



Progress of Tripwire: Multi-modal Distributed Sensing for Repository Verification

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Changing the World's Energy Future

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Progress of Tripwire: Multi-modal Distributed Sensing for Repository Verification**L. A. Ocampo Giraldo, S. J. Thompson, J. D. Hix, J. T. Johnson, D. L. Chichester***Idaho National Laboratory, Idaho Falls, Idaho***Abstract**

This project is developing and demonstrating a multi-modal sensor system, TRIPWIRE, for containment verification in inaccessible radiological and nuclear waste repositories. The TRIPWIRE system will continuously monitor ionizing radiation and electromagnetic properties in the vicinity of emplaced nuclear materials buried in a repository, reporting on disturbances with a real-time alarm control station. The system will use long-length scintillating fiber bundles (SFBs) to perform area radiation monitoring; these will be coupled to kilometer-scale multimodal optical communication fibers – all light sensors and their associated electronic components used with this system will be located above ground. Electromagnetic fields, and changes in local dielectric conditions caused by intrusion and soil movement, will be monitored using commercial grade, ported "leaky" coaxial cables (PCCs), with control electronics also located above ground. This paper documents the results of the simulation and modeling efforts that have helped identify the optimal placement of the SFBs. Additionally, the paper includes the current progress on the multi-modal SFB-PCC system, including the fabrication of long-length (>3-m) SFBs and their coupling to optical fibers.

INTRODUCTION

TRIPWIRE is the first passive underground sensor system suitable for long-term deployment and use within underground geological repositories during both loading operations and in post-operation entombment/closure. Since the TRIPWIRE concept uses below-ground components and keeps all electronics and data processing computers in above ground, accessible areas, it has the potential for extremely long-term deployed operations. If/when photon and electronic measurement equipment fails it can be easily replaced. As new advances are made in instrumentation and computers the entire data acquisition system can easily be upgraded and replaced. Also, since the system serves as a real-time process monitor, the data streams from the emplaced sensors may find use, when integrated with other types of data, within a larger data-analytics architecture supporting machine learning and big data science.

This capability will allow detection of undeclared access to a sealed underground repository; detection of non-natural activity in the vicinity of nuclear storage containers including casks, metal drums, and large metal boxes; and detection of the movement or removal of radioactive and nuclear materials from the repository. To achieve this, system will continuously monitor ionizing radiation and electromagnetic fields in the vicinity of emplaced nuclear materials buried in a repository. Preliminary results have been previously documented [1].

MODELING

A modeling and simulation framework was created using the Monte Carlo N-Particle Transport (MCNP) code [2] to support benchmark test validation. Modeling was based on the planned KBS-3 repository by the Swedish Nuclear Fuel and Waste Management Company (SKB) [4]. The focus was on the spent fuel canister and buffer with the goal of characterizing the radiation

field that could be recorded by the scintillating fiber. An overview of the canister, the buffer, tunnel backfill, and overview of the facility can be seen in Figure 1. A more detailed image of the canister insert can be seen in Figure 2 and the outer canister shell along with the base and lids in Figure 3. Canister designs for boiling water reactor (BWR) and pressurized water reactor (PWR) spent fuel were modeled and their differences are shown in Figure 4.

