 SAND2021-9398C

Proceedings of the INMM & ESARDA Joint Virtual Annual Meeting
August 23-26 & August 30-September 1, 2021

A COLLABORATIVE PARTNERSHIP TO DEVELOP A UNIQUE SECURITY SOLUTION FOR THE PROTECTION OF INDUSTRIAL IRRADIATORS AGAINST RADIOLOGICAL THEFT OR SABOTAGE

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ABSTRACT

Cobalt-60 used in panoramic irradiators for industrial and research applications can be an attractive theft or sabotage target. Sandia National Laboratories, with funding provided by the United States' Department of Energy/National Nuclear Security Administration's Office of Radiological Security (ORS) has partnered with the International Irradiation Association (iia), an organization that supports the global irradiation industry and scientific community, to develop a unique security application.

Industrial Irradiators contain hundreds of thousands, up to several millions, of curies of cobalt-60. Because of this very high level of radioactivity, these facilities have historically been thought to be self-protecting. However, increased awareness of risk and threat by operators of irradiation facilities has resulted in a heightened interest in increasing the security of cobalt-60 sources at their facilities. Cobalt-60 sources are stored in a rack within a water pool at industrial irradiators, so to successfully accomplish the theft of the target sources, adversaries must have visual contact with the sources and source rack within the pool. Therefore, obscuring or visually hiding the sources in the pool can hinder potential source theft.

Sandia National Laboratories' ORS In-Device Delay project developed a low-cost, non-propriety obscurant that quickly deploys into the pool when an adversary action is detected, rendering visual observation of sources problematic. ORS partnered with iia to engage the industrial irradiator community to ensure that this enhancement is consistent with industrial irradiator facility design, operations, safety, and regulatory requirements. The iia, with its global membership of leading international irradiator operators, facilitated a series of webinars that allowed the ORS team to present this project to representatives of the global industrial irradiator community, and to solicit their feedback in a lively and informative virtual format. This partnership with iia provided critical technical input that will enable ORS to develop a viable engineered security solution for industrial irradiators that will help protect the public from the risk of radiological theft or sabotage.

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INTRODUCTION

Sandia National Laboratories (SNL), with funding provided by the United States' Department of Energy/National Nuclear Security Administration's Office of Radiological Security (ORS) has partnered with the International Irradiation Association (iia) to develop a unique security application, involving chemical obscurants that obfuscate the direct view of a source, thereby rendering the potential attacker's work more difficult. The iia is an organization dedicated to the support and promotion of safe and beneficial uses of irradiation to improve the quality of the lives of the world's population.

For this effort, the work focused on developing an underwater chemical obscurant that would be consistent with industrial settings. This was initiated by first discussing the project with industrial contacts that have partnered with SNL on security projects in the past, including Nordion Inc. and Beijing SanQiangHeLi Radiation Engineering Co., Ltd. (SQHL). From these meetings, a set of requirements for the chemical obscurant were detailed. The following list outlines some of the key parameters:

1. obscures vision of the source for a minimum of 20 minutes,
2. obstructs vision within two minutes of alert,
3. easily removed within 24 hours,
4. maintains water conductivity below 10.0 micro-Siemens (μS) per centimeter (cm),
5. maintains the pH of the water in the 5.5 to 8.5 range,
6. keeps the halide content of the water to below 1 part per million (ppm),
7. does not cause the silicon content of the water to exceed 5 ppm,
8. does not chemically react with 316L grade stainless steel, and
9. does not chemically react with source rack or support equipment.

The working life of the cobalt-60 sources is typically 20 years so many of these parameters were established in order to ensure the continued efficacy of the sources after introduction of the chemical obscurant into the pool. With the requirements agreed upon by the stakeholders, SNL began a series of experiments that involved commercial-off-the-shelf (COTS) products that could be evaluated against these requirements.

