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^{3}He and BF_3 neutron detector pressure effect and model comparison

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ABSTRACT

Radiation detection systems for homeland security applications must possess the capability of detecting both gamma rays and neutrons. The radiation portal monitor systems that are currently deployed use a plastic scintillator for detecting gamma rays and ^{3}He gas-filled proportional counters for detecting neutrons. Proportional counters filled with ^{3}He are the preferred neutron detectors for use in radiation portal monitor systems because ^{3}He has a large neutron cross-section, is relatively insensitive to gamma-rays, is neither toxic nor corrosive, can withstand extreme environments, and can be operated at a lower voltage than some of the alternative proportional counters. The amount of ^{3}He required for homeland security and science applications has depleted the world supply and there is no longer enough available to fill the demand. Thus, alternative neutron detectors are being explored.

Two possible temporary solutions that could be utilized while a more permanent solution is being identified are reducing the ^{3}He pressure in the proportional counters and using boron trifluoride gas-filled proportional counters. Reducing the amount of ^{3}He required in each of the proportional counters would decrease the rate at which ^{3}He is being used; not enough to solve the shortage, but perhaps enough to increase the amount of time available to find a working replacement. Boron trifluoride is not appropriate for all situations as these detectors are less sensitive than ^{3}He, boron trifluoride gas is corrosive, and a much higher voltage is required than what is used with ^{3}He detectors. Measurements of the neutron detection efficiency of ^{3}He and boron trifluoride as a function of tube pressure were made. The experimental results were also used to validate models of the radiation portal monitor systems.

1. Introduction

Radiation portal monitor (RPM) systems are used to interdict illicit radioactive sources being transported across international borders. RPMs must meet specified criteria for both gamma ray and neutron detection [1,2]. Currently, plastic scintillators are used to detect gamma rays and ^{3}He gas-filled proportional counters are used to detect neutrons [3]. However, the supply of ^{3}He has become limited and the present demand level can no longer be sustained [4]. Alternative technologies that can fulfill the homeland security neutron detection requirements are being explored [5]. Options to extend the available ^{3}He until an alternative can be identified may need to be considered. One possibility for reducing the amount of ^{3}He used in the RPMs is to decrease the partial ^{3}He pressure in the tubes [6]. Decreasing the tube pressure will decrease the neutron detection efficiency; however, if a lower pressure ^{3}He tube can meet the required neutron detection capability then the amount of ^{3}He required for each RPM will be reduced [7].

Another technology that has been identified as a candidate for replacing ^{3}He is boron trifluoride (BF_3) gas-filled proportional tubes [8]. Boron trifluoride gas has the disadvantage of being corrosive, having a lower neutron cross-section and requiring a higher operating voltage than ^{3}He. The efficiency of BF_3 tubes increases with increasing tube pressure; however, the required operating voltage also increases. Higher voltages are more difficult to deploy in field conditions where high humidity can produce breakdown. Thus, using an increased number of lower pressure tubes to decrease the required voltage, while maintaining the required neutron efficiency, may be a more practical option for BF_3 proportional counters. One of the constraints for any ^{3}He replacement for use in RPMs is that it fits into the space available in the systems that are currently deployed. Therefore, the number of tubes that were tested simultaneously was limited to what would fit into the existing RPM moderating box. Models of the systems have been created and used for parametric studies to predict system response. The models were validated by comparing the theoretical results of the system efficiency generated with different ^{3}He and BF_3 pressures and various numbers of tubes with the experimental data.

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2. Equipment and experiments

Pacific Northwest National Laboratory (PNNL) has made measurements to test the neutron detection efficiency of ^3He and BF_3 tubes as a function of tube pressure. The measurements were performed by positioning the tubes in the existing polyethylene moderating assembly in a Science Applications International Corporation (SAIC) re-locatable RPM system (Fig. 1a). External electronics were used for all the measurements to increase the range of voltages available for testing, as not all the tubes were operated at the standard operating voltage for the currently deployed 300 kPa (3 atm) ^3He tube. The appropriate operating voltage for each tube pressure was determined by generating a voltage plateau curve. The same electronics were used for all the tests except for the 120 kPa BF_3 test, which used a different multi-channel analyzer than subsequent measurements.

Four different ^3He partial pressure tubes and two different BF_3 pressure tubes, manufactured by LND Inc. (height 182.88 cm (72 in.), diameter 5.08 cm (2 in.)) were tested. The tube pressures and configurations tested are shown in Tables 1 and 2. The experimental and theoretical efficiencies for each configuration are further discussed in Section 3.

The measurements were made with a ^{252}Cf neutron source. The source activity at the time of the measurements was 21.5 ± 1.23 μCi. The source was located in a polyethylene pig positioned 2 m from the front panel of the RPM with the center of the pig at the same height as the midpoint of the moderating box.