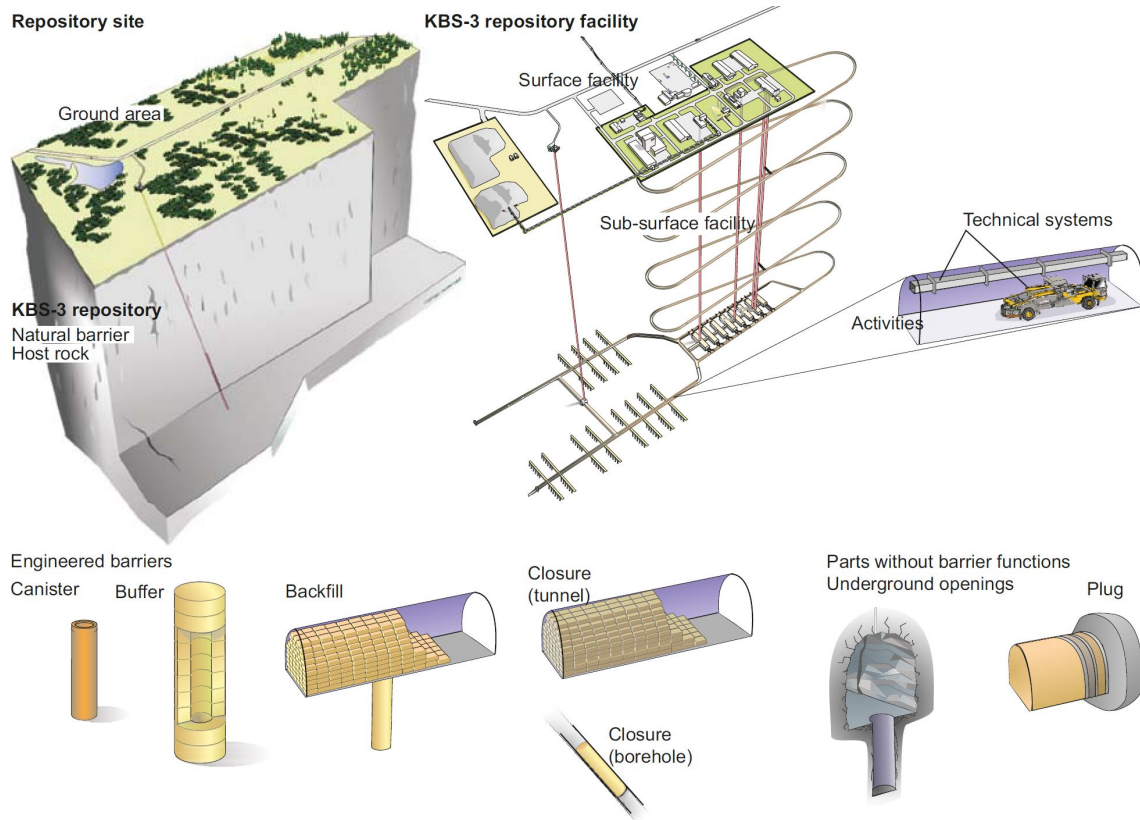


Figure 1. KBS-3 repository design showing the entombment of the canister with a buffer and backfilling of the tunnel [3].



Figure 2. Cast iron insert with steel lid (left) designed to hold the steel tube cassette shown on the right photograph. The spent fuel will fit inside the cassette [4].

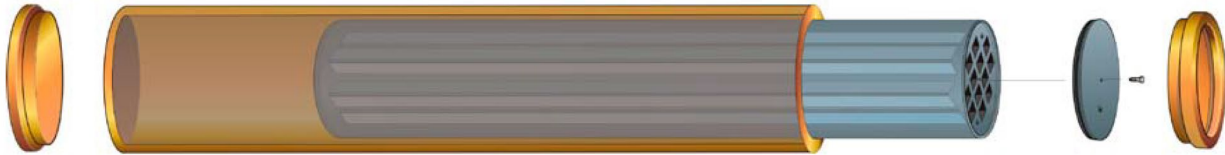


Figure 3. Exploded view of the canister with copper base, copper shell, cast iron insert, steel lid, and copper lid [4].

