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EXABCal: A program for calculating photon exposure and energy absorption buildup factors

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ABSTRACT

This research presents a new Windows compatible program (EXABCal) for photon exposure and energy absorption buildup factors for standard energy grid from 0.015- 15 MeV for elements, mixtures and compound. This program was written using Python programming language and the calculation of buildup factors was based on the well-known Geometric Progression (GP) fitting procedure. The equivalent atomic numbers and GP fitting parameters of mixtures and compounds can also be evaluated using this program. The program has been used to evaluate the photon exposure and energy absorption buildup factors for standard energy grid from 0.015- 15 MeV for water, air and concrete, compared with values from the American Nuclear Society (ANS) standard reference data (ANSI-6.4.3) and found to be of high accurate with minimal errors. The program is fast and easy to use and will be of valuable interest to medical Physicist, radiation Physicists, Radiation shielding design engineers, students, teachers and researchers and other experts working in areas where nuclear radiation is applied.

1. Introduction

Adequate knowledge of radiation interaction with a material medium is important in medicine and other radiation applications in order to control radiation exposure. This will indicate how much energy of the radiation is deposited in the medium (dose) or how much of a protective material is needed for structural shielding design. The transmission of photons through a material for dose calculation or shielding requirement is governed by the Lambert-Beer law:

$$I = I_O e^{-\mu t} \tag{1}$$

Where the incident photon intensity $I_{o,}$ is reduced to I after passing through the absorbing material of thickness t and linear attenuation coefficient, μ. However, this law assumes mono-energetic photons; thin absorbing material; and narrow beam geometry. These assumptions for most practical applications are invalid thus the Lambert-Beer law is modified to account for multiple scattering of photons in the form:

$$I = BI_O e^{-\mu t} \tag{2}$$

The correction factor B is referred to as the buildup factor. B is always greater than 1 where the Lambert-Beer assumption does not apply otherwise it is equal to unity. Thus, B accounts for the ratio of broad beam to that of narrow beam and directly influences radiation dose. Two types of buildup factors are considered here: (i) the energy absorption build up factor (EABF) in which the quantity of interest is the absorbed or deposited energy in the interacting medium and the detector response function is that of absorption in the interacting medium. (ii). the exposure buildup factor (EBF) in which the quantity of interest is the KERMA and the detector response function is that of absorption in air (Sayyed et al., 2017a; Olarinoye, 2017; Harima, 1993). The buildup factor is a function of photon energy and penetration depth. The penetration depth is however always expressed in terms of a dimensionless quantity (μt) called the mean free path (mfp). The mean free path refers to the average thickness of an absorber with which a beam of photons propagates such that the intensity of the beam is reduced by a factor *1/e*. The B is a factor that assists in determining and controlling the thickness of material required for photon shielding.

The American Nuclear Society (ANSI/ANS-6.4.3, 1991) has compiled photon point isotropic source data for both EABF and EBF using Geometric Progression (GP) fitting method for 23 elements (Be, B, C, N, O, Na, Mg, Al, Si, P, S, Ar, K, Ca, Fe, Cu, Mo, Sn, La, Gd, W, Pb and U), one compound (water) and two mixtures (air and concrete) only for standard photon energies in the range 0.015 MeV–15 MeV for penetration depth up to 40 mean free path (mfp). The developed G-P fitting formula has been known to be accurate within a few percent errors (Harima et al.,

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1986 and Harima, 1983). Consequently, many researchers have reported buildup factors for materials not mentioned in the ANS report, using the GP fitting Method (Issa et al., 2018; Obaid et al., 2018; Sayyed et al., 2017a, 2017b; Olarinoye, 2017; Mann and Korkut, 2013; Kurudirek et al., 2013; Singh and Badiger, 2012). However, this method requires five different coefficients (fitting parameters-a, b, c, d, and X_k) which depends on photon energy and chemical composition of the material (equivalent atomic number). Furthermore, the calculations are not easy and consequently the method require lots of data and mathematical operations which many researchers do not find interesting. Therefore, this research presents a window executable program (EXABCal) written in Python programming language for the calculation of exposure and energy absorption buildup factors for standard photon energies in the range 15 keV -15 MeV for penetration depth up to 40 mean free path (mfp).

