4.5 above.

A comparison of the grab samples, taken from the effluent being returned to the supply tank, with the grab samples taken adjacent to the RFD inlet will provide data on the ability of the system to "pump" the simulant. A comparison of the bottle samples taken in the sampling station with the reference grab samples will provide data on the sampling performance of the sampling station. This test will be completed for sampling systems setup for 24 and 57 ft lift heights.

Each sample (bottle and grab samples) will be analyzed for total solids content and for particulate size distribution. Statistical methods will be used to calculate the average and standard deviation of the solids content for each sample group. The ability to extract representative samples will be assessed by comparing the averages and the standard deviations. This sample analysis will be completed, as a minimum, for a 24 ft and a 57 ft lift height.

Table 1. Particle Size Range For Test Simulants

Particle Size Range (microns)	Allowable Weight Percent Solids in Size Range
> 4000 μm	0 wt. %

500 to 4000 μm	< 1 wt. %
50 to 500 μm	< 5 wt. %
< 50 μm	> $\approx$ 94 wt. %

Performance Criteria:

The sampling system will be considered able to “pump” representative waste samples if:

- the mean values of the total solids content of the samples from the sample channel return effluent are within $\pm 5\%$ of the inlet grab sample mean values, with a 95% confidence level, and the standard deviation is approximately equal to that of the inlet grab sample's standard deviation.
- the particle distributions of the samples from the sample channel return effluent are within $\pm 5\%$ of the particle distributions of the inlet grab samples with a 95% confidence level.

The sampling station will be considered to be capable of extracting representative samples if:

- the mean values of the total solids content from the bottle samples are within $\pm 5\%$ of the mean value of the samples from the sample channel return effluent, with a 95% confidence level, and their standard deviations are approximately equal.
- the particulate distributions from the bottle samples are within $\pm 5\%$ of the particulate distributions from the samples from the sample channel return effluent, within a 95% confidence level.

5.3 PLUGGED SAMPLE SYSTEM RECOVERY

This test will demonstrate that the sampling system can recover from credible stoppages or plugged conditions caused by the tank wastes.

Although the physical and chemical properties for waste envelopes A, B, and C are limited to a relatively narrow range (characteristic of supernatant wastes with a fairly dilute solids content - less than 10 wt%), the source tank wastes from which these supernatant wastes will be extracted will have a wider range of properties. In addition, to bring some of the waste feeds into compliance with the A, B, and C envelopes, dilution and settling may be required. During operation, the sampling hardware could become plugged either from the settling of suspended particles or from the precipitation of saturated solutions. To support timely delivery of waste batches to the privatization contractor, the sampling system must be capable of

recovering from a stoppage or plugged condition in a reasonable time and continuing sampling, producing representative waste samples.

Test Objective:

Demonstrate that the sampling system can recover, either with or without auxiliary flushing capabilities, from credible stoppages or plugged conditions caused by the tank wastes and produce representative waste samples after recovery.

Test Simulant:

The test simulant for this unplugging testing will be a 15 wt% Min-U-Sil 30 sand/water slurry (Min-U-Sil 30 Silica Flour with 30 micron particulates). When completely settled, this should form a settled bed of particles with a high mechanical strength and low permeability.

Test Setup:

The sampling system will be an optimized sampling channel setup according to the description in Section 4.1.1 and with the optimized components described in section 5.1.1. and optimized operating parameters as identified in Section 5.1.2 above. It is critical that the setup be constructed with representative materials (stainless steel) having representative surface roughness and have components with representative dimensions (internal and external), volumes, bends, and piping runs that are expected to be in the prototype nested, fixed-depth sampling system design. The test setup will initially provide for sample acquisition with the sampling station for a lift height of 57ft above the RFD inlet. Other heights (24 and 42 ft) may also be tested if lift height is a factor in plugging recovery.

Prior testing shall have identified if auxiliary flushing capabilities are required to recover from plugging. If required, this auxiliary flushing hardware shall be installed and tested prior initiating this unplugging test. This testing will demonstrate the unplugging potential with and without the auxiliary flushing.

