Calculation of Dose Gamma Ray Buildup Factor Up to Thickness of $20\,mfp$ Using Taylor's Method

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Abstract

The dose gamma ray buildup factor for different materials (*Al*, *Cu* and *Pb*) up to $20\,mfp$ had been calculated using computer programs, which were constructed to calculate this factor for different materials using **Taylor's formula** for point isotropic source .The programs had been designed to work with any atomic number and energy by adapting Lagrange interpolation method according to the studied factors (thickness of the shielding, energy of the gamma ray and atomic number of the shield).

Key words:

Dose gamma ray for point isotropic source-Dose gamma ray buildup factor-Taylor's formula-Lagrange interpolation method.

حساب عامل تراكم جرعة اشعة
جاما حتى سمك $20\,mfp$
باستخدام طريقة تايلور

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الخلاصه

تم حساب عامل تراكم جرعة اشعة جاما للمواد المختلفة (المنيوم، نحاس، رصاص) حتى سمك $20\,mfp$ ، باستخدام برامج حاسوبيه باستخدام **صيغة تايلور** للمصدر النقطي المتناظر. البرامج صممت لتعمل عند اي قيمة للعدد الذري والطاقة باستخدام طريقة استكمال لاجرانج بالاعتماد على العوامل التالية(سمك الدرع وطاقة المصدر المشع والعدد الذري لمادة الدرع).

1-Introduction

The gamma ray buildup factor represents a necessary correction factor in the designed calculations of the reactors shielding, medical physics field and nuclear laboratories, where the shielding is an important part to the protection from nuclear radiation.

A simple definition of the buildup factor is the ratio of any desired quantity characteristic of the total gamma ray flux to the same quantity characteristic of the unscattered flux. The two most useful buildup factors are; the dose and energy absorption. Applying the above , the dose buildup factor defined as the ratio of the total dose at a given point in a given medium to the dose at that point due to the unscattered flux which is generally relatively easy to calculate .The energy absorption buildup factor is similarly defined [1].

Eisenhauer & Simmons [2]; Hirayama [3]; Morris [4]; Morris et al.[5] ,Shimizy et al[6] , and Al-Baiti[7] have made a number of calculations involving single-layer shields of gamma ray buildup factor.

A number of methods and formulae have been used to calculate the dose gamma ray buildup factor (B). Some of the more commonly used of these formulae are linear formula, Berger's formula, Capo's formula and Taylor's formula [8].

In this work, the dose gamma ray buildup factor for some selected material *Al*, *Cu* and *Pb* (more interested to the shielding materials), in single layer shields has been calculated using **Taylor's formula**.

2-Calculation Method

The dose gamma ray buildup factor for single-layer shields has been studied using computer programs. **Taylor's formula** has been used to calculate this factor in single-layer shields for point isotropic source.

The programs had been designed to work with any atomic number and energy by adapting Lagrange interpolation method [9] according to the studied factors (thickness of the shielding, energy of the gamma ray and atomic number of the shield).

The dose gamma ray buildup factor in this work has been calculated as follows [8]:

$$B = Ae^{-\alpha_1 \mu x} + (1-A)e^{-\alpha_2 \mu x} \quad \textbf{... (1)}$$

where B: The buildup factor,
The three parameters A, α_1 and α_2 are functions of the attenuating medium and the source energy [1].

μ : Absorption Coefficient for the shield material [10].
x :the thickness of shield material in cm.
The thickness in mean free path $\boldsymbol{(mfp) = x(cm).\mu(cm^{-1})}$ **…(2)**

The percent deviation (%):

The percent deviation from the standard data has been calculated by [11]:

P. D. (%) = [(calculated value –standard value)/ (standard value)] x100% **… (3)**

3- Results and Discussion

The results and discussion included the effects of thickness of shield, the energy source and atomic number (Z) on the dose buildup factor for all selected materials and energies as follow:

Effect of the thickness of shield on the buildup factor:

The calculated values of dose gamma ray buildup factor for *Al*,*Cu* and *Pb* as single-layer shields of different thicknesses, at energies (0.5,1,3 and 10 MeV) are tabulated in tables (1,2 and 3) respectively. To compare these values for *Al* and *Pb* with the previous studies and reports, (Eisenhauer & Simmons Ref.[2]) and (Goldstein & Wilkins Ref.[10]) have been used and for *Cu* (Al-Baiti Ref.[7]) was used.

