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Calculation of gamma buildup factors for point sources

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Abstract. Objective of this study is to calculate gamma buildup factors for pointed and isotropic gamma sources in depleted uranium, uranium dioxide, natural uranium, tin, water and concrete using MCNP4C code. The thickness of the media ranges from 0.5 to 10 mean-free-path (mfp) and gamma energy ranges from 0.5 to 10 MeV. Owing to the outstanding accuracy of MCNP in calculation involving gamma interaction, results fairly match those reported previously. The maximum relative error is 2%.

Keywords: MCNP code; radiation shielding; buildup factors; mean free path; gamma

1. Introduction

When will the intensity of gamma rays passing through matter fall exponentially? In good geometric condition, i.e. when the thickness of the absorbent is low and the beam is parallel, the following relationship (1) describe the gamma attenuation through the shield (Kiyani *et al.* 2011)

$$I = I_0 e^{-\mu x} \tag{1}$$

Where I_0 is the incident beam and I is the transmitted radiation intensity, x is the thickness of the shield and μ is the linear attenuation coefficient of absorbent. The linear attenuation coefficient is a function of the incident photon energy and atomic number of the media. For weak geometry (in which photons are diverging and the shield is relatively thick) Eq. (1) is not valid and may be modified by inserting a buildup factor, B, into the Eq. (2) (Kiyani *et al.* 2011)

$$I = B(E,x) I_0 e^{-\mu x} \tag{2}$$

The buildup factors, B (E, x), is generally defined as the ratio of the total dose to the unscattered dose (Shultis and Faw 2000). The buildup factor is of most important parameters in designing the shields for radioactive sources including power reactor cores. It is widely used in calculations of gamma dose absorbed in the issues. Buildup factors are greater than unity and approach to unity when the absorption is dominant or when the scattering cross section vanishes (Jiang 1980).

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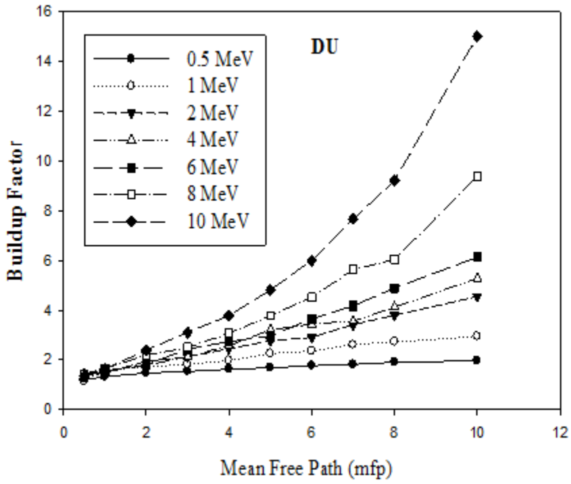

Fig. 1 Gamma buildup factors for depleted uranium (DU)

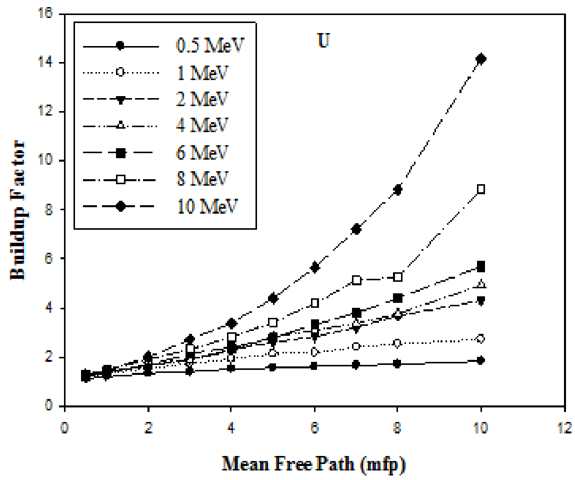

Fig. 2 Gamma buildup factors for natural uranium

Table 1 Gamma buildup factors for depleted uranium (DU)

Energy (MeV)	Thickness (mfp)									
	0.5	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**
0.5	1.21	1.33	1.48	1.54	1.63	1.69	1.77	1.82	1.91	1.97
1	1.15	1.61	1.73	1.82	1.98	2.26	2.36	2.61	2.73	2.94
2	1.35	1.48	1.94	2.13	2.45	2.77	2.91	3.42	3.79	4.55
4	1.42	1.53	1.79	2.13	2.57	3.21	3.44	3.57	4.12	5.28
6	1.33	1.56	1.81	2.44	2.74	2.96	3.65	4.17	4.89	6.13
8	1.44	1.66	2.19	2.50	3.07	3.78	4.52	5.63	6.04	9.36
10	1.36	1.63	2.41	3.11	3.78	4.81	6.04	7.66	9.23	15.01

2. Study procedure

The Mont Carlo nuclear code, MCNP4C, is used in this study. The simulated geometry consists of an isotropic point source at the center of a sphere. The material of the sphere is considered to be depleted uranium, uranium dioxide, natural uranium, tin, water and concrete. Gamma detector surrounds the sphere (Briesmeister 2000).

