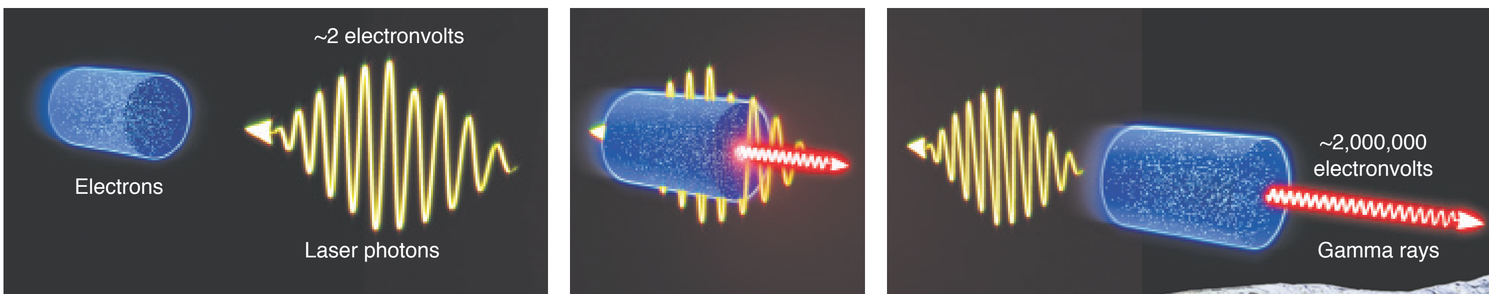
Going Deep with MEGa-Rays

WITH a name like MEGa-ray, for mono-energetic gamma-ray, it is tempting to imagine this light source being used as a weapon by Luke Skywalker, especially when one considers that its beams will be the most powerful and brightest ever. In fact, the MEGa-ray light source is much like a laser, but it generates gamma rays rather than a visible-light beam, and the device is certainly not a weapon.

Project leader Chris Barty, chief technology officer for the National Ignition Facility and Photon Science Principal Directorate, says, “This new technology will produce photons at extremely high energies with the brightness and the spectral, spatial, and temporal density needed to study the nuclei of individual isotopes.” Backscattering is key to MEGa-ray brightness and density. In laser-Compton backscattering, short laser pulses collide head-on with short bunches of electrons moving at relativistic speeds, or almost the speed of light. (See the figure below.) The collision creates photons that backscatter, or move in the original direction of the electron beam. This scattered gamma radiation is Doppler upshifted in energy by more than a million times and directed forward in a narrow, polarized, laserlike beam that can be “tuned,” or adjusted, to different wavelengths. “We have spent almost a decade optimizing Compton backscattering to achieve such high-brightness, narrow-bandwidth gamma rays,” says Barty.

By tuning the MEGa-ray light source to very precise energy levels, researchers can detect, image, and even assay specific



(above) In the mono-energetic gamma-ray (MEGa-ray) device, electrons and laser photons crash head-on, creating a backscatter of gamma rays that is 1 million times more powerful than the incoming photons. (Rendering by Kwei-Yu Chu.) (below) A new-generation MEGa-ray device is named for the velociraptor dinosaur.

nuclei in objects containing a variety of isotopes. In 2008, proof-of-principle experiments demonstrated a first-generation MEGa-ray machine's ability to detect isotopes of low-density lithium shielded behind high-density lead and aluminum. Lead can effectively shield many materials from the prying eyes of conventional radiation detectors, so the MEGa-ray capability is truly remarkable.

MEGa-ray experimental systems can occupy an entire large room, but making one small enough to fit into a portable truck trailer is high on Barty's agenda. With a MEGa-ray device and its accompanying detector in a truck trailer, it can be moved, say, to a port for examining the contents of cargo containers or to a nuclear power plant for measuring precisely how much usable fuel remains in fuel rods.

Far Beyond X Rays

X rays have been used since their accidental discovery in 1895 to view the invisible: bones beneath skin, silver fillings in teeth, and metal enclosed in plastic. The shadow pattern of an x ray results from the absorption of photons by the higher density material.