Figures (1, 2 and 3) show the graphs of the buildup factor against the thickness (*mfp*) of the shields at the selected energies in this work.

10	P. W.	1	1.28	1.562	2.132
	Ref.[2]	-	(1.36)	-	(2.22)
	PD%	-	-5.88	-	-3.96
	Ref.[10]	-	(1.28)	(1.55)	(2.12)
	PD%	-	0	0.77	0.57

The results show that the buildup factor increases with the increase of the thickness (*mfp*) of the shields for all energies. This behavior as a result to the increase in the scattering probability with small angles, when the thickness of the shield increases.

Table (1) The values of dose gamma ray buildup factor of *Al* for the present work compared with (Eisenhauer & Simmons Ref.[2]) and (Goldstein & Wilkins Ref.[10])

E MeV	Work	Thickness(*mfp*)			
		0	1	2	4
0.5	P. W.	1	2.629	4.528	9.284
	Ref.[2]	-	(2.27)	-	(9.14)
	PD%	-	15.8	-	1.58
	Ref.[10]	-	(2.37)	(4.24)	(9.47)
	PD%	-	10.93	6.79	-1.96
1	P.W.	1	2.193	3.504	6.519
	Ref.[2]	-	(1.98)	-	(6.48)
	PD%	-	10.76	-	0.60
	Ref.[10]	-	(2.02)	(3.31)	(6.57)
	PD%	-	8.56	5.86	-0.78
3	P. W.	1	1.677	2.366	3.786
	Ref.[10]	-	(1.64)	(2.32)	(3.78)
	PD%	-	2.26	1.98	0.16

Continue…

E MeV	Work	Thickness(*mfp*)			
		7	10	15	20
0.5	P. W.	19.466	34.662	77.066	154.406
	Ref.[2]	-	(37.6)	-	(137)
	PD%	-	3.37	-	12.71
	Ref.[10]	(21.5)	(38.9)	(80.8)	(141)
	PD%	-9.46	-10.89	-4.62	9.51
1	P.W.	12.184	19.525	36.663	62.24
	Ref.[2]	-	(21)	-	(58)
	PD%	-	-7.02	-	7.31
	Ref.[10]	(13.1)	(21.2)	(37.9)	(58.5)
	PD%	-6.99	-7.9	-3.26	6.39
3	P. W.	6.031	8.44	12.903	18.07
	Ref.[10]	(6.14)	(8.65)	(13.0)	(17.7)
	PD%	-1.78	-2.43	-0.10	2.09
10	P. W.	3.008	3.922	5.564	7.411
	Ref.[2]	-	(4.12)	-	(7.74)
	PD%	-	-4.81	-	-4.25
	Ref.[10]	(3.01)	(3.96)	(5.63)	(7.32)
	PD%	-0.07	-0.96	-1.17	1.24

Table (2) The values of dose gamma ray buildup factor of ***Cu*** for the present work compared with (Al-Baiti Ref.[7])

E MeV	Work	Thickness(*mfp*)			
		0	1	2	4
0.5	P. W.	1	2.178	3.454	6.331
	Ref.[7]	1	2.006	3.123	5.731
	PD%	0	8.574	10.599	10.469

1	P. W.	1	1.911	2.895	5.107
	Ref.[7]	1	1.916	2.918	5.205
	PD%	0	-0.261	-0.788	-1.883
3	P. W.	1	1.609	2.248	3.624
	Ref.[7]	1	1.561	2.155	3.442
	PD%	0	3.075	4.316	5.288
10	P. W.	1	1.192	1.404	1.896
	Ref.[7]	1	1.193	1.412	1.936
	PD%	0	-0.084	-0.567	-2.066

Continue

E MeV	Work	Thickness(*mfp*)			
		7	10	15	20
0.5	P. W.	11.572	18.135	32.808	53.659
	Ref.[7]	10.735	17.354	33.134	57.126
	PD%	7.797	4.50	-0.984	-6.069
1	P.W.	9.111	14.092	25.131	40.655
	Ref.[7]	9.446	14.847	27.128	44.825
	PD%	-3.546	-5.085	-7.361	-9.303
3	P. W.	5.954	8.648	14.102	21.037
	Ref.[7]	5.646	8.217	13.446	20.079
	PD%	5.455	5.245	4.879	4.771
10	P. W.	2.853	4.174	7.624	13.676
	Ref.[7]	2.984	4.436	8.101	14.046
	PD%	-4.39	-5.906	-5.888	-2.634

Table (3) The values of dose gamma ray buildup factor of ***Pb*** for the present work compared with (Goldstein & Wilkins Ref.[10]).

