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Replacement of ^{3}He in Constrained-Volume Homeland Security Detectors

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***Abstract*—We have developed a boron-coated straw (BCS) detector to replace a ^{3}He-based design for homeland security. BCS detectors are distributed inside a high-density polyethylene (HDPE) moderator, occupying the exact same volume of the ^{3}He-based design. The design challenge was to achieve similar neutron detection efficiency as the ^{3}He design, without increasing the overall size and weight of the assembly, while at the same time providing robust operation in the field. Prototype detectors of this design were built and tested with a ^{252}Cf source. The ^{3}He-based detector was also tested under identical conditions for comparison. Results show that the BCS-based design has comparable response to the ^{3}He detector, and can thus be an attractive replacement detector. The high detection efficiency of the proposed design is partly due to the small diameter of the BCS, which allows for the detection medium (^{10}B) to be efficiently dispersed throughout the moderator, dramatically increasing the probability that neutrons are captured in the detector, rather than escape, or be absorbed in the moderator itself. As a result, the BCS using distributed moderation can perform very well in sensitivity comparisons with ^{3}He gas where other technologies fall short. At the same time, the BCS offers distinct additional advantages over conventional ^{3}He-based detectors, and alternate technologies such as $^{10}BF_3$ tubes and ^{10}B-coated rigid tubes. These include many-times faster electronic signals, no pressurization, improved gamma-ray rejection, no toxic or flammable gases, easy maintenance, and effective field use compatibility.**

I. Introduction

HIGH sensitivity, robust operation, portability and low weight are critical requirements for radiation monitors used in homeland security. ^{3}He-based neutron detectors have been an attractive solution, satisfying the above requirements, however, existing designs cannot be sustained in the near future due to the severe shortage of ^{3}He gas in the US and worldwide. This makes it imperative to develop replacement detectors that do not depend on ^{3}He for operation.

A currently employed design, illustrated in Fig. 1, incorporates 3 ^{3}He tubes, each 5.08 cm in diameter, 91.4 cm long, and pressurized to 3 atm. The tubes are wrapped in polyethylene, as shown in the figure. The total volume of ^{3}He gas employed by this design is 16.7 liters.

II. Methods

We have developed a replacement design based on boron-coated straw (BCS) detectors, as illustrated in Fig. 2. The ground rules for this replacement required utilization of the precise form factor dimensions of the existing ^{3}He device. In our design, BCS detectors are distributed inside a high-density polyethylene (HDPE) moderator, with dimensions 20.1 cm × 6.63 cm × 91.4 cm (7.9"×2.6"×36"), occupying the exact same volume of the ^{3}He-based design of Fig. 1. The moderator has 76 holes accommodating an equal number of detectors. Each BCS detector is 4.43 mm in diameter, 91.4 cm long, and lined with 1 μm thick $^{10}B_4C$. The weight of the whole assembly is 18 lbs. The design challenge again is to achieve similar neutron detection efficiency as the ^{3}He design, without increasing the overall size and weight of the assembly, while at the same time providing robust operation in the field.

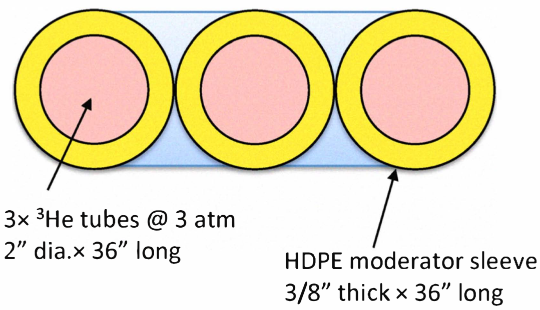

Fig. 1. Detector design with 3 ^{3}He tubes.

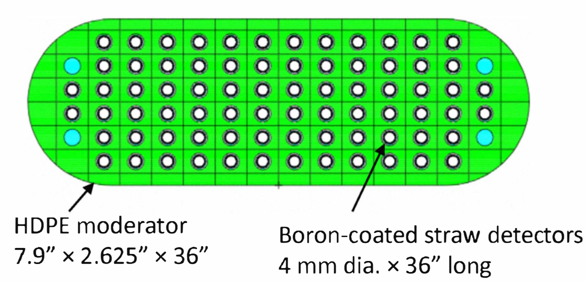

Fig. 2. Proposed detector design with 76 boron-coated straw detectors.

