DOE Hanford Tank Side Cesium Removal System (TSCR) Update: Fabrication and Factory Acceptance Testing – 20300

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ABSTRACT

The Tank Side Cesium Removal (TSCR) System is a modular, quickly-deployable, and passively safe system for efficiently removing solids and cesium from alkaline liquid waste raffinate created by fuel processing on the Hanford site. This paper provides an overview of the project with particular emphasis on completion of fabrication and factory acceptance testing (FAT).

All TSCR System components are inside three enclosures known as the Process Enclosure, Ancillary Enclosure, and Control Enclosure. The Process Enclosure is seismic design category II (SDC-II) and built to withstand the rigors of transportation and lifting, high winds, volcanic ash fall, and heavy precipitation (snow) over a temperature range of -25 to 115°F. The Process Enclosure and Control Enclosure were fabricated in AVANTech's Columbia, SC facility, while the Ancillary Enclosure was fabricated in AVANTech's Richland, WA facility. The design and preliminary documented safety analysis were completed in December 2019, with all work being performed in accordance with ASME NQA-1 quality assurance requirements. The Process Enclosure, Ion Exchange Columns (IXCs), and several other TSCR components have a nuclear safety function and are designated as safety significant structures, systems, and components (SS-SSCs). The NQA-1 Commercial Grade Dedication (CGD) process was used to identify critical characteristics in order to accept materials and items used for fabrication of several safety significant TSCR components. This paper also addresses unique aspects and challenges of implementing CGD in DOE facilities and systems.

After fabrication and preliminary testing, the Process and Control Enclosures were shipped to AVANTech's Richland facility where the complete TSCR System was setup and connected in a represented layout and configuration that will be used on the Hanford site. Test tanks and pumps were put in place and connected to the TSCR Process Enclosure in a manner that mimicked interfacing Double Shell Tanks in the 241-AP Tank Farm. The TSCR System was then tested/operated under conditions equivalent to those planned for onsite operation. Testing was separated into five separate phases as defined below:

- Phase 1: Confirmation of TSCR System readiness for the FAT;
- Phase 2: Verification of TSCR System operation under standard conditions;
- Phase 3: Demonstration of TSCR System operation under non-standard conditions;
- Phase 4: Demonstration of ion exchange media removal from an IXC; and
- Phase 5: Completion of TSCR System lift plans and site mobilization.

The Hanford Tank Operations Contractor, Washington River Protection Solutions (WRPS), participated in all phases of testing. Testing at AVANTech's Richland Facility allowed WRPS personnel to familiarize themselves with TSCR operations in a radiologically clean facility prior to onsite mobilization. Engineering and operations personnel gained valuable experience that allowed them to better refine onsite operational protocols and procedures – including handling and movement of IXCs with a forklift.

This paper describes the technologies used by the TSCR System as well as how these technologies are deployed and operated to advance the Hanford mission of safely, efficiently, and effectively treating tank waste. It also provides detailed information on fabrication and FAT, including operational data from simulated tank waste runs. A project schedule for WRPS' planned construction acceptance testing, operational acceptance testing, and actual tank waste treatment is provided. This presentation should be of great interest to parties responsible for the design, testing, and mobilization of modular NQA-1 technologies for the treatment of raffinate and similar liquid wastes containing high concentrations of radioactive cesium.

INTRODUCTION

The US DOE, Office of River Protection's (ORP's) primary mission is to retrieve and treat Hanford's tank waste and close the Tank Farms to protect the Columbia River. Radioactive liquid waste is stored in 177 underground tanks at the Hanford Site as reported in the Inventory Data Package (DOE/ORP 2003-02). The 177 underground tanks are estimated to contain about 56 million gallons of waste in the form of supernatant, salt cake, and/or sludge. The TSCR System is a component of the Direct Feed Low Active Waste (DFLAW) initiative, which provides for early production of low-activity waste (LAW) that can be fed directly to the Waste Treatment Plant (WTP) LAW Vitrification Facility, thus bypassing the WTP Pretreatment Facility. Tank supernatant waste will be pretreated in the TSCR System to remove solids and reduce Cs-137 below the WTP LAW Waste Acceptance Criteria (WAC).

The TSCR System uses a modular design with all components, controls, and ancillary components located within three enclosures that will be placed tank-side in the 241-AP Tank Farm at Hanford as shown in Fig. 1. The TSCR system is of a very compact design; all three enclosures - together with the space needed for fork lift travel - takes up a space of about 1/10th acre at the edge of the AP-Tank farm.

