Bringing Cutting-edge Technology to the Nuclear Engineering Classroom

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Abstract

As more countries turn to nuclear power to meet their electricity demands, the threat of clandestine nuclear weapons development increases substantially. As a result, it is important to develop and train the next generation of engineers interested in developing techniques and technologies to detect and track illicit nuclear activities. However, exposing these students to the types of research being performed in this field can be challenging because much of that research is performed on the cusp of state-of-the-art. This paper will detail how advancements made in the Retrospective Dosimetry and Nuclear Assay lab at North Carolina State University have made it possible to potentially allow graduate and/or undergraduate students in nuclear engineering to perform novel retrospective dosimetry experiments in an educational setting. It has been demonstrated that with relatively modest sample preparation, radioactive sources can be identified, located and even imaged using thermally and optically stimulated luminescence signals from ubiquitous building materials. This means that over the course of a few laboratory classes, students could actually carry out educational experiments involving techniques that are the subject of active research.

Keywords

STEM, nuclear security, outreach, nonproliferation

Introduction

As the threat of nuclear weapons grows, whether real or perceived, nuclear scientists and engineers are tasked with developing new technologies to protect the public and quell fears. However, the development of human capital to support the nuclear security needs of the United States is often criticized as being insufficient to meet the demand for qualified professionals trained in nonproliferation and nuclear security.[1] This growing problem can be attributed, at least in part, to the lack of educational programs dedicated to introducing STEM (Science, Technology, Engineering and Math) students to these fields.

In response to the lack of visibility of the fields of nuclear security and nonproliferation, some institutions have begun creating and implementing initiatives to introduce graduate and undergraduate students to the nuclear security mission. For example, Los Alamos National Laboratory is actively engaged in multiple programs that are intended to create a pipeline of qualified nonproliferation and nuclear security professionals, beginning at the undergraduate level and extending through graduate level students.[2] In addition, Universities across the country, such as the University of Texas at Austin, have begun to implement curricula focused on training the next generation of nonproliferation and nuclear security professionals.[3]

In order to meet the security needs of the domestic and international communities, more institutions should make a concerted effort to introduce STEM students to the fields of nuclear security and nonproliferation. Advances made at North Carolina State University, in luminescence dosimetry, have made these techniques potentially accessible to classroom students. The goal of this paper is to summarize those techniques and illustrate how they might be used to illustrate research methods in nonproliferation inside the classroom.

Luminescence Dosimetry in Nonproliferation

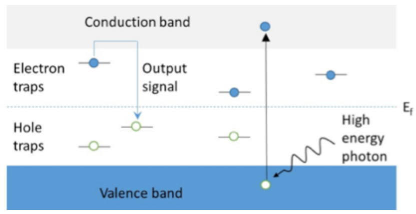

Figure 1: Schematic representation of the OSL phenomenon.

The phenomenon of optically stimulated luminescence (OSL) is described by the band gap model of solid state physics, show schematically in Figure 1. In short, the interaction between radiation and crystalline insulators creates electronic changes in the material that result in a long-lived record of the radiation interaction. Retrospective dosimetry refers to the determination of the dose received by a material, after the source has been removed. Nearly all inorganic, insulating crystals have the capability to perform as dosimeters using OSL. Two of the most attractive natural materials for OSL dosimetry are quartz and aluminum oxide, primarily owing to their widespread inclusion in ubiquitous materials. Quartz, for example is found in all earthen building materials such as bricks and cinderblocks, while aluminum oxide is commonly found in porcelain tiles and dishes. In this context, the entire industrialized world is covered in materials that are constantly keeping a tally of their radiation environments.

Materials and Methods

Two generic, red bricks were purchased at a local supply store. A 100 mCi, encapsulated ^{241}Am source was placed between the two bricks for 3 hours and 18 minutes. Four Landauer nano-Dot optically stimulated luminescence dosimeters (OSLDs) were placed around the source as a means of independent verification and characterization. Figure 2 shows the exposure configuration with the top brick removed. The encapsulated ^{241}Am source was laid on top of the bottom brick and then another brick was placed on top of the first brick, sandwiching the source and OSLDs. The location of the source, relative to the OSLDs was determined, using MCNP©, by optimizing the dose to the OSLDs as a function of source position.

Figure 2: Experimental exposure configuration. The source, centered metal rod, was placed on the brick between 4 nano-Dot OSLDs. The OSLDs served as independent verification of the exposure to the brick sample

After localizing the source position, a 1-inch diameter core was taken from directly under the inferred source location. During the drilling of the core, chatter in the drill bit damaged the top layer of the sample. The removed core was then soaked overnight to ensure that the brick matrix was saturated. After soaking, the volume of the core was measured using liquid displacement. Following the volume measurement, the core was then oven-dried at 40ºC for three days and the mass was measured. The density of the core was then determined to be 2.24 g/cc. The measured core density was used to update the original MCNP© model for subsequent calculation of the theoretical dose to each layer of the sample core.

The brick core was then sliced, along its length, into twelve approximately 2-mm thick wafers using a low-speed water cooled Buehler IsoMet saw. Based on the MCNP© calculations, the dose to the brick at depth of 4 cm was expected to be approximately 30 mGy, close to the detection limit for luminescence studies, therefore only 12 slices were taken. The 12 slices were then crushed and sieved into two grain size ranges, 90 to 250µm and less than 90µm. To test the abilities of OSL to measure dose depth profiles with minimal processing, the less than 90um grains were used. With no further processing, TL/OSL measurements were made on the less than 90um grains using a Risø TL/OSL-DA-20 reader (DTU Nutech, Denmark) fitted with blue light emitting diodes for OSL stimulation.

Results

The location of the source was able to be determined to within 2 mm, compared to the imaged location of the source. It should be noted, some parallax in the photo was possible and thus the true spatial resolution of this method is still considered undetermined at this time. The energy spectrum of the source was determined to be 60.17 keV, 27.07 keV, and 14.57 keV compared to the three most prominent photon energies in the Am-241 spectrum (59.5 keV, 13.9 keV and 26.4 keV). Although subsequent analysis techniques have been used to attain better results, those methods were considered too advanced for undergraduate students to perform.

Conclusions

The results show that the energy and position of a radioactive source can be inferred with only a modest amount of sample preparation. As a result, it is being proposed that a variant of this experiment be adapted as a laboratory module for undergraduate nuclear engineering students at North Carolina State University. The module would involve an instructor irradiating a brick with a small array of Landauer nano-Dot OSLDs on the source side surface. The students would then be able to construct a dose map using the OSLDs and use that dose map to determine the probable position of the source. The students could then use their experimentally determined source location to decide where to drill their brick. Finally, following the method outlined above the students would be able to reconstruct the dose deposition profile in the brick and determine the source's energy. It is the opinion of the authors that all of the sample preparation techniques utilized here are accessible to undergraduate STEM students.

The global risk of the proliferation of nuclear weapons will continue to grow as more nations turn to nuclear energy as a secure, clean form of power. It is critical that steps be taken to ensure a reliable pipeline of qualified and interested STEM students into the nonproliferation and nuclear security fields. One way to create such a pipeline is to introduce students to cutting-edge techniques in the classroom. The method outlined in this paper is an attempt to bring a set of state-of-the-art nonproliferation techniques into the nuclear engineering classroom.

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