Protecting the Columbia River through Removal and Packaging of Radioactive Sludge in Hanford's K Area (ID# 16572)

Ray Geimer, CH2M HILL Plateau Remediation Company, Richland, WA 99354

ABSTRACT

The Columbia River once provided power and cooling water to operations on the Hanford Site; today, more than a million people downstream from Hanford rely on the river for agriculture, fishing and recreation. The Department of Energy and contractor CH2M HILL Plateau Remediation Company (CH2M) is making significant progress in protecting that vital resource. Eight of nine reactors along the river have been cocooned and soil and groundwater remediation is successfully reducing the concentration of contaminants in groundwater.

The 100-K area is the last area where significant work remains to protect the river. CH2M has accomplished much in the past ten years, including demolishing the K East reactor fuel storage basin in 2009. Prior to demolition of the basin, highly radioactive sludge from that basin was transferred into containers located in the nearby K West reactor fuel storage basin. Today, the K East reactor is in interim surveillance mode, and work is underway in the K West basin to remove the sludge, which is a mixture of tiny fuel corrosion particles, fuel rod and metal fragments and soil and sand less than ¼-inch in diameter.

CH2M has designed a sludge removal system that will safely and efficiently remove the sludge from the K West basin and deposit it into specially designed containers which will be relocated to a storage facility on Hanford's Central Plateau. Procurement, fabrication and delivery of the sludge removal system is underway, with extensive testing and training planned for 2016 and 2017 ahead of the goal of removing sludge from the river by September 30, 2018.

This project must account for many technical and safety considerations that render the project very challenging. Several safety measures have been incorporated as a result of safety evaluations. This paper will describe the issues facing the project team in developing the safety basis requirements and incorporating them into the design of the process equipment and construction of the facility to house the repackaging operations.

This paper will allow CH2M and DOE-RL to share lessons learned and progress to date with other complex and hazardous projects across the DOE complex.

BACKGROUND

The K East and K West reactor basins, shown in Figure 1, were constructed in the early 1950s to support the reactor operations. These basins were placed in long-term standby in February 1970 and January 1971, respectively, but reactivated in 1975 and used for N reactor fuel storage.

Fig. 1. K East and K West Reactor Basins

When plutonium recovery stopped in the early 1990s, some 2,300 metric tons of irradiated fuel remained in storage in the K East and K West basins. This inventory was irradiated uranium metal fuel, some of which was aluminum clad and the majority of which was Zircaloy clad. Some of the fuel suffered cladding damage or breaches during reactor operation, primarily during discharge and handling. This provided a pathway for water contact of the fuel and, eventually, corrosion of the metallic uranium fuel. Over time, well beyond the design basis of the fuel (approximately 20 years for K East and 15 years for K West), significant fuel element corrosion occurred and the resulting corrosion products escaped from the canisters to the floor, similar to that shown in Figure 2. The basin superstructures are not sealed from the environment, which allowed sand, dirt, and organic material (weeds, bugs, etc.) to be deposited in the basins. Normal and off-normal basin operations contributed spent ion exchange resins and other detritus-like spalled concrete and sand filter material and polychlorinated biphenyls (PCB)-bearing materials. By DOE definition, sludge became anything in the basins that would pass through a 0.64 cm (1/4-inch) screen. Material larger than that has been separated and managed as spent fuel or debris. Sludge accumulations in the K West Basin were considerably less due to the sealed fuel storage canisters, better condition of the fuel placed into the basin, better control of the basin water quality, and a prior basin cleanout campaign.