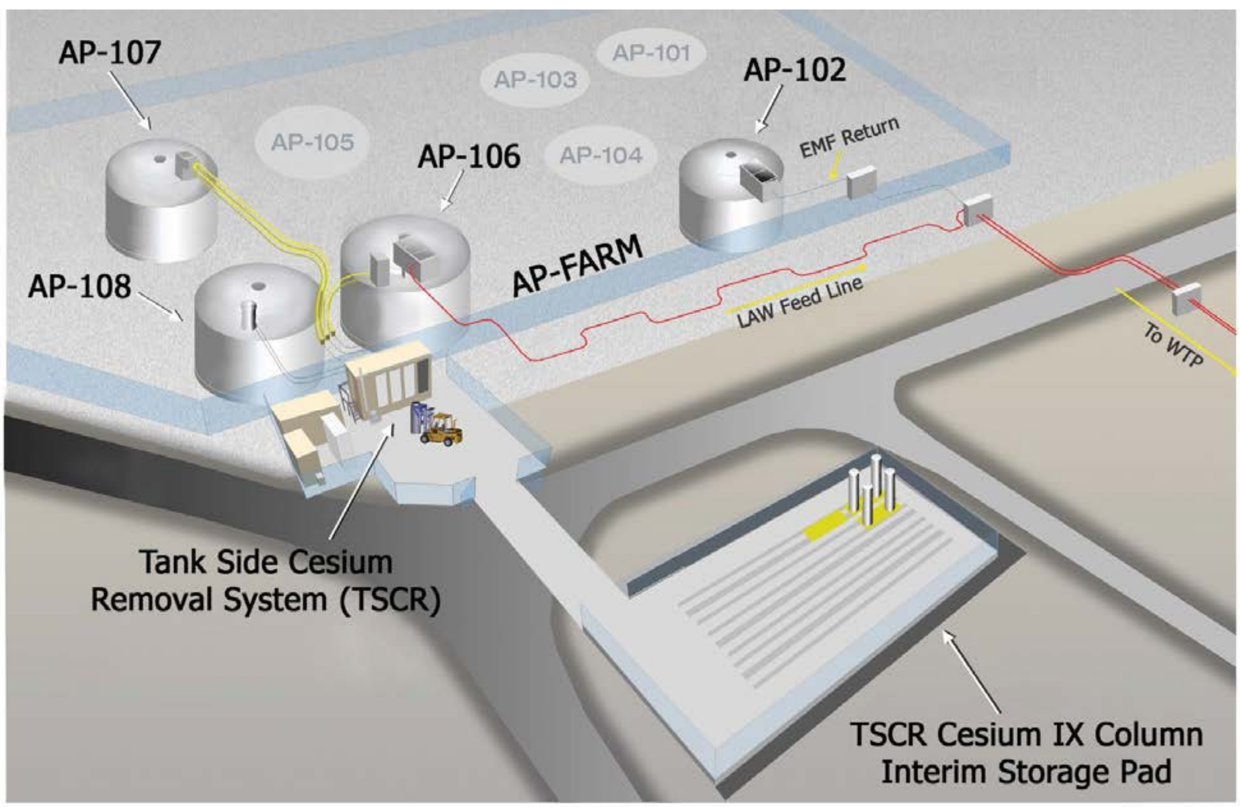

Fig. 1. TSCR AP-Farm Layout.

From a process perspective, the TSCR System is very simple as it contains no process pumps and few moving parts. Liquid waste will be pumped from 241-AP-107 through the TSCR System to 241-AP-106 where treated waste will be stored until needed at the WTP LAW facility. Secondary fluids associated with filter backwashing, flushing, and venting will be sent to 241-AP-108. Liquid waste entering the TSCR System will flow through a backwashable Dead End Filter (DEF), Fig. 2, and a series of IXCs, Fig. 3, for the removal of solids and cesium, respectively. Cesium loaded (spent) IXCs will be replaced in a manner very similar to that used at Fukushima where specialty couplings facilitate hose removal and a forklift is used for IXC handling and movement to the nearby interim storage pad shown in Fig. 1.

Fig. 2. TSCR Filter.

Fig. 3. TSCR IXC-150.

TSCR Process Information

The TSCR process is designed to remove undissolved solids (UDS) and cesium from tank waste at a constant treatment rate of 5 gpm. The average feed will contain about 8×10^{-5} gmol/L of total cesium (Cs^+), which correlates to approximately 8.5 ppm. Included with the total Cs^+ is a nominal 0.163 Ci/L of Cs-137. Other characteristics of the average waste are as follows:

- Sodium (Na^+) ....5.6 M
- Hydroxide (OH^-) ......1.35 M
- Solids (UDS) .....~200 ppm
- Viscosity ....3.7 cP
- Specific gravity.... 1.27
- Temperature........ 25°C

The TSCR System treated waste (effluent) must meet the LAW WAC of 3.18E-05 Ci Cs-137/mol Na (as listed in Document No.: 24590-WTP-ICD-MG-01-030, Interface Control Document for Direct Feed LAW). For the average waste stream, TSCR must achieve an instantaneous Cs-137 decontamination factor (DF) of approximately 900-1,000 to meet the WAC.

