3D SONAR for Tank Waste Quantification – 15430

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ABSTRACT

An innovative remote 3D SONAR technology adapted from the oil and gas industry has been successfully applied to the mapping of radioactive sludge deposits during tank, fuel pool and silo remediation operations at the Sellafield site in the UK. The technology can:

- Measure the disposition and calculate the volume of settled solids in a waste tank thereby supporting tank closure objectives
- Produce accurate 3-D images of solids disposition, structure and tank internals to help identify where sludge deposits and debris are located
- Capture real time 'SONAR video' of movement of solids in the tank in real time to aid retrieval
- Detect and monitor gas release and bubble generation

Aside from direct safety, cost and schedule benefits, improved accuracy and confidence in residual waste volume determinations can lead to increased level of regulator confidence in meeting closure objectives. This technology has potential to bring such benefits to challenges in the DOE estate, such as Savannah River Site (SRS) and Hanford Tank Farms remediation, and operations at the Hanford Waste Treatment Plant. This paper describes the 3D SONAR technology and its applications, and reviews a 3D SONAR demonstration project specifically aimed at enhancing retrieval and closure operations at SRS.

INTRODUCTION

3D SONAR technology has been successfully applied to the mapping of radioactive sludge deposits during tank, fuel pool and silo remediation operations at the Sellafield site in the UK.

Under funding provided by the US DOE, NuVision Engineering carried out a demonstration project to investigate the benefits of applying remote 3D SONAR technology to improve the cost, schedule and safety of tank closure operations at SRS. The SONAR technology has a successful record of accomplishment in remediation projects at the Sellafield site, but has not been used on very large tanks with complex internals such as those in the SRS Tank Farms. The demonstration project was therefore focused on proving the technology for this application. This included testing the equipment in a large-scale mock-up of a Savannah River Tank with representative tank internals and simulated sludge and solid deposits.

PRINCIPLES OF SONAR TECHNOLOGY

General

SONAR (originally an acronym for SOund Navigation And Ranging) is a technique that uses sound propagation (usually underwater, as in submarine navigation) to navigate, communicate with or detect objects on or under the surface of the water. Modern SONAR technology dates back to the early 20th century. There are two fundamental types of SONAR; "passive" SONAR is essentially listening for the sound made by submerged objects e.g. vessels; “active” SONAR is emitting pulses of sounds and listening for echoes. In turn, there are four basic types of active SONAR.

Ultrasound
This is essentially a one-dimensional depth “pinger” a good example of which is the fishing echo sounder. It provides high accuracy single point measurements

Imaging/Sidescan
This is a technology which provides fast, practically real-time visual feedback. Output is similar to an underwater “photograph” and it is ideal for marine safety purposes such as collision avoidance. The output is limited however to low accuracy linear measurements.

2D Profiler/Multibeam
This technology provides rapid (~1-2 second) 2D cross-sections and provides high accuracy linear measurements. It is often used in marine survey applications and may be deployed remotely e.g. via a remotely operated (underwater) vehicle (ROV). Such a system is typically used for offshore submerged pipeline surveys.

3D SONAR
3D SONAR technology generates high accuracy spatial measurements. It is relatively slow compared to other types of active SONAR but generates true 3D data, similar to a laser scanner.

3D SONAR TECHNOLOGY

General
3D SONAR like all other forms of active SONAR operates on the ‘time of flight’ principle i.e. measurement of the time taken for a sound pulse to travel to, and return from an object or interface. In order to calculate time of flight, the velocity of sound (VoS) is needed for the medium through which the SONAR pulse is travelling. This can be measured directly using a calibrated instrument or inferred by comparison of time of flight with a known distance to an object or feature. VoS is typically in the range 1475 – 1500 m\sec.

