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Dual-chamber/dual-anode proportional counter incorporating an intervening thin-foil solid neutron converter

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ABSTRACT

A dual-chamber/dual-anode gas proportional counter utilizing thin solid ^{6}LiF or ^{10}B neutron converters coated on a 2-micon-thick Mylar film that is positioned between the two counter chambers and anodes has been designed, fabricated, and tested using a variety of fill gases—including naturally abundant helium. In this device, neutron conversion products emitted from both sides of the coated converter foil are detected—rather than having half of the products absorbed in the wall of a conventional tube-type counter where the solid neutron converter is deposited on the tube wall. Geant4-based radiation transport calculations were used to determine the optimum neutron converter coating thickness for both isotopes. Solution methods for applying these optimized-thickness coatings on a Mylar film were developed that were carried out at room temperature without any specialized equipment and that can be adapted to standard coating methods such as silk screen or ink jet printing. The performance characteristics of the dual-chamber/dual-anode neutron detector were determined for both types of isotopically enriched converters. The experimental performance of the ^{6}LiF-converter-based detector was described well by modeling results from Geant4. Additional modeling studies of multiple-foil/multiple-chamber/anode configurations addressed the basic issue of the relatively longer absorption range of neutrons versus the shorter range of the conversion products for ^{6}LiF and ^{10}B. Combined with the experimental results, these simulations indicate that a high-performance neutron detector can be realized in a single device through the application of these multiple-foil/solid converter, multiple-chamber detector concepts.

1. Introduction

The relatively large thermal neutron cross section of ^{3}He, and in particular, its ability to discriminate between neutron and gamma ray events when used as the fill gas in proportional-counter-type devices makes this material ideal for use in a wide range of homeland security, nuclear nonproliferation, defense, and research applications. However, a significant decrease in the production of ^{3}He from the decay of tritium subsequent to the decline of nuclear weapons production at the end of the Cold War, coupled with increased demands for this isotope for use in neutron detection devices, has led to a recent and continuing critical international ^{3}He shortage. Accordingly, the objective of the present research effort is to develop an alternative technique for efficient thermal neutron detection and gamma ray rejection by using a gas proportional counter approach that incorporates solid, thin foil forms of ^{6}Li or ^{10}B isotopes as the neutron converter instead of ^{3}He. By virtue of its adaptability for use in a variety of device geometries and sizes (as well as with a variety of fill gases), this thin-foil solid-neutron-converter proportional counter approach has the potential for providing a direct mechanical/geometrical "plug-in" replacement for existing ^{3}He tubes as well as offering alternative detectors for applications in hand-held, portable neutron detection devices. Furthermore, the use of stable solid neutron converters avoids the environmental and other problems associated with alternative detectors that use toxic and corrosive BF$_{3}$ gas and that, accordingly, are often not utilized for safety and related reasons. Since the devices described here can operate using naturally abundant He, in addition to other proportional counter fill gases, it should be possible to realize a gamma-ray signal rejection ratio that is effectively the same as that of conventional ^{3}He tubes. Reviews of various proportional counter designs and their capabilities—as well as those of other thermal neutron detectors can be found in Knoll [1], Peurrung [2], and Runkle et al. [3].

The isotopes ^{6}Li, ^{157}Gd, and ^{10}B are all well known materials that are characterized by neutron capture cross sections and reaction products that can be exploited in making devices for neutron detection. In the case of Gadolinium (characterized by

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a large neutron cross section in either an isotopically enriched or naturally abundant form), the low-energy gamma ray and conversion electron reaction products from neutron capture often (but not always) mitigate against the use of this material as a solid neutron converter, and we have also chosen to concentrate initially on the use of ^{6}Li and ^{10}B as neutron converters in the present work. The use of metallic lithium in neutron detection devices is frequently rejected due to the reactive/corrosive nature of this material, and although we were able to initially make a functioning conventional proportional counter device that utilized metallic lithium-6, this approach proved not to be robust. Accordingly, we have utilized isotopically enriched ^{6}Li in the relatively chemically stable and non-hygroscopic form of ^{6}LiF in the work described here, while isotopically enriched ^{10}B was used in its elemental form.

In the present work, we report on the details of the design, fabrication, and performance of a dual-chamber/dual-anode proportional counter configuration that utilizes either ^{6}LiF- or ^{10}B-coated thin Mylar film converter screens. Specifically, we describe the response of this type of detector to moderated neutrons from an AmLi neutron source and to gamma rays. The dual chamber/dual anode detector treated here is essentially based on a concept initially illustrated on page 167 of the 3rd Edition of *Radiation Detection and Measurement* by Glenn Knoll [4]. The device consists of a gas-filled proportional counter with two chambers (and two anodes) that are separated by a thin planar source. This configuration provides for a 4π-detection geometry [5,6] so that radiation emanating from either side of the source is detected. In the case of neutron detection, the signal is provided by the conversion products from a thin planar neutron converter such as ^{6}Li or ^{10}B. This dual-chamber concept was adopted here based on the apparent potential to ultimately extend it to a more advanced device with multiple chambers, multiple thin solid converter foils, and multiple anodes with the goal of realizing a detector whose performance could be competitive with that of a ^{3}He proportional counter. Modeling studies of multiple thin solid screen neutron converters (to be described in a subsequent section of this work) coupled with the experimentally determined performance characteristics of the actual dual-chamber/dual-anode proportional counter device show that this potential is, in fact, realizable.

