

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof. Reference herein to any social initiative (including but not limited to Diversity, Equity, and Inclusion (DEI); Community Benefits Plans (CBP); Justice 40; etc.) is made by the Author independent of any current requirement by the United States Government and does not constitute or imply endorsement, recommendation, or support by the United States Government or any agency thereof.



TRIPWIRE – Deployment and Field-Testing Report

Luis A. Ocampo Giraldo

Scott J. Thompson

James T. Johnson

Jay D. Hix

David L. Chichester

Applied Radiation Measurements and Systems



DISCLAIMER

This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

TRIPWIRE – Deployment and Field-Testing Report

FY2022 Deliverable

**Luis A. Ocampo Giraldo, Scott J. Thompson
James T. Johnson, Jay D. Hix, and David L. Chichester**

September 2022

**Idaho National Laboratory
Idaho Falls, Idaho 83415**

<http://www.inl.gov>

**Prepared for the
National Nuclear Security Administration
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517**

Page intentionally left blank

CONTENTS

1.	INTRODUCTION.....	6
1.1	Report Overview	7
1.2	Previous Work.....	7
2.	SCINTILLATING FIBER FIELD TESTING	8
2.1	Facility Overview.....	8
2.2	Field Testing Set-up	9
2.2.1	Scintillating Fibers	10
2.2.2	Electronics and Data Acquisition.....	11
2.2.3	Power Supplies.....	11
2.3	Scintillating Fiber Deployment.....	12
2.4	Background & Data Fluctuation	15
3.	INTERIM STORAGE CONTAINER MOVEMENT.....	17
4.	FIRST ISC MOVEMENT RESULTS	22
5.	SECOND ISC MOVEMENT & RESULTS	25
6.	CONCLUSION	29
7.	OPTIMIZATION NEEDS	30
	References.....	31

Page intentionally left blank

FIGURES

Figure 1. Radioactive Scrap Waste Facility south storage and staging areas with several interim storage containers.....	6
Figure 2. Aerial view of the RSWF storage facility with nine ISCs.....	8
Figure 3. Field testing trailer outside the RSWF storage area.	9
Figure 4. Field testing trailer with external generator to provide power.	10
Figure 5. Data acquisition system inside the trailer.....	11
Figure 6. Long-length scintillating fiber positioned 1 meter away from the three ISCs.	12
Figure 7. Survey meter positioned 1 meter away from an ISC.....	13
Figure 8. Remote-controlled rover system equipped with a sodium iodide gamma-ray detector.....	13
Figure 9. Visualization of the scan matrix recorded with the rover.....	14
Figure 10. Data recorded in 5-minute intervals over 22 hours using the 50-m fiber.....	15
Figure 11. Temperature data from two different sources. The blue line represents the temperature of the PMT recorded by a thermocouple. The red line represents the outdoor temperature as recorded by the NOAA sensors at MFC.	16
Figure 12. Storage facility configuration identifying the ISC to be moved and filled.	17
Figure 13. Lifting of ISC-007 with a forklift (left) and removal of the ISC from the storage area (right).....	18
Figure 14. Positioning of the ISC at the staging area next to the overpack containing the new drum.	19
Figure 15. Removal of the ISC lid (left) and removal of the overpack cap (right).	19
Figure 16. Lifting of the new 50-gallon waste drum out of the overpack with the crane.....	20
Figure 17. Photographing the new configuration of the ISC (left). The photograph taken identifying the new drum's position in the ISC (right).....	20
Figure 18. Returning of the ISC to the original location, 1-m from the scintillating fiber.....	21
Figure 19. Recorded number of counts per bin over 30 seconds during the lifting of the drum out of the overpack cask.	22
Figure 20. Field-testing results from the movement of ISC-007 and placement of a new waste drum inside.	24
Figure 21. Dual fiber configuration for the second ISC movement.	25
Figure 22. Optical fiber coiled inside a light-tight box to prevent unwanted photons from light sources in the trailer.....	26
Figure 23. Light-tight box containing the optical fiber and the PMT.....	26
Figure 24. Lowering of the 50 gallon drum into the fourth position of ISC-007.	27

Figure 25. ISC-007 movement results for the two fibers normalized to the total counts before the transfer began. The 50 meter fiber data is shown in blue and the 20 meter fiber in red..... 28

TABLES

Table 1. Single point dose rate readings before the ISC movement.....	14
Table 2. Single point dose rate readings after the ISC movement.....	21

TRIPWIRE – Deployment and Field-Testing Report

1. INTRODUCTION

TRIPWIRE is a multi-modal system for containment verification in inaccessible radiological and nuclear waste repositories. The sensing modes are focused on radiation, electromagnetic and vibration. The radiation detection component has been developed over the last three years at Idaho National Laboratory (INL). This development has focused on the fabrication, characterization, and testing of long-length (greater than 10-m) plastic scintillating fibers. This fiscal year, the focus of TRIPWIRE has been on field testing and demonstration of the radiation sensing component in a relevant environment. After reviewing the static storage facilities at INL, the Radioactive Scrap Waste Facility (RSWF) south storage area outside the Materials and Fuels Complex (MFC) was selected due to its periodic changes in configuration and inventory. An overview photograph of the facility can be seen in Figure 1.



