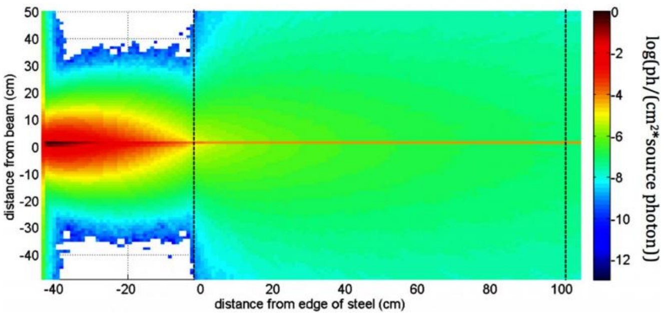
Compact, precise photon beam could aid in nuclear security, report says

19 July 2017, by Glenn Roberts Jr.



This image shows how a compact, precise photon beam (red line) could penetrate through 40 centimeters of steel (left side of image). The beam could be useful for detecting and identifying nuclear materials, among other uses. Credit: Berkeley Lab, University of Michigan

A new, compact technique for producing beams of high-energy photons (particles of light) with precisely controlled energy and direction could "see" through thick steel and concrete to more easily detect and identify concealed or smuggled nuclear materials, according to a report led by researchers at the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab).

These photons are similar to X-rays but have even higher photon energy than conventional X-rays, which lets them penetrate thick materials.

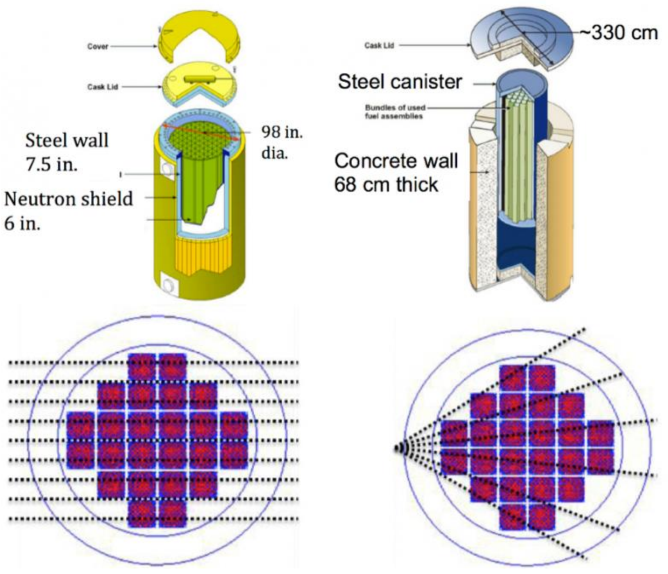
Past techniques have had broad spreads in energy and angle that limited their effectiveness. New developments could bring the capabilities of highly precise, building-sized facilities to room-sized or mobile platforms that enable a range of high-priority nuclear nonproliferation and security uses.

This precision can simultaneously increase resolution while producing a lower radiation dose for many uses in and beyond nuclear security, such as:

- Detecting contraband or explosives.
- Verifying the contents of casks that store spent nuclear reactor fuel.
- Monitoring nuclear treaty compliance.
- Detecting a concealed nuclear device.
- Characterizing hazards after a nuclear accident.
- Industrial quality control – and potentially medical X-rays.

"This report is focused on what type of source is needed to have the biggest impact rather than what has been developed to date," said John Valentine, Berkeley Lab's program manager for National & Homeland Security. "It lays out the roadmap to realizing applications." The report was prepared for the National Nuclear Security Administration (NNSA), a DOE agency responsible for national security-focused applications of nuclear science.

"One major application for this type of technology is the detection of concealed nuclear material – for example, hidden in cargo containers or a vehicle – but it has broad use for detecting other types of contraband," said Cameron Geddes, a staff scientist in the Lab's Berkeley Laboratory Laser Accelerator (BELLA) Center. Geddes led the preparation of the report with Bernhard Ludewigt, a staff scientist in the Lab's Fusion Science and Ion Beam Technology Group, part of the Accelerator Technology and Applied Physics (ATAP) Division.



A "monoenergetic" photon source could be used to verify the contents of nuclear reactor fuel storage casks (top). The beam could be patterned in a "parallel" scan (bottom left) or a "fan" scan (bottom right). Credit: Berkeley Lab, University of Michigan

Geddes and Ludewigt worked with a team of scientists from Pacific Northwest, Idaho, and Lawrence Livermore national labs, as well as the University of Michigan, to conduct detailed simulations that showed the improved capabilities that the new techniques would make possible.