OPERATIONAL DESCRIPTION

TSCR uses filtration and non-elutable ion exchange media to remove solids and cesium from liquid waste; the system operates on a once-through basis at 5 gpm. The ion exchange media is manufactured by Honeywell UOP and is marketed as either R9120-B (H^+) or R-9140-B (Na^+), which are the engineered forms of crystalline silicotitanate (CST) in which powdered CST crystals are mixed with a binder to form nominally spherical beads that are compatible with column operations. Liquid exiting the IXCs passes through a media trap and delay tank prior to passing through online gamma detectors. If treated waste Cs-137 concentrations rise above a pre-determined limit of 178 nCi/L (for 5.6M Na^+), then the TSCR System is shut down and one or more of the IXCs are replaced.

TSCR System Layout

The TSCR System will be housed in three enclosures to facilitate simple installation, operations, and maintenance. The purpose of each enclosure is described below; the TSCR System general arrangement is provided in Fig. 4.

- All process components that contact liquid waste will be inside the “Process Enclosure”.
- Non-radioactive support components such as the air compressor, reagent supply, and potable water purification system will be in the “Ancillary Enclosure”.
- The operator workstation and all system controls (human machine interface, etc.) will be in the “Control Enclosure”.
- The enclosures are compact, but they aren’t lacking space for operation and maintenance. For example, the Process Enclosure has a 64-in. wide walkway in front of the IXCs to accommodate worker access for disconnecting and connecting hoses associated with IXC replacement.

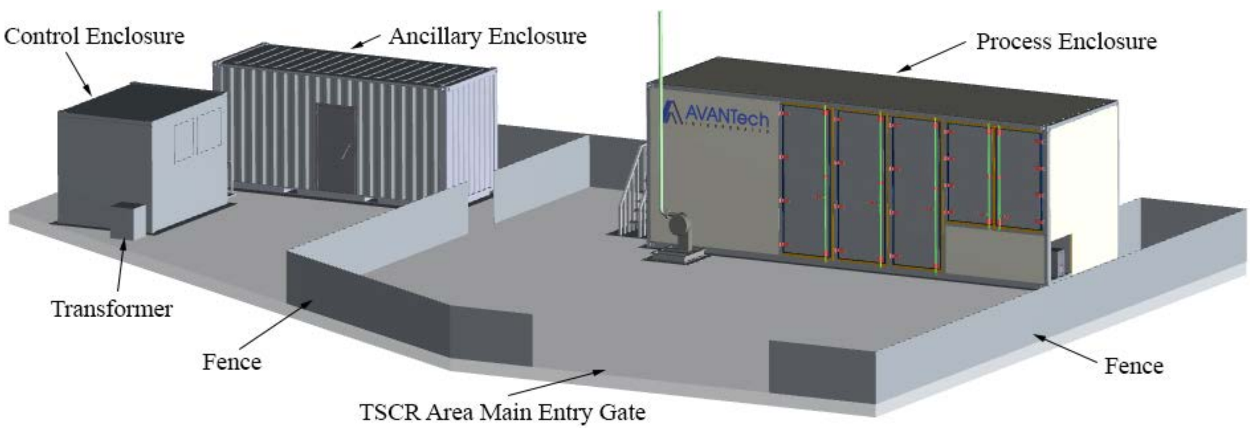

Fig. 4. TSCR System General Arrangement.

Process Components and Flow Logic

The TSCR process will use metallic backwashable filters and non-elutable CST ion exchange media to remove solids and cesium, respectively. The process is very simple with no process pumps and minimal flow control valves and programmable logic controller (PLC)-based controllers. Liquid waste originates from AP-107 where it is pumped through hose-in-hose-transfer-lines (HIHTLs) to the TSCR System. The liquid passes through a recirculation loop inside the Process Enclosure and then returns to AP-107 as shown in Fig. 5, TSCR Flow Diagram. An orifice plate in the return line creates a recirculation line pressure of over 140 psig. After all is satisfactory, flow/pressure control valves open, thus allowing waste to flow through the TSCR System. Liquid waste will flow through one of two filters. The filters operate in a duplex configuration with one filter in-service while the other is in the backwash or standby mode. After 24 hours, the second filter is brought online, and the first filter is taken out of service for backwashing. The filters cycle back-and-forth every 24 hours throughout the processing campaign. This continuous/ uninterrupted operational methodology enables TSCR to produce 7200 gal/day of treated waste. All secondary liquids associated with backwashing are sent through a drain manifold to AP-108.

