LLNL researchers create tool to monitor nuclear reactors

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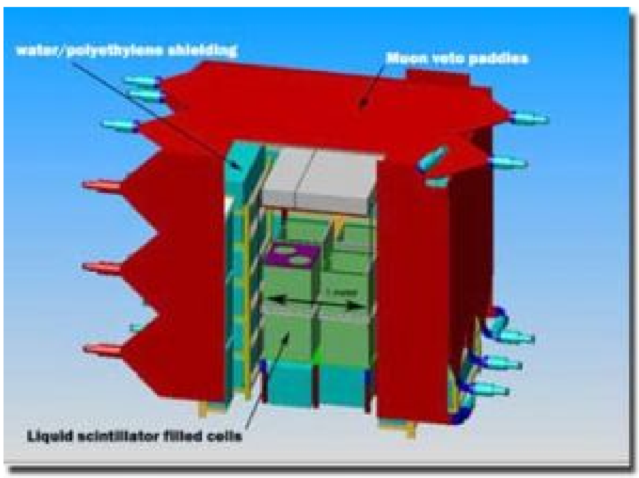

A conceptual drawing of the new antineutrino detector. Credit: LLNL

International inspectors may have a new tool in the form of an antineutrino detector, that could help them peer inside a working nuclear reactor.

A Lawrence Livermore National Laboratory-Sandia National Laboratories' team recently demonstrated that the operational status and thermal power of reactors can be quickly and precisely monitored over hour-to month-time scales, using a cubic-meter-scale antineutrino detector.

Adam Bernstein, leader of the Advanced Detectors Group at LLNL, is the project's principle investigator. He works on the detector development project with colleagues Nathaniel Bowden, Steven Dazeley and Robert Svoboda at LLNL; David Reyna, Jim Lund and Lorraine Sadler from Sandia National Laboratories' California branch in Livermore, and Professor Todd Palmer and graduate student Alex Misner at Oregon State University,

Antineutrinos are elusive neutral particles produced in nuclear decay. They interact with other matter only through gravitational and weak forces, which makes them very difficult to detect. However, the number of antineutrinos emitted by nuclear reactors is so large that a cubic-meter scale detector suffices to record them by the hundreds or thousands per day. As the team has demonstrated, this new detector makes practical monitoring devices for nonproliferation applications possible.

The detector could be used to determine the operational amount of plutonium or uranium necessary to run the reactor and place a direct constraint on the amount of fissile material the reactor creates throughout its lifecycle.

It is a long-recognized and fundamental dilemma of the nuclear age that nuclear reactors and nuclear weapons use very similar fuels. The fuels are generically known as fissile material – principally uranium and plutonium, either of which elements, in appropriate isotopic mixtures, can be used to build a nuclear device. Reactors consume uranium and produce plutonium, typically over periods of a year or so. Bombs consume either or both materials, in a few microseconds.

According to the National Academy of Engineering, nearly 2 million kilograms of highly-enriched uranium (90 percent or greater U-235) and plutonium have already been produced and exist in the world today – some from military and some from civil production. While these fuels can be and are used to produce electric power with incredible efficiency, it takes less than 10 kilograms of plutonium, or a few tens of kilograms of highly-enriched uranium, to build a bomb. There lies the nonproliferation problem.

Because reactors consume uranium and are the source of all the world's plutonium, they are a critical nuclear fuel cycle element within the jurisdiction of the International Atomic Energy Agency's (IAEA) Safeguard Regime. The regime was put in place by international treaty (the Nuclear Nonproliferation Treaty) to detect the diversion of fissile materials from civil nuclear fuel cycle facilities into weapons programs. Part of the nonproliferation program involves comparing the actual operations of a reactor – specifically its changing plutonium and uranium inventories – with operator declarations of what the reactor is expected to produce during its normal operations.

That's where the new detector comes in. It provides a direct measurement of the operational status (on/off) of the reactor, measures the reactor thermal power and places a direct constraint on the fissile inventory of the reactor throughout its lifecycle. All three parameters are derived directly from the antineutrino rate, measured nonintrusively and continuously by the detector. The data can be acquired directly by the safeguards agency (for example, the IAEA) without any intervention or support from the reactor operator. The detector is located on the reactor site in an out-of-the-way location tens of meters from the core, and outside the containment dome.

In a 2006 article in the journal *Nuclear Instruments and Methods*, the team presented the first data from a prototype detector, SONGS1, deployed at the San Onofre Nuclear Generating Station in Southern California. Those results confirmed the successful detection of antineutrinos with this simple prototype, which was shown to be continuously and stably operable for yearlong periods with remote and automatic data collection and detector calibration.

"Our forthcoming *Journal of Applied Physics* paper provides a fuller analysis of the data," Bernstein said. "By comparing our antineutrino rate with the publicly available records of the reactor's thermal power and using a detailed simulation of the reactor dynamics over time, we've now been able to quantify the precision with which the detector can monitor the reactor power and operational status over hourly to monthly time scales using only the antineutrino signals.

"What's interesting is that the precision of our simple prototype is limited only by counting statistics – there was no evidence for long-term drifts or other confounding detector problems that could have compromised the detector performance. This robust, predictable behavior bodes well for the deployability of these devices, which have previously and mistakenly been considered delicate apparati, squarely within the realm of fundamental physics.

"Through our work, and that of a growing community of researchers around the world, it is appropriate to speak of a new kind of applied physics – applied antineutrino physics. Assuming this technology is broadly adopted as a nonproliferation tool, it's not much of a stretch to imagine a small industry springing up in a few years, churning out antineutrino detectors for nuclear safeguards."

Antineutrino emission in nuclear reactors comes from the decay of neutron-rich fragments produced by heavy element fissions and is linked to the fissile isotope production and consumption processes. On average, a single fission is followed by the production of approximately six antineutrinos. However, above a certain energy threshold, the average number of antineutrinos produced per fission is significantly different for the two major fissile elements, uranium-235 and plutonium-239. This difference results in measurable changes in the antineutrino rate over the course of the reactor fuel cycle, as the ratios of these two elements change.

The new detector operates unattended for long periods without significant maintenance, is self-calibrating, and does not affect plant operations in any way. Data from the detector is acquired remotely in real time, Bernstein said.

As for the detector being tampered with: “There are a host of pretty much standard techniques, used by the IAEA and others to guard against tampering,” Bernstein said. “Furthermore, the antineutrino signature seen by the detector is hard to mimic with surrogate neutron or gamma sources.”

The detector can be used to monitor reactor activities at different time scales of interest for safeguards. The reactor can be monitored on an hourly basis to look for sudden outages or other short-term anomalies in reactor operations. Or it can verify long-term stable operation of the reactor by measuring the antineutrino rate over the course of weeks, months and even years.

“It’s important to emphasize that the monitoring need not depend on operation declarations,” Bernstein said. “It can be kept under the control of the safeguard agency, providing a completely independent measure of reactor status.”

The research will appear in an upcoming issue of the *Journal of Applied Physics*. In addition, the National Academy of Engineering referenced the antineutrino detection work as one of 14 Grand Challenges for Engineering under the grand challenge “Prevent Nuclear Terror." The work already has garnered national and international attention as a possible new tool in IAEA’s set of methods used to detect diversion of fissile materials.

Source: Lawrence Livermore National Laboratory