DOCUMENT RELEASE AND CHANGE FORM

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

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Test Specification for the Low-Activity Waste Pretreatment System Full-Scale Ion Exchange Column Test and Engineering-Scale Integrated Test (Project T5L01)

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Originator	ARD, KEVIN E	ARD, KEVIN E	06/23/2015
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Responsible Engineer	ARD, KEVIN E	ARD, KEVIN E	06/23/2015
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RPP-RPT-58683, Rev. 1

Test Specification for the Low-Activity Waste Pretreatment System Full-Scale Ion Exchange Column Test and Engineering-Scale Integrated Test (Project T5L01)

Author Name:
K. E. Ard
Washington River Protection Solutions, LLC
Richland, WA 99352
U.S. Department of Energy Contract DE-AC27-08RV14800

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Abstract: This test specification establishes the description and requirements for the full-scale ion exchange column test and the engineering-scale integrated test for the Low Activity Waste Pretreatment System. The engineering-scale test will integrate cross flow filtration, cesium ion exchange using spherical resorcinol-formaldehyde, and the Filter Feed Tank loop supplying untreated supernatant tank waste to the Cross Flow Filter. Testing will be conducted using prototypic equipment.

Test Specification for the Low-Activity Waste Pretreatment System Full-Scale Ion Exchange Column Test and Engineering-Scale Integrated Test (Project T5L01)

K. E. Ard
Low Activity Pretreatment System Project
Washington River Protection Solutions LLC

Date Published
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Prepared for the U.S. Department of Energy
Office of River Protection

washington river protection solutions

P.O. Box 850
Richland, Washington

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List of Acronyms

ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BV	Bed Volume
CFF	Cross Flow Filter
CFR	Code of Federal Regulations
Cs	Cesium
CV	Column Volume
DOE	U.S. Department of Energy
DST	double-shell tank
FFT	Filter Feed Tank
FQA	Full Quality Assurance
HLW	high-level waste
ILAW	immobilized low-activity waste
IX	ion-exchange
K	Potassium
LAW	low-activity waste
LAWPS	Low Activity Waste Pretreatment System
LFL	Lower Flammability Limit
ORP	U.S. Department of Energy, Office of River Protection
RCW	Revised Code of Washington
RDT	Resin Disposal Tank
RPP	River Protection Project
sRF	spherical resorcinol-formaldehyde
UL	Underwriters Laboratories
WAC	Waste Acceptance Criteria
WRPS	Washington River Protection Solutions, LLC
WTP	Waste Treatment and Immobilization Plant

1.0 SCOPE

This document establishes the description and requirements for the full-scale ion exchange (IX) column test and the engineering-scale integrated test for the Low Activity Waste Pretreatment System (LAWPS). The engineering-scale test will integrate cross flow filtration, cesium (Cs) ion exchange (IX) using spherical resorcinol-formaldehyde (sRF), and the Filter Feed Tank (FFT) loop supplying untreated supernatant tank waste to the Cross Flow Filter (CFF). Testing will be conducted using prototypic equipment.

The use of words “shall”, “should”, “may”, and “will” within this document express the following meaning:

- Shall – Denotes a requirement.
- Should – Denotes a recommendation. If a “should” recommendation cannot be satisfied, justification of an alternative design shall be submitted to the Design Authority for approval.
- May – Denotes a recommendation.
- Will – Denotes a statement of fact.

1.1 INTRODUCTION

The U.S. Department of Energy (DOE), Office of River Protection’s (ORP) primary mission is to retrieve and treat Hanford’s tank waste and close the tank farms to protect the Columbia River. Mixed radioactive waste is stored in 177 underground tanks at the Hanford Site as reported in DOE/ORP 2003-02, *Environmental Impact Statement for Retrieval, Treatment, and Disposal of Tank Waste and Closure of the Single Shell Tanks at the Hanford Site, Richland WA*, Inventory and Source Term Data Package. The 177 underground tanks are estimated to contain about 56 million gallons of waste.

The DOE ORP is responsible for management and completion of the River Protection Project (RPP) mission, which comprises both the Hanford Site tank farms and the WTP. A key aspect of the RPP mission is to construct and operate the WTP (ORP-11242, *River Protection Project System Plan*). The WTP is a multi-facility plant that will separate and immobilize the tank high-level waste (HLW) and Low Activity Waste (LAW) fractions for final dispositions.

The LAWPS Project provides for the early production of immobilized low activity waste (ILAW) by feeding LAW directly from Tank Farms to WTP’s LAW Facility, bypassing the Pretreatment Facility. Prior to the transfer of feed to the WTP LAW Vitrification Facility, tank supernatant waste will be pretreated in the LAWPS to meet the WTP LAW waste acceptance criteria. The LAWPS will also facilitate the return of secondary liquid wastes from the WTP LAW Vitrification Facility to the Tank Farms. Content of this test specification follows the general guidance provided in TFC-ENG-DESIGN-C-34, “Technical Requirements for

Procurement." Technical requirements in this document will be managed consistent with Path 3 defined in Figure 1 of TFC-ENG-DESIGN-C-34.

1.2 TECHNICAL OBJECTIVES

Overarching technical objectives of performing the full-scale ion exchange test and the engineering-scale integrated test are to:

1. Test interactions between unit process operations;
2. Test removal of non-radioactive Cs from process stream;
3. Test removal of undissolved solids from process stream;
4. Confirm an operational flow rate range and stability;
5. Confirm volumetric throughput of waste stream over flow operating range;
6. Confirm a range of process temperatures over planned operating range;
7. Establish system hydraulics and process criteria;
8. Coordinate key control and monitoring components;
9. Establish that treated product chemistry meets requirements (Cs, solids, and pH); and
10. Test the hazard control strategy for a no flow condition through the IX column.

Specific test objectives are defined in Table 3-8 of this document.

The resin management and dewatering equipment functions for resin disposal will be tested separately outside the scope of this testing. Functions associated with fresh resin addition will be tested to verify the ability of the column to accept and properly deposit fresh resin within the IX column. RPP-PLAN-57181, *Technology Maturation Plan for the Low-Activity Waste Pretreatment System Project (T5L01)* indicates that the fresh resin addition system is not a critical technology element, therefore; prototypic representation of the resin addition equipment is not included in the testing scope.

2.0 APPLICABLE DOCUMENTS

This section lists only those documents cited as requirements documents in Section 2.1 and 2.2. The references include the title and/or revision number or date of revision as applicable.

2.1 GOVERNMENT DOCUMENTS

The following documents of the exact issue shown in Table 2-1 form a part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this document, the contents of this document shall be considered a superseding requirement.

Table 2-1. Government Documents

Document Number	Title
Code of Federal Regulations (CFR)	
10 CFR 851	*Worker Safety and Health Program*
29 CFR 1910	*Occupational Safety and Health Standards*
Revised Code of Washington	
RCW 49.17	*Washington Industrial Safety and Health Act*

Copies of specifications, standards, drawings, and publications required by suppliers in connection with specified procurement functions should be obtained from the contracting agency or as directed by the contracting agent. Federal and state regulation are publically available from the internet or libraries.

2.2 NON-GOVERNMENT DOCUMENTS

The following documents of the exact issue shown in Table 2-2 form a part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this document, the contents of this document shall be considered a superseding requirement.

Table 2-2. Non-Government Documents

Document Number	Title
American Society of Mechanical Engineers (ASME)	
ASME *Boiler and Pressure Vessel Code* (2013)	*Rules for Construction of Pressure Vessels*
ASME B31.1(2014)	*Power Piping*
ASME B31.3 (2012)	*Process Piping*
American Welding Society (AWS)	
AWS D1.1/D1.1M (2010)	*Structural Welding Code-Steel*
AWS D1.6/D1.6M (2007)	*Structural Welding Code – Stainless Steel*

Technical society and technical association specifications and standards are generally available for reference from libraries or they may be obtained directly from the Technical Society/Association.

3.0 TECHNICAL REQUIREMENTS

3.1 LAWPS SYSTEM DEFINITION

RPP-SPEC-56967, *Project T5L01 Low Activity Waste Pretreatment System Specification* provides the following system definition. The primary mission of the LAWPS is to provide treated tank farm supernatant LAW feed directly to the WTP LAW Facility in a safe, economic, and environmentally protective manner. The LAWPS will receive tank supernatant waste from the Double Shell Tank (DST) System. The LAWPS will treat the tank supernatant waste by separating entrained solids through a filtration subsystem, and by removing radioactive cesium using an ion exchange subsystem. The solids and cesium removed will be returned to the DST System. Treated waste will be stored in lag waste storage tanks and sampled to confirm the treatment process efficacy. Treated waste compliant with WTP waste acceptance criteria will be fed to the WTP LAW Facility. A line diagram of the LAWPS, consistent with the functional components is provided in Figure 3-1. Components in yellow are specifically addressed by this document.

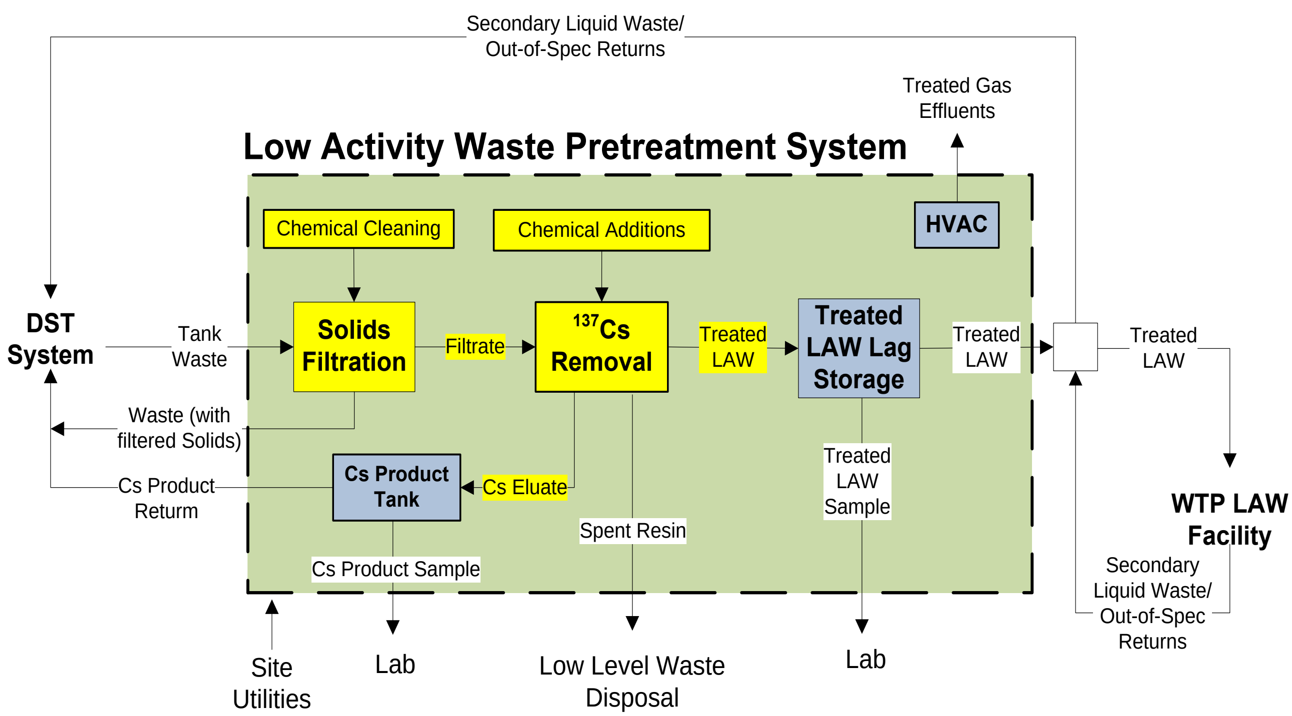

Figure 3-1. Low Activity Waste Pretreatment System Diagram.

