Indian J. Phys. **73A** (6). 811–819 (1999)

NOTE

I J P A
an international journal

Computation of geometrical-progression (G-P) fitting parameters of plastic materials

Gurdeep S Sidhu, Parjit S Singh and Gurmel S Mudahar*
Department of Physics, Punjabi University, Patiala-147 002, India

Received 4 May 1999, accepted 14 June 1999

Abstract : The exposure geometrical-progression (G-P) fitting parameters for seven plastic materials have been computed in the photon energy range of 0.015 to 15.0 MeV. The results are shown in the form of Tables.

Keywords : Geometrical-progression, exposure buildup factor, equivalent atomic number.

PACS Nos. : 32.80 Cy, 32.80 Wr

To provide adequate protection of personnel and equipment against the deleterious effects of nuclear radiation study of materials from the point of view of radiation shielding is important. Shield to protect from X and gamma rays came into existence since the discovery of X-rays. During the developmental stages, the knowledge about shielding and health physics was not available while designing reactors. Considerable efforts have been made in developing analytical methods and techniques to handle shielding problems. Since the 1979 accident at Three Mile Island (TMI), it became increasingly apparent that a comprehensive and reliable buildup factor data would be very useful for post accident analysis, control and for future shield designing. Buildup factors are shielding material and geometry dependent parameters and are applied to correct the attenuation calculations by including the contribution to the radiation field produced by the collided part of the beam.

The buildup factor data has been computed by different computer codes such as ASFIT [1], PALLAS [2] and EGS4 [3]. In many cases the calculated buildup factor data

*Author for correspondance : E-mail-gurmel@phi ernet.in

have been represented by parametrized forms. Over the year, Taylor's [4], Berger's [5] and Polynomial formulas [6] fitted for the Goldstien and Wilkins data [7] have been essentially used by shield designers. Jacob *et al* [8] have calculated the buildup factor of air up to 10 mfp by Monte Carlo method and have fitted these factors by a polynomial form in E^{-1} and μr. Foderaro and Hall [9] pointed out failures in Taylor's and Berger's fits in the water buildup factors of the order of 10^2 for low energies by comparing three exponential representation with both forms.

A new formula called Geometrical-Progression (G-P) fitting formula has been developed by Harima *et al* [10]. This formula can reproduce data over full range of distance, energy and atomic number. Harima *et al* [11] have demonstrated the applicability of G-P method to generate buildup factor data for a wide range of energy and distance.

The objectives of the present investigations is to provide G-P fitting parameters for different plastics in the large energy range so as to enable one to calculate exposure buildup factor at different penetration depths (upto 40 mean free path). The exposure buildup factor is defined as that buildup factor in which the quantity of interest is the exposure and the detector response function is that of absorption in air. The usefulness of these investigations lies in the fact that they assist in recognizing the use of plastics as a potential shielding material. These studies would also be important because the behaviour of buildup factor at various distances and source energies reflects the characteristics of the material.

In the present investigations, the exposure G-P fitting parameters were computed for different plastics namely polypropylene (C_3H_6); aniline formaldehyde (C_7H_7N); nylon ($C_{12}H_{22}O_2N_2$); poly(vinyl acetate) ($C_4H_6O_2$); teflon (C_2F_4); poly(chlorotrifluoro ethylene) (C_2F_3Cl) and poly(vinyl chloride) (C_2H_3Cl) in the incident photon energy range of 0.015 to 15.0 MeV. The chemical composition of these plastics has been taken from literature [12].

The whole of the computational work can be divided into following two steps :

(a) Calculation of Z_{eq};

(b) Calculation of G-P fitting parameters and exposure buildup factor.

(a) Calculation of Z_{eq} :

Firstly, the values of Compton partial attenuation coefficients (μ_{comp}) and total attenuation coefficients (μ_{tot}) in cm^2/g were obtained for elements from $Z = 4$ to 25 and for chosen plastics in the energy range of 0.015 to 15.0 MeV, using the state-of-the-art and convenient computer program XCOM [13]. Further, by using a simple computer program, the ratio μ_{comp}/μ_{tot} was obtained.

