TEST PLAN

Experimental Test Plan to Assess the Utility of 3D Sonars for Monitoring High-Level Radioactive Waste Settled Solids Surfaces for Indicators of Developing Deep Sludge Gas Release Events

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Introduction

The retention of flammable and explosive hydrogen gas within deep sludge layers is of great concern for operational safety and for high-level radioactive waste (HLW) transport and storage systems.[1]

Hydrogen gas is generated in HLW by radiolysis of chemicals and the concentration of soluble sodium nitrate and nitrite salts and organic compounds that were introduced into the radioactive and chemical waste and over time reacted with the chemical waste. Through operational experience and theory, these flammable gases were shown to escape through cracks created in the HLW. The gases generated are continuously released into tank vapor spaces where air is used to sweep out and remove it.

In recent years, several studies have suggested that there was a limited depth in which these fissures would allow gas to escape. This prompted the concern that gas could build up at certain depths deeper than previously stated inside the Documented Safety Analysis. Gases accumulated at depth can cause a deeper level to become lighter than the layer of waste above it. Based on a phenomenon called buoyant displacement, pockets of gas can be stored in a deep layer of the supernatant where a portion of the settled solids accumulates enough gas to become buoyant. A Raleigh Taylor instability[2] could very rapidly release the trapped hydrogen, releasing it much quicker than considered in the safety design basis. This rapid release of gas is called a deep sludge gas release event (DSGRE). This postulated deep sludge gas release event was not described in the Documented Safety Analysis and was the subject of an Unreviewed Safety Question (USQ). This resulted in the high priority given to planning and executing the Deep Sludge Gas Release Event Project and subsequently a sub-project called the DSGRE Tall Column Project.

Washington River Protection Solutions (WRPS) completed the Deep Sludge Gas Release Event (DSGRE) Tall Column project over 9 months in 2015. Testing answered safety concerns while minimizing interruptions of Hanford waste retrieval operations. The test column was filled with waste simulant weighing over 40,000 lbs. These experiments were essential for demonstrating that deep sludge beds do not pose a significant risk for a large spontaneous gas release event.

The single-shell tank plan for the retrieval of C Farm tanks called for sludge waste to be consolidated in the receiver double-shell tanks (DSTs) to waste depths greater than ever before in Hanford Site's operating history.

The principal objective of the DSGRE Tall Column Project was to evaluate the accuracy of the postulated theory that at a representative DST sludge depth, gas would accumulate. In the tall column tests, this theory was directly tested by determining if there was any significant change in gas transport at sludge depths deeper than this representative depth. The test objectives were to measure the retained gas (void) fraction in a column with a simulant depth that was equal or greater than future plausible DST sludge depths. The tests also used lower shear strengths than expected for Hanford Site sludge waste to ensure test conditions would convincingly confirm or refute this postulated theory.

While the DSGRE Tall Column Project was able to quantify upper limits for gas trapping in deep sludge layers, it could not eliminate the possibility of small DSGREs altogether at Hanford. Hanford scientists and engineers identified a technical need to monitor the settled solid surface of HLW in DSTs with deep sludge beds. Specifically this need is for a monitor for settled solids surfaces in tanks to identify increases in the height and volume of these surfaces as indicators of trapped gas and of the potential for evolving deep sludge gas release events (DSGREs). The monitor would allow for prediction of DSGRE onset as well as to ensure that the HLW is not retaining sufficient gas to evolve into a DSGRE.

The purpose of a monitor for DSGREs is to image the settled solids surface layer in deep sludge, DSTs and quantify the change in volume of the waste over time. Hanford personnel would correlate any increase in volume of the waste tank with a mass of trapped gas in the sludge. The monitor could serve two purposes: (1) if the volume of the waste in the tank does not change over time, this can confirm that the mass of trapped gas is low and DSGREs are not of concern; and (2) if the volume of waste does increase over time, then Hanford personnel could estimate the increasing mass of trapped gas and be ready to take action to minimize any risk posed by a DSGRE (e.g., increase flow of sweep gas in the tank headspace).