E MeV	Work	Thickness(*mfp*)			
		0	1	2	4
0.5	P. W.	1	1.233	1.419	1.701
	Ref.[10]	-	(1.24)	(1.42)	(1.69)
	PD%	-	-0.565	-0.07	0.651

1	P. W.	1	1.357	1.686	2.276
	Ref.[10]	-	(1.37)	(1.69)	(2.26)
	PD%	-	-0.949	-0.237	0.708
3	P. W.	1	1.339	1.695	2.462
	Ref.[10]	-	(1.34)	(1.68)	(2.43)
	PD%	-	-0.075	0.893	1.317
10	P. W.	1	1.104	1.231	1.583
	Ref.[10]	-	(1.11)	(1.23)	(1.58)
	PD%	-	-0.54	0.081	0.19

Continue

E MeV	Work	Thickness(*mfp*)			
		7	10	15	20
0.5	P. W.	2.003	2.252	2.657	3.106
	Ref.[10]	(2.00)	(2.27)	(2.65)	(2.73)
	PD%	0.15	-0.793	0.264	13.773
1	P.W.	3.041	3.721	4.784	5.879
	Ref.[10]	(3.02)	(3.74)	(4.81)	(5.86)
	PD%	0.695	-0.508	-0.541	0.324
3	P. W.	3.768	5.288	8.406	12.450
	Ref.[10]	(3.75)	(5.30)	(8.44)	(12.3)
	PD%	0.48	-0.226	-0.403	1.22
10	P. W.	2.509	4.347	12.469	39.174
	Ref.[10]	(2.52)	(4.34)	(12.5)	(39.2)
	PD%	-0.437	0.161	-0.248	-0.066

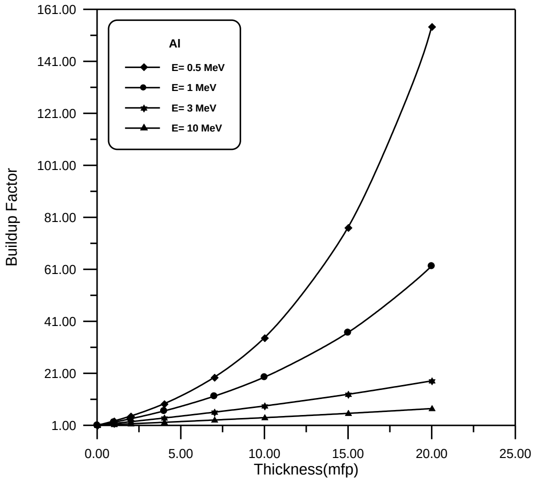


Fig.(1) The dose gamma ray buildup factor for *Al* against thickness (*mfp*)

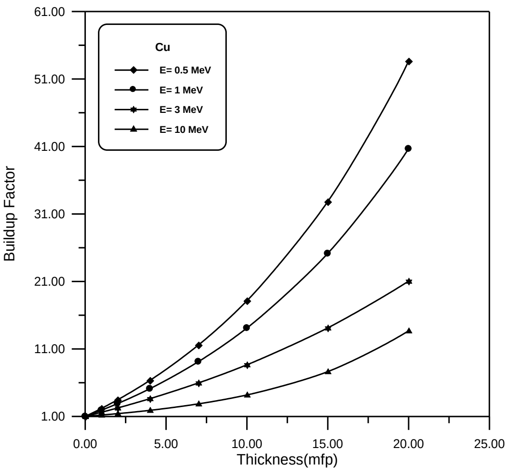


Fig.(2) The dose gamma ray buildup factor for *Cu* against thickness (*mfp*)

