Measuring and Simulation of Dose at Irradiation by Bremsstrahlung Gamma Beam

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Abstract— **The effect of irradiation by gamma quanta of a substance is caused by the absorbed dose. But in the experiment, it is possible to measure the exposure dose. The analysis of the results of sample iirradiation on electron accelerators is complicated by the non monochromatic character of the bremsstrahlung gamma. The procedure for measuring the absolute magnitude of the exposure dose and the calculation of the absorbed dose in the irradiation of samples of different structures by the electromagnetic bremsstrahlung are described.**

Keywords—bremsstrahlung beam, absorbed dose, exposure dose, dose rate, electron accelerator, betatron, microtron, calibration, target, spectrum.

I. Introduction

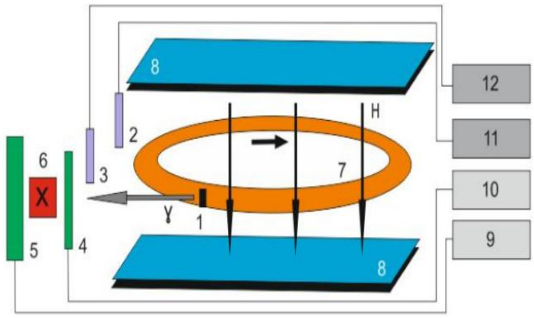
When conducting experiments on brake beams using charged particle accelerators, an exponential dose, which is a measure of air ionization, is equal to the ratio of the total electrical charge of ions of one sign formed by ionizing radiation to a mass of 1 kg of air. In this method, a non-system unit of exposure dose is used - roentgen (R) is a unit of measurement that determines the ionizing capacity of X-ray and gamma radiation in 1 cm3 of air.

$$1\ \mathrm{R} = 2.58 \cdot 10^{4}\ \mathrm{C / kg} \qquad (1)$$

Exposure dose indicates the amount of charge that forms in the air, at the place where the irradiated sample is located. The conventional pattern of irradiation of the sample for determining the absolute value of the exposure dose is shown in Fig. 1.

In order to control the beam of braking radiation in the experiment a passage ionization chamber, an absolute ionization chamber, two ball cameras of the clinical dosimeter RTF27012 were used. A thin ionization chamber is located before the irradiated sample (target) during irradiation. The data the ionization chamber is proportional to the magnitude of the exposure dose. To determine the absolute value of the exposure dose, an absolute ionization chamber is used, which completely absorbs all gamma-ray bundles.

Regardless of the passage chamber and the absolute chamber, the radiation is recorded by two ball chambers located near the beam of gamma quanta. The data from ball chambers is proportional to the intensity of the electron beam. Ball chambers are calibrated using standard sources of beta particles and gamma quanta.



1 - tungsten target, 2-3 - ball cameras, 4 - passage chamber, 5 – absolute chamber, 6 – target, 7 – betatron chamber, 8 – electromagnets, 9 – pulse counter, 10 – voltmeter, 11-12 - clinical dosimeters RTF27012.

Fig. 1. Schematic of the experiment for measuring the exposure dose.

II. Accelerators

In Uzhhorod National University there are two electron accelerators - microtron M-10 on electron energies up to 10 MeV and a betatron B-25, in which the internal beam of electrons is accelerated to 25 MeV. The induction electronic accelerator betatron in comparison with the microtron has a significant advantage in the possibility of a smooth change in the energy value of the accelerated beam of electrons. But the disadvantage of this comparison is a much less (up to three orders of magnitude) the intensity of the accelerated beam. However, this fact does not play a significant role in research on the effects of radiation on the needs of biology and medicine.

A. Microtron M-10

The microtron is an electron accelerator that is accelerated by a high-frequency electromagnetic field, which in turn is creating in a volumetric resonator. In the resonator there is an

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electromagnetic field, whose electrical component reaches - 500 KeV. The electrons accelerated in such a resonator are moving in a magnetic field along the circular orbits whose radius increases with energy, in such a way that the electrons return to the resonator in the required phase of the electric field.

TABLE I. MAIN TECHNICAL CHARACTERISTICS OF MICROTRON – M-10

№	Technical parameters	Size
1	Power consumption	30 kW
2	High-voltage	380 V
3	Magnet current	40 A
4	Weight of the magnet	1.5 tone
5	Maximum energy of accelerated electrons	10 MeV
6	Number of orbits	17
7	Current of accelerated electrons	20 μA
8	Exposure dose on 1 m from the brake target	3000 R/min.
9	The length of the radiation pulse	2.5 μs
10	Frequency of repetition of pulses	400 Hz
11	Efficiency of electron output	90 %
12	Power supply of the resonator	2 MW

The electrons from the accelerator are output through the output channel everywhere, an aluminum window with a thickness of 0.2 mm. When passing through the window electrons lose 32 Kev from their initial energy (TABLE I.).

