CONTACT US

Office of Science
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585
P: (202) 586-5430
More Information »

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Detecting Nuclear Threats

Plasma physics challenge yields portable nuclear detector for homeland security.

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Photo: Denise Applewhite

The MINDS device was invented by a team of engineers at the Princeton Plasma Physics Laboratory, including, from left: Kenny Silber, Henry Carnevale, Charles Gentile, Dana Mastrovito, and Bill Davis.

In 1999, faced with the task of decommissioning the legendary Tokamak Fusion Test Reactor (TFTR), officials at the U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL) realized they needed something that didn't yet exist—a non-destructive, real time device to detect certain "hot" elements lacing the inner vessel of the doughnut-shaped reactor.

So they asked a team from the lab to invent a device that would identify each element in the reactor and how much was there. Ten years later, the group not only has successfully tackled that challenge, but it has won national recognition for a system that offers practical applications for homeland security and deterring radiological terrorist attacks.

The Miniature Integrated Nuclear Detection System (MINDS) was designed by a group led by Charles Gentile, one of the lab's experts in radioactive materials.

Tracking tritium

Since 1982, Princeton's TFTR had been at the forefront of experiments demonstrating the high temperatures and other conditions needed for a significant amount of fusion to occur. By 1999, the reactor had reached the end of its useful life at PPPL, which is funded by the U.S. Department of Energy's Office of Science and managed by Princeton University. The reactor's inner vessel had become radioactive in the final phases of experimentation when small amounts of tritium were injected, enabling the TFTR to attain record levels of fusion power. Tritium is a radioactive isotope of hydrogen.

As part of the decommissioning process, government regulations require the precise labeling of each element in a reactor. There are about 2,000 radioactive materials that exist on Earth. Some are relatively harmless, such as the small amounts of americium-241 used in home smoke detectors. Others, such as highly enriched uranium, can be far more deadly. A Geiger counter, in this case, just wouldn't do.

The team crafted a lightweight, portable detection unit that could be placed in the reactor chamber—a metallic void lined with graphite tiles—by a boom. In the beginning, the system was composed of multiple radiation detectors—pin diodes that could read a gamut of radiation signals, which include x-rays and beta particles. One, a silicon wafer with a beryllium window on its surface, detected X-rays. A second detector, constructed without the beryllium window, captured beta particles. The third, an open-wall ion chamber, registered other radioactive signatures.

Identifying the horde of radioactive elements contained within the vessel walls in a non-destructive fashion proved to be trying. Radioactive materials are inherently unstable. As their inner nuclei spontaneously disintegrate, the materials give off radiant energy in the form of particles or rays. Although not resident in the TFTR vacuum vessel, materials such as uranium, thorium, and plutonium emit characteristic energy signals as distinctive as fingerprints. The challenge rests, however, on ensuring that all are detected, because some materials cast off more powerful signals than others. Sometimes, it is the "quiet" ones with longer half-lives that are the most dangerous.

The first prototype detectors developed by the team missed the tritium signal. This was a problem. "It was like being in a crowded auditorium where everyone was screaming, and you wanted to hear the guy who was whispering," Gentile said.

The PPPL team had to be extremely accurate in its accounting of how much tritium remained in the vessel. They knew how much tritium had been injected into the reactor for the experiments. The team had to prove that every bit was still in there.

The initial failure to accurately account for the tritium drove the team to design a new diagnostic probe that allowed them to find tritiated graphite nestled between linings in various sectors of the reactor. For this, they used a coated optical fiber to enhance the effect they were looking for. A CCD camera recorded the pulses of light emitted when beta particles struck the layer of phosphorus coating, allowing them to pinpoint previously undiscovered tritium in the reactor's nooks and crannies.

They linked the detector to a laptop computer. The PC contained a software program, a database of the characteristic signatures of radioisotopes. Employing artificial intelligence techniques, the program matched the signal being read with one of the "fingerprints" in its library. Finally, the tritium could be detected at the right quantities. They considered their task completed.

Security applications

In December 2001, three months after the 9/11 terrorist attacks, federal

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authorities issued a nationwide call for devices that could detect nuclear materials that might be hidden. The idea was to guard against radiological attacks.

The PPPL team leapt at the opportunity to explore their device's potential for this pressing public need.

The then-developing U.S. Department of Homeland Security received 15,000 rival proposals for funding the development of such devices. Still, the PPPL proposal stood out. The U.S. Army, through the Picatinny Arsenal in New Jersey, selected the PPPL mechanism as one of the top entries and funded it for further development.

Designing the detector for indoor, in-the-lab use by a team of seasoned engineers was simple compared to what was now needed—a device that could be operated by a non-expert outdoors in an ever-changing environment. There, factors like background radiation, signals from medical radiological tests and even weather could easily skew results.

Princeton Plasma Physics Laboratory

The "Miniature Integrated Nuclear Detection System" (MINDS) was developed by engineers at the Princeton Plasma Physics Laboratory while working on decommissioning the Tokamak Fusion Test Reactor. After 9/11, its developers realized they had also come up with a technique to detect and identify nuclear materials. The simple, portable device identifies materials through their characteristic energy signals, as unique as fingerprints.

The PPPL engineers gathered to take on the challenge. They knew they could detect radiological signals and identify their source. In the real world, the bigger problem was sorting out one from a cacophony of signals.

Levels of naturally occurring radiation from elements like radon often vary, depending on whether it rains or the temperature is high. Thousands of people each day go to medical centers where they ingest radiological dyes for imaging and treatment, emitting signals that need to be interpreted as non-hostile. Benign products, including some types of kitty litter and pottery, contain radioactive products that can be detected. And there's the phenomenon of "scatter," where particles bounce off objects or interfere with each other, blurring the "fingerprint" of a substance.

> **“It was like being in a crowded auditorium where everyone was screaming, and you wanted to hear the guy who was whispering.”**

The solution, which came through years of trial and error, was found in combining two software programs using algorithms that were engineered employing techniques associated with specific characteristics of nuclear decay. The programs combined a plasma physics data strategy known as "peak fitting," which directs computer programs to scan for the characteristic energy peaks of a given radionuclide as it decays, and another approach employing artificial intelligence, which uses software to identify features embedded in the data.

The look of the device has evolved with development. The three detectors are now housed in one thermos-sized container, which is attached either by wire or via wireless means to a laptop computer. Portable and easy to use, the device will issue a signal turning the laptop display bright red when nuclear material of interest is identified.

A high point came in 2005 when officials from Princeton signed a licensing agreement with InSitech Inc. allowing it to commercialize MINDS. InSitech is a not-for-profit organization working for the U.S. Army to bring government-developed technology to market.

InSitech, which has the exclusive license for marketing MINDS for the University, is now setting up its clients across the United States with the system. The client list is proprietary to InSitech, but MINDS has been deployed at military installations, ports and a major commuter rail station.

—Kitta MacPherson, Princeton Plasma Physics Laboratory, kittamac@pppl.gov

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Publication

C.A. Gentile, J. Parker, S.J. Zweben, "In-Situ Imaging and Quantification of Tritium Surface Contamination via Coherent Fiber Bundle," *Fusion Science and Technology* **41** 551 (2002).

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