Simulation study of n-gamma shielding for gamma detectors of Tagged Neutron System with D-T neutron

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Introduction

Tagged neutron method (TNM) is being used worldwide for various applications in fundamental and applied research. Some of them are studies of nuclear physics reactions (n, n), (n, n' γ), (n,2n), (n, f) induced by 14.1 MeV neutrons and their use in illicit material detection [1,2], soil carbon measurement etc. For most of the TNM based applications, an array of gamma detectors is used in order to have sufficient counting statistics in small duration of the data acquisition particularly for field applications. One of the most important problems to be taken care is to protect the detectors from direct exposure of source neutrons and to suppress the neutron-gamma background produced by scattered neutrons (or neutron induced gamma produced on neutron interactions with surrounding materials), hitting the scintillation detectors. Thereby enhancing the signal to noise (S/N) ratios. A suitable shielding around gamma detectors can fulfill this aim. To shield high energy neutron (e.g., 14 MeV neutrons) there is no single material providing effective shielding, because the absorption cross sections are very small. In such cases layers of different materials are used together in designing the shielding. Most common fast neutron shielding materials are Lead (Pb), Bismuth (Bi), Tungsten (W), Iron (Fe), Polyethene/ borated Polyethylene of high density (BHDPe) etc. In heavy elements like tungsten (W) and lead (Pb), dominant reactions at 14 MeV are elastic scattering (n, n), (n, 2n) reaction, the cross sections of which are relatively high. The typical energy of the outgoing neutrons from the (n, 2n) reaction ranges from 0.5 MeV to 1.5 MeV. These neutrons should be further slowed down and for that one can use a material with a large inelastic scattering cross section. For example, fast neutrons are inelastic scattered from iron (Fe) or steel via (n, n' gamma) inducing gamma-ray emission, from the 846 keV level. During the inelastic process a number of characteristic gamma rays are emitted. Once the neutrons are slowed, they must be absorbed by a neutron absorber. Boron (^{10}B) has high cross section for capturing thermal neutrons. Borated polyethylene or borated high-density polyethylene (BHDPE) can be placed on the outside of the shield, so that after being slowed down to thermal energy, the neutrons can be captured by boron. Further, to absorb gammas produced during the process of moderation and absorption, a material of high Z like lead is preferred.

The objective of this study is to find effective and optimized shielding made up of combination of different materials lead (Pb), iron (Fe), and borated polyethylene with the constraints of overall shielding length within 50-70 cm and minimum use of lead to avoid heavy shielding design.

Simulation and Results

The simulation was carried out in two different geometric configurations using GEANT4 with BIC_HP physics list. In the first configuration we modelled a point source emitting 14MeV neutrons in a solid angle and a 3-inch size cylindrical BGO detector [3] placed at 75 cm from the source. Blocks of different materials (30cm (width) x 30 cm (height) of varying thickness were placed between the source and detector as shown in Fig.1. Source was at 6 cm from the first sample layer to incorporate the size of neutron generator tube in actual setup. Neutron histories of 10^7 were run. Energy spectrum at BGO detector has the contribution of the source neutron transmitted through shielding, scattered neutrons hitting the detector and the gamma produced on interaction of these neutrons with shielding materials. Simulated energy spectra have been analyzed in terms of the count load to reveal the effects of the shielding material as detailed in table1.

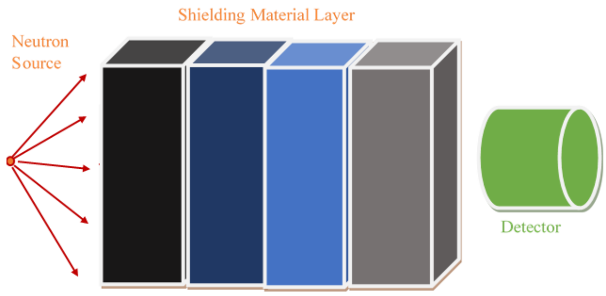

Fig.1 Schematic of the simulated configuartion1 with point neutron source

It can be seen that among various combinations of material, the total count load reduces to minimum with the use of Fe (30cm) + BHDPe (20cm) and Pb (10cm) layers. This combination was taken for the design of shielding structure of geometry holding 12 detectors as discussed below.