At the exit of the accelerator, the electron beam has dimensions 8 - 10 mm horizontally and 2 - 4 mm vertically. When the window and the air layer are diverged, the electrons dissipate and the "dimensions" of the beam are increased, thereby reducing the electron flux density at the same time in the beam.

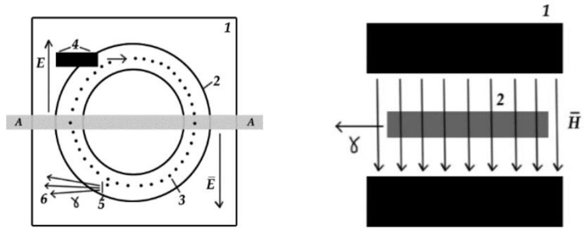
The electron beam flux density in the irradiation zone is measured using a proven Faraday cylinder, which is made of aluminum and has such dimensions that it can be used to measure electrons with energies up to 20 MeV. The cylinder is placed on a steel screen - a shell with an aluminum window with a thickness of 0.2 mm, a diameter of 40 mm, an area 12, 56 cm^2. The possibility of pumping air from the screen is provided, which increases the accuracy of the measurements of the current of electrons by 5%. The Faraday Cylinder is isolated from the screen using teflon insulators.

In order to control the current during irradiation behind the microtron, a passage chamber is set, which is calibrated the Faraday cylinder. Both devices are connected to micro-ampermeters.

B. Betatron B-25

Among the many types of charged particle accelerators for scientific and practical purposes, the electron accelerator, the betatron, plays a special role. In betatron for acceleration of electrons in a circular orbit use electric field, the intensity of which is replaced by a magnetic flux.

The peculiarity of the betatron B-25 lies in the fact that the electron beam (as in linear accelerators and microtron) does not appear from the accelerating chamber, and a bundle of inhibitory gamma quanta formed on the internal target of the accelerator chamber betatron [2]. Conditional scheme of the betatron structure is shown in Fig. 2.



1 – electromagnet, 2 - accelerator chamber betatron, 3 – orbit of electrons, 4 – injector, 5 – brake target, 6 – brake gamma radiation. Vectors E and H are the intensity of a vortex electric and magnetic field.

Fig. 2. Conditional scheme of the structure betatron B-25.

The electrons from the injector 4 are attracted to the equilibrium orbit and accelerated by a vortical electric field caused by an alternating magnetic field of the electromagnet 1. At the end of the acceleration cycle, the electrons get to the brake target 5, after which a deceleration radiation is formed which leaves accelerator chamber. The radiation of betatron B-25 has a pulsed character with a repetition frequency equal to the frequency of the electromagnetic field (50 Hz). The energy spectrum of gamma quanta has a continuous form in the range from zero to the energy of accelerated electrons [3].

TABLE II. MAIN TECHNICAL CHARACTERISTICS OF BETANRON – B-25

№	Technical parameters	Size
1	Power consumption	15 kW
2	High-voltage	380 V
3	Magnet current	75 A
4	Weight of the magnet	2.5 tone
5	The energy of accelerated electrons can vary within limits	4-25 MeV
6	Current in the resonance circuit	175 A
7	Current of accelerated electrons	10 nA
8	Exposure dose on 1 m from the brake target	70 R/min.
9	The length of the radiation pulse	5 μs
10	Frequency of repetition of pulses	50 Hz
11	Camera for accelerated electrons	RBC-25E

The intensity and geometric dimensions of the output beam of gamma quanta depend on the energy of accelerated electrons. Betatron B-25 is optimized for accelerating electrons up to 25 MeV. When the electron energy decreases, the intensity of the beam of gamma-quanta decreases and scattering increases. [4-6]. The most effective use of betatron B-25 is achieved at energies of accelerated electrons in the range of 15-20 MeV (TABLE II.).

III. Brake gamma radiation

Brake radiation in induction accelerators is formed by the interaction of high-energy accelerated electrons with the target. The electrons falling on the target undergo intense inhibition. The beam energy in the collision with the target is lost due to different processes.

These processes include: resonance absorption, excitation of atoms, collisions with nuclei and electrons, radiation of bremsstrahlung and nuclei splitting by electrons.

For high-energy electrons, the main processes are the collision, which is accompanied by ionization and excitation of atoms, and the braking radiation. The amount of energy lost by an electron at a target retardation per unit path is approximately proportional to its energy W and square of the charge of the nucleus Z^2.

If specify the amount of energy loss during a collision as $(dW/dx)_{collision}$, and the amount of energy loss on radiation through $(dW/dx)_{emission}$, then the approximate value of the ratio of losses will look as follows

$$(dW/dx)_{collision} / (dW/dx)_{emission} = 1600 m_0 c^2 / WZ \qquad (2)$$

where W — kinetic energy of the electron. From this expression it follows that the ratio of the probability of radiation losses to the probability of collision losses is inversely proportional to the kinetic energy W and the atomic number Z.

For ordinary x-ray tubes of the order of 0.1 - 0.3 MeV, it turns into radiation of 1.1% of the energy of electrons.