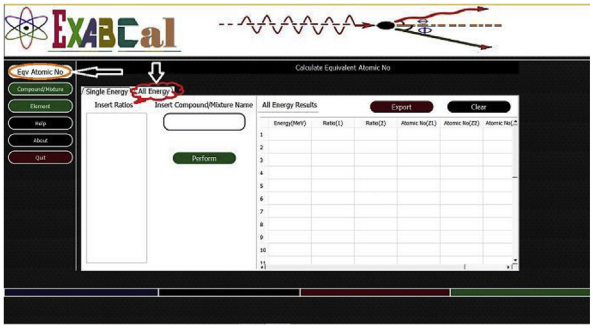
1.1. Theory of method

The computation exposure and energy absorption buildup factor is generally calculated using three distinct steps (Harima, 1983):

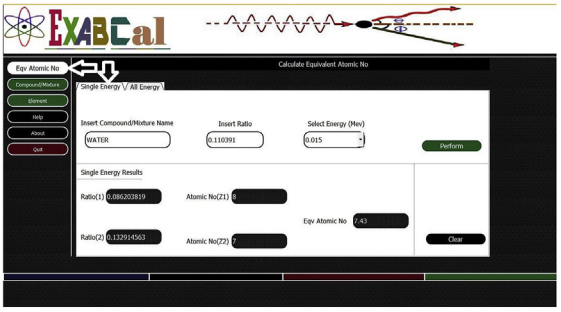
a. calculation of equivalent atomic number, Z_{eq}
b. Evaluation of GP fitting parameters
c. Estimation of exposure and energy absorption buildup factors using the coefficients

1.2. Calculation of effective atomic number (Z_{eq})

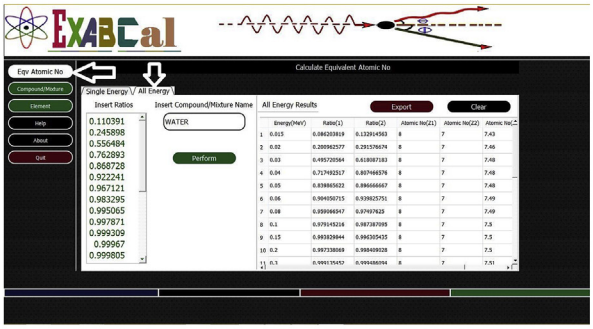
The scattering and absorption of photons in any material at a particular energy is mainly described by the photoelectric effect, Compton scattering, and the pair production coefficients. All of these three interaction modes of photons depends on the atomic number of the interacting medium. The Z_{eq} of a composite material is synonymous to the atomic number of an element. It describes the properties of the material as the atomic number describes the properties of an element with respect to radiation interaction. It represents a weighted average of the electron per atom in a multi-element material. To evaluate Z_{eq} any material (mixture or chemical compound), it's Compton partial interaction coefficient (μ_c) and mass attenuation coefficients (μ_T) (both in cm^2/g) are obtained and then the ratio $R = \frac{\mu_C}{\mu_T}$ of the said material is calculated at the photon energy of interest. Z_{eq} is interpolated using the expression (Mann



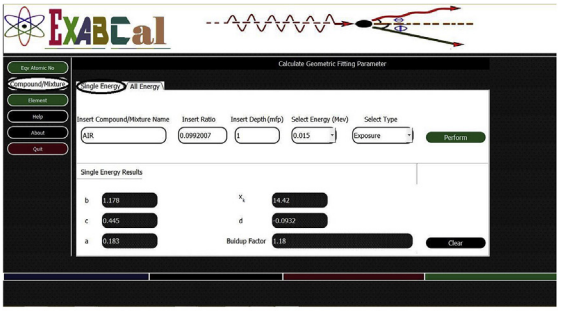
a. Screenshot of the EXABCal GUI.



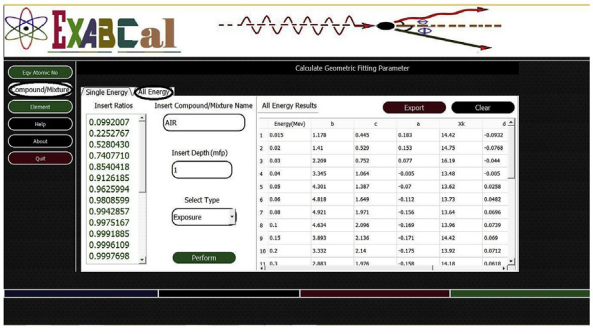
c. Screenshot of the EXABCal GUI showing results for fitting parameters and Z_{eq} for single energy.



b. Screenshot of the EXABCal GUI showing results for fitting parameters and Z_{eq} for all energies



d. Screenshot of the EXABCal GUI showing results for fitting parameters and buildup factor for single energy.



e. Screenshot of the EXABCal GUI showing results for fitting parameters and buildup factor for all energies.

Fig. 1. a. Screenshot of the EXABCal GUI. b. Screenshot of the EXABCal GUI showing results for fitting parameters and Z_{eq} for all energies. c. Screenshot of the EXABCal GUI showing results for fitting parameters and Z_{eq} for single energy. d. Screenshot of the EXABCal GUI showing results for fitting parameters and buildup factor for single energy. e. Screenshot of the EXABCal GUI showing results for fitting parameters and buildup factor for all energies.

and Korkut, 2013; Harima, 1993):

$$Z_{eq} = \frac{Z_1(logR_2 - \log R) + Z_2(\log R - logR_{1)}}{logR_2 - logR_1} \quad (3)$$

Here, R_1 and R_2 are the ratios (μ_c/μ_T) of the two successive elements of atomic numbers Z_1 and Z_2 respectively within which R falls at each energy.

