Photon Radiation Fields Characteristics In Concrete For Photon Sources With Energies From 10 To 50 MeV

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Abstract: According to Monte Carlo calculations of spatial distributions of photon energy in concrete from point isotropic and plane mon-directional monoenergetic sources with energies of 10-50 MeV, define the attenuation coefficient of air Kerma and the dose buildup factors are determined for the studied material. The calculations take into account the contribution of fluorescence, annihilation radiation, and bremsstrahlung radiation. The independence of the Buildup Factors and attenuation coefficient from the angular distribution of the source radiation and the weak dependence of the attenuation coefficient on its energy in the range of 30-50 MeV are shown. Corrections for barrier protection were determined and their independence from the thickness of the shielding material and the photon energy of the source was noted. The obtained information makes it possible to reduce errors in the results of calculations of the thickness for anti-radiation protection of electronic accelerators at high energies, using the developed engineering methods of calculation. The obtained information can also be used in calculations of protection against bremsstrahlung radiation of electronic accelerators by engineering methods.

Keywords : electronic accelerators, bremsstrahlung radiation, protection, dose, accumulation factor, attenuation Multiplicity, Monte Carlo.

1. INTROUDUCTION

The linear electron accelerators use with primary electron beam energy in the range of up to 50 MeV for remote radiation therapy , defectoscopy and an increase in the requirements for ensuring the radiation safety of personnel and the population necessitate the improvement of the methodological base for designing the protection of such installations [1]. It is important to obtain the attenuation characteristics of the bremsstrahlung photons used in their shielding materials. for this energy range, taking into account the scattered radiation. Accounting to scattered radiation in developed engineering methods for calculating photon protection is usually carried out using the attenuation factor and accumulation factorsThe information available in the literature on the transmission of photon radiation in various shielding materials [2],[3],[4] is limited for the photon energies of the source below 15 MeV. The electron accelerators use in industry and medicine with primary electron beam energy in the range up to 50 MeV leads to serious demand to obtain data on the attenuation characteristics of bremsstrahlung photons for this energy range. Concrete, Iron, and Lead are used as shielding materials from the bremsstrahlung of electron accelerators, so the goal of this research was to obtain the characteristics of the photon radiation fields for one of these materials. The material that was studied in this article is Concrete.

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2. GEOMETRY AND METHODOLOGY

The geometries of the studied compositions, differing only in size for different materials, were identical and are show figure 1.

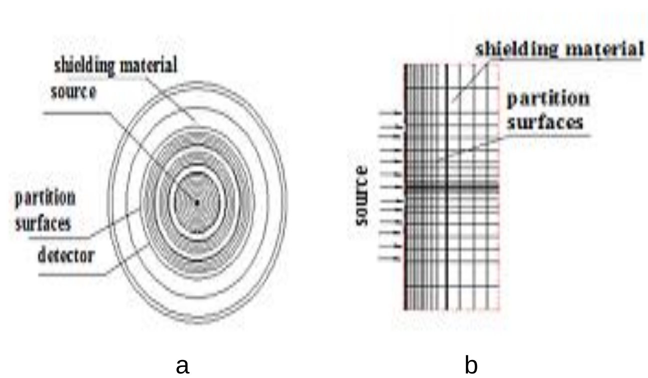

***Fig. 1**. Geometries of the considered compositions: a) – point source, b) – unidirectional source)*

To assess the influence of the composition geometry on the characteristics of the photon fields, two cases were considered: spherical geometry with a point isotropic source in the center of the sphere and cylindrical geometry with a flat unidirectional source whose radiation falls normally on the end surface of the cylinder. The dimensions of the defenses were chosen so that the geometry could be considered infinite. The thickness of the material was 45 mean free path for the photon energy source. The radius of the cylindrical protection was 1000 cm for Concrete. The radius of the unidirectional source was assumed to be 300 cm for Concrete shield. The shielding material under study is Concrete with a density of 2.3 g / cm3 [3]. The photon energies of the source were chosen equal to 10, 20, 30, 40, and 50 MeV. Calculations of the characteristics of photon fields were performed using the Monte Carlo-FLUKA program [5]. An estimate was used for the intersections of the surfaces shown in Fig.1, located at different distances from the radiation source, and local estimation of the flow at a point isotropic source. The absorbed dose rates in the air, dose accumulation factors, and energy distributions of the photon flux density at different distances from the source were taken as characteristics of the photon radiation fields. At the same time, the average of these values on the cylinder axis were estimated for a unidirectional source. The FLUKA program calculates the energy distributions of the photon flux density in the material under consideration. These distributions were calculated at distances from the source from 0.25 to 30 mean free paths. In this case, the photon mass attenuation coefficients [2, 6] given in table 1 were used for the transition from the mean free path to the true distance in linear

