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A Study of ^{3}He Detectors for Active Interrogation

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E. H. Seabury
D. L. Chichester

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E.H. Seabury and D.L. Chichester, *Senior Member, IEEE*

Abstract–**^{3}He proportional counters have long been used as neutron detectors for both passive and active detection of Special Nuclear Material (SNM). The optimal configuration of these detectors as far as gas pressure, amount of moderating material, and size are concerned is highly dependent on what neutron signatures are being used to detect and identify SNM. We present here a parametric study of the neutron capture response of ^{3}He detectors, based on Monte Carlo simulations using the MCNPX radiation transport code. The neutron capture response of the detectors has been modeled as a function of time after an incident neutron pulse.**

I. INTRODUCTION

^{3}He proportional counters have long been used as neutron detectors for both passive and active detection of Special Nuclear Material (SNM). The optimal configuration of these counters as far as gas pressure, geometry, amount of moderating material is concerned is highly dependent on what neutron signatures are being used to detect and identify SNM. In particular, the time regime in which neutron measurements of interest occur is critical in an active interrogation system. Currently there is a shortage [1] of ^{3}He available for production of new proportional counters. Knowing the response of a particular volume and pressure of a ^{3}He-based detector to the expected neutron source might allow use of existing counters rather than having new counters of a different pressure or geometry constructed.

Active interrogations systems rely on a (usually) pulsed source to induce a nuclear reaction in the target. We are interested in particular in distinguishing a pulsed neutron source from neutrons produced by fission in SNM. An example of the response of a ^{3}He proportional counter to a 300 microsecond pulse from a deuterium-tritium neutron generator as a function of time is shown in Fig. 1 below. As can be seen in the figure, the counter reaches a plateau during the neutron pulse, and then the counts decay rapidly to a baseline value associated with cosmic-ray background-induced neutrons scattering about in the room. Detection of neutrons produced through fission of SNM could occur in three different time regimes in this simulation. Counting of neutrons in excess of the generator pulse could occur during the beam pulse. Neutrons could also be counted in the die-away region or in the delayed region. The pressure, amount of moderator, and presence of neutron poisons will determine which of these time regions is most effective in measuring the presence of SNM. Also shown in the figure is the response of the same counter system to several kilograms of depleted uranium (DU) [2], surrounded by moderating materials..

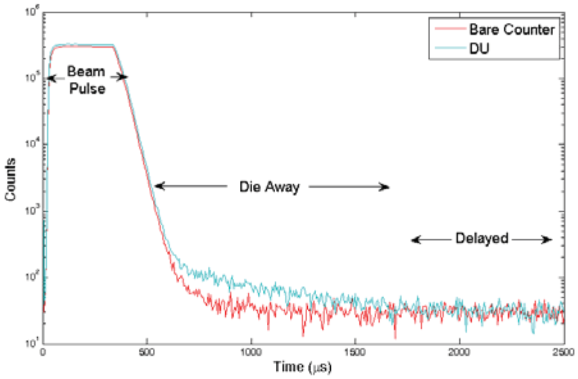

Fig. 1. Time response of ^{3}He proportional counter

We report here on MCNPX [3] simulations of the response of ^{3}He proportional counters to three different neutron sources, a deuterium-deuterium fusion source, deuterium-tritium fusion source, and a Watt spectrum source from ^{235}U fission. Various parameters of the proportional counters have been changed between simulations. These include the ^{3}He tube pressure, the amount of moderating material around the tube, and whether neutron poisons such as cadmium or boron are wrapped around the counter. In particular we at INL are interested in the time-response and efficiency of the counters and their application to the detection of Special Nuclear Material.

II. SIMULATIONS

Simulations of proportional counters were performed using the MCNPX code from Los Alamos. We were interested in determining overall trends in performance by varying parameters such as the ^{3}He tube pressure and moderator. A simple geometry was used in the simulations and is shown in Fig. 2. The ^{3}He proportional counter consisted of an aluminum tube, 0.5-mm thick, surrounded by polyethylene. The tube was filled with ^{3}He gas at various pressures. No additional quench gas was used in the simulations. The polyethylene was surrounded by cadmium in some simulations. The simulation also included a floor consisting of a concrete pad over sandy soil. The center of the counter was placed 50 centimeters above the floor, in air at one atmosphere pressure. Neutron capture events in the gas were tallied as a function of time after the instantaneous neutron burst of the source. The time response of the counter was binned into two microsecond bins, up to one millisecond.

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E. H. Seabury is with Idaho National Laboratory, Idaho Falls, ID 83415 USA (telephone: 208-526-5303, e-mail: Edward.Seabury@inl.gov).

