Journal of Al-Nahrain University Vol.13 (1), March, 2010, pp.78-83 Science

EFFECT OF EXPOSURE BUILDUP FACTORS ON REACTOR SHIELDING

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Abstract

The gamma ray buildup factor for a point isotropic monoenrgetic source (0.1, 1 and 10 MeV) have been studied up to a depth of 10 mean free paths (mfp) for water, iron , lead and uranium dioxide (UO_2). Also the exposure buildup factor for gamma radiation in heterogeneous (double layer) shielding were determined for different order of layer (layer closer to the source consist of either a low atomic number material followed by a high atomic number material or a high atomic number material followed by low atomic number material).

Introduction

In practical gamma ray shielding calculation the most widely used method of determining the total effect of the radiation at point of interest makes use of a parameter called the buildup factor B(μx,E).

In gamma ray transport through a medium, the response of a detector to photons at a distance x from a monoenergetic point source is given by

$$I = B(\mu x,E)\, I_o\, e^{-\mu x}$$

where Io is the detector response in the absence of the medium (*i.e.*, a vacuum between source and detector), μ is the linear attenuation coefficient for photons of the source energy and B(μx,E) is the buildup factor which accounts for photons which are scattered by the shield into the detector

The buildup factor can be considered as a simple correction factor which adjusts the result for the uncollied photons to include the contributions from the scattered and subsidiary radiation. The buildup factor define by[1]

$$B = \frac{\text{Detector response to the radiation at a point of interest}}{\text{Detector response to the uncollid radiation at the same point}}$$

Theoretical investigation shows that the value of buildup factor depends on the following conditions:

1-The nature of the attenuating medium (atomic number z).
2-The energy of the photons source.
3-The distance between the source and the point of interest (mean free path).
4-The geometry of the source.
5-The quantity being considered.

In most shield calculations, buildup factor roughly lies in the range 10 to 200 .The most of the existing gamma ray buildup factor values have been derived by treating only the Compton scattering accurately.

The variation of the buildup factor with penetration distance in multi-layered shields differs from that in homogenous media, mainly because of the change in the angular and energy distribution of the radiation in the vicinity of regional boundaries. This means that in multi-layered systems the buildup effect on the incident radiation depends on the prievously penetrated layers as well as the layer under consideration, and that in which the layers occur may be significant, [1].

The scattered radiation and, the buildup factor increases relative to the unscattered or primary radiation as the shield thickness increases. It is the dominate radiation in the thicker shields. The buildup factor can be obtained in principle by experiment; but since the attenuation coefficients and the scattering cross sections are known with reasonable accuracy, buildup factors are customarily obtained either by the solution of the photon transport equation or by Monte Carlo method. Buildup factors, which are important data in nuclear radiation shielding and absorbed dose calculations, have been widely studied by various research groups,[2].

One must distinguish between the different definition of the buildup factor

1-The number buildup factor is the ratio of the actual flux of photons of all energies to the flux of uncollided photons beyond a shield

2-The energy buildup factor which is the ratio of the actual energy flux to the energy flux of the unscattered beam

3-The absorption of energy buildup factor is the ratio of the specific energy absorbed per unit volume of the absorbing medium to the pecific energy absorbed as a result of absorption of the unscattered beam

4-The dose buildup factor is a special of the absorption of energy buildup factor where the absorbing medium is tissue for calculation the effective dose, or air for the calculation exposure.[1,2].

Theory

The gamma buildup factor represents a necessary correction factor in the design calculations of the reactors shielding where shielding is an important principle to protection from nuclear radiation.

Buildup factor depend on linear absorption coefficient (μ), shield thickness (x), photon energy (E) and atomic properties of shield material (atomic number, scattering and absorption cross section).

A number of methods and formula have been used to calculate gamma buildup factor such as :

1- Taylor's form

$$B(\mu x,E) = A_1 e^{-\alpha_1 \mu x} + (1 - A_1) e^{-\alpha_2 \mu x}$$

where $\alpha 1$, $\alpha 2$ and A_1 are constant

2- Polynomial

$$B(\mu x,E) = 1 + \alpha\, \mu x + \beta (\mu x)^2 + \gamma (\mu x)^3$$

where α , β and γ are constant .

3- Berger's form

$$B(\mu x,E) = 1 + a\, \mu x\, e^{b\mu x}$$

where a and b are constant.