The supply tank will be setup according to the description in Section 4.1.1. This can be a low simulant depth tank as the plugging can be setup by filling the sampler with simulant and letting it settle. The simulant makeup tank will include a mechanical method to ensure sample material and solid content homogeneity during setup and testing.

Waste Plug Setup:

To setup the plug, the inlet of the sampling channel will be plugged and the sampling channel filled with simulant to predetermined levels. The simulant shall be allowed to settle in the sampling system for at least 48 hours (or for a time period that

will ensure that over 80% of the solids have settled). About 80% of the solids mass should be settled out and a plug formed within this time interval. The mixing system in the supply tank should then be operated until a steady-state condition is achieved (30-60 minutes).

Unplugging Tests:

Unplugging operations should commence at the end of the settling time. The sampling channel will be placed in a supply tank with a simulant having the same solids content as used to create the plug. The mixer pump in the supply tank shall be started and run until a steady-state condition is reached. The sample channel inlet will be unplugged and the sampling channel operated. To evaluate un-assisted unplugging, the sampling system should then be run until the plug is breached. The time interval, number of pumping cycles, and the system operating parameters required to unplug the system should be recorded. The unplugging operation should continue until the simulant flow, established prior to plugging, is restored.

If the plug is breached, then the plug will have to be re-installed using the steps above to test the auxiliary flushing system. If the plug has not been breached, then testing with the auxiliary flushing system can begin immediately. The flushing system should be operated until plug breaching is achieved and the simulant flow rates that existed prior to plugging are restored.

Test Measurements and Analysis:

The operating parameters of the sampling system, number of pump cycles, flushing pressure and the flushing fluid flow rate, time to achieve plug breaching, sample channel simulant flow rate before installing a plug and after unplugging, and the time to restore simulant flow to the previous unplugged level shall all be recorded. Grab samples can be taken adjacent to the RFD inlet to assure continuity of the simulant properties (solids wt% content, viscosity, density, etc.).

Performance Criteria:

The sampling system, with or without the auxiliary flushing system, must be capable of recovering from a plugged condition within an 8 hour time period. Unplugging will be considered complete when the simulant flow rate through the sampling channel is restored to levels observed prior to plugging within +/-5% at a 95 % confidence level. The flow rate is defined as that needed through the sampling station to enable the filling of a 500 ml bottle within a 30 minute period.

5.4 TANK HEAD-SPACE GAS INJECTION

The exhaust gas from the sampling systems pneumatic drive (jet pump) is expected to be ported into the head-space of the feed tank in which the sampling system is installed. The pressure in the tank head-space is normally maintained at a negative level as a protection against potential contamination releases. The gas ported into the feed tank head-space cannot raise the tank's head-space pressure to an unacceptable level that compromises the exhaust system function.

The gas pressure and vacuum levels required to drive a sampling channel may be unique for each sampler channel and may also may be a function of the waste depth. In addition, the pressure and vacuum levels to unplug a channel may be higher than these drive levels. Therefore, this test will use the highest pneumatic flow rates and volumes that would be used with the sampling channels, under any operating or recovery condition (unplugging operations could use different vacuum and pressure levels).

Test Objective:

Determine the pressure, flow rate and volume of gas that is vented from the pneumatic drive system (jet pump) during a sampling system pumping operating cycle. The pressure, flow, and volume measurements will cover the range (specifically maximum levels) of operating parameters that will be used with the nested, fixed-depth sampling system, including the optimized parameters identified in 5.1.2. This test may be run at the same time as the testing in 5.1.2 is completed.

Test Setup:

The setup of the sampling channel will be according to the description in Section 4.1.1 above. The testing must include the impacts of restrictions and back pressure from the sampling hardware. Therefore, the sampling channel will have components constructed with representative materials (stainless steel), having representative surface roughness, representative dimensions (internal and external), volumes, bends, and piping runs of that is currently expected for the final nested, fixed-depth sampling system design. Testing will be completed with a 57ft sample lift height setup. The operating parameters of the pneumatic drive will range over those identified in Section 5.1.1 along with other operational functions and the drive levels that are required for unplugging. The supply tank should also be setup according to the description in Section 4.1.1. and the liquid level maintained just above (about 1 ft) the RFD inlet.

