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# Neutrons by the numbers—New counting technique delivers unprecedented accuracy

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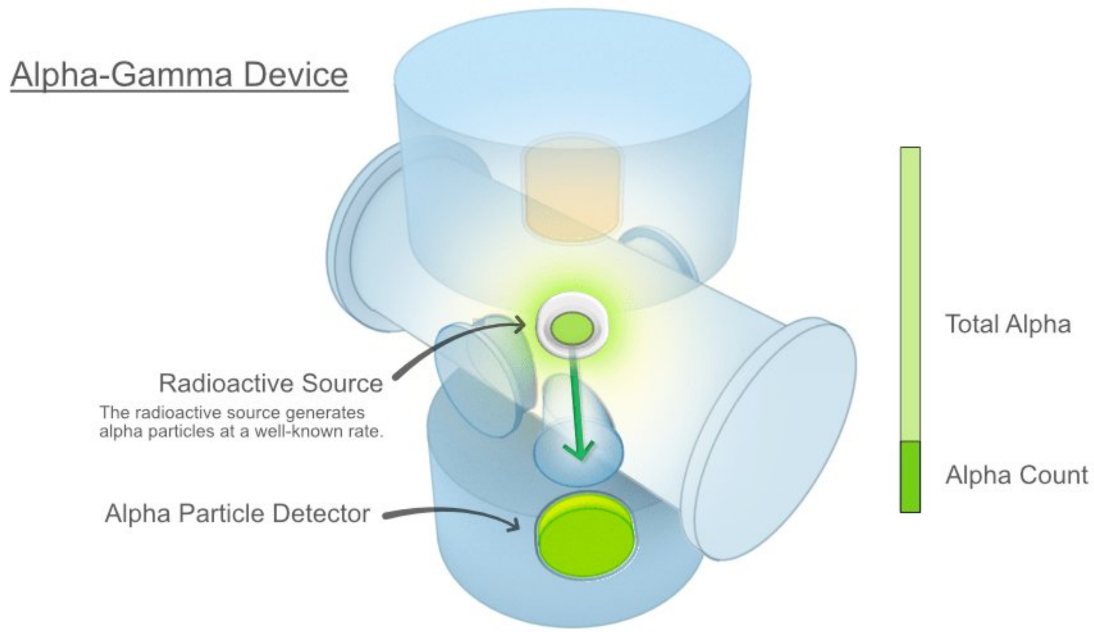


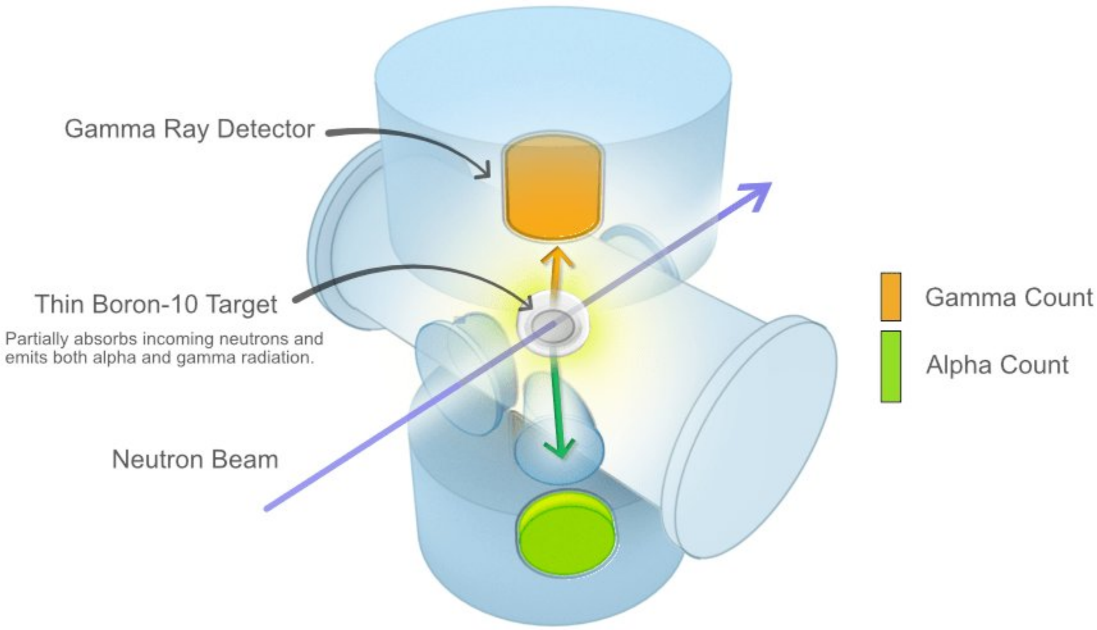

Step 1 – An extremely well characterized radiation source is placed in the alpha-gamma device. Credit: Sean Kelley/NIST

After years of research, scientists at the National Institute of Standards and Technology (NIST) have developed and demonstrated a way to count the absolute number of neutrons in a beam that is four times more accurate than their best previous results, and 50 times more accurate than similar measurements anywhere else in the world.

