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Title: **AN APPROACH TO MULTIPLICITY COUNTING FOR A VERSATILE NEW SENSOR FOR PLUTONIUM ASSAY WITH A VERY SHORT DIE-AWAY TIME, AND INDEPENDENT MEASUREMENTS OF NEUTRONS AND GAMMA RAYS**

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An approach to multiplicity counting for a versatile new sensor for Plutonium assay with a very short die-away time, and independent measurements of neutrons and gamma rays

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Abstract

A unique detector design incorporating a ^{6}Li-based capture medium, ZnS scintillator, and wavelength shifting optical fibers is the basis of a new neutron coincidence counter for measurements of plutonium in highly-impure residues. The sensor elements have a high efficiency for detecting neutrons and exhibit excellent gamma-ray discrimination based on pulse-shape analysis. The short die-away time of the counter that is based on these detector elements allows coincidence-gate settings shorter than 10 microseconds. This qualifies the technology for measurements of materials with high yields of uncorrelated neutrons from ^{241}Am(alpha,n) reactions. The characteristics of the new neutron counter will be illustrated with test data from measurements of plutonium, ^{252}Cf, and gamma-ray sources. The integrated electronics design of the new detector also permits the simultaneous but independent measurement of both neutrons and gamma rays. Recent test results that illustrate some unique applications of the sensor's versatility will also be presented.

Keywords: neutron; coincidence; multiplicity; plutonium; assay; directional

1. Introduction

Neutron coincidence counters (NCC's) [1-3] have been in use for many years to quantify the mass of special nuclear material (SNM). Coincidence counting is a nondestructive assay (NDA) technique that detects the coincident neutrons from spontaneous fission of the even isotopes of plutonium. The coincidence (doubles) rate is directly proportional to the effective mass of ^{240}Pu present in the sample.

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This technique is proven to work well with samples that have a relatively low "background" of uncorrelated neutrons from, for example, (α,n) neutron sources. Neutron coincidence counting has been used widely in international inspections. However, because of large errors that can occur if the technique is applied to impure materials, it has had limited application in domestic accountability measurements. The fundamental limitation of coincidence counting is that it measures only two parameters: the singles and doubles rates. A typical sample has at least three unknowns: plutonium mass, *m*; sample self-multiplication, *M*; and the ratio of neutrons that come from (α,n) reactions to those from spontaneous fission, α. For relatively pure sources, α ~ 0 (plutonium metal), or is well known (PuO_2, etc.). However, for impure samples, one must either know or guess α or *M* and solve for the mass. Inaccurate knowledge of either can cause large biases. Neither the multiplication nor the (α,n) yield can be known for many heterogeneous impure samples. It is the goal of neutron multiplicity counting to correctly assay in-plant materials without prior knowledge of the sample matrix, chemical form or spatial distribution of the plutonium in an item. The measurement of a third quantity, the triple coincidence rate, makes this possible for many materials including, moist or impure plutonium oxide, oxidized metal, and some categories of scrap and residues.

2. New well counter

A well counter has been designed and built with a new type of neutron sensor. This sensor has been described previously [4]. A four-sided well counter has been constructed with this new sensor, and is shown in Figure 1.

The counter uses 12 pulse-shape analysis (PSA) electronics boards, one for each detector element. The PSA board takes advantage of the different pulse shapes for gamma rays and neutrons. Neutrons and gamma rays are readily differentiated using delay-line shaping and time-to-amplitude conversion electronics.

2.1. Coincidence and multiplicity counting

Recent measurements have been made and

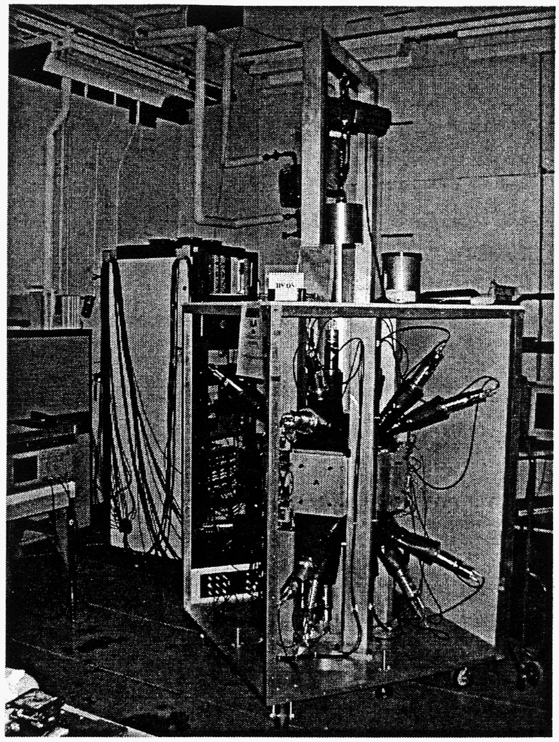

Figure 1. Completed well counter (all but one side panel is removed) with lift mechanism. Electronics rack is in background.

