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Layer-splitting technique for testing the recursive scheme for multilayer shields gamma ray buildup factors

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ABSTRACT

This study illustrates the implementation of the newly suggested layer-splitting testing technique. This technique is introduced in order to be implemented in examining suggested formalisms for the recursive scheme (or iterative scheme). The recursive scheme is a concept used in treating and producing the gamma ray buildup factors in the case of multilayer shields. The layer-splitting technique simply enforces the scheme to treat a single layer of one material as two separated layers with similar characteristics. Thus it subjects the scheme to an abnormal definition of the multilayer shield that will test its performance in treating the successive layers. Thus, it will act as a method of verification for the approximations and assumptions taken in consideration.

A simple formalism was suggested for the recursive scheme then the splitting technique was implemented on it. The results of implementing both the suggested formalism and the splitting technique are then illustrated and discussed. Throughout this study, cubic polynomial fitting functions were used to generate the data of buildup factors for the basic single-media that constitute the multilayer shields understudy. This study is limited to the cases of multiple shields consisting of repeated consecutive thin layers of lead–water and iron–water shields for 1 MeV gamma rays.

The produced results of the buildup factor values through the implementation of the suggested formalism showed good consistency with the Monte Carlo simulation results of Lin and Jiang work. In the implementation of the introduced technique, the deviation caused by the splitting of the layers in the multilayer shields understudy did not reach extreme limits and remains well below 16%. The proposed formalism showed good stability with the introduced changes, at least within the frame of this study. The implementation of the layer splitting technique was easy and it can be conducted on many other formalisms of the recursive approach.

1. Introduction

The point kernel theory is one of the unique methods that are implemented in radiation shielding analysis. Nevertheless, it encounters various difficulties in certain implementations. One of these implementations is the case of multilayer or stratified shields that consists of multiple layers of different material compositions. The drawback of this method in such application is mainly due to the lack of suitable buildup factors data.

One of the trends in dealing with such a problem is to generate the buildup factor data sets for certain configurations of multilayer shields (two layers or more) either as tabulated data or as figures (Bakos and Tsagas, 1994; Hirayama and Shin, 1998; Lin and Jiang, 1996; Shin and Hirayama, 2001; Harima and Nishiwaki, 1969). Such treatment of the buildup factors in the multilayer shields creates a huge bulk of data for the various possible configurations of the multilayer shields. Another approach is to generate empirical formulae that can be applied in certain or general cases (Lin and Jiang, 1996; Shin and Hirayama, 2001, 1998; Harima and Nishiwaki, 1969; Guvendik and Tsoulfanidis, 2000). Such approach is much easier to deal with and it also includes multiple configurations in a certain formula or relation with less limitations.

Recently, machine learning and neural networks are being implemented in the treatment of multilayer shields buildup factors. Where, large number of training and testing datasets of buildup factors are processed to treat the case of multilayer shields (Trontl et al., 2007; Assad et al., 2000; Suteau et al., 2004). A great progress is noted in the work of Suteau et al. based on this concept (Suteau et al., 2004). Such approach is considered a great step in

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dealing with the multilayer shields based on the single-media data of buildup factors.

The recursive approach for treating the gamma ray buildup factors in multilayer shields will be investigated in this work. This will be done through suggesting the new layer-splitting testing technique. This technique is ought to subject the formalism of the recursive scheme to a unique definition of the case understudy testing its handling of the changes between the layers. This is ought to provide a better understanding of this approach and will provide us with a better insight of its advantages and its drawbacks. Both the results of the implementations of the suggested formalism and the testing technique will be discussed.

2. The suggested formalism

The recursive scheme for obtaining the buildup factor of multilayer shields (three layers or more) can be considered as a strong approach that resolves many drawbacks in the point kernel theory. The approach is simply based on combining two layers to produce one equivalent layer (starting from the source side). Then, in the following step; this equivalent layer is combined with the following layer to produce a second equivalent layer. This process is to be repeated until $N-1$ iteration/repetition, where N is the total number of layers in the multilayer shield. This is illustrated in Fig. 1, where we can see that after each iteration an equivalent layer is produced replacing the previously two combined layers. The characteristics of the equivalent layer that will substitute the previously combined layers are of great importance. These defined characteristics are what it is called the formalism of the recursive scheme.

