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The Case Study Review

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Scintillators

As concerns about the illicit movement of radioactive materials across international borders increase, so too has the need for increased protection of those borders both foreign and domestic. The challenge is not only to detect hidden radioactive materials, but also to distinguish them from legitimate radionuclides such as radio-pharmaceuticals that are often transported across borders and shipped throughout a country.[1] With more than 600 U.S. border sites to protect, screening imported radioactive material requires a careful balance of high throughput and high search efficiency. However, these requirements are difficult to meet as rapid screening operations leave less time for radiation detectors to efficiently evaluate materials.

In support of border security, Sandia developed organic glass scintillators...

IPO

Sandia National Laboratories

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

U.S. DEPARTMENT OF ENERGY NNSA

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BACKGROUND

Radiation detection is either passive (e.g., searching for special nuclear materials) or active (e.g., monitoring or interrogating objects of interest). The most common radiation detectors are based on scintillating materials that convert hard radiation (e.g., gamma, x-ray or neutron) into visible light registered by a photodetector. Scintillation materials exist in many physical forms, including crystals, glasses, powders, ceramics, plastics, liquids, and gases. These capabilities are widely used as radiation detectors in medical diagnostics, high-energy physics, geophysical exploration, and national security applications.

There are two major types of scintillators that are used in nuclear and particle physics: inorganic and organic scintillators. Inorganic scintillators are usually comprised of crystals grown in high temperature furnaces. Scintillation in inorganic crystals is typically slower than in organic ones. They exhibit high efficiency for detection of gamma rays and are widely used for the identification of ionizing radiation isotopes via gamma-ray spectroscopy. Inorganic crystals also can be cut or grown in small sizes and arranged in an array configuration to provide position sensitivity, which is widely used in medical imaging to detect X-rays and/or gamma rays. Inorganic scintillators can better detect gamma rays and X-rays than organic scintillators due to their high density. A disadvantage of some inorganic crystals is their hygroscopicity, a property which requires them to be housed in an airtight container to protect them from moisture.[2] Inorganic crystals are also difficult to scale to the large sizes required by some radiation detection applications due to prohibitive raw material and crystal growth costs.

> *"screening imported radioactive material requires a careful balance of high throughput and high search efficiency"*

Organic scintillators are kinds of organic materials that provide detectable photons in the visible part of the light spectrum, following interaction with ionizing radiation. The scintillation mechanism in organic materials is quite different from the mechanism in inorganic crystals. The fluorescence mechanism in organic materials arises from transitions in the energy levels of a single molecule; therefore, the fluorescence can be observed independently of the physical state (e.g., vapor, liquid, solid). Organic scintillators comprise crystalline, liquid, plastic, and glassy forms. All of these are characterized by having a high hydrogen content, making them useful for fast neutron detector applications such as indicating the presence of illicit nuclear materials. Despite their advantages, organic scintillators generally produce less light and interact less strongly with X-rays/gamma rays than inorganic materials and are thus better suited for applications that involve large volumes, neutron detection, and/or very fast timing characteristics.

BACKGROUND Cont.

Organic Scintillators

- Neutrons
- Cheap
- Extremely fast response time
- Less interaction with gamma rays

Inorganic Scintillators

- Gamma radiation
- More efficient at converting radiation into usable light
- Can emit for longer periods
- Slower timing resolution

TECHNOLOGY DEVELOPMENT

In 2010, a team of researchers at Sandia National Laboratories began to develop new types of organic scintillators based on polymers to improve the cost-to-performance ratio of radiation detectors for nuclear nonproliferation and border security applications. The most commonly used scintillators at borders and ports of entry are currently plastics, which are comparatively inexpensive at less than a dollar per cubic inch and can be molded into very large shapes. Larger shapes allow for more sensitive scintillators resulting in a higher likelihood that the scintillators will detect radiation. Despite clear benefits, plastic scintillators are unable to efficiently differentiate between various types of radiation — a separate helium tube is required for that. The type of helium used in these tubes is rare, non-renewable, and significantly adds to the cost and complexity of a plastic scintillator system. And plastics are not particularly bright which means they are not sufficient for detecting weak sources of radiation. To address these limitations, Sandia researchers developed organic glass scintillators, which provide more than twice the light output of plastic scintillators and can differentiate between various types of radiation.[3]