TABLE 1. photon- mass attenuation coefficient for Concrete, cm2 / g

Energy of photons Source, MeV	shielding material Concrete
10 [2]	0.02311
20 [2]	0.02105
30 [2]	0.02105
40 [6]	0.0212
50 [6]	0.0217

Dimensions The transition from the energy distributions of the photon flux density to the power of the dose absorbed in the air was carried out based on specific dose factors calculated by the formula (1):

$\delta = 10^5 E_\gamma\ 1.6 \cdot 10^{-13} \mu^m_{eni}(E_\gamma)$, c Gy cm^2 / photon, (1)

in which Eγ is the photon energy, in MeV;

μ^m_{en}, (Eγ) – photon energy-absorption coefficient for air with energy Eγ;

in cm^2/g, 1,6·10-13 J/MэB - transition coefficient from joules to MeV.

The values of δ for photon energy less than 10 MeV were taken from article [3], and for large photon energies are calculated using the formula (1) using μmen, (Eγ), taken from article [6]. The obtained values δ are shown in table 2
The total absorbed dose rate was then calculated using the formula (2):

$$\dot{D} = \int \varphi(E)\delta(E)dE\,, \qquad (2)$$

Obtaining the characteristics of the photon fields at source energy of 10 MeV allowed us to compare the results obtained in this study with the available literature data and thus was used to test the calculation methodology and software used in this study.

TABLE 2. Specific dose coefficients for photons of different energies, c Gy cm2 / photon*10-9

E_γ	δ_γ
0.1	0.0037
0.2	0.0086
0,5	0.238
1	0.45
2	0.756
3	1
4	1.22
5	1.43
6	1.62
8	2.01
10	2.33
15	3.26
20	4.26
30	6.19
40	8.13
50	10.6

3. RESULTS AND DISCUSSIONS

3.1 Spatial Distributions of the Absorbed Dose.

Figure 2 and figure 3 show the spatial distribution of the total absorbed dose rate in air, taking into account the scattered radiation in Concrete for two types of photon radiation sources, normalized to the unit source power. Moreover, in the figure 1 for a point isotropic source, the results are multiplied by 4πR2, where R is the distance from the source to the detection point, to take into account geometric attenuation.

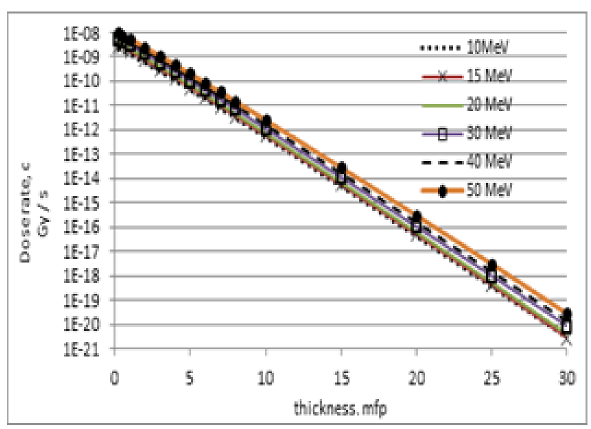

Fig. 2. Spatial distributions in Concrete of the power of the absorbed dose of photons in the air from point isotropic photon sources with different power energies 1 photon./s (results multiplied by 4πR^2)

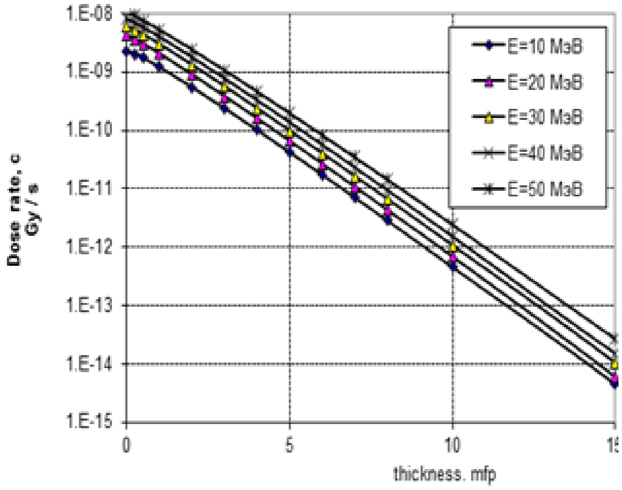

Fig. 3. Spatial distributions in Concrete of the power of the absorbed dose of photons in the air from flat uninirectional photon sources with different power