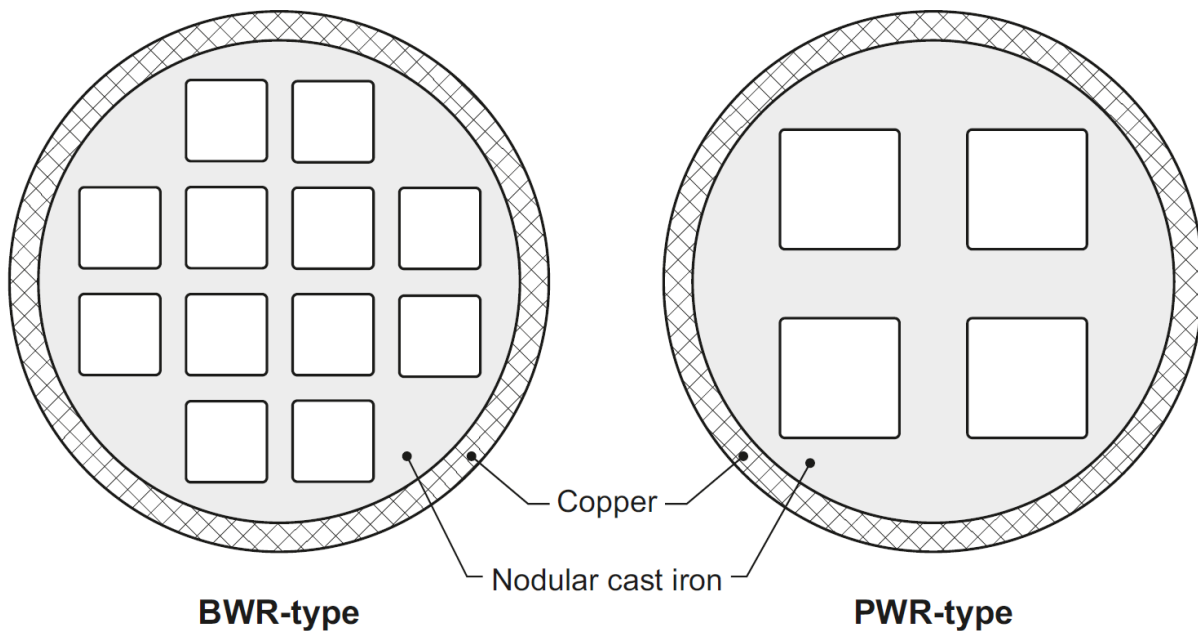


Figure 4. BWR and PWR canister designs [4].

A visualization of the MCNP simulation is shown in Figure 5 and Figure 6. The yellow sections are bentonite MX-80 which is planned to be used in the repository as a buffer to prevent flow of water and protect the canister [5]. The material composition was defined in accordance with the Wyoming MX-80 bentonite characterization previously published by SKB [6]. The green shapes inside the bentonite (yellow) are the copper canister and the lids. The lighter shades of yellow represent the cast iron insert and respective lids. The spent fuel bundles have been modeled using the spent fuel library for Next Generation Safeguards Initiative calculations [7]. Each bundle consists of a 17 x 17 PWR assembly with initial enrichment of 5% and a 60 gigawatt-days/metric ton of uranium burnup. The cooling time was 40 years.

