MONTE-CARLO METHOD SIMULATION OF THE BREMSSTRAHLUNG MIRROR REFLECTION EXPERIMENT. PRELIMINARY RESULTS

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ABSTRACT
The preliminary results for Monte-Carlo simulation of the experiment on total external reflection (TER) of hard ($E_x >> 100$ keV) γ-radiation are presented. These results allow us to hope for successful performance of the experiment.

In 1923 Compton discovered the effect of total external X-ray reflection (TER) [1]. This well-known effect is observed when soft X-ray radiation ($E_x \leq 10$ keV) is incident on the smooth boundary between two media provided the incidence angle is less than the critical angle α_c:

$$\alpha_c = (eh/E_x)\cdot(ZN_a\rho/\pi Am)^{1/2} \quad (1)$$

here, e and m are the electron charge and mass, respectively, Z, A and ρ - atomic number, atomic mass and density of surface substances, respectively, E_x - energy of radiation, h – Planck's constant and N_a – Avogadro's number.

The TER is used in many X-ray optical systems such as Kumakhov's optics [2]. At present, the focusing of high-energy X-radiation and γ-radiation is an important direction of research. The creation of an optical system for high-energy ($E_x > 100$ keV) radiation will open new frontiers in such areas as astronomy and X-ray lithography. Here, however, the researchers are to face many experimental challenges due to small wavelength of rays and, thus, their high penetrating ability.

One of the possibilities to guide hard X-rays is through the TER effect. So far, we are aware of only one work that was carried out in this area [3], where authors reported the TER angle of $2.64\cdot10^{-4}$ radian for 122 keV ^{57}Co γ-quanta scattered from a glass surface. Apparently, the studies of TER for $E_x >> 100$ keV require very long flight basis for the quanta. Such flight channel (length ~ 300 m) together with a powerful source of γ-radiation (bremsstrahlung from microtron MT-22C) is available in Nuclear Physics Laboratory (NPL) of Samarkand State University. The experimental data obtained at NPL so far is summarized in [4].

In this paper, we report the preliminary results on the simulation of TER experiment for hard γ-radiation by Monte-Carlo method.

The experimental setup is shown on fig.1 (detailed) and 2 (simplified). The obtained beam of electrons (E_e = 13 MeV, $I_{beam} \leq 30$ μA, pulse duration τ = 2.5 μs, repetition rate f = 396 Hz is supplied by HFG – high frequency generator, beam cross-section ~ ∅ 5 mm) is transported to the converter T (horizontal tungsten wire ∅ 1 mm) by dipole d and quadruple q magnet lenses. Collimators K1-K4 and magnets M1-M4 are used to reduce the background from non-interacting electrons, secondary charged particles and scattered γ-quanta. The obtained bremsstrahlung radiation (BR) is incident on the slit collimator G (two lead-doped glass plates polished by 14th grade of accuracy, dimensions 30×270×800 mm, adjustable slit width 0-1000 μ). After the G (vertical aperture of the beam $\delta \geq 15$ μradian), the formed bremsstrahlung beam impinges on the surface of the reflector R (the same type of glass as in G, dimensions 30×300×500 mm). The angle of inclination is adjusted in the range α = 0 - 1,5 mradian with the increment $\Delta\alpha \geq 15$ μradian). The lower part of the beam (θ < 0) is absorbed in the front plane of the reflector while the upper part is reflected if θ = 0 ÷ α or does not interact if θ > α. At 300 m, γ-quanta are registered by the set of three detectors – D_S (spectrometric detector, NaI(Tl) 63×63 mm), D_C (fast counting detector, POPOP 5×50×100 mm), and D_m (beam monitor, NaI(Tl) 63×63 mm). The operation of the microtron and the shift of detectors in vertical direction together with the acquisition of the data are done remotely from rooms VI and V, respectively.