Aware of Florida International University's (FIU's) past work in high resolution sonar imaging of settled solids layers and in estimating waste volumes, Hanford personnel suggested that FIU test its 3D sonar to address this technical need. FIU initially developed the Solid-Liquid Interface Monitor (SLIM) for mapping the interface layer between supernatant and settled solids in large HLW tanks at Hanford. The current need also requires this mapping in the same 1 million gallon HLW tanks at Hanford but has additional requirements of monitoring the surface over time and quantifying the change in volume of the solid waste in the tank. A summary of the previous SLIM research effort is provided in Appendix A.

Test Plan Objective

The objective of this test plan is to quantify the accuracy of FIU's 3D sonar in monitoring over time the volume of settled solids in a tank within a particular field of view and to do this for a range of fields of view.

Test Plan Details

To develop the test procedures for this plan and to demonstrate that FIU's 3D sonar could indeed image small changes in the settled solids layer in a tank, a simple proof-of-principle test was completed and is described below.

Proof-of-Principle Test

FIU mounted an air bladder to a 40 cm diameter plastic lid with 3 mm high lip and then loaded paving sand onto the lid with a depth of 3 mm at the edge of the lid and 4.5 mm in the center. Figure 1 contains a photograph of the bladder mounted inside the lid. The lid with wet sand in it and over the bladder can be seen in Figure 2. The lid filled with sand sitting on a large metal plate at the bottom of the test tank is shown in the photo in Figure 3.

Figure 1. Photograph of the air bladder mounted with tape to the underside of a plastic lid.

Figure 2. Photograph of air bladder mounted inside plastic lid with sand covering the bladder.

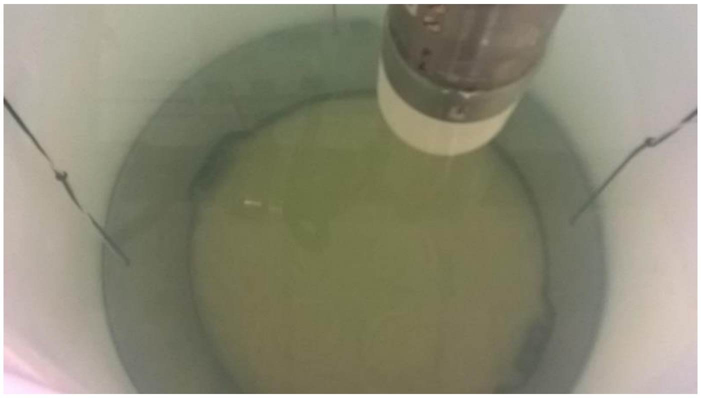

Figure 3. Photograph of the plastic lid filled with sand on a metal plate on the tank bottom.

Air was added to the bladder in increments that added height to the sand on the bladder. The height increases at the edges were less since the bladder is constrained by tape to the lid at the edges. The height increases were largest in the center of the bladder which is in the central area of the field of view. The changes in height and volume of the sand as air was inserted can be seen in Figures 4 and 5. Figure 4 shows the sonar image of the sand surface over the bladder when it was mostly deflated as the baseline measurement.

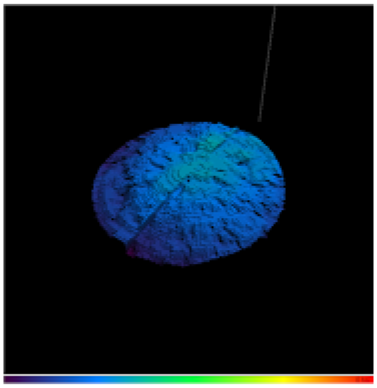

Figure 4. Sonar image of the sand over a deflated bladder (baseline).