3.2 PERFORMANCE CHARACTERISTICS

Performance requirements from RPP-SPEC-56967 applicable to the full-scale LAWPS design are listed below.

a) The LAWPS shall have an instantaneous processing rate of at least 185 kg Na per hour[1] from waste[2] (corresponding to approximately 1,600 MT of waste Na per year at 100% operating efficiency).

b) The LAWPS shall have an average processing capacity of 1,120 MT of waste Na per year corresponding to an integrated system availability of 70%.

c) The LAWPS shall be designed to receive waste with the estimated radiological, chemical, and physical properties shown in Table 3-1, Table 3-2, and Table 3-3.

d) The LAWPS shall be capable of removing undissolved (entrained) solids from tank supernatant waste.

e) The LAWPS shall be capable of selectively removing Cs from filtered waste through the use of spherical resorcinol-formaldehyde (sRF).

f) The concentration of radioactive cesium in treated LAW waste shall comply with the requirements of ICD-30. Pending finalization of ICD-30, the concentration of radioactive cesium in treated LAW should not exceed 3.18 E-05 Ci/mol sodium[3].

g) The design of the LAWPS equipment for removing Cs shall use the values for potassium, cesium, and ^{137}Cs for LAW waste that are shown in Table 3-4; the average values shown in Table 3-1 and Table 3-2 should be used for all other constituents. Ion exchange column sizing calculations shall consider down time due to regeneration and resin replacement. In addition, the column sizing calculation shall assume a resin capacity that is degraded due to radiation and oxidation.

h) To compensate for the potential of solids precipitation from waste, the LAWPS process shall be designed with appropriate capability (e.g., waste temperature control features) to minimize solids precipitation. As needed, mixing and flushing capabilities shall be provided within the LAWPS process to prevent accumulation of precipitated solids.[4]

i) The LAWPS shall minimize oxygen entrainment to reduce IX resin degradation.

[1] 185 Kg Na/hr equates approximately to 6.3 gpm at an assumed 5.6 molar Na concentration in the feed.

[2] The processing rate excludes any Na added (e.g. NaOH added to control aluminum solubility).

[3] Table 6 of draft 24590-WTP-ICD-MG-01-030_Rev v017 (ICD-30) – Interface Control Document for Direct LAW Feed.

[4] The design basis salts for precipitates downstream of filtration are NaF, with density of 2.78 g/mL and particle size of 7 µm, and $Na_3PO_2 \bullet 0.25NaOH \bullet 12H_2O$ (sodium phosphate dodecahydrate), with density 1.62 g/mL and particle size of 1200 µm based on RPP-RPT-58509.

j) The LAWPS design shall be based on a range of values for specific parameters considered important to the LAWPS process. Variations of parameters that affect LAWPS throughput include:

i. Sodium molarity: 4-6 M,
ii. Viscosity: see Table 3-3,
iii. Density: see Table 3-3,
iv. Solids concentration: see Table 3-3,
v. Cesium and ^{137}Cs concentration: see Table 3-4,
vi. Potassium concentration: see Table 3-4,
vii. Susceptibility to precipitation.

Table 3-1. Summary of Average Radionuclide Components in Waste Feed for LAWPS[a].

Component	Liquid Phase	Solid Phase	Component	Liquid Phase	Solid Phase
	Ci/liter	Ci/liter		Ci/liter	Ci/liter
106-Ru	4.84E-12	0.00E+00	236-U	1.97E-10	2.07E-11
113m-Cd	7.30E-06	0.00E+00	237-Np	8.71E-08	1.52E-11
125-Sb	5.39E-07	0.00E+00	238-Pu	1.02E-07	0.00E+00
126-Sn	1.07E-06	0.00E+00	238-U	4.06E-09	4.07E-10
129-I	1.43E-07	4.35E-14	239-Pu	1.17E-06	0.00E+00
134-Cs	7.20E-08	0.00E+00	240-Pu	2.66E-07	0.00E+00
137-Cs	2.36E-01	0.00E+00	241-Am	1.66E-06	3.02E-09
137m-Ba	2.36E-01	0.00E+00	241-Pu	1.36E-06	0.00E+00
14-C	2.27E-06	0.00E+00	242-Cm	6.14E-10	0.00E+00
151-Sm	0.00E+00	4.22E-04	242-Pu	3.10E-10	0.00E+00
152-Eu	0.00E+00	7.01E-08	243-Am	5.49E-10	1.45E-12
154-Eu	0.00E+00	4.37E-07	243-Cm	1.52E-08	0.00E+00
155-Eu	0.00E+00	2.10E-07	244-Cm	2.64E-07	0.00E+00
226-Ra	5.56E-11	0.00E+00	3-H	2.34E-06	0.00E+00
227-Ac	7.85E-09	0.00E+00	59-Ni	7.98E-08	5.76E-08
228-Ra	4.08E-09	0.00E+00	60-Co	0.00E+00	4.78E-08
229-Th	0.00E+00	9.23E-11	63-Ni	6.40E-06	4.60E-06
231-Pa	0.00E+00	2.71E-10	79-Se	6.58E-07	0.00E+00
232-Th	0.00E+00	1.22E-10	90-Sr	1.45E-04	7.34E-05
232-U	5.04E-10	4.86E-11	90-Y	1.45E-04	7.34E-05
233-U	7.81E-09	7.48E-10	93-Zr	0.00E+00	1.22E-06
234-U	4.69E-09	4.73E-10	93m-Nb	0.00E+00	1.22E-06
235-U	1.89E-10	1.91E-11	99-Tc	1.64E-04	0.00E+00

[a] Table extracted from SVF-2912, *Low Activity Waste Pretreatment System Flowsheet*, worksheet “LAWPS Capacity,” worksheet “Table 3-1”. Analysis of HTWOS modeling indicates above values are an appropriate representation of a nominal feed to LAWPS. System design will be based on a range of values for specific waste parameters important to LAWPS processes.

Table 3-2. Summary of Average Chemical Components in Waste Feed for LAWPS[a].

Component	Liquid Phase, gmole/liter	Solid Phase, gmole/liter	Component	Liquid Phase, gmole/liter	Solid Phase, gmole/liter
Ag+	5.20E-06	7.56E-08	NH3	1.34E-02	0.00E+00
Al(OH)4-	1.66E-01	0.00E+00	NH4+	1.29E-04	0.00E+00
Al+3	0.00E+00	2.20E-06	Ni+2	3.51E-05	2.62E-05
As+5	1.81E-04	0.00E+00	NO2-	1.02E+00	0.00E+00
B+3	1.39E-03	0.00E+00	NO3-	1.78E+00	0.00E+00
Ba+2	2.64E-08	2.20E-07	O(BOUND)	1.11E-04	2.23E-05
Be+2	7.09E-05	0.00E+00	OH(BOUND)	1.41E+00	0.00E+00
Bi+3	1.00E-04	0.00E+00	OH-	1.41E+00	0.00E+00
C2O4-2	1.27E-02	1.12E-03	Pb+2	7.26E-04	0.00E+00
Ca+2	1.91E-05	5.47E-05	Pd+2	4.52E-05	0.00E+00
Cd+2	2.00E-05	0.00E+00	PO4-3	4.32E-02	5.35E-06
Ce+3	0.00E+00	2.10E-06	Pr+3	0.00E+00	6.93E-07
Cl-	9.46E-02	0.00E+00	Pu+4	0.00E+00	0.00E+00
CN-	1.76E-05	0.00E+00	Rb+	1.38E-06	0.00E+00
Co+3	0.00E+00	1.70E-06	Rh+3	0.00E+00	4.74E-06
CO3-2	5.23E-01	4.54E-07	Ru+3	4.05E-05	0.00E+00
Cr(OH)4-	0.00E+00	0.00E+00	Sb+5	8.21E-05	0.00E+00
Cr(TOTAL)	0.00E+00	0.00E+00	Se+6	1.96E-04	0.00E+00
Cs+	1.04E-04	0.00E+00	Si+4	8.02E-03	1.16E-06
Cu+2	1.62E-05	6.37E-12	SO4-2	6.61E-02	5.55E-05
F-	6.51E-02	5.82E-05	Sr+2	6.69E-07	4.10E-07
Fe+3	5.23E-04	0.00E+00	Ta+5	1.84E-10	2.70E-06
H+	5.12E-02	0.00E+00	Tc+7	0.00E+00	0.00E+00
H2O	4.74E+01	5.09E-05	Te+6	2.78E-05	2.44E-06
Hg+2	3.14E-05	0.00E+00	Th+4	0.00E+00	8.87E-11
K+	1.22E-01	0.00E+00	Ti+4	0.00E+00	1.02E-06
La+3	0.00E+00	8.52E-07	Tl+3	0.00E+00	4.78E-06
Li+	3.97E-04	0.00E+00	TOC	1.77E-01	0.00E+00
Mg+2	0.00E+00	2.02E-05	U(TOTAL)	0.00E+00	0.00E+00
Mn+4	0.00E+00	3.28E-06	V+5	1.88E-08	9.62E-07
MnO4-	0.00E+00	0.00E+00	W+6	3.91E-05	0.00E+00
Mo+6	1.86E-04	0.00E+00	Y+3	1.42E-06	6.09E-08
Na+	5.61E+00	2.43E-03	Zn+2	9.99E-05	0.00E+00
Nd+3	1.57E-05	0.00E+00	Zr+4	0.00E+00	1.94E-07

[a] Table extracted from SVF-2912, worksheet "Table 3-2". Analysis of HTWOS modeling indicates above values are an appropriate representation of a nominal feed to LAWPS. System design will be based on a range of values for specific waste parameters important to LAWPS processes.

Table 3-3. DST Feed Physical Characteristics

Parameter	Unit	Nominal Value	Range
Density[a, b]	g/ml	1.28	1.0 – 1.35
Viscosity[c]	Centipoise (cP)	11	1 – 15
Temperature[d]	°C	25	20 - 45
Solids Concentration[e]	wt%	0.8	0 – 3.3
Solids Particle Size[e]	μm	7.5	0.01 - 210

[a] The upper bound value originates from TFC-ENG-STD-26, in which supernatant is defined as having a specific gravity of ≤ 1.35 and containing minimal solids.
[b] The upper-bounding solid particle density is 5.68 g/mL which corresponds to ZrO_2 based on engineering judgment and data from PNNL-20646, *Hanford Waste Physical and Rheological Properties: Data and Gaps.*
[c] The upper value originates from draft 24590-WTP-ICD-MG-01-030_Rev v017, ICD-30 – Interface Control Document for Direct LAW Feed.
[d] The temperature upper limit is based on WTP-RPT-214, *Ion Exchange Kinetics Testing with SRF Resin*. This report demonstrates that sRF resin degrades when the temperature exceeds 45 °C and so the upper bounding temperature is set at 45 °C to protect the resin.
[e] Suspended particle properties are based on the recommendations of RPP-RPT-58509, *Solids Properties in Tank Waste for the Low Activity Waste Pretreatment System Feed.*

Table 3-4. Design Source Term (Liquid Phase).