The procedure followed in this work is to produce the equivalent buildup factor of the equivalent layer through the Kalos' formula (Shultis and Faw, 2000). This formula is one of the well-known formulae for such configuration. The Kalos' formula for two successive layers (i and $i+1$; where i is nearer to the source side) can be written as below. This form is suitable to be implemented into the recursive scheme algorithm.

$$B_{eq} = B_{i+1}(l_{i+1}) + \frac{B_i(l_i) - 1}{B_{i+1}(l_i) - 1}\left[B_{i+1}(l_i + l_{i+1}) - B_{i+1}(l_{i+1})\right] \tag{1}$$

for $Z_i > Z_{i+1}$, and:

$$B_{eq} = B_{i+1}(l_{i+1}) + \left[\frac{B_i(l_i) - 1}{B_{i+1}(l_i) - 1} e^{-1.7 l_{i+1}} + \frac{(\mu_c/\mu)_i}{(\mu_c/\mu)_{i+1}}\left[1 - e^{-l_{i+1}}\right]\right] \times \left[B_{i+1}(l_i + l_{i+1}) - B_{i+1}(l_{i+1})\right] \tag{2}$$

for $Z_i < Z_{i+1}$. Where,

- i = 1, 2, 3 ... $N-1$. Where, N: is the total number of layers,
- B_{eq}: the value of the buildup factor of the combined layers,
- l_i: the thickness of layer i in units of mfp,
- $B_i(x)$: the value of the buildup factor of layer i for thickness of x (mfp),
- μ_c/μ: the ratio of the Compton scattering coefficient to the total attenuation coefficient.

While the thickness of the equivalent layer will be the summation of the combined layers in the units of mfp. That's as illustrated in Fig. 1; $X_{eq1} = X_1 + X_2$ (for the first step). The equivalent layer will be assigned an average atomic number (Z) value of the combined two. This will be produced using the formula: $Z_{avg} = (Z_1\mu_1 x_1 + Z_2\mu_2 x_2)/(\mu_1 x_1 + \mu_2 x_2)$.

Thus, these three main parameters (the buildup factor value, the layer thickness, and the material composition) of the equivalent layer are what formulate the recursive scheme. The only remaining parameter is the Compton scattering to total attenuation cross section ratio, which appeared due to the use of the Kalos' formula. In our formalism, the equivalent layer is assigned the ratio of the second layer of the combined ones.

3. Buildup factor data for single composition

The recursive scheme (and similarly; the implementation of the Kalos' formula) is based on the availability of the buildup factor data of each of the single-layer media that constitute a multilayer shield. Such data is already provided in literature for various

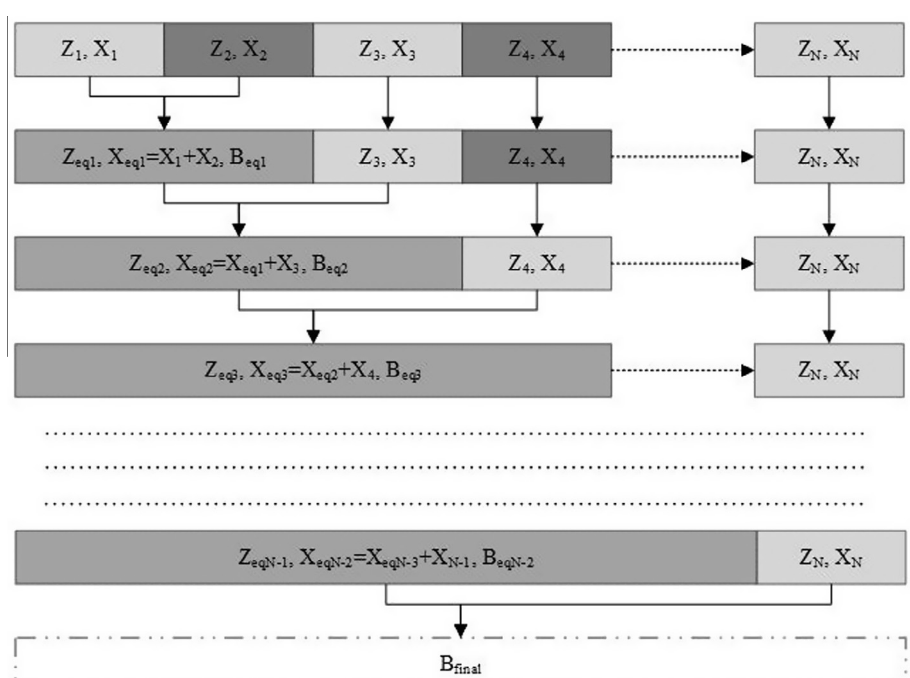

Fig. 1. An illustrative figure showing the recursive scheme applied on N-layer shield.