Figure 1. Radioactive Scrap Waste Facility south storage and staging areas with several interim storage containers.

1.1 Report Overview

This report summarizes the research outcomes for the work performed in fiscal year (FY) 2023. The report is divided into two sections addressing the field testing of the scintillating fiber and a discussion on the results. The report is the key deliverable for Task 7: Test and Evaluation – Field Testing. This task involves support work needed to enable field testing of the scintillating fiber and ported coaxial cable (PCC) detectors, integrated into the TRIPWIRE system, along with direct Test and Evaluation of these detectors. The field testing of the PCC was already completed as part of its integration into the data acquisition system.

1.2 Previous Work

The plastic scintillating fiber fabrication, characterization, testing, improvement, and ruggedization has been documented in the FY-2020 [1] and the FY-2021 [2] reports. Additionally, papers have been presented at the Institute of Nuclear Materials Management annual meeting in 2021 [3] and 2022 [4]. An INL invention disclosure record (#12840) has been filed titled “Fieldable long-length scintillating fibers for radiation monitoring” related to the use of scintillating fiber optics as ruggedized detectors in long-length (greater than 10 meters) sections coupled to long-length (greater than 100 meters) standard optical fiber segments.

2. SCINTILLATING FIBER FIELD TESTING

2.1 Facility Overview

The RSWF facility contains several interim storage containers (ISC). Each ISC measures 2 x 2 x 1.5 meters and has several 50-gallon drums filled with radioactive waste ranging from spent fuel to laboratory waste products. An aerial view of the south storage area is shown in Figure 2 with three ISCs in the center and another six in the top left corner. The configuration of the facility remains intact for several weeks as the movement and filling of each container requires the coordination of several teams. This made the facility and its timeline ideal for TRIPWIRE's field testing and demonstration.



Figure 2. Aerial view of the RSWF storage facility with nine ISCs.

2.2 Field Testing Set-up

A schedule of the facility allowed the deployment of the system to be coordinated weeks in advance of the next transfer. However, due to the lack of shore power at the storage area, a trailer with generators served as the base station for all the electronics and data acquisition systems. Photographs of the trailer outside the storage area are shown in Figure 3 and Figure 4. To ensure a controlled temperature range, an air conditioning unit was active during the day to mitigate the high environmental temperatures of the summer.



Figure 3. Field testing trailer outside the RSWF storage area.



Figure 4. Field testing trailer with external generator to provide power.

2.2.1 Scintillating Fibers

The deployment fibers were fabricated using single 1-millimeter diameter BCF-10 (Saint Gobain) scintillating fibers. The fiber was placed inside a tubing sleeve with light-tight black coating (Thor Labs Inc.). A cap was placed over each tubing end and a SubMiniature A 905 connector was attached 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. One side is covered with a light-tight cap and is marked to be used as the end opposite the photomultiplier tube (PMT).

2.2.2 Electronics and Data Acquisition

The photomultiplier tubes were powered via Hamamatsu C7169 power supplies. The data output was connected to Easy-MCA 2k channel multichannel analyzer (AMETEK) and recoded via Maestro (ORTEC) software running on a standard laptop computer. The data acquisition electronics and the photomultiplier tubes are shown inside the trailer in Figure 5.



Figure 5. Data acquisition system inside the trailer.

2.2.3 Power Supplies

Electrical power continuity was required for prolonged periods of system operation. This was achieved with the implementation of a Goal Zero portable power station that allowed unattended operation for over 24 hours. The parallel generators were connected to this station to store the excess power generated for later use following generator fuel depletion. A measure of redundancy was also used by connecting all system electronics to an uninterrupted power supply.

2.3 Scintillating Fiber Deployment

The first deployment was focused on the 50-meter scintillating fiber. The photomultiplier tube and power supply were configured inside the controlled trailer environment. The fiber was ported out of the trailer into the storage area, passing between the three containers shown in Figure 6. A distance of 1 meter from each container was maintained. An ion chamber survey meter (FLUKE model 451B-RYR) was used to record single point readings along the fiber and is shown in Figure 7. The dose rate readings are collected in Table 1 in roentgen equivalent man (rem) per hour. To help characterize the radiation field inside the storage area, a scan of the facility was completed using a remote-controlled rover system equipped with a sodium iodide gamma-ray detector positioned 1 meter from the ground. Figure 8 is a photograph of this rover system in use. The rover recorded a scan matrix covering the entire storage area and was then mapped on the photograph shown in Figure 9. This data allowed for the visualization of the ISC radiation field intensities relative to the position of the fiber which is highlighted in white in this figure.



Figure 6. Long-length scintillating fiber positioned 1 meter away from the three ISCs.



Figure 7. Survey meter positioned 1 meter away from an ISC.



