RADIATION PROTECTION OF A COMPLEX OF HIGH-CURRENT DISTRIBUTED ELECTRON ACCELERATORS

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Creation of several high-current distributed electron accelerators for production of medical radionuclides on the base of a linear electron accelerator LUE-2000 has required to use maximally the available equipment, premises and existing radiation shields [1]. Therefore, it was necessary to perform calculations and to choose a relevant variant for arrangement of distributed electron accelerators.

In the process of isotope ^{99}Mo production in enriched and not enriched targets the optimum electron energy is 25 MeV [2] and 40 MeV [3], respectively. In connection with an opportunity to operate with accelerated electron energies up to 100 MeV and currents up to 1 μA it was necessary to calculate the levels of radiation for thick tantalum targets behind the existing shield of the linear accelerator LUE-2000 for 25, 60 and 100 MeV. An absorber dose rate created by the bremsstrahlung and neutrons was calculated in conformity with normative documents and works of [4 - 6]. An agreement between calculations and experimental data at maximum energies of bremsstrahlung up to 25 MeV [7] allows one to extend these calculations to higher currents, and for higher energies of bremsstrahlung one should perform additional calculations of attenuation multiplicity as a function of the concrete thickness.

At present, the normative documents for attenuation multiplicity of the absorbed dose of electron bremsstrahlung are available only to 40 MeV [8]. We have calculated the concrete thickness required for shielding from the bremsstrahlung at different attenuation multiplicities and electron energies up to 100 MeV according to [8, 9]. As for concrete the critical electron energy E_c is close to 40 MeV (by our calculations E_c = 41.5 MeV, and radiation length is 24.5 g/cm^2) the data of [5] on the shield thickness for the maximum energy of bremsstrahlung 38 MeV can be used for any energy more than 40 MeV with taking into account the multiplication factor and, consequently, the increase of the absorbed dose rate. The multiplication factor in concrete is determined using the data for electron-photon cascades in lead at a primary electron energy of 100, 200, 400 and 1000 MeV [9]. The results obtained for E_0 = 100 MeV are in accordance with the results of [10] and are valid for the concrete thickness more than 2.5 radiation lengths. The attenuation multiplicity for concrete required for bremsstrahlung protection with a maximum energy E_0 is given in Table1.

Table 1

E_0, MeV / Atten.multiplic.	10	10^2	10^3	10^4	10^5	10^6
38*([5])	57	105	150	197	241	287
60	60	108	153	200	244	290
100	66	114	159	206	250	296
200	97	145	190	237	281	327
400	104	152	197	244	288	334
1000	118	165	210	257	301	347

Table 2

E_0 /Points	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
25 MeV	1290	3.9	59.5	290	34.4	11.9	53.2	0.06	1.4	0.1
60 MeV	5580	18.6	279	1360	160	55	247	0.3	6.5	0.5
100 MeV	10^5	354	5250	25570	$3 \cdot 10^3$	1050	$4.7 \cdot 10^3$	5.8	123	8.5

The results of calculations on the equivalent dose rate beyond the existing concrete shield of 2 m for electron energies of 25, 60 and 100 MeV, a mean current of 1 mA and for a thick tantalum target are given in Table 2 in μSv/h.

The neutron flow in points A_1 and A_7 (not served rooms) at the electron energy E_0=100 MeV and the mean current 1 mA will be equal to $1.6\cdot10^2$ and 4.4 neutrons/(cm$^2\cdot$s). In the rest points it will be less than 1 neutrons/(cm$^2\cdot$s). At energy of accelerated electrons up to 1 mA the existing shield provides a required level of radiation safety. In the case of operation with energies up to 100 MeV and a current of 1 mA there is a possibility to install a local lead shield (11 cm) or to add on the outside concrete blocks of 1m thick that can decrease the radiation level by a factor of 100. So, radiation conditions for operation of electron accelerators with energy up to 100 MeV in the rooms adjacent to the bunker are determined by gamma-radiation being formed when electron beam interacts with the targets having a high atomic number. Neutrons do not give an appreciable contribution into the equivalent dose rate behind the shield even during operation with the target made of heavy materials. It should be noted that at electron energies up to 100 MeV for radiation angles up to 90° the shield thickness is determined by the bremsstrahlung dose rate and for angles larger than 90° it is determined by the neutron radiation dose rate. At electron energies higher than 100 MeV already beginning from angles of ~ 30° the shield thickness will be determined by the neutron radiation from quasi-deuteron mechanism, and above 200 MeV also by a pi-meson mechanism of neutron formation.

