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Abstract: Mono-Energetic Gamma-rays (MEGa-rays) of unprecedented peak brilliance can be created via the optimized interaction of laser light with relativistic electrons. Development of MEGa-ray technology and related "nuclear" photonics applications are reviewed.
OCIS codes: (350.5610) Radiation; (300.6550) Spectroscopy; (320.7090) Ultrafast Optics; (340.7480) X-ray Optics

Mono-energetic gamma-ray (MEGa-ray) sources can be created via Compton scattering of short-duration laser pulses off of relativistic electrons. In the MeV spectral range, these sources can be tunable, polarized, highly collimated (<mrad), and have low energy spread ($\Delta E/E \sim 10^{-3}$). The peak brilliance of an optimized MEGa-ray source is unprecedented (see figure 1) and allows for the first time the efficient interaction of photons with the nucleus of the atom, i.e. "nuclear photonics".

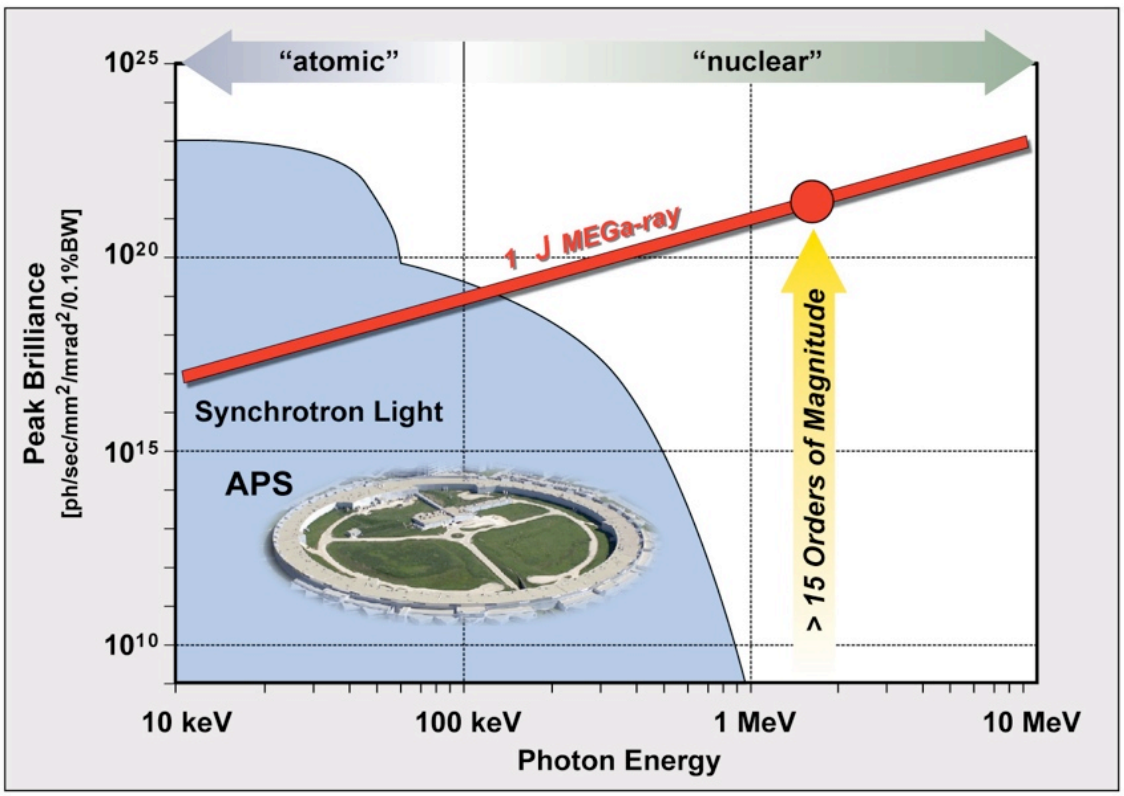

Figure 1. Predicted peak brilliance of an optimized MEGa-ray source created from interaction of a nC electron beam and a 1 J interaction laser vs. the APS synchrotron. Above 2 MeV, MEGa-ray sources exceed the peak brilliance of the best synchrotrons by more than 15 orders of magnitude.

