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A Study on the Iterative Scheme for Stratified Shields Gamma Ray Buildup Factors Using Layer-Splitting Technique in Double-Layer Shields

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***Abstract*—**The iterative scheme which is used to treat buildup factors for stratified shields is being investigated here using the layer-splitting technique. A simple suggested formalism for the scheme based on the Kalos' formula is introduced, based on which the implementation of the testing technique is carried out.

The second layer in a double-layer shield was split into two equivalent layers and the scheme (with the suggested formalism) was implemented on the new "three-layer" shield configuration. The results of such manipulation on water-lead and water-iron shields combinations are presented here for 1 MeV photons.

It was found that splitting the second layer introduces some deviation on the overall buildup factor value. This expected deviation appeared to be higher in the case of low Z layer followed by high Z. However, the overall performance of the iterative scheme showed a great consistency and strong coherence even with the introduced changes. The introduced layer-splitting testing technique shows the capability to be implemented in test the iterative scheme with a wide range of formalisms.

***Keywords*—**Buildup Factor, Iterative Scheme, Stratified Shields.

I. Introduction

DEALING with the gamma ray buildup factors for the case of the stratified shields requires some special treatment. Multiple methods are available for treating such case in radiation shielding.

Many previous works intended to generate buildup factor data for certain configurations of stratified shields (two layers or more) as tabulated data or in figures [1]-[4]. Other works have generated certain empirical formulae that can be applied in such situations [2]-[6]. Overall, much more data need to be provided for the huge (infinite-like) number of the possible configurations of the stratified shields.

A suggested approach for such problem is the iterative scheme, which was first implemented in the work of A. Assad [7]. A great progress is noted in the work of Suteau et al. [8]. The iterative scheme itself is proven to be a very good approach for the case of stratified shields. In addition, great results obtained by Torntel et al. where they implemented this scheme with the use of the machine learning and neural networks, where huge sets of training data and test data are being processed [9].

The purpose of this study is to introduce a testing technique for the iterative scheme for the gamma ray buildup factor in stratified shields. Where, this testing technique can be used in various formalisms of the iterative scheme. In this work, we suggest a simple formalism for the iterative scheme is illustrated. Then, this iterative scheme is used on an assumed "three-layer" shields in which the last two layers are of the same material composition. This configuration represents a double-layer shield with the second layer being split into two equivalent layers. The results of such manipulation are discussed and analyzed.

II. The Iterative Scheme

This recent approach for the stratified shields buildup factors is one of the applicable and easy approaches [7]-[9]. It is based on treating a multilayer shield configuration two layers at a time. In each step (called iteration), two layers are combined to produce an equivalent layer for which a buildup factor value is calculated. Then this layer is combined with the next layer to produce another equivalent layer with another buildup factor value for all the combined layers. This process is to be repeated until we gain the overall value of the buildup factor for the original multilayer shield configuration. This is illustrated by repeating process (2) as shown in Fig. 1.

A. The Suggested Formalism.

As it can be seen, when we combine two layers in an iteration, a description of the characteristics of the resulted equivalent layer must be given. In addition, a clear method for producing the values of the buildup factors from the combined two layers is ought to be provided.

The procedure followed in this work is that the equivalent layer will have an equivalent atomic number (Z) of that of the combined ones. This equivalent Z will be calculated relative to (or weighted by) the thicknesses of each layer in units of Mean Free Path (*mfp*), as illustrated the formula in (1). This weighting process will be conducted on any other parameter of the equivalent layer.

$$Z_{eq} = \frac{Z_1\mu_1x_1+Z_2\mu_2x_2}{\mu_1x_1+\mu_2x_2} \quad (1)$$

where;

- Z_{eq} : the equivalent value of the atomic number for the combined layer,

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- Z_i : the atomic number of the layer i,
- $\mu_i x_i$: the thickness of the layer i in units of *mfp*.

The equivalent layer will also have a thickness equals to the summation of combined two in units of *mfp*. We can notice that the equivalent layers thickness throughout the iterations will differs from the original case in the conventional thickness units as illustrated in Fig. 1.

Secondly, the equivalent value of the buildup factor (for the whole stratified shield) will be produced using the Kalos' formula (illustrated in section II.B.). This step is important since this value is what we are actually seeking.

Throughout this work, previous verified and well-acknowledged buildup factor data of single-media were used here to produce polynomial fitting functions for the three materials included in the study (water, iron and lead). Then, these polynomial functions were implemented in the generation of the buildup factors in our calculations on the stratified shields. The buildup factors data from various methods and references such as ANSI/ANS, Taylors' formula, Bergers' formula and the Geometric Progression formula are included in the fitting process [10]. A polynomial of the third order is proved to be sufficient for the three mentioned materials and for the range of shields thicknesses. It should be noted that the type of buildup factors used is air exposure buildup factors for infinite media.