Taking into account a great demand for ^{99}Tc, real and guaranteed providing of medical establishments with ^{99}Mo one should have as the minimum two accelerators for ^{99}Tc production. Therefore, it was decided to create once more LUE-25 (No 2) in the space of 25-26 sections in the LUE-2000 bunker. For safety of works conducted, it was necessary to install a radiation shield on the accelerator under construction (LUE-10 and LUE-25 (No 1) being in operation) in the LUE-2000 bunker. Arrangement of this shield is shown in Fig. 1.

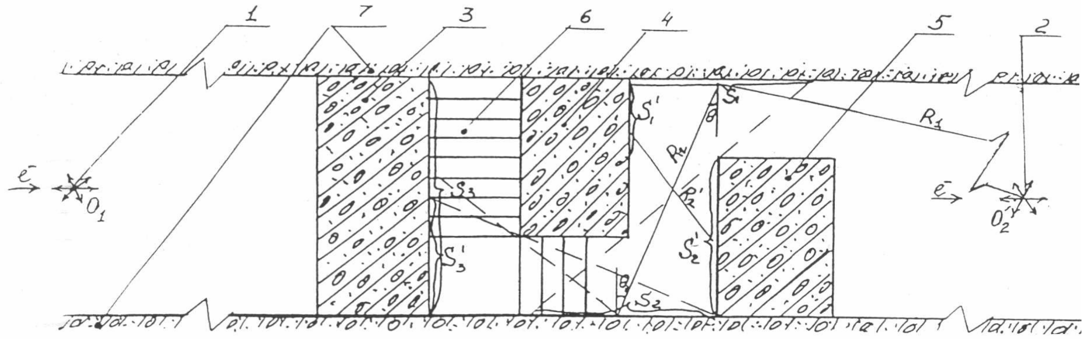

Fig. 1. Arrangement of the concrete shield against radiation of the accelerators LUE-25 (No 1) and (No 2) (cross-section of the accelerator LUE-2000 in the plane passing through the accelerator axis in parallels to its base. 1, 2 - accelerators LUE-25 No 1 and No 2; 3 - concrete radiation shield of accelerator N1; 4, 5 - walls of the labyrinth for the scattered radiation protection of accelerator No2; 6 - ladder for entrance into the bunker of accelerator N2; 7 - existing concrete shield of LUE-2000. S_1 and S_1^1 - reflecting surfaces. R_1 – distance from the target of accelerator N2 to the reflecting surface S_1.

To calculate the thickness of the concrete shield installed in the space of 23 section we have used experimental data on the absorbed dose rate behind the aluminium target at maximum operating beam parameters. It was $2\cdot10^4$ Gy m^2/h. The contribution of LUE-10 into the adsorbed dose rate is less than 1%. To provide the radiation level of 12 μSv/h the required thickness of the concrete shield is 2.5 m. Taking into account the existing shield being equivalent to a lead layer of 6 cm and very severe requirements to shield dimensions we have constructed a concrete shield of 1.8 m in thickness. The equivalent dose rate in the course of accelerator operation measured experimentally in different points just behind the shield 3 was from 4 to 9 μSv/h. The level of neutron radiation did not exceed 1 neutrons/(cm^2 s).

Arrangement and parameters of the accelerator LUE-25 #2 under construction are similar to those of the existing accelerator #1. Therefore, we do not expect the problems related with the direct radiation protection. Considering that it was convenient to make the access into the room of the new accelerator through the top shield which can be opened, and that there was not a massive shielding access-door we constructed the labyrinth for scattered radiation protection. The labyrinth walls were 1.2 m thick. The layout of the labyrinth at the accelerator LUE-25 (#2) is shown in Fig. 1. As basic reflecting surfaces we have chose surfaces S_1 and S_1^1. The absorbed dose rate at surfaces S_1 and S_1^1 from the radiation of LUE-25 is 2.5 Gy/h. The calculation shows that contribution into the equivalent dose rate created by the scattered radiation at the bunker entrance of LUE-25 (#2) in the not served space at a level of the shield surface will be not higher than 1.5 μSv/h.

So, the shield constructed, engineering and arrangement actions ensure the level of absorbed dose rate less than a maximum permissible one.

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