Calibrating the calibrator—the National Standard Neutron Source

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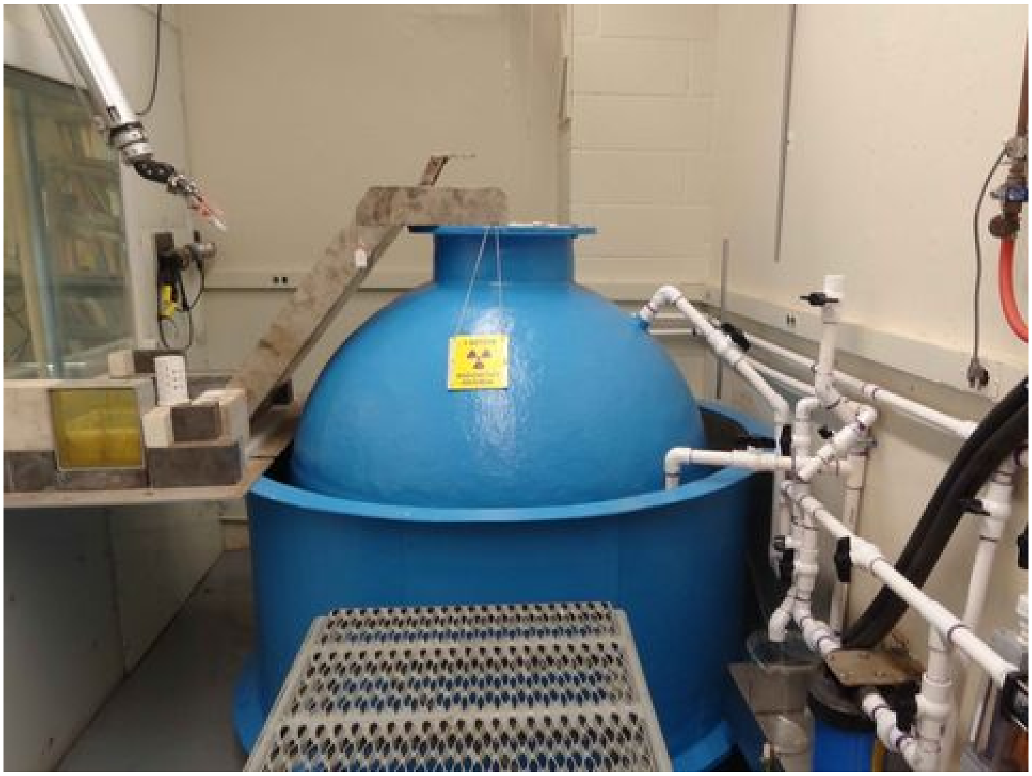

The golf ball-sized U.S. standard neutron emission source is placed at the center of a fiberglass sphere 1.3 meters in diameter containing 1400 kg of a pink liquid solution of water and manganese sulfate. Credit: National Institute of Standards and Technology

Neutron detectors and sources play critical roles in national defense, homeland security, nuclear power plant control, radiation medicine, petroleum exploration, materials science, industrial imaging, and a host of other applications. It is essential that these types of devices be tested periodically for accuracy against a radiation standard that emits neutrons at a precisely known and constant rate.

In the United States, all calibrations of sources and detectors are ultimately tied to NIST's national standard neutron source called NBS-1, a sphere about the size of a golf ball that contains one gram of radium surrounded by beryllium. Because radium-226 has a half-life of 1600 years, the number of neutrons emitted per second by NBS-1—first put into service in the 1950s—is presumed to be extremely stable.

But the source has not been calibrated in more than 40 years owing to the inherent difficulty of the many measurements involved. Now scientists at NIST's Physical Measurement Laboratory Radiation Physics Division have launched a novel experiment designed to calibrate NBS-1 by an entirely new method and, in doing so, reduce uncertainties in its known emission rate by a factor of three.

