# Sonar Testing, Imaging and Visualization for Rapid Scan Applications in High-Level Waste Tanks – 16386

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## ABSTRACT

The development of 2-D and 3-D sonar systems to image solids settled on the floor of tanks and in open water channels has been an active research area at Florida International University for over a decade. FIU has developed and successfully tested the Solid-Liquid Interface Monitor (SLIM) for mapping the interface between supernatant and settled solids in several test tanks. SLIM consists of a sonar and a mechanical deployment system for inserting the system into 1 million gallon, high-level radioactive waste (HLW) tanks at DOE's Hanford site. Commercial sonar visualization software is not able to create 3D images with too few 2D scans (e.g., 15-60 second rapid scans) and during mixing operations the scattering off suspended particles renders images useless. FIU collects the sonar scan data, filters it, and displays it in 3D showing the settled solids layer for these short scans and for monitoring the floor during mixing. Previous testing showed that SLIM: (1) functions accurately in liquid radioactive HLW tank conditions [i.e., caustic (pH>14), warm (up to 45 degrees Centigrade), and highly radioactive]; (2) provides accurate 1-2% relative error in the height of interfaces; and (3) allows for volume estimation of the solids, allowing tanks to be filled closer to the maximum levels permitted. Results presented here include sonar images for rapid scans, during mixing with suspended solids, and to quantify the accuracy of the sonar as a monitoring device for the settled solids, important for monitoring HLW conditioning tanks and storage tanks at Hanford tank.

## INTRODUCTION

The U.S. Dept. of Energy's Hanford Site in Washington has the majority of DOE's 88 million gallons of liquid high-level radioactive waste (HLW) in large, single-shell and double-shelled, underground storage tanks. Hanford will use smaller tanks to condition some of the HLW. In addition, the Waste Treatment and Immobilization Plant (WTP) undergoing construction at Hanford also has smaller HLW tanks. The current DOE estimated cost for retrieval, treatment and disposal of this waste exceeds $50 billion to be spent over several decades. There are a variety of applications that a sonar as a monitoring device can provide for these HLW tanks including the capabilities to: ascertain the effectiveness of mixing operations during mixing; image the settled solids layer in tanks allowing them to be loaded to the maximum volume as allowed by safety requirements; imaging of the surface of a tank to view sub-centimeter increase in the surface level that might indicate the buildup of hydrogen gas in the solids; monitor the solids left behind during waste retrieval operations; and more. The primary Hanford need for this research during the first 8 months of 2015 was focused upon demonstrating the ability of the commercial sonar to rapidly (20-30 seconds) image the settled solids layer over a smaller tank floor area. The smaller areas are dead zones midway between adjacent pulsed jet mixers in the tanks. In Fig. 1 is a schematic diagram for a conditioning tank at Hanford and it includes the "batwings" shaped areas where solids have been seen under certain circumstances in these mixing tanks.