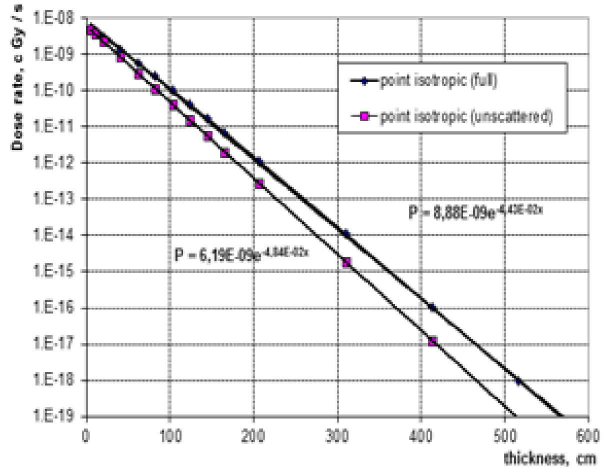

Fig. 4. (b).

The attenuation character of the total absorbed dose rate and the dose of non-scattered radiation is close to exponential except for the initial section at small shielding thicknesses. This is clearly seen in the examples shown in Fig. 4 , data on the spatial distribution of the absorbed photon dose in concrete from a photon source with an energy of 30 MeV. The attenuation characteristics of the total dose rate for point isotropic and flat unidirectional sources are almost the same, but depend on the thickness of the shielding. The trend lines show that when interpolating distributions for a section of concrete thickness of 0-600 cm, the exponent index is 0.0443 cm-1, and for a section of 0-200 cm, it is 0.0418 cm-1.

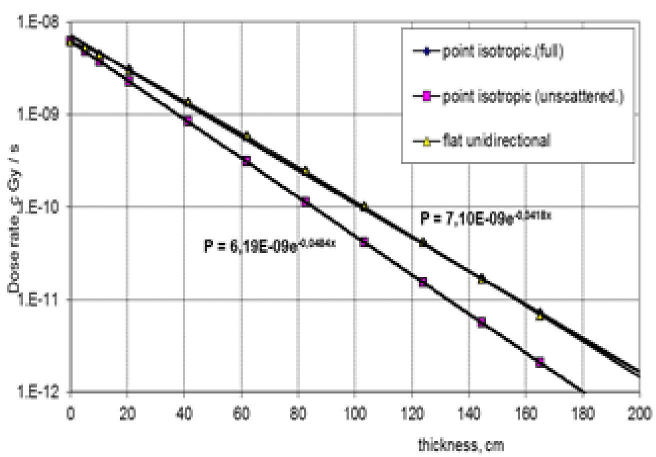

Fig. 4. (a)

Fig. 4. Spatial distribution of the absorbed dose rate of photons in Concrete at thicknesses (0-9) cm **(a)** and (0-40) cm **(b)** from a point isotropic power of 1 s^{-1} and a flat

The attenuation characteristics of the total dose rate for a point isotropic and a flat unidirectionalsource practically coincide. The drawn trend lines show that upon interpolation of In the data practical use, the attenuation of photons in Concrete, it seems advisable to use Dose Buildup Factor of photons that take into account the difference in the nature of attenuation from exponential or to use the Attenuation coefficient of the total absorbed dose rate. These results are consistent with those reported in [10].

3.2 Attenuation Coefficient of Absorbed Dose Rate

These data show that for a concrete shielding thickness below 20 mfp, regardless of the photon energy of the source, the attenuation coefficient of the absorbed dose for concrete does not depend on the angular distribution of the source photons with an error of less than 10%. At large thicknesses, the difference increases, which may be due to errors in dose calculations for a unidirectional source. The dependence of the the attenuation coefficient of the absorbed dose for concrete thickness for point isotropic photon sources of different energies is shown in Fig.5. It can be noted that the attenuation coefficient of the absorbed photon dose at source energies from 10 to 50 MeV practically does not depend on this energy, if Concrete thickness is measured in linear dimensions, and not in mean free path lengths of the source photons. These results are consistent with the results given in the [10].

