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Neutron attenuation studies with borated polyethylene slabs containing 30% natural boron and its comparison with hydrogenous materials

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Providing suitable shielding for neutrons is one of the challenging tasks in fast reactor fuel reprocessing facilities. The shield material should have good moderating and absorbing properties. In order to find cost effective prospective materials, a series of neutron attenuation measurements are performed with hydrogenous materials at the south beam end of Kalpakkam Mini (KAMINI) reactor to understand their attenuation characteristics. In the present experiment, the neutron attenuating properties of borated polyethylene (BPE) containing 30% natural boron have been studied. The thermal and fast neutron flux attenuation characteristics of the material have been compared with 5% and 10% BPE and other hydrogenous materials. The thermal/epithermal neutron flux attenuation obtained with 30% BPE for a thickness of 30 cm is 1.5 times more than 5% and 10% BPE and 10 times more than normal polyethylene. It is also observed that there is no significant difference in the fast flux attenuation of 30%, 10% and 5% BPE. The outcome of the study indicates that if 30% BPE is used instead of normal polyethylene in fuel reprocessing facilities, 50% reduction in volume of shields can be achieved for thermal and epithermal neutron flux attenuation and 16 to 22% reduction in volume shields for fast neutron flux attenuation.

Keywords: KAMINI, Borated polyethylene, Polyethylene, Neutron flux, Attenuation

1 Introduction

A shield is interposed between source of radiation and the object to protect and to mitigate the radiation damage. Selection of shield for a particular application depends on the type of radiation and its energy dependent cross sections. For gamma ray shielding, high Z materials (like lead, tungsten, etc) are utilized and for attenuating neutrons, moderating (low Z) and absorbing (like boron, cadmium, etc) materials are preferred. Designing cost effective low volume shields for different types of radiations, especially for neutrons is a strenuous task. To understand the neutron attenuation characteristics of shield materials, a series of experiments are performed at the south beam end of KAMINI reactor. Apart from prospective shield materials such as ferro boron[1], ferro tungsten[2] etc., hydrogenous materials are also studied. Hydrogen content in hydrogenous materials makes thema better neutron shield at lower temperatures (<80 ^{o}C). They have potential shielding applications in the fast reactor fuel cycle facility (FRFCF) being built at Kalpakkam and also in irradiated material shipping casks. The present experimental study was conducted with 30% BPE blocks. BPE is a product typically used forradiation shielding applications. It is made from high density polyethylene plastic with various boron weight percentages ranging from 5% to 30%. It is available in standard-sized sheets as well as in blocks, slabs, and custom-size sheets. BPE is easy to work with, fabricate, and install, making it ideal for shielding applications.

The experiment was conducted by stacking 30% BPE slabs of thickness 40 cm at the south beam end of KAMINI reactor. KAMINI is a ^{233}U-fueled, light water moderated; natural convection cooled, and beryllium oxide reflected research reactor. It is located at the Indira Gandhi Centrefor Atomic Research, Kalpakkam, India. Because of the highly efficient reflector material BeO, it has a very low fuel inventory (~612 g). The reactor is designed to operate at a nominal power of 30 kW. The neutron flux available atthe South beam end is ~10^{6}–10^{7} n/(cm^{2}s).

Various activation foils[3] were fixed in between the BPE slabs and activated when subjected to neutron flux. The measurement of their induced activities at different locations and their ratios provided information on the neutron flux attenuation behavior of thermal, epithermal and fast neutrons with respect to BPE containing 30% natural boron.

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2 Materials and Methods

2.1 Experimental details

Four blocks of 30% BPE of dimensions 30×20×10 cm are used in the experiments. The density of 30% BPE material is 1.16 g/cc. The overall thickness of the shield model is 41.6 cm. Figures 1 and 2 show the slabs and their arrangement with foil holders at the KAMINI south beam end.

The activation foils were placed at five different locations in between the blocks and at each location one foil of each category was placed. The foils were so selected that their activation characteristics covered the energy spectrum from thermal to fast neutron region. The first location was at the exit of the south end beam slit and at a distance of 5 cm from the slit. The second, third, fourth, and fifth locations were at a distance of 10.4 cm, 20.8 cm, 31.2 cm and 41.6 cm, respectively, from the first location.

