EVALUATION OF EFFICIENCY OF CONCRETE SHIELDING AGAINST BREMSSTRAHLUNG OF 5 MEV ELECTRONS AT PRE-COMMISSIONING OF THE ACCELERATOR ILU-10

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The results of analysis of efficiency of concrete shielding at slant penetration of 5 MeV electrons bremsstrahlung with due account of the angle-energy distribution of radiation from target are presented. The initial angle-energy distributions of photon radiation from aluminum, iron and tungsten targets have been obtained by direct Monte-Carlo simulation of main interactions with the use of the program package SCIN_PC. Then the kerma value in the air and its attenuation by the concrete shielding were estimated analytically using the available reference information. Kerma rate values at checkpoints beyond the concrete shielding of the existing bench, which is intended mainly for electron accelerators of smaller energy, have been estimated. Recommendations and restrictions for bench adjustment and tests of the ILU-10 accelerator have been stipulated.

ILU-10 is an RF electron accelerator with the following characteristics of the accelerated beam:

- electron energy ……………………….…5 MeV
- average current of the electron beam.…...10 mA
- electron beam direction ……………….downwards

The planned time of bench operation with the electron beam is about 20 hours per week.

The walls and ceiling of the shielded hall of the test bench are made of monolithic concrete, veneered with concrete slabs. The beam is absorbed in dumps with an atomic number not exceeding 13.

The zone of stopping of the accelerated electron beam is significantly below the ground, which means that bremsstrahlung passing through the shielding concrete walls to the control points at the zero and higher marks should be estimated with due account of the effect of the slant incidence of photons onto the shield as well as their initial angle-energy distribution in the half-space back of the target.

For engineering evaluation of shield efficiency with accuracy acceptable for most practical requirements, we can limit ourselves to the analysis of how the shielding attenuates the air kerma.

The rate of air kerma of photon radiation MeV/(g·s) at the not-too-small distance *R* cm from a target with the atomic number *z* after the photons that have not interacted with the shielding material pass the path *x* cm in shielding can be expressed as follows:

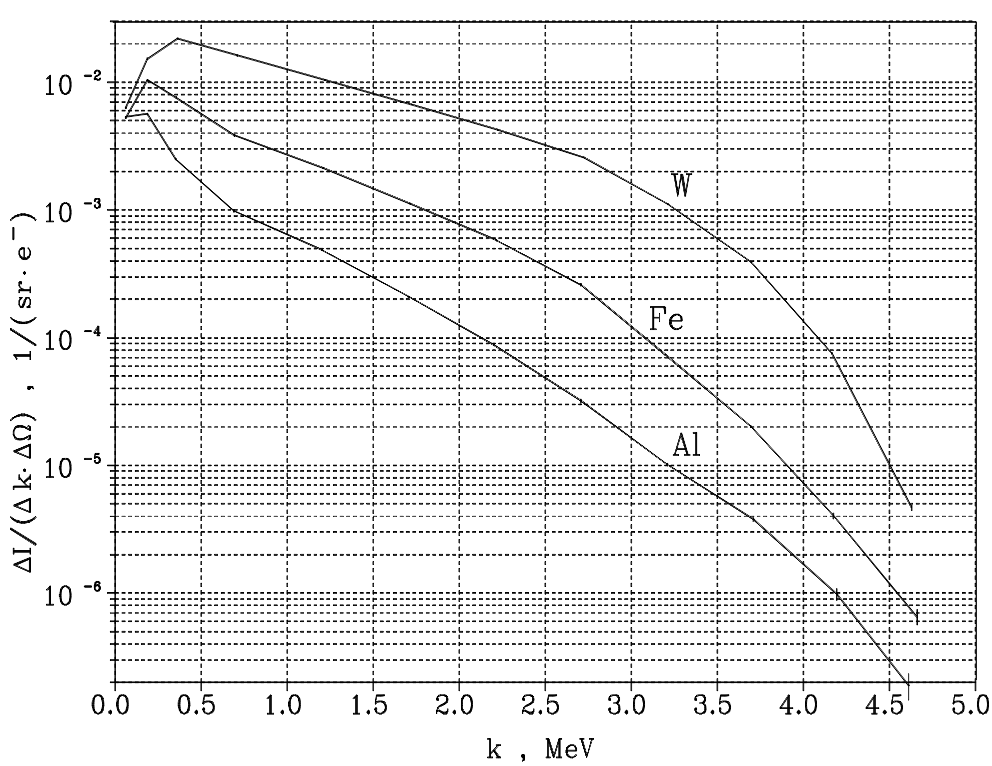

Figure 1: Energy distribution of photon radiation from aluminum, iron and tungsten targets to the angle escape interval 123.75°…135.0°, E_0 = 5 MeV.