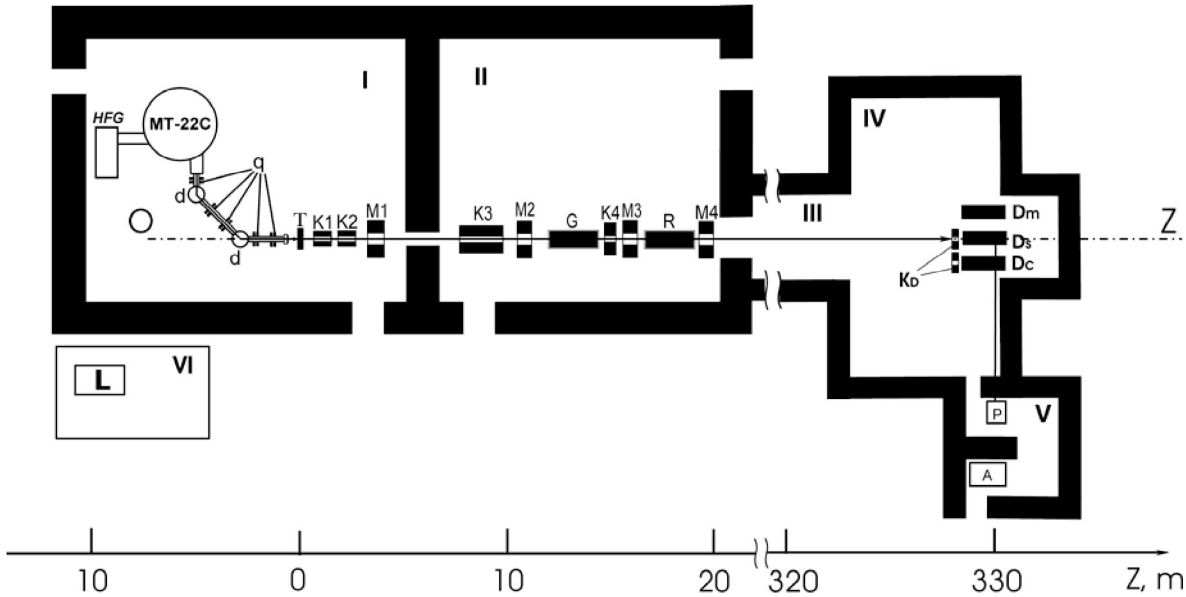

Fig.1. The experimental setup for studies of TER for high energy γ-radiation (see explanation in the text).

The detection angle θ can vary in the range 0 ± 30 mrad. D_S and D_C detectors have horizontal slit collimators K_D with the slit width $\Delta X_K = 1$ mm. These detectors can be moved in the vertical direction in the range h_D = -200÷1300 mm with the step Δh_D = 1 mm. Depending on the beam current, several hundreds of γ-quanta are passed through the detectors in one acceleration cycle (τ = 2,5 μs).

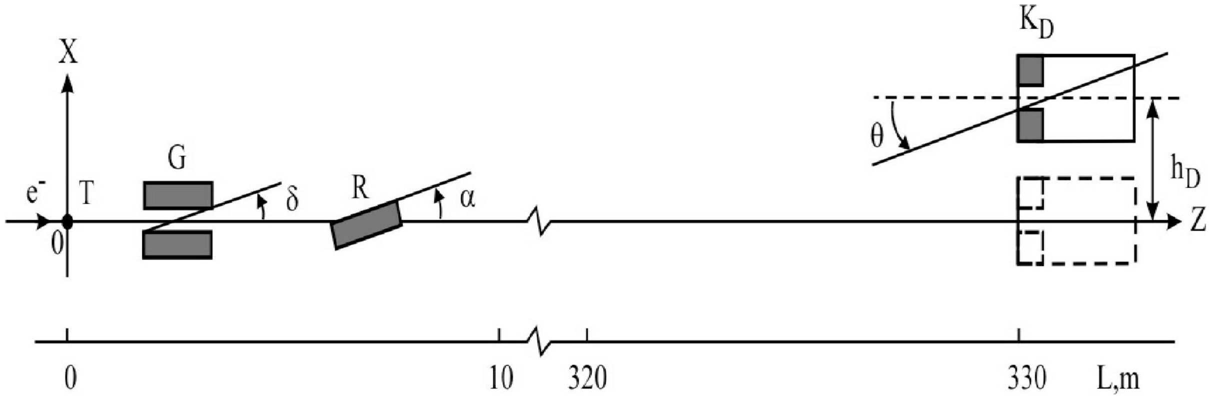

Fig. 2. The simplified scheme of experimental setup (see explanation in the text).

The simulation model was developed using Mathematica ©® Software. The energy distribution of γ-quanta after the target is taken as the Schiff's spectrum [5]. In the target plane, the quanta are described by normal distribution with standard deviation of 1.5 mm. The quantum is considered to disappear if its trajectory crosses any part of the setup except the reflector. Upon the incidence of the quantum on the surface of reflector, the angle of incidence is calculated. If this angle is smaller than α_c, the quantum is considered to reflect from the surface and its further trajectory is simulated. In the case when the angle of incidence is bigger than α_c, the quantum is considered to disappear. The detection efficiency is taken to be 100%. The front part of the reflector R is vertically aligned with the lower plate of the collimator G. The distance between the exit slit of G and the front part of R is 30 cm.