Figure 8. Remote-controlled rover system equipped with a sodium iodide gamma-ray detector.

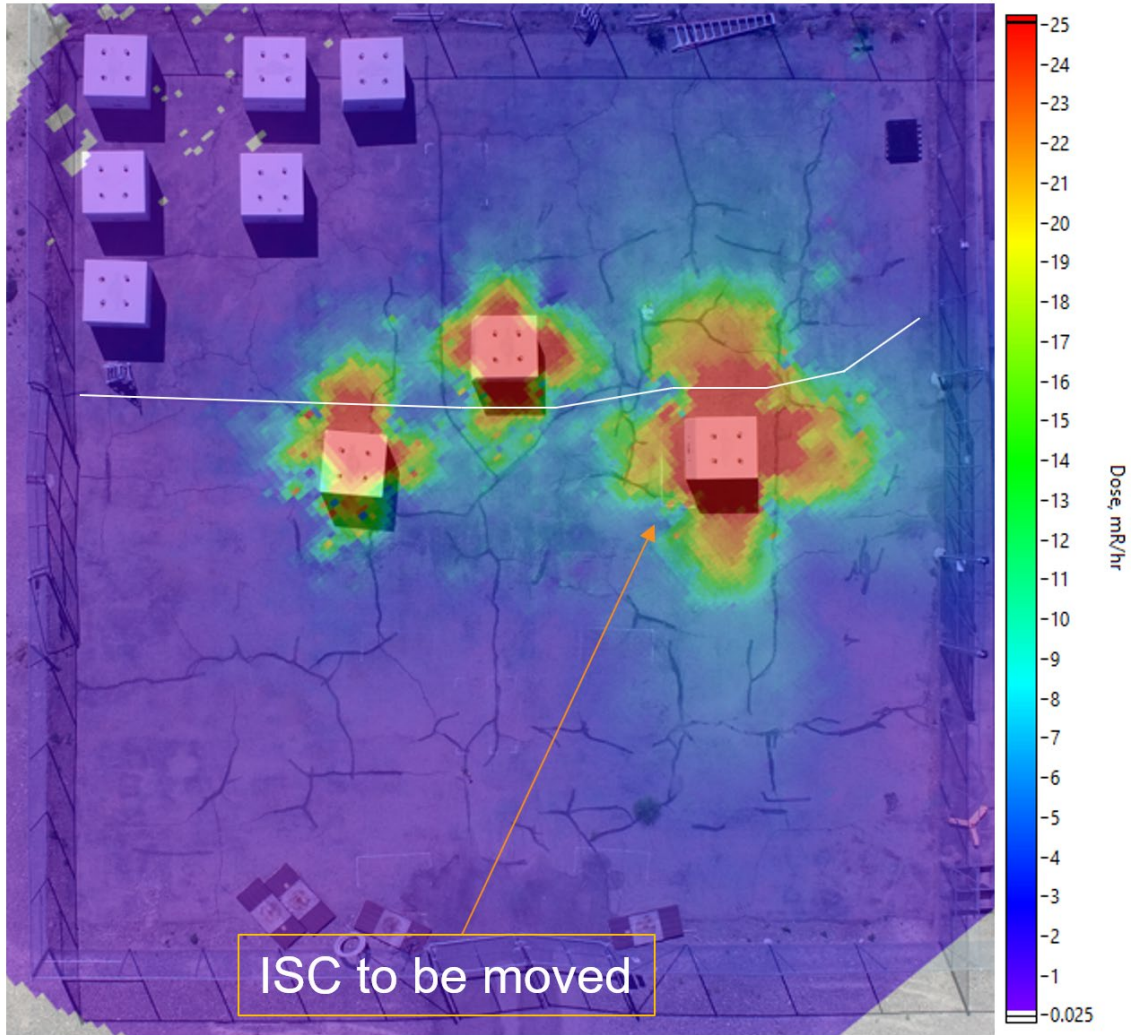


Figure 9. Visualization of the scan matrix recorded with the rover.

Table 1. Single point dose rate readings before the ISC movement.

Location	Dose rate (mrem/hour)
ISC-009 A	20
ISC-009 B	45
ISC-009 C	22
ISC-006 A	14
ISC-006 B	32
ISC-006 C	17
ISC-007 A	21
ISC-007 B	46
ISC-007 C	41

2.4 Background & Data Fluctuation

A preliminary test of the trailer-based system configuration was made prior to material movement. Data were recorded over 22 hours using the 50-m fiber. The total counts for each 5-minute measurement are shown in Figure 10. The difference between the maximum and lower values was 2927 counts. Temperature was recorded inside the trailer next to the PMT with a thermocouple in the same 5-minute intervals as the spectra. Outside temperature was obtained from the National Oceanic and Atmospheric Administration (NOAA) INL weather center which has instrumentation stationed at the nearby MFC facility. The recorded temperatures are shown over the same 22-hour period in Figure 11. The PMT temperature shown in blue appears to have the inverse trend of the total counts data. This could suggest that temperature has a minor effect on the PMT performance. The observed fluctuation of approximately 20 °F (between minimum and maximum temperature) resulted in a 3.7% change in the total counts.

