Next-Generation Compact High-Intensity Neutron Sources for Remote Detection

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Advanced LLNL compact accelerator technology could provide the warfighter with unprecedented remote sensing capability.

One of the most challenging problems in national security is development of the capability to identify hidden threats, such as improvised explosive devices (IEDs) or shielded special nuclear materials (SNM), in the field at large standoff distances. The applications for such a capability range from counter-terrorism to treaty verification. At the conventional level, easy-to-produce, hard-to-detect, and destructive IEDs are likely to remain a key threat to U.S. forces for the foreseeable future.

Actively interrogating possible threats using neutron bombardment is a potential solution that could provide significant standoff or remote identification capability in the field, thus helping to neutralize these dangers. Figure 1 illustrates the concept: penetrating neutrons from a source bombard the unknown threat and induce nuclear reactions that emit characteristic gamma rays or neutrons. This induced radiation can be detected and used to identify the unknown material. For example, for IED detection, the quantity

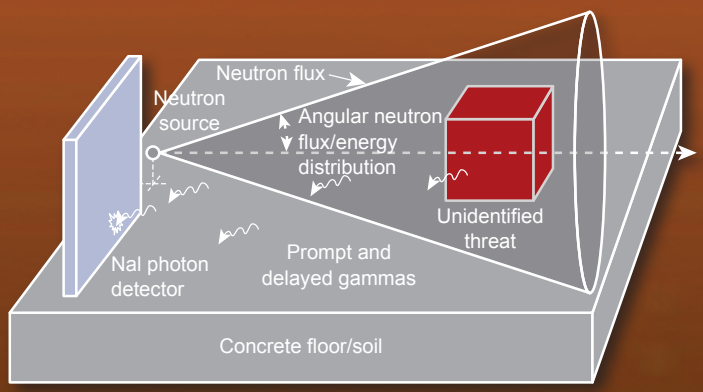


Figure 1. **(Left) Neutron pulses penetrate shielding and produce gammas through (n, n') or (n, γ) reactions, or neutrons from induced fission in SNM. This produced radiation can be used to identify materials in the threat. (Right) Possible concept-of-operation involving standoff detection of IEDs.**

Figure 2. (Left) A conventional ~10-m-scale 7-MV DC accelerator. (Right) The Compact Directional Neutron Source seeks to achieve similar voltages at the ~ scale to enable portable operation. A test accelerator column utilizing LLNL advanced high-gradient insulator technology designed for MV potential is being assembled.

of different MeV-level characteristic gammas emitted via inelastic neutron scattering reactions off carbon, nitrogen, and oxygen nuclei in the threat can be used to determine the unknown material's ratios of these elements. These ratios are known for a wide variety of organics and are good identifying markers for IEDs since explosives typically contain significant amounts of nitrogen. From a system point of view, the difficulty with achieving significant standoff distances stems from the size of conventional neutron generators and detectors, which are required to overcome signal-to-noise ratios that typically scale inversely with distance to the fourth power. The ideal neutron source would emit forward-directed and mono-energetic neutrons in order to maximize the signal-to-noise ratio and yet be compact enough for field operation. Because of physics considerations, directional sources typically require large accelerators operating at multi-MV potentials.

At LLNL, we are developing both isotropic and directional next-generation neutron sources centered on two new remote detection concepts of operation (CONOPs). For the directional source, we seek to shrink MV-level DC accelerators for making directional neutrons by an order of magnitude in order to achieve field portability. For the isotropic source, we aim to develop a self-contained, lightweight, palm-scale device operating at a ~100-kV potential. Such a device could easily be delivered to the unknown threat, thus maintaining user standoff. Since for this situation the source would be exceptionally close to the threat, an isotropic rather than directional source could be used. In both concepts, the sources would produce neutrons with energies in the MeV range and enable operation scenarios not possible before because of size constraints.