In fig.3, the simulated spectra of bremsstrahlung radiation in the absence of the reflector are shown for slit width of 50 μ and for the case of vacuum and various positions of the detector along OZ axis. As it is seen from the figure, the program correctly describes the suppression of the spectrum upon increasing collimator-detector distance.

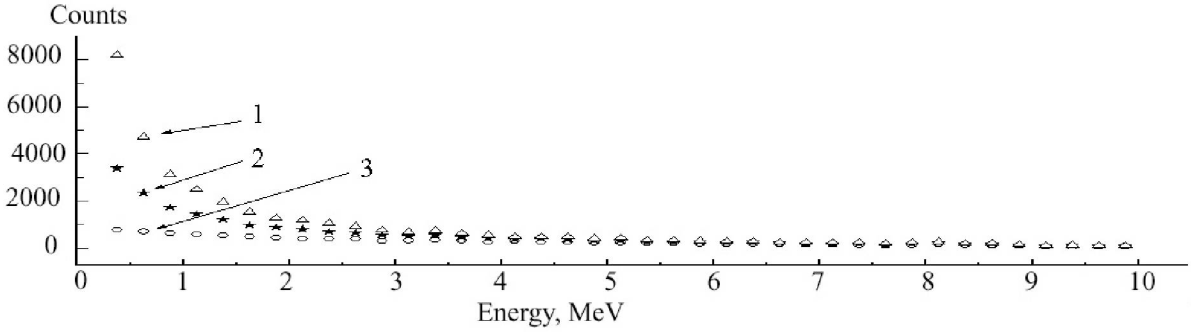

Fig. 3. The simulated spectra of BR without the reflector at δ = 62 μradian (1 – in vacuum, 2 – at L = 120 m, 3 – at L = 330 m).

The simulation results obtained after the introduction of the reflector R are shown on fig.4. Here, once again, the simulation correctly describes the suppression of the spectrum when placing the detector farther from the reflector (spectra 4 and 5). The change in the inclination angle of the reflector does not significantly influence the spectra. There is, however, a slight decrease in the low-energy part of the spectrum when increasing the angle α (spectra 5 and 6).

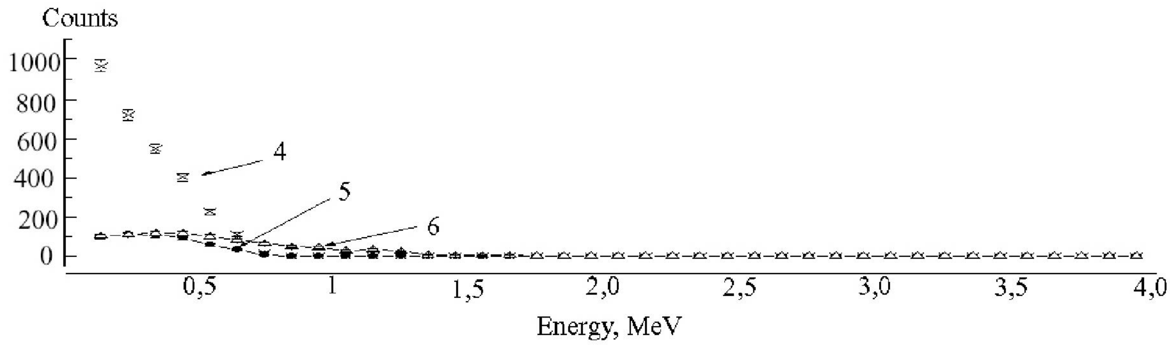

Fig.4. The simulated spectra in the presence of the reflector R at δ = 62 μradian (4 - α = 40 μradian, L = 120 m; 5 - α = 40 μradian, L = 330 m; 6 - α = 20 μradian, L = 330 m).

In the future, the upgrade of the developed program is planned. The new simulation program will take into account such effects as Compton scattering of radiation on setup's parts and in the air as well as the detector's efficiency (response function) for registering the quanta.

Despite the simplicity of the program, the obtained computer simulation results create promising prerequisites for the successful experiments on the possibility of TER phenomenon for high-energy γ-radiation.

REFERENCES

1. Compton, Phys. Rev., v.20, p.84 (1922); Phil. Mag., v.45, p.1129 (1923)
2. M.A. Kumakhov, NIMB, v.48, p.283 (1990)
3. V.I. Glebov, et al., J. Tech. Phys., v.55(9), p.1785 (1985)
4. G.R. Alimov, et al., NIMB, v.222, p.681 (2004)
5. L.I. Schiff, Phys.Rev., v.83., p.252 (1952)