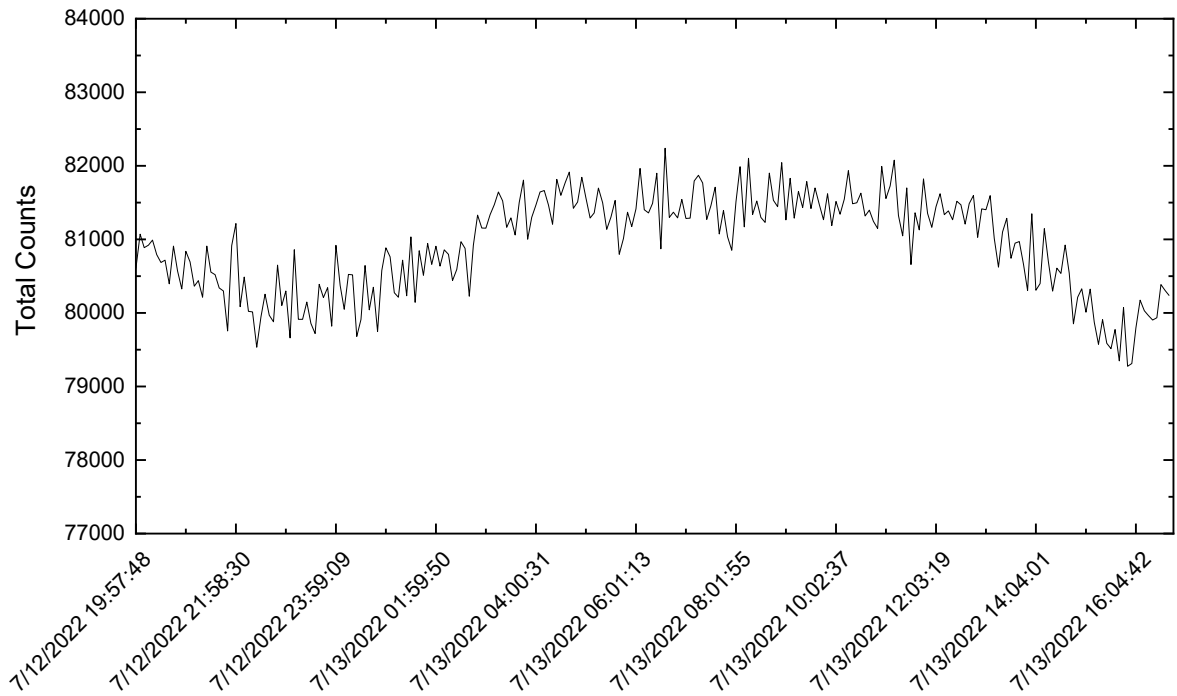


Figure 10. Data recorded in 5-minute intervals over 22 hours using the 50-m fiber.

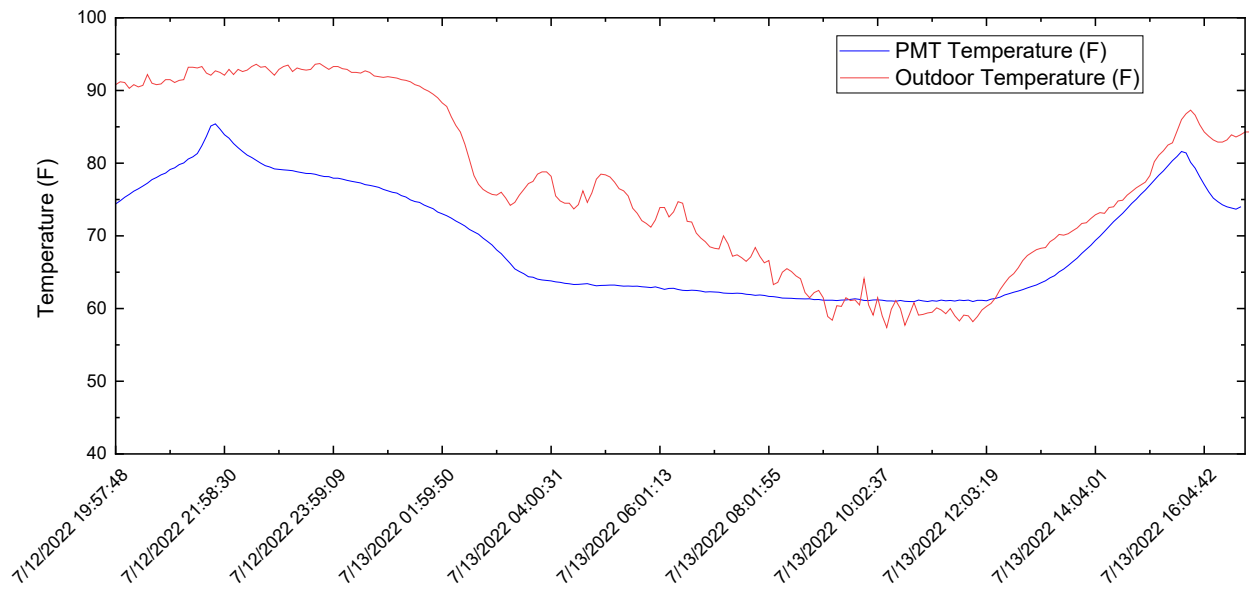


Figure 11. Temperature data from two different sources. The blue line represents the temperature of the PMT recorded by a thermocouple. The red line represents the outdoor temperature as recorded by the NOAA sensors at MFC.

