AMERICAN JOURNALS
Open Access, Peer Reviewed Journals
American Journal of Pedagogical and Educational Research
ISSN (E): 2832-9791| Volume 26, | July - 2024

COMPARATIVE ANALYSIS OF GAMMA RAY DOSE BUILDUP FACTOR CALCULATION METHODS IN AIR

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ABSTRACT	KEYWORDS
The dosage buildup factors for gamma rays in air are thoroughly examined in this work using four different formulations: the linear, quadratic, Berger, and Capo forms. We compute the accumulation factors and analyze their behavior as a function of the number of mean free pathways, using isotope data and attenuation coefficients. At lower photon energy, the data indicate notable variances, especially between the linear and Capo forms; at higher energies, there is convergence. Furthermore, for photon energies of 0.04, 0.38, and 1.09 MeV under various stability classes and release heights (20 m and 100 m), we examine gamma doses as a function of downwind distance. The results offer important insights into gamma radiation and emphasize the significance of choosing suitable buildup factor formulations depending on photon energy.	Gamma radiation, Linear form, Quadratic form, Berger form, Capo form, Photon energy, Attenuation coefficients, Gamma doses, Downwind distance, Radiation shielding

Introduction

The ratio of any desired quantity characteristic of the total gamma ray flux (such as the gamma dose) to the same quantity characteristic of the unscattered flux is the basic definition of the accumulation factor.

According to the above definition, the ratio of the total dosage or dose rate in a given medium at a given point to the dose or dose rate at that point because of unscattered flux is known as the dose buildup factor[1].

The buildup factors are highly helpful since they may be used in relatively basic calculations that produce results that are reasonably accurate. To estimate dose accumulation factors, many functions are employed; in this work, four distinct forms have been used.

Linear form

One of the formulas used earliest for the buildup factor was the linear form given by

$$B(E, \mu R) = 1 + K(E))\mu R \quad (1)$$

where

E is the photon energy, μ is the linear attenuation coefficient, R is the distance to the source.

In this report K(E) for air is calculated from

$$K(E) = \frac{\mu(E) - \mu_{en}(E)}{\mu_{en}(E)} \qquad (2)$$

where μ_{en} is the linear energy absorption coefficient. The values for μ and μ_{en} are taken from Table 1 [2].

Table 1. Isotope data and attenuation/energy absorption data for air

No	E_γ , MeV	y, fot·dis^{-1}	μ, m^{-1}	μ_{en}/ρ, cm^2 g^{-1}
Isotope 1	0.04	1	0.0315	0.0657
Isotope 2	0.38	1	0.0128	0.0294
Isotope 3	1.09	1	0.0079	0.0273
Isotope 4	2.53	1	0.0050	0.0217

The quadratic form

The quadratic formula for the buildup factor is given by

$$B(E, \mu R) = 1 + A_1(E)\mu R + A_2(E)\,(\mu R)^2 \qquad (3)$$

The values of A_1 and A_2 are given by [3] for water at photon energies above 0.255 MeV. As the effective atomic number for water is approximately identical to the effective atomic number for air, the buildup factors for water and air will be nearly identical.

Berger form

The formula for the buildup factor introduced by Berger [4] is given by

$$B(E, \mu R) = 1 + C(E)\mu R \cdot e^{D(E)\mu R} \qquad (4)$$

The values of C and D are given by [3] for water at photon energies above 0.255 MeV and by [4] for air at photon energies from 0.020 MeV to 6 MeV.

Capo form

The Capo formula for the buildup factor is a bivariate polynomial given by

$$B(E, \mu R) = \sum_{i=0}^{3} \sum_{j=0}^{4} c_{ij} E^{-j} (\mu R)^i \qquad (5)$$

which can be re-written as a 4-term polynomial

$$B(E, \mu R) = \sum_{i=0}^{3} \beta_i (\mu R)^i \qquad (6)$$

where

$$\beta_i = \sum_{j=0}^{4} c_{ij} E^{-j} \qquad (7)$$

Capo [5] has published a rather complete set of coefficients, c_{ij}, for many materials including water. For water the coefficients are given for energies above 0.255 MeV.

Unlike all other formulations of the buildup factor, Capo's coefficients result in an expression which does not reduce exactly to one for $\mu R = 0$. However, the Capo formula has the advantage that one may generate a set of β-values for any energy.

Table 2. Capo coefficients for dose buildup factors in water.

j/i	0	1	2	3
0	1.01094	1.16772e-1	-7.65869e-3	1.67068e-4
1	-6.00394e-2	2.32125	-1.79023e-2	5.69295e-4
2	7.20778e-2	-2.12801	2.41735e-1	-7.96332e-3
3	-3.01498e-2	7.67783e-1	-4.34443e-2	7.23758e-3
4	3.94733e-3	-9.08139e-2	-1.34203e-3	-9.87237e-4

Discussion of Results

Calculated γ-doses using the 4 different buildup factor formulas are shown in figure 1 as a function of downwind distance.