reported on the neutron detection efficiency and die-away time of this counter. The total neutron efficiency, measured with ^{252}Cf, is 20%, and the neutron die-away time is 5.7 ± 0.0037 μs. Following the measurements with ^{252}Cf, uncorrelated (α,n) sources were added to the well to determine if the counter exhibited any bias with respect to the doubles rate. With a truly uncorrelated source of neutrons the real-plus-accidental coincidence rate in the prompt gate, (R+A), should be equal to the accidental rate, A, since there are no real coincidences from such a source. Thus the doubles rate (D), calculated by D = (R+A) – A, should be zero. Varying numbers of AmLi sources were added to the well to verify this. It was expected that the doubles rate should be indistinguishable from zero; however, a large negative bias was observed. Of the same order or larger in magnitude than what is predicted for the doubles rates from actual samples this counter will measure. This negative bias is a consequence of a counter with a short die-away time and an electronic dead-time that is a significant fraction of that die-away time. In this case, the electronic dead-time, or pulse processing time, is between 1.5 and 2 μs. This means that for 1.5 to 2 μs after a pulse enters a PSA board, that channel is not able to process any subsequent pulses. Therefore, counts are lost in (R+A), resulting in a negative doubles rate. Note that the only pulses that are lost are those coming into the same channel that is being processed. A possible correction is to calculate the loss in accidental rate for each channel in the (R+A) gate. This can be estimated by: $A_i' = S_i^2 B_i$, where A_i' is the calculated accidental coincidence rate in the i^{th} channel, S_i is the singles rate, and B_i is the length of time the channel is dead. This leads to the following modified equation for doubles:

$$D = (R + A)_m + \sum_{i=1}^{12} \left(S_i^2 B_i\right) - A_m \qquad (1)$$

where $(R+A)_m$ is the measured (R+A) rate, and A_m is the measured accidental coincidence rate. A consequence of using this correction is that the predelay (PD) plus the prompt gate width cannot be longer than the dead time. Otherwise, this correction overcompensates for the lost accidental coincidences in the (R+A) gate. Setting a gate width of 1.5 – 2 μs in a counter with a 5.7 μs die-away time is clearly too short, therefore, two of the twelve PSA boards were modified to extend the dead time, for neutron events only, to 4.5 μs. This allows setting PD = 0.5 μs and G = 3.5 μs. These settings completely block any same-channel correlations so that (R+A) = 0 for a single channel. Now, because PD + G is less than the extended dead time of the electronics (4.5 μs), the B_i in equation (1) are set equal to G. This is done because the only pulses that are lost to the (R+A) are lost in the time G. This method gives zero doubles, within the uncertainty, for a single element and for two elements when measuring AmLi neutron sources. However, at this time, this method does not correct the triples rate for losses due to blocking. This correction is much more complicated, and will require more effort.

3. Other uses for this sensor

Because of the good separation of neutrons and gamma rays, this sensor may have some applications in anti-terrorism / homeland defense. Figure 2 shows this separation of neutrons and gamma rays. The

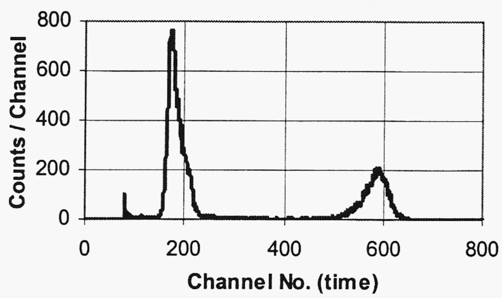

Figure 1. PSA spectrum for Plutonium metal. The counts under the peak at channel 175 are from gamma rays, and the peak at channel 590 is from neutrons.

dual sensitivity makes it possible to detect the presence of a neutron source or gamma-ray source (or both) with the same detector. By the nature of its construction, the sensor is also malleable, and can be shaped. The sensor is even rugged enough to be used as a light structural element. Figure 3 shows three elements of the well counter in an unfinished state. The capture/scintillator screens are the thin white sheets between layers of the green WLS fiber-optic