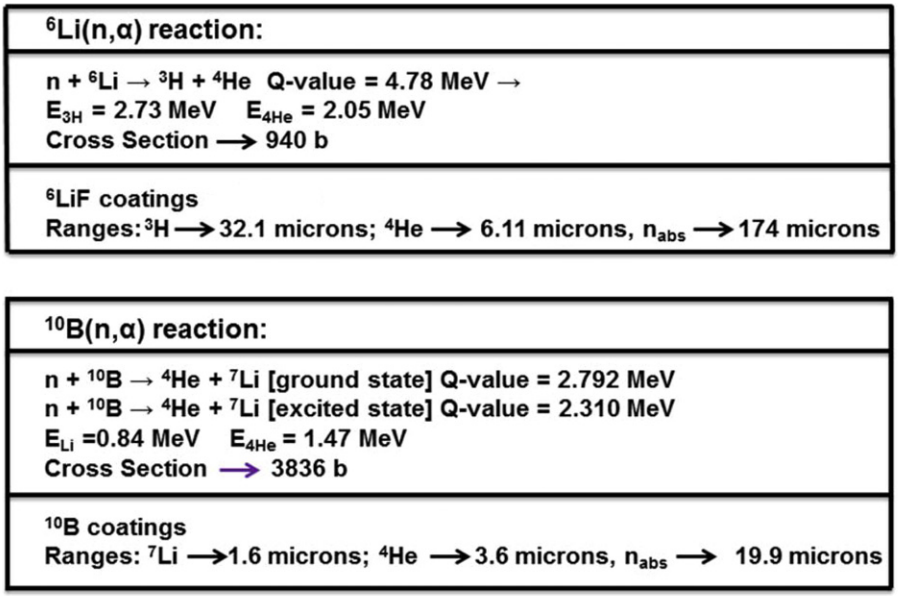
2. Neutron detector design and fabrication

2.1. General features and properties

An important feature that differentiates a thermal neutron detector based on the use of ^{3}He as the neutron converter in a proportional counter type device from a device that uses solid neutron converters is associated with differences in the thickness of the material required to absorb the neutrons versus the range of the conversion products in the absorber itself. The fundamental problem arises from the fact that the absorption length of thermal neutrons in solid converters such as ^{6}LiF, ^{6}Li, or ^{10}B is significantly longer than the range of the alpha, triton, proton, or ^{7}Li reaction-product particles. Accordingly, once the absorber thickness becomes greater than the conversion product ranges, only those reactions occurring within a depth of the absorber that is less than the product ranges result in detectable particles that can escape from the absorber. Solid neutron converter characteristics and calculated neutron absorption and reaction product ranges as calculated by McGregor et al. [7] are given in Table 1 for ^{6}Li, ^{6}LiF and ^{10}B.

As a result of the neutron-absorption and resulting conversion-particle range differences, conventional proportional counters with coatings of solid neutron converters on the interior wall of the detector (e.g., boron-lined proportional counters, boron-coated straws, etc.) are severely limited in the amount of useful converter that can be effectively utilized in a single detector. In the case of boron straws, this aspect is addressed through the use of bundles of multiple "straws" each of which has a boron wall coating that is sufficiently thin to permit the escape of some (but not all) of the reaction products—i.e., in proportional counter designs where the wall is simply coated with a solid converter, half of the reaction products are immediately lost in the detector wall, and therefore, these particles do not deposit any of their energy in the fill gas. This Solid-Converter Wall Effect (SCWE) is to be distinguished from the more conventional wall effect that occurs when the proportional counter fill gas is also the neutron converter—e.g., when the fill gas is, for example ^{3}He or ^{10}BF$_3$. In the conventional situation, any combination of detector geometry, fill gas pressure, or fill gas properties that results in conversion product ranges that are greater than the dimensions

Table 1
Solid thermal neutron converter properties.



^{6}Li(n,α) reaction:

n + ^{6}Li → ^{3}H + ^{4}He Q-value = 4.78 MeV →
E_{3H} = 2.73 MeV E_{4He} = 2.05 MeV
Cross Section ⟶ 940 b

^{6}LiF coatings
Ranges: ^{3}H ⟶ 32.1 microns; ^{4}He ⟶ 6.11 microns, n_{abs} ⟶ 174 microns

^{10}B(n,α) reaction:

n + ^{10}B → ^{4}He + ^{7}Li [ground state] Q-value = 2.792 MeV
n + ^{10}B → ^{4}He + ^{7}Li [excited state] Q-value = 2.310 MeV
E_{Li} =0.84 MeV E_{4He} = 1.47 MeV
Cross Section ⟶ 3836 b

^{10}B coatings
Ranges: ^{7}Li ⟶1.6 microns; ^{4}He ⟶3.6 microns, n_{abs} ⟶ 19.9 microns

Range calculations: McGregor, D. S., et al., NIMA 500 (2003) 272–308.