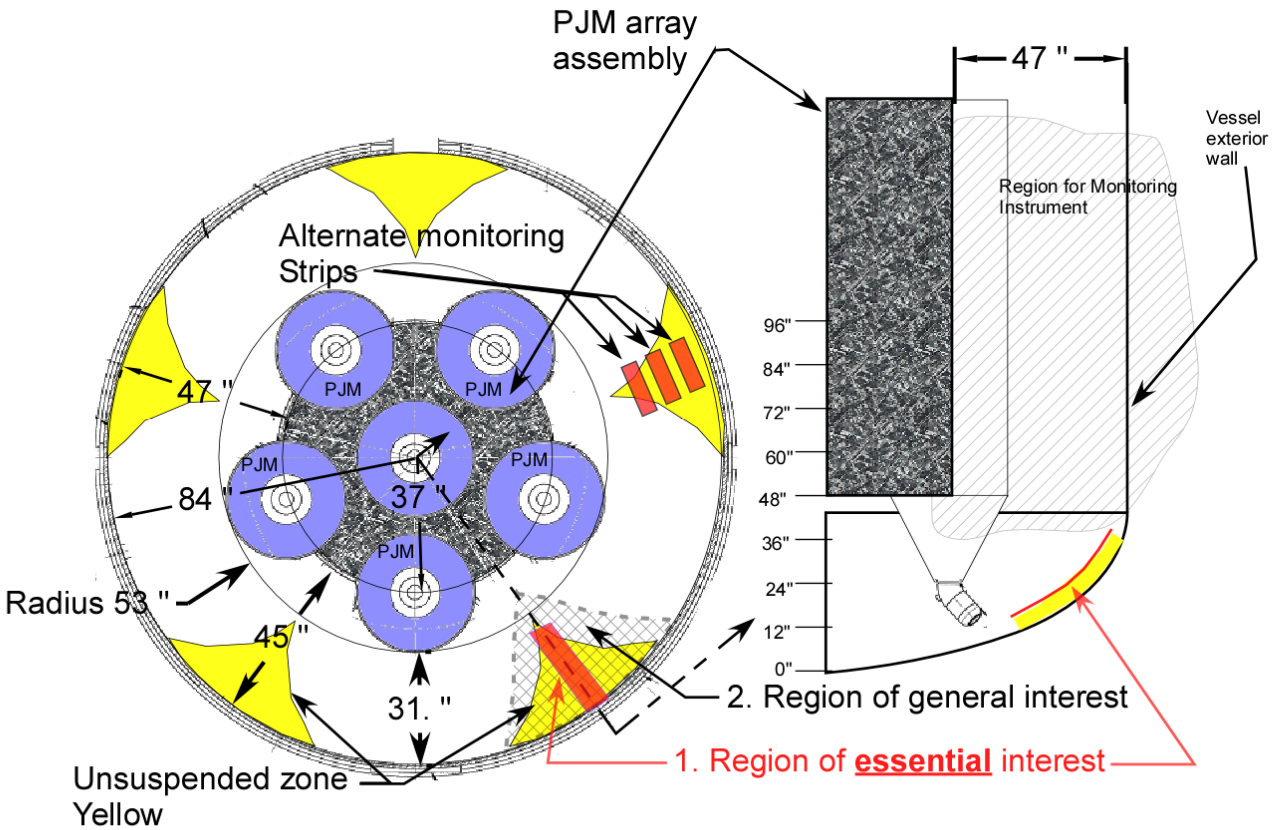



Fig. 1 Schematic Diagram of the HLW Conditioning Tanks for Hanford

In September research was initiated on a new Hanford technology need for monitoring the settled solids layer in a tank to ascertain any increase in the height of the solids layer as a possible indicator of hydrogen gas buildup. This is part of a larger effort to understand and monitor for Deep Sludge Gas Release Events (DSGREs). An initial test matrix for this research is under development and will be completed by Dec. 18, 2015 and included in the poster presentation.

As an example of other HLW applications for sonars in HLW tanks outside of this project scope, PNNL, Energy Solutions and Bechtel expressed interest in this sonar research and its use in HLW applications related to the Waste Treatment & Immobilization Plant (WTP). In July, FIU with support from PNNL responded to a call for technology for WTP. FIU's proposed testing program was awarded a contract with Energy Solutions in November to complete several tests on the Imagenex 2D profiling sonar. The call for technology contained three measurement challenges: bottom mobilization, bulk or slurry mobilization, and relative concentration of gas bubbles related to vessel mixing. FIU's sonar addressed the bottom mobilization need. The measurement challenges are associated with full-scale non-hazardous material testing of the mixing system design. WTP measurement needs pose challenges (e.g., vessel configurations: enclosed metal tank with internal structure; fluid conditions: opaque and periodic/cyclic flows) and will require customized techniques to obtain the desired data. All results of the testing for WTP will begin in January 2016 and will be shared solely with the Bechtel team.

A photograph of the Marine Electronics Inc. commercial 3D Profiling sonar at Florida International University (FIU) is shown in Fig. 2 below. It is a split-head design with most of the electronic located outside the sonar and hence outside the tank making it more impervious to nuclear radiation dosage. It also has a titanium hull and polyurethane cap which can withstand highly caustic (pH>14) solutions.

Fig. 2. The 3-D Profiling Sonar at FIU

FIU's early testing of a 2D profiling sonar for imaging HLW settled solids surface in tanks was performed with a commercial sonar by Imagenex Inc. It too had a split-head design, titanium hull and polyurethane cap and it demonstrated that sonar signals can easily penetrate 1-3 meters of fluid with up to 30% solids suspended in it, to image the settled solids layer on the floor. A few exciting results related to accuracy of imaging included:

- 0.36 cm accuracy through 2 m of liquid;
- 0.91 cm accuracy through 2 m of liquid with 30% solids suspended;
- 1.2 cm accuracy through 6 m of liquid.

In Fig. 3 below is the 3' diameter, 6' 6" height, test tank with external pump and with mixing apparatus and sonar installed inside.

Fig. 3. The Test Setup for the Imaging During Mixing

Tests with the 3D sonar have shown that post-processing of sonar data from scans stopped after 15 seconds allow for effective imaging of an area of the tank floor. In the next section results are presented separately for these two technology need areas (rapid imaging during vigorous mixing in HLW conditioning tanks; and continuous monitoring of the settled solids layer in tanks for small increase in volume that might indicate hydrogen gas buildup.)

## DISCUSSION OF RESULTS

### Rapid Scans During Mixing Operations

A summary of accomplishments for this research in 2015 include:

- Tested 3D sonar for performance in imaging objects and solids on a tank floor with imaging times of 15 - 45 seconds (successful)
- Developed and tested sonar data interpolation software to allow for estimation of volume of solids on tank floor (4-8% error limited by the visualization algorithm and not the sonar data and can be improved for better accuracy should Hanford require it)
- Developed and tested several data processing algorithms to remove signals from reflections off particles in the slurry and from signals scattered twice in the tank
- Identified optimal sonar settings for rapid, accurate sonar imaging for this application which are: highest setting of 2D swath pings which maximizes the number of pings in each 2D swath; the lowest setting for the rotation motor

which minimizes the number of 2D swaths since the motor rotations between 2D swaths takes seconds; and the minimum 30 degrees viewing angle setting.