To calculate the average flux of tally, the output of the MCNP code F2 is used that calculated the average flux on the surface using following equation (Briesmeister 2000).

$$F2 = \iiint_{A,t,E} \Phi(r,E,t) dEdt \frac{dA}{A} \quad (3)$$

To reduce the error, 10^6 histories are considered. For materials with a thickness of 0.5-10 mfp (mean free path), gamma buildup factors are calculated using the relation (4) (Sardari *et al.* 2009, Shultis and Faw 2000). In which μ is the absorption coefficient photon, x is medium thickness, I_0

the total number of photons emitted from source, and I is number of photons counted by detector (Shirakawa 2000).

$$B = \frac{I}{I_0 \exp(-\mu x)} \tag{4}$$

The use of depleted uranium depends on its density and relatively low cost. Depleted uranium a widely used as the shield of gamma radiation, balance weights in aerospace application such as aircraft control surfaces (level).It is also employed in the drilling of oil well, rotors of gyroscope, wheels of aircraft , ballistic transport and rebalancing the weight of the racing yachts.

Table 2 Gamma buildup factors for uranium dioxide (UO2)

Energy (MeV)	Thickness(mfp)									
	0.5	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**
0.5	1.11	1.23	1.42	1.72	1.89	2.08	2.47	2.77	2.95	3.72
1	1.15	1.32	1.74	2.16	2.31	2.77	3.14	3.44	3.81	4.59
2	1.11	1.42	1.84	2.31	2.77	3.03	3.56	4.48	5.12	6.29
4	1.24	1.33	1.91	2.37	3.04	3.18	3.87	4.65	5.78	6.49
6	1.15	1.37	1.83	2.38	3.20	4.00	4.28	5.07	6.12	7.38
8	1.19	1.35	1.88	2.45	3.29	4.37	4.52	5.28	6.46	8.73
10	1.26	1.37	1.93	2.58	3.41	4.16	5.21	6.45	8.19	12.47

Table 3 Gamma buildup factors for natural uranium

Energy (MeV)	Thickness(mfp)									
	0.5	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**
0.5	1.13	1.2	1.34	1.41	1.52	1.56	1.62	1.66	1.71	1.84
1	1.18	1.34	1.55	1.74	1.93	2.14	2.19	2.41	2.54	2.73
2	1.20	1.37	1.7	1.92	2.31	2.61	2.83	3.22	3.68	4.31
4	1.28	1.38	1.66	1.88	2.27	2.83	3.11	3.37	3.77	4.93
6	1.24	1.4	1.68	2.14	2.4	2.79	3.33	3.80	4.39	5.73
8	1.31	1.46	1.91	2.32	2.83	3.43	4.18	5.13	5.26	8.85
10	1.29	1.47	2.03	2.73	3.38	4.39	5.65	7.22	8.84	14.17

Table 4 Gamma buildup factors for tin

Energy (MeV)	Thickness(mfp)									
	0.5	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**
0.5	1.28	1.73	2.33	2.72	3.46	4.04	4.83	5.05	5.27	6.32
1	1.24	1.78	2.53	3.16	3.97	4.88	5.52	6.34	7.28	9.12
2	1.22	1.64	2.18	3.03	3.41	4.45	5.16	6.11	6.8	8.87
4	1.35	1.64	2.07	2.58	3.19	3.72	4.44	5.22	6.08	7.94
6	1.28	1.61	2.01	2.44	2.98	3.62	4.19	5.11	5.81	8.23
8	1.32	1.65	2.14	2.66	3.19	3.84	4.77	5.49	6.51	9.22
10	1.33	1.67	2.12	2.45	3.34	3.96	5.11	6.34	7.78	11.28