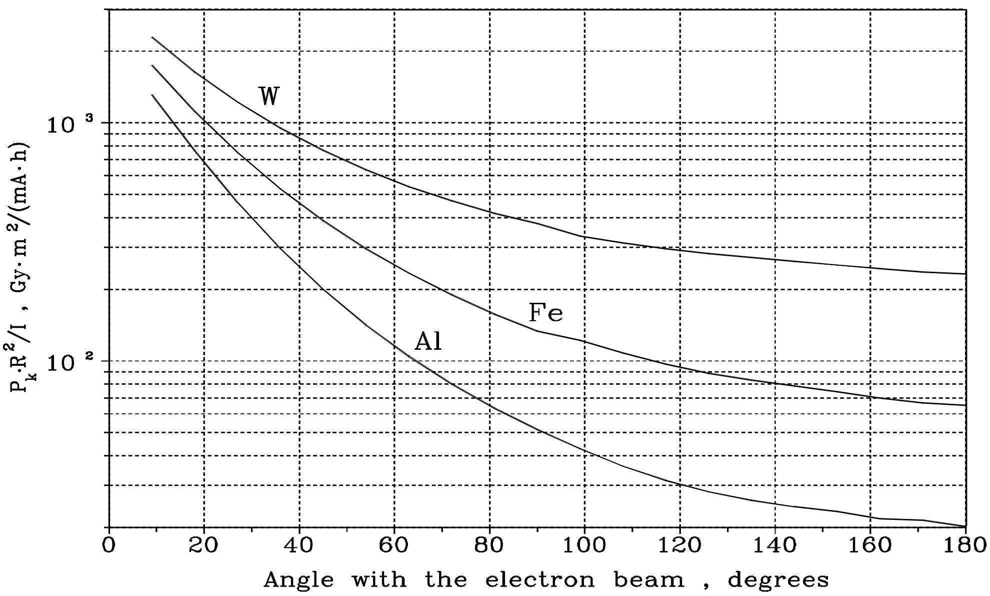

Figure 2: Angular dependences of the air kerma of bremsstrahlung from the targets, E_0 = 5 MeV.

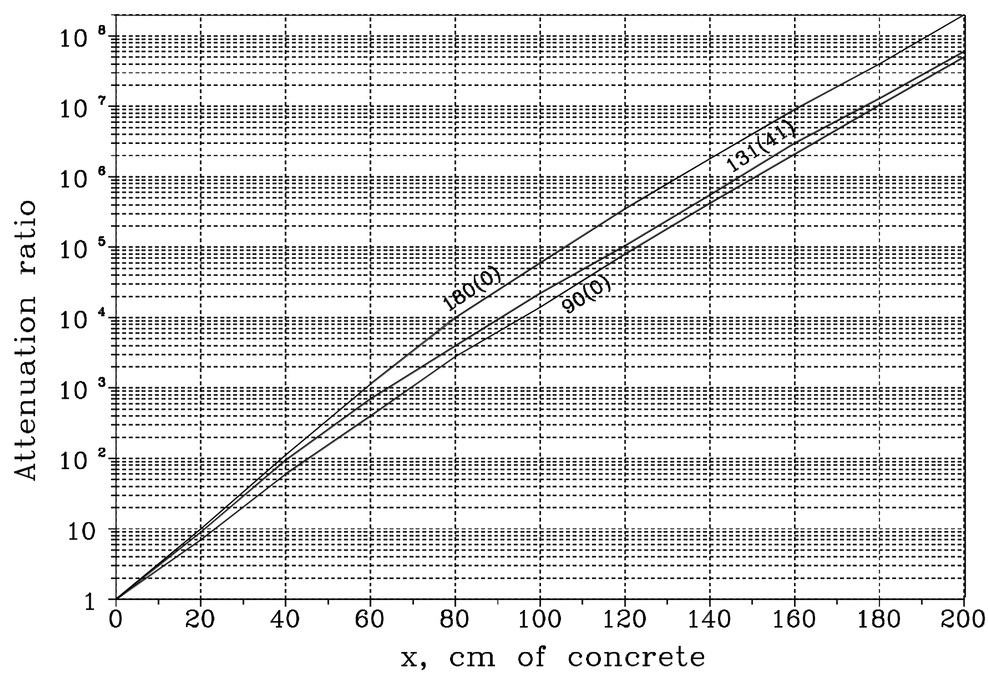

Figure 3: Attenuation by concrete of the air kerma of bremsstrahlung from the Al target, E_0 = 5 MeV (see text).