1.3. Evaluation of GP fitting parameters

The evaluation of photon buildup factors by the GP fitting method require 5 fitting parameters. These coefficients (b, c, a, X_k, and d) depend on Z_{eq} and photon energy. The ANS report (ANSI/ANS-6.4.3, 1991) has provided these coefficients for 23 elements and for 25 standard photon energies. However since the (μ_c/μ_T) of a materials may not match any of the 23 elements, their GP fitting coefficients is also interpolated using the logarithmic interpolation formula:

$$F = \frac{F_1(logZ_2 - \log Z_{eq}) + F_2(\log Z_{eq} - logZ_{1)}}{logZ_2 - logZ_1} \quad (4)$$

Where F_1 and F_2 are the values of the G-P fitting parameters obtained from ANS data base corresponding to the atomic numbers Z_1 and Z_2 respectively.

Table 1
Comparison of GP fitting parameters (Absorption) from EXABCal and ANSI for Water.

Energy (MeV)	EXABCal					ANSI				
	a	c	a	X_K	d	a	c	a	X_K	d
0.015	1.199	0.458	0.179	13.94	-0.0896	1.188	0.464	0.172	14	-0.0829
0.02	1.465	0.542	0.148	14.7	-0.0748	1.449	0.532	0.152	14.61	-0.0764
0.03	2.447	0.751	0.084	13.83	-0.0419	2.411	0.741	0.084	14.62	-0.0452
0.04	3.604	1.132	-0.02	13.52	0.0019	3.597	1.114	-0.018	12.48	0.0013
0.05	4.531	1.471	-0.084	13.68	0.0338	4.554	1.457	-0.084	13.69	0.0341
0.06	4.94	1.747	-0.127	13.72	0.0562	5.018	1.735	-0.127	13.7	0.0676
0.08	4.928	2.066	-0.168	13.57	0.0748	5.03	2.054	-0.167	13.84	0.0763
0.1	4.644	2.163	-0.176	14.09	0.077	4.627	2.207	-0.184	13.27	0.0799
0.15	3.838	2.205	-0.179	14.4	0.0726	3.888	2.206	-0.18	14.27	0.0738
0.2	3.365	2.159	-0.176	14.37	0.0737	3.462	2.132	-0.173	14.51	0.075
0.3	2.872	2.013	-0.163	14.15	0.0645	2.897	2.008	-0.162	14.18	0.0641
0.4	2.636	1.871	-0.147	14.15	0.0585	2.646	1.874	-0.148	14.16	0.0591
0.5	2.471	1.764	-0.135	14.2	0.054	2.4999	1.749	-0.132	14.36	0.0517
0.6	2.365	1.667	-0.122	14.28	0.0487	2.383	1.662	-0.121	14.19	0.0482
0.8	2.208	1.531	-0.102	14.29	0.0414	2.223	1.524	-0.101	14.31	0.0403
1.0	2.106	1.428	-0.086	14.45	0.0351	2.106	1.436	-0.088	14.19	0.0367
1.5	1.934	1.276	-0.06	14.35	0.0263	1.948	1.265	-0.057	14.98	0.0245
2.0	1.838	1.173	-0.039	14.16	0.0161	1.843	1.169	-0.038	14.22	0.0157
3.0	1.711	1.054	-0.012	13.25	0.0036	1.716	1.05	-0.011	13.63	0.0027
4.0	1.628	0.984	0.005	13.75	-0.0051	1.633	0.979	0.007	14.23	-0.006
5.0	1.566	0.937	0.018	14.09	-0.0118	1.571	0.928	0.022	13.2	-0.0157
6.0	1.504	0.922	0.023	15.31	-0.0167	1.521	0.893	0.033	11.92	-0.0208
8.0	1.43	0.875	0.037	12.07	-0.0206	1.432	0.873	0.038	11.56	-0.0204
10.0	1.369	0.866	0.039	14.33	-0.0222	1.378	0.849	0.045	14.34	-0.028
15.0	1.276	0.839	0.048	15.36	-0.0343	1.28	0.829	0.052	14.85	-0.0367

Table 2
Comparison of GP fitting parameters (Exposure) from EXABCal and ANSI for Water.