4- Linear form

$$B(\mu x,E) = 1 + b(\mu x)$$

Where b is a constant

It is well known that the penetration of photon in the matter obeys the exponential attenuation rule

$$I = I_o e^{-\mu x}$$

when buildup is considered the relation becomes

$$I = B(\mu x,E)\, I_o e^{-\mu x}$$

Buildup factor always greater than one

$$B(\mu x,E) \geq 1 .$$

For a completely absorbing medium with scattering cross section $\sigma s = 0$, buildup factor would be unity. Buildup factor satisfies these limit conditions [3,4]

$B(\mu x,E) = 1$ at $\Sigma a = \infty$

$B(\mu x,E) = \infty$ at $\Sigma s = \infty$

$$1 \leq B(\mu x,E) \leq \infty$$

Results and Discussion

Buildup radiation is due to the processes involving when gamma radiation hits a high atomic number material used in shielding,the net result is additional radiation adding to the incident gamma as a result of interaction with shielding

Gamma ray exposure buildup factors were studied for material used in reactor shielding water, iron , lead, and UO_2 at energies 0.1 , 1 and 10 MeV up to a depth of 10 mfp was shown in Figs.(1,2,3) . At low energy Fig.(1) shows that buildup factor increases as atomic number decreases (i.e. buildup factor for low atomic number (z) is higher than that for low atomic number). The same behaviors shown in Fig.(2) at energy 1 MeV.At high energy Fig.(3) buildup factor take the opposite behavior buildup factor increasing with increasing atomic number (i.e. buildup factor for higher atomic number (z) is higher than that for low atomic number) [5].

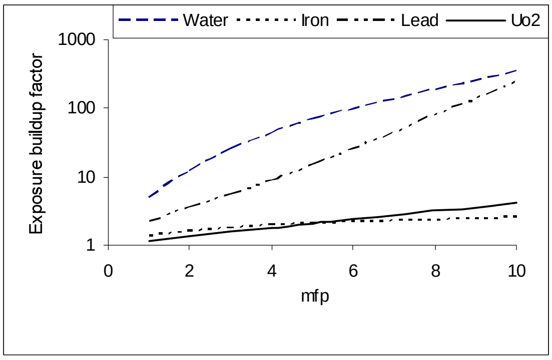

Fig.(1) : Exposure buildup factor VS.mfp at gamma energy 0.1 MeV.

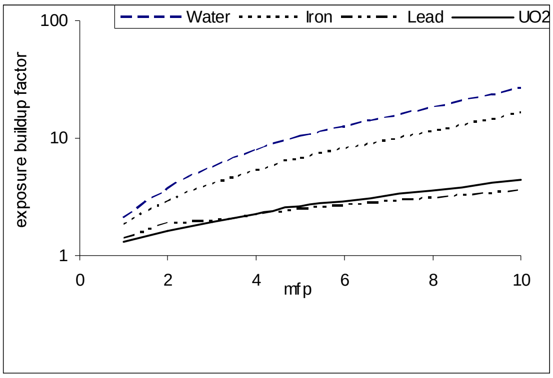

Fig.(2) : Exposure buildup factor VS.mfp at gamma energy 1 MeV.

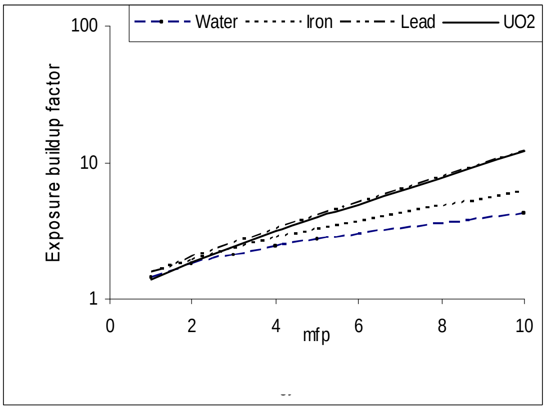

Fig.(3) : Exposure buildup factor VS.mfp at gamma energy 10 MeV.

The effect of gamma ray exposure buildup factor with gamma energy was shown in Figs.(4,5,6) at different mean free path, which show that exposure buildup factor increases with the increasing of mean free path. Exposure buildup factor for water and lead have a high value at low energy and their values decreases with increasing energy .The exposure buildup for UO_2 increases with energy, while in iron the exposure buildup factor increases with energy up to a bout 1 MeV then it decreases when energy increases for different mean free path [6,7].

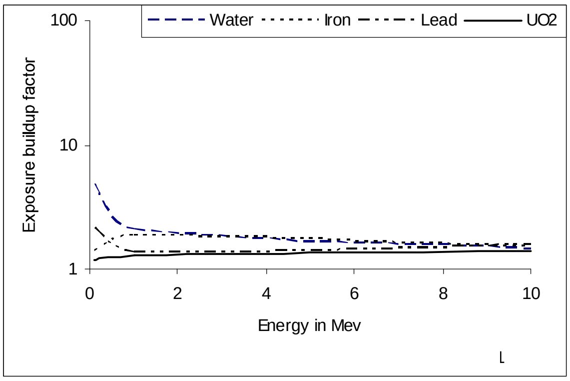

Fig.(4) : Exposure buildup factor VS. energy at mfp =1.