The SONAR frequency is also an important factor.
High frequency = better resolution, less penetration of sludge
Low frequency = greater range, less resolution

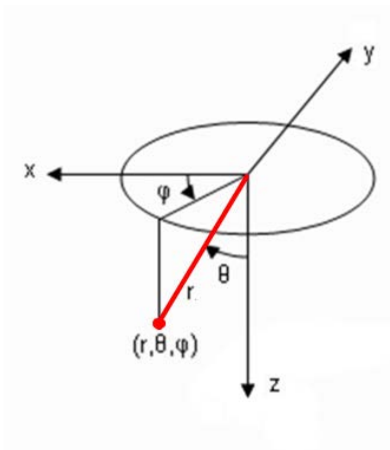


Figure 1 Principles of 3D SONAR

- Sequential ‘pings’ build the 3D coverage.
- Acoustic pulse fired along ‘r’
- Defined by a rotational angle, ψ, and a swath angle, θ
- Pulse travels until a material interface is encountered
- Range & bearing calculated from time of flight of echo
- X, Y and Z are calculated from range and bearing

Each measurement environment is different and the SONAR power, gain, detection thresholds, etc. must be adjusted to accommodate for variation in factors such as the properties of the sound transmitting medium (particularly VoS), and the properties and disposition of the objects and surfaces to be detected. Factors affecting the outcome of a 3D SONAR survey are as follows:-

Resolution
This is defined by the distance between the individual points scanned, referred to as ‘dots’. Generation of more dots and therefore more scan time is required to achieve higher resolution, so resolution is primarily governed by the angles θ and ψ in Figure 1. A high resolution scan taken at 1° x 1° will typically take 40 minutes to complete, whereas a low resolution scan of 5° x 5° would take about 5 minutes.

Accuracy
This largely depends on the mechanical accuracy of the drive motors as they position the transducer at each scan location. A secondary factor is the beam width of the acoustic pulse which diverges with distance, and loses positional accuracy at higher ranges.

Shadowing
Although acoustic in nature, SONAR behaves similarly to a line of sight device, i.e. it cannot see around corners. Multiple scans from differing locations/orientations can be used to fill in the blind spots resulting from obstructions. Note that multiple scans require careful compilation of the scans into a single data set, a process known as ‘Registration’.

Head Positioning
Knowledge of the SONAR head position in XYZ and (sometimes) Ψ is important, and the head needs to be kept stable during scanning. In determining the optimum head position, the surveyor needs to consider the goals of the survey and subsequent post processing methodology to be used.

Noise Reduction
All SONARs receive noise, e.g. from bubbles, fish, double reflections or electrical interference which can manifest as false signals. Good initial setup of the system reduces but may not eliminate these impacts

Scan Alignment

With knowledge of the exact location of the SONAR head at the time of each scan, registration of the data sets to a common 3D datum point is straightforward. However in practice and especially on aged plant or environments where remote deployment is required, this can be difficult to achieve so a different approach has to be used. Providing there is some overlap in the data, computer techniques can be used to align common features in each scan using established best-fit algorithms developed in the laser scanning industries.

Interpretation

Once the data sets are aligned, further processing is required in order to construct CAD data from the ‘dots’. Depending on the goals of the survey (it may be sludge profiling or mapping of steelwork structures for example) the surfaces of the objects of interest represented by the clouds of dots (known as ‘point clouds’) are created. This process is undertaken using specialised software that utilises feature recognition for regular shaped objects (such as steel beams etc.) or ‘best fit’ smoothing algorithms for extracting the shape of irregular objects, such as sludge beds. Despite the processing power available on today’s computers, it remains a skilled and labour intensive process.

3D SONAR EQUIPMENT

SONAR Head

The SONAR head is the heart of the system which generates the SONAR pulse and detects the returning signal. The SONAR head is immersed into the liquid and is either suspended (e.g. from an umbilical) or attached to a rigid support. Components vulnerable to radiation e.g. circuit boards are divorced from the head and located in a low dose area. Testing for a Sellafield project, requiring a nine SONAR head array in a dose field of 1.5 Sv/hr (150 rem/hr) over 5 years showed no failure of components (total dose applied over 1 month = 70 kGy (7,000,000 rad)). To avoid costly replacement SONARs can be ‘over-canned’ with only a minor loss of signal strength. The outer can and exposed cable can be replaced or disposed of when contamination levels become problematic. This requires a precision machined, secondary sonar transparent “PEEK” dome. Extensive trials and field experience have optimised the design.