Ion Exchange Sizing Source Term		
Component	**Limit**	**Unit**
Potassium (min)[a]	0	gmole/L
Potassium (max)[a]	0.35	gmole/L
Cesium[b]	1.04E-04	gmole/L
^{137}Cs[b]	1.99E-05	gmole/L
^{137}Cs[b]	2.36E-01	Ci/L
^{137}Cs: Total Cesium Ratio (max)[a]	0.24	
Shielding Design Source Term		
^{137}Cs[c]	5.23E-01	Ci/L
^{137}Cs Max Loading for IX Columns[a]	106,000	Ci

[a] Value based on the recommendations of RPP-RPT-58445, *Basis for Sodium, Potassium, and Cesium Values Used in the Design of LAWPS Ion Exchange System*.
[b] Value based on SVF-2912, worksheet "Table 3-5" and the recommendations of RPP-RPT-58445, *Basis for Sodium, Potassium, and Cesium Values Used in the Design of LAWPS Ion Exchange System*.
[c] Value adopted from RPP-SPEC-56967, Table 3-6, to provide bounding limit of ^{137}Cs.

3.3 FULL-SCALE ION EXCHANGE COLUMN TEST

The following subsections describe the full-scale IX column test. The IX column test includes integration of a resin disposal valve and a Resin Disposal Tank (RDT) as the planned hazards mitigation approach for a flammable gas deflagration or detonation, and over-temperature event as a result of a no flow condition in the IX column. Figure 3-2 provides a diagram showing the layout concept for the full-scale IX column test. Support tests that are needed to support the full-scale IX testing are also described. These support tests will be conducted by WRPS in conjunction with a national laboratory, and the necessary data provided to the Subcontractor.

3.3.1 Ion Exchange Column Description

The test design incorporates a single full-scale column, which represents either a lead column or the identical sized lag column. A prototype column will be constructed to enable real-time observations of resin bed stability, internal flow characteristics, and mixing dynamics. The following assumptions and input from RPP-RPT-57120, *Conceptual Design Report for the Low-Activity Waste Pretreatment System (Project T5L01)* are used for design of a test column.

1. Flow rate shall be maintained between 4 gpm and 17 gpm.
2. It is estimated that resin replacement will occur after approximately 30 load/regenerate cycles, at which point the resin is estimated to degrade to 64% of its initial efficiency.
3. The sRF resin bead diameter is approximately 460 microns in its sodium form.
4. The resin bed has a void volume (fraction) of 0.42.
5. The normal column loading cycle flow rate is three bed volumes per hour (BV/hr) for resin bed sizing purposes.
6. A resin bed length to diameter ratio of 1.2 is used, based on pilot column demonstrations. The overall column length to diameter ratio of two has been used, which is consistent with a WTP Pretreatment column design and provides adequate space for bed fluidization during regeneration and resin expansion.

The IX column used in the LAWPS design has a sRF resin bed diameter of approximately 3.5 feet, a bed length of 4.2 feet, and a volume of 308 gallons (41.2 ft^3) in sodium form. The vessel has a straight side length of 7 feet and a vessel volume of 588 gallons. The total column height accounts for the resin expansion, the liquid distributor/collector, and allowance for head/tail space. At a flow rate of 8.9 gpm, the resin bed is expected to have a pressure drop of 6.9 psig/bed for resin beads at 354 microns, and 4.1 psig/bed for resin beads at 460 microns as described in RPP-RPT-58631, *Advanced Conceptual Design Delta Report for the Low Activity Waste Pretreatment System (Project T5L01)*. Resin bead swelling pressure tests are provided in J. Walker, et. al., 2015, *Confined Swelling Pressure Tests for Spherical Resorcinol Formaldehyde Resin*. A diagram showing the proposed IX column concept is shown in Figure 3-3.

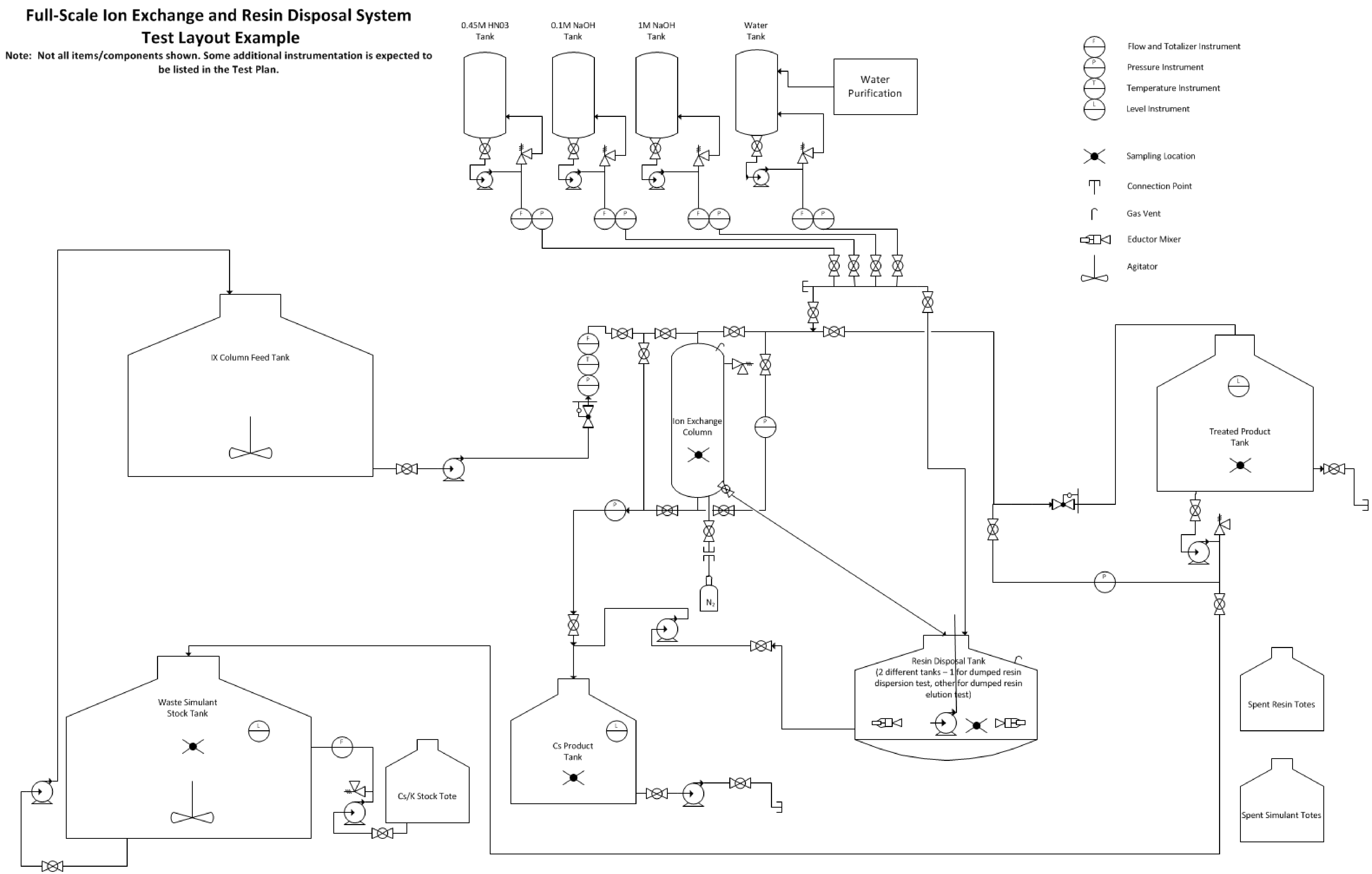

Figure 3-2. LAWPS Full-Scale Ion Exchange Column Test Conceptual Schematic.

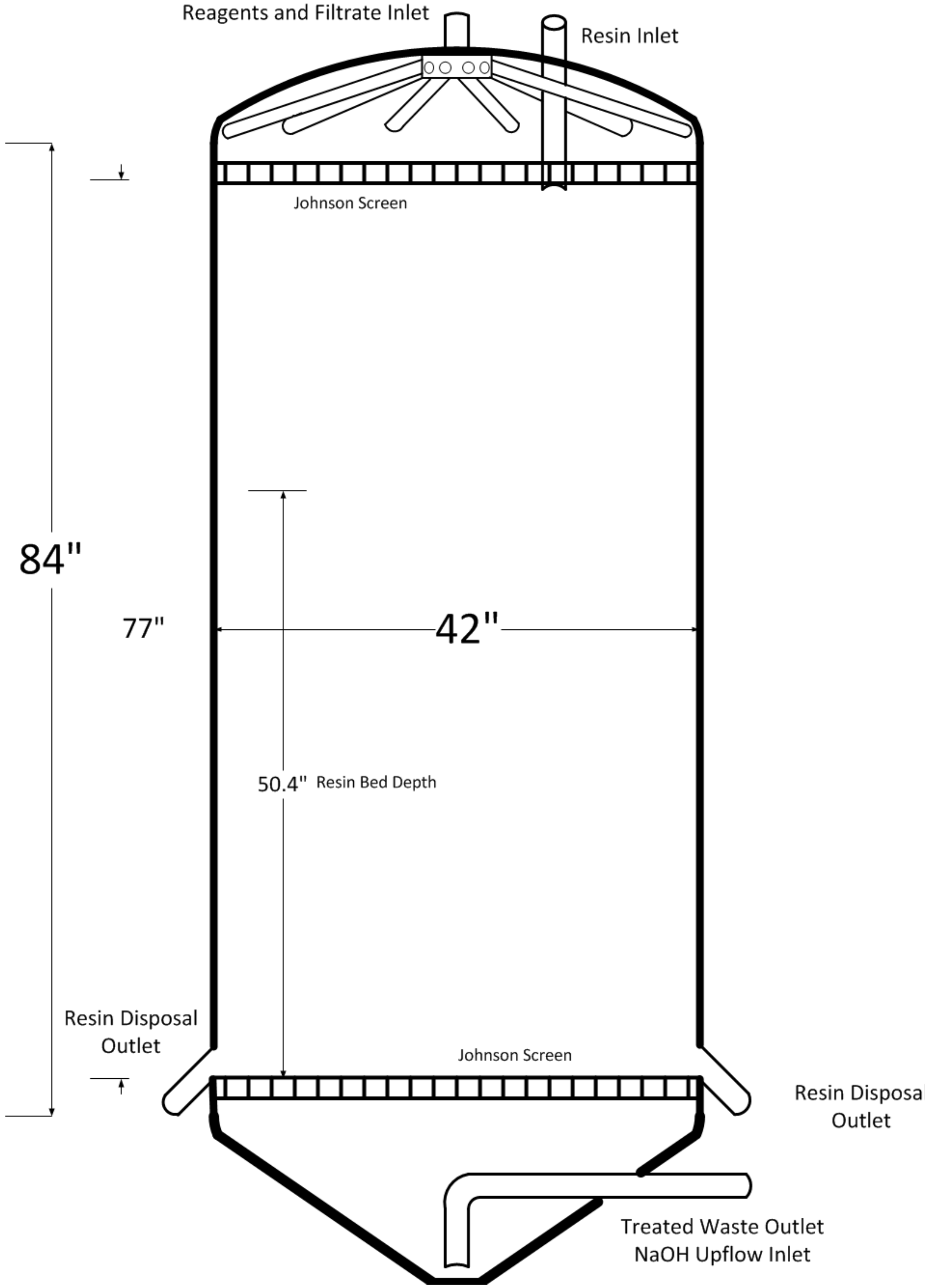

Figure 3-3. Full-Scale Ion Exchange Column Concept.

