Volume 1 No.5, November 2011 ISSN 2224-3577
International Journal of Science and Technology

©2010-11 IJST Journal. All rights reserved

http://www.ejournalofsciences.org

Determination of Photon Ambient Dose Buildup Factors for Radiological Applications for Points and Plaque Source Configurations Using MCNP5

P. Deatanyah[1], C.C. Arwui[1], S. Wotorchi- Gordon[1], H. Lawluvi[2], D. O. Kpeglo[2], J. Ankaah[2], G. Emi-Reynolds[2], E. O Darko[2].

[1]Regulatory Control Division, Ghana Atomic Energy Commission, P. O. Box LG80, Legon, Accra, Ghana
[2]Radiation Protection Institute, Ghana Atomic Energy Commission, P. O. Box LG80, Legon, Accra

ABSTRACT

Photon ambient dose equivalent buildup factors were calculated for point and plaque isotropic cobalt-60 and cesium-137 radioactive sources irradiating a finite slab shield materials of ordinary concrete, barite concrete, lead, lead glass and water using MCNP5 code. Studied shield thickness ranged from 1 to 15 mean free paths (mfp). A variance reduction technique available in the code was used to reach accurate results. These results are suitable for photon shielding and dosimetry calculations. It was concluded that for the same shield thickness and photon energy, the ambient dose equivalent of a plaque source configuration is higher than that of a point source configuration.

Keywords: *Monte Carlo method; Ambient dose equivalent; Buildup factors; MCNP5 code; Radiation shielding.*

I. INTRODUCTION

Buildup factor is defined as the ratio of the observed ionization to the ionization expected from the primary gamma rays only, disregarding multiple scattering [1]. In 1954, the first comprehensive sets of photon buildup factors were developed and reported by Goldstein and Wilkins' for point, isotropic and monoenergetic gamma sources in infinite homogeneous media [2]. These buildup factors, along with others, were based on moment's method calculations and only accounted for Compton (incoherent) scattering [3]. As transport codes became more sophisticated and computational power increased, it became possible to develop buildup factors which also take into consideration secondary photons from coherent scattering, pair production and photo-electric absorption into account. As buildup factors came into wider usage, several approximations were developed [4] for homogeneous materials of varying thickness. The most successful of these approximations has been the geometric progression approximation [5, 7]. Despite the accuracy with which buildup factors for homogeneous shields have been developed, precise treatments for heterogeneous shields are rare and such data for non-spherical geometry is virtually nonexistent. Most early attempts to develop buildup factors for stratified shields consisted of combining buildup factors calculated for homogeneous shields to approximate experimental data [8, 11]. More recent attempts have used transport codes to generate response data for stratified shields which is then used to develop buildup factors. [12]

The Monte Carlo method does not explicitly solve the transport equation, but instead obtains answers by simulating individual particles and recording aspects of their average behavior. These methods have provided a means to develop empirical formulas for buildup factors. Along with these methods, the development of photon cross sections with the inclusion of coherent scattering, the electron binding effect on incoherent scattering, bremsstrahlung, and fluorescence has greatly improved buildup factor studies and analysis [13, 16]. The four major photon interactions that significantly contribute to the attenuation of photons through a given material for the energy range of 1 keV to 10 MeV are the photoelectric effect, Compton scattering, coherent scattering, and pair production. Photoelectric effect is usually an important process for low-energy photons, where an energetic incident photon interacts with an atomic electron, usually ejecting an energetic photoelectron from the K shell. Compton scattering is a major photon interaction for energies above 100 keV, in which a photon of energy *E* interacts with an electron initially at rest where both energy and momentum are conserved. This interaction results in the transfer of kinetic energy from the photon to an electron that moves at an angle measured from the initial direction of the photon, while the secondary photon has an energy which moves at angle of scattered photon. The Compton effect is the cause of many difficult problems encountered in the shielding of photons. This is because the photon does not disappear in the interaction as it does in the photoelectric effect and in pair production, so this Compton-scattered photon is free to penetrate the shield or interact again. Two interactions that are in competition with one another at low photon energies are coherent and incoherent scattering. In coherent scattering, photons interact with the collective atomic electrons of an atom, while incoherent scattering occurs when photons interact with individual electrons. For coherent scattering, there are minimal changes in photon energy and direction because the recoil momentum of the interaction is taken up by the atom. The last major photon interaction discussed is pair production, which occurs when an incident photon is completely absorbed and is replaced by a positron-electron pair with kinetic energies respectively. The phenomenon is an interaction with a strong electric field in the vicinity of the nucleus, and has photon threshold energy of 1.022 MeV. The annihilation process of the positron usually results in the creation of two photons of energy 0.511 MeV moving in opposite directions [17, 18].