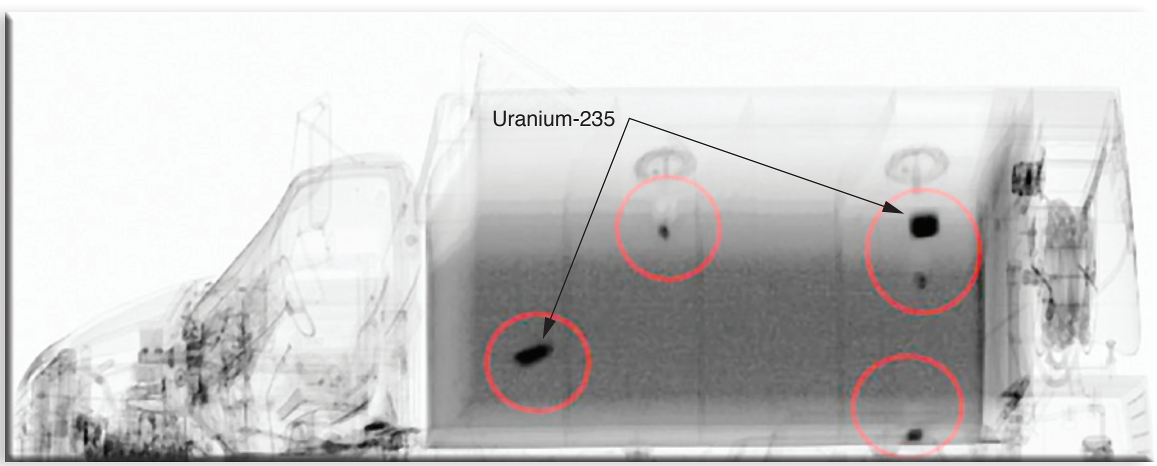
However, x rays have their limits. Distinguishing weapons-grade uranium from depleted uranium requires higher energy and more sophisticated photon beams than conventional x-ray machines can provide. Synchrotron beams are likewise lower in energy and incapable of characterizing heavy elements such as uranium. In contrast, the vastly increased brightness and monochromatic nature of a MEGa-ray beam can efficiently excite, or fluoresce, specific isotopes of both light and heavy elements to identify an object's isotopic contents. In addition, the higher energy of these gamma rays allows scientists to see objects more deeply buried. At 2 million electronvolts, a MEGa-ray beam has roughly 50 times the penetration capability of a conventional chest x ray.

Fluorescence is the emission of radiation by a substance during exposure to external radiation. The most common form of fluorescence is visible light that comes from exciting electrons in an atom. Nuclear resonance fluorescence (NRF) goes deeper. As its name implies, NRF's gamma rays excite the nucleus, which fluoresces as it relaxes.

Says physicist James Hall, who leads the team developing the MEGa-ray detector, "Each isotope has a fundamentally different resonance. For a nuclear power plant fuel rod, we would tune the MEGa-ray beam to uranium-235 to measure how much of the isotope remains in the rod." It would be tuned differently to identify shielded plutonium. To aid the Department of Homeland Security's FINDER Project for detecting nuclear materials at ports, the light source could be tuned to search for the particular material of concern. All identifications could be made unobtrusively, nondestructively, and at very low dose levels, well below allowable limits for humans.

Smaller, More Powerful

Construction has begun at Livermore on a smaller, next-generation MEGA-ray light source called VELOCIRAPTOR (Very Energetic Light for the Observation and Characterization of Isotopic Resonances and the Assay and Precision Tomography of Objects with Radiation). The new light source builds on the Thomson-Radiated Extreme X-Ray (T-REX) system, Livermore's first MEGa-ray project funded by the Laboratory Directed Research and Development Program. (See *S&TR*, December