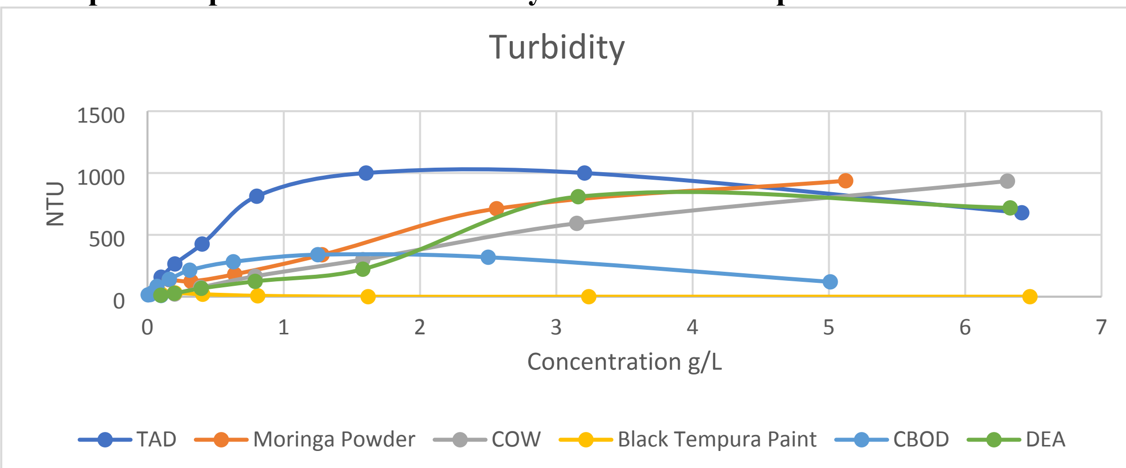
OBSCURANT SELECTION

Initial efforts focused on identifying commercially available obscurants and down selecting them based on availability, cost, and expected utility. From this large number of potential obscurants, five met the majority of the criteria noted above, including titania aqueous dispersions (TAD – cheap water soluble white paint), Chlorazol Black (CBOD – Chlorazol Black organic dye), powdered milk (COW – calcium obscurant in water), diatomaceous earth (DEA – diatomaceous earth additive), and rhodamine 6G (R6G). For these samples, beaker tests using deionized (DI) water were performed to determine if they met the above criteria for pH, conductivity, and turbidity. The conductivity and pH were measured using an APERA PC60 Premium Pocket pH/ Conductivity meter. The turbidity was independently measured using an APERA TN400 Turbidity Meter.

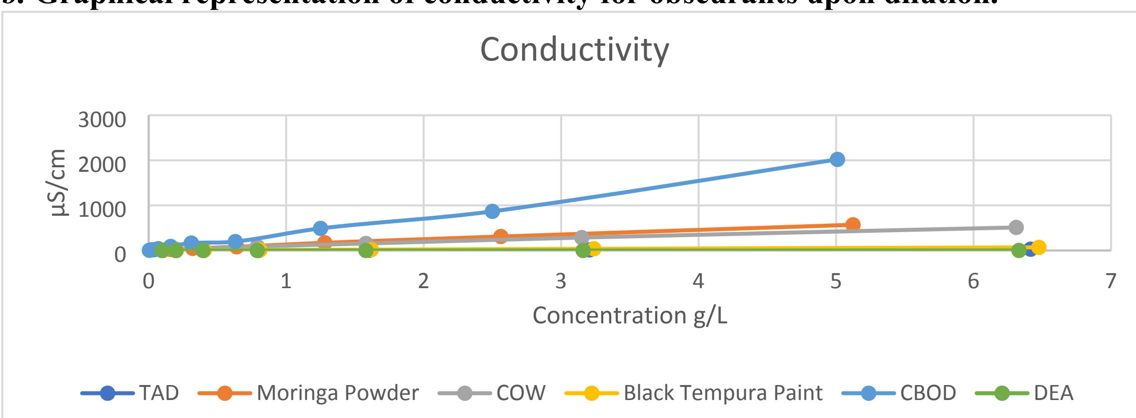
Prior to use, the maximum turbidity, resultant pH, and conductivity were determined for each sample based on dilution of concentrated solutions through a series of beaker-scale experiments.

The resultant plots are shown in Figure 1. a-c for turbidity, conductivity and resultant pH, respectively.

***a.* Graphical representation of turbidity for obscurants upon dilution.**



***b.* Graphical representation of conductivity for obscurants upon dilution.**



c. Graphical representation of pH for obscurants upon dilution.