Then Z_{eq} was calculated by matching the ratio of a particular material at a given energy with corresponding ratio of an element at the same energy. In the cases where this ratio lies in between the two ratios of known elements, the value of Z_{eq} was interpolated by using the following formula of interpolation :

$$Z_{eq} = \frac{Z_1(\log R_2 - \log R) + Z_2(\log R - \log R_1)}{\log R_2 - \log R_1} \quad (1)$$

where Z_1 and Z_2 are the elemental atomic numbers corresponding to the ratios (μ_{comp}/μ_{tot}), R_1 and R_2 respectively, and R is the ratio for the given material at a particular energy.

(b) Calculation of G-P fitting parameters .

The obtained values of Z_{eq} for the chosen materials were then used to interpolate the G-P fitting parameters (b, c, a, X_k and d) for the chosen energy range of 0.015 to 15.0 MeV [14]. The formula used to interpolate these parameters is given as follows :

$$P = \frac{P_1(\log Z_2 - \log Z) + P_2(\log Z - \log Z_1)}{\log Z_2 - \log Z_1} \quad (2)$$

where P_1 and P_2 are the values of the parameters corresponding to the atomic numbers Z_1 and Z_2 respectively [15] at a given energy, whereas Z is the equivalent atomic number of a given plastic at a particular energy. The computed values of the G-P fitting parameters of the chosen plastics are given in Tables 1 to 7. The exposure buildup factor

Table 1. Exposure G-P fitting parameters of polypropylene

E (MeV)	b	c	a	X_k	d
0150	1 5540	6097	.1209	14.6588	–.0591
.0200	2.2456	8433	0506	15 1827	–.0289
.0300	4.1506	1 4287	- 0755	13 7138	.0308
0400	6.0308	1 9782	–.1548	14 2378	.0673
.0500	7 4062	2 3574	- 1941	14.3991	.0843
.0600	8.0614	2 7337	–.2285	14.4243	.1004
.0800	7.3969	2 9196	–.2437	14 5450	1056
.1000	7.0220	2.8846	- 2385	15.1874	1003
.1500	5.1265	2.9686	–.2508	14.7318	1062
2000	3.8345	2 9481	–.2550	14 6314	.1139
.3000	3.1513	2 6588	- 2368	14 2048	.1100
.4000	2.8521	2.4036	–.2173	13.0453	.0950
.5000	2.6675	2 1847	- 1953	13.4694	.0913
.6000	2.5449	1.9989	–.1734	13 6430	.0806
.8000	2 3344	1 7879	- 1492	13.5996	.0754
1 0000	2.2235	1.6060	–.1219	13'6607	.0621
1.5000	2.0415	1.3401	–.0757	13.7330	.0398

Table 1. *(Cont'd.).*

E (MeV)				X_k	
2.0000	1.9252	1.2020	–.0469	14.2048	.0240
3.0000	1.8296	1.0793	–.0214	12.9230	.0141
4.0000	1.6972	.9799	.0051	15.2991	–.0029
5.0000	1.6174	.9326	.0176	15.9409	–.0093
6.0000	1.5468	.9016	.0267	14.8652	–.0144
8.0000	1.4528	.8691	.0361	14.2425	–.0201
10.0000	1.4009	.8262	.0509	13.6981	–.0275
15.0000	1.2923	.8212	.0508	13.4777	–.0244

Table 2. Exposure G-P fitting parameters of aniline formaldehyde

E (MeV)	b	c	a	X_k	d
.0150	1.4137	.5507	.1419	14.3675	–.0697
.0200	1.9282	.7475	.0751	16.3774	–.0380
.0300	3.6260	1.2026	–.0357	12.9807	.0127
.0400	5.3416	1.7697	–.1317	13.9447	.0582
.0500	6.6521	2.0929	–.1682	14.3241	.0727
.0600	7.3252	2.4308	–.2022	14.5156	.0895
.0800	7.3969	2.9196	–.2437	14.5450	.1056
.1000	7.0220	2.8846	–.2385	15.1874	.1003
.1500	5.1265	2.9686	–.2508	14.7318	.1062
.2000	3.8345	2.9481	–.2550	14.6314	.1139
.3000	3.1513	2.6588	–.2368	14.2048	.1100
.4000	2.8521	2.4036	–.2173	13.0453	.0950
.5000	2.6675	2.1847	–.1953	13.4694	.0913
.6000	2.5449	1.9989	–.1734	13.6430	.0806
.8000	2.3344	1.7879	–.1492	13.5996	.0754
1.0000	2.2235	1.6060	–.1219	13.6607	.0621
1.5000	2.0415	1.3401	–.0757	13.7330	.0398
2.0000	1.9252	1.2020	–.0469	14.2048	.0240
3.0000	1.7617	1.0612	–.0152	12.2041	.0074
4.0000	1.6720	.9811	.0052	20.4126	–.0059
5.0000	1.5860	.9363	.0175	14.7058	–.0104
6.0000	1.5339	.9058	.0260	14.6711	–.0145
8.0000	1.4429	.8701	.0368	15.8746	–.0289
10.0000	1.3795	.8537	.0414	13.0514	–.0189
15.0000	1.2802	.8364	.0468	14.7395	–.0274