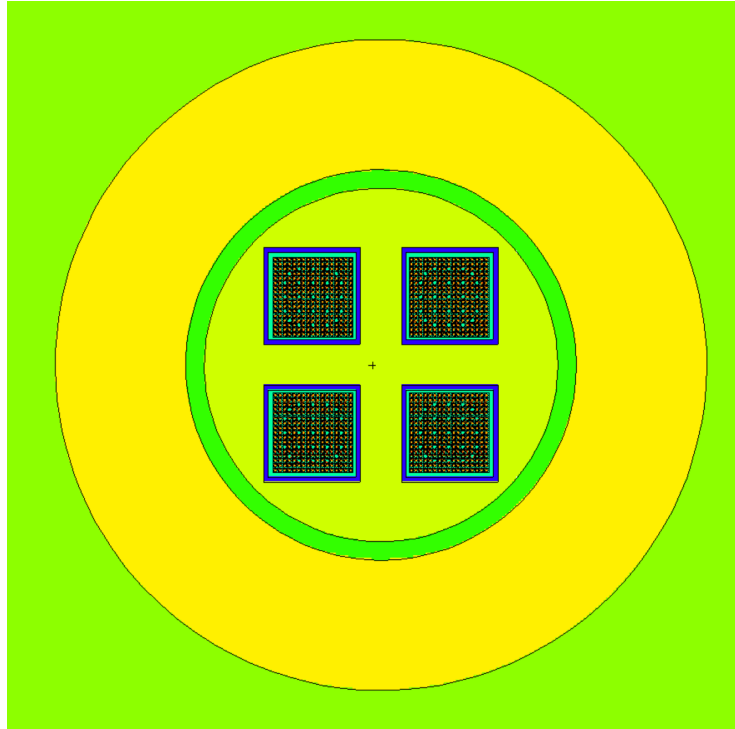


Figure 5. Top view visualization of an MCNP PWR KBS-3 canister model.

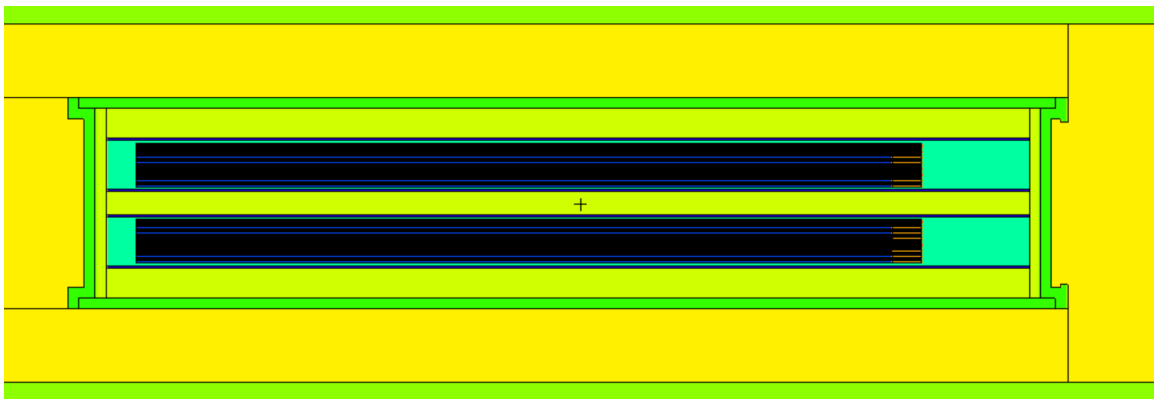


Figure 6. Cross-sectional view of an MCNP PWR KBS-3 canister model.

Initial results from this model indicated that the dose rate at the surface of the floor is at background levels. These background levels are due to the approximately 2.5 meters of bentonite between the tunnel nominal floor and the top of the canister. The preliminary conclusion is that laydown of the scintillating fiber at the floor level would not be able to report continuous monitoring of the presence of the canister. In this scenario, the fiber could potentially indicate the removal of the canister because it would need to be brought closer to the fiber on its way out. A profile of the dose rate around the canister is shown in Figure 7. Given that the dose rate is higher on the sides of the canister an alternate placement configuration using shorter scintillating fiber segments placed alongside the canister can be used. This alternate configuration is shown in Figure 8.