3.3.2 Resin Disposal Tank Description

Two separate RDT configurations will be used for testing. The first test configuration will use a full-scale mockup of the tank bottom to test dispersion of the resin in the bottom of the tank, and to check that the resin is maintained submerged. The mockup will include the bottom portion of the tank shown in Figure 3-4. The mockup will include sufficient freeboard to hold a liquid volume of approximately 3,000 gallons and approximately 616 gallons of resin in sodium form. The second test will be performed at $1/9^{th}$ scale by volume to test the ability to elute the resin in the RDT and discharge the resin from the RDT.

The following key inputs and assumptions from RPP-RPT-58631 are applied to the RDT:

1. The RDT must be configured such that the contents of both IXCs dumped into the RDT at the end of a worst case waste loading cycle is maintained < 100°C.
2. The initial RDT sizing is based on a 50 percent gas retention and release based on 616 gallons of resin received. The tank headspace is initially sized such that the released gas does not exceed 25 percent of the Lower Flammability Limit (LFL).
3. The RDT is designed such that sRF elution can take place in the RDT should sRF that is fully loaded with Cs be dumped into the RDT.
4. Tank agitation will be evaluated and included in the RDT design for resin removal, if needed. Tank agitation for elution will be evaluated and space allocated for elution agitation provisions, if necessary.
5. A liquid volume of 3,000 gallons is assumed to be maintained in the RDT to ensure that resin is dispersed evenly in the vessel and maintained submerged.
6. It is assumed the RDT elution process will be similar to the elution steps listed for normal elution performed in the IX column (Section 3.4.2).

A headspace volume of 30,800 gallons (616 gallons of resin x 50% H_2 retention /1% vol H_2/vol), plus 3,000 gallons of fluid to support distribution of resin, plus two IX column volumes (1,200 gallons), and volume from piping and equipment that may drain back to the IX columns (assumed to be 1,000 gallons) results in a RDT volume of 36,000 gallons. Figure 3-4 represents the basic size and shape of the disposal tank. This tank is approximately 200 inches tall (bottom head is 60 inches while the top head is 41 inches). The liquid level will be 41 inches in the bottom head. This includes 3,000 gallons of water to keep the resin covered. Resin will enter the tank through the disposal pipe and internal distributor. The distributor will direct and spread the resin along the bottom surface. Two transfer pumps will be mounted in the center portion of the tank. The suction opening will be as low as possible in the heel in order to remove as much resin as possible.

To aid in collecting the resin near the suction inlet of the pumps, the disposal tank would utilize eductors or water lances to move the resin toward the center of the bottom head. The motive fluid for the eductors or lances will be water. Additional features of the RDT include chemical addition and level indication.

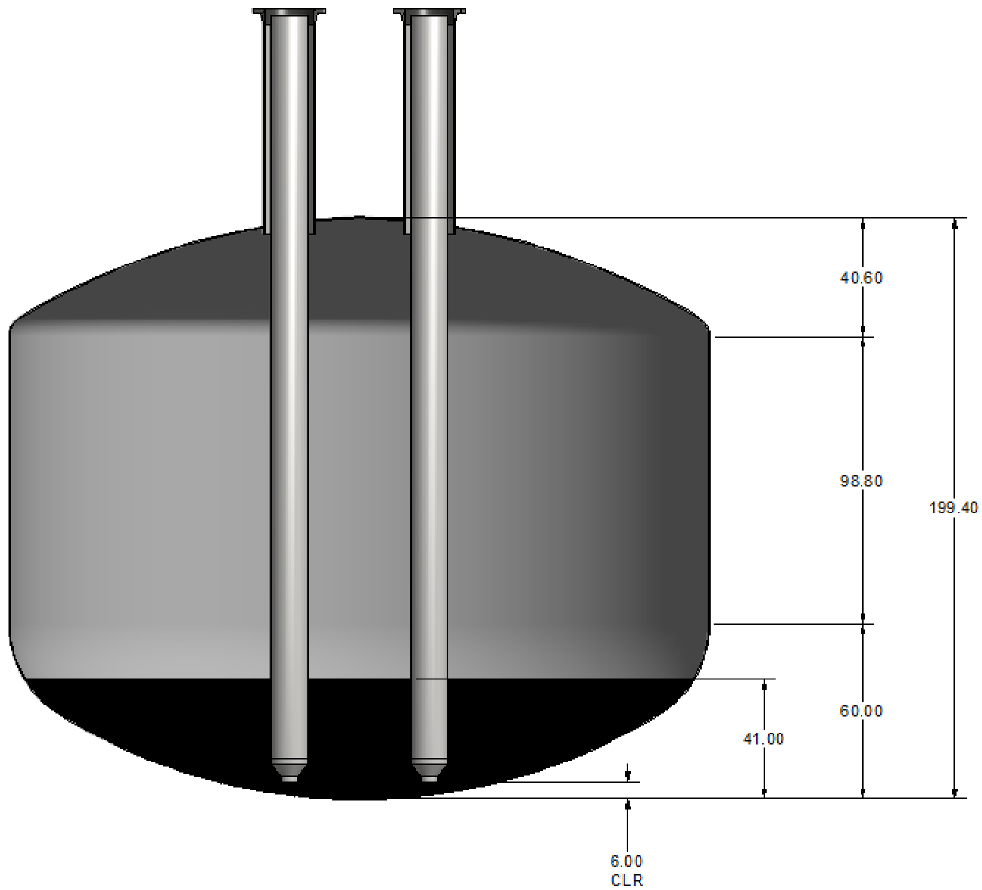

Figure 3-4. Full-Scale Semi-Elliptical Head Resin Disposal Tank Concept.

3.3.3 Support Tests for Full-Scale IX Column Test

Support tests will be performed by WRPS in conjunction with a national laboratory, and are intended to provide information that can be used to support the full-scale IX column test. The tests are not part of the Subcontractor's work scope, however; test data from the support tests will be made available in support of the Subcontractor's test scope. Support testing will determine if elevated resin temperatures and solids accumulation influence the ability to discharge resin under a loss of flow emergency resin discharge scenario. A simulant development study is also being performed as input to testing.

3.4 ION EXCHANGE TEST PROCESS DESCRIPTION

The following subsections from RPP-RPT-57120 and RPP-RPT-58631 provide a detailed description of the IX column normal processing operation to remove Cs, the resin elution and regeneration process, spent resin discharge using the RDT under normal operations, addition of fresh resin, and hazards mitigation using the RDT under a no flow condition. The sRF resin bed shall be loaded with cesium, eluted and regenerated all in a "plug flow" condition through the IX column.

3.4.1 Normal Processing

The sRF resin is received in hydrogen form meaning that the IX sites are loaded with hydrogen. Prior to use, the resin is converted to sodium form, meaning that the hydrogen is removed, and replaced with sodium ions. The resin is converted to sodium form by exposing the resin to NaOH solution. During processing, sodium ions on the IX resin are released to the waste stream and cesium ions are adsorbed in the same location vacated by the sodium ion. The first step in the elution process includes conditioning the bed by first displacing the waste from the bed with dilute NaOH, followed by a water rinse, followed by a dilute acid solution rinse. The acid solution causes the sodium and cesium to be released from the IX resin and be replaced by hydrogen. During processing, the resin is in sodium form and during elution the resin is converted to hydrogen form. Conversion of the resin from hydrogen to sodium form causes the resin beads to swell. Conversion of the resin from sodium to hydrogen form causes the media to shrink. The final step of the regeneration process converts the resin from the eluted hydrogen form, back to the sodium form for further processing. Because the resin swells during the final step of regeneration, the final step is performed in up-flow versus the normal down-flow. Additionally the resin bed is relatively short and squat (1.2 height to diameter ratio) to help ensure that the beads have adequate space to expand.

Ion exchange column normal processing mode is in a down-flow configuration and the technology relies on simultaneously trapping and exchanging an ionic species in solution with another ionic species contained in an IX resin support structure. As the sRF resin adsorbs a Cs ion, a Na ion is released. As the resin in the column nears its capacity for Cs, the number of sites in which Cs can be retained is reduced so a higher concentration of Cs passes through the column (a significant change in capture rate is termed breakthrough). Once Cs breakthrough is detected at a significant level, flow to the IX column is stopped and the elution process is started. Note that the cesium concentration in the simulant stock may be elevated above the expected normal feed concentrations to reduce the total volume of simulant and reduce the total run time.

3.4.2 Elution and Regeneration Process

The process cycle for use of sRF elutable resin for the removal of Cs includes loading, elution, rinse, regeneration, and waste re-introduction. After the loading phase, the Cs will be eluted from the resin bed in a down-flow configuration. After approximately 30 load/regenerate cycles, the resin has reached its life expectancy; it will be first eluted of Cs and then dumped from the column into a RDT. Testing should include three complete load/regeneration cycles, with a forth load cycle resulting in a subsequent resin discharge test that simulates an IX column no flow emergency discharge condition. Under normal operating conditions, the elution process will be completed prior to discharging the resin from the IX column in to the RDT. The final elution cycle prior to resin removal will include twice the normal volume of dilute acid to ensure that as much of the cesium has been removed from the resin as is practical.

The elution process will utilize both sodium hydroxide as well as nitric acid. Currently, the two concentrations of sodium hydroxide include 0.1 M and 1.0 M NaOH. The normal operating elution/regeneration process sequence in an IX column is as follows:

- Displacement of the filtrate present in the IX column with 0.1M NaOH. This is performed with 1.5 column volumes (CV) of the NaOH at a rate of 3 BV/hr.

- Pre elution water rinse to remove the 0.1M NaOH. This is achieved with 1 CV at a flow rate of 3 BV/hr.
- Elution of the sRF resin with 0.45M HNO_3. This is achieved with 15 bed volumes (BV) of acid through the bed. The flow rate will be at 1.5 BV/hr. The final elution prior to resin discharge will be 30 BV to ensure as complete cesium removal as is practical.
- Post elution water rinse to remove HNO_3. This is done with 1.3 CV of water at a flowrate of 3 BV/hr.
- Regeneration of the resin with 1M NaOH. This will be achieved with 3 BV of base at a velocity of 12.5 cm/min. This is followed with 0.3 BV at a velocity of 2 cm/min. Thus, the total volume of regeneration solution through the bed is 3.3 BV, though the actual volume will be larger to account for the larger vessel volume and the connecting pipe.
- Displacement of the regeneration solution with LAW product with 0.9 CV at a superficial velocity of 2.5 cm/min, followed by 0.13 CV at a rate of 4.0 cm/hour. Thus the total volume of displacement fluid is 1.03 CV. This “regenerative displacement” step is proposed for elimination based on its evaluation during testing.

The elution process begins once the feed to the IX column is stopped. Treated waste will be first displaced in a column by introducing the NaOH through the inlet of the column (down-flow). The treated waste will be pushed out the bottom of the column. The NaOH from the displacement step will be flushed from the column (also in down-flow) in the pre-elution rinse with the use of treated process water to minimize the acid/base neutralization reaction that would occur if the NaOH was not removed from the column prior to the introduction of HNO_3. Nitric acid (down-flow) will then be passed through the IX column to release the Cs from the sRF. Through the use of HNO_3, the sRF will release the sodium, potassium, and cesium and adsorb hydrogen at the resin activation sites (sRF is converted from sodium form to hydrogen form during elution). A post elution rinse of process water (down-flow) will remove HNO_3 from the column before introduction of NaOH during the regeneration stage.

