Effects of Filler Size on Radiation Shields

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1. Introduction

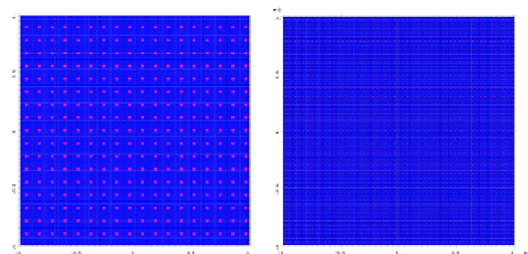
Conventionally, gamma radiation can be attenuated by a material containing the high density elements such as iron, lead, tungsten or cement, etc. On the other hand, neutron is absorbed by a mixture of a polymer or metal matrix with the fillers with the large thermal neutron absorption cross-section such as boron, lithium and gadolinium, etc. The performance of the radiation shields is known to be determined by the properties of radiation shields. It depends on the thermal absorption cross-section in the case of neutrons or on the decay constant in the case of gamma rays, the amount of radiation absorbing or attenuating material in the matrix, and the thickness of the shields. The size of the fillers mixed in the radiation shields is in general not known to greatly affect the radiation shield efficiency. Furthermore, there are not many reports related to the preparation of a radiation shields using homogeneous dispersion of a radiation resistive material in the form of nano-particles in a polymer or any metallic matrix. Only micro-sized B_4C dependency on neutron absorbing Boral is reported for the criticality aspects [1,2]. In this investigation, MCNP simulation which was developed by using a lattice model shows the strong dependency of the filler size on the shield efficiency; also it shows strong dependency on the energy.

2. Methods and Results

In this section, we describe the method of MCNP simulation which could deal with the filler size dependency on the gamma attenuation as well as thermal neutron absorption. Especially, Polymer matrix such as HDPE and PVA was used as a base material. B_4C or B_2O_3 compounds as a neutron absorber and PbO as a gamma attenuator are used as a filler in the medium.

2.1 MCNP Simulation Method

To perform this simulation, the lattice model in MCNP LAT card was used. We assumed that a filler with a certain diameter is located in the center of a cubic cell whose size determines the density of a filler in a base material. That is, a filler is assumed as a perfect sphere whose diameter is determined by the given mass density condition. The filler sizes for comparison were basically 300μm and 0.5μm. And other filler sizes were also evaluated at different conditions. When the radiation shields are evaluated in general by using a MCNP code, it is assumed that the atomic boron or Pb is homogeneously distributed in the medium. However, the size of the fillers in the medium in fact is not atomic level rather it is particulate levels from the several μm to the several hundred μm. Both conventional MCNP simulation and filler size dependent MCNP lattice model were compared at the same conditions. Neutron energy was set at 0.025eV and gamma energy was varied from 0.1MeV to 1.0 MeV. Radiation source was parallel or isotropic dependent on the given situation. Fig.1 shows the images of MCNP model whose filler sizes as 300μm and 0.5μm respectively.



(a) 300μm diameter (b) 0.5μm diameter

Figure1. MCNP model images containing different sized B_2O_3 fillers.

In the images, the mass density of B_2O_3 is 2.5wt%, that is, mass density of boron is 0.776wt%. The length of the lattice is $1.12583x10^{-2}$cm while the diameter of the filler located in the center of the cubic cell is 300μm, and the length of the lattice is $1.87638x10^{-4}$cm for the 0.5μm sized filler respectively.

2.2 Neutron Absorption

In general, thermal neutron absorption in the materials is determined by the density of B-10 isotope whose thermal neutron absorption cross-section is much larger that that of B-11. If the atomic density of boron is the same in a certain material, then neutron absorption should be the same as expected according to general nuclear physics. However, as it is shown in Fig. 2, conventional MCNP simulation which is assuming the homogeneous distribution of atomic boron in the medium has the largest neutron absorption behavior, while 300μm filler case shows the lowest and the medium level for 0.5μm filler case. This size dependent absorption characteristic is similarly observed in the PVA based experiments [3,4] and for Boral criticality estimation [1,2] which is the case for a neutron absorber between 150μm and 75μm B_4C fillers.

