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Backscatter gauge description for inspection of neutron absorber content

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ABSTRACT

This paper describes design, calibration, and testing of a dual He-3 detector neutron backscatter gauge for use in the Savannah River Site Mixed Oxide Fuel project. The gauge is demonstrated to measure boron content and uniformity in concrete slabs used in the facility construction.

1. Introduction

The Savannah River National Laboratory (SRNL) was requested by the Mixed Oxide Fuel (MOX) project to provide a gauge to measure boron content in concrete. At the MOX facility, boron will be added to the concrete moderator and shielding used in the facility in order to reduce and manage neutron flux. The requested gauge is to measure boron content and uniformity in concrete slabs used in the facility construction. Among candidate gauges to measure boron content the authors considered γ-ray spectroscopy to measure ^{10}B content using the ^{10}B(n,γ)^{11}B reaction as well as the ^{10}B(n,α)^{7}Li reaction and neutron backscatter. After scoping experiments in our nuclear nondestructive assay facility, the authors selected the backscatter probe. This paper describes development, testing, and calibration of our composite gauge.

The conceptual design of our neutron backscatter gauge is similar to that used by the Troxler moisture gauge of reference [1] and to several additional transmission and backscatter neutron gauges of references [2–5]. The Bastruk JEN-3 gauge [2] and the Korkut gauge [4] relate boron content in stainless steel and colmanite concrete using neutron transmission. The Tsao gauge uses neutron backscatter in a single-detector gauge to probe for discontinuities of absorber content with under-moderated neutrons [5]. Our gauge design is shown in a conceptual diagram in Fig. 1 and is described thoroughly in the invention disclosure of reference [6]. It consists of an encapsulated neutron source located in the center of the gauge. The source is surrounded by a 1.29 in. ID, 3.38 in. OD polyethylene cylinder. This cylinder slows the neutrons to thermal or near-thermal so they can be absorbed by the 2 mm cadmium foil that wraps the cylinder. This foil (plus an additional 2 mm Cd disk on top of the source not shown in Fig. 1) is for shielding purposes to protect the neutron detectors from observing neutrons coming directly from the source. The bottom of the polyethylene cylinder is open to allow the neutrons to freely enter the concrete component to be inspected for boron content.

The neutrons that enter the concrete may backscatter toward the gauge where they can be detected by the neutron detectors. The neutron detectors are embedded in ultra-high molecular weight (UHMW) polyethylene slabs whose function is to lower the energy of the backscattered neutrons so they can be detected with higher efficiency. Two detectors are used with the source in the middle so that the gauge will provide a symmetric response. That is, with the single detector used in the gauges of references [1–5], a different response would be obtained near edges of the observed component depending on whether the source or detector is closer to the edge. A thin aluminum (Al) "scuff" plate is included to prevent damage to the polyethylene slabs. Al is essentially transparent to the neutrons. The outside dimensions of the probe are 9.5 in. x 9.5 in. with a height of 2.75 in.

The gauge functions on the principle that energetic neutrons from the Am(Li) (α,n) reaction are exposed to the boron-containing concrete slab. A large fraction of these neutrons are then scattered back toward the gauge, where they are moderated to near thermal by the polyethylene and detected by the dual He-3 detectors. For concrete with no boron (or other neutron absorber) the backscatter detection rate will be N_o. With non-zero boron content the backscatter flux and detection rate are reduced. Therefore the backscatter detection rate will be inversely related

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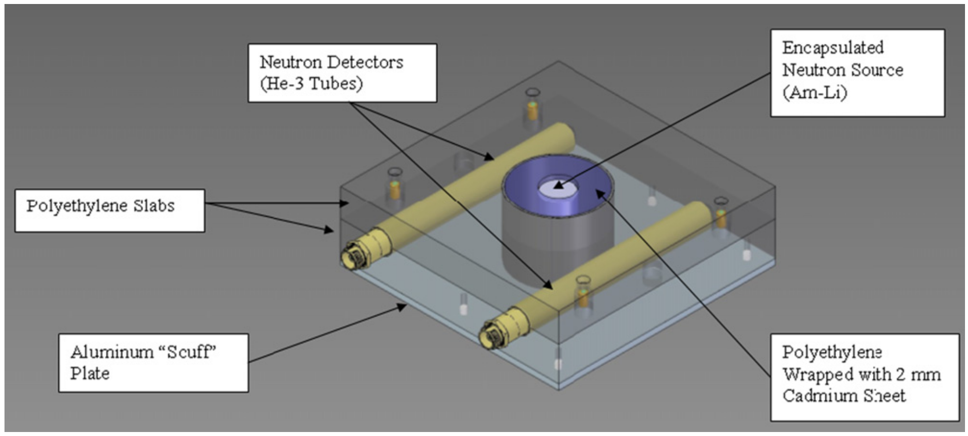

Fig. 1. Conceptual design of the neutron gauge. (Not to scale).