The regeneration stage will convert sRF from the eluted hydrogen form to sodium form for processing with the introduction of NaOH and the exchange of Na+ for H+ at the resin activation sites. This step will be performed in up-flow bed-fluidizing process to relieve stresses arising from constrained bed expansion as the sRF expands to the sodium form.

Past IX column pilot scale testing incorporated a “regenerative displacement” step that displaced the regenerant NaOH solution with previously treated waste (up-flow through the column). Filling the IX column with liquid of the same density as the waste to be treated was intended to reduce the likelihood of agitating the resin bed as the system is placed back into service in down-flow. Testing shall evaluate resin bed stability based on elimination of the regenerative displacement step.

3.4.3 Spent Resin Replacement

The final step in managing resin is the removal and replacement step, which is only performed as part of changing out the spent resin as radiation and exposure to oxygen in the waste will degrade the capacity of the resin to remove cesium from the waste. The resin will need to be replaced about 2 to 3 times per year in regular production operations. Before resin can be dumped from a column it must first have as much Cs removed as is practical from the sRF by the elution process as described in the above steps. In this final elution step, this is accomplished by using twice the normal volume of HNO_3. It is not necessary to convert the resin back to sodium form; therefore, resin dump will be performed after the post elution rinse of HNO_3 from the IX column. Resin dump may include introduction of some fluid to help mobilize the resin toward the disposal port. The final fluid properties, volume, flow rate, etc. will be determined during testing.

The resin will be pretreated with 1.0M NaOH to convert the resins to the sodium form prior to introduction into an IX column. Pretreatment of the resin allows the necessary expansion to occur outside of the IX column so that a controlled volume of resin can be introduced by direct measurement after expansion has occurred. Resin and 1M NaOH will be transferred into the IX column. Sluicing of the resin is preferred over the use of a diaphragm pump to minimize damage to the resin during the transfer.

3.4.4 Ion Exchange Column Hazards and Control Strategy

The LAWPS conceptual design effort included an evaluation of the heat generated by a fully loaded lead IX column. This heat load condition is initiated by a power outage/process upset in which the lead column is fully loaded with cesium in a no flow condition. Calculations project that a maximally loaded lead IX column with 106,000 Ci ^{137}Cs will generate enough decay heat to reach boiling. Additionally, flammable gases are generated in the no flow condition creating a deflagration/explosion hazard.

The hazard control strategy for a no flow condition, from RPP-RPT-58553, *Low Activity Waste Pretreatment System Safety Control Development and Design Integration*, is to discharge the un-eluted resin from the column to the RDT. The control strategy currently relies on the ability to open the resin disposal valve to discharge the resin to the RDT using gravity. No liquids are planned to be added to assist with resin fluidization and discharge. The cesium in the RDT is then eluted from the resin to enable disposal (Section 3.4.5). The cesium-loaded resin discharged to the RDT is expected to be in a safe configuration and does not require further controls. Elution of the loaded resin within the RDT is a post-accident recovery measure and is not required to be performed to reach a safe state. The hazard control strategy for dumping the resin from the IX column, and measures for elution of the cesium in the RDT will be tested in concert with the full-scale column test.

3.4.5 Resin Disposal Tank Elution Process

Chemical addition is required to elute resin if resin is received in the RDT loaded with cesium. RPP-RPT-58631 describes a resin elution process in the RDT. The resin in the RDT will be decanted to approximately 1,000 gallons, and then 0.1M NaOH added to the tank to refill to approximately 3,000 gallons to rinse/dilute any LAW waste from the resin. The contents are then mixed and decanted again to approximately 1,000 gallons. Water is then added to the RDT to refill the tank to approximately 3,000 gallons. This dilutes the NaOH prior to the addition of the nitric acid used for elution. The diluted solution is then decanted a third time to approximately 1,000 gallons. Nitric acid eluant (0.45 M) is then added to the resin in batches of approximately 3,000 gallons, recirculated and decanted. The batch elution process will likely need to be performed three to four times to adequately elute the resin to meet disposal limits. Sampling during testing will be used to confirm elution endpoint has been met. Testing of the process steps will be performed to confirm this method of elution is adequate to meet the disposal requirements for resin.

3.4.6 Test Sequence

The steps listed below outline the major tests planned for the full-scale IX column test. Non-radioactive cesium will be used for testing in lieu of radioactive cesium. Simulant will have elevated cesium levels to accelerate loading and reduce the amount of simulant. Detailed test sequences will be finalized during development of the test plan.

- *Grooming Tests:*

  Equipment setup/alignment will be verified with water to fine tune flow rates, pressure loss baselines, and operating procedures. Grooming tests will be performed without resin so that the resin is not exposed to oxygen or otherwise damaged.

- *Test 1 and 2 – IX Column Loading, Elution and Regeneration Tests*:

  The IX column will be loaded with cesium in the regular down-flow waste processing direction. The column will be eluted in down-flow and regenerated in up-flow for both the first and second IX column tests. The need for two tests is to compare the loading and elution of fresh resin in comparison to used/regenerated resin.

  Samples will be collected as shown in Table 3-5.

  Test 1 and 2 are each expected to take approximately 2 weeks (24/4 operations).

- *Test 3 – IX Column Loading and Gas Migration Test*:

  As with Test 1 and 2, the IX column will be loaded with cesium in down-flow. Fine, low pressure inert gas (e.g. helium) will be injected under the resin bed, and visually evaluated to determine the ability of the gas to migrate through the bed. Following this initial evaluation under processing conditions, the elution and regeneration cycle used in Tests 1 and 2 will be initiated. Visual evaluation will be performed to determine the movement of the gas into/away from the bed during the elution and regeneration flow. Note that laboratory testing will be performed by WRPS in concert with a national laboratory to determine gas retention within the IX column, which could potentially influence the design of the gas migration and retention aspect of this test.

  Samples will be collected as shown in Table 3-5.

  Test 3 is expected to take 1 week of 24/4 operations.

- *Tests 4 and 5 – IX Column Cesium Loading and Emergency Discharge Test*

  As with Tests 1, 2 and 3, the IX column will be loaded with cesium in down-flow. After the resin is loaded under normal operating conditions, the flow will be stopped to simulate a loss of flow condition. The resin emergency discharge operation will be initiated to dump the resin through the resin disposal valve by gravity flow into the RDT. Visual observations and measurements will be conducted to determine the amount of resin remaining in the IX column after discharge, and to observe the dispersion of the resin in a tank bottom mockup holding 3,000 gallons of liquid. Resin will be collected and preserved for Test 7 (RDT elution test). The resin sample will be stored in liquid and covered by an inert gas such as nitrogen at a slight pressure over atmospheric pressure with a pressure gauge to verify (visually) the inert gas cover. Test 5 will use a second column load of resin. The resin will be conditioned in sodium form and regular processing flow established. The batch of resin will not be loaded with cesium. After regular process flow is established through the column, flow will be stopped and emergency discharge of the resin from the column will be initiated. Visual observations and measurements will be conducted to determine the amount of resin remaining in the IX column after discharge, and to observe the dispersion of the resin in a tank bottom profile.

Samples will be collected as shown in Table 3-5.

A large volume resin sample will be collected in support of Test 7 of which laboratory samples will be extracted to verify resin loading.

Tests 4 and 5 are expected to take 1 week with 24/4 operations.

Table 3-5. Full-Scale IX Column Test Sample Planning Basis.

Tests 1,2,3 - IX Column Loading, Elution and Regeneration Tests	Process Step							
Location	Start Up	Loading	Displacement (0.1 M NaOH)	Pre Elution (water)	Elution (0.45 M HNO3)	Post Elution (water)	Regeneration (pt 1 and 2) (1 M NaOH)	Displacement (pt 1 and 2) (Treated Simulant)
Simulant Tank	3							
IX Column		5				5		
Treated Product Tank		10						
Cs Product Tank						5		
RDT								
Total per cycle	3	15	0	0	0	10	0	0
Chem Samples/Test Run	28							

Test 4 - IX Column Loading and Emergency Discharge Test	Process Step		
Location	Start Up	Loading	Post Resin Dump
Simulant Tank	3		
IX Column			
Treated Product Tank		10	
Cs Product Tank			
RDT			1 *For Test 7
Total per cycle	3	10	1
Chem Samples/Test Run	14		

Test 7 - RDT Resin Elution and Removal Test	Process Step				
Location	Start Up	Loading	Post Resin Dump	Elution (0.45 M HNO3)	Post RDT Elution
Simulant Tank					
IX Column					
Treated Product Tank					
Cs Product Tank				5	
RDT					5
Total per cycle	0	0	0	5	5
Chem Samples/Test Run	10				

Pre Start-up Activities	Number of Samples
Cold chemical supply (chem)	9
Total	9*

*Sampling must be repeated for every new batch of chemicals.

Note: Tests 5, 6, 8, and 9 have no sampling associated with those test runs.

- *Test 6 – Normal Operating Resin Discharge for Resin Disposal*

  This test will be conducted using a column load of resin retrieved from the RDT. The resin will be loaded into the column, eluted and regenerated to achieve a conditioned resin bed. Regular process flow will be established. The resin will not be loaded with cesium. Once regular process flow is established, flow will be stopped and the resin will be eluted and discharged to the RDT under normal operating conditions. Note that the resin will not be regenerated to sodium form before the resin is discharged to the RDT. Visual observations and measurements will be conducted to determine the amount of resin remaining in the IX column after discharge.

  Samples will be collected from reagents only.

  Test 6 is expected to take 1 week with 24/4 operations.

- *Test 7 – RDT Resin Elution and Removal Test*

  This test will evaluate the ability to elute and discharge the resin in a 1/9th scale test mockup of the RDT. The large resin sample collected during Test 4 will be used for this test. This test may be conducted in parallel with Test 5. The elution test will be based on the elution process description provided in Section 3.4.5. The final evaluation will be removal of resin from the RDT by pumping. Pumping is expected to damage the resin, therefore, the resin should be held separately after pumping and not remixed with other resin.

  Samples will be collected as shown in Table 3-5 from the eluted resin, and from the elution washes, i.e., each acid soak will be sampled.

  Test 7 is not expected to add to the overall test duration because the test will be performed in parallel with other tests. Allow 1 week of parallel work activity.

- *Test 8 - Solids Accumulation Test*

  Feed with solids will be fed to the column and the column internals will be visually inspected for solids accumulation. The solids will simulate precipitants that may form and potentially accumulate in the IX column, which could cause plugging or interfere with cesium ion exchange. This test will be performed after Test 6 because solids may contaminate resin. Evaluations will be performed under regular process flow, elution, regeneration, and resin removal. Loading the resin with cesium is not required for Test 8.

  Test 8 is expected to take 24 hours to perform.

- *Test 9 – IX Column Emergency Discharge Test Under Non-Ideal Column Condition*

  This test will evaluate the ability to discharge the resin from the IX column during a no flow emergency condition in which solids have accumulated in the resin bed, and a gas bubble has displaced some of the liquid in the column. Solids will be added back to the resin bed if solids are not present after completing Test 8. Displace some of the liquid in the column with no flow through the column. Discharge the resin to the RDT. Loading the resin with cesium is not required for Test 9.

  Test 9 is expected to take 1 week with 24/4 operations.