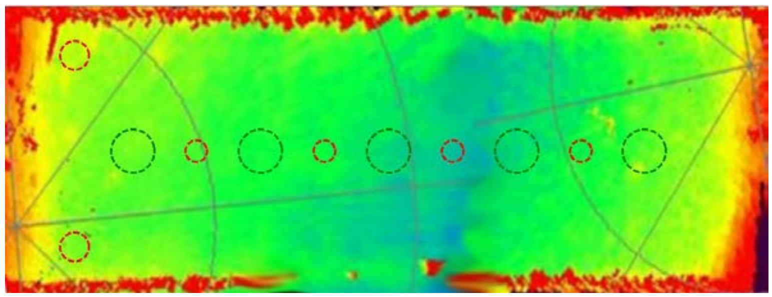
Figure 2 Standard 50&90mm Sonar Heads (Left) and Ruggedized Control Box (right)

Control Box

The Control Box houses the SONAR data signal processing boards, power supplies and an industrial grade embedded PC that is used to display the live SONAR results. Depending on the application this equipment may either be housed within a ruggedized case or, for permanent installations, within a control room desk.

Software

The SONAR is operated using a dedicated software package that allows the operator to tune the transducer parameters, such as survey range, transducer gain and operating frequency, to suit the particular environment. As the survey progresses the SONAR software displays both a vertical cross section and a composite plan view that builds up as the SONAR data is acquired and processed.



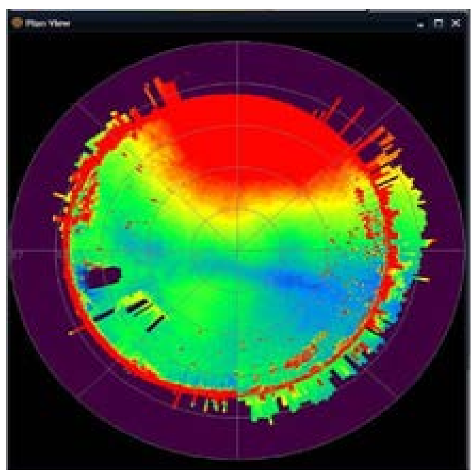


Figure 3 Composite Plan View of a Circular Nuclear Sludge Storage Tank at Scan Completion (colored by target height)

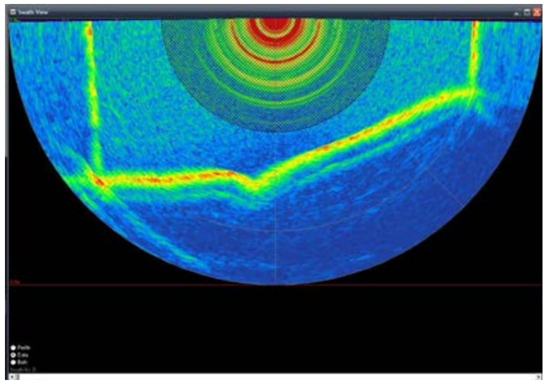


Figure 4 Cross Sectional View through Sludge Bed Nuclear Sludge Storage Tank (colored by signal intensity)

SUCCESSFUL APPLICATIONS OF 3D SONAR FOR TANK WASTE QUANTIFICATION

The following are some examples of many projects where this technology has been used successfully to aid in clean up planning and operations in the energy and nuclear industries

Surveying of an 80 m Diameter Crude Oil\Seawater Separating Tank from Three Locations.
In this application the SONAR was pushed through the 1m thick layer of floating semi-solid crude oil and into the underlying seawater where the scans were taken and used to map the drop-out sediment lying on the tank floor. The line of elevated material (in red) is typical of the drop out profile adjacent to the 50" tank inlet pipe. Shadowing from the roof support pillars and the lack of other penetrations prevented full coverage of the tank base.

