Nuclear Instruments and Methods in Physics Research A 686 (2012) 100–105

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima


NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH

A novel method for detecting neutrons using low density high porosity aerogel and saturated foam

Kyle A. Nelson *, James L. Neihart, Todd A. Riedel, Aaron J. Schmidt, Douglas S. McGregor

S.M.A.R.T. Laboratory, Mechanical and Nuclear Engineering, Kansas State University, Manhattan, KS 66506, USA

ARTICLE INFO

Article history:
Received 18 November 2011
Received in revised form
3 April 2012
Accepted 27 April 2012
Available online 11 May 2012

Keywords:
^{3}He replacement
Neutron detection
Aerogel
Foam

ABSTRACT

As a result of the recent shortage of ^{3}He for neutron detection, several new detectors have been proposed as viable alternatives. Thin-film coated diodes and boron-lined proportional counters are suggested options, but both suffer from the "wall-effect", where only one interaction product can be measured per event. The "wall-effect" greatly reduces the neutron detection efficiency of the device. A new method is presented using low-density high-porosity materials where both reaction products can escape the absorber and contribute to a single event. Measuring both reaction products simultaneously greatly increases the detection efficiency of the device. Experimentally obtained pulse-height spectra from saturated foam and borosilicate aerogel detectors are presented. Aerogel is a low-density solid, typically less than 50 mg/cm^3, and can be developed with ^{10}B in the structure. The thermal neutron response pulse-height spectrum from borosilicate aerogel is presented. Additionally, polyurethane foam, another low-density high-porosity material, was saturated with LiF and B_2O_3 to levels greater than 20 percent by weight and tested as a neutron detection medium. The foam saturated with 4.5 percent ^{6}LiF was cut into 10 sheets, each 2 mm thick, and a neutron response pulse-height spectrum was collected. The thermal neutron detection efficiency was measured to be 7.3 percent, and the neutron to gamma-ray rejection ratio, acquired using a ^{137}Cs gamma-ray source, was calculated to be 1.71×10^6. Theoretical calculations also show that neutron detection efficiencies above 60 percent can be easily achieved using enriched ^{6}LiF foam at 20 percent or higher saturation levels.

1. Introduction

There is a critical ^{3}He shortage and significant effort has been invested to find and/or develop a practical alternative medium for neutron detection. To replace a ^{3}He gas-filled proportional counter, the detector is required to have high neutron sensitivity, large area, and high gamma-ray discrimination. Several options have been proposed [1,2], but suffer from either low efficiency, poor gamma-ray discrimination, or high cost. A number of different materials are known to absorb neutrons readily, e.g., ^{6}Li, ^{10}B, ^{113}Cd, and ^{157}Gd, and have been used as neutron reactive materials for detection systems [3–15]. However, the focus can be narrowed to ^{6}Li and ^{10}B due to the large *Q*-value and short ranges of their reaction products, which are ideal for gas-filled neutron detectors. The microscopic thermal neutron (0.0259 eV) absorption cross-sections for ^{6}Li and ^{10}B are 940 b and 3840 b, with natural abundances of 7.59 and 19.9 percent, respectively. The ^{6}Li(n,t) ^{4}He and ^{10}B(n,α) ^{7}Li reactions lead to the following reaction products, with reaction *Q*-values of 4.78 MeV and 2.79 MeV, respectively. The ^{10}B(n,α) ^{7}Li reaction has two branches, one branch occuring 94 percent of the time and the other the remaining 6 percent.

$$^{10}\mathrm{B}+{}^1_0\mathrm{n}\rightarrow{}^7\mathrm{Li}(1.015\ \mathrm{MeV})+\alpha(1.777\ \mathrm{MeV}) \qquad 6\%$$

$$^{10}\mathrm{B}+{}^1_0\mathrm{n}\rightarrow{}^7\mathrm{Li}(0.840\ \mathrm{MeV})+\alpha(1.470\ \mathrm{MeV})+\gamma(0.480\ \mathrm{MeV}) \qquad 94\%$$

and

$$^{6}\mathrm{Li}+{}^1_0\mathrm{n}\rightarrow{}^3\mathrm{H}(2.73\ \mathrm{MeV})+\alpha(2.05\ \mathrm{MeV})$$

Typically, when a coated detector absorbs slow neutrons, the reaction products are emitted in opposite directions from the ^{6}Li(n,t) ^{4}He and ^{10}B(n,α) ^{7}Li reactions. Hence, only one reaction product may enter the detecting medium, be it gas, scintillator or semiconductor, and the other reaction product will not be detected. The alternative neutron detection candidates mentioned (^{113}Cd, ^{157}Gd) emit gamma-rays and low energy conversion electrons, which are difficult to discriminate between neutron-induced events, electronic noise, or background gamma-ray interactions. Thus, these materials are non-ideal for gas-filled neutron detectors.

Some proposed alternative neutron detectors are unable to measure both reaction products simultaneously, a disadvantage that greatly lowers the neutron detection efficiency [16]. For a

---

* Corresponding author.
E-mail address: knelson1@ksu.edu (K.A. Nelson).

0168-9002/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.nima.2012.04.084

common ^{10}B-lined gas-filled detector, one reaction product will enter the wall onto which the coating was applied. This "wall effect" causes the loss of substantial energy, and therefore, a reduced signal-to-noise ratio. Raising the LLD to increase the signal-to-noise ratio will cause a portion of the counts from neutrons to also be lost, thereby, reducing the neutron detection efficiency. Therefore, using a detector design such that both reaction products contribute to the detection signal becomes important. In order to detect both reaction products simultaneously from a solid-form neutron sensitive material, the absorber must be thinner than the summed ranges of the interaction products.