B. The Kalos' Formula

The Kalos' formula for a double-layer shield is one of the well-known formulae for such a configuration. Many further works have been conducted in order to provide some additional correction factors into this formula [2].This formula is the basis of this study as it will be used to produce the value of the overall buildup factor of the stratified shield. The formula used in this work for two successive layers numbered based on their order from the source is as following [10]:

$$B = B_2(l_2) + \frac{B_1(l_1)-1}{B_2(l_1)-1}[B_2(l_1+l_2) - B_2(l_2)] \qquad (2)$$

for $Z_1 > Z_2$, and:

$$B = B_2(l_2) + \left[\frac{B_1(l_1)-1}{B_2(l_1)-1}e^{-1.7l_2} + \frac{(\mu_c/\mu)_1}{(\mu_c/\mu)_2}[1-e^{-l_2}]\right] \times [B_2(l_1+l_2) - B_2(l_2)] \qquad (3)$$

for $Z_1 < Z_2$. Where,

- B : the equivalent value of the buildup factor of the two layers 1 and 2,
- l_i : the thickness of layer i in units of Mean Free Path (*mfp*),
- $B_i(x)$: the value of the buildup factor of layer i for the thickness of x in *mfp*,
- Z_i : the atomic number of the layer i,
- $(\mu_c/\mu)_i$: the ratio of the Compton scattering coefficient to the total attenuation coefficient.

This formula was used due to its simple criterion of comparing the Z-values of the two layers, and it has an energy range from 0.5 up to 20 MeV. It was originally produced for shield combinations of lead and water [10].

III. Splitting the Second Layer

The splitting of the second layer in a double-layer shield configuration should not introduce any physical effects or distortions on the overall buildup factor value. However, as we are implementing an approximating scheme to find it, such manipulation is expected to raise some deviation. Thus, the splitting will provide a test mean to the restrictions of the iterative approach and its effectiveness. In reality, this is also tests the usefulness of implementing Kalos' formula into it and to the procedure of this work in general.

In a double-layer shield, the second layer is replaced by two layers of the same material composition each with half of the original layer thickness. The resulted "three-layer" shield is then implemented into the iterative process to produce the overall buildup factor value. Process (1) in Fig. 1 shows an illustration of the splitting of the second layer in a double-layer shield.

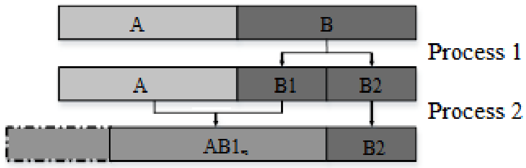

Fig. 1 An illustration of the splitting process of the second layer (Process 1) and of the implementation of the iterative scheme (Process 2) (Thicknesses are in units of mfp)

IV. Analysis and Results

Implementing the formalism as given in section II, multiple double-layer shield configurations are tested. The results of testing thin slabs combinations of water-lead and water-iron are presented here. The study is limited to photon energy of 1 MeV.

Table I shows the results obtained for four main cases of double-layer shields plus their perspective split-second-layer cases. The deviations of the split form the original cases (without splitting) producing using the suggested formalism are given in brackets. In addition, the results of the Monte Carlo code EGS4 are also given in this table along with the deviation of both the original cases and the split cases from it. When analyzing the results of tests in Table I, we can clearly notice that splitting the second layer in a double-layer shield causes some disturbance in the values of the buildup factor but not in an extreme way.

We can see that the deviations of the split cases from the original cases produced by the suggested formalism are within the deviation margins of the original cases from the EGS4 simulation results. The maximum deviation is less than 16%, which occurs between the split cases and the results of the EGS4 for the case of 2W+2L configuration.

Additional observations are to be made based on the results of Table I. We can find that the effect of the splitting of the second layer is larger in the last two cases (water followed by lead or iron), where a low Z layer is followed by the higher one. While in the case of the high Z layer followed by the lower Z (lead or iron followed by water), the deviations can be considered low.

TABLE I
RESULTS OF SPLITTING THE SECOND LAYER IN A DOUBLE-LAYER SHIELDS FOR 1 MEV PHOTON COMPARED WITH THE ORIGINAL CONFIGURATIONS AND THE EGS4 RESULTS OF [2]

Shield Configurations	Buildup Factor Value from This Work	EGS4 Results [2]	Deviations from EGS4 Results
2I+2W[a]	**6.637**	**6.370**	+4.19%
2I+1W+1W	6.614 (-0.35% [b])	----	+3.83%
2L+2W	**4.896**	**4.490**	+9.04%
2L+1W+1W	4.844 (-1.06%)	----	+7.88%
2W+2I	**5.218**	**4.710**	+10.79%
2W+1I+1I	4.727 (-9.41%)	----	+0.37%
2W+2L	**2.364**	**2.490**	-5.08%
2W+1L+1L	2.095 (-11.36%)	----	-15.86%

[a]2I+2W: 2 *mfp* of Iron followed by 2 *mfp* of Water (W: Water, L: Lead and I: Iron).
[b]Relative errors with respect to the original shield configuration.

V. CONCLUSIONS

Using the fitting functions of buildup factors provides much easier handling during implementation, where huge tables of data are replaced with small number of coefficients. In addition, the results of such data is guaranteed to match at least the four method implemented in the fitting process.

Of course, transmission buildup factor data is more suitable to be used in the case of stratified shields. The lack of a various and huge database of such a kind of buildup factors made it difficult to undergo the fitting process.

The conditions of the equivalent layer that it has an equivalent atomic number (Z) and the summation of the both of the combined layers thicknesses in unit *mfp* is proved to be acceptable. In addition, the Kalos' formula showed great consistency while dealing with the manipulated shield configurations. Thus, we can say that the effectiveness of the iterative treatment with the suggest formalism is proved to be good.

The implementation of the splitting technique on the suggested formalism showed that the formalism need additional improvements. The observed behavior of the effect of the splitting on the studied cases is subjected to change if we change the formalism and/or the shields configurations.

It can be shown that creating a well-defined *general* and *simplified* approach to such a problem (the stratified shields) seems difficult and thus it requires additional works based on the existing database of the buildup factors.

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