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Utilization of boron oxide glass and epoxy/ilmenite assembly as two layer shield

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ABSTRACT

In the present work, authors are studying the use of Boron Oxide Glass/Epoxy Ilmenite assembly (BOG/EI) as a two layer shield. Experimental work regarding measurements of fast neutrons and gamma ray leaking behind homogenous and two layer shield of (BOG) and (EI) composite have been carried out to investigate their radiation attenuation capabilities in terms of flux degradation. The measurements have been performed using a collimated beam emerging from spontaneous fission ^{252}Cf (100 μg) neutron source and the neutron-gamma spectrometer with stilbene organic scintillator based on the zero crossover method of the pulse shape discrimination (PSD) technique. The MCNP-4C2 code was used to simulate the experimentally measured transmitted fast neutrons and gamma ray fluxes theoretically for confirmation.

1. Introduction

In recent years, there has been an increasing interest for the use of new composite materials at many applications in various fields. In parallel, there has been a continuous expansion in the number of nuclear applications such as nuclear power plants, research reactors, medical and industrial facilities. Such installations emit radiations of highly penetrating power that are known of their deleterious effects on receiver's whither they are personnel or sensitive equipment. Therefore, provision must be made for the attenuation of such radiations by means of shield. The term shield would interpret the introduction of a special material between such radiation sources and the receiver(s) in order to protect them against hazards (Profio, 1979; Schaeffer, 1973).

In the shielding problem, neutrons and gamma-rays are mainly considered since they have the most perpetrating power and any material regarded enough to attenuate both radiations to permissible level would be adequate for all other types of radiations (Goldstein, 1959; El-Sayed Abdo et al., 2003).

At many situations it is necessary to introduce two layer or multilayer shield to obtain constructed shield quite effect for radiation attenuation and of reduced weight. In such applications, it would be desirable to place dense gamma-ray shielding material at the inner regions since it would occupy less volume (less weight) and low density neutron shielding materials at the outer regions. However, the production of secondary radiations in the inner phase would produce new radioactive sources distributed throughout the shield. These secondary sources are suppressed by arranging the γ-ray and neutron shielding materials in alternate layers or 'multilayer' arrangement.

When the radioactive source term is supposed to produce large amount of capture gamma rays inside the shielding material, as in the case of medical applications that utilize neutrons of low energies, shielding protection could be achieved by introducing slow neutrons absorber at the first layer followed by high density layer on the outside. As well, heavy elements like iron will generate high energy capture gamma radiation in the presence of the remaining neutrons and alternate layers would be also required.

The arrangement of shielding layers depends on their number and composition for each defined process (International Standard, 2001; McGinley and Butker, 1994; Ledesma, 1998).

The present study has focused on two layer assemblies of Boron Oxide Glass (BOG) and Epoxy Ilmenite (EI) composite that could present one compartment of a multilayer shield. The BOG layer role was to absorb the thermal neutrons through boron in order to diminish the induced n–γ reaction in the alternate EI composite layer. The heavy EI would play the key factor in attenuating both fast neutrons and gamma rays.

The assemblies radiation attenuation capabilities were investigated by measuring the fast neutrons and gamma ray spectra

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leaking behind them and comparing the experimental results with theoretical results obtained by using MCNP-4C2 code (El-Sarraf, 2011).

2. Experimental and calculation methods

2.1. Materials and samples preparation

The two layer assembly consisted of two phases; the first, BOG (ρ = 1.81 g/cm^3) phase in the form of disks 10 cm in diameter and one cm thick in average. The second layer was the EI (ρ = 2.51 g/cm^3) phase which consists of standard Bisphenol-A based Epoxy resin (EP) with commercial name "DGEBA DER331 product of DOW Chemical Company in USA with technical purity 95% and epoxide weight: 182–192" hardened by polyoxyporopylendiamine "Cetepox 1465 H product of Chemical & Technologies for Polymers Co. – Egypt" along with erosail additive to prevent filler sedimentation, and ilmenite filler (Ilm) a product of "El-Nasr Phosphate Co. – Abu Galaka – Red Sea mines – Egypt". This layer was prepared by crushing the ore to mesh size –500 μm and dispersing it in Epoxy formula (resin 100 phr, hardener 33 phr and erosail 1 phr) to produce the EI composite (EP/Ilm) of 20 wt%/80 wt% loading fractions (El-Sarraf, 2011).

The mixture was stirred at room temperature and degassed to allow entrapped air to be released, then poured with great courtesy into teflon cylindrical sample molds of $\varnothing$ = 10 cm in diameter and ∼5 cm in thickness, and was left to cure. After 24 h, the samples were extruded from molds and left 7 days for ultimate cross-linking before their surfaces were flattened by lathe.