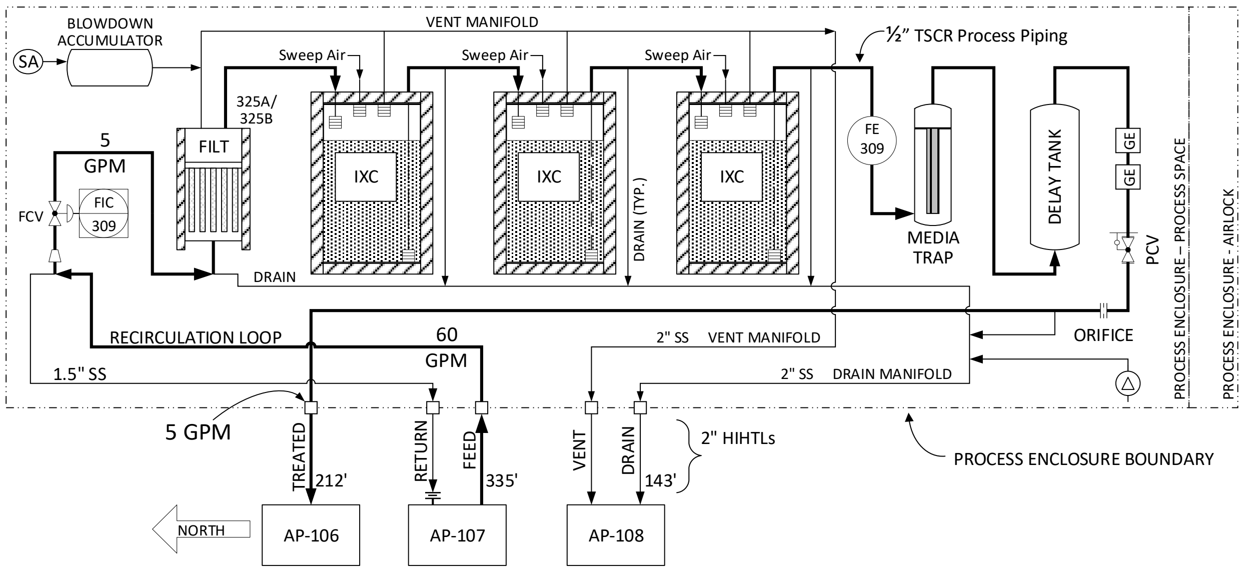

Fig. 5. TSCR Flow Diagram.

Filtered liquid continues through two or three IXCs operating in a lead-lag, or lead-lag-polish carousel, respectively. The IXCs are filled with CST that selectively removes cesium from the high pH waste. Waste processing continues until Cs-137 in the treated waste approaches the WTP WAC, thus meaning that the IXCs are loaded. Spent IXCs are removed from the process and replaced with fresh IXCs to resume operations. Downstream of the IXCs, treated waste passes through a Media Trap and then enters a treated waste Delay Tank to allow the short-lived Ba-137m isotope to decay. The Delay Tank contains internal baffles to facilitate plug-flow as waste slowly migrates through this component. Treated waste leaving the TSCR System is monitored by two in-line gamma detectors to verify effluent meets cesium removal requirements. When the cesium concentration in the process stream downstream of the IXCs approaches the target cesium limit in the lead-lag-polish configuration, the process flow is stopped and the loaded IXC replacement commences.

A treatment campaign is expected to last for 25 to 35 days prior to IXC replacement. TSCR operation will be continuous and uninterrupted throughout the treatment campaign. Filters will be cycling online and offline every 24 hours, but backwashing will not interrupt operations. An IXC replacement outage is expected to last for 10 days, thus a complete treatment campaign and IXC replacement cycle will last about 40 days, during which time approximately 200,000 gallons of liquid waste will be treated. Assuming aggressive performance metrics, The TSCR System could complete nine treatment campaigns in a year, thus treating approximately 1.8 Mgal/yr. Nine treatment cycles would require 18 IXC-150s, which equates to 100,000 gallons of waste treated per spent IXC-150; wherein each IXC-150 would be loaded with an average of 75,000 Ci Cs-137 based on an influent waste stream with a Cs-137 concentration of approximately 0.2 Ci/L.

- **40-day treatment/ IXC replacement cycle**
- **1.8 Mgal/yr treated waste**
- **18 Spent IXC-150s**
- **100,000-gal treated waste per spent IXC**
- **75,000 Ci Cs-137 per IXC**

Process Enclosure

The Process Enclosure is subdivided into two general areas: 1) an airlock area located on the far right of Fig. 6, and 2) the process equipment area which will occupy most of the process enclosure space. The design and layout ensure full containment in the unlikely event of contamination inside the enclosure.

Both areas within the enclosure will be unoccupied during waste processing activities. Personnel will only access the enclosure when liquid waste has been removed from the process components.