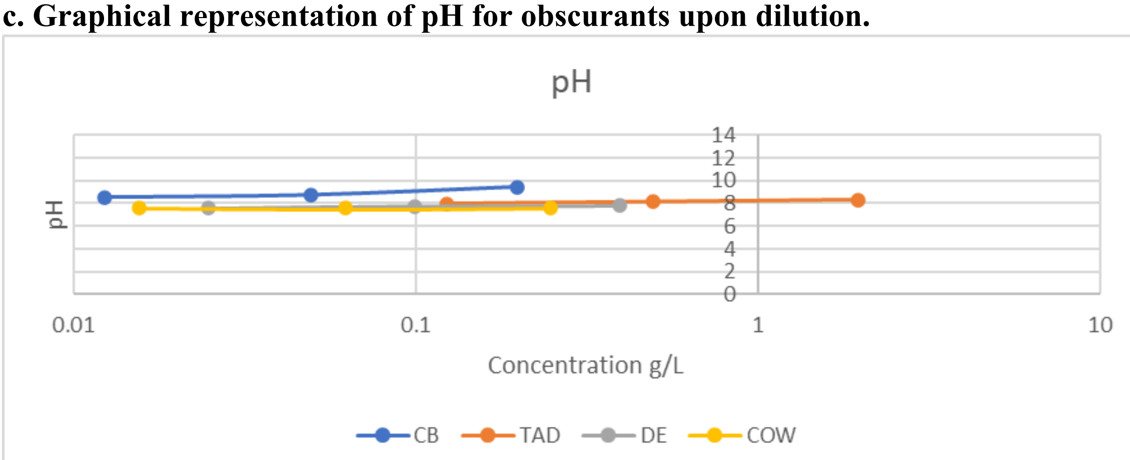


Figure 1. Prior to use, *a.* maximum turbidity, *b.* conductivity, and *c.* resultant pH

Complimentary studies used a 75-gallon aquarium with a recirculation system to provide a scaled test bed to see how quickly the materials would disperse through water. An image is shown in Figure 2. All samples were slurried in 200 mL of DI water, poured directly into the tanks as rapidly as possible, near the outlet side, and a timer started to determine obfuscation. Samples were also visually monitored by cameras located externally and internally. Measurements, similar to the beaker efforts were conducted at a pre-selected time (3 minutes) that was sufficient to allow for full distribution.