In this study, ambient dose buildup factor studies was has been carried out for ordinary concrete, barite concrete, lead, lead glass and water for a finite homogenous material configurations. Two source geometries were considered, a point isotropic geometry and a plaque isotropic geometry for both Cesium-137 and Cobalt-60 monoenergetic radiation sources.

II. MATERIALS AND METHOD

The MCNP5 calculations was based on a finite slab geometry in a vacuum that was achieved by using reflective boundary conditions on the slab side-walls to ensure any particles that may exit the sides of the material slab will be reflected and re-enter the slab. In the geometry of this work, a point isotropic and a plaque isotropic sources each of definite energy 1.25MeV and 0.662MeV for cobalt and cesium respectively were assumed to be located at one side of the finite slab shield of definite thickness given in mean free path and a point detector placed at the other side of the shield with a line of sight between source and detector normal to the slab surfaces as shown in figure 1 below.

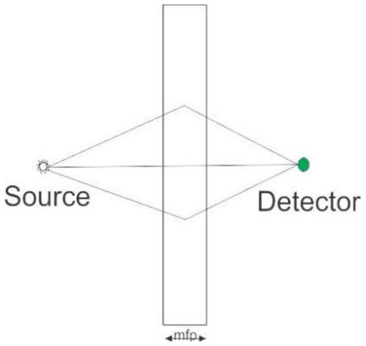

Figure 1: Setup of the photons buildup factor geometry

The mcnp5 code calculates the transport of photons through the material medium taking into consideration the various types of photon interactions. The most suitable library that was used for the primary photon transport cross sections in this research work was the Evaluated Nuclear Data File (ENDF/B-VI) [19]. The shield materials composition data used was obtained from “Compendium of Material Composition Data for Radiation Transport Modeling” [20].The photons are then tallied on the slab’s exit surface 0.3 meters with a cumulative tally (F5) and with a sensitive area of 1.81 cm in diameter giving both the un-collided and the collided dose respectively. The resulting flux was then modified by an ambient dose equivalent response function obtained from the compilation of the International Commission on Radiological Protection (ICRP) Publication 74 [21]. Enough particles were run in each case and the entire ten statistical tests were observed. Geometry splitting and cell importance were used to improve on the run and statistics. The photon ambient dose build-up factor, *B*, was then calculated as the ratio of the total response from all photons to the response from un-collided photons after transmission through a slab of a given optical thickness [22].

$$B = \frac{\int R(E)\emptyset(E)dE}{R(E_o)\emptyset_o(E_o)}$$

Where $R(E)$ = response function for quantity desired, $\emptyset(E)$ = total flux spectrum
and $\emptyset_o(E_o)$ = un-collided flux at initial energy $E_{o.}$

III. RESULTS AND DISCUSSION

The photon ambient dose equivalent buildup factors calculated in this work with mcnp5 code are presented in figures 3, 4, 5 and 6. Figure 3 and 6 for plaque configuration and figures 4 and 5 for a point source configuration. Figure 2 also shows the fraction of photons absorbed during the interaction of photon generated by the code and the material shields. The fraction of photons absorbed was defined as the difference between the amounts of dose collided with the shield and the un-collided dose. This is represented by figure two below.

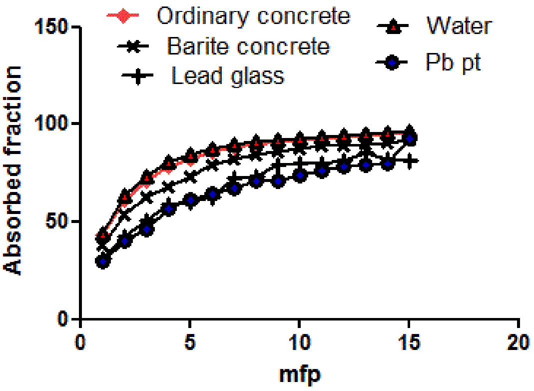

Figure 2: Fractions of photon absorbed by the slab shielding materials.