The TSCR Process Enclosure is a safety-significant component that is anchored to a concrete pad to prevent uplift and tipping in seismic and high-wind events. The enclosure is designed to provide spray leak knockdown, and knockdown of liquid waste and CST during a flammable gas detonation or deflagration. The enclosure includes a ventilation system with HEPA filtration, capable of maintaining a slight negative pressure during manned entry. The HEPA train and ducting is located under a platform in front of the process components. Safety functions of the enclosure are as follows:

- Spray leak knockdown with no straight-line release path before, during, or after being exposed to the following conditions: deflagration/detonation and Natural Phenomena Hazards (NPH) including wind, seismic, ash fall, and snow.
- Safety significant components within the enclosure must be protected from NPH.
- The enclosure must be capable of being locked.
- Seismic restraints within the enclosure for the filters, IXCs, and Delay Tank are required to limit movement of these components such that the enclosure itself is not damaged.
- Restraints associated with the filters and IXCs must protect the enclosure from damage from the forklift yoke.

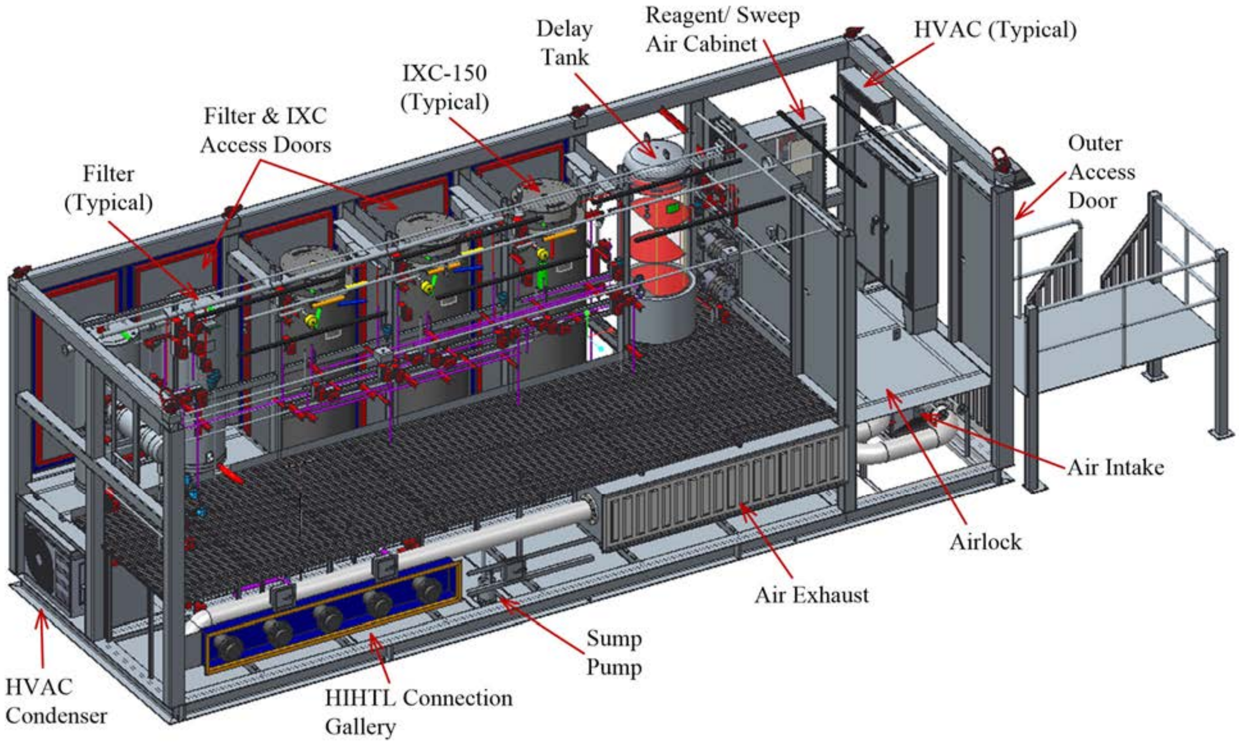

Fig. 6. Process Enclosure Arrangement.

Radiation Safety

Steel and steel encapsulated lead are extensively used on process piping and components within the Process Enclosure to protect workers to ALARA levels of radiation during waste processing operations, surveillance, and maintenance. The filter and ion exchangers have integral radial, top, and bottom shielding, as shown in Fig. 7, that permits contact handling. For example, contact dose rate on a cesium loaded IXC-150 is approximately 5 mrem/hr. Workers are further protected by the following operational protocols:

- All operations are performed from the non-radiological Control Enclosure.
- No work takes place inside the Process Enclosure while operating, and liquid waste is removed from all piping and components prior to worker entry.

Fig. 7. IXC Shielding.

Spent IXC Storage Pad and TSCR Forklift

As shown in Fig. 1, TSCR AP-Farm Layout, a storage pad is located directly across the street from the TSCR System. The TSCR IXC Pad is a concrete pad used for interim storage of spent IXCs generated by the TSCR process. The pad is made of reinforced concrete and is sized accommodate approximately 160 IXC-150s with additional room to maneuver the forklift transport and allow personnel to inspect and maintain IXCs. The IXC-150s are moved to the storage pad with a purpose-specific TSCR Forklift, which is shown in Fig. 8. The TSCR Forklift is fitted with a special yoke designed for lifting the Filter and IXCs by the trunnions located near the top of each of these components. The yoke on the TSCR Forklift is designed without tines and specifically designed to limit the height that an IXC-150 can be lifted. Additionally, the TSCR Forklift is supplied with: 1) a load height restrictor that protects workers from the consequence of an IXC drop, and 2) a factory-installed Wet Chemical Fire Suppression System that is activated by heat or by the operator to control fire associated with the rupture of a forklift fuel or hydraulic line.