$$P_k \simeq \frac{\dot{n}}{R^2}\int_0^{T_0}\gamma(k)\frac{d^2I(z,T_0,\vartheta_0,k)}{d\Omega dk}e^{-\mu x}B(\mu x,z_{sh},\vartheta_{sh},k)dk\,, \qquad (1)$$

where T_0 is the kinetic energy of primary electrons falling onto the target (this energy defines the upper limit of the spectrum of bremsstrahlung photons $E_0 = T_0$); $\dot{n}$ is the number of electrons dropped onto the target per second; k is the bremsstrahlung photon energy, MeV; ϑ_0 is the angle between the electron beam direction and that from the target to the sighting point; $\frac{d^2I}{d\Omega dk}$ is the angle-energy distribution of the energy of photon radiation from the target, $(sr\cdot e^-)^{-1}$; $\gamma(k)$ is the mass energy-transfer coefficient for photons with the energy k for air, cm^2/g; $\mu = \mu$ (k, z_{sh}) is the linear attenuation coefficient for a shielding material with the effective atomic number z_{sh}, for photons with the energy k, cm^{-1}; ϑ_{sh} is the angle of radiation incidence onto the shield; B is the build-up factor.

The angle-energy distributions of photon radiation leaving the targets was obtained via the direct Monte-Carlo simulation of main interactions with the help of the program SCIN_PC [1]. The modification consisted in a serious improvement of the random number generator, to provide correctness of statistical data collection to within the number of histories of the order of one milliard and random numbers within 300…20000 per one history. The estimation target was a cylindrical pellet with radial and longitudinal dimensions close to the path of a 5 MeV electrons. It was bombarded axially by a narrow electron beam from the side of the upper end surface.

Fig.1 presents as illustration photon radiation energy distributions averaged over the interval 123.75° < ϑ_0 < 135° for the aluminum, iron and tungsten targets.

The build-up factor in (1) depends, besides the photon energy and shield material and thickness, on the angular distribution of the photons emitted from the target, shielding geometry and mutual arrangement of the target, shielding and detector. In our case, the shielding structures are sufficiently far from the target. Therefore, for engineering evaluations of kerma attenuation, we can use the build-up factors derived from the information in [1], presented for a flat, monodirectional source in infinite concrete medium.

Fig. 2 presents the angular dependences of the kerma rate of photon radiation from the aluminum, iron and tungsten targets, computed at $x \approx 0,6$ cm of 2,3 g/cm^3 concrete, for the case of perpendicular incidence onto a layer of such thickness. For thicker concrete the kerma attenuation ratio was estimated as follows:

$$K \simeq P_k(x) / P_k(0.6) \,. \qquad (2)$$

Fig. 3 illustrates attenuation by concrete of the kerma of bremsstrahlung from the aluminum target, E_0 = 5 MeV, for three different geometries (angle of photon direction relatively of primary electrons direction and the angle of photon incidence on the shielding are specified).

In accordance with [3] and [4], for accelerator operating in the regime of radiation hazard for 20 hours per week in average, the following equivalent dose rates at control points can be taken as the design values:

I. The external side of the wall of the shielded hall beyond the BINP area: 0,6 μSv/h.

II. The external side of the end wall of building 18: 2,7 μSv/h.

III и IV. The external sides of the shield in the vehicular lane and in bunker 2, respectively: 24 μSv/h.

V. Roof: (24 μSv/h).

VI. Room occupied by people all the time: 12 μSv/h.

Results of evaluations of the dose (kerma) rate P_{ksh} behind the shielding at ILU-10 operation with the aluminum target are summarized in Table 1.

It is seen from the table that the expected levels of radiation at points I, IV, VI, which are the most critical, conform to the allowable design norms with a double allowance.

Table 1. Evaluations of the kerma rate P_{ksh} at control points behind the shielding.

Control point	ϑ_0	R, m	$P_k R^2 / i$, Gy·m^2/(mA·h)	P_k, Gy/h	ϑ_{sh}	x, m	K	P_{ksh}, μGy/h	Design value [P_{ksh}], μGy/h
I	131°	5,97	24	6,7	41°	1,86	2,2·10^7	0,31	0,6
II	139°	5,23	20	7,3	49°	2,12	8,3·10^7	0,088	2,7
III	133°	5,77	21,5	6,5	43°	1,67	4·10^6	1,6	24
IV	90°	9,89	50	5,1	0°	1,45	5,5·10^5	9,3	24
V	180°	11,5	17,3	1,3	0°	1,10	1,4·10^5	9,3	(24)
VI	164°	11,96	17,3	1,2	16°	1,14	2,1·10^5	5,8	12

However, if the accelerator has to work for heavy targets (Ta, W), the radiation levels may increase by a factor of 50 to 100, if there is no additional hardening. The following measures can be foreseen for this case:

- Mounting of additional shielding screens of heavy materials on the concrete walls inside the shielded hall, in the most loaded directions.
- Equipping the beam stopping zone with a local shield of heavy materials.
- Cutting the time of operation with such targets.

REFERENCES

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[3] Radiation safety standards (NRB-99). SP 2.6.1.758-99.

[4] Main sanitary regulations for radiation safety (OSPORP-99). SP 2.6.1.799-99.