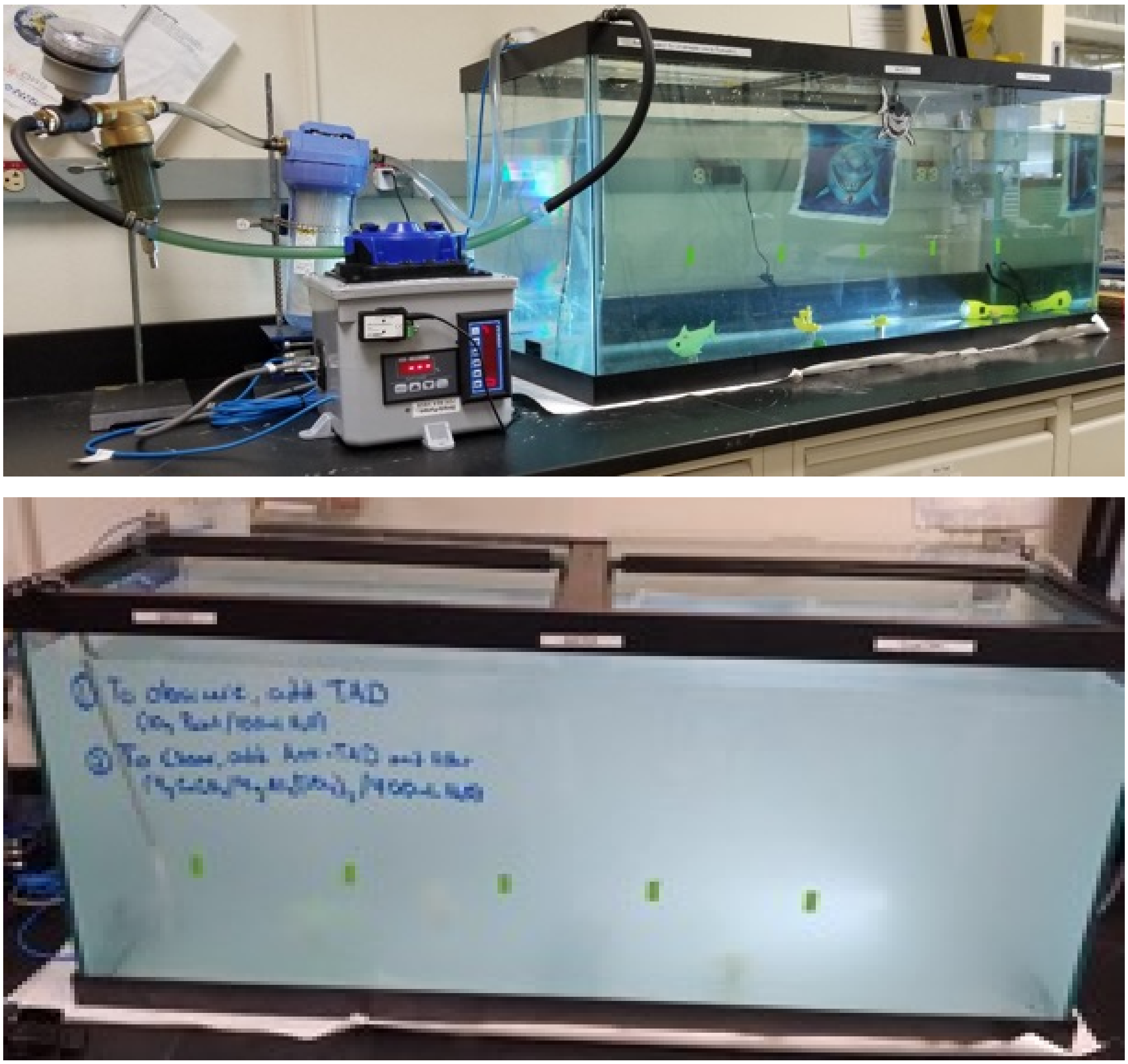


Figure 2. Large-scale tank (75 g) for testing obscurant (a) pre-TAD, and (b) post-TAD.

Attempts to remove TAD were successfully realized with the addition of anti-TAD, which formed a precipitate that could be filtered out or vacuumed out from the bottom of the pool. This process took 48-72 hours to reach a completely clear pool.

Other Considerations and Tests

Because the obscurant would be used in a high radiation environment, another consideration investigated was the effect of radiation on the obscurant. To test this, the team prepared samples of several potential candidate solutions and exposed them to cobalt-60 sources at SNL's Gamma Irradiation Facility (GIF). In these tests, several of the obscurants broke down in the radiation environment. For example, the R6G shown in Figure 3. (i) shows the loss of color imparted by gamma radiation. The TAD sample (Figure 3. (ii)) appeared to be one of the most stable and was selected as the obscurant that best met all the requirements. The darkening of the glass in both Figure 3. C images is associated with the reduction of iron in the glass upon exposure and not a reflection of any obscurant decompositions.