Fig. 8. TSCR Forklift.

When required, the TSCR Forklift will be used to replace both Filters and IXCs. The used filters will be placed in a disposal box for burial in the 200 area Environmental Restoration Disposal Facility (ERDF). IXCs will be transferred along a transfer path between the TSCR System and the Storage Pad. Once in position, the spent IXCs are lowered into a seismic restraint where they are locked in a manner that prevents IXC tip-over due to NPH, seismic events, etc.

COMMERCIAL GRADE DEDICATION (CGD)

AVANTech’s staff has used the Commercial Grade Dedication (CGD) process to accept a variety of components and materials that perform a safety function within TSCR. CGD plans incorporate functional requirements and critical characteristics identified in safety basis documentation and establish acceptance criteria for those critical characteristics related to the safety function. Due to the size of the project and the limited number of components and material in the design, AVANTech primarily used Inspections/ Tests/ Analysis from the four CGD methods to accept a part or component for safety significant applications:

1. Inspections/ Tests/ Analysis
2. Commercial Grade Survey
3. Source Verification, and/or
4. Acceptable Supplier/ item performance record.

AVANTech developed CGD plans and reports for TSCR for items such as structural material, pipe and fittings, fasteners, flow instruments, instrument displays, instrument enclosures, and lead shielding. In some cases, the CGD obstacles were overcome by taking a simplified approach to the safety function, e.g., use of a simple rotameter with a closed-circuit TV monitor to monitor flow instead of a more automated/ complicated instrument to read critical flow rates. This eliminated additional complicated active CGD requirements related to electronics and software within the instrument.

Detailed TSCR procurement strategies were developed to ensure WRPS' expectations and AVANTech's procurement and dedication approach were aligned. The procurement controls outlined reasonable assurance while minimizing impacts on cost and schedule. TSCR quality controls and procedures are based on ASME NQA-1 requirements and incorporate the CGD guidance of Revision 1 to EPRI NP-5652 and TR-102260 in addition to EPRI TR-017218-R1.

FACTORY/FUNCTIONAL ACCEPTANCE TESTING (FAT)

The TSCR System will undergo extensive testing by multiple groups before becoming operational in early 2021. AVANTech, together with WRPS' TSCR Project team, will complete the FAT on the Process Enclosure, Ancillary Enclosure, Control Enclosure, Step-down Electrical Transformer, and Ventilation Exhaust Blower Skid. After Hanford site installation, WRPS' Waste Feed Delivery (WFD) group will complete a TSCR post-installation Construction Acceptance Test (CAT), and then operations will complete an Operational Acceptance Test (OAT).

Preliminary Testing

A variety of preliminary tests were performed during fabrication. TSCR process piping and components are designed for an operating pressure of 400 psig. Design standards such as ASME B31.3 and ASME B&PV Code Section VIII require hydrostatic testing to confirm the design and manufacturing integrity. Hydrostatic testing took place directly after fabrication at pressures of 600 psig (*1.5× design pressure per B31.3*) as indicated in Fig. 9. Other preliminary testing involved dimensional verification, load testing of lifting components (lugs, trunnions, hoist rings, etc.), electrical point-to-point checks, and control software testing based on simulated inputs.

Fig. 9. Hydrostatic Pressure.

Test Setup and Confirmation of FAT Readiness

After fabrication and preliminary testing, the enclosures were setup and connected at AVANTech's Richland, WA facility in a represented layout and configuration that will be used on the Hanford site. Test tanks and pumps were put in place and connected to the TSCR Process Enclosure in a manner that mimicked interfacing Double Shell Tanks in the 241-AP Tank Farm. Fig. 10 shows the arrangement of the TSCR Enclosures at AVANTech's Richland, WA facility.