3.4.7 Scale

A full-scale IX column test is needed to support integration of the IX column into the overall testing strategy because some IX parameters such as column residence time, superficial lineal velocity, and properties affected by height to diameter ratio cannot be simultaneously and effectively scaled. A full-scale RDT tank bottom is incorporated into the test design that is sized to observe discharge and dispersion of the resin in the tank bottom. A separate 1/9th scale RDT will be used to test elution of resin and recovery of resin for disposal after a no flow, emergency resin discharge event.

3.4.8 Sampling

Sampling locations to obtain chemical data are denoted in Figure 3-2 above. A sample planning basis is provided in Table 3-5. The samples noted are the minimum number of samples planned to be collected. Note that resin sampling using a pump may damage resin and alternate means to sample resin shall be incorporated into the design.

3.5 ENGINEERING-SCALE INTEGRATED TEST

The following subsections describe the test process and equipment used for the engineering-scale integrated test. Support tests that are needed to support the engineering-scale integrated testing are also described. These support tests will be conducted by WRPS in conjunction with a national laboratory, and the necessary data provided to the Subcontractor.

3.5.1 1/9th Scale Process and Equipment Description

The process for the engineering-scale integrated test contains two key functions, 1) remove solids from the waste simulant stream and 2) remove Cesium (Cs) from the waste simulant stream. The first step is accomplished by passing waste through a Cross Flow Filter (CFF) to remove the solids. The second step in accomplished by passing the waste simulant through an Ion Exchange (IX) system. For details associated with the IX process see Section 3.4.1 and 3.4.2.

The integrated test shall reflect the LAWPS planned design configuration at a 1/9th process scale. A conceptual schematic of the planned test layout is shown in Figure 3-5. The integrated test set up shall have, as a minimum, all of the components/items shown in the schematic. The following sections describe the key features of the main systems.

1. Simulant Stock Tank System – The simulant stock tank system shall have the following features:
    - Capable of adjusting cesium and potassium levels to support each process run
    - Configured to provide waste simulant to the FFT at 10 gpm using a variable speed pump
    - Configured with temperature pressure and flow instrumentation for the feed line
    - Configured such that the simulant return line discharges below the liquid surface
    - Capable of holding enough simulant to support an entire process run
    - Contains liquid level indication
    - Support on line sampling
    - Contain valving for system isolation

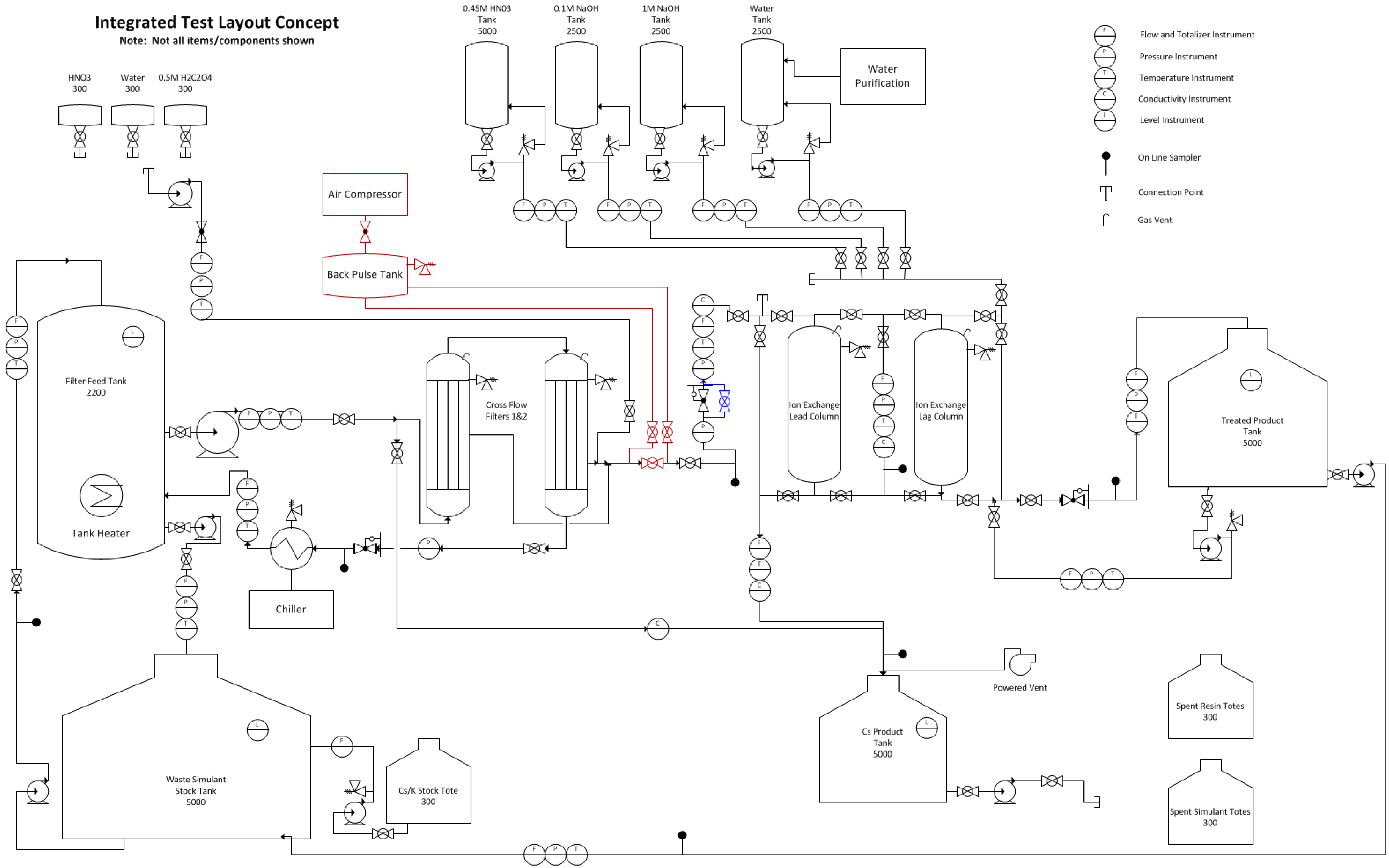

Figure 3-5. LAWPS 1/9th Scale Integrated Test Conceptual Schematic.

2. Filter Feed Tank System – The filter feed tank shall have the following features:

   - Configured to return waste simulant to the simulant stock tank at 8 to 10 gpm using a variable speed pump
   - Configured with temperature pressure and flow instrumentation for the return line
   - Configured such that the return line exits from the bottom of the FFT
   - Configured with a bottom slope such that solids are directed to the return line
   - Configured such that the simulant feed line discharges below the liquid surface
   - Provide heating capability to support elevated temperature test runs
   - Contain liquid level indication
   - Contain valving for system isolation

3. Cross Flow Filter System/Loop – The CFF system/loop shall have the following features:

   - Configured to recirculate waste simulant from the FFT using a variable speed pump through a heat exchanger, CFFs, and return to the FFT at 100 gpm.
   - Configured with temperature pressure and flow instrumentation on the supply and return line.
   - Configured with flow/pressure regulation to control transmembrane pressure
   - Contain a heat exchanger to remove pump heat and adjust process temperature
   - Contain valving for system isolation
   - Support on line sampling
   - Contain two (2) - Mott 8-inch HyPulse[5] LSX Dual-Pass filters with filter tubes that are 120-inch long, ½-inch ID, a media grade of 0.1 µm, and a material type of 316L
   - Contain appropriate pressure vessel pressure relief for each CFF
   - Contain connections to support CFF cleaning solution
   - Contain a CFF back pulse system with appropriate pressure vessel pressure relief

4. Ion Exchange System - The IX system shall have the following features:

   - Contain two (2) translucent 14-inch inner diameter full height IX columns each capable of containing approximately 34 gallons of sRF resin in sodium form
   - Configured with conductivity, temperature, pressure, and flow instrumentation on the supply and exit of each column
   - Contain a flow/pressure regulator before and after the IX system
   - Contain a bypass around each flow/pressure regulator
   - Contain valving that allows for multidirectional operation of the IX column and isolation
   - Contain appropriate pressure vessel pressure relief for each IX column
   - Support on line sampling
   - Contain a Crispin X Series gas vent for each IX column
   - Contain connections to the Cs product tank system
   - Contain connections to the cold chemical supply system

[5]HyPulse is a trademark of Mott Corporation, Farmington, CT

5. Treated Product Tank System - The treated product tank system shall have the following features:
    - Configured such that the treated simulant inlet line discharges below the liquid surface
    - Configured to return waste simulant to the simulant stock tank system
    - Configured with temperature pressure and flow instrumentation for line feeding the simulant stock tank system
    - Capable of holding enough treated simulant to support an entire process run
    - Contain liquid level indication
    - Support on line sampling
    - Contain valving for system isolation

6. Cold Chemical System – The cold chemical system shall have the following features:
    - Capable of providing the required chemical solutions at the flow rates and volumes necessary to support a process run
    - Configured with temperature pressure and flow instrumentation
    - Contain liquid level indication
    - Support sampling
    - Contain valving for system isolation

7. Cesium Product Tank System – The cesium product tank system shall have the following features:
    - Capable of containing the waste products for each process run.
    - Configured to provide off gas exhaust
    - Contain liquid level indication
    - Support on line sampling
    - Contain valving for system isolation
    - Provide a mechanism for removal of liquids and solids

8. Sampling System – The sampling system shall have the following features:
    - Capable of taking samples on-line without interruption to the process

9. Control System – The control system for the integrated test shall have the following features:
    - Utilize an ABB programmable logic controller and human machine interface
    - Capable of operating the process system automatically
    - Capable of interfacing with all of the instrumentation to collect data and make adjustments to the operation based on the instrument inputs
    - Capable of controlling the pumps, valves, and chiller system automatically

Testing will be conducted as part of the 1/9th scale integrated test to determine the feasibility of cleaning the CFF using IX column elution reagent. To enable elution acid to be used for cleaning the CFF, valves shall be re-configured to enable elution acid to be directed to the CFF. The test layout for the alternative CFF cleaning method is shown in Figure 3-5 with the back pulse system, shown in red, valved out. A bypass line/valve, shown in blue, is included around the pressure regulating device after the CFF. The bypass line/valve facilitates the alternate filter cleaning method to be tested using a portion of the IX elution reagent.

3.5.2 Support Tests for Engineering-Scale Integrated Test

Support tests will be performed by WRPS in conjunction with a national laboratory, and are intended to provide information that can be used to support/refine the engineering-scale integrated test. The tests are not part of the Subcontractor's work scope, however; test data from the support tests will be made available in support of the Subcontractor's test scope. Support testing will consist of a small-scale CFF. The testing is planned to include a simulant tank, pump, CFF heat removal system and various control and instruments. This CFF test loop will be operated to refine the simulant and cleaning approaches to be used for the engineering-scale integrated test.

3.5.3 Test Sequence

The following provides a general description of the proposed testing sequence for the engineering-scale integrated test. Support tests, described in Section 3.5.2, will provide input to refine the integrated test. Detailed test sequences will be finalized during development of the test plan.

3.5.3.1 Initial Start-up

After initial assembly and leak testing, the integrated system shall be incrementally brought on-line to ensure each portion of the system is working as intended. The planned start-up increments are identified below. This activity shall be performed initially with water followed by waste simulant for each system.