"Existing technologies commonly use so-called 'Bremsstrahlung' sources to detect and identify nuclear materials," said Ludewigt. This kind of radiation source is not tightly directed and delivers a fan-shaped spread over a broad energy range of radiation. Those characteristics can limit imaging capabilities and require higher doses of radiation.

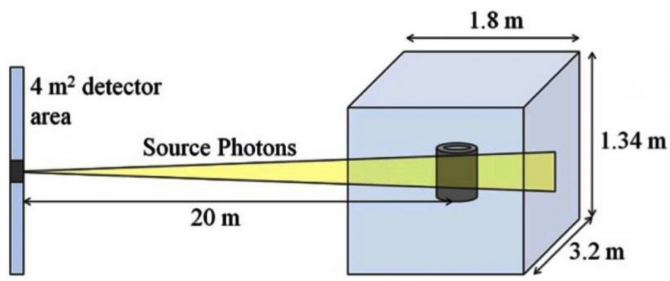
Known as a "monoenergetic photon source," the new technology would have a tightly collimated beam – meaning its photons would travel nearly parallel to one another in a narrow path. Those photons would also have a narrow and precisely tunable energy range. These properties would reduce the radiation output needed during scans compared to other technologies in use today. They would also reduce the effect of undesired signals, such as noise from scattered photons, that can interfere with the detection of nuclear materials.

When scanning for hidden nuclear materials, Ludewigt said, "You don't want to have to open up every container that has something dense in it." The ability to quickly scan large objects, such as cargo containers, is also key, as millions of cargo containers pour into the U.S. every year.

The scanning technique's beam must also be safe for humans who may inadvertently come into contact with it, Geddes added. "That means we need to perform detection with high specificity while keeping dose low, so that if someone is hiding in the cargo container the scan won't hurt them," he said.

Simulations show, for example, that scanning at two separate ranges of energy would enable operators to identify the general type of materials that are present. If an object is discovered in this initial scan that is so thick or dense that it requires a more deeply penetrating scan to explore its contents, then by tuning the energy to specific values the same photon source could be used to identify whether an item is nuclear material.

With very tight control over the beam energy, the new source could also identify the exact element – including isotopes of elements, which have a different atomic weight and can be important in gauging nuclear security threats.



This diagram shows how a high-energy photon beam penetrates inside an unknown object (cube) to detect highly enriched uranium. Credit: Berkeley Lab, Idaho National Laboratory

The report also notes that the beam's reduced radiation dose and increased specificity in materials detection could have a strong impact in other fields that use high-energy photons, including medical and industrial uses. Such a source would, for example, improve nondestructive industrial analysis – the ability to look inside machinery without the need for disassembly.

While building-sized particle accelerators have long been able to make precise, monoenergetic photon beams, new technology could shrink these systems, making them more affordable and compact to enable broad use.

"Instead of bringing the applications to the machine, we hope to bring the machine to the applications, whether that means scanning cargo, verifying treaty compliance, or many other uses," said Wim Leemans, director of the Berkeley Lab Laser Accelerator (BELLA) Center and the Lab's ATAP Division.

Berkeley Lab is among the leaders in the worldwide effort to develop new, compact acceleration technologies at its BELLA Center. BELLA uses lasers to generate a superhot state of matter known as a plasma, and to generate bunches of electrons and rapidly accelerate them to high energies over a very short distance.

Experiments have already shown that BELLA's plasma-based accelerators can produce the types of electron beams needed to realize a controlled high-energy photon beam that would meet the requirements described in the report.

Geddes is leading a separate BELLA Center project to demonstrate a compact monoenergetic source. The beams would be generated by scattering of a separate laser beam off of the high-energy electron beam from a plasma accelerator to produce pulsed photon beams with a narrow range of energies and controlled angles, a process called Thomson scattering. The new report details how such beams could improve the identification and imaging quality of nuclear materials.

"We are testing new technologies that can reduce the massive scales and costs of next-generation accelerators, enabling us to explore new realms of physics," Leemans said. These include next-generation high-energy particle colliders, and free-electron lasers that produce the world's brightest X-rays. All of these demand faster pulsing rates for the lasers that drive the new sources, and R&D is also underway toward pulse rates that would enable the techniques outlined in the report.

Provided by Lawrence Berkeley National Laboratory

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