Table 3. Exposure G-P fitting parameters of nylon.

E (MeV)	b	c	a	X_k	d
.0150	1.3612	5285	1501	14 3035	- 0741
.0200	1.8088	7022	.0894	16.2492	- 0443
.0300	3.3506	1.0970	- 0126	13 3408	0000
0400	4.9803	1.6459	-.1128	13 8398	0490
0500	6.1715	1 9579	-.1517	14 1829	.0656
.0600	7.0322	2.3366	- 1934	14 4416	0861
.0800	6.2380	2.5297	- 2140	13.9893	.0956
.1000	5.5359	2.5576	-.2141	14 3948	.0931
.1500	4.1676	2.6515	-.2268	14 1244	1003
2000	3 5657	2.5474	-.2200	14.1661	0972
.3000	3.0509	2.2723	-.1949	14 2283	0846
4000	2.7687	2.0822	- 1769	13 7712	.0745
.5000	2.5952	1.9196	- 1580	14 1588	0700
.6000	2.4719	1.7918	- 1422	13 8648	.0590
.8000	2 2751	1.6334	- 1221	13.9194	.0560
1 0000	2.1562	1 5077	- 1027	13.8787	0477
1 5000	1.9887	1 2897	- 0633	14.2716	0287
2 0000	1.8772	1 1837	- 0419	13 9692	.0190
3 0000	1.7671	1 0630	- 0158	12 3283	0081
4 0000	1.6659	.9827	0048	22 0809	-.0065
5.0000	1.5920	9347	0177	14.8193	-.0102
6.0000	1.5327	9061	0260	14.6278	-.0146
8.0000	1 4427	.8700	0368	15.9407	-.0292
10.0000	1.3799	.8536	0413	13 1005	-.0188
15.0000	1.2826	8337	0473	14.4308	-.0261

Table 4. Exposure G-P fitting parameters of poly(vinyl acetate).

E (MeV)	b	c	a	X_k	d
.0150	1.2849	4964	.1626	14 2834	- 0811
.0200	1.6473	.6316	1141	15.4903	-.0558
.0300	2.9024	.9403	.0277	14.7962	-.0245
.0400	4.3442	1.4205	-.0761	13.6802	.0306
.0500	5.5872	1.7939	-.1317	14.0111	.0570
.0600	6.1485	2.1046	-.1705	13.9994	.0776
.0800	6.1907	2.5152	-.2128	13.9489	.0952
.1000	5.5359	2.5576	-.2141	14.3948	.0931
.1500	4.1676	2.6515	-.2268	14.1244	.1003

Table 4. *(Cont'd).*

E (MeV)	*b*	*c*	*a*	X_k	*d*
2000	3.5657	2.5474	–.2200	14.1661	.0972
.3000	3.0509	2.2723	–.1949	14.2283	.0846
.4000	2.7687	2.0822	–.1769	13.7712	0745
.5000	2.5952	1.9196	–.1580	14.1588	0.700
6000	2.4719	1 7918	–.1422	13.8648	.0590
8000	2.2751	1.6334	–.1221	13.9194	.0560
1.0000	2.1562	1.5077	–.1027	13.8787	.0477
1.5000	1.9887	1.2897	–.0633	14 2716	0287
2.0000	1.8772	1.1837	–.0419	13 9692	.0190
3.0000	1 7445	1.0587	–.0140	12.4135	.0057
4.0000	1.6625	.9835	.0046	23.0294	–.0069
5.0000	1.5721	.9392	.0172	14 2956	–.0113
6.0000	1.5244	.9075	0263	14.2170	–.0152
8.0000	1 4350	.8736	0365	15 4793	- 0294
10.0000	1.3728	.8552	.0419	12.3741	–.0208
15.0000	1.2759	8410	.0460	15.2648	–.0297

Table 5. Exposure G-P fitting parameters of teflon.