Figure 5 shows sonar images of the sand surface after the insertion of air that resulted in rises in the sand layer.

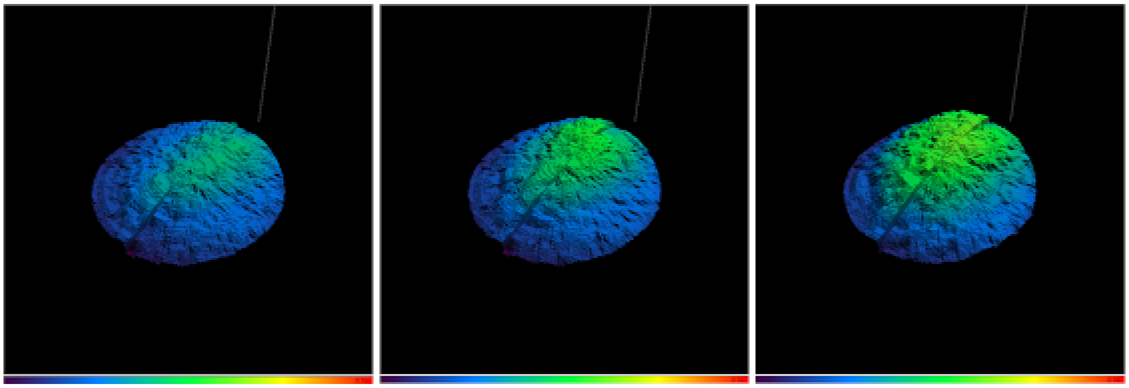

Figure 5. Sonar image of sand over the bladder after: the first increment of added air (left), the second increment of added air (middle), and the third increment of added air (right).

Physical measurements of the highest point of sand on the bladder resulted in roughly 1 cm, 1.5 cm, and 2 cm increases for the 3 increments of air. The sonar has an accuracy of 3 mm at a distance of 30 cm (1%) but the 3D visualization software has an accuracy of +/- 1 cm. For the physical measurements of 1.0 cm, 1.5 cm and 2.0 cm, the sonar 3D image recorded 1 cm, 1 cm, and 2 cm for the highest point. Again, post-processing with FIU's software will allow for much higher resolution imaging (e.g., 3-4 mm) for points on the settled solids (sand) surfaces. Post processing of these images will allow FIU to develop the algorithm or identify an existing routine (e.g., in MatLab) for calculating the volume of solids and its change over time.

Experimental Setup

The experimental setup includes the 3-D sonar mounted inside a plastic tank that is 28 inches in height and 23.5 inches in diameter (ID) with a floor that slopes downward in the center to allow liquid to be drained from the bottom. FIU has obtained a circular aluminum plate that is 23 inches in diameter and creates a flat floor surface in the tank. The tank with the plate inside and the sonar inserted and with sand covering a bladder will be used for this test plan (as shown in Figure 3 above). Sand to 3 mm thickness will be extended beyond the 15.5 inch diameter plastic lid in order to fill the field of view with sand (i.e., for the 18 and 22 inch sonar heights).

Test Plan Matrix

To assess the resolution of the sonar to image changes in settled solids and for post-processing algorithms to calculate changes in solids volume, the below test plan matrix was developed. The initial sonar height above the plate defines the field of view (FOV) floor area for the sonar set at 30 degrees (FOV). The highest point of the sand on top the air bladder will be increased via insertions of air into the air bladder to allow for the determination of the ultimate accuracy of the sonar in measuring changes in volume of solids on the tank floor. The theoretical limit of the sonar in measuring height is 1% (e.g., 0.12 inches (3 mm) at a sonar height of 12 inches). The initial height of the sand over the center of the fully deflated bladder is 4.5 mm.