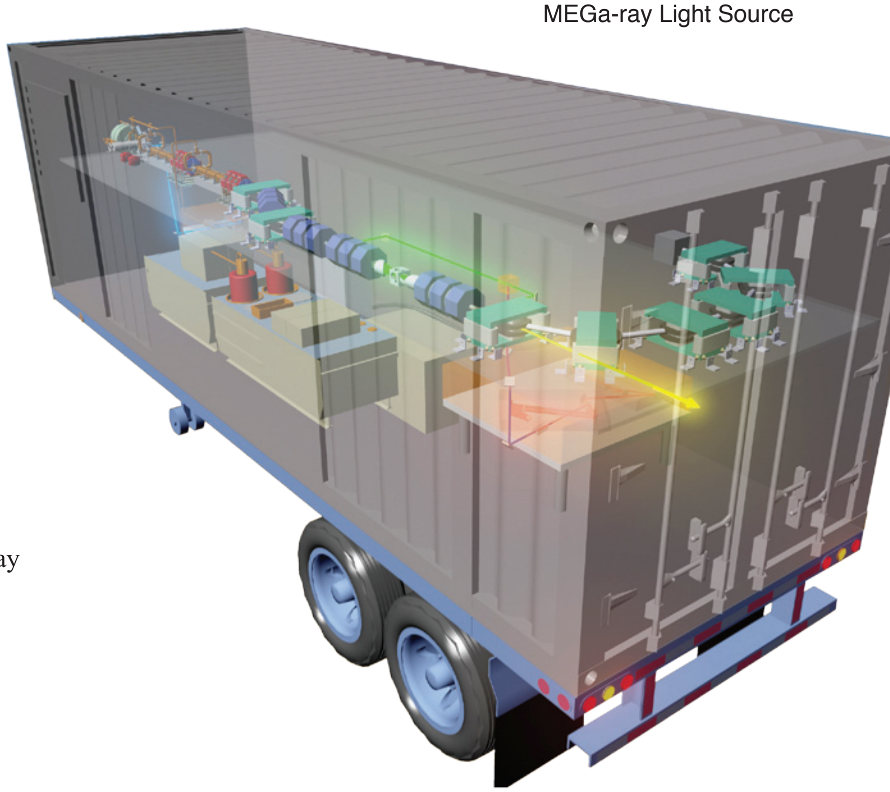


MEGa-ray beam absorption technologies currently under development could detect a piece of uranium-235 smaller than 5 millimeters in less than a second. This speed and accuracy would make the MEGa-ray system an excellent tool for examining cargo containers, trucks, and other loads on the move.

2006, pp. 16–17.) (Thomson and Compton backscattering are closely related.)

The very name of the next-generation light source indicates its smaller size. Anyone who saw the movie *Jurassic Park* will remember the tough, nasty little velociraptors. Livermore's VELOCIRAPTOR won't be tearing scientists limb from limb but will, over just a few meters, produce about a million times higher peak brightness than its predecessor. Collaborators include the Department of Homeland Security's Domestic Nuclear Detection Office and SLAC National Accelerator Laboratory. The latter contributes its advanced accelerator technology to the project.

"Demonstrations of the technologies required for the MEGa-ray truck-trailer assembly are anticipated in 2013, with an integrated portable source demonstration possible by 2018," says Barty. A portable MEGa-ray source and detector will enable hands-free precision assays and images of nuclear waste canisters, cargo containers, nuclear fuel rods, and other objects that might house uranium or plutonium.



A MEGa-ray device and its accompanying detector in a truck trailer could allow rapid detection of nuclear materials in the field. (Rendering by Clayton Dahlen.)

The DINO Detector

While work on the MEGa-ray light source progresses, Hall's team is developing the Dual Isotope Notch Observer (DINO), a detector system that should be capable of measuring NRF reactions in materials induced by intense MEGa-ray beams. The DINO NRF detectors will use pairs of "witness foils," the first made of the resonant isotope of interest such as uranium-235, and the second made of a nonresonant counterpart, such as uranium-238.

Says Hall, "If the resonant isotope being scanned is not present in the object under inspection, then a significant amount of NRF will be generated in the resonant witness foil of the DINO detector system. On the other hand, if the resonant isotope is present in the object, then the resonant photons at the peak of the MEGa-ray beam will be heavily absorbed in the object, creating a 'notch' in the transmitted beam. Less NRF will thus be generated in the resonant witness foil."

In practice, one would evaluate the ratio of NRF signals obtained from the resonant and nonresonant DINO witness foils, because this ratio is, in principal, sensitive only to the resonant isotope of interest in the object being inspected. The method should thus allow for very clean and accurate isotopic measurements.

An object would be exposed to a continuous flux of MEGa-ray photons whose energy had been tuned to the NRF absorption resonance in the isotope of interest. The interrogating photons, whose energies might range from 1 to 8 megaelectronvolts, would be highly penetrating and able to "see" through many centimeters of steel. DINO detector systems are being designed to require minimal operator intervention and deliver minimal dose to the object, while also providing high throughput at commercial seaports, airports, and other points of entry.

A New Science

VELOCIRAPTOR will be located in a building at Livermore that formerly housed the Nova laser system. It is an ideal location for this powerful new gamma-ray light source in part because of the facility's existing 2-meter-thick walls.

"We have created a new science, one we call 'nuclear photonics,'" says Barty. "We believe that MEGa-rays have the potential to do for isotopes what the laser did for the atom." VELOCIRAPTOR will serve as the cornerstone for the Laboratory's unique Nuclear Photonics Facility.

—*Katie Walter*

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