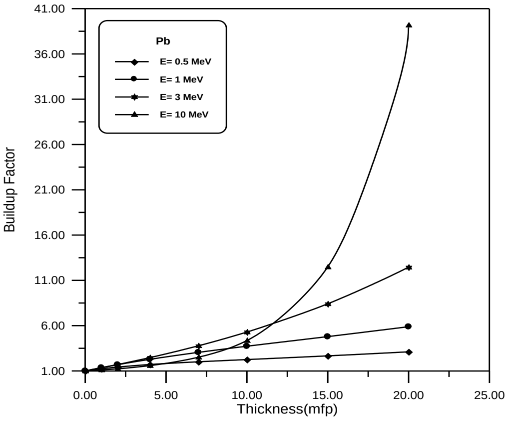
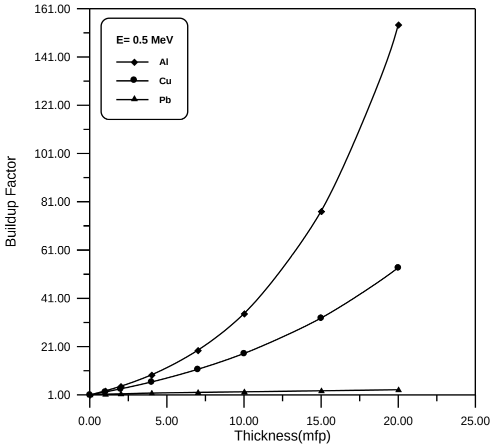


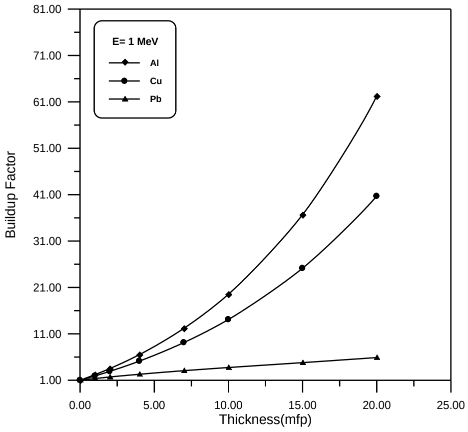
Fig.(3) The dose gamma ray buildup factor for *Pb* against thickness (*mfp*)

Effect of the energy source on the buildup factor:

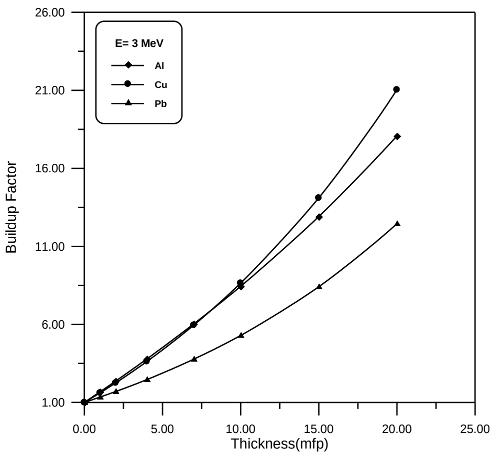
Inspection of figs.(4a,b, c and d) for the dose buildup factor for the selected materials of the shielding at the energies 0.5,1,3 and 10 MeV respectively, at E=0.5 MeV and 1 MeV the buildup factor for *Al* is higher than that for *Cu* and *Pb* (the buildup factor for the low atomic number Z is higher than that for the high Z). At E=3 MeV the behavior shows the interference between *Al* and *Cu* but the buildup factor for *Pb* still less than that for *Al* and *Cu*. The buildup factor at E=10 MeV, take the opposite behavior compared with the previous cases of energy.