Two prototype modules, like the one shown in Fig. 3, were built and tested. The modules were installed inside a pod-like fixture that supported them together with gamma detectors (NaI crystals) in-between. Testing was conducted with a ^{252}Cf source placed 2 m away, as pictured in Fig. 4. Both the source and the pod were supported 1.3 m above the floor. The source was configured with and without a HDPE moderator. The ^{3}He-based pod (2 modules) was also tested under identical conditions for comparison.

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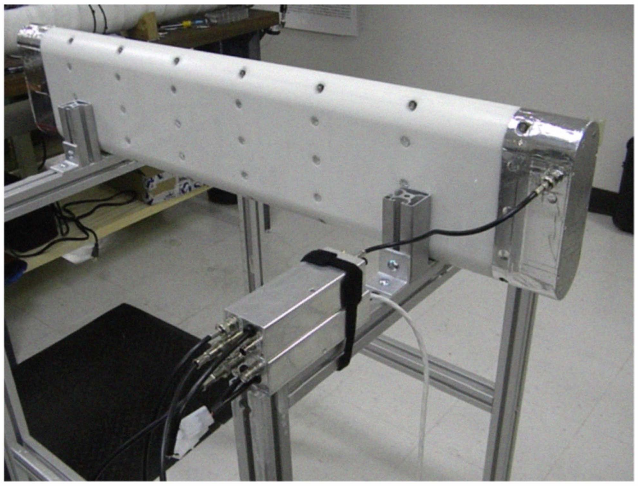

Fig. 3. Prototype populated with 76 straw detectors.

Fig. 4. Experiment setup with a ^{252}Cf source, shown on the left, supported 2 m away from the detectors.

III. Results

The count rate measured in 2 modules combined (i.e. 76+76 straws, or 3+3 ^{3}He tubes) was for the straw-based system:

- 0.76 cps/ng for the bare source, and
- 1.0 cps/ng for the moderated source

For the ^{3}He-based system the rates were:

- 0.81 cps/ng for the bare source, and
- 1.4 cps/ng for the moderated source

These rates are depicted graphically in Fig. 5.

The measured background rate (single module) was 0.55 cps for the BCS-based module, and 1.7 cps for the ^{3}He-base module.

The ratio of minimum detectably activities (MDA) between the two detectors will be proportional to $\sqrt{Rb}/Rs$, where R_b is the background rate, and R_s is the source rate. Since the background rate in the BCS-based detector is 3 times lower than that of the ^{3}He-based system, the MDA of the straw replacement is substantially lower (better), as illustrated in Fig. 6.

IV. Discussion

It is easy to show, based on neutron cross-section tables, that 34.5 m of a 4-mm diameter BCS detector with a 1-μm

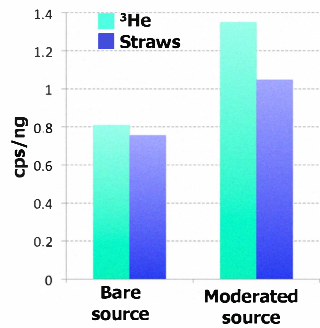

Fig. 5. Rates measured in the BCS-based and ^{3}He-based detectors, for a moderated and bare ^{252}Cf source.

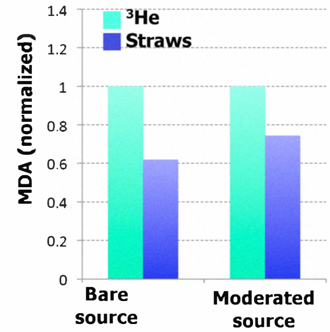

Fig. 6. Minimum detectable activity (MDA) calculated for the 2 detectors.

thick coating offers the same neutron detection efficiency as 1 liter of ^{3}He gas. Based on this equivalency, the 16.7 liters of ^{3}He gas employed in the detector of Fig. 1 would require 576 m of straw detectors. However, results show that the proposed design with only 70 m of straw can achieve similar neutron sensitivity. This 8-fold saving is possible due to the small diameter of the BCS, which allows for the detection medium (boron) to be efficiently dispersed throughout the moderator, dramatically increasing the probability that neutrons are captured in the detector, rather than escape, or be absorbed in the moderator itself.

V. Conclusion

Boron-coated straw detectors distributed in a moderator can perform very well in sensitivity comparisons with ^{3}He gas where other technologies fall short. At the same time, the BCS offers distinct additional advantages over conventional ^{3}He-based detectors, and alternate technologies such as $^{10}BF_3$ tubes and ^{10}B-coated rigid tubes. These include many-times faster electronic signals, no pressurization, improved gamma-ray rejection, no toxic or flammable gases, easy maintenance, and effective field use compatibility.