Energy (MeV)	EXABCal					ANSI				
	a	c	a	X_K	d	a	c	a	X_K	d
0.015	1.198	0.456	0.179	14.37	-0.0906	1.182	0.463	0.175	14.23	-0.0908
0.02	1.454	0.548	0.145	14.83	-0.0724	1.427	0.549	0.143	14.86	-0.0707
0.03	2.342	0.781	0.069	16.04	-0.0427	2.335	0.736	0.087	13.28	-0.0419
0.04	3.543	1.135	-0.021	13.52	0.0029	3.477	1.117	-0.019	11.67	0.0026
0.05	4.551	1.472	-0.084	13.69	0.0336	4.461	1.457	-0.084	13.62	0.0341
0.06	5.057	1.748	-0.127	13.72	0.0562	4.983	1.73	-0.126	13.64	0.0561
0.08	5.102	2.082	-0.17	13.52	0.0765	5.059	2.059	-0.168	13.67	0.077
0.1	4.841	2.174	-0.177	14.11	0.077	4.663	2.221	-0.186	13.33	0.0826
0.15	3.922	2.254	-0.185	14.3	0.0785	3.897	2.242	-0.185	14.19	0.0777
0.2	3.356	2.243	-0.188	13.69	0.078	3.478	2.154	-0.176	14.5	0.0774
0.3	2.914	2.041	-0.166	14.13	0.0672	2.92	2.022	-0.164	14.21	0.0655
0.4	2.663	1.899	-0.151	14.12	0.0615	2.66	1.882	-0.149	14.24	0.0595
0.5	2.505	1.776	-0.137	14.17	0.0547	2.5	1.766	-0.135	14.33	0.0546
0.6	2.383	1.684	-0.125	14.22	0.0502	2.377	1.679	-0.124	14.23	0.0503
0.8	2.212	1.555	-0.107	14.14	0.0455	2.212	1.544	-0.105	14.36	0.0437
1.0	2.11	1.445	-0.09	14.17	0.0377	2.103	1.441	-0.089	14.22	0.0378
1.5	1.982	1.283	-0.062	14.45	0.0274	1.939	1.269	-0.058	14.52	0.0246
2.0	1.873	1.182	-0.041	13.96	0.0186	1.839	1.173	-0.039	14.07	0.0161
3.0	1.731	1.06	-0.014	13.22	0.0052	1.71	1.056	-0.013	11.82	0.0047
4.0	1.639	0.988	0.004	19.43	-0.0058	1.621	0.989	0.004	13.45	-0.0041
5.0	1.567	0.94	0.018	13.93	-0.0121	1.554	0.939	0.018	13.55	-0.0122
6.0	1.52	0.904	0.028	13.19	-0.0172	1.507	0.903	0.029	16.13	-0.0272
8.0	1.43	0.88	0.035	13.76	-0.0233	1.422	0.879	0.035	13.36	-0.0191
10.0	1.366	0.866	0.039	13.49	-0.0216	1.362	0.859	0.042	13.37	-0.0247
15.0	1.273	0.841	0.047	15.13	-0.0322	1.267	0.843	0.047	15.08	-0.0336

Table 3
Comparing equivalent atomic number values of some bricks and rock materials from EXABCal and literature.

Energy (MeV)	Equivalent atomic number (Z_{eq})									
	Black clay		Green brick		Steel slag		Olivine basalt		Green marble	
	EXABCal	Sayyed et al. (2017a),b	EXABCal	Sayyed et al. (2017a),b	EXABCal	Sayyed et al. (2017a),b	EXABCal	Obaid et al. (2018)	EXABCal	Obaid et al., 2018
0.015	14.66	14.63	13.34	13.34	18.0	18.01	14.74	14.76	15.13	15.13
0.02	14.9	14.94	13.5	13.49	18.23	18.23	14.96	14.96	15.31	15.32
0.03	15.08	15.14	13.69	13.67	18.46	18.46	15.19	15.19	15.51	15.51
0.04	15.19	15.28	13.79	13.79	18.59	18.58	15.33	15.33	15.62	15.63
0.05	15.29	15.37	13.87	13.87	18.67	18.68	15.43	15.43	15.72	15.72
0.06	15.36	15.43	13.94	13.93	18.74	18.75	15.52	15.50	15.78	15.78
0.08	15.45	15.53	14.03	14.04	18.84	18.85	15.62	15.62	15.88	15.88
0.1	15.51	15.59	14.1	14.09	18.92	18.92	15.7	15.69	15.94	15.93
0.15	15.58	15.68	14.19	14.17	19.0	19.01	15.83	15.78	16.02	16.00
0.2	15.73	15.82	14.29	14.16	19.09	19.10	15.86	15.94	16.1	16.10
0.3	15.91	15.65	14.27	14.46	19.21	19.13	15.91	16.05	16.23	16.29
0.4	16.03	15.87	14.39	14.31	19.29	19.20	16.03	15.97	16.03	16.24
0.5	15.3	15.89	13.75	14.37	19.16	19.20	16.46	16.04	16.46	16.29
0.6	15.24	16.02	15.24	14.45	19.42	19.20	15.24	16.04	16.9	16.43
0.8	14.68	15.66	14.68	14.87	19.61	19.17	14.68	16.05	14.68	16.02
1.0	16.16	16.03	16.16	14.02	19.42	19.32	16.16	16.05	16.16	16.81
1.5	13.95	14.31	11.03	12.66	16.43	17.47	13.95	14.06	13.95	14.30
2.0	13.16	13.18	11.58	11.84	16.24	16.49	13.16	13.25	13.95	13.70
3.0	13.09	13.09	11.85	11.78	16.08	16.16	12.84	12.96	13.33	13.44
4.0	13.07	13.03	11.79	11.76	16.16	16.07	12.78	12.80	13.36	13.38
5.0	13.01	13.02	11.77	11.76	16.02	16.06	12.8	12.78	13.32	13.37
6.0	12.95	12.97	11.79	11.75	16.05	16.04	12.78	12.76	13.29	13.33
8.0	12.94	12.96	11.72	11.74	16.0	15.99	12.75	12.77	13.35	13.33
10.0	12.96	12.95	11.75	11.75	15.98	15.99	12.78	12.74	13.32	13.32
15.0	12.92	12.96	11.71	11.74	15.94	15.99	12.76	12.74	13.32	13.30

