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MAINTAINING CONTINUITY OF KNOWLEDGE (COK) OF SPENT FUEL POOLS: FIELD TESTING

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Abstract:

Maintaining Continuity of Knowledge (CoK) of spent fuel throughout its life cycle is a key objective of the International Atomic Energy Agency (IAEA). This project is intended to field test two specific technologies, short-wave infrared (SWIR) imaging, and imaging sonar, for augmenting optical surveillance cameras currently used for maintaining CoK for spent nuclear fuel (SNF) staged in spent fuel pools. Furthermore, the project will identify any modifications required to the technologies in order to facilitate deployment for international safeguards purposes. This report presents results for the imaging sonar tested at Sandia National Laboratories (SNL) in a mockup spent nuclear fuel pool.

Introduction

The most widely used Containment and Surveillance (C/S) measures deployed to maintain CoK of spent fuel pools are optical (visible range) surveillance cameras with a view of the pool and portals, and seals on canal gates and portals. A concern, however, is that currently deployed optical surveillance cameras may not be able to provide adequate imagery in the event facility lighting is lost or obscured, which represents a potential single point of failure in CoK. The IAEA cannot simply rely on back-up power or other facility measures. If for any reason they are inadequate or maliciously tampered with, CoK may be lost over the spent fuel in the pool. If CoK is lost, a time-consuming and resource-intensive effort must be undertaken – possibly involving a lengthy process of performing nondestructive assay (NDA) measurements and ID verification on a statistical sampling of spent fuel assemblies in the pool – to reestablish CoK, and to ensure that no diversion or substitution has occurred. This field-test project is a continuation of an FY16 U.S. National Nuclear Security Administration (NNSA) Office of International Nuclear Safeguards (NA-241), Safeguards Technology Development Program (SGTech) project that surveyed supplemental tools that can be used in addition to optical surveillance cameras to maintain CoK in low-to-no light conditions.

In the FY16 tool survey, multiple technologies were identified from in-pool to out-of-pool for maintaining CoK in addition to providing increased effectiveness and efficiency. The most promising technologies were imaging sonar deployed within the spent fuel pool and SWIR cameras deployed outside the spent fuel pool. Each technology provided different benefits and capabilities. The imaging sonar was determined theoretically to be able to detect diversion of fuel assemblies,

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perform item count, and potentially provide fuel assembly identification. The SWIR system theoretically should be able to detect diversion and possibly perform item count.

Implementation of the technologies represented in the FY16 survey ranged from those requiring only minimal adaptation to those needing significant adaptation for international safeguards use. There are currently no technologies identified that would be appropriate for immediate international safeguards use. Imaging sonar required the most adaptation, but seemed to provide the most capability in terms of supplemental C/S measures and improvements to effectiveness and efficiency. SWIR imaging systems may require the least amount of adaptation for international safeguards use, but do not provide the ability to uniquely identify the spent fuel within the pool, and it is unknown at this time if item counting is possible. In this project, further analysis and testing will be performed based on the results of the FY16 study recommendations. In particular, initial testing will be conducted of the imaging sonar and in-depth testing of the SWIR imaging system to demonstrate their ability to determine if fuel assemblies have been moved, to count the number of fuel assemblies present, and to read fuel assembly identification numbers. The imaging sonar requires initial testing in non-radioactive environments with mockup fuel assemblies (MFAs), which will be conducted at SNL. Based on the results of this testing, considerations can be given to protecting the imaging sonar from contamination in an actual spent nuclear fuel pool. The SWIR imaging system will be field tested with a triggering capability and consideration for other specific safeguards requirements at the Oregon State University (OSU) TRIGA reactor. This paper presents the results of the imaging sonar field testing.

Test equipment

SNL rented a BlueView Teledyne P900-2250 dual frequency 2D multi-beam imaging sonar along with a pan/tilt accessory. A mockup fuel assembly (MFA) was fabricated along with a storage rack for the MFA. The MFA was representative of a truncated Boiling Water Reactor (BWR) fuel assembly. A mockup spent fuel pool was developed at SNL using a deep concrete lined floor vault filled with water. Finally, metal plates with various sized engraved characters were fabricated to test range resolution of the system.

Figure 1: Dual Frequency Sonar Sensor Head from BlueView Teledyne.

