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MONTE CARLO CALCULATIONS OF GAMMA-RAY ALBEDO

BY

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ABSTRACT

A Monte Carlo computer program has been used to generate values for the differential dose albedo of gamma rays on concrete. The values have been fit to a semiempirical formula containing two adjustable parameters. Values for the parameters are reported as a function of gamma-ray energy.

This work was sponsored by the Defense Atomic Support Agency.

INTRODUCTION

An earlier note[1] gave interim values of parameters which could be used to calculate the differential dose albedo of gamma rays on concrete as a function of the energy of a broad parallel beam of gamma radiation incident on an infinitely thick slab. Albedo values are important to the calculation of gamma-ray streaming through ducts and passageways leading into protective shelters.

The interim values reported earlier were based on fitting a two-parameter semiempirical formula[2] to the results of Monte Carlo calculations.[3] Subsequently, an improved Monte Carlo program was written.[4] The present note describes the results of fitting the Chilton-Huddleston semiempirical formula to the results of extensive Monte Carlo calculations, performed by the U. S. Naval Civil Engineering Laboratory, based on the improved Monte Carlo code.

CURVE FITTING

Monte Carlo calculations of gamma-ray backscattering from an infinitely thick slab of concrete were performed for each of the energies: 0.2, 0.412, 0.5, 0.662, 1.0, 1.25, 2.0, 4.0, 6.0, and 10.0 Mev. For each energy, 30,000 case histories were performed. The albedo values thus determined were fit to the Chilton-Huddleston semiempirical formula

$$\alpha = \frac{C\,K(\theta_s)\cdot 10^{26} + C'}{1 + \dfrac{\cos\theta_o}{\cos\theta}} \qquad (1)$$

where $K(\theta_s)$ is the Klein-Nishina energy scattering cross section; θ_o and θ are the polar angles of incidence and reflection, respectively; and C and C' are adjustable parameters which depend on the energy of the incident radiation. The best values for the parameters (C, C') were found by an iterative technique. The sum of the squares of the difference between theoretical and Monte Carlo results, weighted by the reciprocal of the theoretical values, was minimized with respect to C and C'. Iterations were performed until a set of self consistent values were found.

A more detailed explanation of the curve-fitting procedure, along with a discussion of the derivation of Equation 1, is given in an earlier report.[2]

RESULTS

Values for the parameters C and C' are listed in Table I as a function of the incident gamma-ray energy for an infinitely thick concrete slab. Also listed are the standard deviations of the values of the parameters. In the estimates of the standard deviations two effects are confounded: (1) statistical fluctuations inherent in the Monte Carlo calculations, and (2) the physical approximations that went into the derivation of Equation 1. It is interesting to note that the standard deviations were multiplied by a factor of approximately 0.7 when the number of case histories was increased from 5000 to 30,000. If only statistical fluctuations were involved, the decrease in standard deviations would have been a factor of $1/\sqrt{6}$. Thus, it must be concluded that most of the error is associated with the physics of Equation 1.

Table II shows values of the parameters for concrete slabs having a thickness of one mean free path of the incident gamma rays. These values can be used in cases of thin-walled ducts. Here again 30,000 case histories were run for each gamma-ray energy.

The same Monte Carlo procedure can be used to generate albedo values for various thicknesses of various materials. For instance, on the assumption that the Chilton-Huddleston formula is valid for materials other than concrete, parameters can be found by fitting Monte Carlo results to Equation 1 for other materials. Table III shows the values of the parameters for thick slabs of aluminum and steel. For comparison, parameters are also shown for the best fit of Equation 1 to the experimental values obtained by Jones.[5]

DISCUSSION

A comparison of available experimental and Monte Carlo values for differential gamma-ray dose albedo for various materials reveals a lack of agreement among investigators. Also, a survey of theoretical approaches to gamma-ray albedo shows the current theories to be in disagreement. Furthermore, since experimenters use different sets of angles in their investigations, direct comparison of albedo values is impossible.