Table 1. Test Matrix

Height of highest point of sand over bladder	Initial Sonar height above plate (FOV Area)
4.5 mm	12 inches or 30.5 cm ($\pi * r^2$ = 113 sq inches)
6.0 mm	12 inches or 30.5 cm (113 sq inches)
7.5 mm	12 inches or 30.5 cm (113 sq inches)
9.0 mm	12 inches or 30.5 cm (113 sq inches)
10.5 mm	12 inches or 30.5 cm (113 sq inches)
12 mm	12 inches or 30.5 cm (113 sq inches)
13.5 mm	inches or 30.5 cm (113 sq inches)
4.5 mm	18 inches or 45.7 cm ($\pi * r^2$ = 254 sq inches)
6.0 mm	18 inches or 45.7 cm (254 sq inches)
7.5 mm	18 inches or 45.7 cm (254 sq inches)
9.0 mm	18 inches or 45.7 cm (254 sq inches)
10.5 mm	18 inches or 45.7 cm (254 sq inches)
12 mm	18 inches or 45.7 cm (254 sq inches)
13.5 mm	18 inches or 45.7 cm (254 sq inches)
4.5 mm	22 inches or 55.9 cm ($\pi * r^2$ = 380 sq inches)
6.0 mm	22 inches or 55.9 cm (380 sq inches)
7.5 mm	22 inches or 55.9 cm (380 sq inches)
9.0 mm	22 inches or 55.9 cm (380 sq inches)
10.5 mm	22 inches or 55.9 cm (380 sq inches)
12 mm	22 inches or 55.9 cm (380 sq inches)
13.5 mm	22 inches or 55.9 cm (380 sq inches)

Test Plan Steps

Measure and compare image resolution for a settled solids layer that is raised 9 mm in height in 1.5 mm increments for the sonar's ability to quantify the surface height and volume of solids.

Step 1: The flat plate will be added to create a flat floor in the 28-inch tall tank. The sonar will be hung from a structure component across the top of the tank as shown in Figure 3. The sonar will be placed 12, 18 and 22 inches from the tank bottom plate.

Step 2: A 3"-6" bladder will be mounted to a 16-inch diameter plastic lid (see Figure 4). The lid will be filled with sand to allow it to sink when slowly lowered to the tank floor. The bladder will be equipped with an air tube and valve to allow air to inflate the bladder. Air will be added in very small increments to the bladder and sonar scans taken until the highest point over the air bladder image of the raised solids is 9 mm, with images taken in 1.5 mm increments.

Step 3: The actual height of the solids surface will be measured for comparison to elevations found from the sonar data.

Sonar Image Resolution Test: *Image a repetitive pattern to ascertain the resolution of the sonar for measuring height and lateral distances to determine the ultimate resolution of the sonar for measuring the volume of solids within its FOV.*

Imaging systems are often tested with specific patterns with changes on the order of the imaging system's ability to resolve them. For a sonar with a 1% resolution (3 mm at 30 cm distance), FIU will develop an object with a pattern of rows and columns with height changes of 3 mm along the column and 5 mm from row to row. FIU envisions creating this test pattern object from plaster. Should the initial test pattern with 3 and 5 mm changes across adjacent cells prove to be unresolved with post processing of the sonar data, then the test pattern object for the 18 inch height test would be used. The ability to quantify the accuracy of the sonar to measure increases in volume in settled solids from entrapped gas is critical to allow site personnel to estimate the mass of this gas and its potential for becoming a DSGRE. In order to assess the ability of an imaging system to accurately image a surface and measure its volume, it is important to assess the imaging resolution across the field of view of the sonar and, therefore, images will be taken directly under and toward the edge of the field of view. Post-processing of these images will determine the ability of the sonar to accurately measure volume changes to the settled solids surface in the field of view. In these tests, as the changes in the height and width of the pattern are decreased, the sonar loses its ability to see images at the edge of the field of view first and ultimately across the entire field of view. The human eye is able to discern a pattern in an image even if the pattern is "washed out" over 90% of the area of the image. FIU will directly image this patterned form on the tank floor. Should the object's varying surface height changes not be resolvable, then another similar object with larger variations in the range between high and low points within each row will be used. Based upon accuracy of the imaging, a calculation will be made for the smallest volume change that can be imaged.