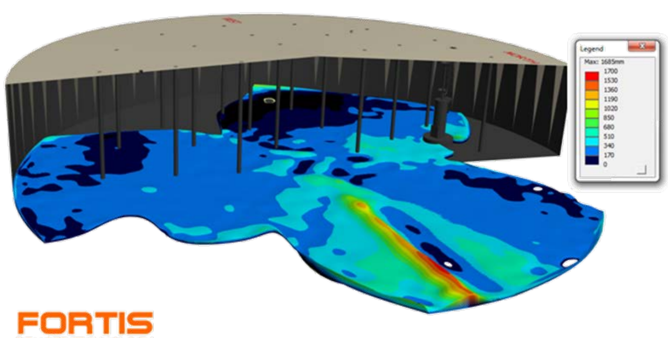


Figure 5 Crude Oil Tank Aberdeen Scotland

Surveying of an Aged Nuclear Fuel Production Plant
Sonar was deployed in multiple locations in an aged nuclear fuel production plant on a UK nuclear site. As well as detecting and mapping sludge deposits the sonar survey was able to achieve the mapping of the internal facility steelwork to assist in decommissioning sequence planning and waste volume estimates. Because of the congested environment the area shown required over 60 registered scans to be completed to overcome shadowing effects.

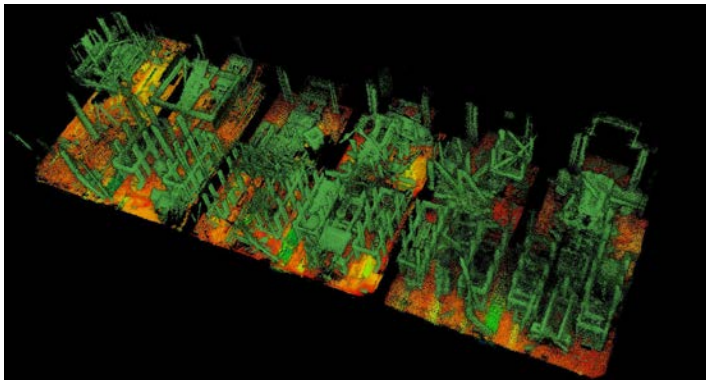


Figure 6 Submerged Fuel Handling Facility Bays

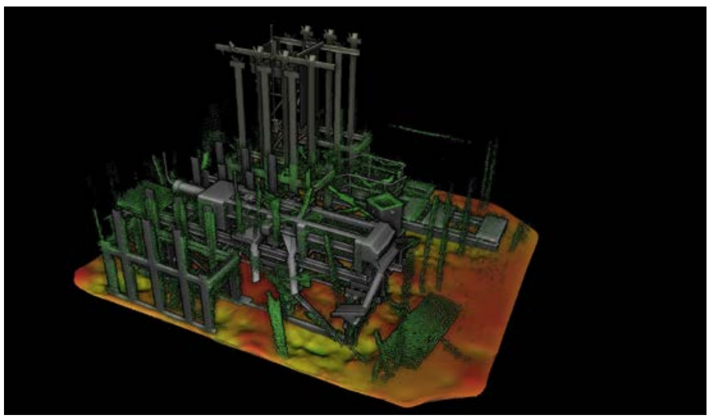


Figure 7 Structural Modeling from SONAR data

Sludge Mapping and Volume Characterization of a Large Nuclear Ion Exchange Sludge Storage Tank

The detailed survey of the sludge profile in the tank seen in Figure 8 was achieved using permanently installed SONARs that are secondary sleeved to prevent radiological contamination.

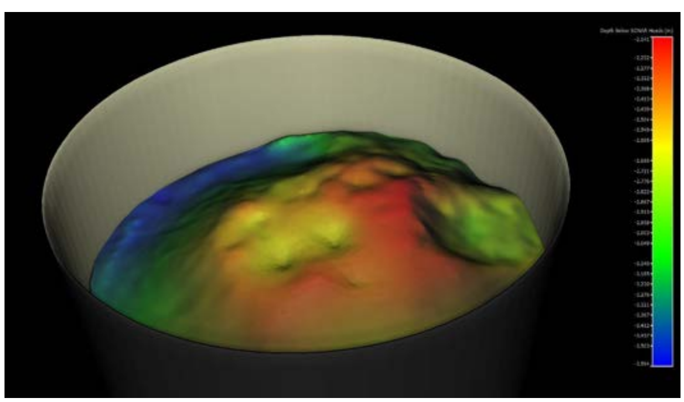


Figure 8 Sludge Profile in 11m diameter Ion Exchange Storage Tanks

DEMONSTRATION OF 3D SONAR FOR TANK WASTE QUANTIFICATION AT SRS

Objectives

At the Savannah River Site, waste volume determinations are needed prior to closure of waste tanks to ensure that the tank closure objectives have been met. The current method used at SRS is to halt mixing operations, allow the sludge to settle to the base of the tank, pump out the liquid from the tank, insert cameras through multiple available risers and visually calculate the remaining volume. If it is decided to continue mixing/pumping operations, the contaminated liquors are returned to the tank and mixing restarted.