Test Simulant:

The simulants that will be used in this testing will be the same EPK Pulverized Kaolin clay (from Feldspar Corporation, Edgar, Florida) and water slurry with a specific gravity greater than or equal to 1.4 that was used for the testing in 5.1.1 above. The

Kaolin content to achieve a 1.4 specific gravity is expected to range from a 25 wt% to 35 wt% mixture. As an example, a 25 wt% Kaolin/water slurry will have a density of about 1.18 g/mL and a yield stress of about 2.0 Pa. Although this is a relatively small yield stress, the tank waste materials are likely to have even smaller yield stresses. The 1.4 specific gravity Kaolin/water slurry is expected to represent a worst-case scenario with its high adherence to piping surfaces, high specific gravity and high viscosity. The solids concentration and yield stress of an actual tank waste sludge layer are expected to be much greater than those offered by this 25 wt% water/Kaolin slurry simulant. A 45 wt% water/Kaolin slurry will have a yield stress of approximately 60 Pa (in the range of a concrete slurry), which is similar to that measured in tank sludge samples that have been recently disturbed (such as the sluicing/pumping actions). More details on Kaolin/water slurries can be found in Powell and Rinker 1998a and 1998b.

After completing the setup of the system and filling of the sample vessel, the system should be operated until steady-state conditions are reached (30-60 minute pumping time period with the supply tank mixer pump operating) prior to initiating testing.

Test Measurements:

Measure the pneumatic drive effluent pressure, flow rate, and volume required to produce the range of drive and suction pressures to operate the sampling system at its optimum levels determined in Section 5.1.2 and at other pneumatic drive operating settings that may be used for other operations such as unplugging of the sampling channel. The sensors shall have an accuracy capability that is better than or equal to 1% of the measure values.

Performance Criteria:

Demonstrate that the peak flow rate from the pneumatic drive is less than 100 SCFM (Standard Cubic Feet per Minute) and an average flow rate that is less than 40 SCFM under all sampling system operating conditions. This includes pneumatic drive conditions for normal sampling operations and any off-normal operations, such as unplugging. It also includes optimized operating conditions (pressures, vacuums, and etc. identified as needed to produce optimized sampling with sampling channels), drives needed for the range of sample lifts (24 to 57 ft) and drives used for the full range of the simulant/waste to be pumped with the sampling system (especially the Kaolin clay/water simulant(s)).

6.0 FUTURE SAMPLING SYSTEM TESTING

Additional tests will be needed for the prototype system and with any alternative system

designs and options that will be used with the sampling system. This will include, but not be limited to, potential options for sample bottle filling that may be needed to fulfill RCRA requirements and the future at-tank analysis system interface. Some of the prototype tests will also include, but will not be limited to:

- Testing the impact of pressure head from waste depths of 1 to 35 ft on the sampling system performance.
- Testing the potential impact of the mixer pump on the sampling system performance.

Deployment testing will be needed that demonstrates the following:

- The diameter of the in-tank sampling system hardware is within acceptable dimensions for the selected tank risers. The current limit is 10.5 inches maximum outside diameter for the sampling system.
- The sampling system can be raised from a horizontal position to a vertical position (ready for riser insertion) and installed in the riser using cranes.
- Deployment in the riser can be completed without damage to the riser or to other tank hardware.
- The static load from the deployed system that must be supported by the tank is within a tank's acceptable limits for the selected riser and tank dome. This includes the sampling system weight and the weight of any entrained wastes.

The operational testing will include tests that demonstrate:

- The dynamic loading from the sampling hardware can be safely supported by the tank or tank riser, such as the reactive loading generated by the cyclic/pulsing movement of waste through the sampling system.
- The tank can withstand any secondary force, shock, or vibration from the sampling system that is a result of other tank operations, such as the side load resulting from the mixer pump effluent impinging on the in-tank hardware, vibration from pumps, etc.
- The sampling system hardware can safely withstand any force, shock, or vibration imposed upon it by the tank
- The exposed tank components will not be adversely impacted by natural weather conditions (wind, dust, moisture, freezing temperature, and temperatures exceeding 100°F).
- The sample bottle filling rate as a function of "pump" cycles and/or sampling time.
- Demonstrate that the sample bottle can be transferred from the sample chamber to the site's shipping cask within acceptable safety and exposure limits.