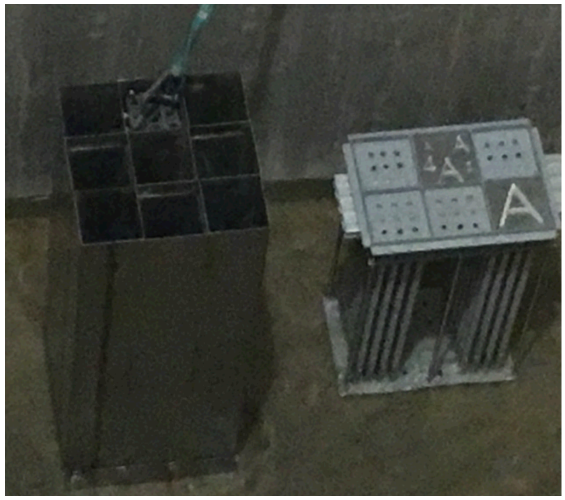

Figure 2: Mockup fuel assembly (MFA) is shown in the back storage location of the storage rack. Engraved characters on a metal plate are placed on top of a piece of metal equipment.

The BlueView Teledyne system (P900-2250) has a field of view (FOV) of 130° x 20°, and excellent range resolution (0.54” for 900kHz and 0.25” for 2250kHz). The software is easy to operate and intuitive. We chose the BlueView Teledyne system based on rental cost and easy to operate software.

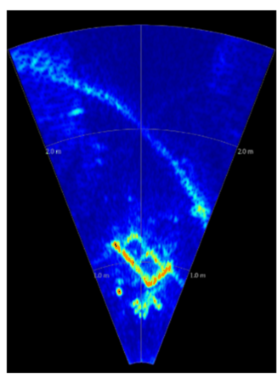

Figure 3: Example of 2250kHz sonar head imagery. Cinderblock and hand. Image courtesy BlueView.

The imaging sonar is primarily a video system, with image rates of 12.5 frames/sec. As such, data volume can be very large. Single frames (pings) can be extracted from the video, which will reduce data volume. There is also a hardware triggering capability that could be explored.

Facility information and test equipment layout

The test was conducted in a floor vault at a facility at SNL New Mexico. The floor vault is a 3.0 m (W) × 4.6 m (L) × 7.6 m (D) concrete-lined dry vault. The depth in feet is approximately 24.9 feet. For the test, the vault was filled with water from a nearby fire hydrant.

Figure 4: Floor vault as it is filled with water. Left object is facility equipment, center is the BWR storage rack with a mockup BWR assembly, right is facility equipment with two metal plates containing engraved characters on its top. Camera view is from opposite side of pool from targets.

The height of the storage rack with the MFA is approximately 5 feet, which allows approximately 20 feet of water above these items. As many spent fuel pools have at least 20 feet of water above spent fuel assemblies, we purposefully truncated the item heights to be most representative of an actual spent fuel pool.

Test activities and results

The overall objective of the test was to determine if the imaging sonar system could acquire adequate imagery to (1) determine if an MFA has been moved within the floor vault (to simulate diversion), (2) count the number of fuel assemblies within the floor vault, and (3) read the fuel assembly identification numbers from the top of the MFA.

Testing began March 27, 2017 and consisted of final facility preparations and equipment setup and checkout. Connecting the sonar components and performing bench top testing was simple and intuitive. The sonar head was attached to the pole mount and pan/tilt, and the entire assembly was bench top tested a second time with no issues. The sonar head was lowered into the water, approximately 8” from the top of the water line.

Figure 5: Sonar head attached to pole mount and pan/tilt accessory – prior to submersion.

Initial testing consisted of collecting baseline information. The pan/tilt was adjusted until the best image of the targets was acquired, for both the 900kHz and the 2250kHz heads. During the baseline testing, we noticed high levels of noise in the imagery. Acoustic reflections and artifacts can be seen on the side walls of the pool. Lights were turned off during testing, with no change to the image, as expected.