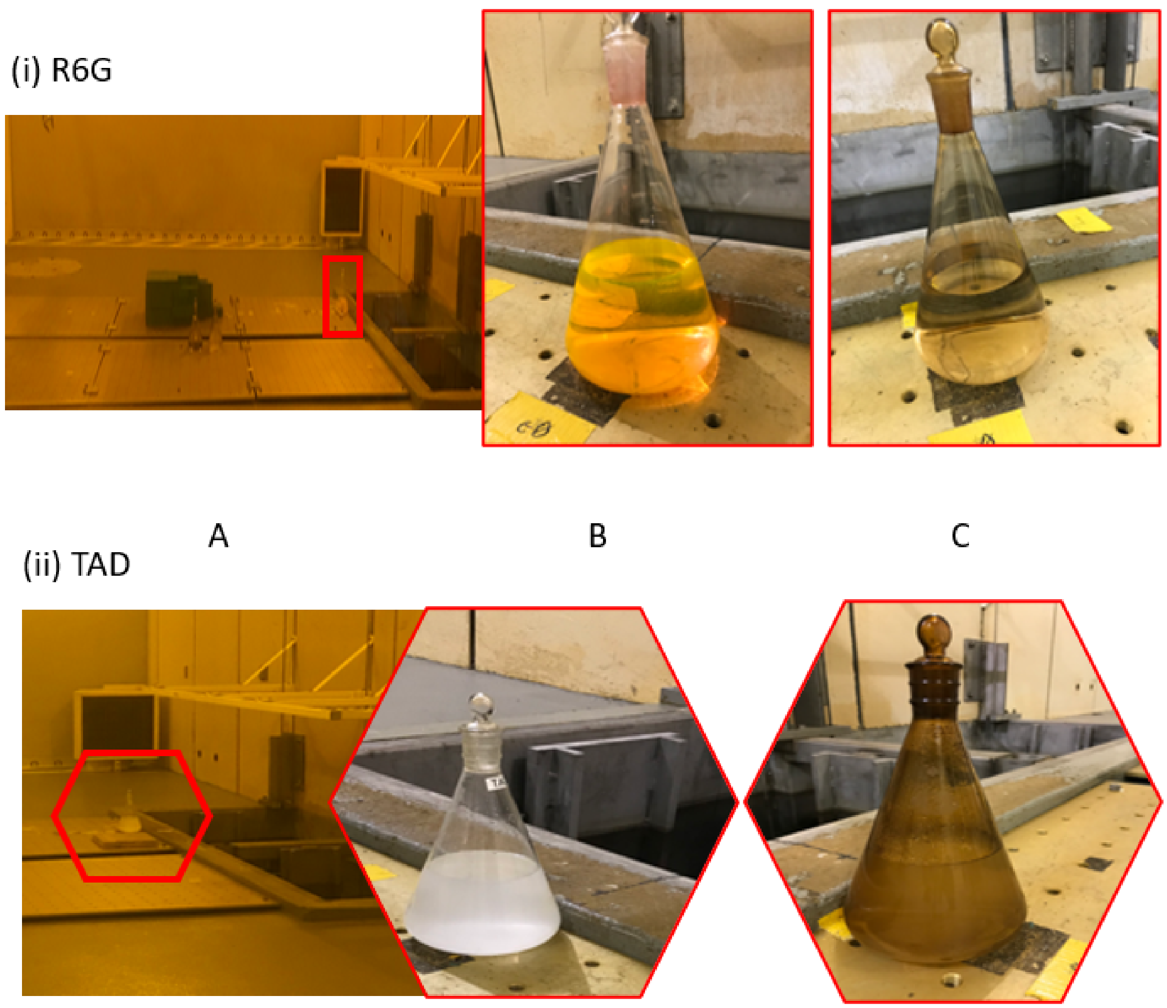


Figure 3. Images of the (i) R6G and (ii) TAD sample (A) near the edge of pool, (b) 0 minutes, and (c) exposure to cobalt-60 sources (R6G, 10 minutes; TAD, 360 minutes).

Early feedback from industry partners indicated that the potential of the obscurant accelerating corrosion of the sources was of concern, so SNL undertook a study to look at potential corrosion effects. For this study, representative stainless-steel samples from inert sources were placed in beakers with the specific obscurants noted above. Figure 4 shows the various results.