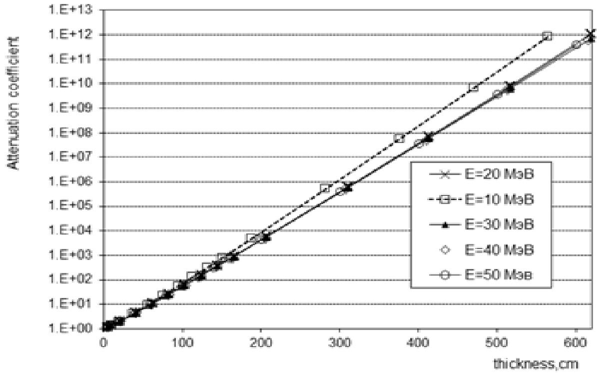

Fig. 5. Dependence of the attenuation coefficient of the absorbed dose in Concrete on the shielding thickness for point isotropic photon sources with different initial energy

3.3 Tenfold attenuation layer

Often, the values of the tenfold attenuation layer are used to calculate the thickness of the shield that provides a given attenuation coefficient, and their dependence on the thickness of the shielding is often neglected. The inadmissibility of this approach is shown in table 3. Calculated tenfold attenuation layer of dose rate attenuation at different Concrete shielding thicknesses for a point isotropic source with different photon energies .

TABLE 3. Tenfold attenuation layer of the absorbed dose power by Concrete shielding, cm

No. layer's	Thickness, cm	Source energy, MeV				
		10	20	30	40	50
1	0-61	58	60.5	60.5	61	60
2	61-120	50	53.25	54.5	54.5	54.5
3	120-180	48	53.25	53.5	54	53
4	180-230	47	51.5	51	51	51.5
5	230-280	46.5	51	51.5	51	51
6	280-330	46.25	51	51.5	51.5	51
7	330-380	46	50.25	51.5	51	51.5
8	380-430	46	50.25		51	50.5
9	430-480	45.5	50			50.5
10	480-530	45	49.75			49.5
11	530-580	45	48.5			49
12	580-630		48			

Analysis of the data shows that the first three layers of tenfold attenuation have a weaker character than the subsequent ones, and this is most clearly visible when the first layer differs from the rest. Starting with a layer thickness of 30 cm, the value of the tenfold attenuation layer is almost independent of the thickness of the concrete shielding, the photon energy of the source from 20 to 50 MeV and from this from this energy. In this range, it can be assumed to be 51.0 ± 0.5 cm. When the photon energy of the source is 10 MeV, the nature of the attenuation differs from that noted above. As a result, table 2.8 can be reduced to a table. 4.

TABLE 4. Averaged tenfold attenuation layer of the absorbed dose power by Concrete shielding, cm.

No. layer's	Thickness, cm	The energy of source photons, MeV	
		10	20-50
1	0-10	58. 0	60.5±0,5
2	10-20	50.0	54.5±0,3
3	20-30	48.0	53.5±0,5
4	30-110	46±0,5	51.0±0,5

3.4 Exposure Buildup Factors

In practical data use for photon attenuation in concrete, it seems appropriate, as for Concrete and iron, to use dose buildup factors of photon that take into account the difference in the nature of the attenuation from the exponential one, or to use attenuation coefficient of the total absorbed dose [1]. Comparison of the exposure buildup factors obtained in this study with similar data given in [2],[9] for the photon energy of a 10 MeV point isotropic source (table 5.) showed their agreement within 5%. This indicates the reliability of the calculated results obtained and the acceptability of the calculation method used. Data in tables 5 and 6 indicate a weak dependence of exposure buildup factors of photons in Concrete for the considered energy range of the source on the angular distribution of the source radiation. The difference between the data about buildup factors for a point isotropic source and the results for a flat unidirectional source does not exceed 5% for a Concrete, which allows using any of them when performing approximate shielding calculations.

TABLE 5. Exposure Buildup Factors for photons in Concrete for point isotropic and flat unidirectional sources of photons with different energies.(P.S: point isotropic source, U.S: unidirectional source)

μd	The energy of source photons, MeV							
	20		30		40		50	
	P.S.	U.S	P.S.	U.S	P.S.	U.S	P.S.	U.S
0.25	1.06	1.11	1.1	1.11	1.1	1.11	1.1	1.11
0.5	1.13	1.19	1.19	1.19	1.19	1.19	1.2	1.19
1	1.27	1.34	1.35	1.34	1.36	1.35	1.37	1.37
2	1.51	1.59	1.62	1.61	1.66	1.65	1.72	1.7
3	1.76	1.84	1.89	1.87	1.95	1.94	2.05	2.04
4	1.99	2.08	2.16	2.14	2.26	2.23	2.42	2.4
5	2.23	2.32	2.44	2.4	2.55	2.53	2.79	2.77
6	2.48	2.57	2.72	2.68	2.88	2.84	3.22	3.17
7	2.73	2.82	3.02	2.96	3.21	3.15	3.65	3.6
8	2.99	3.07	3.42	3.26	3.73	3.49	4.13	4.06
10	3.51	3.6	3.97	3.88	4.3	4.18	5.19	5.08
15	4.98	4.65	5.87	5.56	6.51	6.15	8.61	8.31
20	6.63		8.12		9.32		13.68	12.69
25	8.34		11.38		12.77		20.54	
30	9.11		14.81		17.58		27.46	

Depending on the photon energy of the source, the minimum values of the buildup factors are observed at an energy of 20 MeV, and then they increase with the growth of the photon energy of the source.