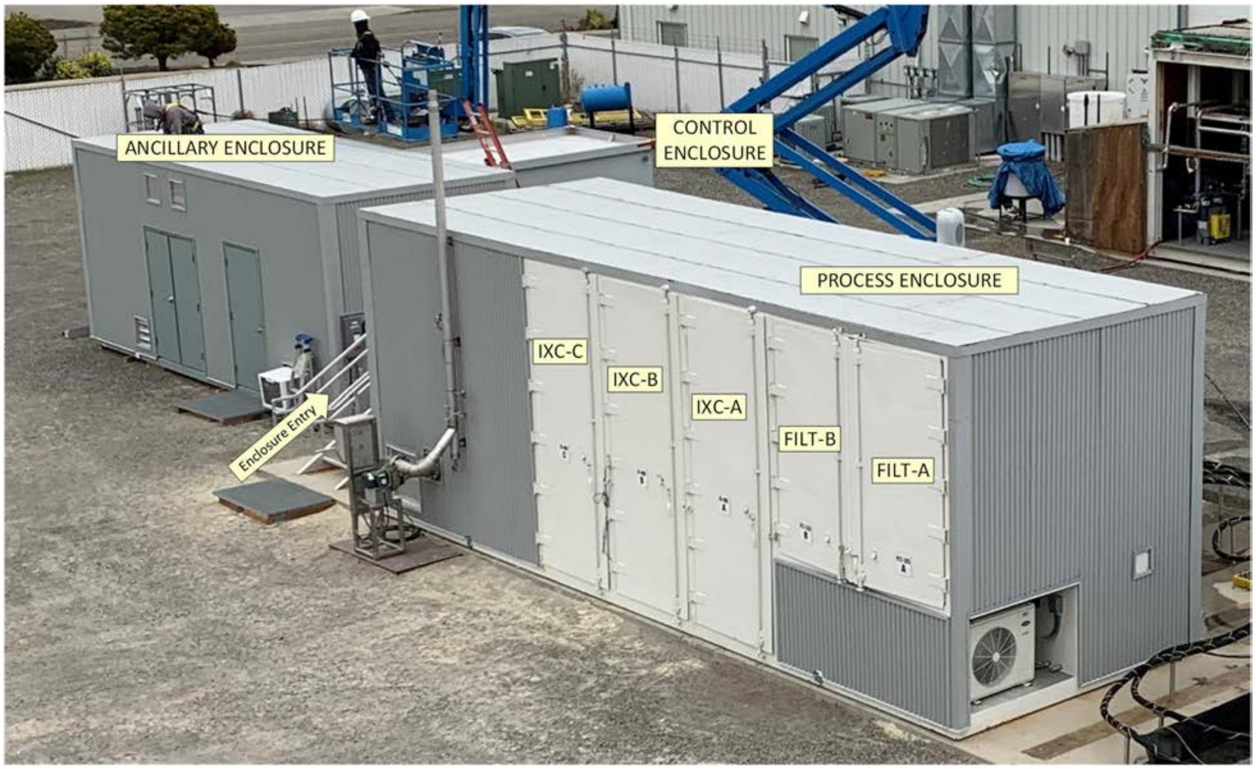

Fig. 10. FAT Enclosure Arrangement. (Final insulation/ siding not installed)

Several lifting tests were completed while preparing the enclosures and components for functional testing; this included lift tests on rigging for each of the three enclosures as well as installation and removal of the filters and IXCs with the TSCR Forklift and yoke.

Once in place, a variety of setup prerequisites were completed. A few of the prerequisite tests are listed below:

- A system walkdown was completed to verify all connections are satisfactory.
- All mechanical connection points were checked to verify proper coupling/ torqueing, as applicable.
- A system leak check was performed.
- Electrical point-to-point continuity tests were performed.
- A control system check was completed to verify control logic and interlocks were active.

Functional Testing

Functional testing was performed with a 5.6 M Na+ Hanford simulant that had been spiked with undissolved solids. Every functional aspect was tested from the HVAC being able to maintain temperature, to process component differential pressure at design flow rates, to the concentration accuracy of the 0.1 M NaOH that is used to displace liquids from the system. Examples are as follows:

- Pressures, flows and temperatures are within specified ranges when operating with simulant.
- Filter backwashing takes place automatically in accordance with programmed control logic.

- Operational routines such as: operation, waste displacement and system blowdown are completed.
- IXC performance testing confirms the absence of channeling within the IX bed.
- Ion-exchange-train valve configurations are implemented, e.g., rotation of the carousel.
- Effectiveness of control response to abnormal conditions is evaluated, e.g., loss of electrical power.

Personnel Training

The Hanford Tank Operations Contractor, WRPS, participated in all phases of testing. Testing at AVANTech's Richland Facility allowed WRPS personnel to familiarize themselves with TSCR operations in a radiologically clean facility prior to onsite mobilization. Engineering and operations personnel gained valuable experience that allowed them to better refine onsite operational protocols and procedures – including handling and movement of IXCs with the TSCR Forklift.

CONCLUSIONS

The TSCR team has designed and manufactured a compact and modular technology, known as TSCR, for near-tank treatment of tank waste supernatant. The team, consisting of WRPS, AVANTech, PNNL and multiple other organizations have shown the following:

1. Crystalline silicotitanate (CST) is capable of removing cesium from tank waste under operating condition equivalent to those used by TSCR.[1]

2. TSCR uses a robust filter technology that enables uninterrupted/ continuous 24-7 operation.[2]

3. TSCR incorporates Seismic Design Category II (SDC-II) restraint that occupies a minimum amount of space and can be quickly engaged by one worker, thus minimizing the use of limited floor space as well as worker radiation exposure.