TECHNOLOGY DEVELOPMENT

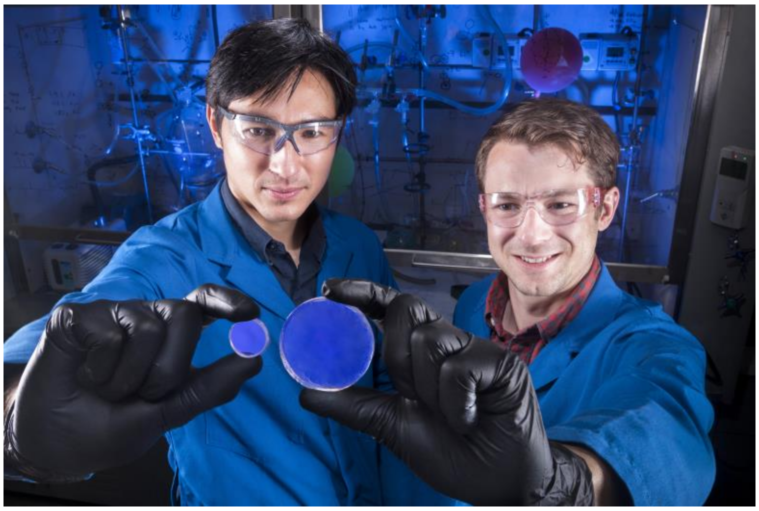
In 2014, researchers at Sandia patented a new class of plastic scintillators which can detect fission neutrons, while also discriminating against interfering gamma rays. These two properties allow for the plastic scintillators to be used as a replacement for liquid scintillator neutron detector materials. The composition of these scintillators consists of a low polymer base, doped with an independent variable fluorescent and triple-harvesting compounds. Triple-harvesting dopants create physical properties in the material that are fundamentally different from those of existing organic scintillators.

These new properties provide advantages including improved luminosities, tunable pulse shapes, and superior scintillation timing characteristics. The new materials also reduce the radiative lifetime of triplet excited states through spin orbit coupling, enable sub-microsecond radiative decay, and eliminate the need for hazardous liquid scintillators. Another advantage of the new properties is that they will allow for synthetic control over the scintillation timing response and wavelength characteristics. This allows for particle discrimination by spectral shape discrimination (SSD) and pulse shape discrimination (PSD). Particle discrimination may also be performed with conventional PSD methods, which allow for simple replacement of existing liquid scintillator cells with minimal hardware configuration. The plastic scintillators developed by Sandia can be used in radiation detection, public safety, national security, and nonproliferation.[4]

In 2015, researchers at Sandia started developing a separate, but also new, class of organic scintillators called organic glass scintillators. Sandia's organic glass scintillators are manufactured using a melt casting method which produces highly transparent glasses that have been shown to provide high light yields. Sandia's scintillators also consist of a combination of two or more organic compounds. These organic compounds can resist crystallization and can be formed into almost any shape, including thin fibers.

The glass scintillators demonstrate high scintillation yields and high selectivity when used to discriminate different types of radiation. The material is also suitable for other applications that require high luminosity, high electron/hole mobilities, and stable film-forming properties such as organic electronics.[5]

These organic glass scintillators have demonstrated indefinite stability within a laboratory setting, meaning that the material does not degrade over time. This indicates that the scintillators are ready for field testing to show that the scintillators can withstand humidity and other environmental conditions that are found at deployment locations such as seaports. In 2017, the National Nuclear Security Administration (NNSA) funded the project for an additional two years so that the team could determine if the scintillators can meet border security requirements.[6] This project served as the foundation for further research and development of organic scintillators at Sandia National Laboratories, which has been funded through 2023.[7]



Sandia National Laboratories researcher Patrick Feng, left, holds a trans-stilbene scintillator and Joey Carlson holds a scintillator made of organic glass.