- Designed experimental setup for testing the 3D sonar with kaolin particles suspended in the liquid and carried out initial experiments.

The objective of this task was to assist site engineers in developing tools and evaluating existing technologies that can solve challenges associated with the high level waste tanks and transfer systems. Specifically for the sonar subtask, FIU is evaluating the capability of custom-built, commercial profiling sonars for detecting residual waste in HLW tanks during pulse jet mixing (PJM). This effort would provide engineers with valuable information regarding the effectiveness of the mixing processes in the HLW conditioning tanks.

To assess the accuracy in which the 3D sonar can monitor the settled solids surface, FIU imaged a section of U-channel and a 6-mm thick, L-shaped piece of metal. In Fig. 4, one can see the test setup with the sonar, U-channel and an L-shaped piece of metal. In the sonar images in Fig. 5 and Fig. 6, the L-shaped piece of metal was moved to 3 different locations and can be identified in the sonar images. A smaller 1' 11" diameter, 2' 9" height test tank was set up to quantify the image resolution of the sonar

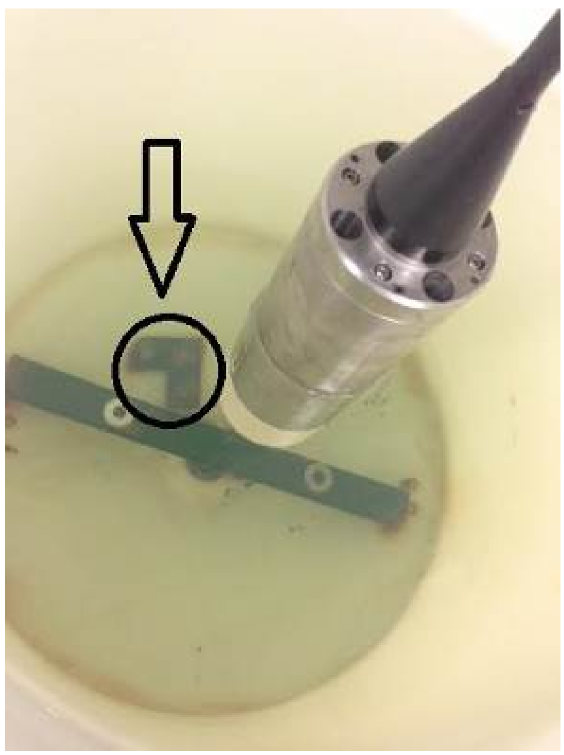


Fig. 4. Setup to test the ability of the 3-D sonar to image a 6-mm thick metal piece.