3. INTERIM STORAGE CONTAINER MOVEMENT

The first deployment's waste transfer consisted of the evacuation of ISC-007 identified in Figure 12 by the orange arrow. The ISC was removed with via forklift from the storage area into the adjacent staging area, see Figure 13. Upon arrival to the staging area, the ISC was placed next to the overpack container. A photograph of the staging area is provided in Figure 14. The ISC lid and the overpack cover were removed by the crane sequentially as seen in the photographs in Figure 15.



Figure 12. Storage facility configuration identifying the ISC to be moved and filled.

A crane lifted the 50-gallon drum out of the overpack cask used to transport it to the facility. This process lasted over sixty minutes as the gripping mechanism from the crane was unable to hold on to the upper lip of the drum at first. Several attempts and some troubleshooting had to be performed to successfully lift the new drum. The successful attempt can be seen in Figure 16. The measured dose rate on contact was 2.8 rem per hour and its contents were listed as radioactive waste from the Hot Fuel Examination Facility in MFC. The drum proceeded to be lowered into ISC-007 in position 4, shown in Figure 17, and the lid was placed back on top. The ISC was moved from the staging area into the storage area and placed back at the original location, 1 m from the fiber seen in Figure 18. The survey meter was used to record the new single point readings along the fiber. The updated dose rate readings are recorded in Table 2 along with the change compared to the previous readings.



Figure 13. Lifting of ISC-007 with a forklift (left) and removal of the ISC from the storage area (right).



Figure 14. Positioning of the ISC at the staging area next to the overpack containing the new drum.



Figure 15. Removal of the ISC lid (left) and removal of the overpack cap (right).



Figure 16. Lifting of the new 50-gallon waste drum out of the overpack with the crane.



Figure 17. Photographing the new configuration of the ISC (left). The photograph taken identifying the new drum's position in the ISC (right).



Figure 18. Returning of the ISC to the original location, 1-m from the scintillating fiber.

Table 2. Single point dose rate readings after the ISC movement.

Location	Dose rate (mrem/hour)	Change (mrem/hour)
ISC-009 A	25	5
ISC-009 B	48	3
ISC-009 C	27	5
ISC-006 A	19	5
ISC-006 B	44	12
ISC-006 C	30	13
ISC-007 A	37	16
ISC-007 B	80	34
ISC-007 C	69	28

4. FIRST ISC MOVEMENT RESULTS

Spectra were recorded in 30-second intervals throughout the movement of the ISC. An example of the data recorded per interval is shown in Figure 19. The total number of counts for each spectrum is shown as a function of time (in Coordinated Universal Time or UTC (bottom x-axis) and Mountain Daylight Time or MDT (top x-axis)) in Figure 20. The change in the number of counts is correlated with the removal of the ISC, which is shown by the drastic drop in total counts after 15:34:25. The decrease in total counts begins with the spectra saved at 15:41:11. The ground truth notes list the forklift backing away at 15:40:47 and out of the storage area by 15:41:10.