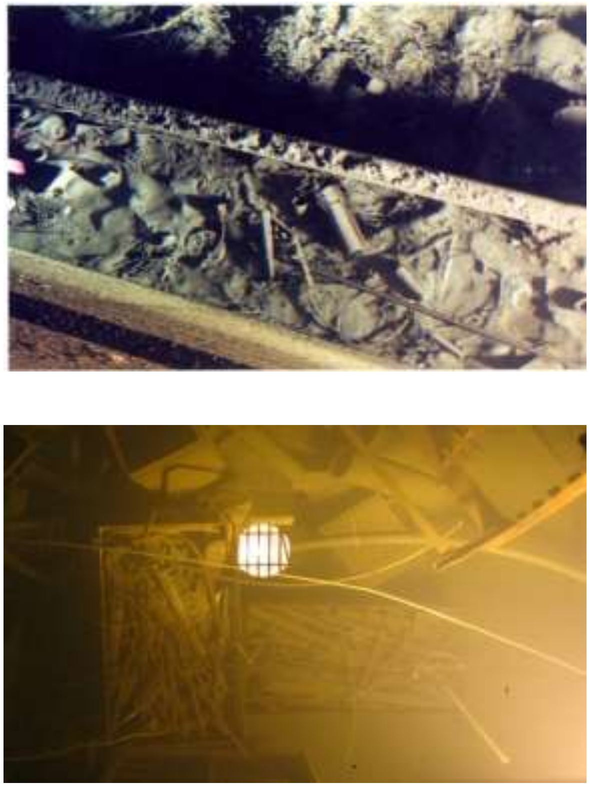


Fig. 2. Sludge and Debris in K East Basin

In the mid-1990s, the decision was made to disposition the fuel stored in the K East and K West Basins by washing the fuel to remove corrosion products and other materials, packaging it into MCOs, drying it, and moving it to dry storage on the 200 Area Central Plateau at the Hanford site. This task was completed in 2004.

A water treatment system, known as the Integrated Water Treatment System (IWTS), captured material washed from the fuel to maintain the clarity of the basin water. The IWTS is equipped with knock-out pots (KOPs) and strainers to capture the larger particles (600 micron to 0.64 cm [1/4-inch]) and a series of settler tanks to allow for settling and capture of the finer material (<600 microns) from fuel washing. In 2012, CHPRC cleaned the KP sludge, placed it into five MCOs, dried, and moved it to dry storage on the 200 Area Central Plateau.

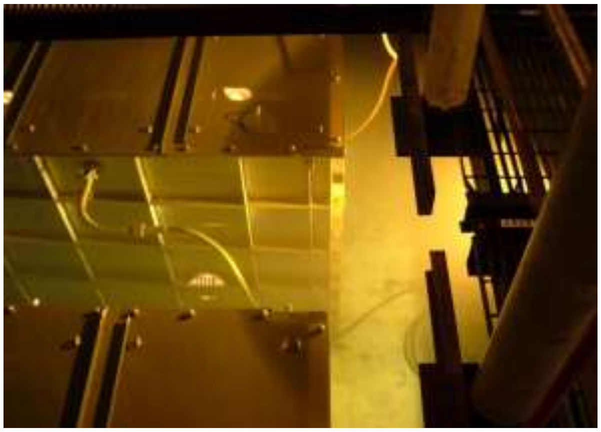


Fig. 3: Engineered Containers in K West Basin

K East Basin sludge was hydraulically transferred beginning in October 2006 from the K East Basin to three out of six engineered containers (see Figure 3) located in the fuel bays of the K West Basin. Removal of all sludge from the K East Basin was completed in June 2007, which allowed basin decommissioning to begin. Sludge retrieved from the K West Basin floor and pits was transferred into two empty engineered containers in the K West Basin, which was completed in July 2007. It is maintained separate from the K East Basin sludge. A sixth container received the sludge retrieved from the settler tanks which was completed in June 2010. The estimated total inventory of sludge currently in the K West Basin engineered containers is ~23 m^3 (~18 m^3 from the K East Basin floor and pits, and ~5 m^3 from the K West Basin floor and pits) and approximately 3.5 m^3 of sludge are stored in the settler tanks.