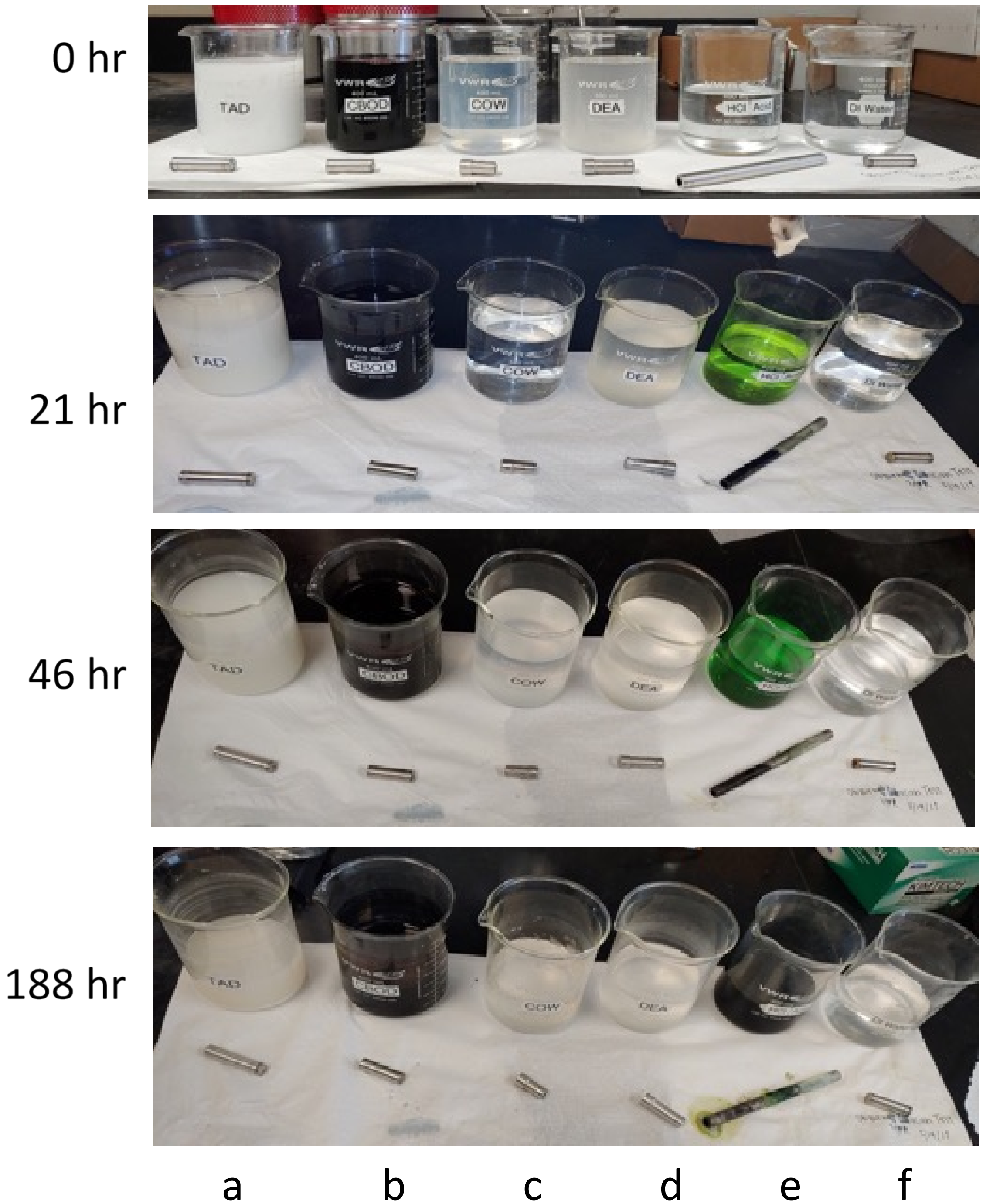


Figure 4. Select optical images of pencil slugs for: (a) TAD, (b) CBOD, (c) COW, (d) DEA, (e) HCl, and (f) DI water at hours listed.

Inspection of the slugs were made and no differences concerning the surface were observed. Using hydrochloric acid (HCl) and water samples as a baseline, corrosion pit-marks were noted. Optical images were not recorded due to the lack of noted changes. The serial numbers on the rods were easily observed for all obscurants.

From these studies, TAD became the obscurant of choice as it met all criteria listed above. Further studies focused on the next scale of testing chamber, a 1000 gallon plastic tank. In order to do this effectively, the team developed an obscurant dispersal system (ODS) that could be used to quickly release the obscurant into a full-size pool. Key requirements considered during the design of the system included keeping the systems cost low, using commercially available parts, keeping the maintenance required low, and ensuring that it would be easy to integrate into both existing and new construction facilities. A series of tests were performed in a 1000 gallon tank to ensure the ODS system would work as intended, as well as to perform a final water quality analysis prior to attempting a full-scale test.

Tests showed that the ODS worked with full dispersion in the plastic tank occurring within 10 seconds. The tank remained obscured for the next two weeks. Attempts to use the anti-TAD were not successful possibly due to the use of the system in an outdoors setup and the use of tap water versus DI water used for the aquarium tests.