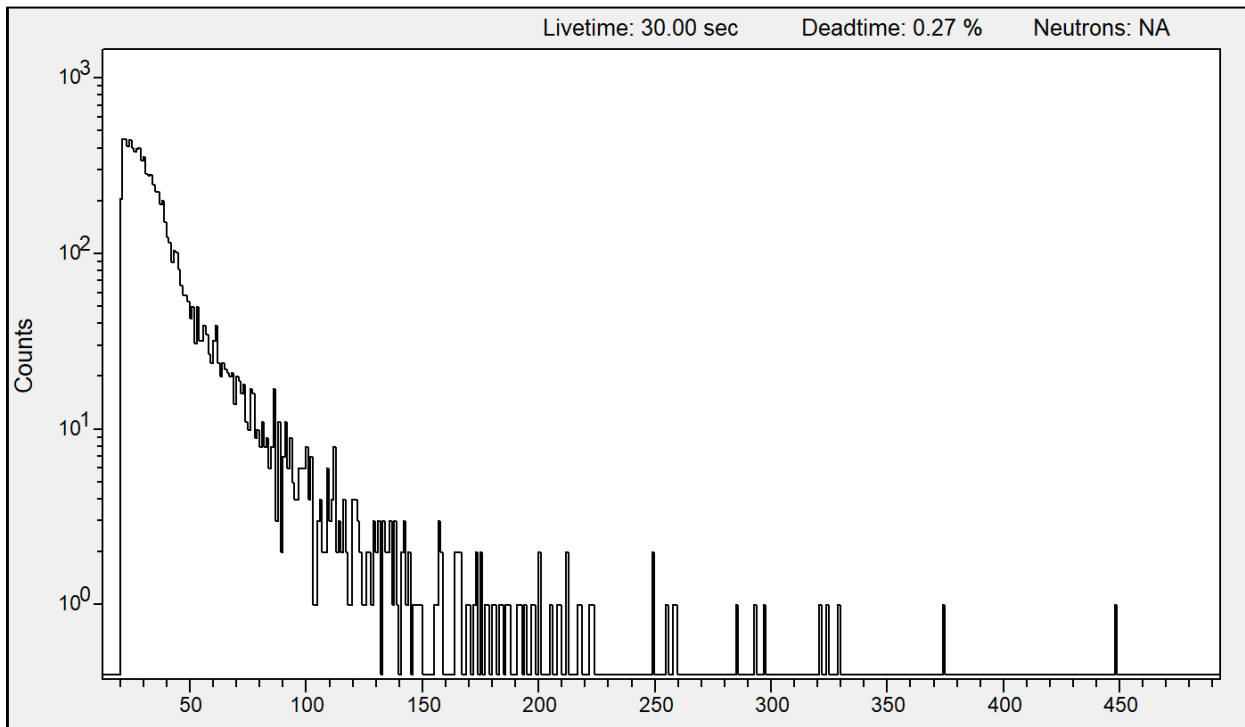


Figure 19. Recorded number of counts per bin over 30 seconds during the lifting of the drum out of the overpack cask.

The lifting of the drum from the overpack produced a spike in the total counts and is seen near 17:18:29. The first spectrum with the increased number of counts was recorded at 17:17:58 which correlates with the ground truth data identifying the drum being fully exposed at 17:17:33. The

next significant event was the return of the ISC to its initial location. This resulted in counts increasing significantly higher than before the removal. This increase can be seen in Figure 20 highlighted by the blue arrow on the far right. Two purple arrows identify an increase and decrease in the total number of counts correlated with the removal and placement of the lid on the ISC. A downward trend can be seen between the placement of the lid on the ISC and the return of the ISC to its original location which is explained by the movement of the ISC from the staging area to the storage area. These events help illustrate the sensitivity of the scintillating fiber at various distances. Comparing the single point readings along the fiber, the center changed from 20 to 80 mrem/hr.