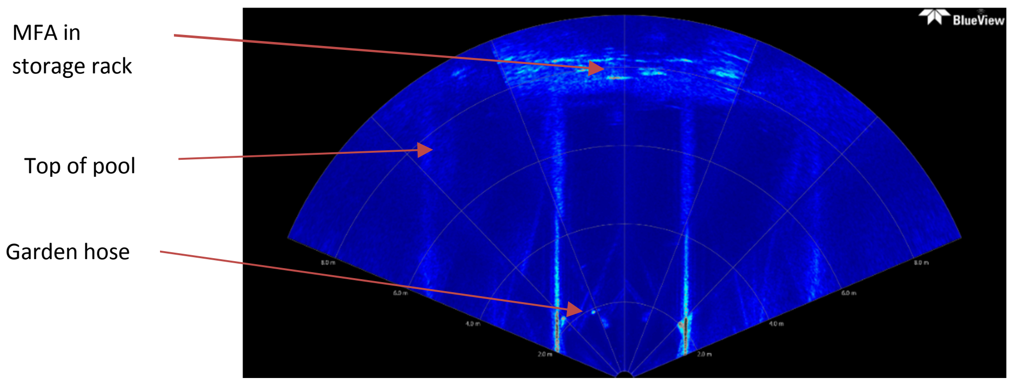

Figure 6: Sonar head is located at end of pool, opposite of targets. Sonar head is 2250kHz. A standard garden hose can be seen at approximately 2 meters from the sonar head. The sets of lines are the top of the pool (outer lines), and the bottom of the pool. Reflective artifacts can be seen on the wall edges. Target is visible at approximately the 8.0-meter mark. Red is the strongest intensity, with blue lowest.

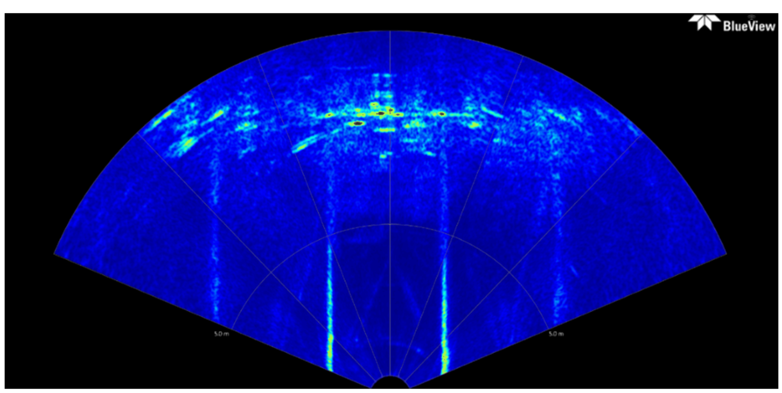

Figure 7: Sonar head is located at end of pool, opposite of targets. Sonar head is 900kHz.

Test objective – reading characters on metal plates

The metal plates with engraved characters were not readable in any configuration of the imaging sonar system (see Figure 6 and Figure 7). It was determined that reading the engravings was not possible; however, it is unknown whether this was due to excessive acoustic noise or simply not enough resolution.

Test objective – counting individual MFAs

There was only a single MFA available for the test, and conclusively determining its shape and location was not possible from the imagery. We could see what appeared to be the shape of the storage rack, and possibly see the three rows and columns of the storage rack. There was a high-intensity return associated with the storage rack, but it did not always seem to coincide with the actual MFA location in the back center slot.

Test objective – diversion/MFA movement

Diversion was tested by using an overhead crane to lift the MFA out of the storage rack and back to either the same location or another location. We expected to see the full MFA geometry as it was moved, e.g. a long red shape in the imagery; however, we only saw a high intensity red region of the image move from one location to another. We were able to see the crane rigging in the water, or possibly the rigging making movements in the water. Before we performed the MFA movements, we moved the sonar to a closer location, approximately 65” from the wall with the target’s below.

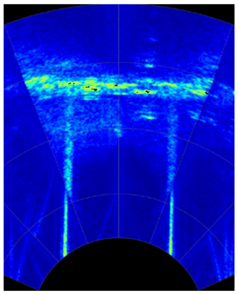

Figure 8: Sonar has been moved approximately 65” from target wall. Settings: 2250kHz.

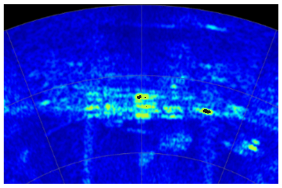

Figure 9: Sonar is approximately 65” from target wall. Settings: 900kHz. It appears that the three rows and columns of the MFA storage rack are somewhat visible, although in this image the MFA is in the back center. The image shows high intensity red returns in six locations, with the back left having the highest intensity.