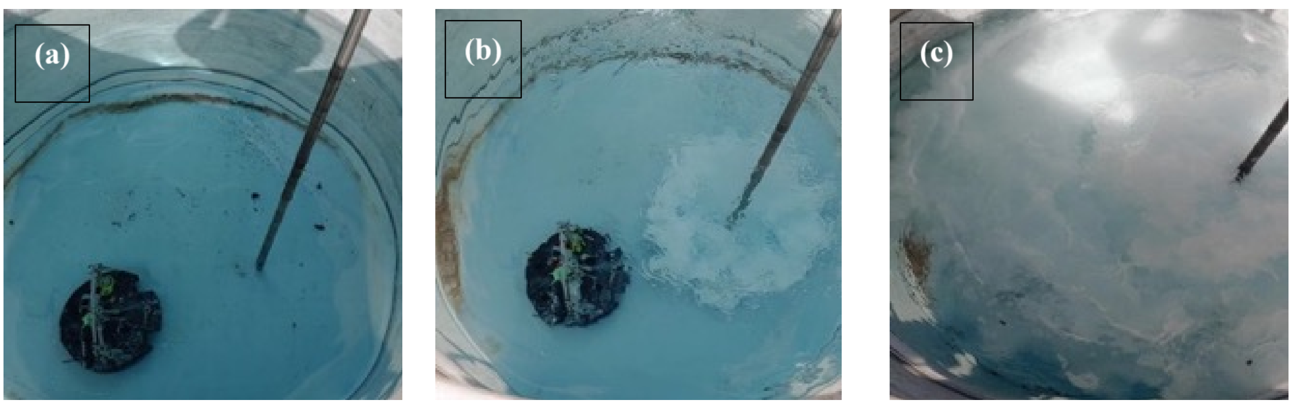


Figure 5. Image of 1000 gallon tank: (a) time zero (filled with water), (b) time 2 seconds (first dispersion), and (c) 10 seconds (full dispersion).

Full-Scale Testing

The most recent test series for this project involved performing a full-scale test of the obscurant system in a pool representative of an irradiator pool. These tests were performed at SNL's GIF in an auxiliary pool (length x width x height, in feet: approximately 10 x 15 x 25) used for tests not involving live sources. A rack filled with inert sources was installed in the pool using an anchor made of several I-beams at the bottom of the pool and a gantry rack to secure the guide cables and allow the rack to be raised and lowered. The ODS system used in the 1000 gallon tank experiments was installed with piping with an outlet placed below the rack. Two test setups were evaluated prior to the use of the obscurant: (1) baseline and (2) bubbles, followed by a series of three obscurant tests with different tools.

The first set of tests allowed our attack team to perform several tests on the rack without the obscurant system active in order to practice with the tools and to develop a baseline time to compare to the results with obscurants.

The second set of tests involved pumping only air through the ODS (i.e., bubble machine). This creates bubbles underwater which could act as an obscurant. This test took the team two to three times longer than the shortest baseline time. As mentioned, the ODS only had a single outlet, this resulted in large bubbles being released from a single point. If further testing is performed using this system, using a series of smaller outlets would provide a higher concentration of smaller bubbles which would be expected to obscure vision more. The benefit of this system is that little to no foreign material is introduced into the pool, allowing the system to fully recover by simply turning the air supply off. (Any obscurant systems carries the risk of an adversary disabling the system prior to activation; but unlike the other obscurants tested, a bubble system is more easily defeated once deployed. These are scenarios not explored in this testing.) Figure 6 shows the view at the surface of the pool with the bubble machine active.

Figure 6. Surface view of pool with bubble machine active

The third set of full-scale tests explored dispersing TAD into the pool using the ODS. Because of the volume of water in the pool and the time needed to clarify it, only one test was performed where the obscurant was released to see how quickly it spread. For this test, the release valve was opened as the attack team's tools entered the water. This is representative of several of the sensor systems that we are investigating to use with the obscurant system. Once the valve was opened, a plume of white began to rise from the bottom of the pool partially obscuring the rack. Once the tanks were empty of TAD, the system continued to pump air for a total time of 90 seconds. The bubbles caused the plume to quickly mix throughout the pool, fully blocking the view of all the cameras that were placed to monitor the test. With the obscurant in the water, the attack team was unable to make any progress towards removing a source from the rack. Figure 7 shows the view of the surface of the pool after obscurant mixing and while still pumping air through the system.