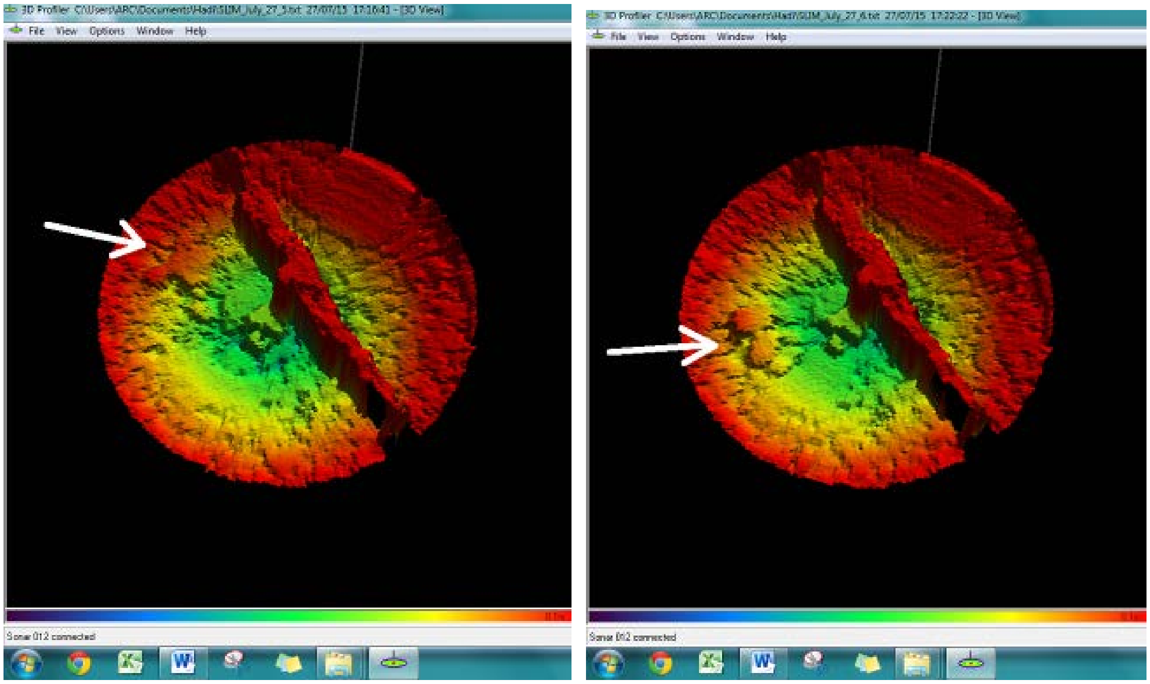


Fig. 5. Image of the U-channel and the 6 mm thick, L-shaped piece of metal in position 1 (left) and position 2 (right)

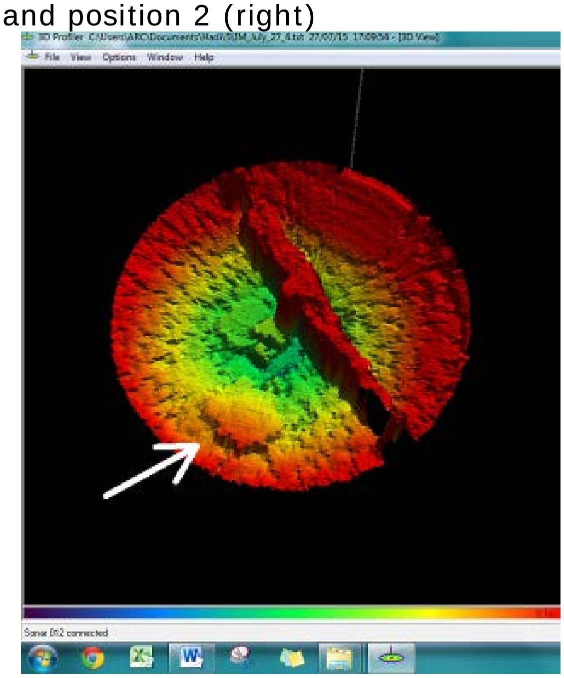


Figure 6. Image of the U-channel and the 6-mm thick L-shaped piece of metal in position 3

Additionally, software for automating the analysis and input of sonar data into imaging software has been developed. In addition, specific data filters developed and/or tested include:

1. A minimum time filter to remove scatters sometimes seen around the sonar head;
2. A maximum time filter based upon tank dimensions and angle that will eliminate most double scattered sonar pings which show as points beyond a surface;
3. A nearest neighbor analyses that eliminates most sonar pings that scatter from particulates suspended in the water tank (important when mixing adds up to 30% by volume of solids to the water in the tank); and
4. Smoothing functions for interpolation of 2-D sonar slices into quality 3-D images even in sparse datasets (i.e., less than five, 2-D sonar slices contributing to the sonar image due to short times available for imaging).

Depicted below in Fig. 7 are images created by two additional processing filters for sonar data. The image is that of a standard brick. Filtering is needed to allow for automated monitoring for the presence or absence of settled solids in the bottom of the mixing tanks at Hanford during the various short stages of each PJM cycle. Should there be settled solids during mixing then the mixing operations engineer would assess whether to modify the operation to enhance the mixing and suspension of solids in the tank.

