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Radiation Templates of Spent Fuel in Casks

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DISCLAIMER

Radiation templates of spent fuel in casks

Project Categories

24.1.3.2 Containment and Surveillance
☐ or 2.3 Other C&S
☒
☐ or ☐

PROPOSED STATEMENT OF WORK

Abstract

BNL and INL propose to perform a scoping study, using heavily collimated gamma and fast neutron detectors, to obtain passive radiation templates of dry storage casks containing spent fuel. The goal is to demonstrate sufficient spatial resolution and sensitivity to detect a missing fuel assembly. Such measurements, combined with detailed modeling and decay corrections should provide confidence that the cask contents have not been altered, despite loss of continuity of knowledge (CoK). The concept relies on the leakage of high energy gammas and neutrons through the shielding of the casks. Tests will emphasize organic scintillators with pulse shape discrimination, but baseline comparisons will be made to high purity germanium (HPGe) and collimated moderated ^{3}He detectors deployed in the same locations. Commercial off-the-shelf (COTS) detectors and data acquisition electronics will be used with custom-built collimators and shielding.

Mission Relevance

IAEA Department of Safeguards R&D Plan (STR-385) Priority Objective and R&D need: "T.1.R6 Develop safeguards equipment to establish and maintain knowledge of spent fuel in shielding/storage/transport containers at all points in their life cycle."

IAEA Development and Implementation Support Program for Nuclear Verification 2018-2020 (STR-386): "SGTS-001 Develop and improve performance and detection capabilities of equipment/ methods to verify, detect, check and monitor nuclear material (including irradiated material) and nuclear activities."

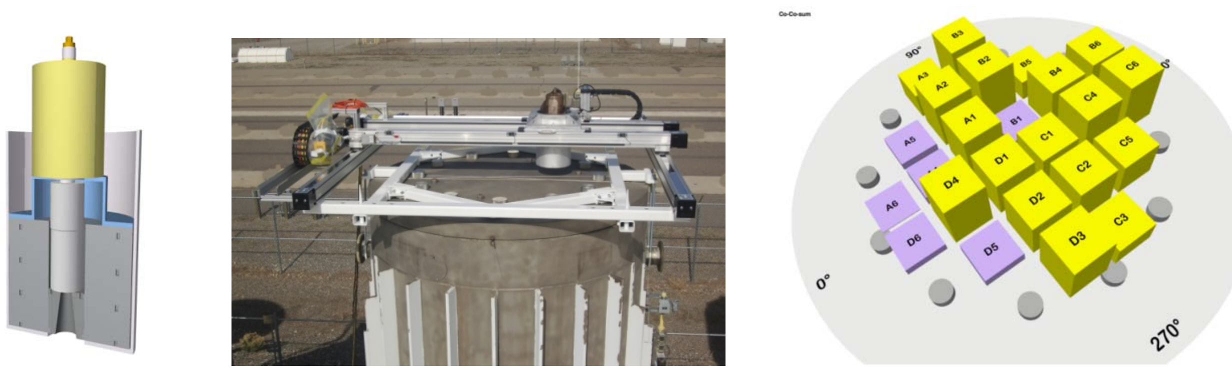
This technology would be used in a template (fingerprint) mode by comparing archived baseline signature data with current measurements, corrected for decay. A more challenging mode would be a comparison of new experimental measurements with a calculated signature based on declared cask loading. Combining neutron scans with gamma scans should provide a more robust fingerprint than either type of radiation by itself, and the combined profile would be more difficult to counterfeit.

Scope of Work

1. **Overview of proposed project including a detailed description of the technology or process to be developed.**

   BNL and INL will design a collimated fast neutron detector to record both the energetic neutrons and gammas emitted from the lid of the cask. Effective collimation is important to reduce the count rates of scattered particles relative to those transmitted directly from the source distribution. By positioning the detector above both filled and empty cask fuel slots, we hope to observe measurable differences in the measured radiation signals.

INL has a 12-inch diameter by 10-inch long tungsten collimator with a 4-inch diameter bore, and a set of 2-inch diameter liquid scintillation detectors, 0.5-, 1.0-, and 2.0-inches long. BNL has a VME-base fast pulse digitizer and the related data-acquisition software for liquid scintillation pulse-shape discrimination. Finally, INL has a computer-controller scanning mechanism for spent-fuel dry storage casks **(see Fig. 1)**. If need be, we will design additional collimation elements using either tungsten, polyethylene, or tungsten-loaded polymer material which is easily shaped to a chosen design. For example, flexible sheets of the polymer can be rolled around a tube to form a hollow cylinder. The collimator design will be optimized with the help of simulations performed with MCNP6. The collimated detector will be tested experimentally using COTS VME electronics at the INL Cask Farm, located at the INTEC technical area of the INL nuclear reactor site, where an array of different types of dry storage casks containing well-documented spent fuel are available for diagnostic measurements **(Fig. 2)**.