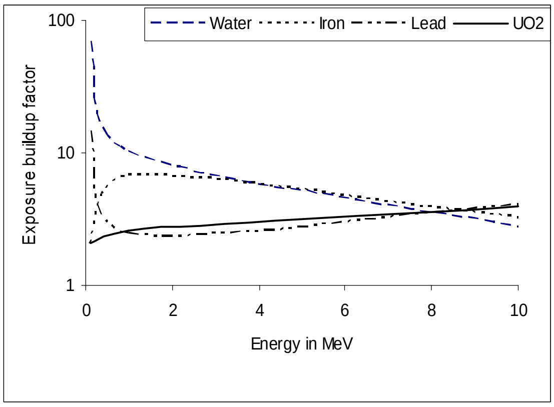

Fig.(5) : Exposure buildup factor VS. energy at mfp =5.

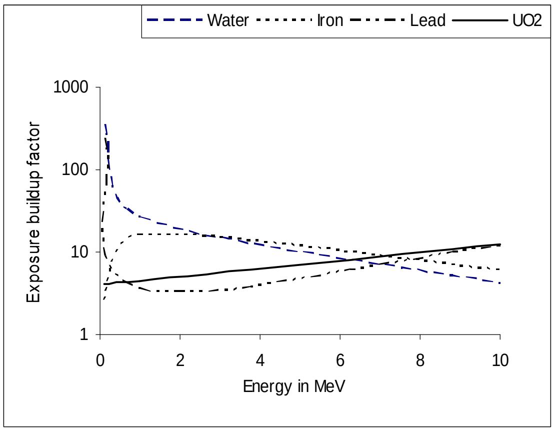

Fig.(6) : Exposure buildup factor VS. energy at mfp =10.

Most shields contain a mixture of different element so the exposure buildup factor for a mixture of iron and water, and a mixture of water and lead was studied for different orders. First when element of a high atomic number is closer to the source, second when element of low atomic number is closer to the source for energies 0.1, 1 and 10 MeV as shown in Figs.(7,8,9).

In case when a layer of high atomic number is closer to the source the effective exposure buildup factor equal the product of the buildup factor for the two layer of the appropriate mean free path, while in case when a layer of low atomic number is closer to the source the effective exposure buildup factor is close to the buildup factor for the high atomic number layer of the appropriate mean free path. Figs.(7,8,9) show that exposure buildup factor for double layer of lead & water(lead closer to the source) is higer than that for water & lead (water closer to the source).The same behavior was shown in iron and water. For both cases exposure buildup factor has a higher value for low energy and its value decreases as energy increases [8].

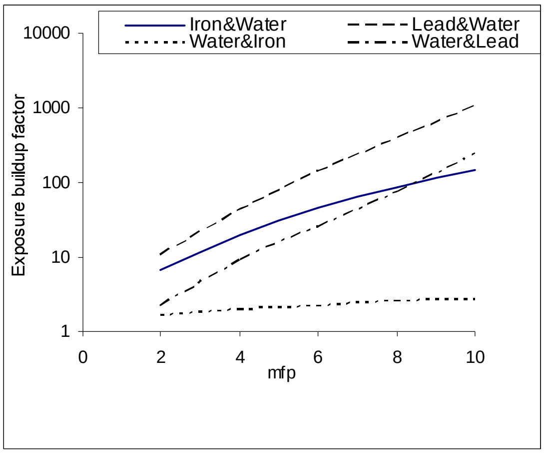

Fig.(7) : Exposure buildup factor VS.mfp for double layer at 0.1 MeV.

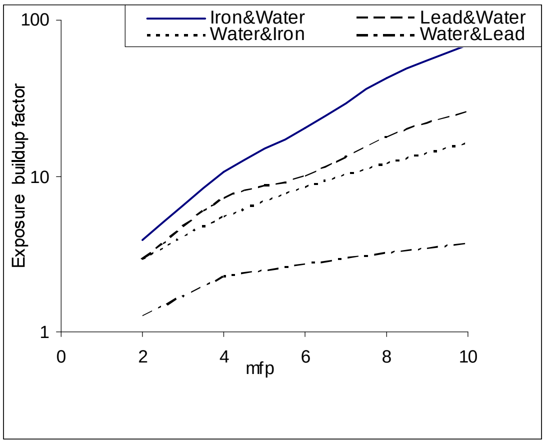

Fig.(8) : Exposure buildup factor VS.mfp for double layer at 1 MeV.