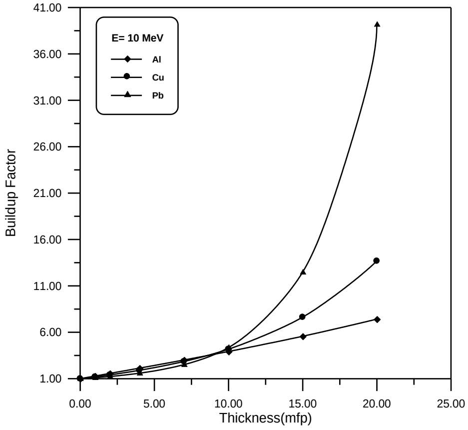
(a)



(b)



(c)



(d)

Fig.(4) The dose buildup factor for *Al*,*Cu* and *Pb* at
(a) E=0.5 MeV (b) E=1 MeV
(c) E=3 MeV (d) E=10 MeV

The behaviors of figs.(4a,b,c and d) as a result of gamma ray interaction with matter, because the probability of Compton scattering effect is greater than the probability of photoelectric effect with the materials of *Al* and *Cu*, and the opposite becomes true for *Pb* at the energies 0.5, 1 and 3 MeV. This means, at these energies the probability of Compton scattering effect is greater than the probability of photoelectric effect for low Z. At E=10 MeV the probability of the pair production effect is greater than the probability of Compton scattering effect for high Z.

See fig.(5) which represents the relative importance of the three major gamma-ray interactions (photoelectric effect, Compton scattering effect and pair production effect).

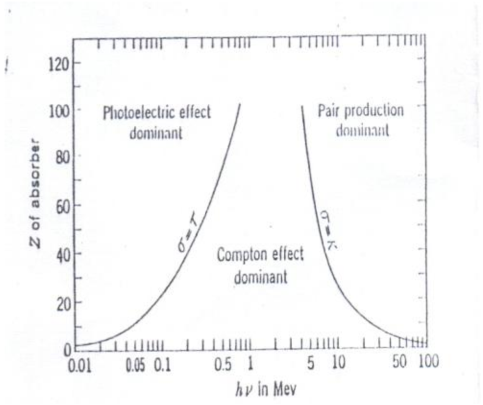


Fig.(5)The relative importance of the three major gamma-ray interactions[12].

Effect of atomic number Z on the buildup factor:

Fig.(6) shows the graphs of the dose gamma ray buildup factor against the atomic number Z of the shields within the constant thickness of 15 *mfp* (where the behavior is clearly).The result shows that the buildup factor decreases with the increase of the atomic number of the shield at the energies 0.5 MeV and 1 MeV .At E=3 MeV the buildup factor begins to increase with the increase of the atomic number of the shield. The buildup factor increases with the increase of the atomic number of the shield at the energy 10 MeV. The behavior of fig.(6) as a result of gamma ray interaction with matter. This means, the probability of Compton scattering effect is greater than the probability of photoelectric effect for low energy. At E=10 MeV the probability of the pair production effect is greater than the probability of Compton scattering effect.

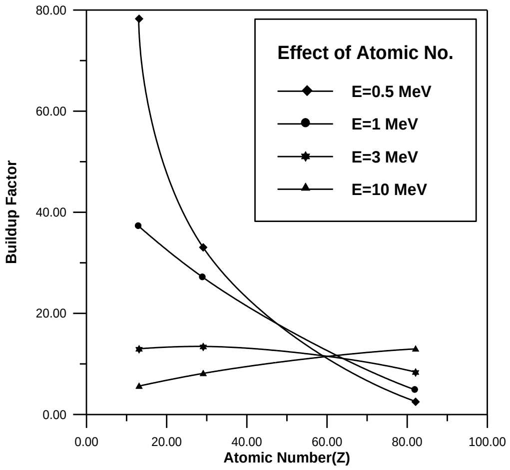


Fig.(6) Effect of the atomic number Z on the buildup factor at energies 0.5,1,3 and 10 MeV at thickness of shield of (15 *mfp*).

4-CONCLUSIONS

1. The dose buildup factor increases with the increasing in the thickness for all the shielding materials.

2. The dose buildup factor of low Z is higher than that of high Z at the energies 0.5 and 1 MeV.At the energy 3 MeV the buildup factor begins to change its behavior, and at the energy 10 MeV the dose buildup factor of high Z is higher than that of low Z.

3. The dose buildup factor decreases when the atomic number Z increases at the energies 0.5, 1MeV, but at the energy 3 MeV the buildup factor begins to increase when the atomic number increases. At 10 MeV the buildup factor changes its behavior completely (the dose buildup factor increases when the atomic number Z increases).

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