D. L. Chichester is with Idaho National Laboratory, Idaho Falls, ID 83415 USA.

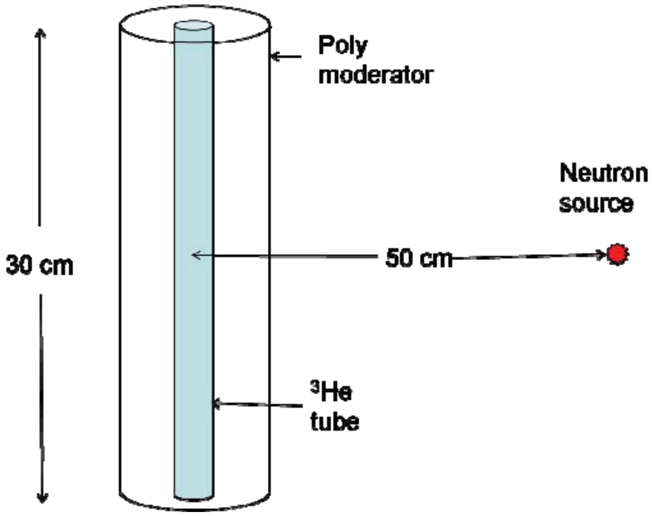

Fig. 2: Simulation geometry

A. *Effect of Varying the Tube Pressure*

The pressure in the ^{3}He tube was varied between 1 and 15 atmospheres. The output is shown in Fig. 3 below. The tube was surrounded by 1-inch of polyethylene, with 1-mm of cadmium outside the polyethylene. The effect of convolving a 300 microsecond neutron pulse from a deuterium-tritium neutron generator is shown in Fig. 4.

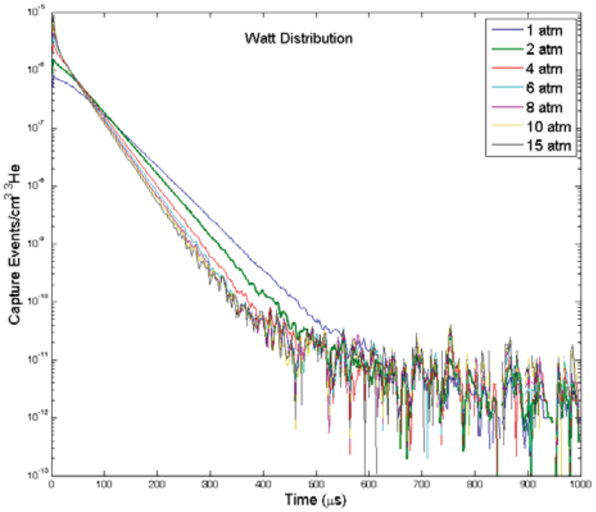

Fig. 3. Effect of Tube Pressure

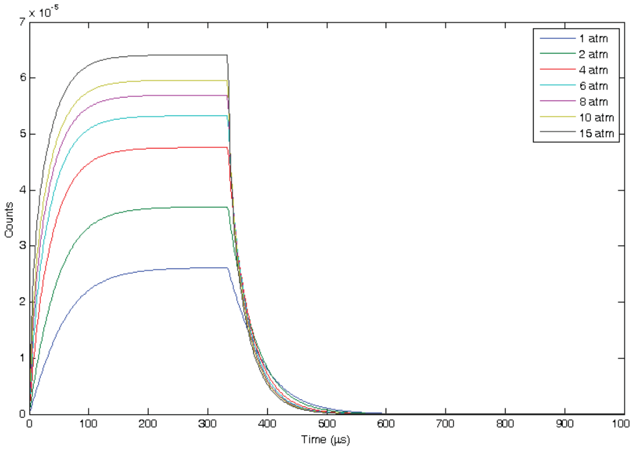

Fig. 4. Effect of tube pressure, convolved with 300µs neutron pulse.

As can be seen in the two figures above, varying the pressure in the ^{3}He tube changes both the relative efficiency and the decay time of the counter. The results for the three different neutron sources are shown in Table 1. The decay time was determined by fitting a decaying exponential to the counter response between 30 and 300 microseconds after the neutron burst. The relative efficiency is the total number of capture events normalized to those of the 1-atm tube with the Watt neutron distribution.

Increasing the pressure increases the overall efficiency of the counter for all three neutron energy distributions used, but not linearly. Similarly, increasing the pressure results in shorter decay constants, but with smaller changes after the gas pressure reaches approximately four atmospheres in this case.

TABLE 1. EFFECTS OF TUBE PRESSURE

^{3}He Press. (atm.)	Rel. Eff. (Watt)	Decay Const (µs)	Rel. Eff. (DD)	Decay Const. (µs)	Rel. Eff. (DT)	Decay Const. (µs)
1	1	49.3	0.65	49.9	0.14	49.6
2	1.4	41.2	0.92	41.4	0.19	42.1
4	1.8	36.3	1.18	36.5	0.25	38.4
6	2.04	34.6	1.32	35.1	0.28	37.2
8	2.18	34.0	1.41	34.2	0.30	36.3
10	2.28	33.8	1.47	33.9	0.31	35.7
15	2.45	33.4	1.59	33.6	0.33	35.4

B. *Effect of Varying the Moderator Thickness*

The effect of varying the thickness of the polyethylene moderator surrounding the ^{3}He tube was also studied. In these simulations, the diameter of the poly cylinder was increased. The polyethylene was surrounded by cadmium, and the ^{3}He gas pressure was held at 4 atmospheres. The distances listed in Table 2 are the distance between the edge of the ^{3}He tube and the edge of the poly cylinder. The results of the simulations are shown in Fig 4 below.

