Preliminary results of a new boron coated neutron detector

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Abstract

The proliferation of neutron detection applications based upon ^{3}He proportional counter has triggered a critical shortage of ^{3}He gas. Nowadays there is an increasing demand for alternative neutron detection technologies that can cover large solid angle, have low sensitivity to gamma background and, last but not least, low cost. We present a low cost neutron detector based upon 3 cm diameter, 150 cm long cylindrical metal tube coated on the inside with a thin layer of ^{10}B-enriched boron carbide ($^{10}B_4C$) fulfilled by 1 atm nytrogen and exposed to a ^{252}Cf source. Neutron relative detection efficiency compared to ^{3}He set-up is evaluated and discussed.

Keywords: boron thin-film detector, radiation portal monitoring, neutron detection
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1. Introduction

Proportional counters filled with ^{3}He are the standard for thermal neutron detection systems. The greatest advantage that ^{3}He has over other neutron detector is its large capture cross-section while its sensitivity to γ-rays is negligible and the associated pile-up effects are consistent, according to [1], only in radiation fields of around 1 R/h. Proportional counter tubes filled with ^{3}He are the most common detection systems in applications like well logging in the oil and gas industry, medical MRI lung imaging and nowadays in homeland security. The current demand of neutron detectors to be displaced as portal monitoring systems has created a shortage of ^{3}He. ^{10}B has been identified as one of the best replacements because of its characteristics. ^{10}B isotope is 20% of natural occurring boron (80% is ^{11}B, all the others isotopes are unstable), and has a thermal neutron cross section of about 3840 barn, smaller than 5330 barn claimed by ^{3}He, but still a very high value indeed. The nuclear reaction that is exploited in order to detect thermal and low energy neutron is ^{10}B(n,α)^{7}Li, that can be written as:

$$\mathrm{n} + {}^{10}\mathrm{B} \rightarrow \begin{cases} {}^7\mathrm{Li}(1.015\,\mathrm{MeV}) + \alpha(1.777\,\mathrm{MeV}), \\ Q = 2.792\ \mathrm{MeV},\ \mathrm{b.r.\ of\ } 6\%, \quad \mathrm{(a)} \\ {}^7\mathrm{Li}(0.840\,\mathrm{MeV}) + \alpha(1.470\,\mathrm{MeV}) + \gamma, \\ Q = 2.310\ \mathrm{MeV},\ \mathrm{b.r.\ of\ } 94\%. \quad \mathrm{(b)} \end{cases}$$

In parenthesis are reported the kinetic energy of the emerging reaction products. The differences of ^{7}Li and α kinetic energies are due because in (b) lithium nuclide is left in the first excited state, while in (a) is in its ground state. The recoil ^{7}Li and α travel off in opposite directions, at 180°, and the Q values of neutron induced reactions on ^{10}B are much higher than for ^{3}He reactions, making it easier to discriminate against pulses associated to γ background. The most popular solution for ^{10}B in neutron detection has been the use of B_3F, a boron molecule gaseous at room temperature like ^{3}He. However B_3F is not a desirable solution because of its toxicity and detector aging. Other non toxic but solid boron compounds as boron carbide ^{10}B-enriched have been studied by many groups [2, 3, 4] with very promising results in portal monitoring applications. Radiation portal monitors are typically based on the assembling of multiple radiation sensor panel (RSP) building blocks long up to two meters. Our investigated solution is a set of 1.5 m long metal tubes coated on the inside with a layer of ^{10}B-enriched boron carbide (straw tubes). The neutron induced reaction products, leaving the layer, ionize the gas filling the tubes and the charges is collected by a high voltage wire placed at the centre of the tube. Multi-tube array packed together in an appropriate technology can reach an efficiency comparable to ^{3}He based detectors and the new systems is inexpensive too. For large radiation detection systems like the ones used for screening vehicles and cargoes, it is required to detect not only thermal neutrons but covering the energy range from thermal up to few MeV. This task is achieved surrounding straw tubes by a suitable moderator: we have studied the use of polyethylene slabs thick from 3 cm to 15 cm depending on the neutron energy spectrum and other constraints. The fissile materials could be revealed by only few neutron counts per seconds due to the short exposition of the vehicle under investigation, but γ ray background counting rate is expected to be much bigger, hence it is mandatory for the detector to be almost blind to γs. We present and discuss the preliminary results obtained with a straw tube prototype based upon boron carbide films for portal monitoring applications.