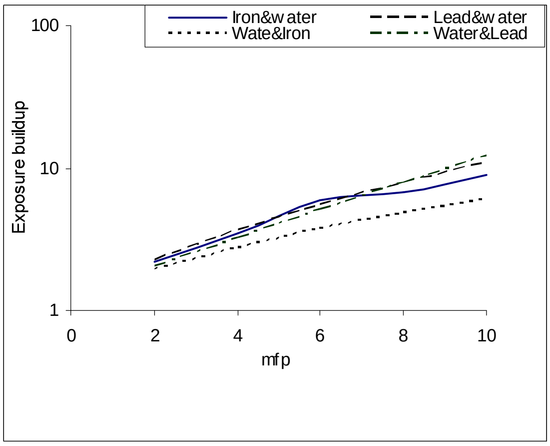

Fig.(9) : Exposure buildup factor VS.mfp for double layer at 10 MeV.

Exposure buildup factor for double layer studied in such case, a one mean free path for first layer and one to five mean free path for second layer are chosen with different orders for lead, iron and water.

Fig.(10) shows the exposure buildup factor for 1 mfp of water followed with 1 to 5 mfp of iron (water closer to the source) at energies 0.1 ,1 and 10 MeV.At 1 Mev the exposure buildup have a higher value while lower value occurs at 0.1 Mev.

Fig.(11) shows the exposure buildup factor for 1 mfp of iron followed with 1 to 5 mfp of water (iron closer to the source) at energies 0.1, 1 and 10 MeV.At 0.1 Mev the exposure buildup factor has a higher value while lower value occurs at 10 Mev[9].

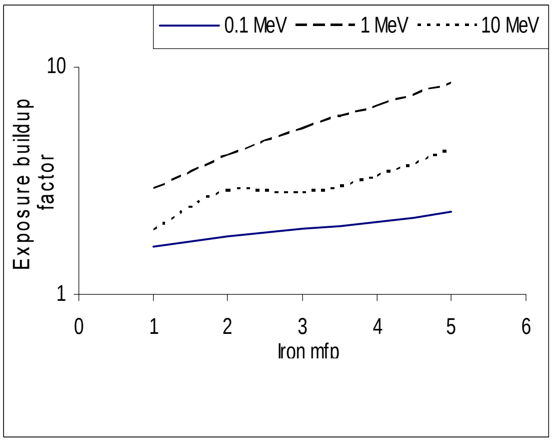

Fig.(10) : Exposure buildup factor for double layer 1 mfp of water with different mfp iron.

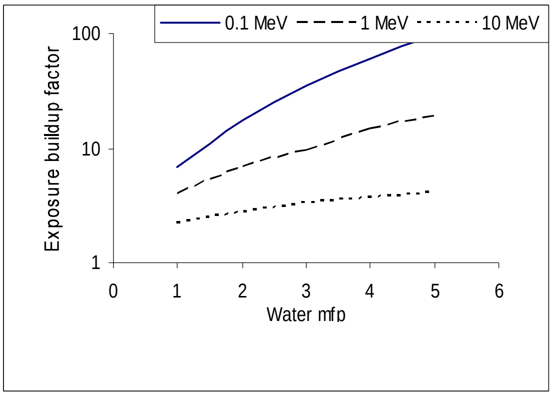

Fig.(11) : Exposure buildup factor for double layer 1 mfp of iron with different mfp of water.

Exposure buildup factor for double layer 1 mfp of water and 1 to 5 mfp of lead shows in Fig.(12). At 0.1 MeV exposures buildup factor have a higher value while its lower value occurs at 1 MeV in Fig.(12) and at 10 MeV in Fig.(13).

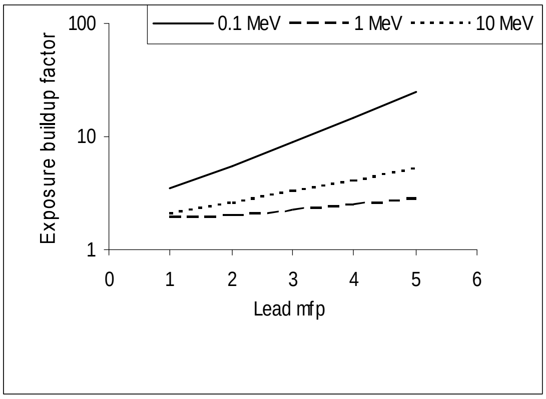

Fig.(12) : Exposure buildup factor for double layer 1 mfp of water with different mfp iron.