Increasing the thickness of the polyethylene moderator has a dramatic effect on both the relative efficiency and the decay constant of the proportional counter. Table II shows the decay constants and relative efficiencies for the three neutron energy distributions. The relative efficiencies in the table are normalized to the Watt energy distribution with ½-inch polyethylene moderator.

For this four-atmosphere case,, the maximum efficiency for the Watt energy spectrum occurs when the moderator is 2.5 inches thick. For the DD spectrum the maximum is at 3.0 inches and for the DT it is at 5.0 inches. The decay constant increases dramatically with increasing moderator thickness, as would be expected.

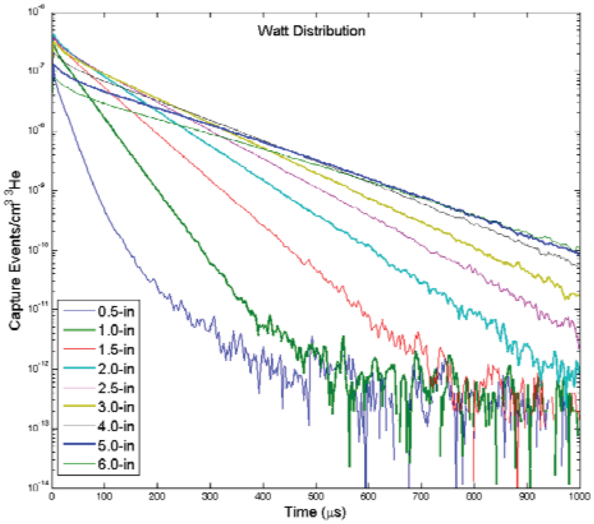

Fig 3. Effect of varying the moderator thickness.

TABLE II. EFFECT OF MODERATOR THICKNESS

Mod. (in)	Rel. Eff. Watt	Decay Const. (μs)	Rel. Eff. (DD)	Decay Const. (μs)	Rel. Eff. (DT)	Decay Const. (μs)
0.5	1	24.0	0.49	26.3	0.10	32.1
1.0	5.55	36.3	3.6	36.5	0.76	38.4
1.5	10.8	56.0	8.4	55.8	2.0	56.1
2.0	14.3	74.4	12.5	73.9	3.5	74.0
2.5	15.5	90.1	14.9	88.9	4.9	88.3
3.0	15.1	104	15.8	101	6.0	99.6
4.0	11.9	130	14.2	121	7.4	114
5.0	8.29	151	10.9	137	8.0	122
6.0	5.48	164	7.67	150	8.0	127

C. Effect of Tube Length & Cadmium

The length of the aluminum tube was varied to determine the overall effect on efficiency and decay time. The ^{3}He gas pressure was held at 4 atmospheres for all simulations and one inch of polyethylene surrounded the tube. The length of the polyethylene cylinder was increased along with the length of the aluminum tube. Each length case was performed twice, once with 1-mm cadmium surrounding the polyethylene, and once with no cadmium. The results are shown in Table III below where the relative efficiencies are normalized to the 3-inch case with cadmium surrounding the polyethylene.

Increasing the length of the ^{3}He tube increases the efficiency per unit length, with the maximum value occurring for the 12-inch tube length. The decay constant of the counter was not affected by the length of the tube in these simulations.

The cadmium surrounding the polyethylene did not have a strong effect on either the relative efficiency of the counters or their decay constants. The relative efficiency of the cadmium-surrounded counters was slightly lower than their bare counterparts.

TABLE III. EFFECTS OF TUBE LENGTH AND CADMIUM

Tube Length (in)	Rel. Eff. (Watt) w/Cd	Decay Const. (μs)	Rel. Eff (Watt) w/o Cd	Decay Const. (μs)
3	1	36	0.98	37
6	2.33	36	2.29	37
12	4.72	36	4.65	37
24	7.91	36	7.84	37
36	9.58	36	9.46	37

CONCLUSIONS

There are a number of properties one could alter in the design of a ^{3}He -based system for the detection of SNM, depending on the time region in which detection is to occur. If the neutron source is not pulsed for example, then the time constant of the proportional counter is largely irrelevant and one would maximize the efficiency of the counter to increase the likelihood of detection of fission neutrons. The choice of tube length, pressure, and moderator thickness would be based on the concept of operations for the system as well as the cost.

Similarly, if one were using a pulsed neutron source and interested in detecting neutrons in the die-away or delayed time regions, one would choose a configuration giving a decay constant suitable for the repetition rate of the neutron source, while still maximizing efficiency. Finally, if one had little choice in tube length or pressure, the efficiency of the configuration can be chosen to give the maximum obtainable efficiency with the desired decay time by adjusting the moderator around the tube.

ACKNOWLEDGMENT

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