In 2008, the Sludge Treatment Project was initiated to remove the KOP, settler and basin sludge streams from K West Basin and place them into interim storage in Hanford's 200 Area Central Plateau. During Phase 1 of the project, the sludge stored in engineered containers will be retrieved into Storage Containers and transferred to T-Plant in Hanford's Central Plateau. The ECRTS subproject was formed to accomplish this task. During Phase 2 of the project, the sludge will be treated to react the metallic uranium and then put in a form that meets criteria for RH-TRU waste disposal at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, NM. As previously noted, the KOP stream has been successfully handled as SNF and is in interim storage at the Canister Storage Building in Hanford's 200 Area Central Plateau with eventual disposal as HLW.

TECHNICAL CHALLENGES

Historically, efforts to transfer and handle K Basin sludge have proven to be very difficult. The IWTS used for cleaning fuel and the pumping systems used to move sludge from K East to K West Basin had very high failure rates due to the abrasive nature of the material. Maintenance was complicated because equipment was typically beneath 16 feet of water and could be obscured by suspended sludge particles. Filtration systems were not easily back-flushed and became blinded. The broad range in particle densities; 1 to 19 g/cc, required retrieval and transfer systems to pump high volumes of water at high velocities to assure relatively uniform transfer. Those density differences created concerns that metallic uranium could segregate, and accumulate, with accompanying thermal and hydrogen gas generation issues. In addition, high dose rates associated with sludge into the 100 rem/hr. range requires remote and automated systems for process equipment.

Consequently, the STP has taken the approach to establish a strong technical basis for the final design of ECRTS. This technical basis is supported by an extensive characterization program that established chemical and physical properties of sludge in each engineered container. This data has been used to develop process parameters and requirements, develop simulants for equipment testing and verification, and establishing a safety basis for ECRTS. In addition, full-scale equipment testing including integrated tests with prototype equipment and a full range of simulants has been completed. Over 30 flocculents were tested to determine which would be most effective at quickly settling sludge turbidity to speed process operations. The prototype test facility is shown in Figure 4.


Fig. 4: STP Full-Scale Test Facility

SLUDGE CHARACTERISTICS AND SIMULANTS

Sludge characteristics vary depending on origin: sludge from the K East Basin floor and fuel storage canisters, sludge from the K West Basin floor and pits, and sludge removed from the K West Basin settler tanks. As noted previously, these sludge streams are stored in different engineered containers in K West Basin and a characterization program was conducted that obtained multiple, full-depth core samples of the sludge in each engineered container (EC). This characterization data was used as a technical basis for process and safety basis analysis, as well as development of a set of simulants that represented the different physical properties of each sludge stream. Characterization included chemical, radiochemical, and mineral forms, and physical properties of each sludge type. Physical properties measured included particle size distributions, densities, and shear strength. Tables 1 and 2 summarize sludge composition and physical properties. Design values are the mean values derived from characterization of the sludge core samples. Safety values were derived from statistical analysis of the core samples and generally are the 95% upper confidence interval value.

The key physical properties of each type of sludge were bounded by the simulants which were used for process equipment testing. Tungsten metal was used to simulate uranium metal particles. Combinations of cerium oxide, aluminum hydroxide, ferric hydroxide, steel grit and sand were used to simulate other components.

TABLE I. Sludge Properties Summary

Property	**Units**	**KW Originating EC 210**		**KW Originating EC 220**		**Settler Tanks EC 230**		**KE Originating EC 240, 250, 260**	
		Design	**Safety**	**Design**	**Safety**	**Design**	**Safety**	**Design**	**Safety**
As Settled Density	gm/cm^3	1.25	1.66	1.47	1.72	2.0	2.8	1.5	1.6
Percent Water in Sludge	Volume %	71%	71%	77%	77%	73%	55%	75%	75%
Total Uranium	g U/cm^3	0.044	0.17	0.188	0.409	0.61	0.84	0.038	0.062
Uranium Metal	g/cm^3	0.0042	0.0593	0.0121	0.0341	0.022	0.163	0.00027	0.005
Decay Heat	W/m^3	2.24	10.1	5.91	12.8	20.5	49.4	1.28	2.45
Fissile Grams Equivalent (FGE)	FGE/m^3	284	1050	1160	2670	4070	5640	244	393
Combined Sludge Expansion From Gas Retention and Uranium Metal Corrosion	unitless	1.41	1.62	1.42	1.59	1.44	1.83	1.41	1.54
Shear Strength (after 2 to 3 months settling)	Pa	280		3000 to 8400		1100		3000 to 5200	