Testing and/or an evaluation will be completed that demonstrates that the sampling system can successfully operate over an expected 20-year lifetime. During this lifetime, the

sampling system must be capable of extracting waste samples that are representative of the wastes that the system is deployed in.

Future revisions will be made to this test plan, as testing needs are identified.

7.0 DOCUMENTATION

Unique, and labeled laboratory notebooks shall be used to record all test data during the completion of the testing activities. These notebooks should have sequentially numbered pages. The entries in the notebooks should be made in ink, with any entry changes crossed out but not erased. The recorded test data will include test description/objectives, test system setups, a description of serial numbers and/or identification numbers for all sensing/measurement systems and/or tools used in the tests, the measurement and test data, and any in-test calculations made. The calibration status of any measurement tool, sensor, or measurement system shall also be recorded.

All data recording media, such as computer disks and strip charts, will be clearly and uniquely identified and stored in a manner to preserve the recorded data. The notebooks will record the identification number of the storage media record, and the file or location where the data for each test can be found.

At the conclusion of the testing, a written test report will be prepared. This report will summarize test purposes and condition, test setups, test data and processed test data, along with conclusions resulting from the completion of the test and reference data extracted from the laboratory notebook. All nested, fixed-depth sampling system testing documentation will be released into the PHMC document control system. Responsibilities, policies, and procedures for completing these documents and the release will follow those described in the Engineering Task Plan (Reich and Smalley, 1998). Any deviations from these documentation requirements shall be technically justified and approved by the PHMC prior to making any changes.

8.0 ORGANIZATIONAL RESPONSIBILITIES

The PHMC Team has the responsibility for identifying all functional criteria, identifying the simulants, and developing the test acceptance/rejection criteria for all testing that will be completed with either the conceptual sampling system or the full-scale prototype system. In addition, the PHMC has responsibility of approving all test implementation plans before testing is started. The Engineering Task Plan identified the roles and responsibilities for these testing activities (Reich and Smalley 1998).

AEAT has the responsibility for performing the necessary design and proof-of-principle testing for the conceptual nested, fixed-depth sampling system. The data, including the notebooks, will be submitted to the PHMC team along with a written summary of the tests completed. AEAT has the responsibility of developing a test implementation plan, based on the criteria in this test plan document. AEAT has the responsibility for fabricating and testing the conceptual and prototype systems to assure welding, assembly, and operational programming are in accordance with the detailed design. AEAT also has the responsibility for assuring that the test setups, for completing the proof-of-principle testing, are as specified in this test plan document. The PHMC will have the responsibility for the testing of the prototype system at the Hanford cold test facility

9.0 QUALITY ASSURANCE

AEAT shall provide for quality assurance, in completion of this test work, that complies with the criteria in 10 CFR 830.120. AEAT shall provide a table that cross-references, as a minimum, the following quality assurance program elements in their quality assurance plan:

- Program (from Section 1.i, in 10 CFR 830.120)
- Personnel Training and Qualifications (Section 1.ii)
- Documents and Records (Section 1. iv)
- Work Processes (Section 2.i)
- Design (Section 2.ii)
- Inspection and Acceptance Testing (Section 2.iv)

The measuring devices used in these tests will be calibrated or characterized before use in any of the tests described in this test plan. Prior to initiating testing, documentation will be available for each measuring device that describes its measuring functions, the property to be measured, and the test/calibration data that shows the performance (accuracy and precision) of the measuring device. Should calibration be required, secondary standards are deemed accurate enough to quantify the performance of the sampling system in this testing.