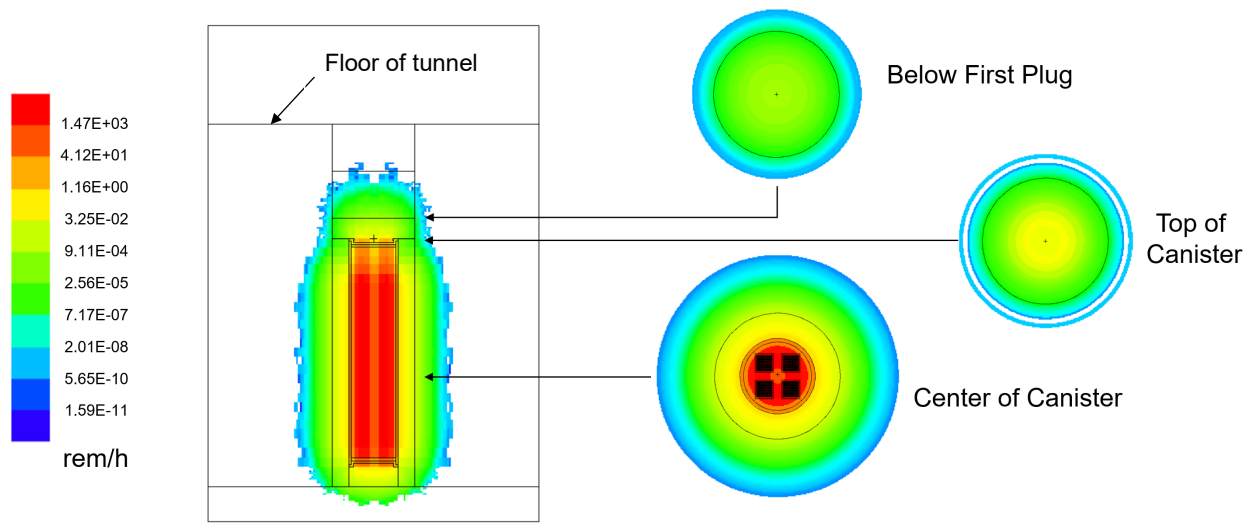


Figure 7. Simulated underground dose rate profiles using the PWR configuration.

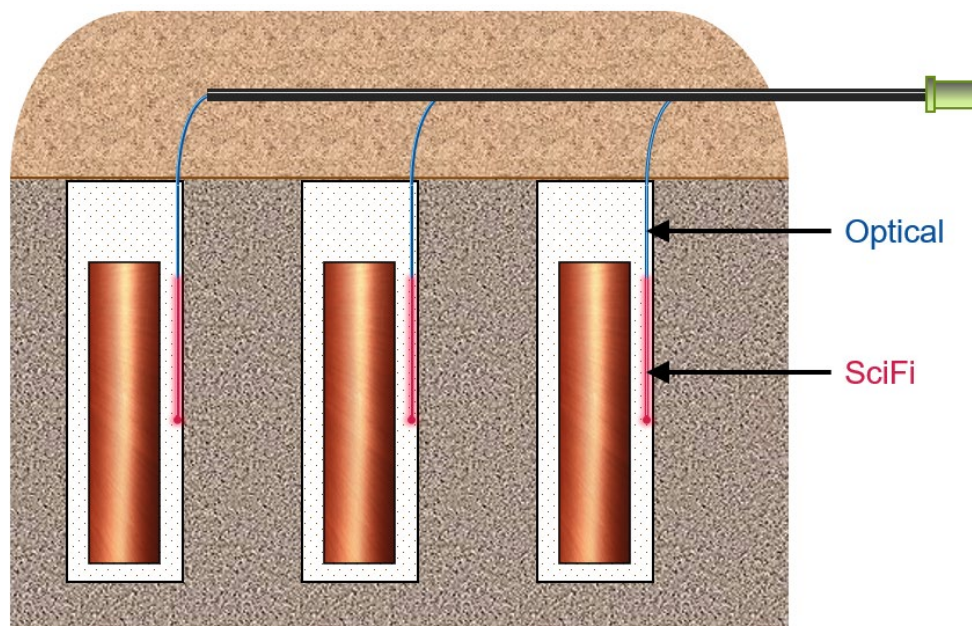


Figure 8. Alternative scintillating fiber placement to take advantage of the higher dose rate near the sides of the canister.

SCINTILLATING AND OPTICAL FIBERS

The fibers previously used were less than 3 m in length, this prompted the need for further testing to understand the limitations in fiber length. New fiber sensors were fabricated to continue using the same laboratory bench set-up. A single 1-millimeter diameter BCF-10 (Saint Gobain) scintillating fiber assembly of 10-m total length was fabricated. The fiber was placed inside a tubing sleeve with light-tight black coating (Thor Labs Inc.). A cap was placed over the tubing end

and a SubMiniature A 905 (SMA) connector was connected to the end of the fiber. Heat-shrink tubing was added to hold the connector, cap and tubing together and to prevent light from entering through the connector casing. The end of the fiber was cleaved at the end of the SMA connector. Polishing was required to create a smooth surface at the edge of the connector.