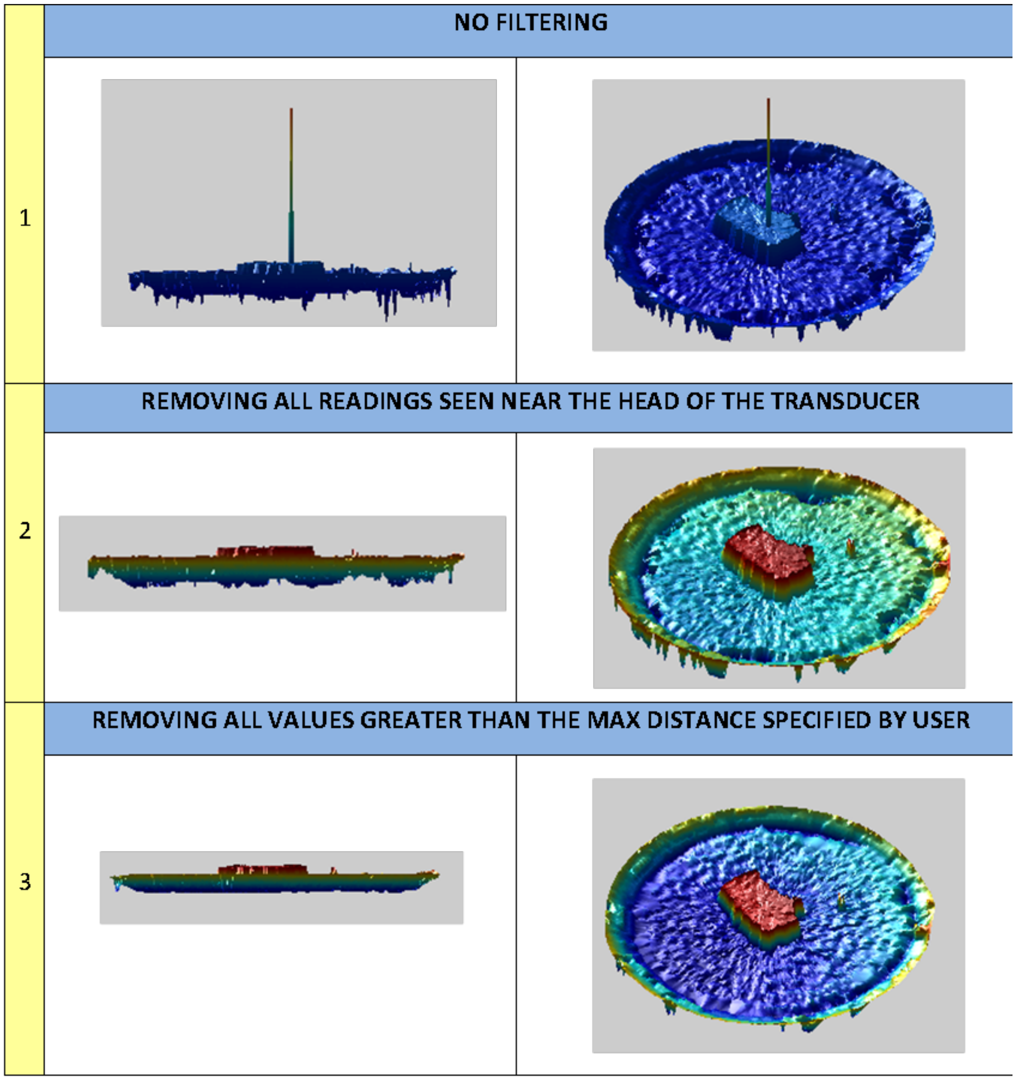



Figure 7. Image results of 3 sonar data filtering techniques

In Fig. 8 below is a photograph of a ceramic rectangular parallelepiped (flat plate 13”x7”x1”) used as an imaging object on the floor for use during mixing operations.

Fig. 8. Photograph of ceramic object used during initial mixing studies

In Fig. 9 below is the commercial sonar's image of the flat ceramic object. Notice the excellent shape of the object and that the field of view has been optimized to minimize the time for scanning and post-processing.