4. Hydrogen produced from the radiolysis of water inside the IXC-150s is effectively managed by TSCR features known as sweep-air and IXC vent system.

5. The TSCR forklift has proven to be an effective method for replacing IXCs and filters and for transporting the IXCs to the storage pad. Maintaining the IXCs within close proximity to the ground (36-in. max. lift height) offer multiple safety advantages, but requires integration of the following:

    a. Hinged enclosure doors with a low threshold

    b. Lifting trunnions on the IXC-150

    c. Swing-arm IXC-150 seismic restraint (inside enclosure), which incorporate a Forklift guide with bumpers

    d. Low ground clearance beam trailer for transporting new IXCs with fresh CST media to the TSCR system.

    e. Use of low-profile/ low-height seismic restraints on the IXC storage pad.

6. The TSCR system, with a liquid waste treatment rate of 5-gpm, together with all its appurtenances fits in an area that is ≈ 1/10th of an acre, which includes the area needed for forklift travel.

7. TSCR appears to be much simpler and more compact as compared to previously planned pretreatment system projects. For example, the spherical resorcinol formaldehyde based Low Active Waste Pretreatment System (LAWPS) was much larger –with a building having several elevations on a plot of land that occupied about 4-acres – yet LAWPS had only about 2X the throughput capacity of TSCR. Fig. 11 provides a perspective of the space occupied by the planned and exiting facilities in Hanford's 200 East area.

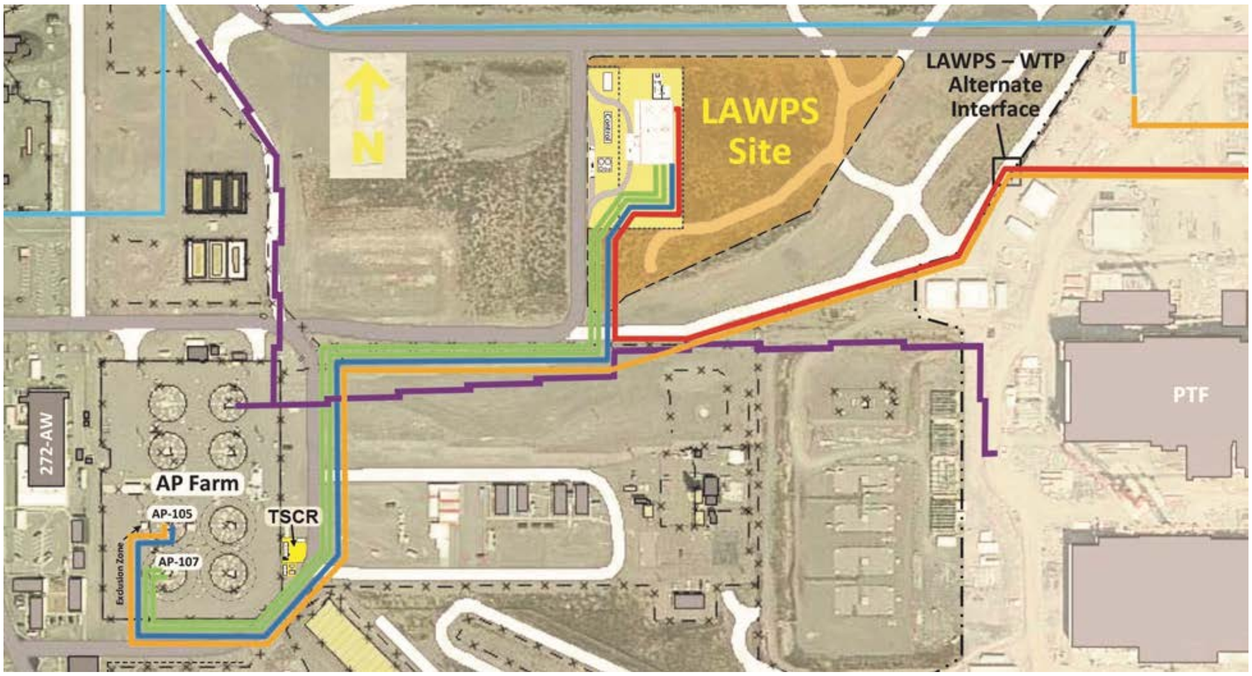

Fig. 11. 200-East Facilities

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[1] Rovira, A.M., et.al., PNNL-27706, *Cesium Ion Exchange Testing Using CST with Hanford Tank Waste 241-AP-107*, *Pacific Northwest National Laboratory*, August 2018

[2] Wilson, Robert A., TR-1813-01, *Dead End Filtration Media Testing Results*, AVANTech Incorporated, February 2019.