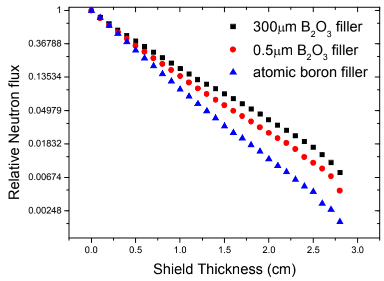
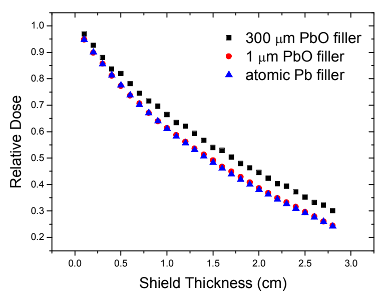


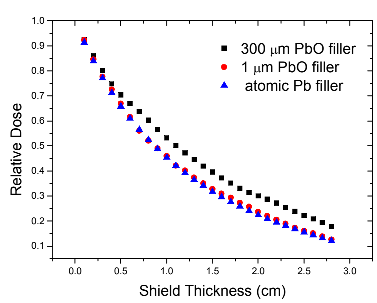
Figure 2. Neutron shielding characteristics dependent on the filler (B_2O_3) sizes, 300μm, 0.5μm, and homogeneous distribution of atomic boron.

2.3 Gamma Attenuation

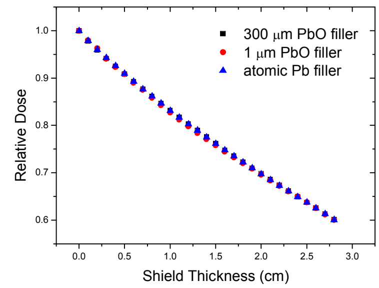
Similar concept was applied to the gamma radiation attenuation in this MCNP simulation. Same as the neutron absorption case, the smaller filler size shows the higher attenuation properties than that for the larger filler especially at low gamma energy region. For high gamma energy (>300 keV), the effects of the filler size were not observed while it is clearly shown for lower energy gamma (<300keV) as shown in Fig. 3. The 5% and 10% PbO fillers sized with 300μm, 1μm, and homogeneous distribution in HDPE polymer matrix respectively were assumed similarly with the neutron cases. Fig. 1(a) shows 5% PbO with 0.1MeV gamma irradiation. The 1μm sized filler and homogeneous distributed filler shows similar attenuation properties while lower attenuation is shown for the 300μm fillers. This trend is same with 10% PbO filler case. However, the filler size effect for 1MeV gamma energy is not observed or minimal as shown in Fig. 3(c).



(a) 5% PbO w/0.1MeV gamma energy



(b) 10% PbO w/0.1MeV gamma energy



(c) 10% PbO w/1.0MeV gamma energy

Figure 3. MCNP simulation for PbO filler size effects on attenuation of gamma radiation for different gamma energies.

3. Conclusions

The size effects of radiation resistive filler dispersed in the polymer matrix was simulated by using the MCNP lattice model. This model works properly when compared with the conventional MCNP simulation which assumes that the atomic fillers are distributed homogeneously in the medium. Consequently, neutron absorption and gamma radiation attenuation are higher for the smaller filler distributed shield than those for larger filler distributed one. Also the size effect for attenuation of gamma irradiation was higher with higher mass density. This investigation shows that radiation absorption and attenuation are dependent not only on the mass density of the filler but also on the size of the filler dispersed in the medium regardless if it is polymer or metallic medium. More detailed explanations and some relevant data about the filler size effects on radiation shields will be given at the conference.

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