This method requires multiple transfers of tens of thousands of gallons of contaminated liquor between tanks, which is time consuming, costly, and a potentially dangerous exercise. In addition, this process takes up valuable tank space on the Savannah River Site that is no longer available for tank closure operations or waste processing. In the demonstration project, an existing large diameter test tank at the NuVision Mooresville, NC facility was used to demonstrate the performance of the in-tank SONAR surveying technology under conditions which mimic the challenges of 'typical' tanks at SRS. The baseline demonstration (Task 1) consisted of the following:

Demonstration Program

A demonstration program was conducted on a representative scale in the 6.1M dia. x 6.1M tall stainless steel test tank modified with representative obstructions (e.g. simulated cooling coils made from PVC) and suitable SONAR targets and/or simulated sludge beds. Simulants/targets included granular inert minerals (e.g. sand or kaolin clay which could be manipulated into different configurations or levels) and large artificial landscaping 'rocks' made from polymer used to simulate settled solids and debris. This test facility was utilized to investigate influence of variables such as liquid depth, size and location of obstructions, and number of SONAR heads on system performance and accuracy.

As the size of the above test set up was limited, a municipal swimming pool, circa 18M wide and maximum 5M deep was also utilized to demonstrate the effective radius of the SONAR in very large tank applications such as those at Savannah River and Hanford tank farms.

Test Equipment

Standard 50 & 90mm SONAR heads with portable control boxes were used in the tests. The test tank and internals (designed to be representative of the internal configuration of a typical SRS tank) are shown in Figure 9 below. To represent the residual solids that the SONAR would be required to detect in the tank, the following were used:-

- Artificial landscaping rocks c 1M sq., irregular in shape and varying from approximately 100mm-400mm in height*
- Sand filled burlap bags
- Granulated magnesium hydroxide

*Also used as targets in the swimming pool tests

Sonar heads were suspended into the test area by umbilical or attached to a deployment pole (Figure 10).

Test Plan

A 10 day test program was conducted, investigating and documenting the SONAR system performance with the following variables:

- Water level heights from 5 to 1M
- Variable location of SONAR head / number of scan locations
- Effect of interferences such as cooling coils / columns
- Variable Simulant (sludge bed) topography

Results – Test Tank

The SONAR scans of the test tank generated clearly representative images of all the tanks internals and targets. Figure 11 is a composite image which identifies the individual features as detected and mapped by the sonar system. Figure 12 through Figure 14 show the level of detail that can be achieved by the SONAR system in mapping of individual features in the tank. The accuracy of the SONAR scans of the individual items is set out in Table 1 below.