1.4. Evaluation of buildup factors

The buildup factors is then estimated for the specific energy and for penetration depth up to 40 mfp by the equations:

$$B(E,x) = 1 + \frac{(b-1)(K^x - 1)}{K-1} \quad ,for\ K \neq 1 \tag{5}$$

$$B(E,x) = 1 + (b-1)x\ for\ K = 1 \tag{6}$$

where,

$$K(E,x) = cx^a + d\frac{\tanh\left(\frac{x}{X_k} - 2\right) - \tanh(-2)}{1 - \tanh(-2)} \quad ,for\ x \leq 40\ mfp \tag{7}$$

1.5. The EXABCal program

EXABCal code was written with Python programming software and it runs under the Windows operating system. The programme was constructed to calculate the photon buildup factors of compound or a mixture of pure elements or compounds for energies between 15 keV and 15 MeV and for any depth up to 40 mfp using the GP fitting method using Eqs. (3), (4), (5), (6), and (7). The EXABCal program has two major database files which contains all the physical data required for the calculations. The data contained in the file include the GP fitting parameters of the 23 elements (Be, B, C, N, O, Na, Mg, Al, Si, P, S, Ar, K, Ca, Fe, Cu, Mo, Sn, La, Gd, W, Pb and U) included in the ANS report, and their respective ratio ($R = \frac{\mu_C}{\mu_T}$) for each of the 25 energies of interest (0.015; 0.02; 0.03; 0.04; 0.05; 0.06; 0.08; 0.1; 0.15; 0.2; 0.3; 0.4; 0.5; 0.6; 0.8; 1; 1.5; 2; 3; 4; 5; 6; 8; 10; and 15 MeV). The GUI allows the user to calculate, display, export and save data for equivalent atomic number, GP fitting

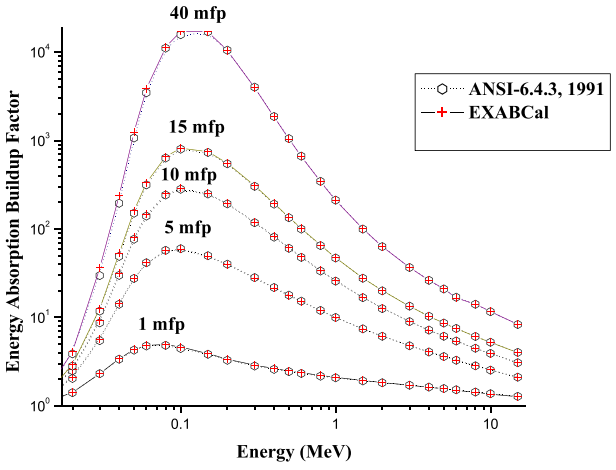


Fig. 2. Comparison of EXABCal and ANSI values of EABF of air at 1, 5, 10, 15 and 40 mfp.

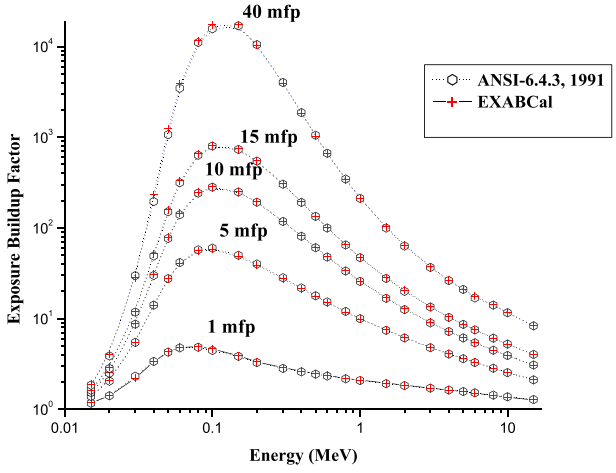


Fig. 3. Comparison of EXABCal and ANSI values of EBF of air at 1, 5, 10, 15 and 40 mfp.

parameters, exposure buildup factor, and energy absorption buildup factor for any given substance (compound or mixture).