As the electron velocity increases, the share of energy increases, and the proportion of loss as a result of the collision decreases. The main characteristics are the spectral and angular distribution of brake radiation.

In real conditions, electrons pass through a substance that results in their multiple scattering. It greatly changes the energy and angular distribution of radiation.

For betatron B-25, the calculation of the spectral distribution of the braking radiation for a thin tungsten target (Z = 74) is proposed by Schiff.

Assume that an electron with energy E_0 passes a layer of braking material of thickness dx; as a result of radiation processes, a certain amount of quanta will radiate. Average electron energy losses per 1 cm of the way can be expressed through correlation

$$-\left(\frac{dE_0}{dx}\right) = N\int_0^1 K \qquad (3)$$

where N is the number of atoms in 1 cm^3;

$\Phi_к$ - is a value proportional to the probability of formation of photons with energy K in the region

$$d\left(\frac{K}{E_0-\mu_0}\right) \qquad (4)$$

Schiff defined an approximate expression for magnitude

$$\hat{E}\hat{O}_{\hat{e}}\, d\left(\frac{K}{E_0-\mu_0}\right) = \frac{8\bar{\hat{O}} E_0 (dK) \sin\theta_0 d\theta_0}{\mu_0^2\left[1+\left(\frac{E_0\theta_0}{\mu_0}\right)^2\right]^2} G \qquad (5)$$

where, $\Phi_к = 5.7\cdot 10^{-28} Z^2$ ($см^2$); θ_0 - the angle between the primary direction of the electron and the secondary direction of the photon; $G = \left[2(1-\varepsilon)(\ln\alpha - 1) + \varepsilon^2(\ln\alpha - 1/2)\right]$ - value proportional to the intensity spectrum (the number of photons with energy K) in the direction of the quantum departure;

$$\alpha = \frac{\alpha_1\alpha_2}{\left(\alpha_1^2+\alpha_2^2\right)^{(1/2)}}; \qquad \alpha_1 = \frac{2E_0}{\mu_0}\frac{E_0-K}{K}; \qquad (6)$$

$$\alpha_2 = \frac{111}{Z^{(1/3)}}; \qquad \varepsilon = \frac{K}{E_0}.$$

Integrating with θ_0, one can get a spectrum whose form is described by the function of G with an accuracy of 10%. The satisfactory ratio of experimental data to the theoretical, calculated by Schiff's formulas, allows, in many practical cases, using betatron, with theoretical calculated spectrum.

One of the methods for calculating such formulas is the GEANT4 software package.

It includes a full range of functions:

- Tracking the particle trajectory;
- The geometry of the experiment;
- Physical models of interaction;
- Simulation of collision of particles with particles of target material.

The GEANT4 software code has been designed and built to apply well-known physical interaction models to evaluate the results of experiments and complex geometry of the experiment, as well as for easy adaptation for optimal use in various experimental techniques. This code uses a software development model and is implemented using the C ++ programming language. In our case, was used the program code "Egamma GEANT4" to model the experiment, which is freely available.

IV. BETATRON CALIBRATION

At the beginning of the experiment, the calibration of clinical RTF27012 dosimeters carried out, which included in kit, ionization ball cameras. From this set also the source of beta particles is used ^{90}Sr – ^{90}Y ($T_{1/2}$ = 29,12 y.). The activity of the source at the time of its release reached 5 μCi. By recalculating the activity of the source by the formula

$$A(t) = A_0 e^{-\lambda t} \tag{7}$$

It was found that at the time of calibration of devices, the activity of the source of β - particles is 2.08 μCi or 3.8 R/min. In turn, dosimetry with a clinical dosimeter RTF27012 for different time intervals showed that the dosimeter works with a 9% error. This value does not significantly change the data obtained during the calibration [10, 11].

Time to set the dose was 15 minutes. The energy varied from 10 to 24 MeV. The obtained data from the passage chamber with a gradual increase and decrease in the energy of the beam differs by an error of 6%, which does not have a significant value for calibration. The data at E = 25 MeV correspond to the passport data of the accelerator. Taking into account mistakes, a table of correlation ratios of the passage camera, and absolute camera, to the indications of the clinical dosimeter was constructed. The obtained data facilitate the operation of betatron operators in the problems of irradiation of substances with a given dose.

CONCLUSION

Radiobiological studies, treatment of malignant tumors, acceleration of chemical processes, study of radiation defects, metal defectoscopy are one of the main tasks that require the use of brake radiation beams. In this regard, the primary task for accelerators of charged particles is to determine the dose of radiation.

In this paper one of the methods for measuring the exposure dose from the accelerator of charged particles for betatron B-25 is described. To determine the exposure dose, an absolute ionization chamber, a passage chamber, and two ball cameras of the clinical dosimeter RTF27012 were used. The ball cameras were independently calibrated with standard sources of beta particles and gamma quanta (a set of clinical dosimeter). The resulting calibration tables make it possible to predict irradiation of different types of targets in research on the effects of radiation for the needs of nuclear physics, biology and medicine.

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