Figure 9 SONAR Test Tank & Internals

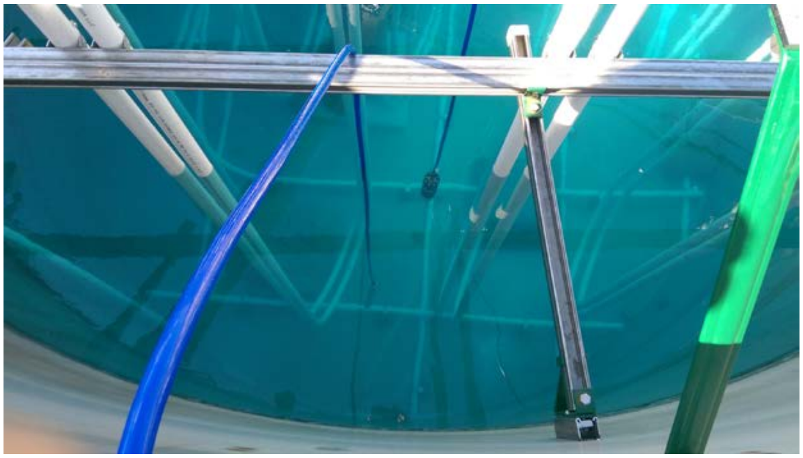


Figure 10 Sonar Head Immersed in the 6.1M Test Tank

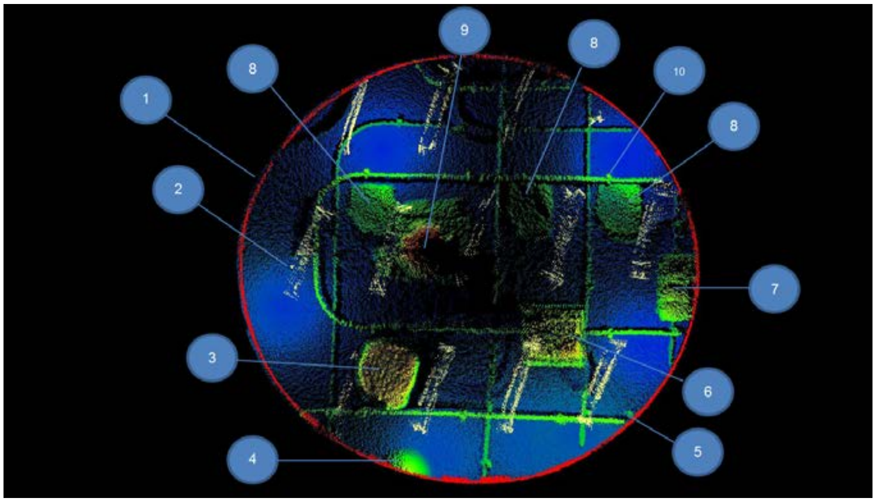
Table 1 Results of Sonar Survey of Test Tank and Targets

Item	Approximate Measured Volume	Sonar Estimated Volume	% Difference
Large Artificial Rock, Figure 12	0.20255 m^3 (7.153 ft^3)	0.1756 m^3 (6.201 ft^3)	13.3
Small Artificial Rock	0.03964 m^3 (1.4 ft^3)	0.03549 m^3 (1.253 ft^3)	10.5
Magnesium Hydroxide Pile, Figure 14	0.0189 m^3 (0.668 ft^3)	0.0198 m^3 (0.699 ft^3)	4.55

It should be noted that the volume estimation variance for sludge bed mapping typically achieved in the field is of the order of that achieved for the Magnesium Hydroxide Pile i.e. less than 5%. The higher variance for the ‘artificial rocks’ was driven by the complex shape and the need to multiply the x,y, and z readings to generate a volume estimate, compounding individual dimensional inaccuracies.

The sonar was able to achieve these results at low water levels in the tank of approximately 1m. The effect of interferences such as the ‘cooling coils’ was readily overcome by relocating the sonar head between scans to eliminate the impact of sonar ‘shadowing’.

Finally, Figure 15 shows how the SONAR scan can be combined with a CAD model of the tank features to produce an accurate depiction of the tank and its contents. A notable feature in this image is a stream of bubbles in the top center. The bubble stream was generated by blowing air into the tank through a pipe at the bottom and shows how effective the system can be in detecting submerged bubble streams.



No	Description
1	Tank Internal Wall
2	Vertical Cooling Pipe
3	Mock Rock (Large)
4	Versamag Pile
5	Bubble Inlet Pipework
6	Mock Small Rock on Square Plinth
7	Sandbags on Tank Periphery
8	Mock Rock (Small)
9	Central Riser
10	Horizontal Cooling Pipe

