Neutron flux attenuation measurements in borated polyethylene blocks at Apsara-U reactor

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Introduction

Borated polyethylene (BPE) is widely used as neutron shielding material. In BPE, neutrons are moderated by elastic scattering from the hydrogen nuclei present in polyethylene and are subsequently absorbed by ^{10}B through the $^{10}B(n,\alpha)$ reaction. With a probability of 0.937, the ^{7}Li nucleus is left in its first excited state by the $^{10}B(n,\alpha 1\ \gamma)^{7}Li^{*}$ reaction ($\sigma_{Thermal}$ ~ 3600 b at 25.3 meV). The excited $^{7}Li^{*}$ decay emits a 478 KeV gamma ray. The other possibility, with a probability of 0.063, is that the ^{7}Li nucleus is left in its ground state via the $^{10}B(n,\alpha)$ reaction ($\sigma_{Thermal}$ ~ 3600 b at 25.3 meV). No gamma radiation is emitted in this case.

In order to study the neutron attenuation properties of this material, an experiment was performed at the exit end of Apsara-U beam tube BT-05 [1]. Apsara-U is a research reactor recently commissioned at BARC. Four blocks of BPE (size-100cm X 50cm X 5cm and density ~ 1.1gm/cc), containing 5% nat. Boron were used for this experiment.

Bare/Cd-covered Au and Ni activation detectors (see Table 1) were installed in between the BPE slabs. The measurement of their induced activities at different locations and their ratios provided information on the neutron flux attenuation behavior of thermal/epithermal neutrons in BPE.

Table 1: Foil reactions used for the study

Foil	Target Reaction	Energy Sensitivity
Au-bare	$^{197}Au(n,\gamma)^{198}Au$	Thermal
Au-Cd	$^{197}Au(n,\gamma)^{198}Au$	Epithermal
Ni	$^{58}Ni(n,p)^{58}Co$	Fast

Experiment Details

For measurement of neutron fluxes and its attenuation in BPE, activation detectors were placed at the surface of the blocks facing the beam hole. The arrangement of the BPE blocks in front of the beam tube is shown in Fig. 1. Activation detectors were placed such that four bare Au foils were installed in same line of sight but at different thicknesses of BPE. At the other edge of the beam tube cross-section, four Cd-covered Au foils were similarly installed. The foils on the front surface of 1st block sees the incident flux, without any attenuation from BPE. For measurement of fast flux, one Ni foil was installed at the front surface of block 1. Another Ni foil was placed at the front surface of block 4.

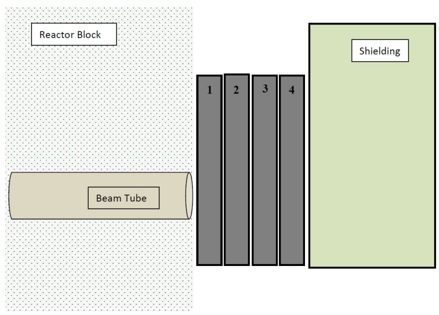

Fig. 1 BPE set-up at the exit end of beam tube BT-05 of Apsara-U reactor

After installation of experimental set-up and activation foils, the reactor was operated at 200 KW for one hour. Effective irradiation time was 4024.7 seconds. Irradiated activation detectors were retrieved after nearly 2 hours of cooling time. Gamma spectrometric analysis of the irradiated foils were carried out in an HPGe detector based high-resolution gamma spectrometer (with PC based 8K multichannel analyser with associated peak analysis software). The spectrometer had a relative efficiency of 50% and resolution of 1.9 keV at 1332 keV gamma energy of ^{60}Co. For energy calibration of the detector system, multi nuclide standard radioactivity sources (namely ^{133}Ba and ^{152}Eu) was used for calibration over an energy range of 80 - 1408 keV. The channel energy calibration data was fitted using a quadratic polynomial for commonly used 8K multichannel analysers. The energy-efficiency values were fitted in Log polynomial of order 3. Measured count rates were converted into saturation activation integral per atom.

Results

Bare and Cadmium covered $^{197}Au(n,\gamma)^{198}Au$ reaction rates per atom at different distances in BPE, are shown in Fig. 2. A sharp fall in the total reaction rate across the first BPE block can be observed. Thereafter, the fall remains exponential. Since, the capture cross-section of ^{10}B is very large for thermal neutrons, there is very high absorption of thermal neutrons in the first BPE block. The neutron spectrum incident on the front face of first block is highly thermal, as is also evident from the Gold Cadmium Ratio (CR^{Au} = 11.80) at this location. CR^{Au} for the neutron spectrum incident on other blocks was found to be close to 1, indicating a predominantly fast neutron.

The fall in Cd-covered Au reaction rate is purely exponential. Also, the slope of the Cd-covered Au reaction rate curve, is similar to that of the latter part of the total reaction rate curve. Fitting a straight line to the logarithmic value of Cd-covered Au reaction rate gives a value of slope as -0.022 (Fig. 3). Thus, to attenuate the epithermal neutron flux value by a factor of 1000, the required thickness of BPE (5% Boron concentration and 1.1 g/cc density) will be 30.9 cm. Subramanian et. al. [2] has earlier reported this value as 28 cm. The two values are close and the small difference could be due to difference in density of BPE blocks used and the difference in incident spectrum. Out of the two Ni foils installed (on the front surface of 1st and 4th BPE blocks), no measurable activity was found in the Ni foil installed at the end of set-up. In the Ni foil installed on the front surface of 1st BPE block, a total count of 47 CPS (for 810.76 KeV peak of ^{58}Co) was observed in a counting interval of 10^6 seconds. This corresponds to above 1 MeV flux of 2.87E+05 n/cm^2/sec. This flux can only be taken as an indicative one, as the statistical error involved is very high and also this flux is near the lower detection threshold of activation methods.

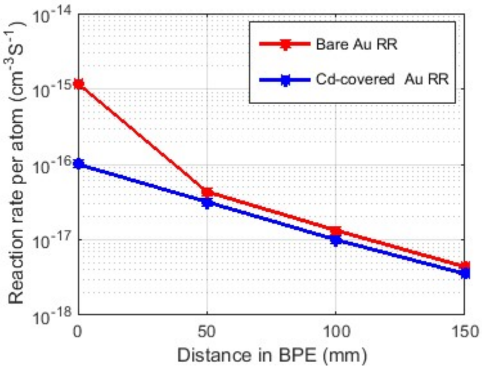

Fig. 2 Au reaction rates in BPE

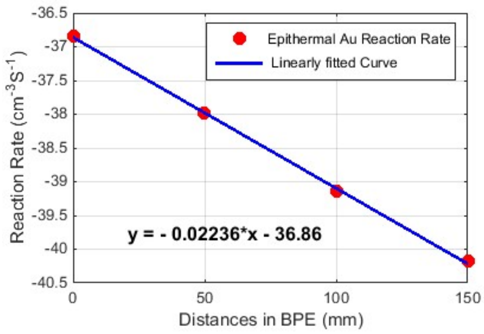

Fig. 3 Least square fit to logarithm of epithermal Au reaction rate

Conclusion

BPE was found to be very effective in shielding thermal/epithermal neutrons. For epithermal neutrons, the flux can be reduced to about 10^3 times using 30.9 cm thick BPE blocks.

References

[1] http://barc.gov.in/reactor/index.html
[2] D. V. Subramanian et. al., Ind. J. of Pure & App. Phy., Vol. 56, August 2018, pp. 583-586