Table1: Different shielding material combination and counts obtained at detector

Shielding Material	Total counts (0-8 MeV)	Counts in the energy range of (1-MeV)
Air	536386	273760
0+65BHDPe+0	5523	2525
0+55BHDPe+10Pb	2415	811
20Fe+35BHDPe+5Pb	806	335
20Fe+30BHDPe+10Pb	712	248
30Fe+20BHDPe+5Pb	528	233
30Fe+25BHDPe+5Pb	454	180
30Fe+20BHDPe+10Pb	396	139

In configuration 2, a distributed source (1mm thick, 30 mm diameter) and a trapezoidal shape structure of 60 cm long with 8 cm thick wall was modeled. At the end of trapezoidal, 12 BGO detectors were arranged in a square, oriented at 30-degree angle (as shown in Fig.2.). This design was an approximation of the experimental setup configuration. Energy spectra were recorded (Fig.3.) for three different positions of the detector array. In the first position, detectors were completely covered with 8 cm thick shielding wall. In the second position, detectors were pulled outside by 3cm such that nearly half part of the detector is covered with shielding wall. In the third position detectors were further pulled out that only 20% of detector part was in shadow of shielding wall. For these different positions results are presented in table 2. We can infer that position 2 is the optimized one for the better S/N ratio.

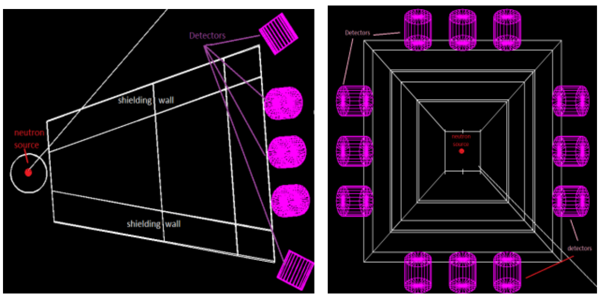

Fig.2 Geometry of configuration2 with gamma detectors arranged (left) side view (right) front view.

Table2: Simulated results and evaluated count values for different detector position in trapezoidal geometry

Shielding material	Total counts (0-8MeV)	Total counts in (1-8MeV)	Count ratio with/without shield for 1-8 MeV
Air	130720	63228	-
30Fe+20BHDPe+10Pb (Det Position1)	65569	11889	19 %
30Fe+20BHDPe+10Pb (Det Position2)	33214	5807	9.2%
30Fe+20BHDPe+10Pb (Det Position3)	31584	6777	10.7%

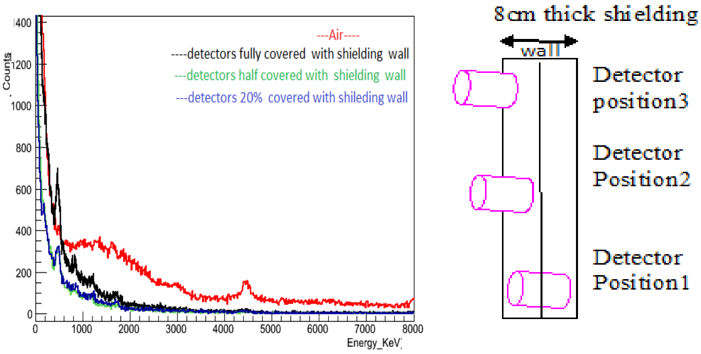

Fig.3 Energy spectra (left) with and without (air) shielding at (right) different detector positions

Results

A composite shielding using different materials was designed via simulation and the optimized size was obtained with 30 cm Fe + 20 cm BHDPe +10 cm Pb. The shielding assembly is under fabrication for experimental implementation with detector holding structure.

References

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