The different buildup factors used deviate from each other particularly at low energies, especially the linear and Capo forms[7]. At higher energies they all converge more or less to the same value[8-9].

When γ-doses from a plume are calculated by use of two different buildup factor forms B_1 and B_2, then the difference between the two sets of γ-doses will increase as the distance from the detector point to the plume, R, increases, if

$$\frac{B_1(\mu R_1)}{B_2(\mu R_1)} > 1 \quad \text{and} \quad \frac{B_1(\mu R_2)}{B_2(\mu R_2)} > 1 \qquad (8)$$

Looking at the calculated doses in figure 1, successively, the effect expressed in (8) is clearly demonstrated as would he expected frost the appearance of the buildup factors shown in Fig. 1.

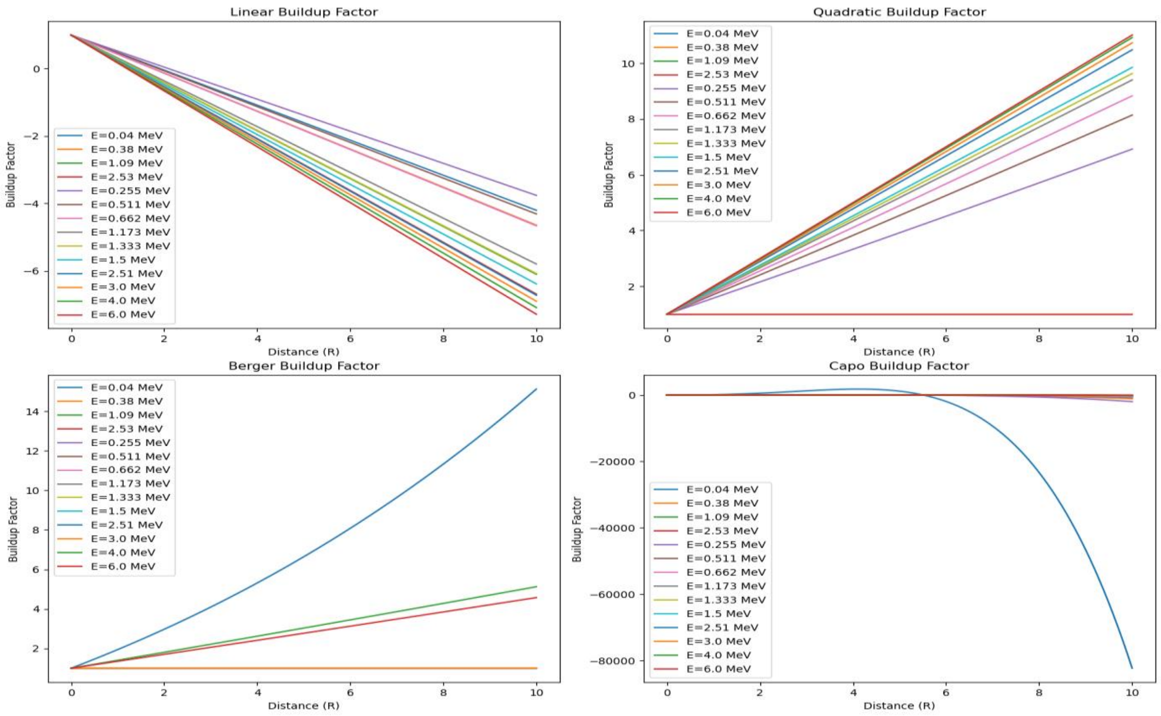

figure 1. Various dose accumulation factors for air depending on the quantity of mean free paths.

The effect is even more marked for increasing stability, because - for a given downwind distance - turn distance from the plume to the detector point then increases. This is illustrated by looking at figure 2 successively.

Conclusion

Most of the buildup factors in current use are based on the fundamental work of Goldstein and Wilkins [6]. Trubey concludes that the Capo-polynomial buildup factor function gives the very best fit of the basic data.

Besides, the Capo formula has the advantage that buildup factors may be generated at any energy from the matrix of coefficients. At a given energy, a repeated calculation of the buildup factor for a numerical integration in a computer is as fast as using the linear buildup factor, when the calculations are performed with $B = B_0 + \mu R(\beta_1 + \mu R(\beta_2 + \beta_3 \mu R))$.

Furthermore, it has been shown from the calculations that the linear and the Capo buildup factors forms should be used with some care, and not at low photon energies in any case.

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