An alternative material to using an ultra-thin neutron absorber, e.g., Li foil [17], is to use a low-density high-porosity material. The low density allows the ranges of the interaction products to extend further than found with typical solid absorbers, thereby, allowing the absorber to be thicker and more structurally rigid. If the electric field is strong enough, free charges generated in the pores of the absorber will be able to escape through the voids in the neutron sensitive material, and contribute to an event. Aerogels and foams, although having different compositions, are both materials with relatively low densities and high porosities compared to typical solid absorbers, consequently allowing the ranges of the reaction products from the ^{6}Li(n,t) ^{4}He and ^{10}B(n,α) ^{7}Li reactions to travel further than a few microns, as expected for typical solids. Aerogels and foams can be manufactured into thin sheets, thus, can be acquired with thicknesses of the order or less than the ^{6}Li(n,t) ^{4}He and ^{10}B(n,α) ^{7}Li reaction product ranges.

In the present work, a single disk of borosilicate aerogel was centered between two anode wires and placed in a thermal neutron beam. The resulting neutron response pulse-height spectrum is presented. Polyurethane foam samples saturated with ^{6}LiF and B_2O_3 were cut into 2 mm thick sheets and suspended in a continuous flow proportional gas chamber. Positioning an anode wire on either side of each sheet allows the device to measure both reaction products simultaneously. By stacking several saturated foam sheets, with alternating anode wires positioned between the absorber sheets, a large area high-efficiency neutron detector can be realized, without the use of ^{3}He gas, and can be manufactured for an extremely low cost compared to current alternatives. Theoretical calculations predict the thermal neutron detection efficiency as a function of absorber thickness and number of sheets stacked together. The experimentally obtained thermal neutron detection efficiency was measured using a ^{3}He tube and compared to the theoretical values. Additionally, a ^{137}Cs gamma-ray source was used to measure and calculate a neutron to gamma-ray rejection ratio (n/γ).

2. Theoretical considerations

Shown in Fig. 1 is a conceptual arrangement of a section of the aerogel or foam multi-wire proportional counter with an inset of a single absorber sheet [18]. Because the range of the triton is longer than the thickness of the neutron absorber, the triton has a high probability of escaping the absorber. There is a low probability that neither reaction product will escape the aerogel or foam, a probability that increases with absorber thickness. Because the summed range of the interaction products is much longer than the thickness of the absorber, there is a considerable chance that the reaction products will escape both sides of the absorber, thereby, leaving more energy in the chamber than in a conventional coated proportional counter. As the reaction products travel through the gas medium, they deposit their energy and generate free electron-ion pairs. The electrons travel to the central anode wire where the device operates as a conventional proportional counter by creating a Townsend avalanche [5,6]. The positive ions travel to the cathode of the chamber and induce a current.

The theoretical calculations used to obtain the expected intrinsic thermal neutron detection efficiency for foam and aerogel detectors have been developed and are well understood [16]. The analytical approach, using a system of equations, allows for calculations of neutron detection efficiencies for thin-film coated diode devices having various neutron absorber layers and layer thicknesses [16]. Although originally developed for coated semiconductor diodes, the same equations can be used for gas-filled detectors. The equations combine the neutron absorption probability with the probability that the reaction products will escape the absorber and enter the detector gas volume.

Using the method in the literature [16], efficiency calculations were performed using an aerogel density of 0.02 g/cm^3 and a foam density of 0.01 g/cm^3 (typical densities provided by the manufacturers) and an LLD of 300 keV. The theoretical ranges of the reaction products in the aerogel and polyurethane foam obtained using SRIM are shown in Table 1 [19]. The macroscopic thermal neutron absorption cross-section of 20 percent ^{6}LiF saturated foam is 0.23 cm^{-1} at a density of 0.01 g/cm^3. The macroscopic thermal neutron absorption cross-section of elemental ^{10}B aerogel is 4.62 cm^{-1} at a density of 0.02 g/cm^3.

Shown in Figs. 2 and 3 are the results of the theoretical thermal neutron detection efficiency calculations for 1–5, 10, 15, and 20 layers of 20 percent ^{6}LiF saturated foam and elemental ^{10}B aerogel. The plots show that for any particular number of layers of neutron absorber there is an optimum layer thickness that maximizes the intrinsic thermal neutron detection efficiency.

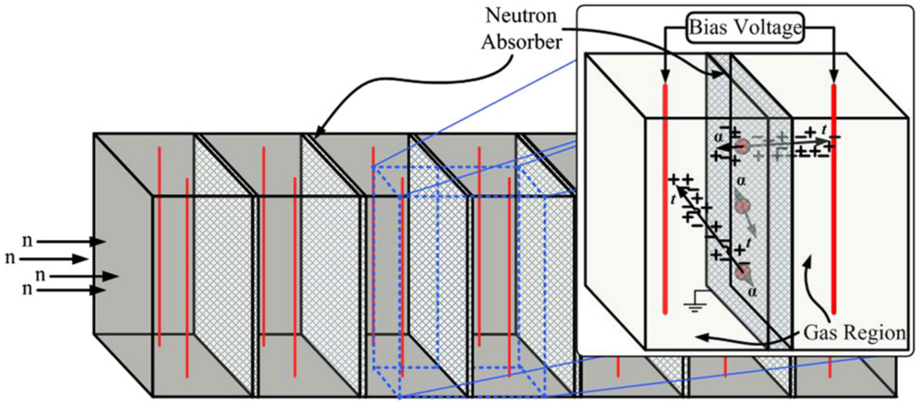

Fig. 1. A cross sectional view of the conceptual arrangement of the multi-wire proportional chamber with either saturated foam or aerogel as the neutron absorber.