- Simulant Feed and FFT: Ensure intended operation and ability to maintain proper level in the FFT and pump control;
- CFF Feed Pump and CFF Loop: Ensure that operation of the CFF feed pump and process parameters for the loop are as intended;
- IX Column System: Ensure that operation of the pressure regulation before and after the IX columns, and process parameters for the system are as intended; and
- Elution and Regeneration: Ensure operation and process parameters are as intended.

3.5.3.2 Simulant Testing

The waste simulant testing shall be performed after initial start-up. A total of ten simulant runs are planned with each run consisting of waste loading, elution, and regeneration activities. The waste simulant for the loading portion of each run will be mixed to support a target of 125 bed volumes of loading prior to elution. This shall be performed by adjusting the concentrations of cesium and potassium. The phases that make up the planned simulant runs are listed below.

- Phase 1 (3 test runs)

This phase will use the 5.6 M (approx) sodium content waste simulant with the CFFs in the vertical orientation. The contents of the simulants are defined in Section 3.6. The temperature of the waste feed for all runs shall be maintained at 25°C in the FFT. The filtrate flow rate shall be maintained at a steady rate to the extent operationally possible for two runs, one at the maximum expected flow rate (1.9 gpm) and the second at the minimum expected flow rate (0.4 gpm).

Cleaning of the filter shall be performed as required to maintain the flow rate. The third run is performed while allowing fading the flow rate from the maximum to the minimum expected flow rate. Cleaning of the filter shall be performed after the minimum flow rate is reached. Sampling shall be performed at various points along the process in accordance with Table 3-6 (as a minimum).

- Phase 2 (2 test runs)

This phase will use the 5.6 M (approx) sodium content waste simulant with the CFFs in the vertical orientation. The contents of the simulants are defined in Section 3.6. The filtrate flow rate shall be maintained at a steady flow rate to the extent operationally possible for two runs. The first run utilizes a constant waste simulant feed temperature of 25°C in the FFT. The second run utilizes a constant waste simulant feed temperature of 45°C in the FFT. Sampling occurs at various points along the process and chemical and operational data is obtained. Cleaning of the filter shall be performed as needed to maintain the flow rate. Sampling shall be performed at various points along the process in accordance with Table 3-6 (as a minimum).

- Phase 3 (2 test runs)

This phase will use the 8 M (approx) sodium content waste simulant with the CFFs in the vertical orientation. The contents of the simulants are defined in Section 3.6. Two runs are performed each utilizing a fading filtrate flow rate from the maximum (1.9 gpm) to the minimum (0.4 gpm) expected. The temperature of the waste feed simulant of the first run is held at 25°C in the FFT. The second run is held at 45°C in the FFT. Cleaning of the filter shall be performed after the minimum flow rate is reached. Sampling shall be performed at various points along the process in accordance with Table 3-6 (as a minimum).

- Phase 4 (1 test run)

This phase will use the 8 M (approx) sodium content waste simulant with the CFFs in the vertical orientation. The contents of the simulants are defined in Section 3.6. One run is performed using a constant filtrate flow rate to the extent operational possibly. The temperature for the run is faded from 45°C in the FFT to 25°C in the FFT over the duration of the run. Cleaning of the filter shall be performed as required. Sampling shall be performed at various points along the process in accordance with Table 3-6 (as a minimum).

Table 3-6. Integrated Test Sample Planning Basis (Samples/Test Run).

(Cs Analysis Only)

Location	Process Step: Start Up	Loading	Displacement (0.1 M NaOH)	Pre Elution (water)	Elution (0.45 M HNO3)	Post Elution (water)	Regeneration (pt 1 and 2) (1 M NaOH)	Displacement (pt 1 and 2) (Treated Simulant)	Return simulant to feed tank	Cs recharge of simulant (adding Cs to simulant)	Cs Product Tank (verification for disposal)
Simulant feed line to FFT	3	3								3	
FFT CFF loop		4									
Before IX lead		30	1	1	5	1	2	1			
Between IX lead and lag		30	1	1	5	1	2	1			
After IX lag		30									
Cs product line			1	1	5	1	2	1			
Treated product return line									3		
Cold Chem (HN03)	2										
Cold Chem (0.1M NaOH)	2										
Cold Chem (1M NaOH)	2										
Cold Chem (water)	2										
Cs Product Tank											3
Total per cycle	11	97	3	3	15	3	6	3	3	3	3
Chem Samples/Test Run	150										

(K+Na Analysis or Chem Analysis)

Location	Process Step: Start Up	Loading	Displacement (0.1 M NaOH)	Pre Elution (water)	Elution (0.45 M HNO3)	Post Elution (water)	Regeneration (pt 1 and 2) (1 M NaOH)	Displacement (pt 1 and 2) (Treated Simulant)	Return simulant to feed tank	Cs recharge of simulant (adding Cs to simulant)	Cs Product Tank (verification for disposal)
Simulant feed line to FFT	3	3								3	
FFT CFF loop		4									
Before IX lead		30	1	1	5	1	2	1			
Between IX lead and lag		30	1	1	5	1	2	1			
After IX lag		30									
Cs product line			1	1	5	1	2	1			
Treated product return line									3		
Cold Chem (HN03)	2										
Cold Chem (0.1M NaOH)	2										
Cold Chem (1M NaOH)	2										
Cold Chem (water)	2										
Cs Product Tank											3
Total per cycle	11	97	3	3	15	3	6	3	3	3	3
Chem Samples/Test Run	150										

(Solids Analysis)

Location	Process Step: Start Up	Loading	Displacement (0.1 M NaOH)	Pre Elution (water)	Elution (0.45 M HNO3)	Post Elution (water)	Regeneration (pt 1 and 2) (1 M NaOH)	Displacement (pt 1 and 2) (Treated Simulant)	Return simulant to feed tank	Cs recharge of simulant (adding Cs to simulant)	Cs Product Tank (verification for disposal)
Simulant feed line to FFT	1	3									
FFT CFF loop		20									
Before IX lead		20									
Between IX lead and lag											
After IX lag		20									
Cs product line											
Treated product return line									3		
Cold Chem (HN03)	2										
Cold Chem (0.1M NaOH)	2										
Cold Chem (1M NaOH)	2										
Cold Chem (water)	2										
Cs Product Tank											
Total per cycle	9	63	0	0	0	0	0	0	3	0	0
Solids Samples/Test Run	75										

Pre Start-up Activities	Number of Samples
CFF Function (solids and chem)	10
IXC (solids and chem)	10
Cold chemical supply (chem)	8
Total	28

Neutralization Activities	Number of Samples
3 samples of end Cs product tank solution to be neutralized per run (3x10) for chem	30
3 samples of end Cs product tank solution to be neutralized per run (3x10) for solids	30
Total	60

- Phase 5 (2 test runs)

This phase will use the 5.6 M (approx.) sodium content waste simulant with the CFFs in the horizontal orientation. The contents of the simulants are defined in Section 3.6. The filtrate flow rate shall be maintained at a steady flow rate to the extent operationally possible for two runs. The first run utilizes a constant waste simulant feed temperature of 25℃ in the FFT. The second run utilizes a constant waste simulant feed temperature of 45℃ in the FFT. Sampling occurs at various points along the process and chemical and operational data is obtained. Cleaning of the filter shall be performed as needed to maintain the flow rate. Sampling shall be performed at various points along the process in accordance with Table 3-6 (as a minimum).

Filter cleaning shall be performed in parallel with the tests listed above, based on a combination of small-scale test results and observed operational conditions. Filter cleaning approaches during testing should use the IX cesium elution/regeneration solutions to the extent practical to demonstrate process optimization. The IX cesium eluate is stored in the cesium product tank. The fluids generated from the elution and regeneration steps (displacement, pre-elution rinse, elution, post-elution rinse, regeneration) are also stored in the cesium product tank. This combination of acidic and basic solutions result in the cesium product tank having an inventory that may be incompatible with AP Tank Farm transfer pH requirements. As such, the cesium product tank will receive the addition of adjustment chemicals from the chemical reagent tanks. Operationally, the tank will be sampled, tested and adjusted through the addition of HNO_3/NaOH until its pH is within the acceptable range designated by the AP Tank Farm.

3.5.4 Scale

The scale for the engineering-scale integrated prototypic test shall be $1/9^{th}$ scale with the primary scaling factor being the volumetric process rates. The size of the scale selected reduces the cost of the equipment, operation, and simulant while still preserving the technology integration functions using simulant with relevant physical and chemical properties. This scaling factor is applied to the overall process and the individual components sized accordingly.

The primary focus of the equipment sizing is to maintain process velocities, residence time, and chemical performance at the scaled process rate. The size of key components to be used as part of the test set up are listed in Table 3-7. As an example of the scaling approach, for a nominal flow rate of 12 gpm (full-scale), the corresponding scaled flow rate is ~1.3 gpm. From this scaled flow equipment is sized to maintain the process velocities, etc. consistent with the full-scale design.

This approach results in a reduction in size for most of the component parameters. However, some attributes are intentionally left at full-scale dimension. This maintains a specific physical performance attribute important to the testing or due to the fact that scaling the item was not practical and could negatively impact the applicability of the scaled results to the full-scale design. Key examples of this include:

- Full height IX column – Maintains the pressure drop across the resin bed, flow velocities, and chemical performance
- Full size sRF resin beads – Maintains the hydraulic and chemical performance characteristics of the resin

Table 3-7. 1/9th Engineering-Scale Equipment Scaling

Test Component	LAWPS Baseline Sizing	Scaled Size (1/9th Scale)	Selected Size for Test Configuration	Scaling Criteria
Line Sizing				
Filtrate Processing Pipe Diameter	1 inch	0.33 inch	3/8 inch Swagelok tube (0.305 ID)	Scaled to match full-scale velocity
Cold Chemical Pipe Diameter	2 inch	0.67 inch	3/4 inch Swagelok tube (0.620 ID)	Scaled to match full-scale velocity
CFF Recirculation Loop Pipe Diameter	8 inch	2.67 inch	3 inch Sch. 40 SS pipe	Scaled to match full-scale velocity
Tank Sizing				
Simulant Tank	1,000,000 gallons	N/A	5000 gallons	Size selected for convenience (not scaled)
Filter Feed Tank	7,181 gallons	798 gallons	800 gallons	Scaled by volume, maintaining L=1.2*D
Cold Chemical Supply Tanks	12,000 gallons	N/A	2500 gallons	Size selected for convenience (not scaled)
Cesium Product Tank	26,000 gallons	N/A	5000 gallons	Size selected for convenience (not scaled)
Treated Product Tank	1,560 gallons	N/A	5000 gallons	Size selected for convenience (not scaled)
CFF and IX Columns				
CFF	532 $ft.^2$ of filter area	59 $ft.^2$ of filter area	62 $ft.^2$ of filter area	Scaling based on filter area and represents two Mott 8" HyPulse LSX Dual-Pass filters. Individual tube diameter, tube length, and porosity all maintained at full scale.
IX Column Resin Bed Length	50.4 inches	50.4 inches	50.4 inches	Full length geometry to simulate pressure drop
IX Column Resin Bed Diameter	42 inches	14 inches	14 inches	Scaled by cross sectional area of column to match full scale velocity
IX Column Resin Bed Volume	308 gallons	34 gallons	34 gallons	Resin volume in Sodium form
IX Column Volume	588 gallons	59 gallons	59 gallons	Column volume
Overall IX Column Height	126 inches	98 inches	98 inches	Column height

- Full diameter CFF tubes and pore size – Maintains the cross sectional surface area and boundary layer filter cake effects at planned velocities

3.5.5 Sampling

Sampling locations to obtain chemical and solids data are denoted in Figure 3-5 above. A sample planning basis is provided in Table 3-6. The samples noted are the number of samples planned to be collected for each test run. Where sample volume allows and analytical laboratory techniques permit, multiple analyses may be run on a single sample to reduce laboratory costs. Sampling systems/methods shall be capable of being used online and not interfere with process operations.