The following table contains height and width parameters for test patterns for various sonar heights above the tank floor.

Table 2. Height and Width Parameters for Test Patterns

Change in height along a row in the test pattern	Change in height along a column in the test pattern	Sonar height above tank floor	Location in FOV
5 mm	3 mm	12 inches	Center
5 mm	3 mm	12 inches	Edge
7 mm	5 mm	18 inches	Center
7 mm	5 mm	18 inches	Edge
8 mm	6 mm	22 inches	Center
8 mm	6 mm	22 inches	Edge

Schedule for Experiments

Table 3. Test Schedule

Test #	Test Description	Begin Date/End Date
1	Settled Solids Imaging and Volume Calculation *Sand over an air bladder for 4.5 mm to 13.5 mm heights for 3 sonar heights*	Jan. 4-Feb. 22, 2016
2	Sonar Image Resolution Test (Test Patterns) *Test patterns imaged directly under sonar and at edge of FOV for 3 sonar to floor heights*	Feb. 8-March 18, 2016

Health and Safety Considerations

There are no radioactive or hazardous materials used in this test plan. The sand used will be medium grain (Pavers sand) without any respirable hazard.

Electrical shock is possible when using electronic equipment. Electric cords will be inspected to ensure no fraying or cuts develop that might lead to electrical shock. The sonar uses high voltage with the electronics housed in the electronics box between the sonar and the computer. There will not be any need to open this box during the execution of this test plan.

Next Steps Upon Completion of this Test Plan

FIU has initiated software development to allow the 3D sonar to run continuously and to automate the image analysis software and the 3D visualization software. Time sequences of sonar images of the solids surface would be shown as a movie or in a .gif format. These would be looped to allow operator to see the sequence of images over the past 5 minutes. The sonar's manufacturer has been contacted about working together to improve the visualization over time of this sonar.

References

1. Understanding Gas Release Events in Hanford Double Shell Tanks, Perry Meyer & Beric Wells, Pacific Northwest National Laboratory, Waste Management 2000 Symposium, February 27 – March 2, 2000, Tucson, AZ.

2. Gas Release Due to Rayleigh Taylor Instability within Sediment Layers in Hanford Double-Shell Tanks: Results of Scaled-Vessel Experiments, Modeling, and Extrapolation to Full Scale, S.D.

Rassat, G.K. Boeringa, P.A. Gauglitz. D.N. Tran, L.A. Mahoney M.R. Elmore, R.P. Pires, W.C. Buchmiller, D.R. Rector, M.L. Kimura, J.A. Fort, April 2014.

Appendix A: Summary of Previous Research Efforts with SLIM

Challenge

The current technology for assessing the solids level inside high-level waste tanks is via a single point measurement through a riser and leads to conservative assumptions of the total level of solids in the tank. A technology able to image the settled solids layer would allow a much better measure of solids and allow more solids to be loaded into tanks during retrieval campaigns.

Solution

Develop a Solid-Liquid Interface Monitor (SLIM) that is impervious to the caustic and highly radioactive waste and that can accurately measure the height of the settled solids layer over a wide area of the tank. A monitor has been developed by integrating commercial off the shelf technologies (COTS). It has been tested in Miami and is ready for testing in the Hanford Cold Test Facility and deployment in a Hanford tank.