TABLE II. KW Basin Sludge Composition

Source		**KW Originating EC 210**	**KW Originating EC 220**	**Settler Tanks EC 230**	**KE Originating EC 240, 250, 260**
Settled Sludge Volume	m^3	4.2	1.0	3.5	18.4
Nominal Chemical Constituent					
Ag_2O	g/cm^3	2.04E-06	3.12E-05	3.97E-04	0.00E+00
$Al(OH)_3$	g/cm^3	4.63E-02	8.09E-02	9.54E-02	6.94E-02
BaO	g/cm^3	2.57E-04	1.34E-04	2.90E-04	1.34E-04
CaO	g/cm^3	5.60E-03	4.62E-03	4.62E-03	6.58E-03
CdO	g/cm^3	2.51E-05	2.28E-05	1.60E-05	6.28E-05
Cr_2O_3	g/cm^3	2.78E-04	4.82E-04	1.26E-03	1.02E-03
FeO(OH)	g/cm^3	6.68E-02	1.62E-01	1.16E-01	3.98E-01
PbO	g/cm^3	1.72E-04	8.83E-04	1.18E-04	4.52E-04
Residual Solids	g/cm^3	0.39	0.22	0.36	0.21
Total Inorganic Carbon	g/cm^3	1.07E-03	7.57E-03	2.61E-03	4.23E-04
Total Organic Carbon	g/cm^3	0.124	0.092	8.07E-03	0.016
Organic Ion Exchange Resin	g/cm^3	0.185	0.138	0.012	0.023
Grafoil®	g/cm^3	1.07E-03	7.57E-03	2.61E-03	4.23E-04

RETRIEVAL, TRANSFER AND STORAGE PROCESS SYSTEM

Final design of ECRTS and construction of a supporting Modified 105-KW Basin Annex building have been completed. This is a Hazard Category 2 facility. Procurement is underway for the process equipment, which will be installed within the Annex and the 105-KW Basin beginning in late FY 2016.

Fig. 5: Modified K West Annex

The ECRTS process involves retrieving sludge from each engineered container with slurry rates in the 5 to 15 volume % range. This slurry is transferred to a Sludge Transport and Storage Container (STSC) that is inside a cask on its transport trailer. The trailer and support equipment are located in the Annex building (Figure 5). Each transfer is approximately 4 m^3 of slurry that fills the STSC. The sludge is allowed to settle for up to 16 hours and then surface water is decanted through a sandfilter to 105-KW Basin.

There are nine different operational modes and flows which are controlled by valves and pumps in the transfer line service box and decant pump box. A flocculent injection system is provided to speed sludge settling if necessary. Approximately five fill and decant cycles will be required to fill an STSC with from ~1 m^3 to 2.0 m^3 of sludge depending on the sludge source. The sandfilter is back-flushed into the STSC after the fill cycles have been completed to maintain filter efficiency and reduce dose rates at the filter. Approximately 18 to 24 STSCs will be filled and transferred to T Plant for interim storage.

Fig. 6: Xago Retrieval Tool

Sludge is retrieved from each engineered container in the K West Basins by using a newly developed XAGO retrieval tool and its associated pump skid. The XAGO retrieval tool, shown in Figure 6, is a combined fluidizer and jet pump system. An adjustable annular jet pump provides both suction and motive force to move the slurry; a low-pressure Coanda fluidizer head entrains solids at the suction end of the XAGO retrieval tool. The XAGO retrieval tool has a set of high-pressure nozzles used to break up high-shear-strength materials. The retrieval system pump skid is fitted with two booster pumps, connected to the XAGO retrieval tool.