NBS-1's neutron output is observed by placing it at the center of a fiberglass sphere, 1.3 meters in diameter. It is filled with over 1400 kg (3200 pounds) of a pinkish solution of water and manganese sulfate (MnSO4), a kind of "manganese bath," which absorbs neutrons. The neutron emission rate can be measured quite accurately using a well-understood process that doesn't count neutrons directly, but rather detects the gamma-ray photons emitted by the complex decay sequence that results, over many hours, when neutrons from the source being measured interact with the nuclei of manganese atoms of MnSO4.

During measurement, the MnSO4 solution is continuously pumped through a tube leading from the bath to a shielded gamma-ray detector, where photons are counted. "It works beautifully," says project scientist Scott Dewey. "The gamma-ray signal is truly proportional to the neutron flux."

But that measurement in itself does not provide a calibration of the emission rate, because the number of gamma-ray photons per unit time depends critically on both the strength of the neutron source and the propensity of hydrogen to absorb a neutron relative to that of manganese in the solution. About half the neutrons emitted by the radioactive source are absorbed by hydrogen atoms in the bath, and do not contribute to the final gamma-ray count; the exact percentage depends on the ratio of water to $MnSO_4$ in the bath, and on the ratio of the manganese to hydrogen neutron absorption cross sections.

So, in conventional calibrations, the source is placed in a manganese bath, and researchers vary the concentration of $MnSO_4$ by specific increments and measure the changes in gamma-ray emissions. "As you change the proportion of manganese to water [H_2O] in the solution, you measure the output at different levels," Dewey says. "Then you can plot the results and extrapolate to zero hydrogen, and that gives you the ratio that you need to know." Using this method, the emission rate of NBS-1 has been determined to an uncertainty of about 0.85 %.

The new calibration scheme is completely different. Its goal is to provide a reference neutron source, separate from NBS-1, whose emission rate will be determined to very high accuracy by comparing it to a cold neutron beam from the reactor at the NIST Center for Neutron Research (NCNR).

The large sphere surrounding NBS-1 is not portable, and cannot be moved to the NCNR hall. So, the calibration will take place in NIST's second, smaller, sphere, which is about half the size of the larger bath but, otherwise, operates identically. NIST built the smaller sphere after the 9/11 attacks in 2001, when the Department of Homeland Security needed calibration of a neutron source approximating the lower level of emissions from materials that might be used by terrorists.

The calibration will take place in two stages. First, a neutron emitter identical to NBS-1 but with half its activity will be placed in the center of the small sphere and its emission rate will be measured by gamma-ray output from the solution. The source will then be removed and a beam of neutrons containing a known number of neutrons per second (or neutron flux) will be directed to the center of the sphere and the gamma-ray signal will again be measured.

"In the small sphere," Dewey says, "we will alternate readings of the neutron beam, then turn it off and insert the radioactive source, and go back and forth in the detector readings. That will calibrate the radioactive reference source. That source will then be placed into the large sphere and used as a standard against which NBS-1 can be calibrated." The lower uncertainty of each stage of the process is expected to reduce the overall measurement uncertainty threefold.

The number of neutrons per second in the beam is known to very high accuracy, thanks to a long series of technology advances made by PML's Neutron Physics Group at the NCNR. "What you get out of the reactor is neutrons with lots of different energies," Dewey says. "For precise measurements of neutron flux, we don't want that. What we want is just one energy, so we put a little piece of graphite in the main beam. The beam passes through it and reflects off only one particular wavelength. That stream then goes into a special detector we made for our neutron lifetime experiment.

"The detector contains a little piece of neutron-sensitive foil made of enriched lithium-6. Ninety-nine percent of the beam passes through it. The other 1 percent constitutes our signal. We've spent years, but now we're sure that it can tell us how many neutrons per second pass through it." with a relative uncertainty of about 0.06 %.

"It's really a novel approach. Nobody else in the world has a reactor and a beam that they can do this on. Nobody else has a smaller-size sphere. The 0.85 % uncertainty that we have now is pretty much a standard among the maybe 10 labs in the world that do this. If we could improve it by a factor of three, that would make us the most accurate in the world."

Provided by National Institute of Standards and Technology

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