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Use of CR-39 Films for Evaluation of Shielding Efficacy of Materials against Fast Neutrons

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ABSTRACT

CR-39 films have been used for evaluation of neutron shielding of metal alloys, different types of rubbers, sand polymers, etc. These films have been chosen because of their ability to record fast neutrons from 200 keV-10 MeV and their insensitivity to gamma radiations. Tenth value layer (TVL) for the materials studied varies from 10.5 to 28.6 cm. In addition, the values of TVL have also been computed for standard material, such as *Al*, steel, etc. Using neutron removal cross-section data, the results have been compared with those of experimentally determined values. The results seem to be in agreement within ±10 per cent variation

NOMENCLATURE

	track density with shielding material
I_o	track density without shielding material
N	number of atoms per cm^3
σ_R	macroscopic removal cross-section
σ_{ab}	microscopic absorption cross-section
	thickness of shielding material
σ_{el}	microscopic elastic scattering cross-section
σ_{in}	microscopic inelastic scattering cross-section

1. INTRODUCTION

Neutrons generated in fission have energies ranging up to several MeV and they lose their energies by inelastic and elastic scattering. The threshold energy for inelastic scattering decreases with increasing atomic weight. In an inelastic scattering with high atomic weight material, except for closed shell nuclei, neutrons loose significant energy. Similarly, in an elastic collision with low-Z material, significant energy is lost by neutrons. Thus, for an effective neutron shield, it is worth having a combination of high atomic weight and low-Z element. Such materials have been produced elsewhere for protecting men and material from harmful effects of neutron and gamma radiations. Among the range of neutrons incident on any material, fast neutrons contribute the most of radiation dose. Hence it will be of interest to measure the dose reduction factor for a certain thickness of material and choose the best material for radiation protection purpose. In the past, dose reduction factors for building material have been reported[1-3] from the radiation protection point of view. The dose reduction factor is the ratio of the dose recorded by a detector without the shield to the dose recorded by the detector with the shield. This can be used to arrive at removal cross-section and hence the tenth value thickness. The dose reduction factor provided by the materials for gamma radiations are easy to calculate; however for neutrons it is a difficult job Shielding calculations are generally based on different assumptions concerning composition, cross-section, etc. In these calculations the assumption of absence of irregularities or voids in the shield material under consideration could lead to erroneous values for dose reduction factor[4]. The irregularities in shield materials are a hidden treasure and can only be known by non-destructive/destructive testing. Hence experimental methods have been adopted for predicting the dose reduction factors for radiation shield under study.

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The attenuation of fission neutrons through most shields can be expressed by a simple exponential using the effective removal cross-section. Here such cross-sections have been measured experimentally and have been applied to arrive at thickness of material required to reduce the neutron intensity by a factor of ten, i.e., neutron dose reduction factors are described in terms of tenth value layers (TVLs).

2. METHODS AND RESULTS

Figure 1 shows the schematic of experimental set-up for measuring the neutron shielding efficacy using 0.3 μg ^{252}Cf neutron source and a solid-state nuclear track detector (SSNTD)[5]. When a charged particle passes through the SSNTD material (CR-39), it causes radiation damage over and above a threshold radiation damage and the particle trajectory can be revealed in the form of a pit. It can be viewed after treating the film with a suitable etchant. These pits are called nuclear tracks.

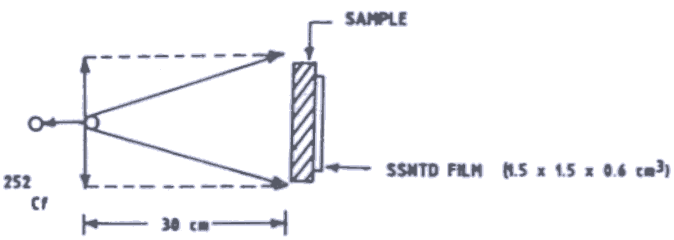

Figure 1. Experimental set-up for exposure of CR-39 films to ^{252}Cf source for measuring neutron shielding efficacy of materials

CR-39 films of size 1.5 × 1.5 × 0.6 cm^3 covered with 1 mm thick polyethylene radiator are exposed to fission neutron fluence emitted from ^{252}Cf source with and without shielding material in a geometry indicated in Fig. 1. After the exposure, films are etched in 6N $NaOH$ solution at 60 °C for 5 hr. These are then washed in distilled water for 5-10 min and dried in dust-free chamber. Recoil proton tracks formed on the film due to fission neutrons are counted using Zenval microscope at 600X magnification. The track densities obtained from the films exposed with and without shielding materials are related to each other by an experimental relation,

$$I = I_o \exp(\sigma_R t) \quad (1)$$

where $\sigma_R = N(\sigma_{in} + \sigma_{el} + \sigma_{ab})$

σ_R is the macroscopic cross-section in cm^{-1} which represents the probability of removal of neutron from the beam by any or a combination of these processes

TVL for a shielding material can be calculated using removal cross-section as,

$$\text{TVL} = \frac{2.3026}{\sigma_R} \quad (2)$$

From the I_o and I measured for fast neutrons, using different shielding materials, TVL has been determined and the results are shown in Table 1. It is observed that TVL values for metal, sand polymer, ceramic matrix and different types of rubbers vary from 10.7 to 22 cm. Using Eqns (1) and (2) TVL for standard materials, viz Al, steel, have been computed from removal cross-sections and compared with the experimentally observed values. The results are shown in Table 2. It is clear from the table that computed values of standard materials are in agreement with those of experimentally observed ones.

Table Shielding efficacy results of different materials

Sample	Density (g/cm^3)	Thickness (cm)	PF	TVL (cm)
Sand polymer	–	2.5	1.60	12.2
Ceramic matrix (containing titanium)	2.0	5.0	1.71	10.7
Rubber containing 50 % lead	1.7	2.5	1.60	12.2
Rubber containing 50 % boron	1.4	2.5	1.62	11.9
Rubber containing 25 % lead + 25 % boron	1.5	2.5	1.55	13.1
Lead-lithium (containing 0.69% lithium)	10.6	5.0	1.11	22.0
Aluminium-lithium (containing 4% lithium)	2.4	15.0	1.43	19.3

Table 2. Tenth value thickness of standard materials

Sample		
Aluminium (up to 15 cm)	29.2	28.6
Iron (up to 1.2 cm)	13.7	10.5

3. CONCLUSIONS

(i) CR-39 films have been used for evaluation of shielding efficacy of materials against fission neutrons.

(ii) Ceramic matrix composite seems to be better and efficient shield for neutron radiation as compared to other materials reported here.

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