Overview of Nuclear Detection Needs for Homeland Security

Timothy E. Valentine*
Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, Tennessee, 37831, USA

Abstract

The need for advanced and improved nuclear detection systems is paramount to address the challenges facing the U.S. Department of Homeland Security. The DHS is responsible for developing broad based nuclear detection architecture for discovery of nuclear materials that may be smuggled into or in transit within the U.S. The implementation of this architecture requires the design, development, and deployment of a suite of nuclear detection systems with varying capabilities and operational constraints. This paper provides an overview of the nuclear detection needs for homeland security applications that encompasses both passive and active detection systems that range from hand-held to vehicle deployable systems.

KEYWORDS: Homeland Security, nuclear material detection

1. Introduction

Science and technology plays a critical role in the prevention of nuclear and radiological terrorism. The growing deployment of nuclear detection systems for detection of illicit trafficking of nuclear materials has renewed interest in the field of radiation detection research. The research has been greatly expanded due to the increasing requirements and demands on radiation detection systems and to the greater use of detection systems by non-expert personnel such as local and state law enforcement officials and customs and border patrol agents. Additionally, few effective, affordable, near-term solutions have been identified for robust detection of shielded special nuclear materials at ports of entry, for radiation monitoring along unattended borders, for in-transit monitoring of cargo, for mobile surveillance tools, and for distributed radiation networks.

The Department of Homeland Security utilizes a defense in depth approach to addressing the problem of illicit trafficking of nuclear materials. This layered defense paradigm is based on having multiple layers of detection capabilities with varying degrees of precision and complication. For example, large plastic scintillation detectors are commonly used as portal monitors for scanning cargo from container ships at our ports, while more precise gamma ray spectroscopy systems are used for more detailed examination of suspicious cargo. This layered defense approach necessitates the development of improved detection materials, methods and systems which are summarized in this paper.

* Corresponding author, Tel. 865-574-0715, E-mail: valentinete@ornl.gov

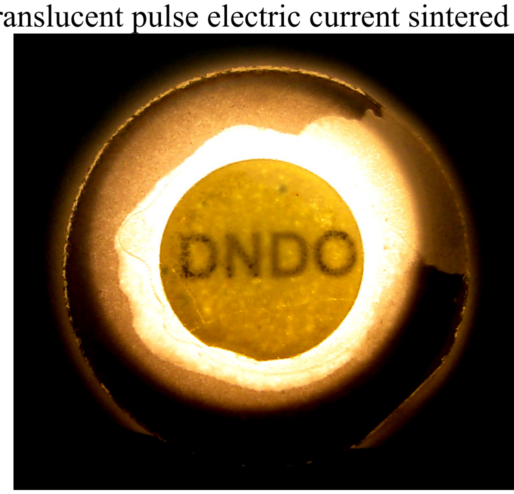
2. Detector Materials

The discovery and development of new detection materials and processes is a major focus of research within the DHS. Advances in radiation detection technology will impact every gap in the present defense structure from distributed inexpensive radiation detectors to highly sensitive, standoff detection systems for mobile threats in transit, and spanning all applications in between. Most technological solutions for detecting gamma rays rely heavily on scintillation detectors and semiconductors. These detectors are plagued by high cost of fabrication and limited supply of high-quality materials.

Inorganic scintillation detectors are commonly chosen as gamma-ray transducers because of their high-Z value and density. Additionally the light output of inorganic scintillation detector is more linear than that of organic scintillation detectors. Inorganic scintillation detectors are commonly fabricated using single-crystal growth methods such as the Bridgman or Czochralski techniques. However, while promising new materials have been grown using these techniques, crystal growth continues to be a time-consuming and expensive method for production of scintillation materials for radiation detectors. Additionally, most single crystals are limited in size thereby imposing constraints on the final radiation detectors. Glass and ceramic scintillation detectors offer the potential for the fabrication of relatively inexpensive and plentiful detectors, yet glass scintillation detectors have suffered from relatively low light output. Ceramic scintillation detectors have received less attention over the past few decades but interest has been growing in the development of transparent polycrystalline ceramic materials.

The development of large, transparent polycrystalline ceramic scintillation materials is of interest to the DHS to supplant the time-consuming and expensive methods of single-crystal growth for a variety of inorganic scintillation materials. Previous ceramic scintillation material processing has been limited to materials with cubic material structure that have a single index of refraction and are optically isotropic. However, recent advances in material processing using controlled sintering methods have demonstrated that translucent polycrystalline can be produced from non-cubic materials that are optically anisotropic. An example of a ZnO ceramic produced using pulse electric current sintering is provided in Fig. 1.

Figure 1: Translucent pulse electric current sintered ZnO ceramic.



3. Passive Nuclear Detection Systems

Passive nuclear detection systems span a wide range of applications for homeland security employing both photon and neutron detection systems. The applications range from portable hand-held units to portal monitors located at ports of entry and at weigh stations along transportation corridors. Passive nuclear detection systems are used for standoff detection of special nuclear materials for search applications, imaging of special nuclear materials, radioisotope identification, and container and vehicle screening, just to name a few.