From figure 2, it became obvious that for the same material thickness, concrete had the highest absorbent fraction whiles lead had the least. This was because lead is more dense than concrete. This implies that among the materials studied, lead is the best material for photon shielding, followed by lead glass, barite concrete, ordinary concrete and water as indicated by figure 2. Comparing figures 3 and 4, it could be said to follow the same trend and that between 1 mfp to 15 mfp studied, there is only a small change in the buildup factor obtained by the point and plaque source configurations. This means that between this ranges point source could be used in place of a plaque source configuration for a cesium source. The dose buildup factor was also found to increase with thickness for the same photon energy.

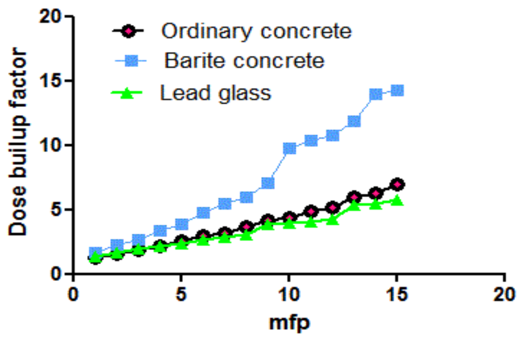

Figure 3: Ambient dose buildup factors for ordinary concrete, barite concrete and lead glass for a plaque isotropic cesium source configuration.

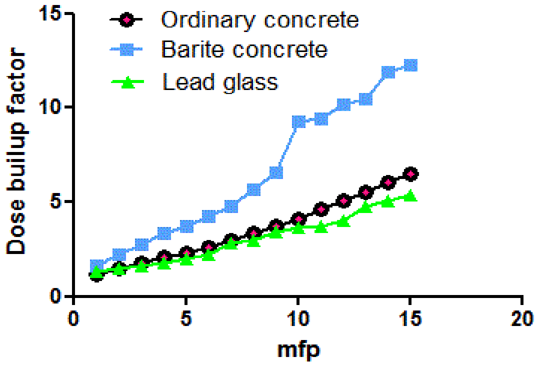

Figure 4: Ambient dose buildup factors for ordinary concrete, barite concrete and lead glass for a point isotropic cesium source configuration.

Similarly, figures 5 and 6 obeys the same trend but deviate slightly after 10 mfp for a cobalt source. Figures 7 and 8 clearly showed higher buildup factors for cobalt than cesium in both the point source and the plaque source configurations.

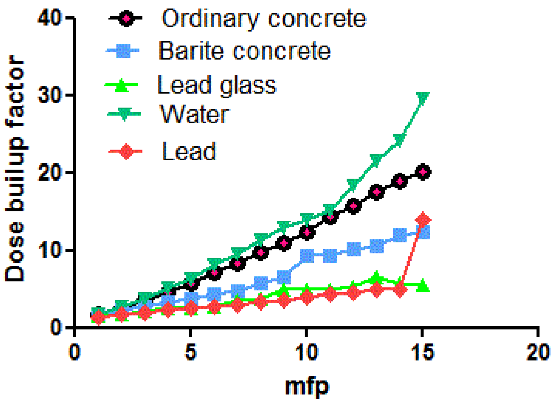

Figure 5: Ambient dose buildup factors for ordinary concrete, barite concrete, lead glass, lead and water for a point isotropic cobalt source configuration.

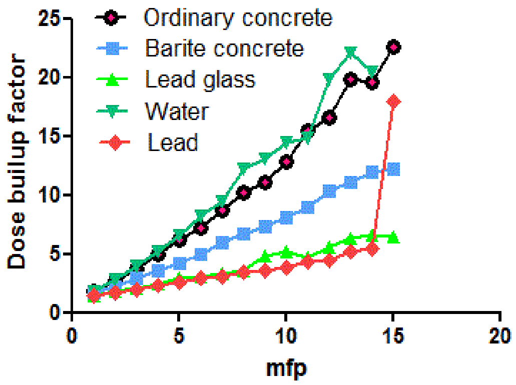

Figure 6: Ambient dose buildup factors for ordinary concrete, barite concrete, lead glass, lead and water for a plaque isotropic cobalt source configuration.