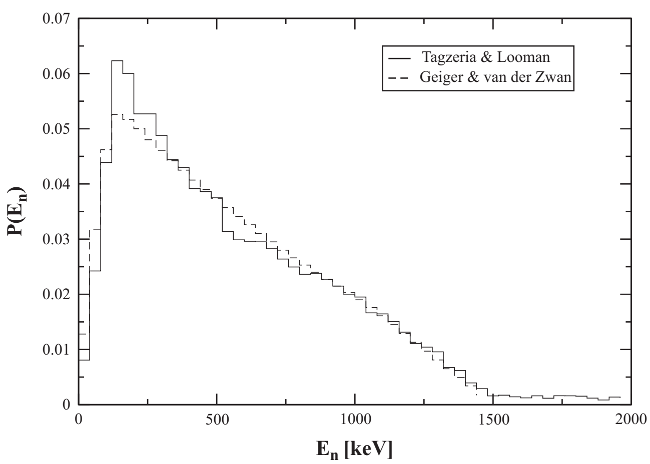

Fig. 2. The ^{241}Am–Li radionuclide neutron source spectrum [2].

to boron content and can likely be modeled with the empirical exponential form

$$\text{Detectionrate} = N_o \exp(-C[B]) \tag{1}$$

where [B] represents known boron content in the observed concrete component, and N_o and C are constants to be determined.

1.1. Detailed gauge description

The gauge consists primarily of the neutron source, neutron detectors, detector pulse counting electronics, and moderator assembly. The source is an Americium/Lithium (Am–Li) neutron source with an initial α-decay activity of 1.2 Ci and a neutron emission rate of 50,000 neutrons per second into a 4π geometry. The (α,n) neutron energy spectrum is approximately reproduced in Fig. 2 [7].

The gauge contains two Reuter-Stokes model RS-P4 He-3 type neutron detectors. This detector design is a gas filled (He-3) steel tube 1 in. in diameter and with an effective length of 8 in.. The helium gas pressure is 4 atm. The two specific detectors were selected to have matching regions of proportional counting near 1500 V determined by experiment.

The detector pulse counting electronics consist of Reuter-Stokes 122 A pre-amplifiers, a Canberra 2015 A AMP/SCA, and a Jomar JSR-11 high voltage supply and shift register to count neutron singles, doubles, and accidentals. These components were connected as shown in Fig. 3. Note the dual detectors are set up in tandem so that they are driven by the same HV supply. Similarly the detector analog output of one passes through the other before being combined as a single signal going to amp/SCA. The SCA out from the 2015 A module is then fed to the JSR-11 input for analysis of the TTL event rate.

The analog *preamp out* signals are approximately 5 mV in amplitude with negative polarity. With suitable amplification we were able to generate a multichannel analyzer (MCA) spectrum expected for properly operating neutron tubes [8]. The tandem counting configuration allows the shift register to analyze the event rate as a single chain as almost all neutron counting configurations are devised.

In our initial testing with both the Am(Li) source and with a 7.9-g Pu-239,240 source we obtained event rates with the detectors disconnected from each other, and also connected in tandem to operate as a single unit, in order to demonstrate we had obtained proper summing of the TTL rates. We do not include these data in this paper. Using the Pu source and with a 64-μs coincidence gate, we also demonstrated the capability of the shift register to observe coincidence neutron events. Like the generation of the MCA spectrum above, observing this neutron coincidence rate is not an important component for use of our probe in the singles backscatter mode, but we believed demonstrating both components was an important feature to prove the gauge's proper operation.

2. Experimental

We tested and calibrated our gauge using five panels of Colemanite Concrete with known boron content that were designated and poured specifically for testing the backscatter gauge of this paper. Panel dimensions are approximately 1 m^2 with a nominal thickness of 5 cm. The boron content ranged from 0.189 g/cm^3 down to 0.038 g/cm^3 as shown in Table 1. Two of the panels had the maximum boron content to allow a determination of measurement precision. The overall dimensions of the panels allowed five distinct backscatter measurements. The five acquisitions were obtained on each panel both with and without a 3 mm stainless steel plate between the gauge and the panel.

One acquisition was obtained in the center of each slab, and one was obtained at each of the four corners. The corner samples were taken with the detector centered at approximately 15 cm from the corners. Three trials were made at each of the five sample points for a total of 15 measurements per panel. The five distinct measurements locations allowed us to demonstrate uniformity for each individual panel and to demonstrate whether our gauge design is successful to eliminate edge effects. The three