E (MeV)	*b*	*c*	*a*	X_k	*d*
.0150	1.1356	.4229	1949	14.0078	–.0996
.0200	1.3140	.4862	.1708	14.4547	– 0880
.0300	1 9358	.6758	.1020	16.0560	–.0538
.0400	2 9006	.9329	0271	13.9653	–.0194
0500	3 7681	1.2052	–.0307	13.6760	.0054
.0600	4 3356	1.4611	–.0787	13.6757	.0296
.0800	4.4854	1.7457	–.1223	13.6979	.0509
1000	4 2749	1.9103	–.1439	13.9483	.0599
.1500	3.7462	1.9750	–.1501	14.5238	.0565
.2000	3.2530	2.0019	–.1564	14.1442	.0602
3000	2.8296	1 8880	–.1449	14.1848	.0535
.4000	2.6008	1.7821	–.1334	14.3613	.0496
.5000	2.4512	1.6897	–.1223	14.3256	.0454
6000	2.3412	1.6089	–.1111	14.5294	.0406
8000	2.1721	1.5109	–.0986	14.4189	.0393
1.0000	2.0837	1.4062	–.0813	14.6070	.0314
1.5000	1.9195	1.2591	–.0555	14.5947	.0222
2.0000	1.8290	1.1621	–.0356	15.2153	.0134

Table 5. *(Cont'd.)*.

E (MeV)	*b*	*c*	*a*	X_k	*d*
3.0000	1.7031	1.0532	–.0110	12.1708	0017
4.0000	1 6224	.9902	.0042	19 7992	– 0072
5.0000	1.5529	.9471	0160	14.4246	– 0112
6.0000	1.5037	.9166	.0257	15.1411	– 0231
8.0000	1.4164	.8916	.0330	12.3670	–.0198
10.0000	1.3571	.8723	.0393	13.9267	– 0259
15.0000	1.2648	.8398	.0516	14.9527	– 0407

Table 6. Exposure G-P fitting parameters of poly (chlorotrifluoro ethylene).

E (MeV)	*b*	*c*	*a*	X_k	*d*
.0150	1.0348	.3991	.2096	13 9360	–.1348
.0200	1.0787	.4198	.1927	14 1550	– 1013
.0300	1.2568	.4360	.1933	14 7256	– 1031
.0400	1.5444	.5284	.1552	14.9633	· 0829
.0500	1.8954	.6531	1092	15 4849	– 0557
.0600	2.2810	7291	.0931	13.5655	–.0574
.0800	2.7396	.9609	.0254	13 2181	- 0303
.1000	2.8495	1 1111	– 0092	12.9734	– 0186
.1500	2.8800	1 3589	– 0583	21.6021	0072
.2000	2.7638	1.4566	– 0743	17.0002	0116
.3000	2.5720	1.5365	–.0894	16.0926	0199
.4000	2.4197	1.5191	– 0889	15 9600	0212
.5000	2.3007	1.4892	–.0859	16.2091	0215
6000	2.2088	1 4603	–.0834	16.1725	.0236
8000	2.0898	1 3923	–.0740	15.9460	.0217
1.0000	1.9989	1.3429	– 0675	15 7716	.0225
1.5000	1.8609	1.2315	–.0485	15 2799	.0170
2.0000	1.7839	1.1540	–.0325	15.7071	.0099
3.0000	1.6877	1.0555	–.0110	10.8005	.0011
4.0000	1.6082	.9918	.0058	13.7927	–.0087
5.0000	1.5381	.9549	.0160	15.1046	–.0194
6.0000	1.4952	.9143	.0304	11.8377	–.0245
8.0000	1.4068	.9012	.0330	13.4412	–.0255
10.0000	1.3478	.8757	.0427	13.2454	–.0329
15.0000	1.2632	.8248	.0627	14.4150	–.0545

Table 7. Exposure G-P fitting parameters of poly (vinyl chloride).