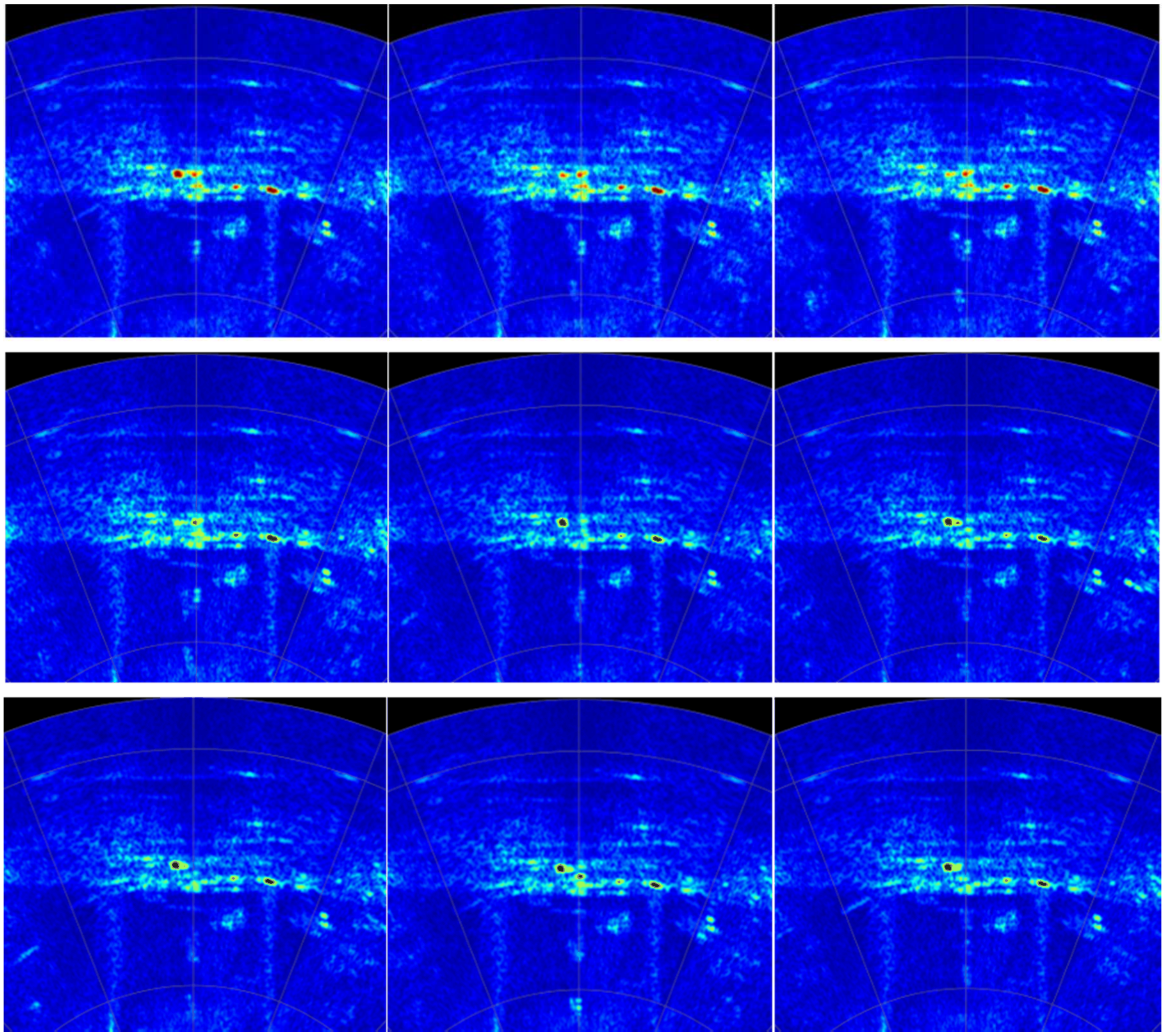

Figure 10: Sonar is 65" from target wall. Settings: 900kHz. MFA is moved out of storage rack, and placed back into same location. Intensity varies during process; however, shown in the Figure are pings separated in time during process. (Sequence is read from top left to right, then down to next rows)