Experimental values for the albedo of gamma rays from Cs-137 on concrete, iron, and lead were obtained by Clifford.[6] Jones et al[5] measured the gamma-ray angular dose albedos of concrete, aluminum and steel. Other experimental measurements of gamma-ray backscattering were performed by Barrett and Waldman.[7]

Chilton and Huddleston[2] developed a semiempirical formula for the differential dose albedo for gamma rays on concrete. Reasonable agreement was found between the predictions of the Chilton-Huddleston formula and the Monte Carlo values of Raso.[3] Another theoretical treatment of the albedo problem has been given by Jones.[5] Wells[8] performed another set of Monte Carlo calculations.

Unfortunately, even with two exhaustive sets of Monte Carlo calculations, three independent sets of experimental measurements, and various theoretical approaches to the problem, there does not exist any unique set of accepted values for differential albedo, simply because of the different results reported by the various investigators.

Nevertheless, calculations based on albedo values have given satisfactory agreement with experiment. For example, Chapman[9] successfully used the albedo values of Chilton and Huddleston[2] to calculate dose rates in concrete entranceways. On the other hand, Chilton[10] used a different set of albedo values to calculate gamma-ray backscattering from an infinite concrete plane when the radiation originated from a point source.

CONCLUSION

In the absence of a well defined unique set of albedo values, the choice of the best values to use in any given case must depend on the particular application and the judgement of the user. The authors believe results of sufficient accuracy for practical thick slab backscattering problems can always be obtained using Equation 1 with the parametric values given in Table I.

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TABLE I. Parameters for Semiempirical Formula for Differential Gamma-Ray Dose Albedo from Thick Concrete Slab

E_o (Mev)	C	σ_C	C'	$\sigma_{C'}$
.200	.0224	.0010	.0366	.0017
.412	.0344	.0009	.0218	.0008
.500	.0364	.0009	.0200	.0007
.662	.0435	.0010	.0161	.0006
1.000	.0557	.0011	.0117	.0004
1.250	.0665	.0012	.0107	.0004
2.000	.0846	.0016	.0081	.0003
4.000	.1222	.0029	.0076	.0002
6.000	.1439	.0041	.0077	.0002
10.000	.1653	.0056	.0071	.0001

TABLE II. Parameters for Semiempirical Fromula for Differential Gamma-Ray Dose Albedo from Thin Concrete Slabs

E_o (Mev)	C	σ_C	C'	$\sigma_{C'}$
.200	.0217	.0010	.0362	.0017
.412	.0344	.0008	.0187	.0008
.500	.0376	.0008	.0159	.0007
.662	.0435	.0009	.0148	.0006
1.000	.0548	.0010	.0108	.0004
1.250	.0657	.0012	.0098	.0004
1.368	.0712	.0012	.0086	.0003
2.000	.0844	.0017	.0079	.0003
2.754	.0087	.0028	.0086	.0003
4.000	.1025	.0037	.0081	.0003
6.000	.1009	.0043	.0086	.0003
10.000	.1066	.0059	.0077	.0002

TABLE III. Parameters for Semiempirical Formula for Differential Gamma-Ray Dose Albedo from Thick Slabs of Aluminum and Steel

	C	σ_C	C'	$\sigma_{C'}$
Aluminum				
.662 Mev, Monte Carlo	.0439	.0010	.0164	.0006
Experiment	.0560	.0037	.0180	.0025
1.250 Mev, Monte Carlo	.0616	.0013	.0127	.0004
Experiment	.0864	.0052	.0108	.0015
Steel				
.662 Mev, Monte Carlo	.0469	.0009	.0073	.0005
Experiment	.0554	.0026	.0079	.0014
1.250 Mev, Monte Carlo	.0664	.0013	.0090	.0004
Experiment	.0877	.0074	.0051	.0018

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