The experiment was done in three phases. In the first phase foils such as Au, Cu, Hf, Pt and Fe were used. During II phase foils of Cd, In, Al and salts of Mn were used. For third phase foils such as Dy, W, Mg and Zn were used. Before irradiation, the foils were cleaned, weighed and packed in paper covers. Individual foils were provided with identification numbers for easy identification during irradiation and measurements. The sets of foils for each location were packed in perforated nylon pouches. Later with the help of foil holders, they were placed in between the BPE (30%) slabs and particularly at the centre of slabs. The arrangement was made in such a way that, centre of the beam slit should coincide with the centre of the slabs. By doing this neutron flux incident on the foils was made to be maximum. During all the phases of irradiation, the reactor was operated at 25 kW for 6 h. A total of 60 foils and 5 pellets of salt were used in the experiment.

Fig. 1 — BPE (30%) slab used in experiment.

Fig. 2 — Arrangement of BPE slabs and foils.

2.2 Measurements and calculations

The irradiated foil activities were measured in coaxial type high performance germanium (HPGe)[4] detector. Before measurements the dose due to various gamma energies of foils should reach tolerable levels for counting. The absolute energy calibration of the detector was done using the certified standard sources. The multi channel analyzer (MCA) software used with the detector system searches and identifies the product isotope gamma energies, from which the net counts due to the energy peak of interest were noted. All foils were counted after sufficient delay to have detector dead time errors < 3%. The delay time varied for different sets of foils starting from 2 h to 8 days. While counting, precautions were taken to keep the foils of different locations on the same position over the detector surface to minimize the errors.

The following expression[5] is used to calculate the reaction ratesfor the measured activities of activation of foils kept in between the BPE slabs:

$$\emptyset\sigma_{\mathrm{a}} = \frac{C\lambda AG}{N_0 y \epsilon w I_{\mathrm{a}} e^{-\lambda t_{\mathrm{d}}}(1-e^{-\lambda t_{\mathrm{r}}})(1-e^{-\lambda t_{\mathrm{c}}})}$$

where, C is total counts due to the peak of interest, Φ is total neutron flux in n/cm^2/s, σ_a is microscopic activation cross section in barns , N_o is Avogadro number, w is weight of foil in gm, I_a is Isotopic abundance, y is yield of gamma rays emitted from the activated foils, ε is detector efficiency at a particular energy, λ is decay constant, A is atomic weight, G is detector geometry factor (1.0 for foil put on the top of the detector), t_d is delay between the end of

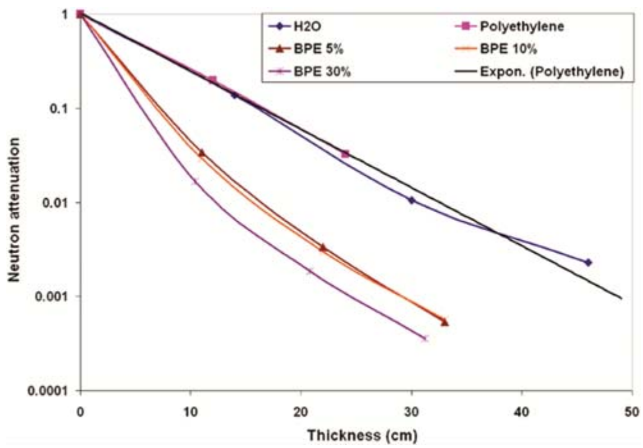

Fig. 3 — Epithermal flux attenuation determined from Au (n,γ) reaction.

Table 1 — Measured attenuation for different activation reactions

Activation reaction		Shield thickness (cm)	Measured attenuation
Thermal	Dy^{164} (n,γ) Dy^{165}	31.2	36950
Epithermal	Au^{197} (n,γ) Au^{198}	31.2	2820
	Cu^{63} (n,γ) Cu^{64}	31.2	1845
	Mn^{55} (n,γ) Mn^{56}	31.2	4529
	W^{186} (n,γ) W^{187}	31.2	4504
Fast	In^{115} (n,n') In^{115m}	31.2	258
	Cd^{111}(n, n')Cd^{111m}	31.2	294
	Pt^{195}(n,n') Pt^{195m}	31.2	480
	Hf^{180} (n,n') Hf^{180m}	31.2	1021
	Zn^{64}(n,p)Cu^{64}	31.2	85
	Mg^{24}(n,p)Na^{24}	20.8	23
	Al^{27}(n,p)Na^{24}	20.8	16

irradiation and the time of counting in seconds, t_r is length of irradiation in seconds, t_c is length of counting in seconds.