Numerous applications are enabled by MEGa-ray sources including: rapid spectroscopy of nuclear resonance fluorescence, precision studies of nuclear photo-fission, generation of pulsed positron sources and isotope specific materials characterization.

At LLNL MEGa-ray sources have been developed specifically to excite narrowband (few eV bandwidth) nuclear resonance fluorescence (NRF) transitions. Since the energy of NRF transitions depends upon the number of protons and neutrons in the nucleus they are an isotope-specific material signature. With appropriately-designed NRF-based detection systems, MEGa-ray sources can be used to

a) rapidly determine the presence or absence of a particular isotope in a complex material system.
b) precisely assay the isotopic content of a material system with better than 100 parts per million accuracy,
c) image the isotopic distribution of materials within a system with 10-micron or better spatial resolution and
d) uniquely determine the velocity and direction of moving isotopic material in a dynamic material system.

To date, three MEGa-ray sources have been constructed, 2 in the US and one in Japan (see Figure 2).

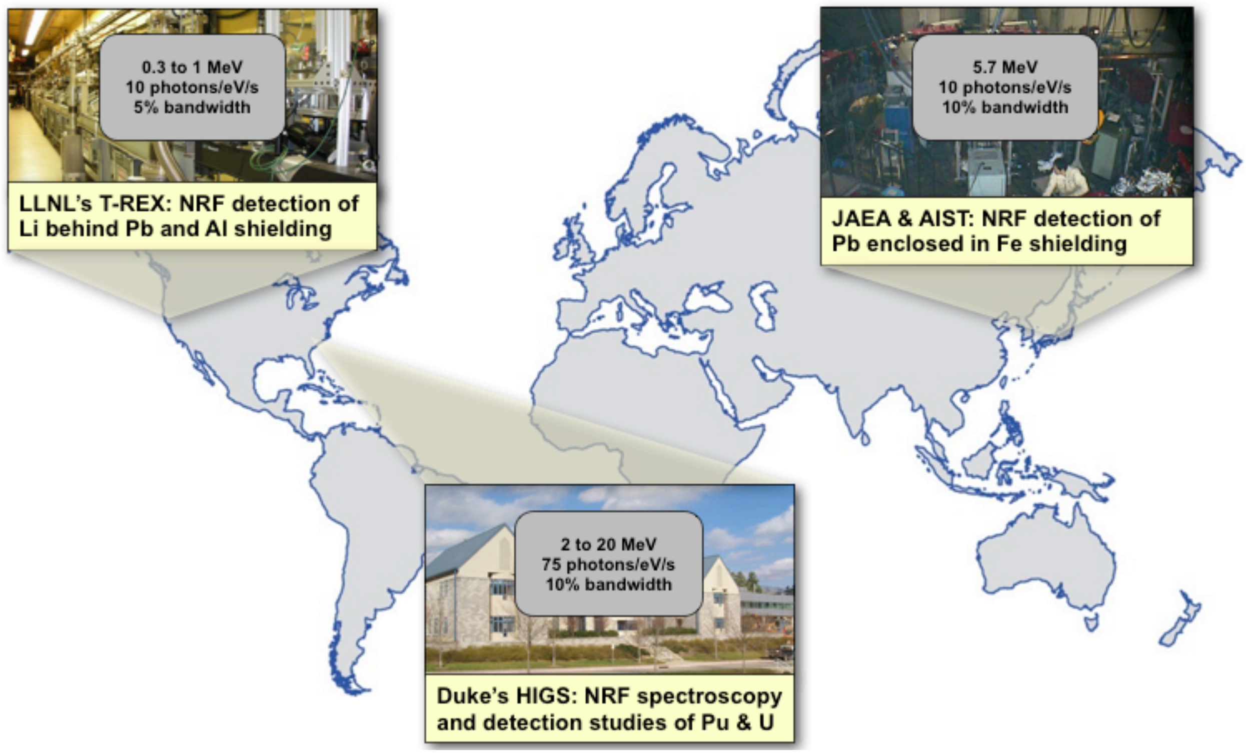

Figure 2. Existing MEGa-ray capabilities constructed for first generation NRF-based material detection proof of principle experiments.