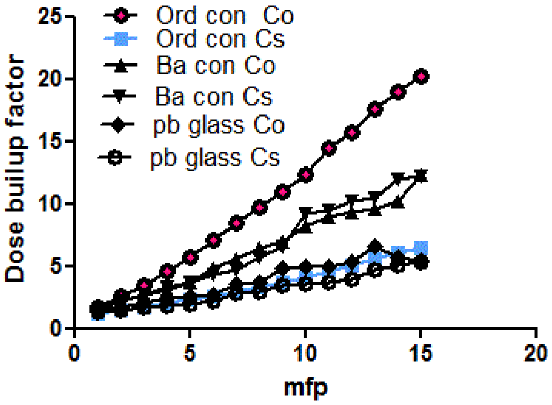

Figure 7: Comparison of ambient dose buildup factors for ordinary concrete, barite concrete and lead glass between a point isotropic cobalt and cesium source configurations.

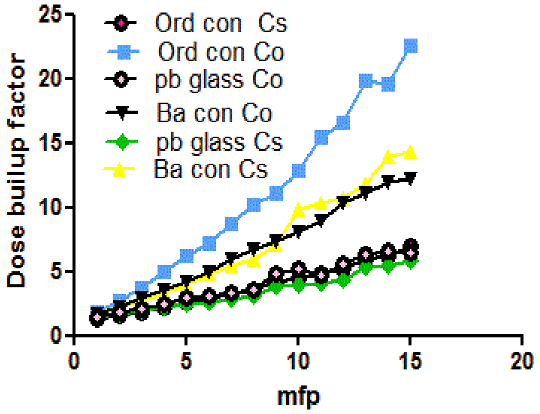

Figure 8: Comparison of ambient dose buildup factors for ordinary concrete, barite concrete and lead glass between a plaque isotropic cobalt and cesium source configurations. Considering the same source configuration, the plaque source configuration had a higher buildup factor than the point source configuration in each source case. That is for both the cobalt and cesium sources.

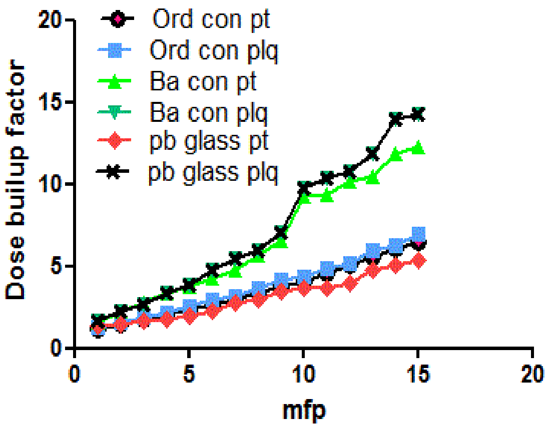

Figure 9: Comparison of ambient dose buildup factors for ordinary concrete, barite concrete and lead glass between a point and a plaque isotropic cesium source configurations.

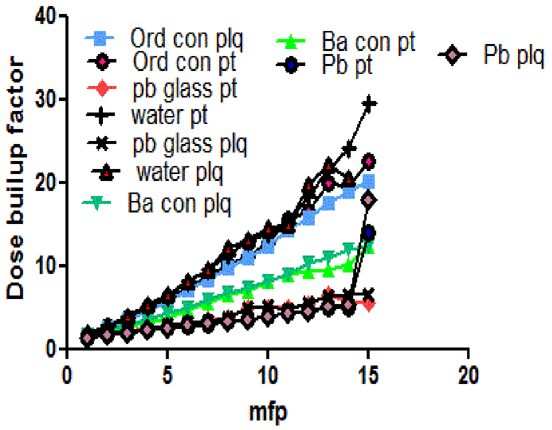

Figure 10: Comparison of ambient dose buildup factors for ordinary concrete, barite concrete, lead, lead glass and water between a point and a plaque isotropic cobalt source configurations.

IV. CONCLUSION

After the studies of the ambient dose equivalent buildup factors, the following conclusions were drawn:

1. Dose buildup factor increases with increasing mean free path (material thickness) for the same photon energy.
2. The amount or fraction of photon energy absorbed as a result of a photon interaction with the material shield is dependent on the material density. The higher the density, the lesser the absorption fraction.
3. Cobalt source had a higher dose buildup factor than cesium source for the same material thickness and source configurations. And
4. Dose buildup factor of a plaque source configuration is higher than that of a point source configuration for the same energy and material thickness.