Figure 11 SONAR Map of Submerged Tank Internals and Targets

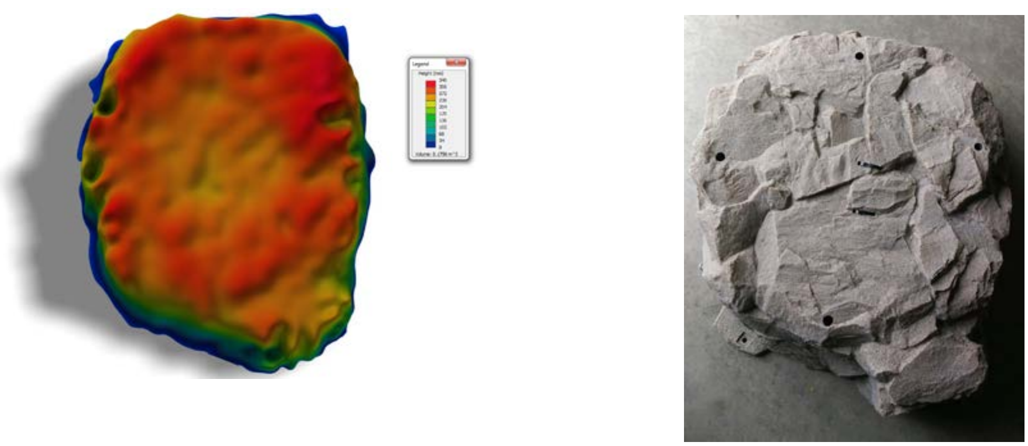


Figure 12 SONAR Image (Left) of Artificial Rock Target (Right)

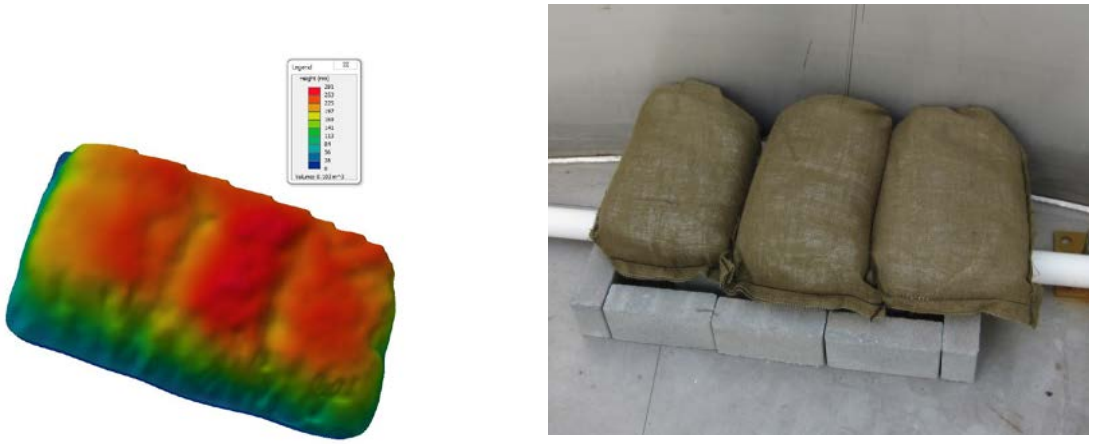


Figure 13 SONAR Image (Left) of Sandbag Target (Right)

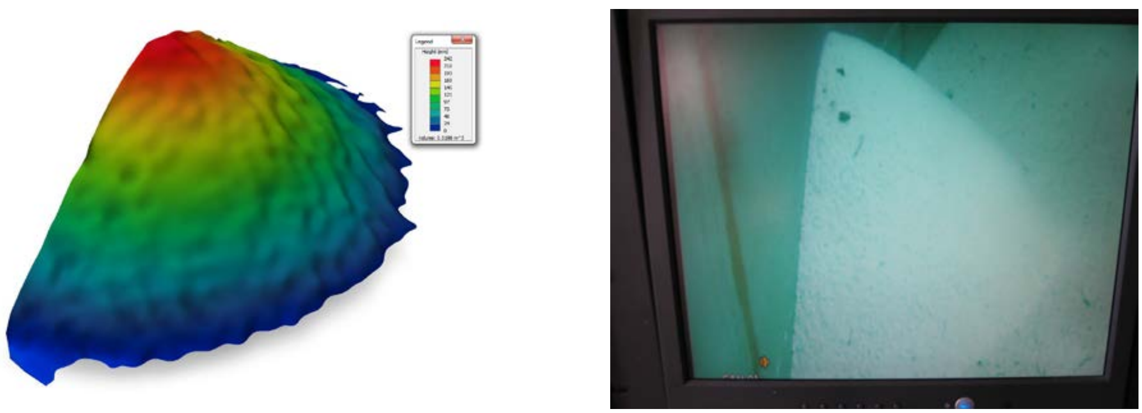


Figure 14 SONAR Image (Left) of Magnesium Hydroxide Pile (Right)