TABLE 6. Exposure Buildup Factors of photon accumulation for Concrete for point isotropic and planar unidirectionalphoton sources with an energy of 10 MeV .(P.S: point isotropic source, U.S: unidirectional source)

The energy of source photons, MeV				
μd	10			
	P.S	[2]	[9	U.S
0.25	1.13		1.14	1.13
0.5	1.24	1.23	1.24	1.24
1	1.44	1.42	1.42	1.44
2	1.78	1.73	1.75	1.78
3	2.12	2.03	2.08	2.12
4	2.47	2.34	2.39	2.47
5	2.81	2.64	2.71	2.81
6	3.16	2.94	3.03	3.16
7	3.51	3.26	3.35	3.51
8	3.87	3.57	3.68	3.87
10	4.63	4.2	4.34	4.63
15	6.5	5.8	6.33	6.5
20	8.56	7.47		8.56
25	10.74	9.18		10.74
30	12.79	11		12.79

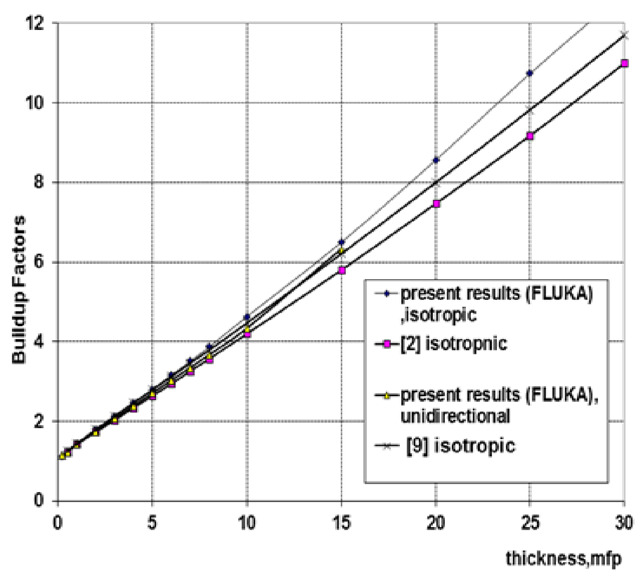

Fig. 6. Comparison of Exposure Buildup Factors of photon in Concrete for a point isotropic photon source (FLUKA) with an energy of 10 MeV obtained in different literatures

TABLE 7. Concrete Barrier Corrections

mfp	5					10				
E, MeV	10	20	30	40	50	10	20	30	40	50
δ	0.950	0.964	0.964	0.962	0.970	0.950	0.954	0.962	0.959	0.968

In the considered range of material thicknesses, these corrections are independent of the photon energy of the source and the thickness of the shield and are equal to 0.980 ± 0.002 for Concrete

4. CONCLUSION

Based on the results calculations of the dose characteristics of photon fields in the materials under consideration in the barrier geometry at shield thicknesses above 3 mfp, corrections for the barrier shielding were determined in the form of the ratio of buildup factors in the barrier geometry to similar ones in an infinite medium. In the considered range of material thicknesses, these corrections do not depend on the photon energy of the source and the shield thickness, which are equal to 0.960±0.006for Concrete. Asymptotic Tenfold attenuation layer for Concrete was obtained in [9],[11] depending on the energy of the electrons accelerators. In the range of electron energies of 20-100 MeV, which corresponds to the effective photon energy of the bremsstrahlung radiation of about 6-33 MeV [7], they are practically independent of the electron energy. The obtained characteristics of the photon dose attenuation in various shield materials for photon sources with energies in the range from 10 to 50 MeV Supplement the data that are not available in the literature for photon energies of sources above 30 MeV and provide more accurate estimates of the required thickness of shielding against the bremsstrahlung radiation of electronic accelerators.

5 ACKNOWLEDGMENT

This research is part of the Dissertation research from Institute of Nuclear Physics and Technology (INP&T), National Research Nuclear University «MEPhI».

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