IX column elution and regeneration streams are directed to the cesium product tank for storage. Some of the Cs product tank content will be sampled and neutralized to demonstrated Cs product tank eluent neutralization to meet acceptance requirements for AP Tank Farm return requirements.

3.6 SIMULANTS

Simulant recipes for DST supernatant waste are under development. Two different simulants are planned for testing, 1) a 5.6 M (approx) sodium base simulant and 2) an 8 M (approx) sodium base simulant. The anticipated chemical and physical characteristics of the simulants are described below.

Important Chemical Species:

- Sodium Oxalate (solids and precipitation)
- Non-radioactive cesium
- Sodium Hydroxide
- Sodium Nitrate
- Potassium containing salts
- Sodium phosphate containing salts

Important Physical Characteristics:

- Sodium Molarity: approximately 4 to 8 M[6]
- Density: 1.0 to 1.35 g/ml
- Viscosity: 1 to 15 cP
- Temperature: 20° to 45°C
- Solids Concentration: 0 to 3.3 wt%
- Solids Particle Size: 0.01 to 210 µm

Simulant may be loaded at cesium concentration that are higher than expected in the tank waste to reduce the overall volume of simulant needed and to reduce the test run time.

[6]The 6M upper bound sodium concentration specified in RPP-SPEC-56967 may be tested to approximately 8 M in support of material balance work and expanded isotherm testing work (by others).

3.7 TEST ENVIRONMENT

The test environment shall be protected from wind, rain, snow, ice, direct sunlight, and harmful levels of pollutants. The test facility shall be capable of controlling the environmental conditions to protect sensitive data acquisition, monitoring and control equipment, and provide a test environment that is not limited in use due to normal seasonal fluctuations in weather conditions. The temperature range of the test environment shall be capable of being maintained within 60°F to 80°F.

3.8 TEST OBJECTIVES AND SUCCESS CRITERIA

Test objectives and success criteria are provided in Table 3-8. These objectives and criteria shall be implemented in test plans and procedures, and demonstrated in the full-scale IX column test and/or the engineering-scale integrated test.

Table 3-8. Test Objectives and Success Criteria.

ID	Description	Test Objective	Success Criteria
P1	Verify material balance for cesium removal.	Using a designed waste simulant, monitor/demonstrate removal of non-radioactive cesium from process stream using IX.	*Cs Limit: ≤ 3.66 E-07 g Cs/gmol Na *Value should be slightly lower because of mass difference between Cs-137 and Cs-133
P2	Verify material balance for undissolved solids removal.	Using a designed waste simulant, monitor/demonstrate removal of undissolved solids from process stream using CFF while feeding process system.	Remove undissolved (entrained) solids larger than 0.1 µm from tank supernatant waste feed.
P3	Verify material and energy balance for process throughput.	Monitor/demonstrate volumetric throughput of waste stream using designed simulant.	Full-scale: 4 to 17 gpm, 1/9th –scale: 0.44 to 1.89 gpm filtrate from CFF to IX column.
P4	Verify integrated system hydraulics and process criteria.	Using a design waste simulant, monitor the following parameters:	
		• flow rates through FFT, CFF, IXC	Full-scale: FFT: 90 gpm (approx.) DST to FFT FFT: 900 gpm (approx.) FFT to CFF tubes CFF: 4 to 17 gpm filtrate production rate IXC: 4 to 17 gpm LAW production rate 1/9th scale: FFT: 10 gpm (approx.) Stock tank to FFT FFT: 100 gpm (approx.) FFT to CFF tubes CFF: 0.44 to 1.89 gpm filtrate from CFF to IX columns IXC: 0.44 to 1.89 gpm LAW production rate
		• critical velocities in process system-mixing parameters in IX: elution, regeneration, loading	Design features, such as features that introduce fluids during regular operating flow, elution and regeneration steps, and safety significant features do not diminish IX column performance.
		• presence of undissolved gas	No visually detectable build-up of undissolved gas in IX column that interferes with column performance.
P5	Verify coordination of key control components.	Using a designed waste simulant, monitor the key control components used in operation of an integrated system for:	
		• FFT and pumps	Recirculation loop operates continuously for 24 hours while maintaining temperature to less than 45°C. Pump cavitation is not detected due to factors such as build-up of undissolved gas in

ID	Description	Test Objective	Success Criteria
			the FFT loop.
		• CFF and pressure control (shell and tube)	Measure and record filtrate production rate with respect to transmembrane pressure. Establish baseline performance of filter in new condition. Test in both horizontal and vertical filter orientations.
		• Product tank (flow restriction)	Observe design features (such as a product tank or other) maintains sufficient backpressure on the IX system to support proper IX column operation.
P6	Verify treated LAW meets WAC.	Monitor the treated simulant product for the following:	
		• Non-radioactive cesium	See P1 criterion.
		• Solids	See P2 criterion.
C1	Verify elution of cesium and resin regeneration effectiveness.	Demonstrate effectiveness of cesium elution.	1. After elution and regeneration, resin bed is deposited entirely in the column location designed to hold the resin. 2. Elimination of the "regenerative displacement" step based on effects on bed stability when column is placed back into waste treatment service in down-flow. 3. Column loading, elution and regeneration steps are in plug flow. 4. IX column elution of non-radioactive cesium meets design specifications for spent resin disposal after eluting with approximately 15 bed volumes/column 0.45 M HNO_3. 5. RDT elution of non-radioactive cesium meets design specifications for spent resin disposal after eluting with approximately 30 to 40 bed volumes of 0.45 M HNO_3 (full-scale IX test only). 6. During a second cesium load cycle, cesium content passing through the resin bed (cesium bleed) does not exceed 10 percent of the limits expected in the WTP LAW

ID	Description	Test Objective	Success Criteria
			glass (3.5 E-03 g Cs/m^3)* when applied to the expected LAWPS feed. 7. Resin elution and regeneration frequency after the first load, elution and regeneration cycle does not exceed expected frequency *Value should be slightly lower because of mass difference between Cs-137 and Cs-133
		Demonstrate effectiveness of resin regeneration.	After regeneration, resin bed is visually level and deposited entirely in the column location designed to hold the resin. Resin has fully converted to sodium form.
		Demonstrate/observe that contaminants (precipitants) can be removed by regeneration and elution.	≤ 70 µm precipitants (sodium oxalate or simulant) removed from column during elution and regeneration cycles (full-scale IX test only).
		Demonstrate sampling and testing of used resin for cesium (at end of testing).[1]	Sampling technique for spent resin can be successfully performed. Cesium residual on eluted spent resin is below limits to allow proposed treatment and disposal of resin.
C2	Verify eluent is treated to meet DST corrosion specification.	Obtain samples of eluent material to support lab analysis.[1]	Demonstrate successful sample collection methodology.
C3	Verify neutralization requirements/lack of undesired products.	Utilizing elution samples, observe neutralization and monitor for precipitates.[1]	Sample is successfully neutralized to meet DST corrosion standard (pH ≥ 8). Observe and record degree of precipitant formation in sample.
C4	Verify CFF cleaning effectiveness.	Monitor effects of using elution stream for CFF cleaning.	1. Measure and record filtrate production rate with respect to transmembrane pressure to establish CFF recovery after cleaning. 2. Measure and record duration between filter cleaning cycles. Test CFF in both horizontal and vertical filter orientations.
R1	Verify resin addition process.	Demonstrate loading resin into IX column.	Resin loads successfully into column at expected rate.
		Demonstrate that resin is uniformly deposited and supported within the column as designed.	Resin bed accumulation is visually level and deposited entirely in the column location designed to hold the resin.

ID	Description	Test Objective	Success Criteria
		Demonstrate that resin is contained within the column.	Resin or resin fragments do not pass outside of ion exchange column during regular process flow, elution, and regeneration steps.
R2	Verify resin removal process. (full-scale IX test only)	Demonstrated/observe discharge of spent resin from column.	1. No Flow Emergency Discharge a. Less than calculated amount of resin remains in IX column after resin discharges to satisfy hazard control strategy in accordance with RPP-RPT-58553, *Low Activity Waste Pretreatment System Safety Control Development and Design Integration*. i. Clean resin bed with filled column. ii. Accumulated solids in resin bed with partially filled column. b. Observe settling behavior of IX media after discharge from the IX column to determine if proposed tank geometry supports dispersion of the resin and the resin is maintained submerged in support of vessel heat generation calculation assumptions. c. Establish RDT elution effectiveness for post-emergency discharge of resin. 2. Normal (non-safety) Operation Discharge a. ≤ 1% of spent resin remains in column after a single discharge cycle. Fluid properties, volume and flow rate is recorded for input to mass and energy balance. 3. Eluted resin can be removed from RDT for disposal.
F1	Verify process parameters are met for waste feed.	Monitor process feed parameters.	Full-Scale: 90 gpm (approx.) flow rate between DST to FFT. 1/9th scale: 10 gpm (approx.) flow rate between

ID	Description	Test Objective	Success Criteria
			stock tank to FFT.
F2	Verify coordination of key control components.	Using a designed waste simulant monitor the key control components used in maintaining appropriate level in FFT.	1. Successful continuous operation of filter feed loop for at least 24 hours without accumulation of headspace gas. 2. Successful feed and bleed waste to/from the FFT loop at least four times during the 24 hour run.
F3	Verify process parameters are met for waste return (liquid and solids).	Monitor for undissolved solids removal from FFT.	See P2 Success Criterion.

[1] These objectives may be performed in a laboratory environment with materials obtained in integrated testing.

4.0 QUALITY ASSURANCE

This testing is developmental in nature and has been determined to be Full Quality Assurance (FQA) for the resultant test data. Results will be used as design input. Testing equipment is prototypic and will follow commercial quality practices. Testing shall be conducted in accordance with the requirements of the Subcontractor's approved quality assurance program and implementing quality assurance procedures. This includes the use of calibrated measurement and test equipment when measurements are taken, and qualified personnel and procedures for testing and special evolutions such as nondestructive testing activities. Test plans and procedures, based on the requirements in this document and the Statement of Work shall be prepared in accordance with the Subcontractor's quality assurance program. The approved and issued test plans and procedures shall be considered the governing documents for the testing work. Changes to an approved test plans and test procedures shall be performed in accordance with applicable change control procedures under an approved NQA-1 quality assurance program. Test exceptions, such as test article malfunction, test design deficiency, failure to meet test success criteria, shall be documented. Buyer quality assurance personnel may perform surveillance oversight of test activities. Testing will be performed under the direction of a qualified Test Director and/or Test Engineer whose qualifications are documented and on file. A personnel qualification matrix shall be kept on file at the test facility identifying those designated personnel and their capabilities to perform test activities as required for the conduct of this testing work.

5.0 INDUSTRIAL SAFETY AND HEALTH

Testing shall be conducted in accordance with the Subcontractor's health and safety procedures in accordance with state and federal regulations. Oversight of safety practices related to Subcontractor testing activities may be performed by WRPS personnel. All personnel on the test team (including subcontractor and WRPS) shall immediately bring any personnel safety concerns to the attention of the Test Director for immediate resolution.

6.0 REFERENCES

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