Testing over the entire range of simulants representing sludge in all engineered containers was performed to establish performance and operating parameters. Tests show that the sludge can be retrieved at high slurry rates in the range of 5 to 15 vol. % solids. The fluidizing pump provides water through the XAGO retrieval tool at up to 42 gpm and 385 psi. The motive flow pump is rated for a capacity of 41 gpm at 213 psi. The system has check valves (safety-significant systems, structures, or components) to prevent sludge back-flowing into the water service header, which supplied by the basin ion exchange module (IXM).

Fig. 7: Booster (Peristaltic) Pump

Retrieved sludge slurry is transferred to a booster (peristaltic) pump (Figure 7) via a 1.5-inch diameter flexible hose. The booster pump is needed to overcome pressure loss in the over 250-ft of in-basin flexible hose and 35-ft change in elevation to deliver sufficient solids concentration in the retrieved sludge slurry to the STSC. Sludge is transferred at up to 15 vol. % solids and approximately 70 gpm.

This pump is a significant advance from the centrifugal pumps that have been used for prior systems handling sludge. Testing has shown that there is much lower wear on its components and the project is confident no replacement will be necessary for the life of the project. These pumps are designed for slurry service so their process performance is good. Use of this pump was made possible by the project specially modifying it for underwater service. In one test, the pump's outlet was gradually valved off until the motor burned out to establish the safety basis spray release pressure at 200 psi and a flow rate of 70 gpm.

Figure 8: Transfer Line Service Box (being fabricated)

The transfer line service box is placed on the Annex mezzanine at the high point of the Transfer System, and is the secondary containment structure for the primary transfer line within the Annex. A model of the transfer line service box is provided as Figure 8. The transfer line service box also houses the air-operated diaphragm overfill recovery pump of the Overfill Recovery Subsystem and provides a tie-in to the Decant/Filter System for recirculation after flocculant injection. Having this equipment at the system’s high point allows

Fig. 8: Transfer Line Service Box (being fabricated)

system flushing with IXM water to be directed either to the STSC or back to the K West Basin, and allows a siphon break and line venting to occur after a vent valve is opened.

Retrieved sludge is transferred to a STSC (Figure 9 and Figure 10) located in a sludge transport system cask on the transport trailer. After each sludge transfer, the line is flushed with 1.5 times the line volume of water (approximately 50 gal) into the STSC. The hose-in-hose slurry transfer line connects to an STSC. A coaxial hose-in-hose connector mates to the container nozzle. The connector includes integral leak detection.