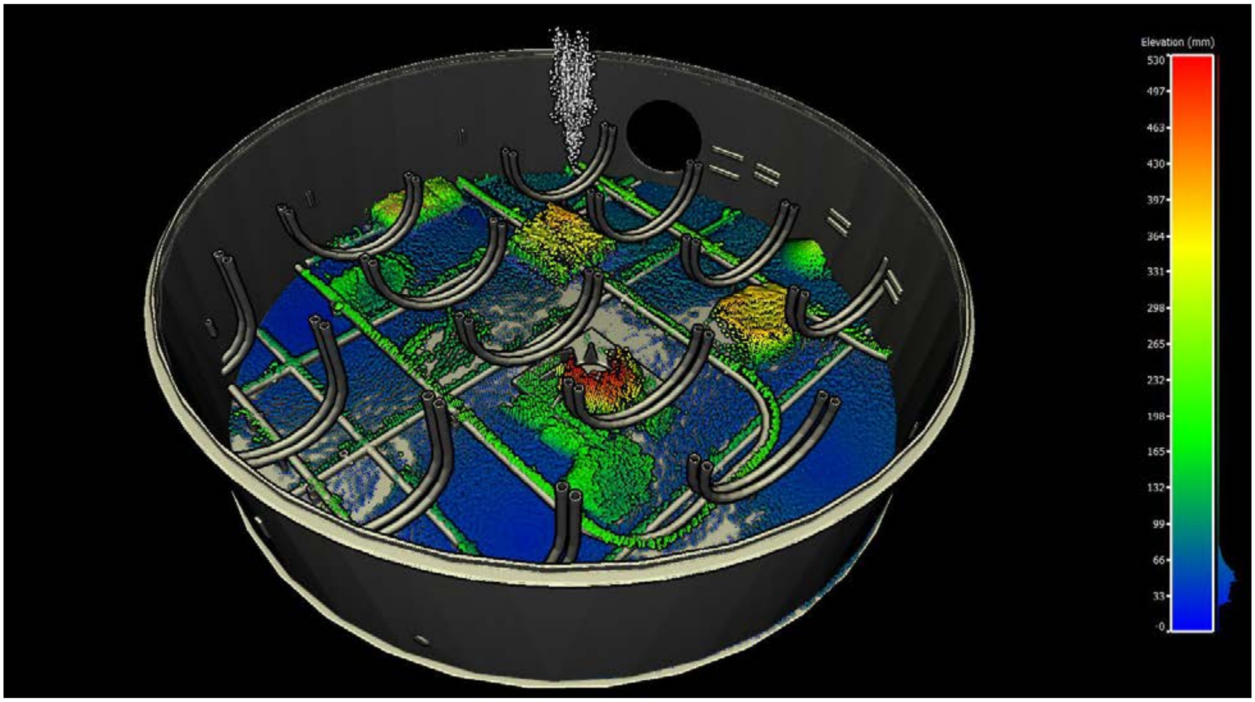


Figure 15 SONAR Scan Overlaid on 3D Tank CAD Model

CONCLUSION

The 3D SONAR surveying technology can remotely quantify the remaining waste volume and can eliminate the need to completely pump the tank down at SRS thereby reducing the turnaround time on survey results. It is relatively inexpensive and simple to deploy and can be removed and re-used or remains permanently installed, resisting high radiation fields without damage. Volume estimation variances are typically in the single digits, which would be a 1-200% improvement over current techniques at SRS.

In summary, sonar surveying technology can substantially improve accuracy over the current baseline measurement technique at SRS and can help to build increased levels of DOE and regulator confidence in meeting closure objectives. In turn, increased safety, reduction in time duration and reduction in overall operational costs are expected to be achieved.

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