Table 5 Gamma buildup factors for concrete

Energy (MeV)	Thickness(mfp)									
	0.5	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**
0.5	1.48	2.33	4.17	6.43	9.12	12.4	16	20.41	25.42	37.14
1	1.58	2.05	3.31	4.88	6.59	8.54	10.22	12.18	15.46	21.09
2	1.44	1.86	2.83	3.72	4.77	5.81	7.12	8.24	9.36	11.88
4	1.37	1.77	2.23	3.01	3.45	4.16	4.88	5.56	6.11	7.32
6	1.31	1.54	2.04	2.46	2.89	3.37	3.81	4.24	4.87	5.78
8	1.27	1.52	1.88	2.23	2.64	2.92	3.27	3.76	4.13	4.63
10	1.22	1.41	1.73	2.02	2.38	2.62	3.11	3.22	3.54	4.23

Table 6 Gamma buildup factors for water

Energy (MeV)	Thickness(mfp)									
	0.5	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**
0.5	1.67	2.57	4.93	8.66	13.21	18.74	25.71	32.54	41.17	63.35
1	1.54	2.22	3.87	5.63	7.89	10.44	13.02	16.14	19.41	26.75
2	1.45	1.92	3.12	4.08	5.26	6.33	7.51	7.92	10.27	13.21
4	1.4	1.72	2.33	2.94	3.61	4.27	4.82	5.59	6.17	7.31
6	1.28	1.62	2.15	2.58	3.06	3.44	3.89	4.31	4.72	5.53
8	1.31	1.5	1.94	2.33	2.56	3.02	3.28	3.71	4.10	4.68
10	1.27	1.46	1.82	2.13	2.46	2.75	2.96	3.19	3.54	4.14

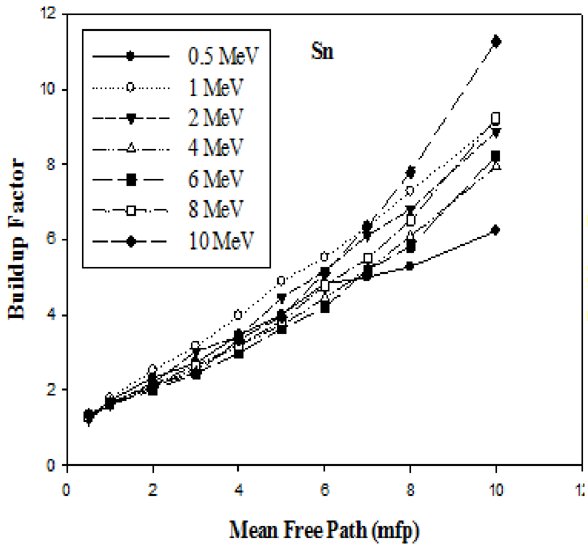

Fig. 3 Gamma buildup factors for tin

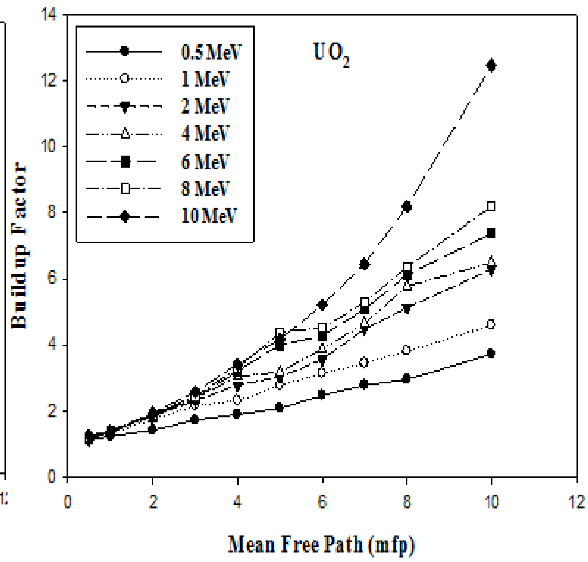

Fig. 4 Gamma buildup factors for uranium dioxide (UO2)