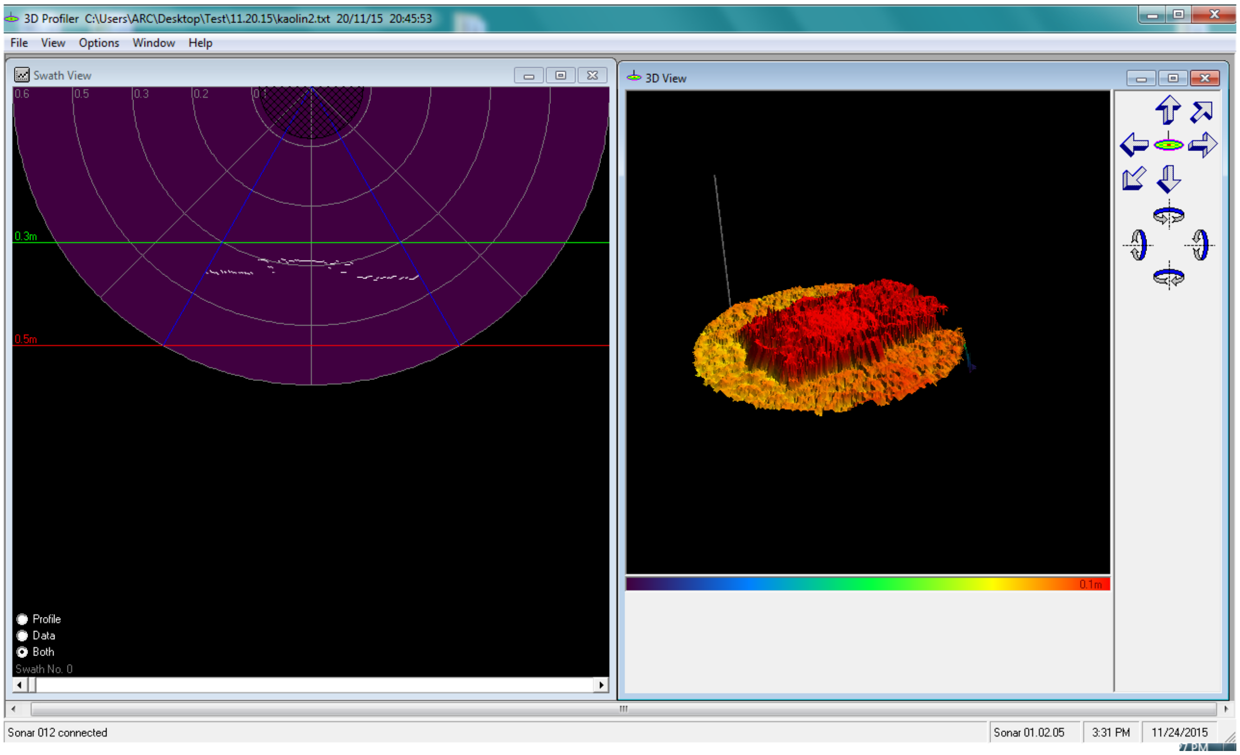



Fig. 9. Baseline sonar 2D and 3D imaging of the rectangular parallelepiped, ceramic object

Data from the above baseline object imaging was imported into MATLAB and the resulting image is shown below in Fig. 10. The sonar and processed images are the same. The importance of the post-processing is more important for short scans and during mixing when the sonar cannot create images.

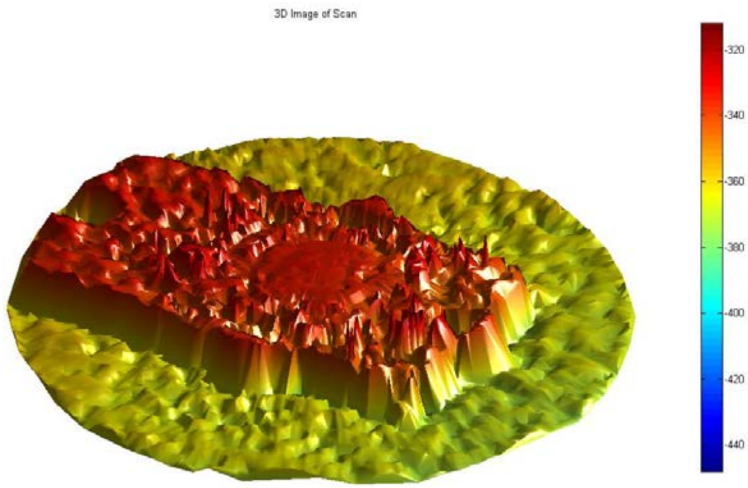
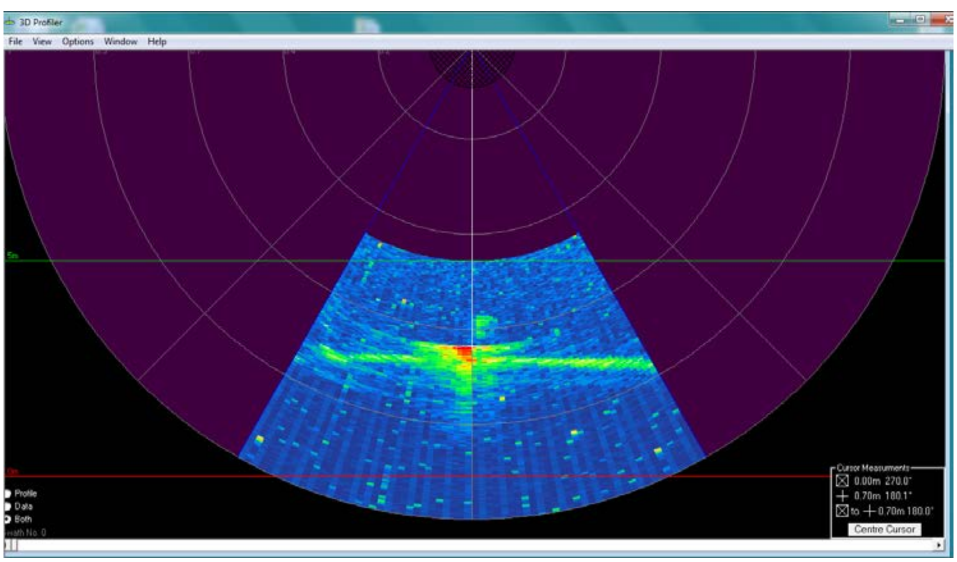



Fig. 10. Sonar data processed in MATLAB for visualization

With baseline testing without mixing suspended solids completed, kaolin clay was now added to the tank for use in mixing studies. Kaolin clay with ~1 micron diameter was added to yield a 5% by volume solids in the liquid with complete suspension of the particles. In Fig. 11 (upper image) the 2D profile clearly shows the tank floor with the flat ceramic object directly under the sonar. Reflections off particles can be seen above the plate and can be removed in the post-processing of the images. Note that the commercial sonar does not filter the data and so all reflections off suspended particles render the direct sonar’s 3D image (lower right) useless. Also note that the 2D profile (lower left) clearly shows the tank floor and the flat ceramic object.