10.0 REFERENCES

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APPENDIX A
FLUIDIC BASED SAMPLING SYSTEM
COMPONENT DESCRIPTION

APPENDIX A - FLUIDIC BASED SAMPLING SYSTEM COMPONENT DESCRIPTION

A.1 SAMPLER GENERAL DESCRIPTION

A fluidic sampler consists of three main components, a charge vessel, the fluidic Reverse Flow Diverter (RFD) Pump, and the fluidic sampling Tee. Both components are integral to the sampler operation: the pump is used to lift the sample to the Tee, and the Tee draws the sample into the sampling bottle. The main elements of a fluidic RFD pump are shown in Figure A-1 and consist of the following:

- **pumping element** - a passive fluidic device through which fluid enters the pump from the supply tank. The details of this element are described later.
- **charge vessel**
- **primary controller** for providing the gas pressure and flow conditions in the charge vessel and acting as a barrier between the clean incoming compressed gas and the potentially hazardous liquid
- **secondary controller** which handles only clean gas and provides the gas flow to the primary controller as required

A.2 OPERATIONAL CYCLE

The pump typically operates in three phases as illustrated below:

Refill Phase:

In this phase, liquid from the supply tank enters the charge vessel through the pumping element, and the phase continues until the liquid level has reached the top of the charge vessel and enters the air link pipe. When required, a partial vacuum is applied to the charge vessel by the primary controller to augment the filling rate.

Drive Phase:

In this phase, compressed gas is passed via the primary controller into the charge vessel which forces the liquid through the pumping element and along the delivery pipe into the delivery vessel. This continues until the air-liquid interface reaches the bottom of the charge vessel, at which time the compressed gas supply is terminated. The role of the pumping element in this phase is to entrain further fluid from the supply tank into the delivery pipe or, at the very least, to minimize the amount of fluid flowing back into the supply tank.

Vent Phase:

In this, the third and final phase, the compressed gas supply to the pump has ceased, and the high pressure gas in the charge vessel is allowed to escape to vent through the primary

Figure A-1. Schematic Showing the Main Elements of a Fluidic RFD Based Pump.

controller. The liquid contained in the delivery pipe also tends to fall back into the charge vessel. The amount by which the pipe empties depends upon the pump design, the imposed operating frequency, and the type of pump element used. When the pressure in the charge vessel has fallen close to atmospheric pressure, the refill phase recommences, and the whole cycle is repeated.

The pump therefore operates in a cyclic manner, delivering intermittent "dollops" of liquid into the delivery vessel.

Figure A-2. Three Phases of Pump Operation; Top to Bottom, Refill, Drive, and Vent

Figure A-3. Reverse Flow Diverter, RFD, Element

A.3 PUMPING ELEMENTS

A.3.1 Reverse Flow Diverter

The pumping element shown in the Figure A-3 is the Reverse Flow Diverter, RFD. The RFD operates like a three-way valve. It consists of two opposed nozzles; a symmetrical design is shown in the Figure A-3.

In operation as a pumping element, fluid enters the inlet nozzle during the drive phase, passes across the gap, entraining fluid from the supply tank, and the static pressure is then recovered along the outlet nozzle/diffuser section. Depending upon the pressure in the delivery line, fluid from the supply tank is either entrained by the flow emerging from the nozzle or, alternatively, a small proportion of the nozzle flow is fed back into the tank--so called "negative entrainment."

During the refill phase, liquid passes through the inlet nozzle (now acting as a diffuser) and into the charge vessel with only a relatively low resistance to flow produced by the well-rounded entry to the diffuser.

Figure A-4. Drive Phase

Figure A-5. Refill Phase.

A.3.2 Primary Controller

From the preceding paragraphs it can be seen that the requirements of the primary controller are to provide a positive gas flow and pressure to the charge vessel during the drive phase to allow a vent path for this gas during vent and then to provide a partial vacuum in the charge vessel during refill. This is normally accomplished using a jet pump pair which is shown schematically in Figure A-6, together with the modes of operation for the three phases of the pump's cycle.

A.3.3 Secondary Controller

The requirements of the secondary controller are to provide compressed gas to the "drive" part of the primary controller during the drive phase, to switch off the gas supply during vent,

Figure A-6. Jet Pump Pair Used to Produce Drives for the Three Modes of Operation for the Three Phases of the Pump's Cycle.

and then to supply the "suction" part of the primary controller during refill. This task is often accomplished using conventional solenoid valves which need to handle only clean gas and are

installed in an accessible position so that maintenance can be performed.