(a) **(b)** **(c)**

Fig. 1. (a) Collimated HPGe detector, (b) INL motor-driven cask scanner, (c) data showing relative intensities of ^{60}Co lines at the locations of spent fuel assemblies (yellow) and empty locations (purple). This project would provide similar patterns of fast neutron count rates using collimation.

Fig. 2. Array of different types of spent fuel dry storage casks at INL with well documented contents.

In parallel, benchmark measurements will be performed with a collimated HPGe detector and a collimated, moderated ^{3}He detector. These additional COTS instruments will provide the best possible identification of neutron and gamma events at the same source positions as the scintillator. The goal is to determine whether a single scintillator detector can provide a useful template of both gammas and neutrons that is sensitive enough to rule out the possibility of a missing fuel assembly. This proposal is only a scoping study to determine the typical count rates and the contrast between filled and empty locations in the casks. If the results are promising, additional work will be necessary to mount the detector and collimator in the INL motor-driven cask scanner and survey a number of casks with known contents. The robust, gamma and neutron templates obtained in this way can then be stored and used to compare with later measurements if there is a loss of CoK.

Previously used electronics for this type of measurement have been designed for use in the laboratory and involve heavy bulky crates of modules wired together to build a complete configurable system. As part of this scoping study, we will test a modern compact COTS data acquisition system that makes use of digital signal processing to perform all the functions required for pulse shape discrimination in one software-configurable module. We will make recommendations in the final report regarding field deployment of such systems by the IAEA.

2. **Description of project trajectory events, including overview of tasks, milestones, deliverables, and decision points**

Task 1. *Perform MCNP6 simulations of detector and collimator designs*. Some modifications or additions could be made to the previous design of the gamma collimator (shown in Fig. 1a) so as to obtain optimum collimation of fast neutrons. The simulations should provide predictions of the penetration of the radiation through the lid of the cask, and the amount of angular dispersion of the high energy components to be expected. (BNL).

Task 2. *Fabricate collimators and perform angular response tests with detectors*. We plan to make use of commercially available flexible tungsten-loaded polymeric shielding material that can be rapidly shaped to fit the detectors and can be reconfigured if necessary without major machining. All hardware and electronics will be bench tested using check sources. The important metrics are the angle of the cone of detected radiation and the rejection ratio of background outside of that cone. (BNL and INL).

Task 3. *Write a field test plan and make logistics arrangements.* The plan will include safety reviews, and description of support needed, such as cranes, scissor lifts, forklifts, etc. required to perform the measurements on casks. (INL).

Task 4. *Perform Field Test on casks at INL*. This test would be performed in the presence of observers from NA-241 and IAEA. The resulting data will be analyzed and summarized in a technical report showing measured gamma and neutron count rates as a function of position, and comparing the pattern (or template) with the known contents of the cask. (BNL and INL).

Milestone: Completion of Field Test

Deliverable: Report on results of Field Test and recommendations.

Participating Laboratories

Principal Investigator Table

Lab	Lab Program Manager	Principal Investigator	PI's Email	PI's Phone
***BNL**	Peter Vanier	Peter Vanier	vanier@bnl.gov	631-344-3535
INL		Gus Caffrey	Gus.Caffrey@inl.gov	208.526.4024

Summary Table

Task No.	Event Type	Event Title	Responsible Lab	Event Date
1	Milestone	Completion of modeling and simulation	BNL	12/31/2018
	Deliverable	Report summarizing modeling results	BNL	01/15/2019
2	Milestone	Completion of testing of detectors with collimators	BNL	01/31/2019
	Deliverable	Report describing collimator bench tests	BNL	02/15/2019
3	Field Test Plan	Completion of Field Test Plan	INL	02/28/2019
	Deliverable	Field Test Plan document	INL	03/15/2019
4	Field Test	Completion of Field Test at INL	INL	04/30/2019
	Deliverable	Report on results of Field Test	BNL	05/15/2019

Pertinent references

In 2005, a team consisting of ORNL, BNL and INL with an observer from the IAEA investigated the feasibility of using radiation imaging devices to obtain signatures of individual dry storage casks for safeguards purposes **(ref 1)**. The instruments included a coded aperture gamma camera, a coded aperture thermal neutron imager and a HPGe spectrometer. The results clearly showed different radiation leakage from the various cask types although the signatures were deemed insufficient to uniquely identify individual casks of the same type. However, the HPGe spectra indicated that some photopeaks of the spent fuel were detectable, implying that some fraction of the gammas could penetrate unscattered through the cask walls and lid. This insight led to a project funded by DNN R&D in which INL constructed a scanning device for positioning the HPGe detector with a heavy collimator at chosen locations on top of the cask lid looking downwards. The cask scanner **(ref 2)** was successful at identifying the locations of the cask that contained spent fuel bundles (see **Fig. 1**).

One limitation of this technology is that in some cases the lid of the cask is very heavily shielded with thick steel. The gamma lines that represent unscattered emission may be so weak that they cannot be measured above the Compton continuum background, so directional information is lost. Since attenuation of neutrons in steel is less than for gammas, we expect that fast neutron detection will provide even better contrast ratios between filled and empty slots.