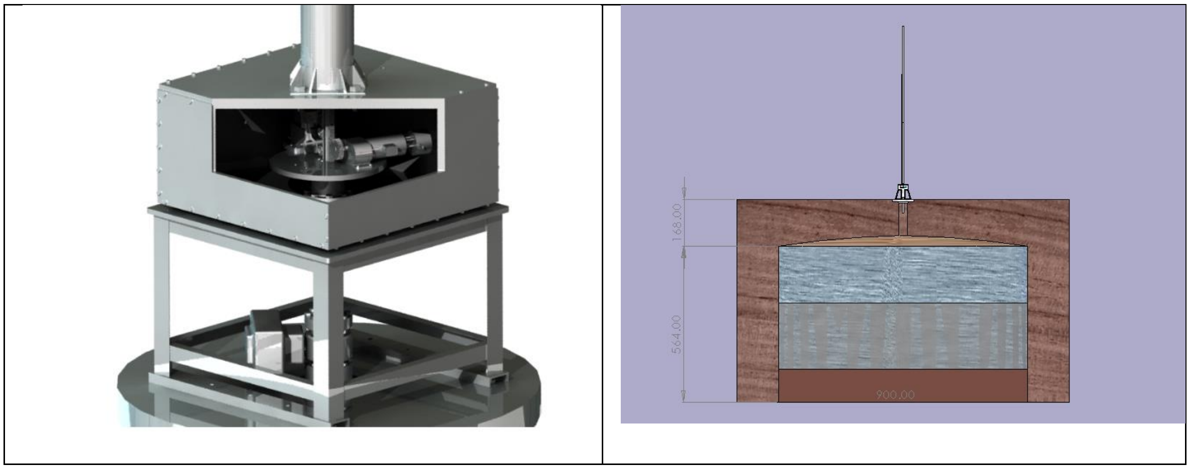

Figure 6. Cutaway of SLIM deployment system (left). Schematic of SLIM installed in a Hanford tank (right).

Technical Accomplishments

- The SLIM underwent a series of full-scale testing at FIU in 2007 and 2008.
- The hardware, software and system design has gone through the Hanford engineering planning process and was ready for deployment by FY09.
- Changing design requirements from Hanford has led to the design, construction and testing of 3 prototypes and 1 final system.

Potential Impacts

- The SLIM can be used to optimize the retrieval of solids from Hanford waste tanks by allowing engineers to fill the tanks closer to the maximum allowed level for solids due to safety considerations. This is expected to save many millions of dollars at Hanford. The technology is also applicable for the Savannah River Site.
- SLIM can also be used to better place pumps inside the tanks during retrieval. This is important because the pumps can become plugged if lowered directly into the solids on the bottom of the tank during retrieval.

Functional Requirements for Early Application of SLIM in Million Gallon Tanks (demonstrated)

- Detect a solid-liquid interface during and after settling.
- Withstand exposure to both high-level radiation dose and highly caustic solution (pH > 14).
- Operate in a range of 75-320 inches above the bottom of the tank.
- Be deployable through a 4-inch riser at the top of the tank.
- Operate in liquid 2 feet or more above the settled solids layer.
- Identify the average interface elevation integrated over an area of at least 5 ft^2.
- Avoid disturbing the interface by the act of measuring.
- Be capable of at least hourly readings of the interface.
- Provide isolation from system and tank during retracted state.
- Provide system containment from outside environment.
- Minimize potential for shear loads to be applied to riser.

Test Results for SLIM (2007-2008)

- Profiling sonar images several square meters of interface of solids surface in the large HLW tank. The accuracy of the height of the interface is ±0.36 cm or better at a 2 m range.

- Even with 30% by weight of solids suspended in the liquid sonar is able to accurately measure the solid-liquid interface with ±0.91 cm or better at a 2 m range.

- Sonar can detect with accuracy of ±0.36 cm (at 2 m range) settled solids having a density of 4% greater than the fluid in which they are immersed. These lighter solids are easily suspended and can take some time to resettle.

- Based upon the material selection for the sonar head (titanium hull) and its cable (polyurethane outer coating), caustic solution (pH>14) does not have an effect on the sonar's ability to generate images and function properly.

- Sonar's imaging is not affected by changing either the solution density or the temperature. Only measurements between the relative points are affected. This is due to the change in sound speed with density and temperature.