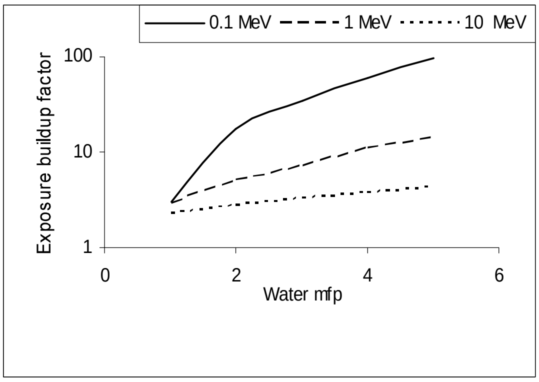

Fig.(13) : Exposure buildup factor for double layer 1 mfp of lead with different mfp of water.

Conclusion

Exposure buildup factor is directly proportional with mean free path even we have a single layer or double layer shield.

The buildup factors are higher in shields composed of the lighter element (such as water) than the heavier elements. The reason that the energies of the scattered photons are lower than the energy of the primary radiation, and attenuation and absorption increase as the energy decreases at energies characteristically emitted by radionuclide.

The increase in absorption with lower energies is more marked in elements with higher atomic number because of the photoelectric effect; hence the buildup factor in heavier element decreases much more slowly than the buildup factor in lighter element as the shield thickness increases.

Exposure buildup factor depend on atomic number, increasing as atomic number decreasing at low energy and increasing with increasing atomic number at high energy.

For double layer shield exposure buildup factor depend on order of the layer closest to the source (have a high atomic number followed by a low atomic number or a low atomic number followed by a high atomic number). In case when a layer of high atomic number is closer to the source gamma ray energy decreases slightly in first layer and are weakly absorbed in the second layer so that the effective exposure buildup factor is higher than that when a low atomic number followed by a high atomic.

References

[1] James Wood, "computational methods in reactor shielding", pergamon press, (1982).

[2] M.H. Alamatsaz and A. Shirani," *A STUDY OF GAMMA RAY EXPOSURE BUILDUP FACTORS IN STRATIFIED SHIELDS FOR POINT ISOTROPIC SOURCES, INCLUDING THE EFFECTS OF INCOHERENT AND COHERENT SCATTERING*", Journal of Sciences, Islamic Republic of Iran Vol.13, No.3, (2002), pp 271-279.

[3] J.R. Lamarsh, "Introduction to nuclear engineering", Addison Wesley, (1975).

[4] L.Robert, Jr. Wright "*Basic Nuclear engineering*", Allyn and Bacon Inc., (1983).

[5] H. Hirayama, "*Calculation of gamma-ray exposure buildup factors up to 40 mfp using the EGS4 Monte Carlo code with a particle splitting*," *J. Nucl. Sci. Technol.*, 32, 1207 (1995).

[6] Marinkovic, Predrag," *A 3D point-kernel multiple scatter model for parallel-beam SPECT based on a gamma-ray buildup factor*", Physics in Medicine and Biology, Vol. 52, No.19, 21 September (2007), pp. 5785-58024.

[7] I.N.Butueva , N.L.Kuchin,"Buildup factors of gamma radiation with energy 6-10 MeV in a large depths of lead Shielding", Vol. 45, No. 2 ,(1978), pp. 794-795.

[8] A. Shimizu, ''*Calculation of gamma-ray buildup factors up to depths of 100 mfp by the method of invariant embedding* ",J. Nucl. Sci. Technol., 39, 477 (2002).

[9] Hideo HIRAYAMA and Kazuo SHIN, "*Application of the EGS4 Monte Carlo Code to a Study of Multilayer Gamma-Ray Exposure Buildup Factors of up to 40mfp*", Journal of Nuclear Science and Technology, Vol. 35, No.11 (1998), pp.816-829.

[10] Guvendik, Mevlut," *Buildup factor formulae for multi-layer shields*", Thesis (PhD). UNIVERSITY OF MISSOURI-ROLLA, Jun (2000).

الخلاصة

تم دراسة عامل التراكم لاشعة كاما للطاقات 0.1 ، 1 و 10 ميكا الكترون فولت ولعمق 10 معدل مسار حر للماء والحديد والرصاص واوكسيد اليورانيوم .كما تم دراسة عامل التراكم لاشعة كاما ولطبقتين مختلفتين، اولا عندما تكون الطبقة ذي العدد الذري العالي قريبة من المصدر تتلوها طبقة ذي عدد ذري واطئ وثانيا عند عكس الحالة ولمسارات حرة مختلفة ولنفس الطاقات المذكورة.