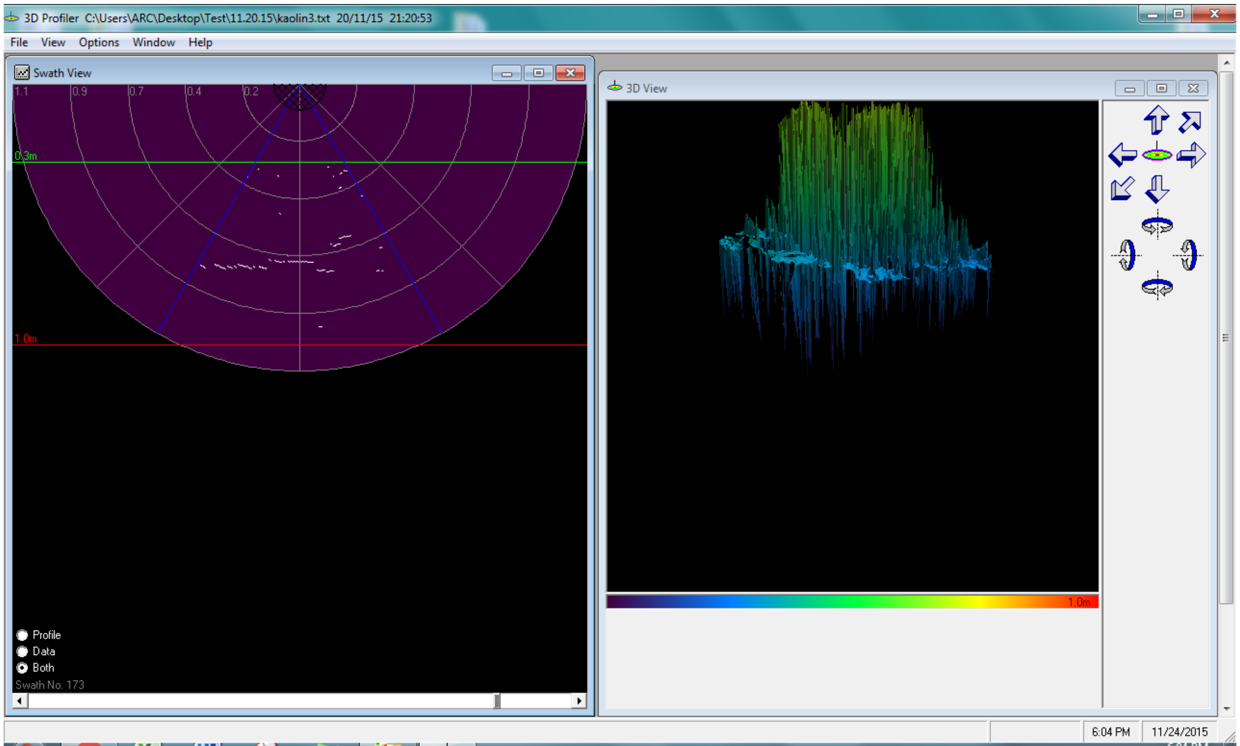



Fig. 11. Commercial sonar image windows for test involving suspension of 5% kaolin clay in the liquid

**HLW Tank Settled Solids Surface Monitoring for Gas Buildup**

The research focus for this effort shifted for September 2015 through August 2016 to two new objectives: (1) imaging a solids layer that is growing due to gas generation and retention in the solids layer; and (2) determination of settling rates of various surrogate HLW particulates.

In tank sonars could provide continuous monitoring of the floor and show when a solids layer is present on the floor and if it is growing over time due to settling or the buildup of gas in the solids layer.

FIU initiated a literature review of this new application for the imaging sonar in HLW. The first report reviewed was by Dr. Terry Sams and colleagues entitled, “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.” FIU also identified some possible software which would support part of the near continuous monitoring of a tank floor (goal for automated imagery collection, porting, filtering, other post-processing, and visualization in images and movie format).

FIU continued to evaluate the resolution of the repaired 3D sonar by imaging a stack of 3-mm thick plates. The three sonar images below use the commercial sonar imaging software and have imaging times of 90 – 100 seconds. As FIU post-processes the data in 2016, FIU will extract the number of 2D scans for any given short imaging time (e.g., 20 second scans) and then filter and improve the image resolution and quality in our visualization software. For tanks with the sonar installed, the short scan imaging of the HLW layer on the floor would be continuous, allowing for comparison of multiple scans to see solids being swept across the floor, areas of solids accumulation and any growth in the thickness of the solids layer.

Fig. 12. The 3D sonar set to view a stack of small metal plates on top of a larger metal plate. The sonar has been set for a field of view of 30.

Fig. 12. Test setup in small tank with 3D sonar and small stacked metal plates

Fig. 13 is a sonar image of the tank bottom (dark green); the large metal plate (lighter green) and the stack of 6 small metal plates (yellow green) with a total thickness of 18 mm.