RETURN ON INVESTMENT

Sandia's Integrated Partnerships Organization (IPO) has successfully established several Strategic Partnership Agreements (SPP) and one license, which utilize Sandia's scintillators.

DEFENSE

MEDICINE

Strategic Partnership Agreements

National Security Research

Within tech transfer, Strategic Partnership Projects (SPP) Agreements facilitate the availability of Sandia's unique resources to private industry and individuals, state and local governments, colleges and universities, non-profit organizations, international organizations, foreign governments, and foreign companies to validate or improve technologies. Sandia has multiple SPP agreements utilizing Sandia's scintillators dating from the 2010 to 2021.

LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

LDRD

The Laboratory Directed Research and Development (LDRD) program invests in high-risk, potentially high-payoff activities that enable national security missions and advance the frontiers of science and engineering. The LDRD program provides the flexibility to anticipate and respond quickly to future mission needs and to explore potentially revolutionary advances in science and technology.

Over the past 20 years, 20 LDRD projects were conducted utilizing scintillators.

PUBLIC IMPACT

Sandia's organic scintillators are used with neutron imaging which is a non-destructive method that shows the internal structure of a sample by subjecting it to a neutron beam. Because this method is particularly useful in examining objects with dense outer shells and an inner structure compromised of lighter material, it is a useful tool for manufactures in a wide range of industries including defense and healthcare.

Defense
The organic glass scintillators developed by Sandia National Laboratories have the ability to strengthen U.S. national security thanks to their ability to discern between normal everyday radiation sources such as those used for medical devices and threatening sources of radiation. This capability promotes public safety and makes it more difficult for illicit and dangerous materials to enter through borders and ports of entry. The low production cost also allows for a higher production volume, encourages widespread use of the technology border crossings and ports of entry, further emphasizing public security applications. Neutron imaging is also of interest to entities such as the Department of Defense (DOD) to conduct tests in the field to determine the makeup of an object. The Army is interested in this technology to inspect high-density components, visualizing defects that could potentially lead to loss of life or loss of major military assets.[8]

Medicine
Sandia's organic scintillators also offer possible improvements over existing medical imaging techniques such as X-ray, CT (computed tomography), and/or PET (positron emission tomography), owing to their excellent spatial and timing resolution. These attributes are important for imaging applications to differentiate between benign/malignant lesions and healthy tissue. Ongoing efforts at Sandia have shown that it is possible to increase the X-ray/gamma-ray interaction cross section of organic scintillators through loading with high atomic number compounds. This will enable patient imaging in the fastest amount of time and at the lowest possible radiation dose.[9]

"The low production cost also allows for a higher production volume, encourages widespread use of the technology border crossings and ports of entry, further emphasizing public security applications."

SOURCES

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The Case Study Review

Scintillators

> *Sandia's scintillators "strengthen national security by improving the cost-to-performance ratio of radiation detectors at the front lines of all material moving into the country"*

Sandia's organic glass scintillators offer applications in radiation detection, public safety, national security, and nonproliferation. These organic glass scintillators have demonstrated value through indefinite stability within a laboratory setting, meaning that the material does not degrade over time.

There are two primary types of scintillators used in nuclear and particle physics:

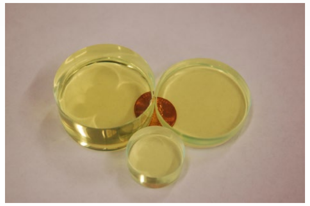
- *Organic (plastic) scintillators*
- *Inorganic (crystalline) scintillators*

Return on Investment:

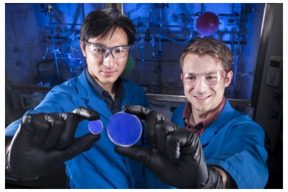
- *Supporting border security*
- *Promoting medical advancements*
- *Counterproliferation mission*

2001
First LDRD

2010
Work begins on new class of organic glass scintillators



2015
Sandia develops organic scintillators



2017
Scintillator work is funded until 2023