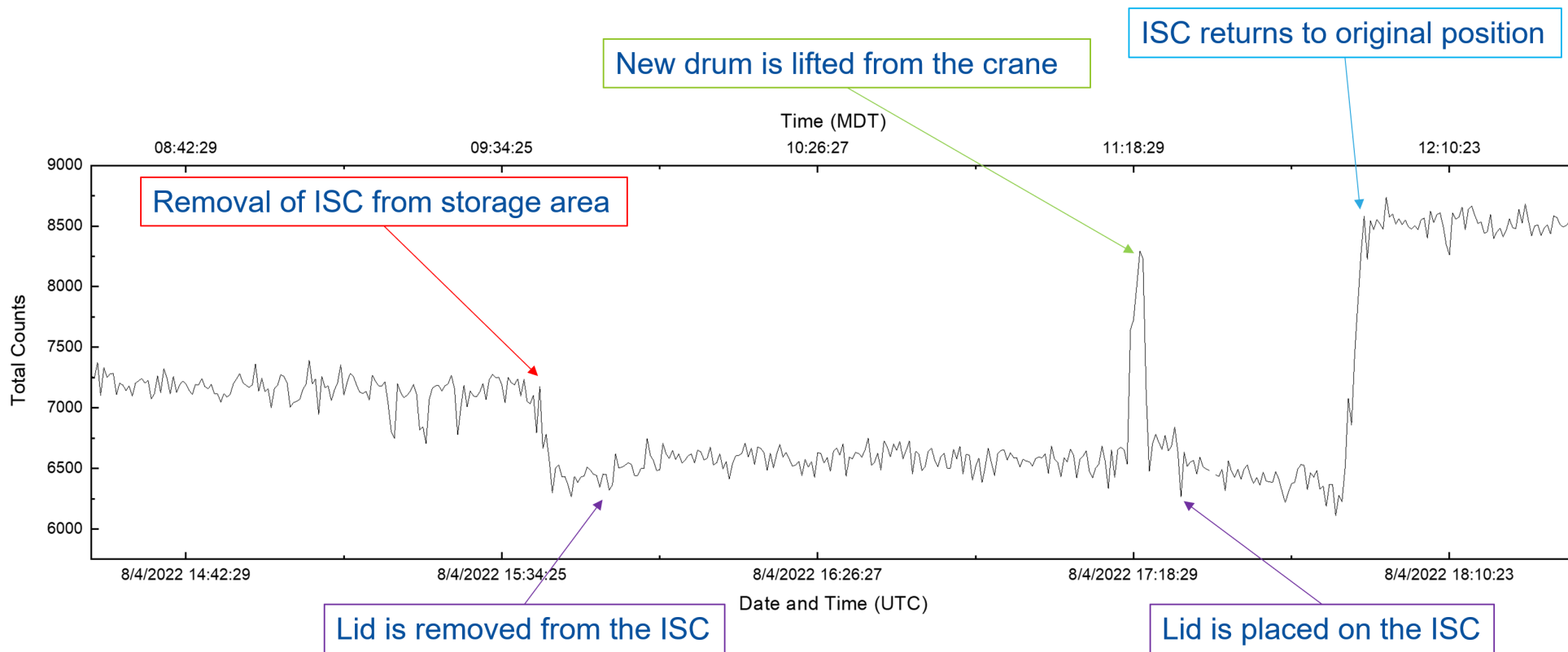


Figure 20. Field-testing results from the movement of ISC-007 and placement of a new waste drum inside.

5. SECOND ISC MOVEMENT & RESULTS

A second transfer was scheduled for several weeks after the initial transfer. In preparation for this deployment, the team deployed a secondary scintillating fiber measuring 20 meters in length and coupled to 100 meters of optical fiber. The 20 meter scintillating fiber was placed from the edge of the fence between the storage and staging area to the middle of ISC-009. The optical fiber was placed in light-tight tubing to prevent environment perturbations. A photograph of these fibers is shown in Figure 21 with the widest fiber being the optical fiber and the thinnest the 50 meter fiber used previously. The rest of the optical fiber was coiled inside a light-tight box to ensure photons from light sources inside the trailer would not affect the signal. The coiled fiber is shown in Figure 22 and the closed box with the PMT is shown in Figure 23.



Figure 21. Dual fiber configuration for the second ISC movement.



Figure 22. Optical fiber coiled inside a light-tight box to prevent unwanted photons from light sources in the trailer.



Figure 23. Light-tight box containing the optical fiber and the PMT.

ISC-007, which was previously moved, was chosen to be moved once again to have another drum be placed in the last available spot. The same procedure was conducted as described in section 3 and data was recorded in 60 second intervals. A photograph of the crane transferring the drum from the overpack cask to the ISC is shown in Figure 24. The ISC was subsequently returned

to its original location (within 15 centimeters) in the storage area. The results from both of the fibers are shown in Figure 25 which follow the same trends from the first ISC movement. Both fibers display a sharp drop in total counts when the ISC was removed after 19:12:30 and a sharp increase on its return near 20:26:04. The two fibers also recorded an increase in counts when the drum was lifted from the overpack (measuring 737 mrem per hour) before being placed in the ISC. These results demonstrate the long-distance and long-length capability of the scintillating fiber when coupled to an optical fiber.



Figure 24. Lowering of the 50 gallon drum into the fourth position of ISC-007.