"Our technique is entirely unique," said NIST physicist Jeffrey Nico, who with colleagues report the findings in an accepted article for *Metrologia*. "Nobody else has this capability." The new method utilizes a novel, NIST-built "alpha-gamma" apparatus and an exacting, multi-stage process that results in final measurement uncertainties of 0.058 %—about six parts in ten thousand.

Determining the number of neutrons moving in a beam per unit time is required for applications from nuclear power management to neutron therapy in medicine. In particular, it is critically important for calibrating NBS-1, the U.S. national standard neutron source and for measuring the lifetime of free neutrons. It also provides a new, independent means of verifying a key property of elements.

In general, measuring the rate at which neutrons are moving in a beam (called neutron flux) involves aiming the beam at a target and counting the number and kinds of products emitted when neutrons interact with atoms in the target. Typical products are alpha particles and gamma rays, two of the three main products of radioactive decay. Alpha particles contain two protons and two neutrons — basically a helium atom stripped of electrons (a helium nucleus). Gamma rays are high-frequency photons with more energy than x-rays. Both are relatively straightforward to detect.



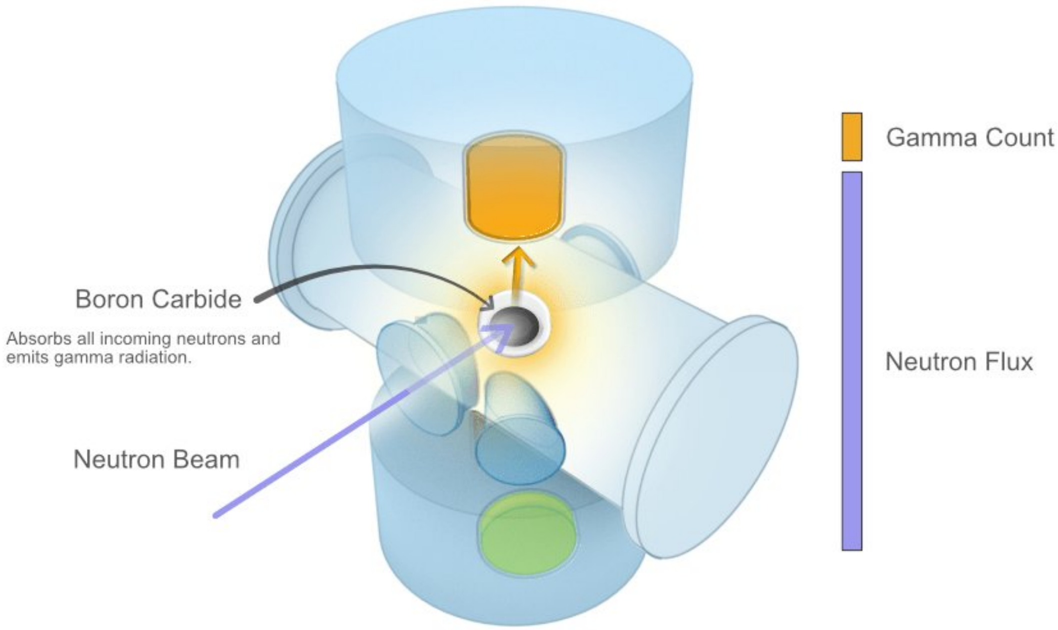

Step 2 – A controlled beam of neutrons passes through the device, striking a thin target. Credit: Sean Kelley/NIST

But counting emissions is not enough. It is also necessary to know the probability that a neutron will slam into the nucleus of an atom in a particular target; that probability, called the "cross section," is different for each element and for different neutron energies, among other factors. Conventionally, the cross section is obtained from database tables of world average values obtained from experiments.

The new NIST method avoids that dependence and uses only "things that are directly measurable by us," said project scientist M. Scott Dewey. "Before, we had to get values from elsewhere. And if they're wrong, we get the wrong answers. For example, in the case of the neutron lifetime, every time the database revises its numbers, our lifetime measurement changes because it tracks those numbers. Now we don't have to rely on databases, or cross sections, or branching ratios, etc. The new approach uses the constancy of these fundamental interactions to turn it into a counting experiment."

The four-stage process begins in a NIST-designed "alpha-gamma" device that has detectors for both alpha particles and gamma rays. A radioactive alpha-particle source whose emission rate is known to within a few hundredths of one percent is placed in the device, and a reading is taken from the alpha detectors. That reading establishes exactly what fraction of alphas register in the detectors compared to the well-known output of the source; that is, it calibrates the alpha detectors.