The other function of the secondary controller is to control the duration for which the gas is supplied to the primary controller, i.e., to set the phase times of the cycle. The method of achieving this is dependent upon the type of pumping element used as outlined below.

A.3.4 Operating Cycle Limits

During the drive (or vent) phase, if the air liquid interface passes beyond the base of the charge vessel, the compressed gas will be blown into the supply and delivery tanks which can lead to over-pressurization of these vessels and the creation of airborne aerosols. This is a potential fault condition known as overblow. By correct design, it is not a disastrous situation, but steps are normally taken to avoid it if possible.

At the other extreme, if an excessive vacuum is supplied to the charge vessel during the refill phase, there is the potential for sucking liquid into the primary controller and thereby discharging it into the vent system. This condition, known as flooding, is normally obviated by the correct positioning of the primary controller in relation to the charge vessel.

A.3.5 Cycle Control and Stability

The RFD pump system is normally designed with the charge vessel volume several times greater than the volume of the delivery pipe. Consequently, at the end of the refill phase, the delivery pipe has emptied (down to the level of the liquid in the supply tank), and the level of liquid in the charge vessel has risen into the air link pipe to a level compatible with the amount of vacuum supplied by the primary controller. The system is then in hydrostatic equilibrium and the liquid flow rate is zero everywhere within the pump. This condition represents a datum from which each cycle of the pump commences and is necessary to avoid cycle instability which could result in overblow.

The phase sequencing of this type of pump can therefore be achieved in an open loop manner with electronic timers, where the time of each phase of the pump is predetermined from experiment or theoretical predictions.

In a pumping system, irrespective of the type of pumping element employed, the time taken to refill the charge vessel increases as the level of liquid in the supply tank falls. The drawback to the use of electronic timers, therefore, is that in order to ensure reaching the datum position, the time for the refill phase must be set such that the charge vessel will fill even at the lowest supply tank level. This leads to very inefficient operation.

A solution to the problem is provided by the Prescon (PRESSure CONTROL) method which makes use of the observation that there is a characteristic pressure change as measured at the point X when the charge vessel becomes full. By detecting this pressure change, it is possible to start the drive phase at the moment when the charge vessel is completely filled, which will optimize the operation of the sampling system. This, therefore, provides a reliable, non-intrusive, closed-loop control method. In addition, the occurrence of overflow can be detected by analyzing the pressure measured at point Y.

A.3.6 Sampling Procedure

Each sampler comprises an RFD fluidic pump connected to a single specially designed sampling tee installed in the discharge pipework which delivers a sample of the liquid through a sample needle to the sample bottle, as indicated in Figure A-8. The flow from a fluidic pump is intermittent, i.e., there is a delivery of liquid followed by a period when the pump is refilling. This intermittent flow is used to make the sampling system operate. When the pump is delivering liquid along the delivery line, the liquid will have some velocity. As the liquid passes the end of the sampling needle there is a venturi effect which draws air down the needle from a sample bottle on the other end of the needle (usually plastic with a rubber seal on the other end). As the delivery pulse from the pump ends, the liquid velocity past the needle decreases and the partial vacuum in the bottle draws liquid back into the bottle.

A sample is normally collected over a number of cycles in this manner; the total amount of sample collected is governed by the length of the needle penetrating into the bottle.

Note that the sample tee design ensures that, when no sample bottle is on the needle, no liquid passes up through the needle. If a sample pump is run without a bottle, for example to purge the sample lines, the liquid flow draws a small amount of air down through the needle into the tank. Without a bottle to hold suction, there is no driving force for liquid flow up through the needle.

Where tests require it, secondary samples for comparison purposes will be taken from the sampler feed tank adjacent to the RFD using a simple 'grab' sampling technique derived from ASTM E300-92, "Standard Practice for Sampling Industrial Chemicals."

a. Electronic Timer System (Open Loop)

b. PresCon System (Closed Loop)

Figure A.7. Cycle Control with Timer and Pressure Control Systems.