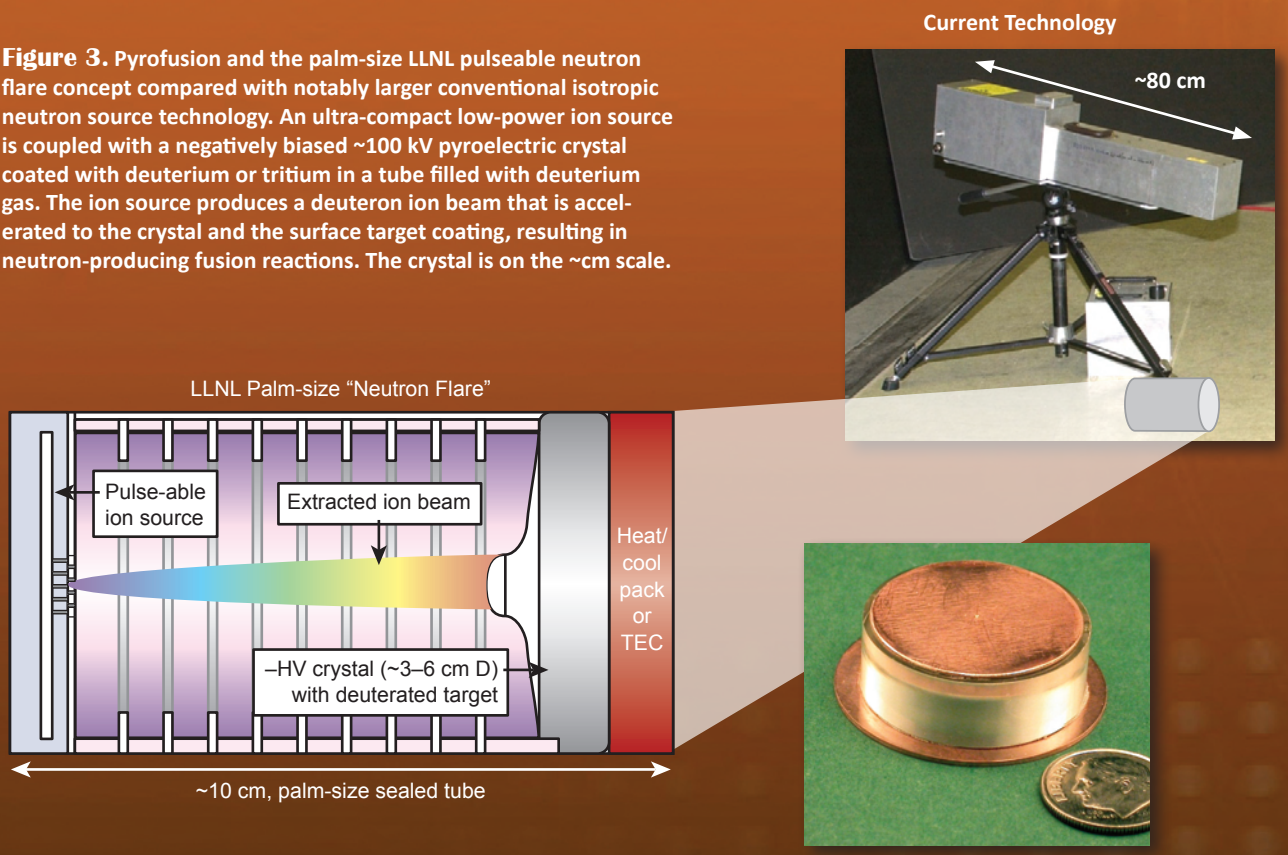
The Compact Directional Neutron Source (funded by the Defense Advanced Research Projects Agency) aims to take advantage of the D-D fusion reaction at greater than 4 MeV D ion beam energies to achieve forward-directed neutron output. The project is developing high DC-gradient accelerator technology to shrink conventional sources to achieve field portability. We are advancing new, compact piezoelectric power supplies; insulator technologies; and new, pulsed high-current ion sources in an integrated manner to achieve these objectives. Figure 2 provides a dramatic size comparison of existing technology against an experimental accelerator column using high-gradient insulator technology; the goal is to achieve DC