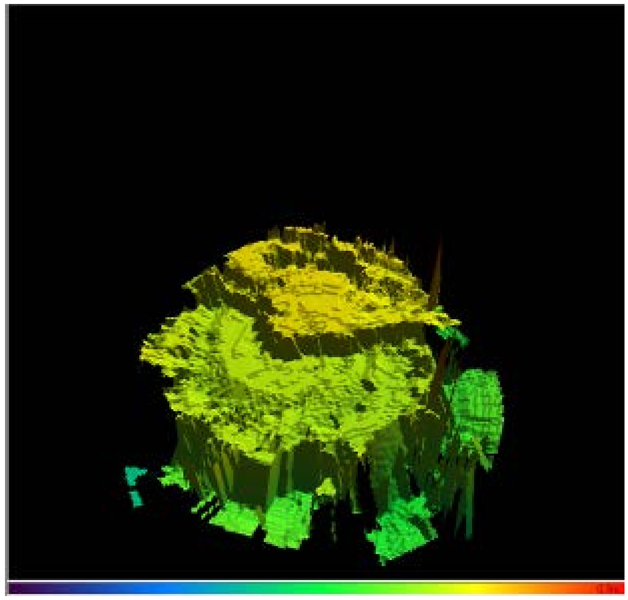


Fig. 13. Sonar image of 6 stacked metal plates, each 3 mm thick

The sonar image in Figure 14 clearly shows the 2 stacked plates (6 mm total thickness).

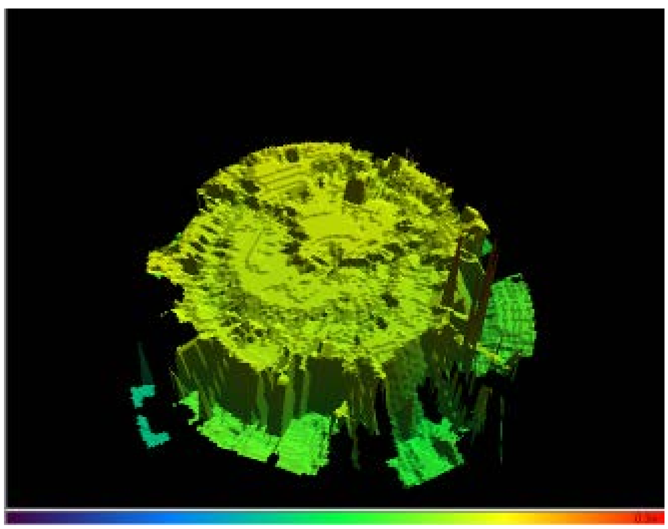


Fig. 14. Sonar image of 2 stacked metal plates, each 3 mm thick

Finally, the last sonar image in Fig. 15 shows the difficulty in identifying the single 3-mm thick plate.

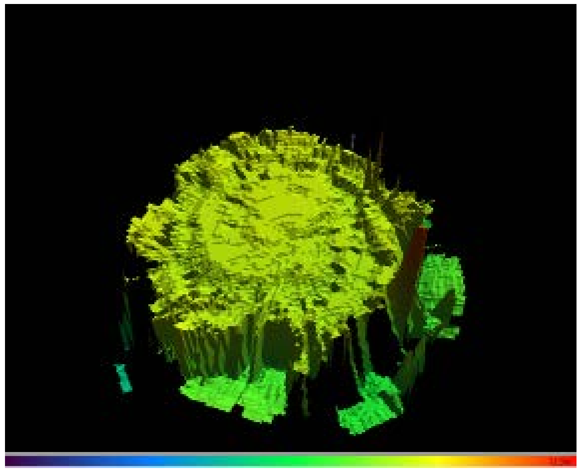


Fig. 15. Sonar image of 1 metal plate, 3 mm thick

Multiple images of the same area allows one to see traces for the single 3 mm thick plate as it is moved across the field of view. Use of processed sonar data increases resolution and improves accuracy of heights. Images for the 1, 2, and 6 stacked plates will be processed in early 2016 to better define the ultimate accuracy and utility of these sonars for solids monitoring.

## CONCLUSIONS

Since the planned operation of the sonar is to monitor the floor continuously, FIU has the ability to automate the continuous monitoring with continuous visualization (e.g., movie format). Tests during mixing shows that sonars can see through 2-3 meters of liquid with as high as 30% solids suspended. For the new research need for imaging small changed in height as small as 3 mm.

Combining successive sonar scans into a video clip would allow operators to visualize how the solids layer grows, shifts, or disappear entirely (to the sonar's image resolution).

The MATLAB processed sonar images have shown improved image quality and improved distance measurements for the sonar. The continuing research will demonstrate the ability of the sonar to image 3-6 mm changes in the height of settled solids layers on tank floors.

## REFERENCES

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, PNNL-23060 Rev. 1, DSGREP-RPT-002, Rev. 1, SD Rassat, PA Gauglitz, LA Mahoney, RP Pires, DR Rector, JA Fort, GK Boeringa, DN Tran, MR Elmore, WC Buchmiller, ML Kimura, April 2014.