Over 7 million cargo containers enter U.S. ports each year. However, less than 2% of the actual containers are surveyed for the presence of radioactive materials when they arrive. The U.S. Department of Commerce anticipates the number of cargo containers entering the U.S. to quadruple over the next 20 years. This high volume of material movement is a significant challenge for interdicting any attempted shipment of nuclear material into the U.S because a balance between security and commerce must be established. Radiation portal monitors (RPMs) used in ports are mostly comprised of plastic scintillation detectors and some have additional neutron detectors that monitor containers by looking for counts that exceed a threshold. These portal monitors have cost that can exceed $150K. An example of the use of RPMs is shown in Fig. 2. However, these systems are susceptible to variations in background radiation. Additionally, naturally occurring radiation material (NORM) commonly encountered in commerce further exacerbates the problem.

Figure 2: Radiation Portal Monitor for cargo screening.

To address these shortcomings, the DHS is supporting the deployment of advanced spectroscopic portals (ASPs) that have the capability to distinguish NORM from special nuclear materials. However, cost and production capacity limit the widespread deployment of ASPs.

Handheld and portable radiation detection systems are used as a supplement for radiation portal monitors in some cases. These handheld and portable radiation detection systems can be gross counting systems or spectroscopic systems. The limitations of existing spectroscopic systems, be it resolution or the need for cryogenic cooling, require development of new detection systems based on new or improved detection materials or alternate cooling systems such as thermoelectric coolers. For high-resolution gamma spectroscopy measurements, the goal for energy resolution at full-width half maximum is less than 0.5% at 662 keV for a room temperature scintillation detector. This goal cannot be achieved with existing room temperature detectors; for example, the resolution for state of the art CZT detectors is approximately 1.7% at 662 keV (with very low detection probability).

The DHS is also examining the use of radiation detection systems for in-transit monitoring of containers. These technologies would take advantage of the relatively long transit times for commerce shipments. The goal of these sensors is to be small, low-cost, tamper proof, and provide reasonable probability of detection of materials of interest. An extremely low false alarm rate would be a necessity as an alarm from one of these on-board sensors would require the ship to be delayed from docking. Hence, such in-transit sensors would need spectroscopic capability to distinguish special nuclear material from NORM and cosmic ray induced radiation.

4. Active Nuclear Detection Systems

Active nuclear detection systems are commonly used for radiography or for secondary inspection. These systems employ neutron or gamma rays sources or both to either provide a detailed image of the cargo container, or to specifically identify special nuclear materials in cargo or containers. Such systems have been deployed at U.S. ports of entry and are used to further characterize items that are removed from containers.

Transmission radiography is commonly employed to image suspect containers or containers chosen at random. These systems typically use an x-ray generator or mono-energetic gamma ray source to provide images of high-density and low-density materials in containers. Such systems are either fixed or mobile depending on the needs at the particular location (see Fig. 3). Transmission radiography technologies may be useful to detect high Z materials that are often used in shielding, but these measurements do not verify the presence of special nuclear materials (SNM). Additionally, these systems cost nearly $1M each.

The detection and verification of SNM is an important challenge for the DHS. While advances in spectroscopic measurement systems will greatly enhance the probability of detecting non-shielded or weakly shielded SNM, the detection of shielded SNM and in particular shielded high-enriched uranium (HEU) poses a significant challenge that is best addressed using active detection systems.

Active interrogation techniques utilize both neutron and gamma ray sources and includes nuclear resonance fluorescence, neutron and gamma ray multiplicity, neutron radiography, and neutron and gamma ray induced fission. These systems can be utilized to inspect cargo in shipping container at seaports and border crossings, air transport containers, or to be deployed as mobile inspection systems. To support the development of these systems, additional research and development is needed in neutron and gamma ray sources, detection models, neutron and gamma ray emission data, and neutron and gamma ray simulation codes.

Figure 3: Mobile x-ray transmission radiography screening measurements.

5. Conclusion

Science and technology will continue to play a critical role in the prevention of nuclear and radiological terrorism. The deployment of nuclear detection systems for detection of illicit trafficking of nuclear materials has renewed interest in the field of radiation detection research. The Department of Homeland Security utilizes a defense in depth approach to addressing the problem of illicit trafficking of nuclear materials. This layered defense paradigm is based on having multiple layers of detection capabilities with varying degrees of precision and complication. This layered defense approach necessitates the development of improved detection materials, methods and systems covering a wide spectrum of applications. The DHS will continue to need to support research and development in basic nuclear detector materials; the development of passive detection systems and methodologies for standoff detection of special nuclear materials for search applications, imaging of special nuclear materials, radioisotope identification, and container and vehicle screening; and the development of active detection systems for imaging of containers and verification of the presence of shielded special nuclear materials.