All ^3He and BF_3 calculated results shown were obtained using the Monte-Carlo N-Particle transport code, MCNP, and by tallying on the total number of neutron capture reactions in the target gases [9]. One and two ^3He tubes with pressures up to 300 kPa and one through four 107 and 120 kPa BF_3 tubes were modeled in the SAIC re-locatable base (Fig. 1b). The theoretical results were compared with the data from the experimental measurements.

3. Measurements and results

The detection efficiency of the ^3He tubes increased with increase in pressure (Tables 1), following a logarithmic trend. The model predicted the same trend that was observed experimentally; however, the models under-predicted the values of the experimental results by approximately 7–9% (Fig. 2). The neutron

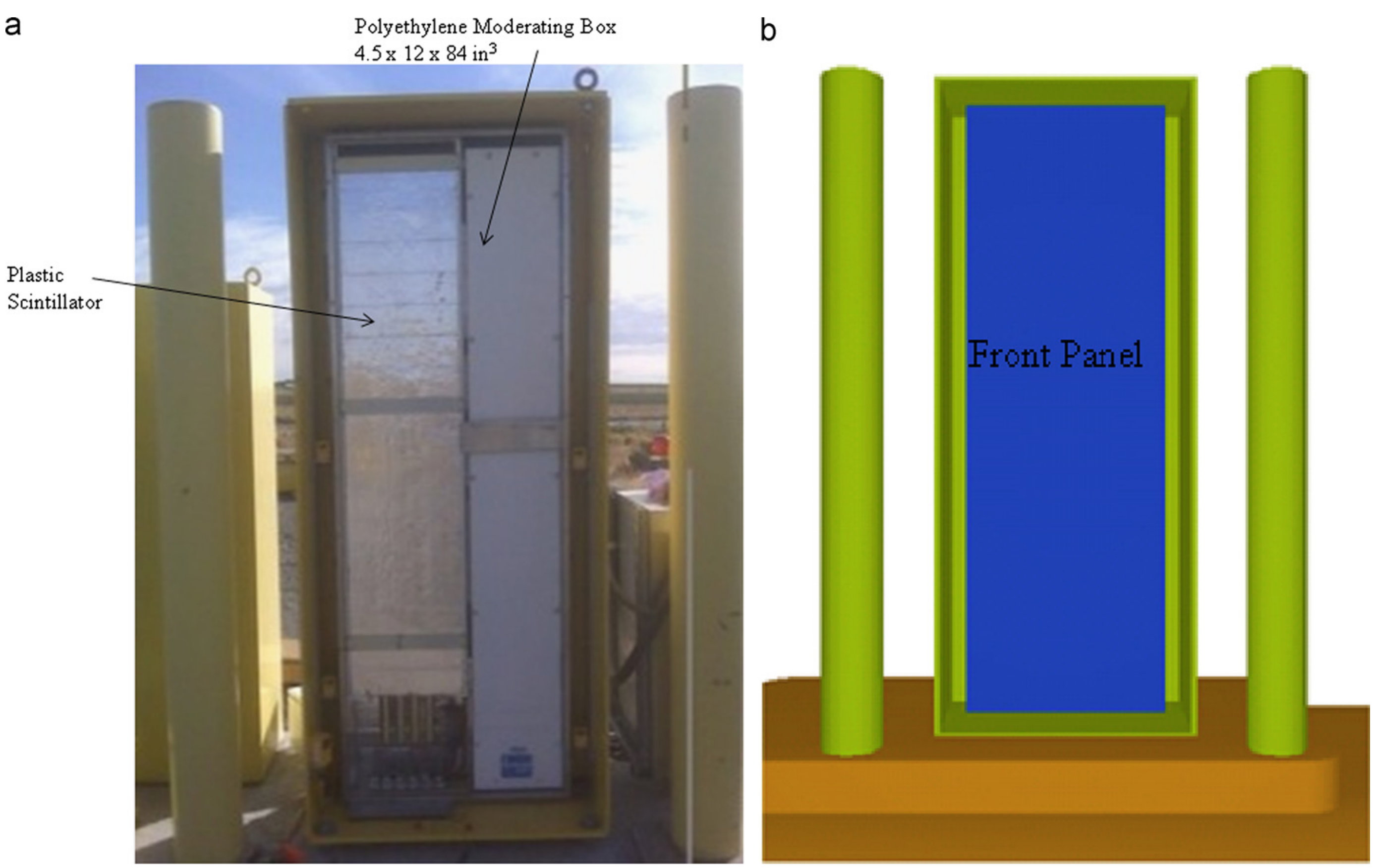

Fig. 1. (a) SAIC re-locatable RPM used for these measurements (with the front panel removed) and (b) MCNP model of the SAIC re-locatable base.

Table 1
^3He tube pressures and configurations tested and the corresponding neutron detection efficiencies.

Pressure (kPa)	Number of tubes	Theoretical efficiency (cps/ng ^{252}Cf)	Experimental efficiency (cps/ng ^{252}Cf)
101	1	1.75	1.90
101	2	2.88	3.10
200	1	2.37	2.63
253	1	2.57	2.81
300	1	2.73	3.05
300	2	4.14	4.04