Fabrication and Testing of Beam dump shielding for Neutron detector array at IUAC

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Introduction

This article reports the design and test results of the beam dump shielding fabricated for the neutron detector array at IUAC, New Delhi. The detector array in its final phase will consist 100 neutron detectors mounted on a 175 cm radius dome structure. The beam-line will be terminated by a dump 4 m upstream, collecting the beam on a tantalum sheet. The beams can interact with the material of the dump initiating secondary radiations including fast neutrons. In order to limit the background radiation reaching the neutron detectors, an effective shielding surrounding the beam dump needs to be installed. We have designed and fabricated a beam dump shield for the neutron detector array beam line at IUAC. To design the beam dump shielding, detailed analysis of the material composition and geometry has to be considered. For this purpose, the scattering of neutrons from different materials and their energy attenuation was studied by performing Monte-Carlo calculation using FLUKA[1], particle transport and interaction code developed at CERN.

We have selected paraffin wax as the shielding material as it is enriched with hydrogen and due to its easy availability. As the fast neutrons get thermalized in the medium, there is a high probability of thermal neutron capture by hydrogen, emitting 2.225 MeV gamma rays. This can be minimized by adding boron into the shielding medium which leads to ^{10}B(n, ^{4}He)^{7}Li reaction giving only 0.478 MeV gamma rays and also reduces the probability of thermal neutron capture by hydrogen. The mixing ratio of paraffin and borated material is optimized using FLUKA. The composition of the shielding material is finalized as 70% (mass fraction) of paraffin wax mixed with 30% of boric acid (giving 5% of boron).

The shielding geometry has rectangular shape consisting of borated paraffin blocks. Overall dimension of the shielding blocks are 100 (l)x80(h)x80(w) cm^3 and total weight is 500 kg. An outer layer of 7 cm lead is sufficient to attenuate the secondary gamma rays produced by the beam dump. The shielding blocks are fabricated at IUAC workshop by melting and mixing the composition of paraffin and boric acid under temperature controlled environment. Multiple blocks of 20 cm thickness were fabricated to assemble the whole unit.

The effectiveness of borated paraffin in neutron shielding is tested in an off-line experiment using a neutron source ^{252}Cf. This is done by studying the time of flight (TOF) of neutrons having different energy from the ^{252}Cf source. ^{252}Cf emits neutrons as a result of spontaneous fission. About 3.1% of decay of ^{252}Cf is via spontaneous fission, giving nearly 6-8 gamma rays and an average of 3.75 neutrons [2]. The time of flight of neutrons in coincidence with gamma rays is studied using two fast detectors. For this, we used a 5”x5” BC501-A organic liquid scintillator and an inorganic scintillator, BaF$_2$ of crystal thickness 2". In addition to being a fast scintillator, BC501-A provides excellent n-gamma discrimination as well. BaF$_2$ is an efficient gamma detector and also provides excellent timing.

Experiment Setup

In the time of flight setup BaF$_2$, placed very close to the source position, is used as the start detector and BC501-A as stop detector providing a flight path of 70.5 ± 0.5 cm. The gamma rays emitted from the source is detected almost instantaneously (compared to TOF of neutrons) and the detector signal is sent to a CFD of threshold ~30 mV for time pick-off. The CFD output is given as the START to Ortec TAC 566 with range of 500 ns. The neutrons or gamma rays detected in BC501-A in is fed into custom made PSD (Pulse Shape Discrimination) module [3]. The threshold and gain of PSD module are adjusted to accept neutrons in the energy range ~500 keV to 20 MeV. The CFD output from the PSD module STOP's the TAC. The TAC and PSD outputs are fed to a Phillips ADC 7164.

In order to find a reference point in the time of flight spectra, we have used ^{22}Na gamma source. The pair annihilation gamma rays are detected in both the detectors. A peak in the time of flight spectra is observed at channel number 2170 corresponding to gamma ray flight time of 2.35 ns. Then the ^{22}Na is replaced by the ^{252}Cf and the coincidence spectra is collected for nearly nineteen hours which is shown in Fig.1(solid lines).

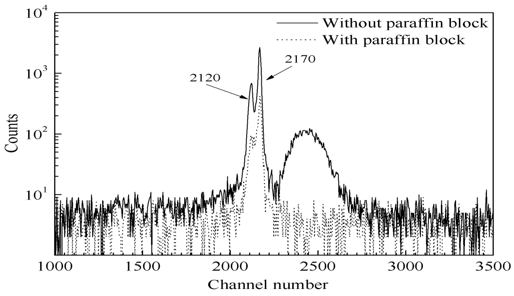

Fig. 1 TOF spectra of neutrons and gamma rays from ^{252}Cf. Solid line spectrum represents TOF distribution without paraffin block and doted line spectrum is with paraffin block.

The solid line spectrum shows three distinguishable peaks; two sharp peaks at channel number 2120 and 2170 and a broad peak. The peak at 2170, coincides with reference gamma peak, results from gamma-gamma coincidence and the broad peak corresponds to gamma-neutron coincidence [4]. The energy spectrum of neutrons from ^{252}Cf is evaluated from the time of flight of neutrons. The neutron energy varies from ~500 keV to ~10 MeV and it is shown in Fig.2. The peak, at channel number 2120, on the left shoulder of the gamma-gamma coincidence peak is purely of background origin. The background spectra is shown in Fig. 3.

Now a borated paraffin block of thickness 40 cm is introduced in between the source and the neutron detector BC501-A. The TOF spectrum obtained with this setup is shown in Fig. 1 (with doted line).

The spectrum shows excellent shielding of fast neutrons by the borated paraffin block.

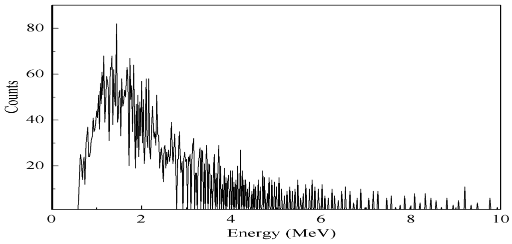

Fig. 2 Energy spectrum of neurons from ^{252}Cf.

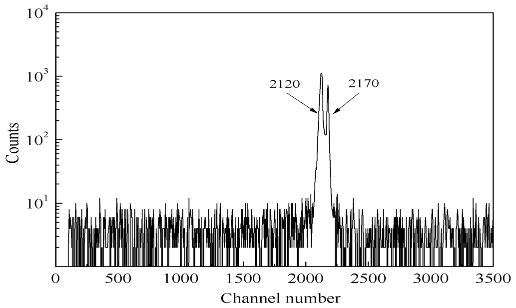

Fig. 3 Time of flight spectrum without source

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