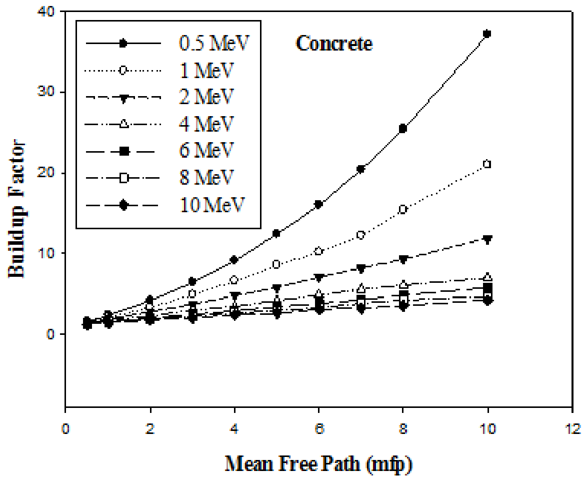

Fig. 5 Gamma buildup factors for concrete

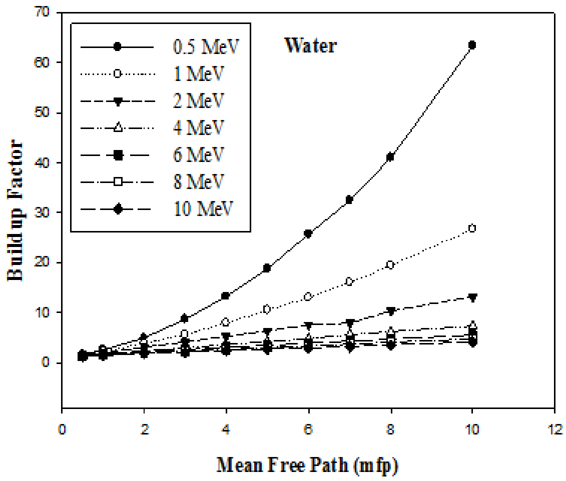

Fig. 6 Gamma buildup factors for water

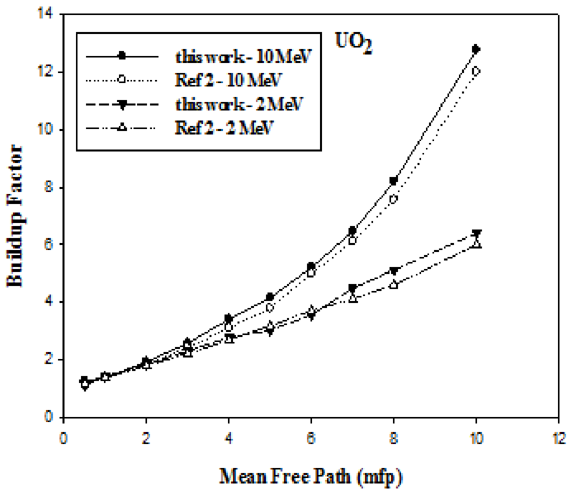

Fig. 7 Comparison of buildup factors obtained in this work with those of Ref. (Bozkurt and Tsoulfanidis 1996) for uranium dioxide (UO2) at 10 MeV

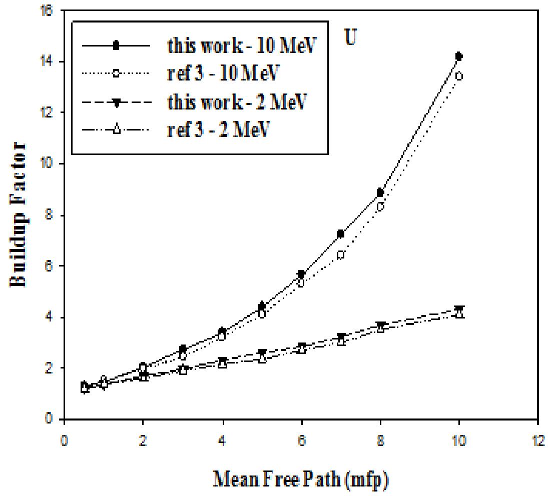

Fig. 8 Comparison of buildup factors obtained in this work with those of Ref. (Martin 2006) for natural uranium (U) at 10 MeV

3. Conclusions

Gamma buildup factors for a point isotropic source of depleted uranium, uranium dioxide, natural uranium, tin, and water and concrete were calculated for energies ranging from 0.5 to 10MeV and shield thicknesses from 0.5 to 10 mfp using MCNP4C code. Tables 1 to 6 and figures 1 to 6 represent the buildup factors. The buildup factors are obtained very accurately using various interactions between gamma and matter and latest cross-section available. As seen in the figures, as the energy of photon increases, buildup factors increase for uranium, uranium dioxide, natural uranium, tin and decrease for concrete and water. The maximum difference between the factors obtained in this work, and those of other is 6 percent that may be attributed to the method of calculation. To compare the result with other works, buildup factors of natural uranium and uranium at 2 and 10 MeV are considered in Figs. 7 and 8. The maximum error is 2 percent (Kiyani *et al.* 2011, Bozkurt and Tsoulfanidis 1996).

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