In the second stage, the alpha source is removed, and a thin target made of boron-10 is placed in the chamber, which allows a carefully controlled beam of neutrons from the reactor at the NIST Center for Neutron Research to enter from one side. The beam hits the target, which emits both alpha particles and gamma-ray photons. Comparing the counts from the calibrated alpha detectors and the highly sensitive gamma detectors results in a ratio. (For example, it might be that for every 1,000 alphas detected, 50 gammas are detected.) That ratio calibrates the gamma detectors.



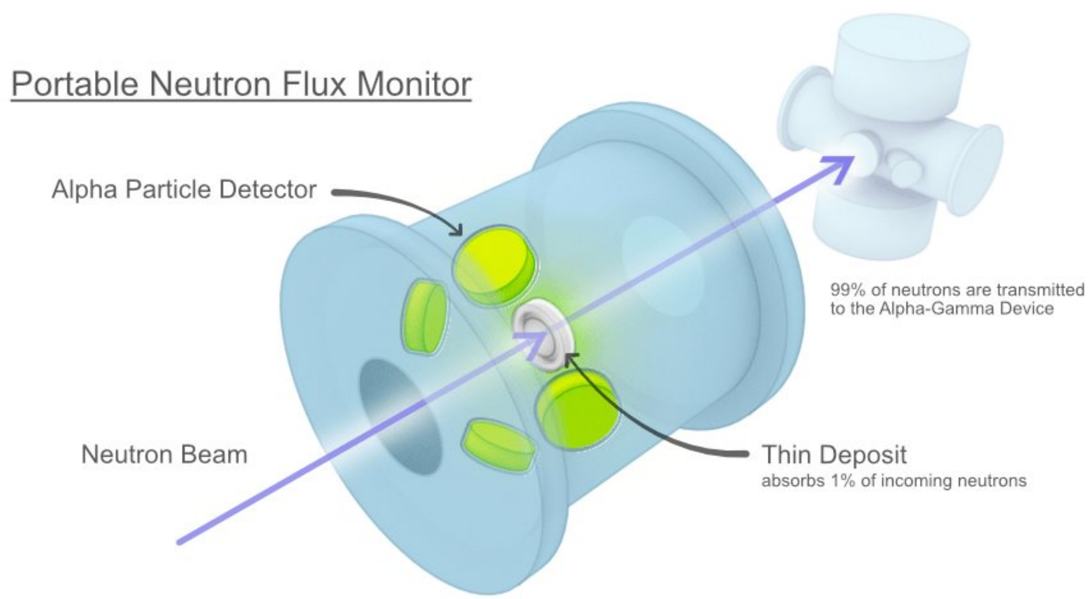

Step 3 – The thin target is replaced by a thick target that absorbs all incident neutrons. Credit: Sean Kelley/NIST

In the next stage, the thin boron-10 target is removed and replaced by a piece of boron carbide thick enough to absorb every neutron that strikes it. Not all alpha particles can make it out of the thick target, but the highly energetic gamma rays do. Because of the chain of calibrations described above, the gamma count can be used as an accurate measure of the neutron flux.

In the final stage of the process, the rate measured by the alpha-gamma device is simultaneously used to calibrate a neutron flux monitor, a separate instrument that sits in the neutron beam line just upstream of the alpha-gamma device. It absorbs 1 percent of the incoming neutrons; the alpha-gamma device absorbs the other 99 percent. So, relating the flux monitor detector output to the known neutron flux from the alpha-gamma device is a matter of simple mathematics.

The calibrated portable flux monitor, containing four detectors that count emissions of alphas and other heavy particles, will be used as a central part of a new way to measure the neutron output from NBS-1, improving its accuracy by a factor of three or four. It will also play a key role in NIST's ongoing program to nail down the lifetime of a free neutron. Although it can last for eons when inside an atomic nucleus, a neutron on its own breaks down within about 15 minutes into a proton and other particles. The exact lifetime is of intense interest to scientists because, among other things, it determines the types of light atoms in the early universe.

Research teams using different measurement techniques have come up with lifetimes that differ by about eight seconds, around 1 percent. Using the new alpha-gamma device, "we hope to get the uncertainty in our measurements down to one second," Nico said.



Step 4 – The flux-rate measurements are used to calibrate a portable monitor. Credit: Sean Kelley/NIST

Meanwhile, the alpha-gamma device will also prove itself by playing a key role in nuclear metrology. "This way of measuring things just didn't exist before," Dewey said. "And because nobody in the world has the capability to do it, we only have our own word that the thing really works. That's kind of scary. We'd like to have the community check us on this."

One way to validate the method is to use the alpha-gamma device "to measure a cross section that is already well known, and see if we get the same values," said project scientist Hans Pieter Mumm. "Our plan is to do a preliminary measurement of uranium-235 as a cross-check of the alpha-gamma device. The U-235 cross section is known to great precision. Not only will that demonstrate the capabilities of our technique, but it could open up an entirely new way of verifying the values in standard cross-section databases."

**More information:** Andrew Yue et al. Precision determination of absolute neutron flux, *Metrologia* (2018). DOI: 10.1088/1681-7575/aac283

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