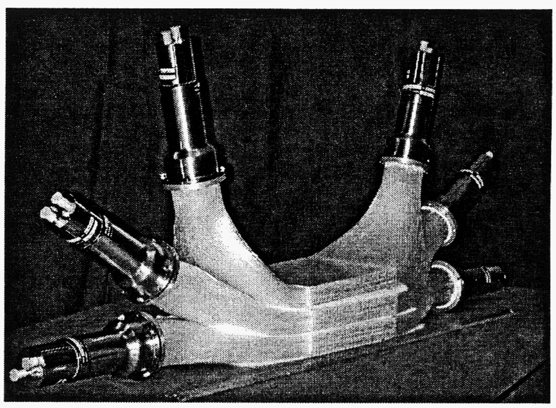

Figure 3. Three unfinished elements of the well counter. The capture / scintillator screens are the thin white sheets between the layers of WLS fiber-optic ribbon.

ribbon. Another aspect of this sensor that makes it attractive is that by its design it is inherently position sensitive. With the use of fast timing electronics it is possible to determine where along the length of the fiber ribbon the radiation interaction took place. The simultaneous arrival of light pulses at each end of the fiber bundle indicates that the interaction took place at the midway point. The light pulse will arrive first at the photodetector closest to the interaction location.

3.1. 4π directional detector

Only slight modifications are required to build a detector that is directionally sensitive in 4π. Two "U"-shaped halves that fit together to form a cube with capture / scintillator screen on all six sides and an appropriate core make the 4π directional detector. This design is shown in Figure 4. The core is required to prevent radiation incident on one side of

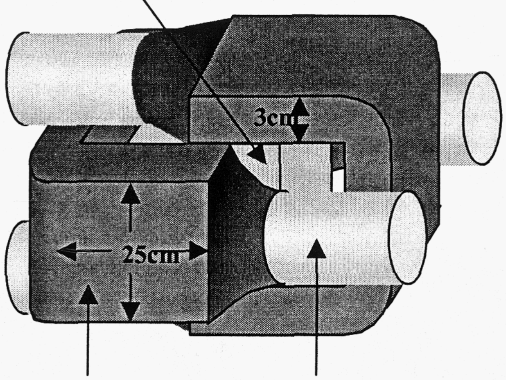

Figure 4. Conceptual six-sided (two-element) detector. Two sensor elements surround the polyethylene and tungsten core on its six sides.

the cube from interacting with the opposite side of the detector, thus making it directional. The optimum core design, from MCNP [6] calculations is polyethylene with an outer shell of tungsten to attenuate gamma rays. Experimental benchmarking of the MCNP design of the six-sided detector verified its calculated directionality (ratio of events detected on the side facing the source to those detected on the side opposite the source, determined by MCNP) of ~50:1 for far-field fission neutrons and 662-keV gamma rays. Also, timing experiments with off-the-shelf electronics modules showed a position sensitivity of ~20 cm along the length of the fiber. Faster and more optimized electronics should improve this sensitivity by an order of magnitude. Several of the devices deployed at various points within a train terminal, bus station, airport, shipyard, border crossing, or any other point of entry will detect the presence, spatial position, and direction of motion of a gamma ray or neutron radiating substance, indicating both types of radiation independently. The directional sensors are ideal for innocuous deployment around any strategic building or site inside lampposts, trashcans, junction boxes, or other common city structures.

References

[1] N. Ensslin, et al., Proc. 7th Nondestructive Assay Waste Characterization Conf., Salt Lake City, Utah, 23-25 May, 2000, LANL doc. LA-UR-00-1742.

[2] H. Menlove, et al., Proc. 7th Nondestructive Assay Waste Characterization Conf., Salt Lake City, Utah, 23-25 May, 2000, LANL doc. LA-UR-00-1687.

[3] H. Menlove, et al., Proc. 6th Inter. Conf. on Facility Operation - Safeguards Interface, Jackson Hole, Wy., 20-24 Sep., 1999, LANL doc. LA-UR-99-2861.

[4] A. Belian, et al., Proc. 12th Biennial RPSD Topical Meeting, Santa Fe, NM, 14-17 Apr., 2002, LANL doc. LA-UR-02-0542.

[5] M. Abhold, M. Sweet, "AMSR Training Course Manual," Ispra, Italy, 20-23 June, 2000, LANL doc. LA-UR-00-2764.

[6] J. F. Briesmeister, Ed., "MCNP - A General Monte Carlo N-Particle Transport Code, Version 4C," LA-13709-M, Los Alamos National Laboratory, April 2000.