A screenshot of the GUI of the code after it is launched is shown in Fig. 1a. To calculate the equivalent atomic number of any substance, the user writes the substance name in the space provided and selects the "*Equivalent atomic number*" button on the top left of the screen, next the user choses if the calculation is for single energy or the 25 standard

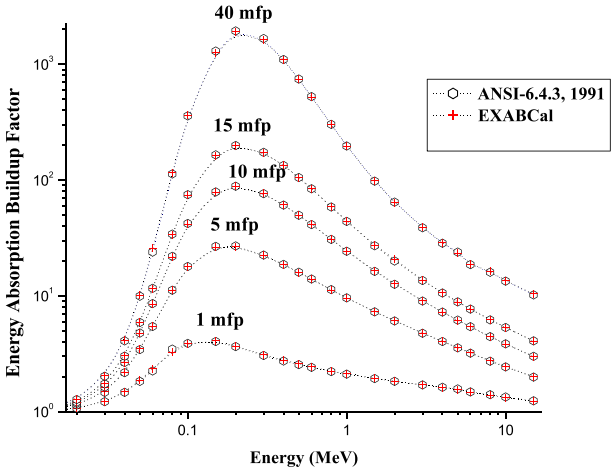


Fig. 4. Comparison of EXABCal and ANSI values of EABF of concrete at 1, 5, 10, 15 and 40 mfp.

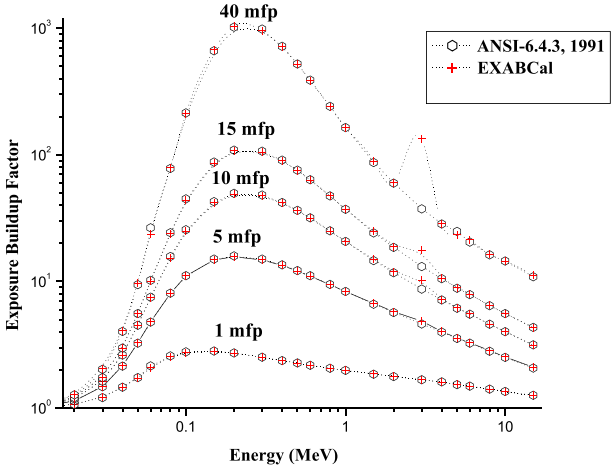


Fig. 5. Comparison of EXABCal and ANSI values of EBF of concrete at 1, 5, 10, 15 and 40 mfp.

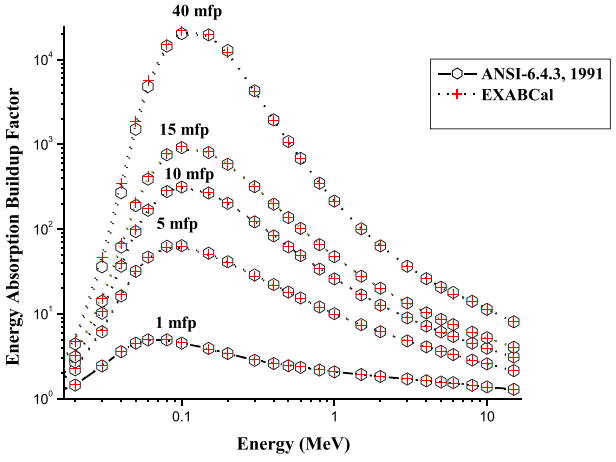


Fig. 6. Comparison of EXABCal and ANSI values of EABF of water at 1, 5, 10, 15 and 40 mfp.

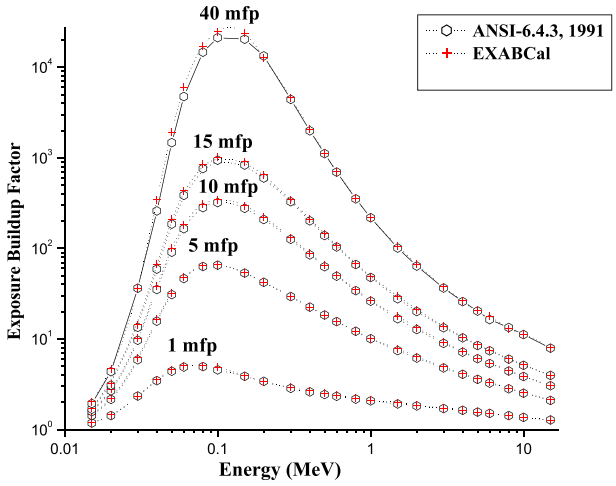


Fig. 7. Comparison of EXABCal and ANSI values of EBF of water at 1, 5, 10, 15 and 40 mfp.