3 Results and Discussion

The measured attenuation factors were obtained indirectly from the ratios of reaction rates of various locations calculated from the measured activities of activation foils. The overall error in the measured reactions rates is found to be less than 10%. Capture reactions on dysprosium, gold, manganese, copper and tungsten represent attenuation of thermal and epithermal fluxes. Table 1 shows the measured attenuation for different activation reactions.

Measured attenuation $= \frac{\emptyset\sigma a\,(0)}{\emptyset\sigma a\,(x)}$; here 0 and x represent locations of foil at first and 31.2 cm, respectively.

Figure 3 shows the comparison of measured neutron flux attenuation of Au^{197} (n,γ) Au^{198} reactions of BPE 30% slabs with BPE 5%, BPE 10%, water and normal polyethylene.

This clearly shows that for 1000 times reduction in epithermal neutron flux, the thickness of 30% BPE required is 24 cm. Whereas 28 cm of 5% BPE and 49 cm of normal polyethylene are needed to achieve the same reduction. In case of polyethylene the measured attenuation factors are available up to a thickness of 24 cm. The extended trend line option is used to find attenuation factors for polyethylene beyond 24 cm. This clearly shows 50% reduction in volume of shield, if 30% BPE is used instead of normal polyethylene for 1000 times reduction in thermal and epithermal neutron flux. Similarly inelastic reactions on indium, cadmium, platinum and hafnium and (n,p) reactions on zinc, aluminium and magnesium represent the reduction of fast neutron fluxes. Zn^{64}(n,p)Cu^{64} reaction represents the 2.8 MeV neutron reduction. Figure 4 represents comparison of fast flux attenuation of Zn^{64}(n,p)Cu^{64} reactions in BPE 30% and polyethylene (PE). For 100 times reduction in fast flux, 31 cm of 30% BPE and 40 cm of normal polyethylene are required. It indicates that 22% reduction in volume of shields if 30% BPE is used for fast flux attenuation. It is also observed that there is no significance difference in the fast flux attenuation of 30%, 10% and 5% BPE.

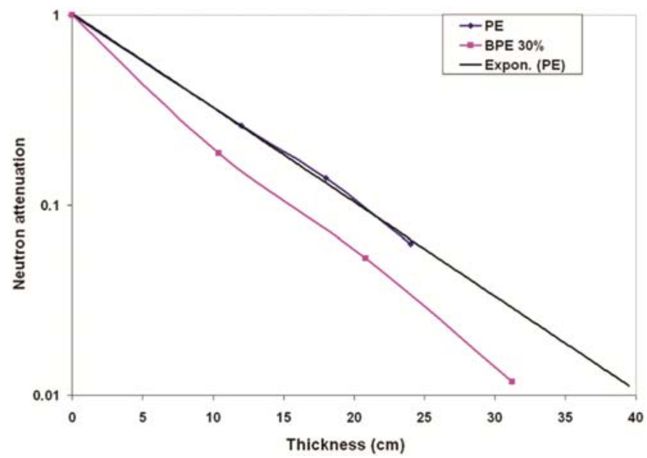

Fig. 4 — Fast flux attenuation determined from Zn^{64}(n,p)Cu^{64} reaction.

4 Conclusions

The neutron attenuating properties of BPE containing 30% natural boron are studied in this experiment. The thermal and fast neutron flux attenuation characteristics of the material are compared with 5% and 10% BPE and other hydrogenous materials. Experimental results implicated that if 30% BPE is used instead of normal polyethylene, 50% reduction in volume of shields can be obtained for thermal and epithermal neutron flux attenuation and 16 to 22% reduction in volume shields can be obtained for fast neutron flux attenuation. Significant difference is observed in the thermal flux attenuation for 30%, 10% and 5% BPE slabs but it is not seen in the case of fast flux attenuation. The measurement data will be used as reference for future measurements with other hydrogenous materials and prospective shield materials.

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