With spectral fluxes of approximately 10 of photons per eV per second, these machines have been used for proof-of-principle, isotope-specific, material detection demonstrations and nuclear spectroscopy applications [1-5]

At LLNL a new generation of compact, higher energy, higher flux, higher brilliance and narrower bandwidth MEGa-ray sources is currently under development. By utilizing compact X-band linac technology developed in collaboration with the SLAC National Accelerator Laboratory and high power, diode-pumped laser technology developed at LLNL, this next generation machine will advance MEGa-ray peak brilliance by up to 1,000,000x, MEGa-ray average flux by up to 100,000x and reduce MEGa-ray bandwidth by up to 100x.

Such capabilities would be transformational to an astonishingly wide variety of applications. For example, they would allow the detection of concealed nuclear material [6], in less than a second, would enable precision assay of nuclear fuel assemblies with precision well beyond any current technology and would provide the flux and precision necessary to isotopically image objects in ways not possible with conventional x-ray and gamma-ray technology. (Figure 3).

An introduction to MEGa-ray machine design and optimization as well as a survey of nuclear techniques and high impact applications of these new light sources will be presented.

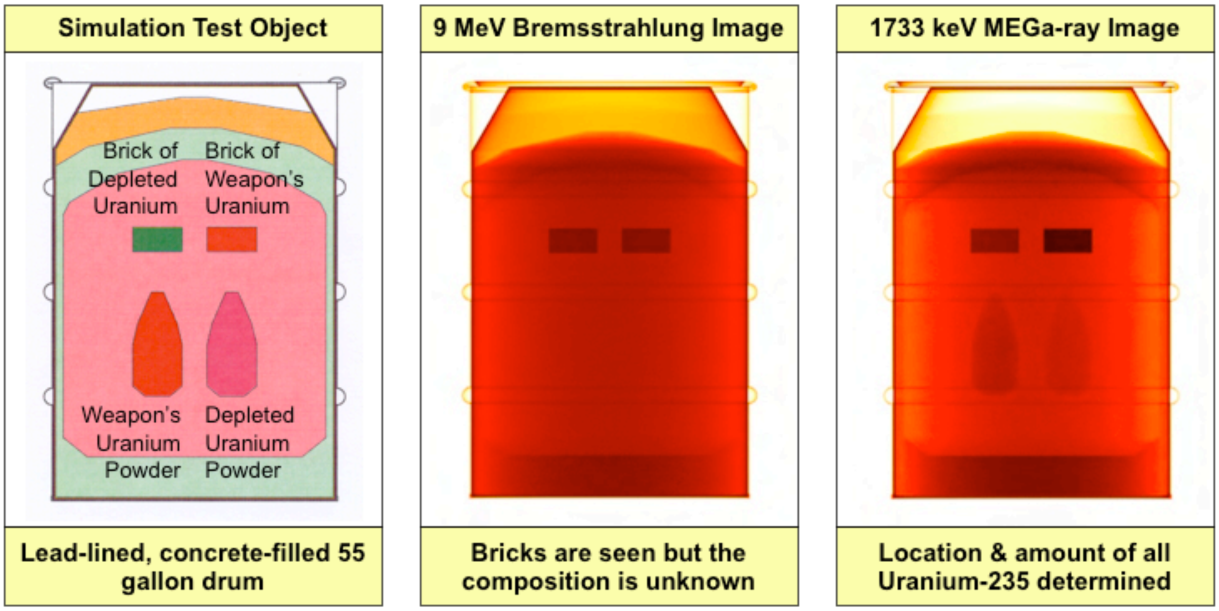

Figure 3. Monte Carlo simulation of a 55 gallon waste drum containing 4 uranium test objects surrounded by lead and concrete shielding and suspended within a vermiculite drying agent. The top two objects are bricks of U with varying 235U concentration and the bottom two objects are powders whose density matches that of the drying agent but also have differing 235U concentrations. Conventional x-ray image is with a 9 MeV bremsstrahlung source. MEGa-ray image is with a source tuned to the 235U resonance at 1733 keV.

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