IV. ACKNOWLEDGEMENT

The authors will like to acknowledge the management of the Radiation Protection Institute of the Ghana Atomic Energy Commission (GAEC) for their support.

REFERENCES

[1] White G.R (1950) the penetration and diffusion of cobalt-60 gamma-rays in water using spherical geometry. Phys. Rev. 80,154.

[2] Goldstein, H. and Wilkins, Jr., J.E., (1954) “Calculations of the Penetrations of Gamma rays,” NDA/AEC Report NYO-3075,US Government Printing Office, Washington, DC.

[3] Shultis, J. K. and Faw, R.E., (1996) *Radiation Shielding*, Prentice Hall PTR, Upper Saddle River, NJ, p.215.

[4] Harima, Y., (1986) “An Approximation of Gamma-Ray Buildup Factors by Modified Geometric Progression,” Nucl. Sci. Eng., 83 299-309.

[5] Berger M.J. (1956) Proc. of shielding symposium, Naval radiological defense laboratory, USNRDL Reviews and lectures No. 29, p. 47.

[6] Capo M.A (1959) Polynomial approximation of gamma rays buildup factors for a point isotropic source.APEX-510.

[7] Taylor J.J (1954) Application of gamma ray buildup data to shield design, WAPD-RM-217.

[8] Bünemann, D. G. Richter, (1968) “Multilayered shields”, Engineering Compendium on Radiation Shielding, Vol. I p 230 .G. Jaeger (ed.), Springer-Verlag, New York.

[9] Shultis and Faw Y. Harima (1983) “An Approximation of Gamma-Ray Buildup Factors for Two Layer Shields,” Nucl. Sci. Eng. 85 45-79.

[10] Harima, Y., Y. Sakamoto, S. Tanaka, M. Kawai, (1986) “Validity of the Geometric Progression Gamma-Ray Buildup Factors”, Nucl. Sci. Eng., 94 24-25.

[11] Melvut Guvendik, Nicholas Tsoulfanidis, (2000) “Formulas Giving Buildup Factor For Double-Layered Shields”, Nucl. Tech. 131 332-336.

[12] Wooten, H.O., (2005) “Time Dependent Neutron and Photon Dose-Field Analysis,”LA-14245-T, Los Alamos National Laboratory.

[13] Hirayama, H., (1995) “Calculation of Gamma-ray Exposure Buildup Factors up to 40 mfp Using the EGS4 Monte Carlo Code with a Particle Splitting,” *J. Nucl. Sci. Tech.*, **32**, 12, 1201-1207.

[14] Chibani, O., (2001) “New Photon Buildup Factors,” *Nuc. Sci. Eng.*, **137**, 215-225.

[15] Shimizu, A., Hirayama, H., (2003) “Calculation of Gamma-Ray Buildup Factors up to Depths of 100 mfp by the Method of Invariant Embedding, (II),” *J. Nucl. Sci. Tech.*, **40**, 4, 192-200.

[16] Lamarsh, J.R., Baratta, A.J., (2001), Introduction to Nuclear Engineering, Third Edition, Prentice Hall, New Jersey.

[17] Cullen, D., Hubbell, J., Kissel, L., (1997) “EPDL97: The Evaluated Photon Data Library, ’97 Version,” UCRL-50400 Vol. 6 Rev. 5, University of California.

[18] Faw, R.E., Shultis, J.K., (1999) Radiological Assessment: Sources and Doses, American Nuclear Society, La Grange Park, Il.

[19] R.A... Schwarz, A.L... Schwarz, and L. L. Carter, (2006) " Wizards and Visualization Features for MCNP Geometries and Sources," The American Nuclear Society’s 14th Biennial Topical Meeting of the Radiation Protection and Shielding Division, Carlsbad New Mexico, USA. April 3-6.

[20] R.G. Williams III, C.J. Gesh, R.T. Pagh: (2006) Compendium of Material Composition Data for Radiation Transport Modeling.

[21] International Commission on Radiological Protection, (1997) “Conversion Coefficients for use in Radiological Protection against External Radiation,” ICRP Publication 74, Pergamon Press, Oxford.

[22] Yoshiko Harima (1993) Historical review and current status of buildup factor calculations and applications. Radia. Phys. Chem.Vol. 41, No.4/5, pp. 631-672.