2. Experimental

A straw tube prototype was realized using an aluminium cylinder, 150 cm long, 3 cm inner diameter. ^{10}B enriched up to 93% material is available as colloidal suspension in mineral oil. After painting the inner walls of the cylinder, the mineral oil was evaporated in an electrical furnace. Higher sensitivity is achieved by increasing the detector length rather than the diameter, because counters with larger diameters have greater environmental γ background and require higher operating voltage. In the other hand tubes of very small diameter give problems with the boron deposition on the inside walls. A thin tungsten wire is stretched along the axis of the cylinder, acting as anode. The tube is fulfilled with nitrogen as ionizing gas at 1 atm. Nitrogen is only one of the many possible solutions as counting gas, there is no need for pressurization. The inside $^{10}B_4C$ film has an average thickness from 2 μm to 2.4 μm, equivalent to around 0.55 10^{-3} g/cm^2. The painting technique does not guarantee a great thickness uniformity along the inside cylinder walls, surely inferior to dip-coating deposition, but it is the least expensive process. To optimize the counter performance the ^{10}B-enriched film thickness must be less than the ranges of the charged reaction products in the $^{10}B_4C$, to smash down absorption inside the film. The average ranges of α-particles in boron are 3.6 μm (6% branching ratio) and 4.4 μm (94% branching ratio) respectively, and 1.9 μm (6%) and 2.2 μm (94%) for ^{7}Li. A Monte Carlo simulation has been performed to study the effect of single $^{10}B_4C$ layer thickness on the counter efficiency. Only neutrons at thermal energies have been considered with a constant capture cross section for ^{10}B equal to 3840 barn. Both emerging particles have been taken into account with their kinetic energy distribution. In Fig. 1 it is shown the sum of the efficiency *vs* the ^{10}B thickness in μm for all the reaction products. The efficiency refers to the probability of the charged reaction products to reach the nitrogen volume with enough kinetic energy to produce a sufficient amount of primary ion pairs in the gas able to create a readable electronic pulse on the anode wire. Charge collection efficiency at the anode is taken equal to 100%. In Fig. 1 a peak can be seen at around 2.7 μm $\div$ 2.8 μm thickness, in agreement with [2]. From efficiency value quoted in Fig. 1 it is evident that a detection system could not rely on a single straw tube, but an array of multi-layer tubes must be designed. Assuming each tube with the optimal thickness of $^{10}B_4C$ film, it is computed the behaviour of efficiency *vs* the number of layers, without taking into account γ background. The simulation clearly shows a saturation effect around 40% $\div$ 43%, reached with 19 $\div$ 21 layers. The straw tube prototype was tested by exposition to a neutron fission source of ^{252}Cf of around 20 μCi. The tube was surrounded by 7 cm thick polyethylene and was operated with the central wire (the anode) at 2300 V (from CAEN HV Power Supply) and the cathode at ground potential (the wall of the aluminium cylinder). The γ-rays produce relatively small pulses that can be easily rejected by properly setting the threshold. The equivalent of 150 keV was used as the lower energy threshold for ion detection, which is still significantly higher than the energy depositions by Compton electrons in an ionizing chamber. Fig. 2 shows the acquired spectrum of the pulse height.

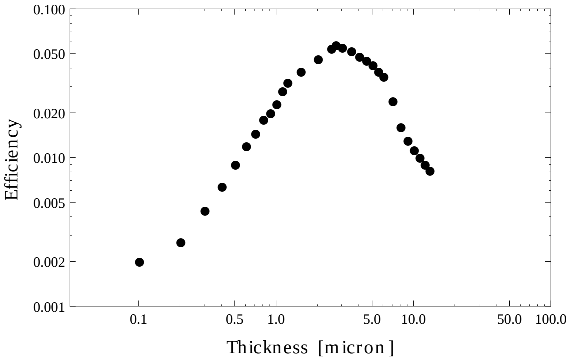

Figure 1: Efficiency of boron carbide layer enriched to 93% with ^{10}B *vs* layer thickness exposed to thermal neutron flux. A peak is observed at 2.7 μm $\div$ 2.8 μm.

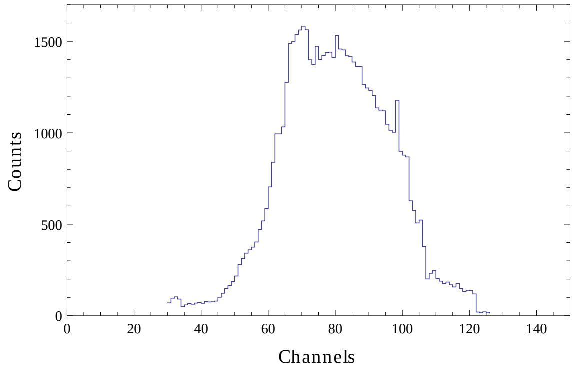

Figure 2: Pulse height spectrum from boron coated straw tube surrounded by 7 cm thick polyethylene and irradiated by 20 μCi ^{252}Cf neutron source.

3. Conclusions

^{10}B enriched boron carbide is easy to produce, inexpensive and has interesting characteristics that make it a good choice to be extensively used in neutron counters deployed for homeland security and portal monitoring. Boron coated straw tubes offer some clear advantages over ^{3}He-based detectors, nitrogen can be a good, inexpensive choice of ionizing gas (that can be replaced with something else if needed), it works in non pressurization condition and guarantees good γ-rays discrimination with simple pulse height discrimination. The proposed counter could be an inexpensive solution in any application where large sensitive volumes are required.

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