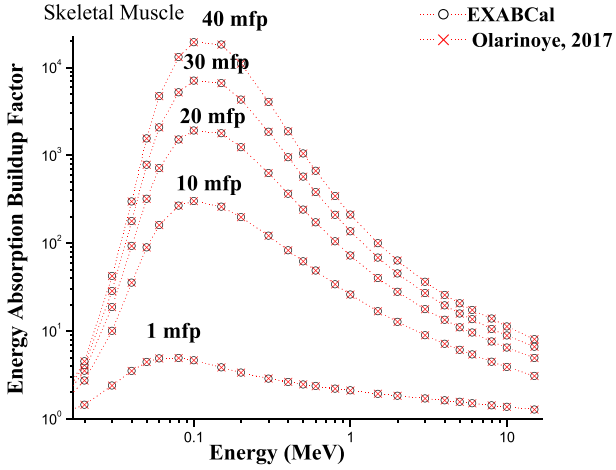


Fig. 8. Comparison of EXABCal and published values of EABF of human skeletal muscle at 1, 10, 20, 30 and 40 mfp.

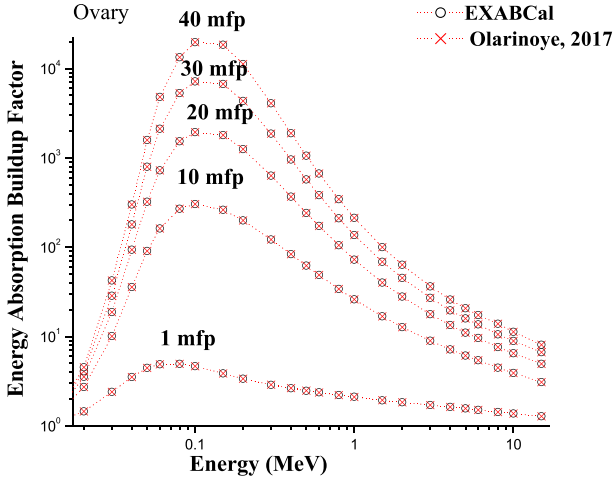


Fig. 9. Comparison of EXABCal and published values of EABF of human ovary at 1, 10, 20, 30 and 40 mfp.

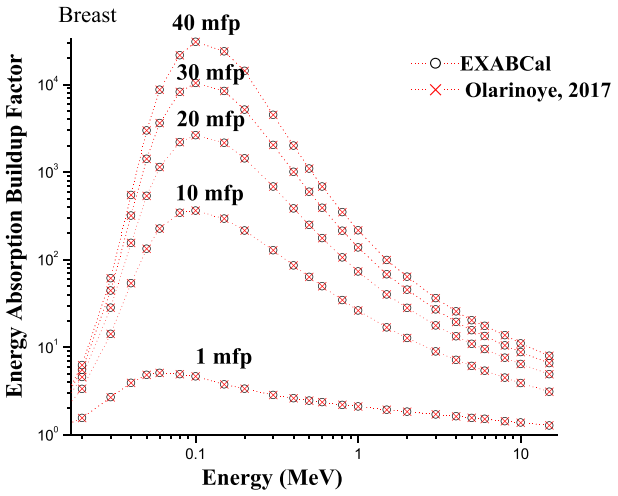


Fig. 10. Comparison of EXABCal and published values of EABF of human breast at 1, 10, 20, 30 and 40 mfp.

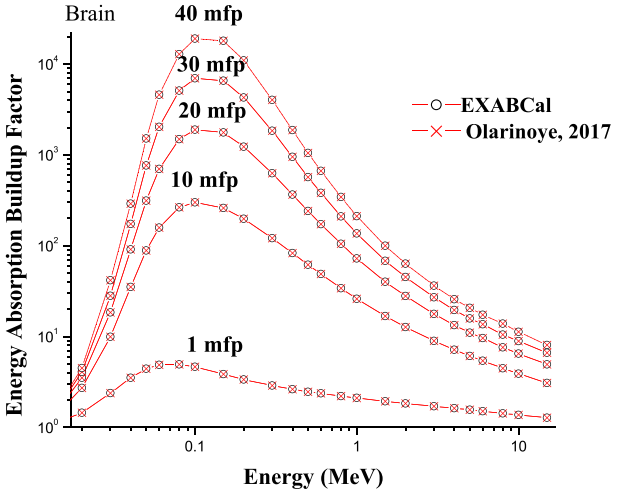


Fig. 11. Comparison of EXABCal and published values of EABF of human brain at 1, 10, 20, 30 and 40 mfp.

energy grid ("All Energy"). Then the ratio(s) (R) for the said material at the interested energy is (are) inserted in the space provided. The ratio, "$R = \frac{\mu_c}{\mu_T}$" is as explained earlier and the values can be independently obtained from XCom or its window version WinXCom (Berger and Hubbell, 1987; Gerward et al., 2004). The user at this stage then clicks the "*Perform*" button. The calculation is done following Eq. (3) by the code and the result appears on the result space in grid form showing values for: energy, R1, R2, Atomic number (Z_1), Atomic No (Z_2) and Atomic No (Z_{eq}) for the substance. The result displayed can be extracted using the "*Extract*" button to Microsoft Excel for further data analysis. The screenshot of the GUI of the result for water for all energies and single energy are shown in Figures 1b and c respectively. Similar procedure is followed for calculating the GP fitting parameters and the buildup factors and the appearance of the GUI for single and all energies configurations are shown in figures 1d and e.