The assemblies were constructed from phase one followed by phase two to construct four configurations which have the same diameter $\varnothing$ = 10 cm and a total thickness of ∼22 cm. The weight per cm^2 of the different assembly constructions is shown in Table 1.

Table 1
Unit weight per cm^2 for BOG/EI.

	BOG (wt%)	EI (wt%)	Sample weight per cm^2 (g cm^{-2})
BOG/EI 1	15	85	55
BOG/EI 2	30	70	50.8
BOG/EI 3	50	50	47.3
BOG/EI 4	70	30	42.9

2.2. Fast neutrons and gamma ray measurements

Measured fast neutron and total gamma ray spectra behind the cylindrical assemblies (BOG/EI 1, BOG/EI 2, BOG/EI 3 and BOG/EI 4) of the mentioned dimensions have been investigated. Measurements have been carried out using a collimated beam emitted from the radioactive spontaneous fission (^{252}Cf 100 μg – June 2001) neutron source. The collimated beam was provided by the narrow beam experimental facility, which consisted of a source collimator, a samples holder and a detector. The arrangement layout and was shown elsewhere (El-Sarraf, 2011).

The assemblies were juxtaposed on the samples holder, where the BOG phase faced the beam exit followed by the EI phase.

The purpose of beam and detector collimation is to provide a beam of specific intensity and geometry, as well as, protecting the detector against side scattered radiation and to reduce the incident thermal neutrons to enhance the discrimination capability. The neutron-gamma spectrometer with stilbene scintillator (4 × 4 cm) was introduced in the detector collimator and was used to measure the proton and electron pulses distributions. The undesired recoil proton and electron pulses due to neutrons and gamma rays were processed using the pulse shape discrimination technique (PSD) based on the zero – cross over method. The spectrometer set up, pulse amplitude distribution measurements as well as discrimination have been given in detail elsewhere (Miller, 1968; McBeth et al., 1971).

Spectrometer discrimination capability and energy scaling were reviewed before starting measurements on the assemblies by accumulating spectra of gamma rays emitted from ^{22}Na, ^{137}Cs, ^{60}Co and Pu-α-Be neutron source. Checks indicated that the discrimination capability and pulse pile up rejection of recoil protons were good over a range of energy from 1.5 to 10 MeV. A block diagram of the spectrometer components was shown elsewhere (Bashter et al., 1996).

The measured pulse amplitude distributions of the recoil protons or electrons were converted into energy spectra of the fast neutrons and gamma-rays using the unfolding codes NSPEC and GSPEC based on double differentiation and matrix correction methods respectively (Toms, 1971; Kolevatov et al., 1969).

2.3. MCNP 4C2 calculation technique

A typical and exact three dimensional model was designed using MCNP-4C2 computer code for matching the experiment geometry. In the model, a built in ^{252}Cf neutron source with spontaneous fission was used for the source term and the variance reduction method DXTRAN sphere was used at the detector term to improve and increase the results accuracy.

The program is designed to conduct the calculations using analytical methods starting from the radioactive source up to the DXTRAN outer sphere, hence, it starts using the MCNP technique reaching the DXTRAN inner sphere. The program is operated in the neutron–photon mode in order to accumulate the fast neutron and neutron induced gamma ray tallies. Then it was operated in the photon mode to obtain the gamma ray tallies which were added to the first run second term in order to get the total transmitted gamma ray component. A number of 10^8 neutron and 5×10^7 photon histories were performed to simulate the measurements and the tallies were scaled to the source strength using tally multiplying cards (Briesmeister, 2000).

3. Results and discussion

Measurements of the transmitted fast neutron and gamma ray spectra through homogeneous and two layer shields of BOG and EI have been carried out to investigate the nuclear attenuation capability for homogenous and two layer shields. Homogenous shields of BOG or EI composite were performed using cylinders of 10 cm in diameter and a total length of ∼22 cm. In case of two layer assemblies the shield media was constructed of both layers having the same diameter, however their relative thickness differ making four configurations of two layer shield assemblies having ∼22 cm total thickness according to Table 1. The BOG Disks were put to face the beam exit in order to absorb thermal neutrons to reduce the n–γ reaction with iron present in the EI samples.

Spectra of fast neutron flux (neutrons cm^{-2} s^{-1} MeV^{-1}) versus the neutron energy in (MeV) behind homogenous and two layer assemblies of BOG and EI composites using ^{252}Cf source were displayed in Figs. 1 and 2a and b respectively.

In Fig. 1, the displayed spectra have almost the same shape and profile for the two investigated samples. The general trend for the intensity of the neutron spectra is a decrease with the increase in the energy. It is apparent that, the passage of fast neutrons through the investigated composite EI which contain heavy materials causes softening to the spectrum, i.e. an increase in the portion