TRIPWIRE aims to couple scintillating fibers to optical fibers to deploy long-length sensors given the extended tunnel distances in an underground repository. Optical spectrometry was performed to understand the sensitivity and response of the optical fiber coupling to a scintillating fiber. To study the attenuation loss of longer optical fibers, a new benchtop set-up was designed to use a 100-m spool of optical fiber coupled to various lengths of BCF-10 scintillating fiber, using a 365-nm LED. The first scintillating fiber coupling evaluated in this set-up was 30-cm in length. The emission spectrum is shown in Figure 9, the attenuation loss was minimal.

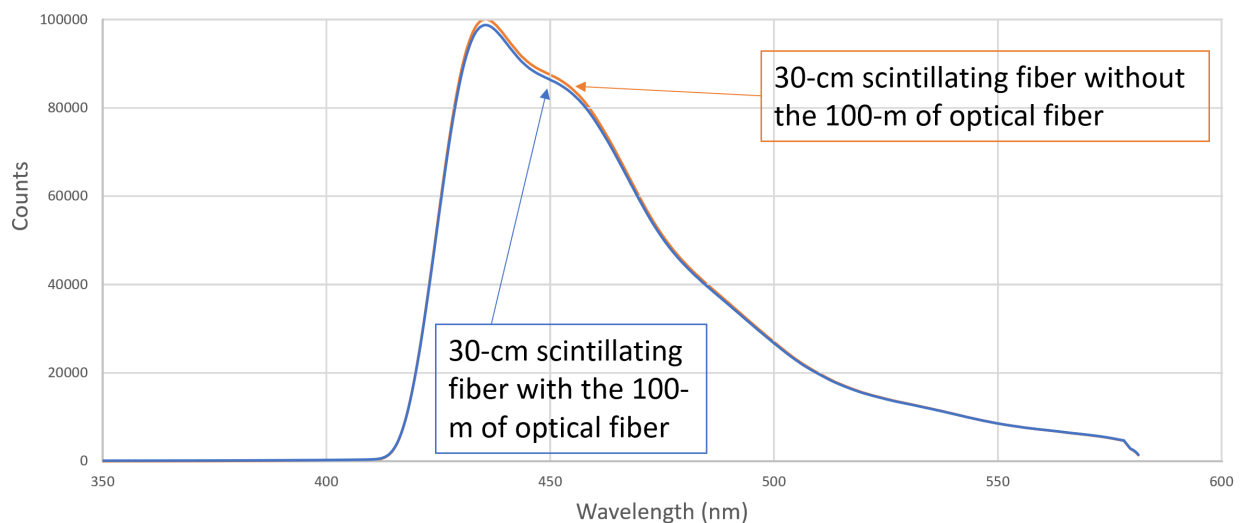


Figure 9. Comparison of 30-cm scintillating fiber with and without 100 m of optical fiber.

CONCLUSION

Research is underway to develop and demonstrate a multi-modal sensor system for containment verification in inaccessible radiological and nuclear waste repositories. The TRIPWIRE system will continuously monitor ionizing radiation and electromagnetic fields in the vicinity of emplaced nuclear materials buried in a repository, reporting on disturbances with a real-time alarm control station. The modeling and simulation results identified the shortcomings of the original scintillating fiber placement position and helped identify an alternate fiber placement near the sides of the canister. Significant progress has been made in testing and understanding long-length (>3-m) fibers and their coupling to optical fibers. The attenuation loss for 30-cm scintillating fiber coupled to 100-m of optical fiber is minimal. Long-length scintillating fiber bundles are instrumental in the TRIPWIRE system. A field demonstration of the SFB is planned for this fiscal year.

ACKNOWLEDGEMENTS

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