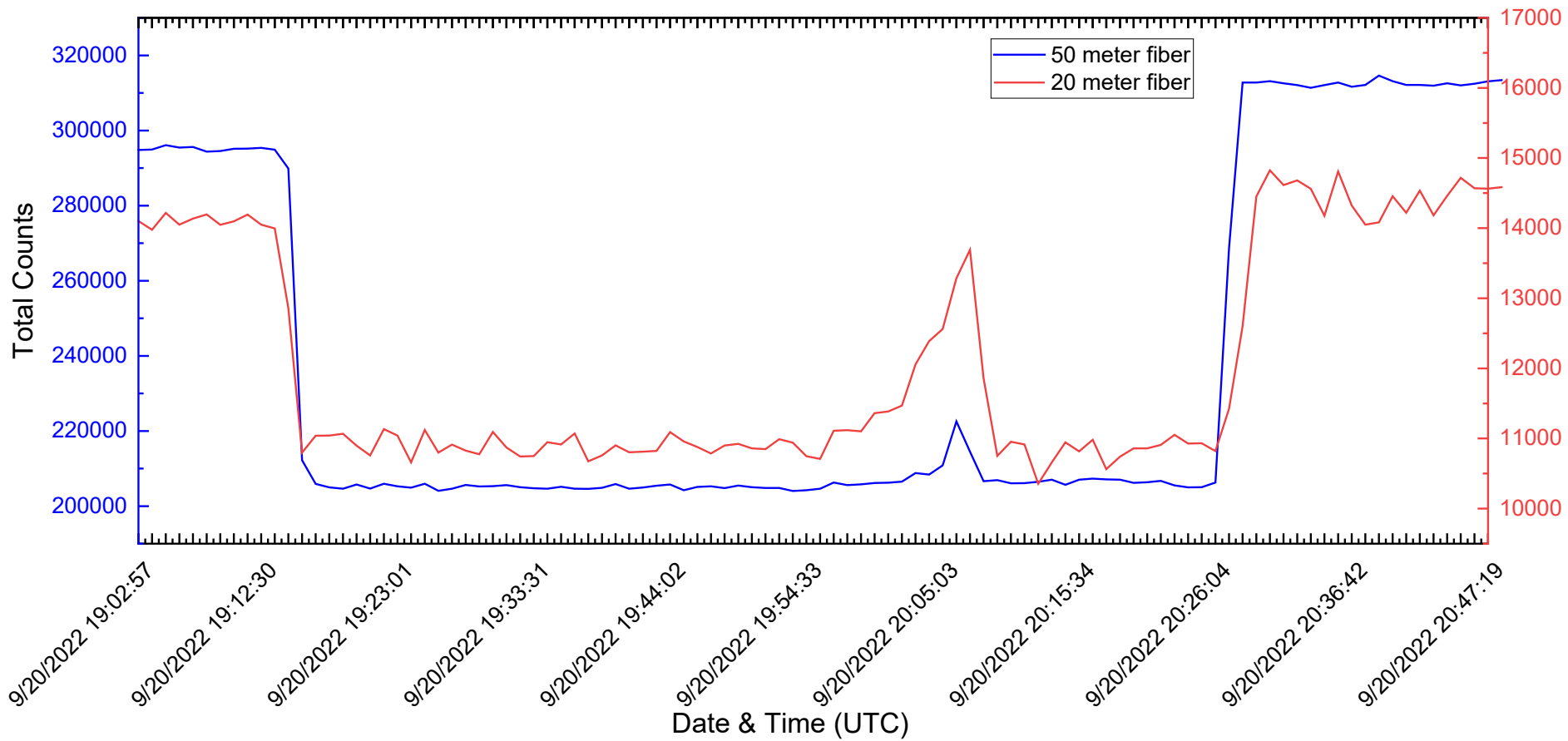


Figure 25. ISC-007 movement results for the two fibers normalized to the total counts before the transfer began. The 50 meter fiber data is shown in blue and the 20 meter fiber in red.

6. CONCLUSION

This report aims to fulfill the deliverable for field testing under task 7 of the project. The ported coaxial cable (PCC) detectors were tested and demonstrated as part of the prototype system deliverable demonstrated in the independent project review in December 2021. The OCC was successfully integrated into the Central Alarm Station prototype along with the radiation sensing system. The PCC system is a commercially available technology at Technology Readiness Level (TRL) 9. However, the scintillating fiber system was at TRL 4 at the start of this fiscal year due to successful testing and development throughout this project. Ultimately, field testing in a relevant environment was necessary to further improve the TRL to 5 in order to meet the project's original proposed goal. The deployment, field testing and results shown in this report demonstrate the capability of the technology for monitoring nuclear waste. Additionally, the long-distance and long-length detector concepts based on the coupling of scintillating fibers to optical fibers were confirmed. This capability can potentially solve the needs of the International Atomic Energy Agency to monitor entombed spent fuel in geological repositories. Overall, this validation not only improves the TRL but also demonstrates the radiation sensing capability of scintillating fibers for nonproliferation purposes.

7. OPTIMIZATION NEEDS

The independent project review panel had a recommendation of including a list of optimizations needed to address real world environments (CONOPS).

- The data acquisition system will need to be scaled in order to accommodate the many fibers needed per tunnel or per configuration.
- The effects of temperature on the scintillating fiber, albeit minimal during the field test, could be less noticeable in a geological repository once backfilled.
- The scintillating fiber health monitoring was conceptualized through the use of a pulsing diode opposite the PMT but needs to be fully tested and improved.
- The sensitivity of the ported coaxial cable system and the vibration system will need to be reevaluated according to the facility configuration. The operation mode of the tunnels (open, being filled, being backfilled, or backfill) will have a significant effect on the number of alarms and false positives.
- The overall concept needs to be socialized with stakeholders to help address additionally boundaries or restrictions in the physical placement of the sensors.
- The data acquisition graphic user interface will need to be reconfigured to address the needs of the stakeholders and to optimize status information in a format that is most effective for the user.
- The Central Alarm Station algorithms will need to be optimized to meet the needs of the stakeholders.

References

- [1] L. A. Ocampo Giraldo, D. L. Chichester, S. M. Watson, “TRIPWIRE - Radiation and Electromagnetic Laboratory Work Report,” INL/EXT-20-59814, 2020.
- [2] L. A. Ocampo Giraldo, D. L. Chichester, S. J. Thompson, S.M. Watson, “TRIPWIRE - Radiation and Electromagnetic Laboratory Work Report,” INL/EXT-21-64485, 2021.
- [3] L. A. Ocampo Giraldo, S. J. Thompson, S. M. Watson, J. D. Hix, J. T. Johnson, D. L. Chichester, “TRIPWIRE: Multi-Modal Distributed Sensing for Repository Verification,” Proceedings of the Institute of Nuclear Materials Management 62nd Annual Meeting, 2021.
- [4] L. A. Ocampo Giraldo, S. J. Thompson, J. D. Hix, J. T. Johnson, D. L. Chichester, ” Progress of Tripwire: Multi-modal Distributed Sensing for Repository Verification,” Proceedings of the Institute of Nuclear Materials Management 63rd Annual Meeting, 2022.