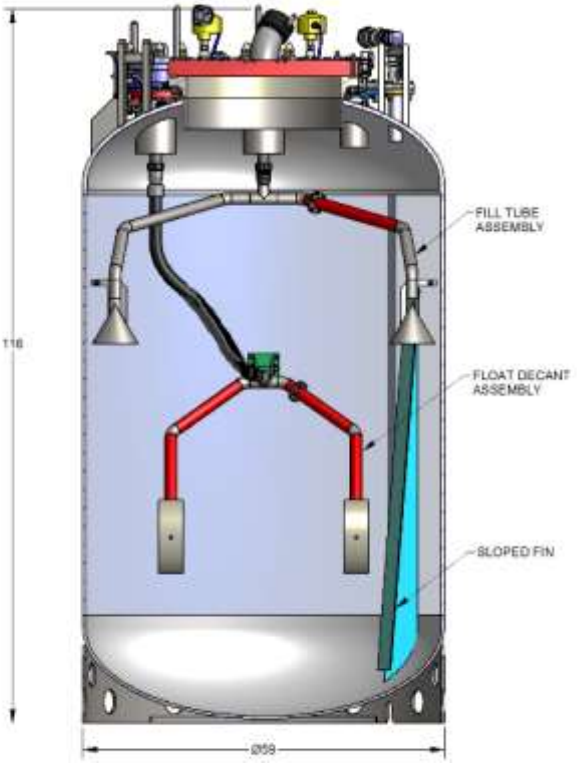


Fig. 9: Cutaway of STSC

Fig. 10: Completed Fabrication of First STSC

The STSC is approximately 5 feet in diameter and has approximately 4m^3 volume. The STSC has twelve penetrations in the elliptical head, including the 26-in.-diameter access port. These ports are used for sludge transfer, decanting, overfill recovery tool, level-monitoring instrumentation, ventilation, and purging nozzles. The STSC has a float system that shuts off the decant system when the settled sludge level is reached.

Fig. 12: Sand Filter (Shielding Not Shown)

Supernate is removed from the STSC using an air-operated, double-diaphragm decant pump that is located in the decant pump box, shown in Figure 11. The decant pump is supplied with air at a maximum of 85 psi gauge. The decant pump box includes a leak detection system and is connected to the Process Ventilation System.
The decanted supernate is then transferred at approximately 10 gpm through a sand filter skid (Figure 12) to remove residual solids before being discharged back into the K West Basin via hose-in-hose transfer lines. The decanted supernate can be recirculated at nominally 75 L/min (20 gal/min) through the decant pump and piping in the decant pump box, the transfer line service box, and back into the STSC. A turbidity probe is installed in the decant line to indicate whether the suspended solids content in the decanted supernatant stream is high.

Flocculant can be added to the decanted supernate if the level of turbidity observed in the decanted supernate is higher than acceptance limits. These limits will be established from operating experience and will depend on the need to shorten settling times or improve quality of decanted water being returned to K West Basin.

At mission end, the sand filter media will be retrieved from the sand filter to a separate STSC, which also will be transported to T Plant for interim storage because the sand filter media will likely contain residual sludge particles. All water used in the sludge transfer process is recycled back to the K West Basin except for the relatively small amount left in the STSC to provide radiation shielding.

The process systems are integrated and operated by an instrumentation and control system. In general, this is a fully automated system with the XAGO retrieval tool being the only direct operator interface during retrieval operations. The system has process control panels and dedicated safety control panels to provide separation for safety systems.

The STSC will be transported to T Plant in Hanford's Central Plateau for interim storage. After interim storage, sludge will be retrieved from the STSCs for final packaging and disposal at WIPP. Several tools have been developed to facilitate removal of sludge from the STSC. One retrieval tool, which is permanently installed inside the STSC, is intended to be used to

Fig. 11: Decant Pump Box at Fabrication Shop

Fig. 13: Overfill Retrieval Tool (Left) and Spray Nozzle Detail (Right)

remove excess sludge during loading but can also be used for future retrieval of sludge from the STSC. This overfill retrieval tool uses direct suction in conjunction with a mobilization spray nozzle to pull sludge out of the STSC. The tool, shown in Figure 13, is connected to a water supply line that provides dilution water to the tool during sludge transfer. A high-pressure pump provides fluidization water to mobilize the sludge for transfer.

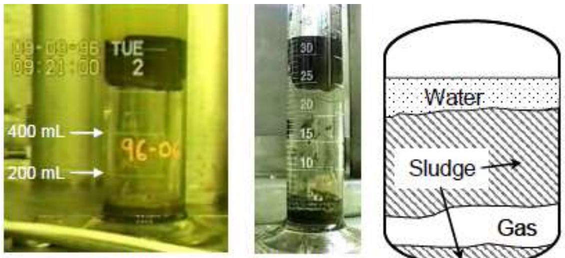
Following the storage period, sludge will be treated and packaged for disposal at WIPP as RH-TRU waste as part of Phase 2 of the STP. Phase 2 is currently in a pre-conceptual design phase and a baseline process has not been defined. However, the ECRTS Subproject does have a requirement to demonstrate that sludge can be retrieved from an STSC after storage. Characterization, simulant development, equipment development and equipment testing were performed to demonstrate a method for sludge retrieval. These tests showed that the expected condition of the sludge is most likely to be very similar to the condition shortly after it is loaded into the STSC. Bounding testing was done to determine what the worst case physical conditions might be and testing to demonstrate removal was completed.