Figure 7. Surface view of pool with obscurant and air system active

After the first test, the team was then allowed to use a camera used for system maintenance and reloading operations to see if it would allow them to make more progress. The camera was able to get a good view of the rack from approximately six inches away. At this distance, the assault team succeeded at removing a surrogate source, but it still took approximately five times longer than baseline. While this was successful, the camera may not survive long enough to complete the attack depending on how resistant to radiation the camera is, and the activity of the sources in the rack.

The final portion of the full-scale test was to investigate methods of removing the TAD after it has been released into the pool. A mixture of chemicals intended to precipitate the TAD out of the pool (anti-TAD), allowing it to be vacuumed off the bottom of the pool, was added. After approximately five days, there was no significant reduction in the visibility into the pool, as determined by visual inspection only. Before and after images can be seen in Figure 8, with little to no difference in the clarity of the pool. This was an unexpected result, and the team is pursuing potential reasons why, as well as looking into alternative methods for clarifying the water. One potential cause is that due to the volume of water and the timeline of the test, tap water was used in the pool rather than DI-water and higher concentrations of elements in tap water, such as high levels of calcium, may have interfered. A white precipitate was observed forming over the time frame which proved by X-ray fluorescence studies to be calcium-rich. This implies the anti-TAD is functioning, and even small amounts of suspended TAD may make it difficult to see the source. Future work will focus on more complete removal of the suspended TAD through alternate precipitating agents or an external filtration system will be evaluated.

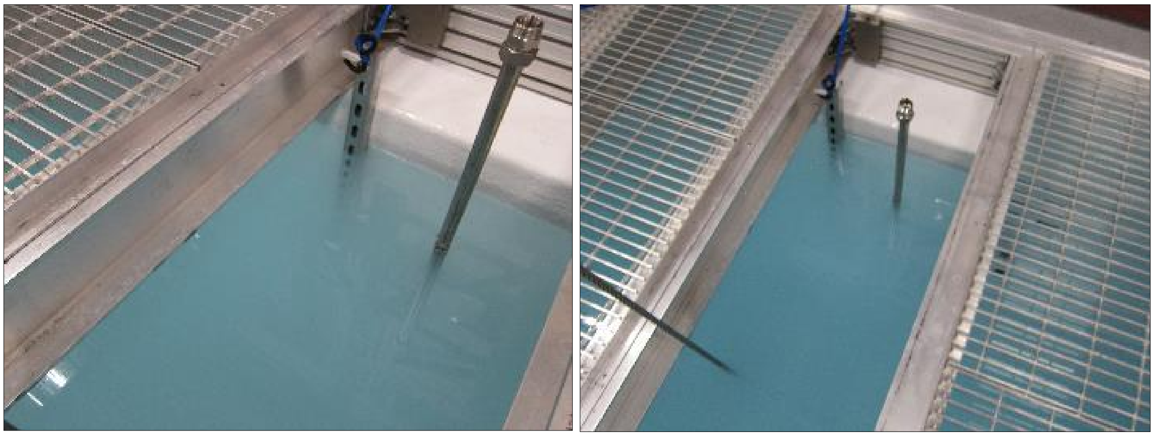


Figure 8. View into pool immediately after testing (left) and 5 days later (right)

CONCLUSION

The joint project between SNL, iia, and industry partners has shown promising results in developing an obscurant to increase the time needed for unauthorized removal of a source from the rack of an industrial irradiator. The project has demonstrated the importance and value of collaboration to ensure that appropriate security measures are developed that are acceptable and adoptable by industry.

Small-scale testing identified several promising obscurants that directly correlated with larger-scale testing. The optimal obscurant identified currently that meets the industrial parameters in terms of water quality, corrosion, radiation effects, and their effectiveness at delaying an attack appears to be TAD (diluted white paint). It has performed well as a low-cost, non-hazardous, effective obscurant. A retrofittable ODS was developed and testing demonstrated the effective distribution of the TAD using this system. Further, TAD was found to be extremely effective at delaying source removal on a large-scale test in the GIF at SNL. The process for removing the obscurant did not perform as well as expected, and further research and testing will be necessary before the system is acceptable to the industrial irradiation industry and ready to be fielded.

ACKNOWLEDGMENTS

SNL and iia would like to thank all the staff who made these test efforts possible, as well as our industry partners and the iia Gamma Working Group members for providing valuable feedback.

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