A number of attempts have been made in the past to map the contents of spent fuel dry storage casks using neutron counting. Measurements were made on the side (vertical surface) of the cask at various locations around the periphery. These methods (refs **3-8**) have not used collimated detectors, but instead measured (and modeled) fast neutron spectra, or attempted to subtract background from nearby interfering casks using dual slabs of moderated ^{3}He detectors. Removal of the central fuel assembly from a 21-assembly cask was calculated (refs **3, 5**) to produce a 2% percent difference in response for a 4-sided measurement. However, such measurements are made difficult if the number and location of nearby casks change substantially between measurement campaigns. Ref. **5** concluded from uncollimated measurements that –

> *"Passive neutron measurements can potentially detect the removal of interior assemblies in multi-element casks using four- or six-sided measurements. The interior assemblies were found to contribute nearly the same neutron flux when averaged over the outside vertical surface of the cask as the exterior assemblies. Passive neutron measurements made at the top of the cask can also potentially see the central assemblies."*

Thus, **collimated** scanning of the top of the cask could be used in conjunction with **collimated** scanning of the sides, which should be an improvement over what was done in Refs **3-8**.

Proposals to perform tomography of casks using active interrogation with 14 MeV neutrons have provided modeling results indicating that very few **unscattered** neutrons will pass through the shielding **twice**, as well as the fuel assemblies **[9]**. Scans would require a week. Cosmic ray muons can pass through the entire cask, and models suggest that very revealing muon tomography images are possible, but the cosmic ray flux is low, about 0.01 muons/cm2-sec, and the scan could take a week or much more **[10]**. The muon tracking detectors are large and fragile.

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4. "Recent Developments in the Testing and Implementation of Measurement Equipment for Safeguards", P. Chare, W. Kloeckner, M. Swinhoe, and P. Schwalbach, Directorate of Euratom Safeguards, Proceedings of the 39th Annual Meeting of the Institute of Nuclear Materials Management, Naples, FL, July 1998.
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6. "Neutron Measurements outside Containers of Spent Fuel for Safeguards", Turner and Swinhoe, European Safeguards Directorate, INMM 1999.
7. "Testing of the Dual Slab Verification Detector for Attended Measurements of the BN-350 Dry Storage Casks", P.A Santi, M.C. Browne, R.F. Parker and R.B. Williams, LA-UR-09-03480, Proceedings of the 50th Annual Meeting of the Institute of Nuclear Materials Management, Tucson , AZ, July 2009.
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U.S. DEPARTMENT OF ENERGY

NNSA | OFFICE OF NONPROLIFERATION AND ARMS CONTROL (NPAC)

INTERNATIONAL NUCLEAR SAFEGUARDS

Radiation templates of spent fuel in casks

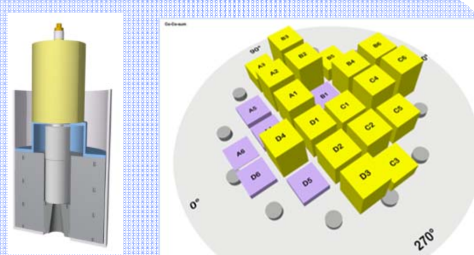
Confirm presence of all declared fuel assemblies in a cask after loss of Continuity of Knowledge

Background/State of the Art

INL Cask Farm

- Gamma and neutron dose rates confirm presence of radiation sources in casks
- Seals and TIDs applied
- If CoK is lost, no way to detect a missing fuel assembly but by opening cask
- Requires high bay hot cell
- Recent attempts to use muon tomography

Innovation



- Scan lid with collimated detectors
- Use highest energy neutrons and gammas
- Reject down-scattered radiation
- Pulse height and shape discrimination

R&R #: BNL-203645-2018-FORE

Approach, Metrics and Outcomes

MAIN GOAL

- Automated scanning system for gammas and neutrons

Computer-controlled scanner atop INL MC-10 dry-storage cask

HOW IT WORKS

- Liquid organic or plastic scintillators
- Narrow field of view aligned with one assembly
- Detectors are COTS, scanner and collimator are GOTS
- Combined gamma and neutron radiation profiles
- Compare with known contents of casks

ASSUMPTIONS, LIMITATIONS & CONSTRAINTS

- Assumes some leakage through shielding
- Assumes direct signal is measurable over scattered
- Constraint is the time to acquire significant contrast

Impact

- Safeguards relevance
  - Characterization of dry fuel storage casks
  - Recover from loss of CoK
- Long-Term R&D STR-385 Need T.1.R6
- Detect one missing assembly with high confidence
- IAEA STR-386 SGTS-001
- **Start of FY TRL = 5**
- **End of FY TRL (Planned) = 6**

Goals/Action Plan

Current FY

- Detectors and electronics exist
- Design additions to collimator for neutrons
- Test system in lab and demo in field

Future FY

- Couple neutron detector to scanner
- Perform scanning on multiple casks

Team

BNL, INL

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