E (MeV)	b	c	a	X_k	d
.0150	1.0249	.3635	.2440	13.1162	-.1661
.0200	1.0543	.4174	.1874	16.8589	-.1104
.0300	1.1803	.3958	.2155	14.0221	-.1159
.0400	1.3813	.4589	.1884	14.3352	-.1066
.0500	1.6257	.5711	.1386	15.0624	-.0740
.0600	1.8617	.6864	.0976	15.1747	-.0543
.0800	2.3697	.8255	.0620	14.3943	-.0507
.1000	2 5677	.9940	.0178	13.7791	-.0330
.1500	2.6918	1.2477	-.0369	10.8256	-.0087
.2000	2.6366	1.3493	-.0534	8.3207	-.0069
.3000	2.4566	1.4507	-.0749	18.0497	.0130
.4000	2.3397	1.4562	-.0779	16.5066	.0150
.5000	2.2378	1.4438	-.0780	16.3051	.0169
.6000	2.1617	1.4199	-.0755	17.5358	.0197
.8000	2.0438	1.3799	-.0720	15.4631	.0208
1.0000	1.9693	1.3230	-.0630	16.4254	.0194
1.5000	1.8379	1.2280	-.0475	15.2421	.0158
2.0000	1.7669	1.1555	-.0330	14.7734	.0001
3.0000	1.6849	1.0559	-.0110	10.5530	.0009
4.0000	1.6060	.9920	.0060	12.8600	-.0089
5.0000	1.5371	.9480	.0202	12.5299	-.0211
6.0000	1.4898	.9224	.0281	11.6450	-.0224
8.0000	1.4055	.9020	.0335	13.6935	-.0273
10.0000	1.3456	.8789	.0424	13.1611	-.0334
15.0000	1.2599	.8304	.0618	14.3160	-.0546

$B(E, x)$ can be calculated using the above parameters from the G-P fitting formula of Harima *et al* [10].

$$B(E,x) = 1 + \frac{(b-1)}{K-1}(K^x - 1) \quad \text{for } K \neq 1$$
$$B(E,x) = 1 + (b-1)x \quad \text{for } K = 1 \tag{3}$$

where $$K(E,x) = cx^a + d\,\frac{\tanh\left(\frac{x}{X_k} - 2\right) - \tanh(-2)}{1 - \tanh(-2)} \quad \text{for } x \leq 40 \text{ mfp}, \tag{4}$$

where x = source-detector distance of the medium in mean free path (mfp). Mean free path is the average distance that photons of a given energy travel before an interaction in a given medium occurs. The term $K(E, x)$ is the dose multiplication factor and b, c, a, X_k and d are the computed exposure G-P fitting parameters.

References

[1] D V Gopinath and K Samthanam *Nucl. Sci. Eng.* **94** 24 (1971)

[2] K Takeuchi and S Tanaka *JAERI-M* **84** 214 (1984)

[3] W R Nelson, H Hirayama and D W O Rogers *SLAC-265* Stanford Linear Accelerator Center, Stanford California (1985)

[4] J J Taylor *WAPD-RM-217* Bettis Atomic Power Laboratory (1954)

[5] M J Berger USNRDL Reviews and Lectures No 29, held at the U. S. Naval Radiological Defense Laboratory *Proceeding Shieldiing Symp.* (1956)

[6] M A Capo *APEX-510* General Electric Company (1958)

[7] H Goldstein and J E Wilkins *NYO-3075* Nuclear Development Associates Inc (1954)

[8] P Jacob, H G Paretzke and J Wolfel *Nucl. Sci. Eng.* **87** 113 (1984)

[9] A Foderaro and R J Hall *Nucl. Sci. Eng.* **78** 74 (1981)

[10] Y Harima, Y Sakamoto, S Tanaka and M Kawai *Nucl. Sci. Eng.* **94** 24 (1986a)

[11] Y Harima, Y Sakamoto, S Tanaka, M Kawai, T Fujita, T Ishikawa, M Konno, K Hayashi, Y Matsumoto and T Nishimara *JAERI-M* **86** 071 (1986b)

[12] Robert O Bolt and James G Carroll Academic Press New York and London **240** p 183 (1963)

[13] M J Berger and J H Hubbell *NBSIR* **87** 3597 (1987)

[14] Y Harima, Y Sakamoto and S Tanaka *Nucl. Sci. Engg.* **100** 33 (1988)

[15] American National Standard Gamma-ray Attenuation Coefficients and Buildup Factor for Engineering Materials *ANSI/ANS-6.4.3.* (1991)