1.6. Code validation

GP fitting parameters for exposure and energy absorption for water and Buildup factors from the program for water, air and concrete are compared with those reported in the ANSI report (ANSI/ANS-6.4.3, 1991) at selected depths and are presented in Tables 1 and 2 and Figs. 2, 3, and 4. From the figures it can be concluded that the program reproduces the parameter with reliable level of accuracy. For further validation purpose, the Z_{eq} values from EXABCal for some bricks and rocks samples were compared with published values (Obaid et al., 2018; Sayyed et al., 2017a) and presented in Table 3. Also, the energy absorption buildup factors at selected depths for some selected human (skeletal muscle, ovary, breast and brain) tissues obtained from EXABCal and manual calculations (Olarinoye, 2017) were compared and presented in Figs. 8, 9, 10, and 11. The comparisons further emphasise the validity of the code.

Generally, the variations of buildup factor with energy using the GP fitting procedure and thus EXABCal follow similar pattern as predicted by Eqs. (5), (6), and (7). Consequently, according to Figs. 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11, the buildup factor of all materials are generally low in the low and high energy regions but high in the intermediate energy region. This can be attributed to the photon interaction mode dominating in each of the three energy regions. At the low and high ends of the energy spectrum, the photoelectric and pair production interaction processes dominate respectively. Both of these interaction modes removes photon from incident beams, thus the low photon buildup recorded in these regions.

Table 4
Comparing exposure buildup factors from EXABCal and those from other methods and codes.

Material	Energy (MeV)	Depth (mfp)	Method			
			EGS4 (Hirayama, 1995)	IE (Shimizu, 2002)	GFFNN (Kucuk, 2010)	EXABCal
Water	0.1	1	4.68	4.59	4.55	4.84
		5	70.1	65.2	65.2	65.72
		10	354	321	321	342.61
	1	1	2.1	2.08	2.07	2.11
		5	10.3	10.2	10	10.13
		10	26.4	26.3	25.6	26.73
	10	1	1.44	1.39	1.37	1.37
		5	2.72	2.56	2.51	2.56
		10	4.16	3.91	3.71	3.88
Concrete	0.1	1	—	2.75	2.78	2.75
		5	—	11	11	11.05
		10	—	25.4	26.1	25.01
	1	1	—	1.99	1.97	1.98
		5	—	8.36	8.3	8.3
		10	—	20.7	21	20.64
	10	1	—	1.44	1.35	1.34
		5	—	2.79	2.56	2.53
		10	—	4.47	4.33	3.99

However, in the intermediate energy zone, the buildup is higher due to the dominance of incoherent (Compton) scattering. The Compton scattering process does not remove photons completely from a beam but rather slow them down due to photons collisions and scattering with atomic electrons of the absorbing medium. The scattered photons with lower kinetic energies lead to increase in buildup of photons in the medium at the intermediate energy region (Olarinoye, 2017; James, 2006).

Furthermore, exposure buildup factor values obtained from the EXABCal code were compared with those from the Monte Carlo code-EGS4 (Hirayama, 1995); Invariant Embedding (IE) (Shimizu, 2002); and the Generalised Feed Forward Neural Network (GFFNN) (Kucuk, 2010) methods for selected energies and depths and presented in Table 4. From the results, the EXABCal values were in good agreement with the mentioned earlier data (methods). The results from the presented code was within 7% of the EBF data for water for all the three methods and for all depths and energies considered. While for concrete, the difference was less than 4% for most cases and 10% for all cases when compared to these three methods. The presented code thus has the advantage that it is easier to use, faster and accurate.

2. Conclusion

A freely available Windows compatible program (EXABCal) is presented for the calculation of equivalent atomic number of any compound or mixture, exposure and energy absorption buildup factors from photon energy of 15 keV to 15 MeV and penetration depth up to 40 mfp. The code is able to calculate the intended data to a high degree of accuracy and it is easy to use. The code will interest medical Physicist, radiation Physicists, Radiation shielding design engineers and all expert working in fields where nuclear radiation is applied. The program is freely available for use on request from the authors of this article through the e-mail (leke.olarinoye@futminna.edu.ng).

Declarations

Author contribution statement

I. O. Olarinoye: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Raymond I. Odiaga, Silas Paul: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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