INNOVATIONS INCORPORATED INTO THE ECRTS PROJECT

The list of innovations incorporated into the ECRTS Project is far too large to incorporate here. Instead, a few of the more significant accomplishments are featured.

Integration of Safety in Design: Nuclear safety analysts, radiological engineers and design engineers are an integrated team with members collocated. The co-location of team members fostered rapid communications, ensured safety was integrated in the design and avoided costly rework activities. Nuclear safety analysts, radiological engineers, and operators participated in identifying test objects and identifying key improvements to enhance safety, operability, and maintainability of equipment as part of the Technology Maturation process. Test results provided the technical basis for design basis accident calculations that underpin the Project Preliminary Documented Safety Analysis.

Technology Maturation Process: The principles of the DOE-EM Technology Readiness Assessment (TRA) / Technology Maturation Plan (TMP) Process Guide were implemented from the beginning of the ECRTS Project. A Technology Maturation Plan was prepared and implemented to conduct full-scale, integrated testing of all ECRTS process components, including all critical technology elements. Full-scale process equipment testing was conducted in a relevant environment using a range of simulants that represent the key properties of the sludge. Laboratory scale testing was also conducted with actual sludge samples to verify the full-scale test results. Modifications to the full-scale test system were conducted as the process design and safety basis matured and the modified, full-scale, integrated system was retested to verify performance.



KE Canister Sludge (96-06)

KW Canister Sludge (96-17)

Fig. 14: Vessel Spanning Bubbler with K Basin Sludge Samples

(From PNNL-19345, 9/2010, *The Disruption of Vessel-Spanning Bubbles with Sloped Fins in Flat-Bottom and 2:1 Elliptical-Bottom Vessels*, PA Gauglitz et al, Pacific Northwest National Laboratory)

Optimizing the Number of STSC: The ECRTS design originally included an STSC with a water filled inner core to enhance heat dissipation from Settler Tank sludge. The other sludge types did not require the use of the water filled inner core in an STSC. After rigorous safety analysis and cost benefit analysis, a decision was made to layer the Settler Tank sludge beneath the KE Originating sludge in the same STSCs. This innovation results in a savings of six STSCs needed for interim storage of sludge, eliminated the need to use a water filled core in an STSC, and reduced the modifications at T Plant required for storing STSCs, thus reducing project costs.

Bubble Buster Fin: Radiolysis and uranium metal reaction with water produces gases that could be trapped beneath sludge inside the STSC, if the sludge shear strength is sufficiently high. The gases could accumulate and form a vessel spanning bubble that would propel the sludge out of the STSC. This phenomena, known as Raleigh-Taylor instability, was first observed in actual sludge samples contained in a graduate cylinder, as shown in Figure 14.

CHPRC, working with Fauske and Associates LLLC and the Pacific Northwest National Laboratory, developed and tested at several different sizes concepts for disrupting the formation of a vessel spanning bubbler in the STSC. The results of these tests lead to the inclusion of a sloping metal fin inside the STSC to disrupt the formation of a vessel spanning bubble. Gases formed in a sludge layer will begin to displace the sludge layer upward in the STSC. As the sludge moves along the metal fin, an instability is imposed on the sludge layer, which results in the gas escaping from beneath the sludge layer. Figure 15 depicts the so-called "bubble buster fin" during fabrication and installed in an STSC.

Fig. 15: Bubbler Buster Fin Inside STSC