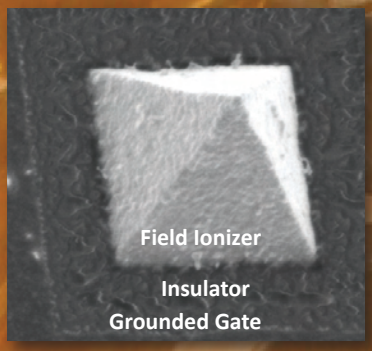
gradients greater than ~4 MV/m, which would enable field operation. We have so far achieved ~2 MV/m and multi-MeV neutron output with a greater than 3:1 forward flux directionality and have identified a technical path to the required 4 MV/m DC gradient.

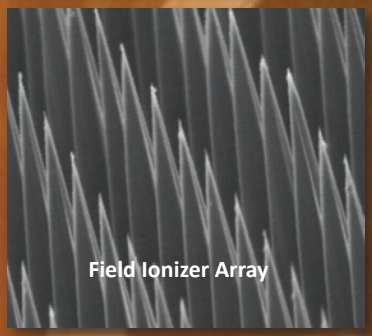
For the isotropic approach, the LLNL Crystal Driven Neutron Source project exploits ~cm-scale pyroelectric crystals for producing ~100-kV-level voltages, with gradients in excess of 10 MV/m, for use in a novel, self-contained, palm-size D-T fusion-based isotropic 14.1-MeV neutron source. Figure 3 illustrates these pyrofusion sources schematically and also shows the LLNL pulseable pyrofusion "neutron flare" concept. By studying these novel high-voltage sources and mating them to advanced microelectromechanical systems (MEMS)-scaled ion sources, we have demonstrated pyrofusion operation with pulsed neutron output. Figure 4 shows our pyrofusion experiment using a micro-gap flashover ion source, and also depicts our ongoing development of nanoscale field-emitter ion sources. Our pyrofusion source holds records in neutron yields and is the first to show pulsed output, with peak rates greater than 10^{10} D-D neutrons per second. As a next step, we seek to further develop these sources to achieve average D-T neutron rates greater than 10^7 per second while maintaining pulsing capability. At this level, significant opportunities exist for practical applications.

As we continue to develop our neutron source technologies, we will integrate them into system experiments designed to test our proposed CONOPs for standoff detection. Ultimately, we expect our leading high DC-gradient accelerator research to enable new possibilities for remote detection, thus providing critically needed solutions to the warfighter as well as answering key national security challenges.

Figure 3. **Pyrofusion and the palm-size LLNL pulseable neutron flare concept compared with notably larger conventional isotropic neutron source technology. An ultra-compact low-power ion source is coupled with a negatively biased ~100 kV pyroelectric crystal coated with deuterium or tritium in a tube filled with deuterium gas. The ion source produces a deuteron ion beam that is accelerated to the crystal and the surface target coating, resulting in neutron-producing fusion reactions. The crystal is on the ~cm scale.**







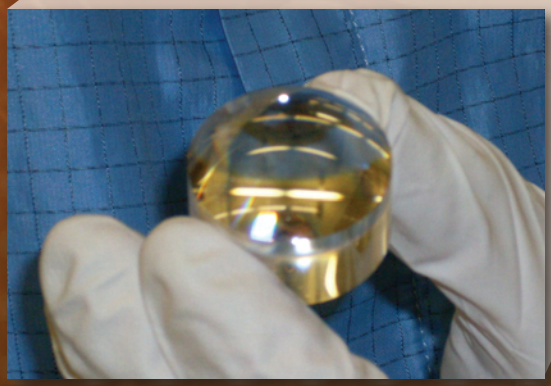


Figure 4. (Right) The LLNL pyrofusion experiment. The experiment produced the first pulsed pyrofusion neutrons with peak rates greater than 10^{10} D-D n/s and ~100-ns pulse widths. (Above) MEMs field ionizer arrays under development for efficient nanoscale ion sources for coupling to our pyroelectric accelerator.