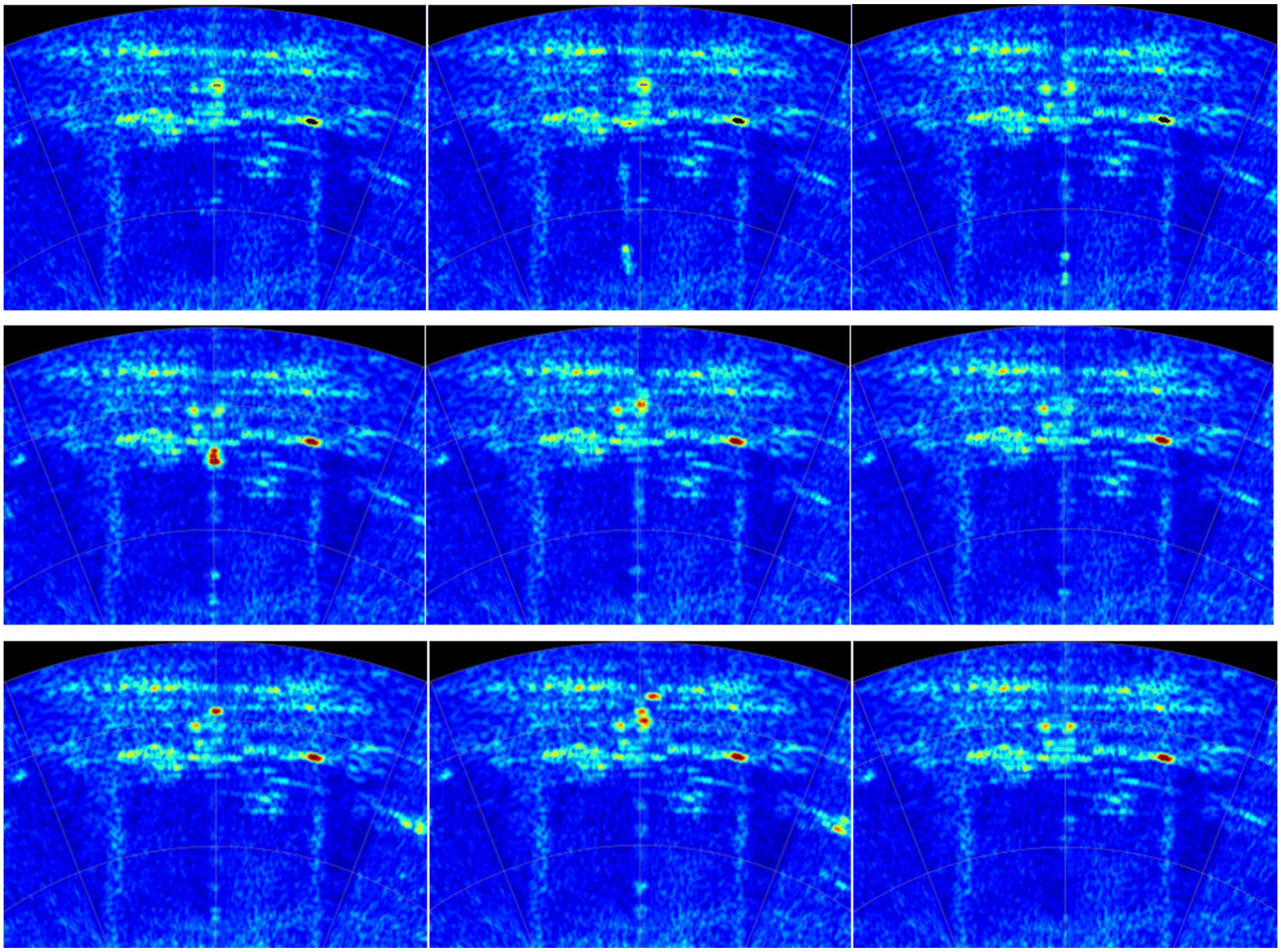

Figure 11: Sonar is 7’ 2” from target wall. Settings: 900kHz. MFA is moved out of storage rack, and into another location.

We also used the pan/tilt accessory to change the angle of the FOV of the imaging sonar. Using the 900kHz head at the position of 7’ 2” from the target wall, the optimal pan/tilt angles were -15.6° pan and 59.3° tilt. The limits for recognizing features of the target were between -6.7° and -31.5° pan and 49.3° and 64° tilt.

Conclusions and Next Steps

The imaging sonar tests demonstrated that identification of fuel assemblies by reading the engraved characters on the top is not possible. Item counting is not as clear as was hypothesized; however, the high intensity locations within the pool are distinguishable in general. Detecting diversion is possible. During the movement, the fuel assembly body is not clear in the image; however, performing change detection between images taken during the movement shows change.

Next steps are to identify and document modifications to the equipment for deployment to international safeguards applications, as well as further image processing to highlight the diversion objective.

Acknowledgements

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References

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