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MODELING THE CHARACTERISTICS OF e-γ-n PARTICLE FLUXES FORMED BY DOUBLE-LAYER TARGETS ON THE M-30 MICROTRON

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The results of modelling the characteristics (energy spectra, integral values and transverse distributions in the plane of potential sample placement perpendicular to the electron beam axis) of particle fluxes (e, γ, n) formed by double-layer targets (Ta + C, Ta + Al, Ta + Pb) on the M-30 microtron electron accelerator are presented. In carrying out the calculations using the GEANT4 toolkit, the technical characteristics of the M-30 microtron were taken into account. The simulation results make it possible to optimise the process of studying the radiation resistance of structural nuclear materials to particle fluxes (e, γ, n) on the M-30 microtron. This approach can be used to predict the characteristics of particle fluxes (e, γ, n) on different types of electron accelerators and to optimise irradiation schemes for experimental samples.

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INTRODUCTION

Electron accelerators (linear accelerators and microtrons) [5, 6] are widely used in studies of the radiation resistance of structural nuclear materials to mixed particle fluxes (electrons (e), photons (γ) and neutrons (n)) and in investigations of the influence of radiation fields on their properties [1–4].

Their use makes it possible to obtain mixed beams containing particles (e, γ, n) with a continuous energy spectrum and different particle ratios. For example, this enables the radiation emitted by nuclear reactors to be simulated when studying the radiation resistance of structural nuclear materials to different types of particles (e, γ, n) [2, 3].

To form beams of mixed particle fluxes on electron accelerators with predetermined ratios of e, γ and n that interact with the experimental samples under study, double-layer targets are used. These targets consist of materials with different nuclear-physical characteristics, such as tantalum (Ta), reactor graphite (C), aluminium (Al) and lead (Pb) [7].

When studying the radiation resistance of structural nuclear materials to mixed particle fluxes (e, γ, n) and examining their effect on material properties, reliable and complete information is required on their spectral characteristics (energy spectra), integral characteristics and transverse distributions in the plane of potential placement of the experimental samples.

It should be noted that the characteristics of mixed particle beams (e, γ, n) interacting with the materials under study are substantially affected by the technical characteristics of the electron accelerators, namely the design features of the electron beam extraction units, which differ considerably for different types of accelerators [8, 9], as well as by the geometric factors of the irradiation schemes.

This paper presents the results of Monte Carlo modelling of the characteristics (energy spectra, their integral values and transverse distributions in the plane of potential placement of the samples under study) of the component parts (e, γ, n) of beams formed by double-layer targets (Ta + C, Ta + Al, Ta + Pb) on the electron accelerator of the Institute of Electron Physics of the National Academy of Sciences of Ukraine, the M-30 microtron, taking into account its technical parameters.

1. MATERIALS AND METHODS

The nuclear Monte Carlo code GEANT4 [10-12] was used to model the characteristics (energy spectra, their integral values and transverse distributions in the plane of potential placement of experimental samples) of particle fluxes (e, γ and n) in beams generated on the M-30 microtron electron accelerator. The use of the GEANT4 toolkit made it possible to calculate the characteristics of the component parts (e, γ, n) of the beam in the closest possible approximation to the real conditions of their formation, taking into account the design features of the M-30 microtron electron extraction unit and the irradiation schemes for experimental samples [13, 14].

Calculations of the characteristics of particle fluxes (e, γ and n) in the beam generated by tantalum (Ta) and by three combinations of double-layer converter targets with the component materials Ta + C, Ta + Al and Ta + Pb were carried out for an initial electron energy of 17.5 MeV. The scheme for which the calculations were performed is shown in Fig. 1: 1 – electron extraction unit; 2 – titanium window of the extraction unit (shape: ellipse; dimensions 22x6 mm; thickness 50 μm); 3 – Ta layer (plate dimensions 40x50 mm; thickness 1 mm); 3 – C, Al or Pb layer (discs with a diameter of 20 mm and a height of 180 mm); 5 – experimental sample.

During the simulations, all particles (e, γ, n) reaching the potential plane of placement of the experimental samples (1000x1000 mm), perpendicular to the axis of the initial electron beam, and the samples themselves (diameter 11.2 mm) were recorded. The calculated energy spectra of particles (e, γ, n) and their integral values were normalised to one initial electron. Based on the simulation results, probability maps of the transverse distribution of photons and residual electrons in the plane of placement of the experimental samples were created.

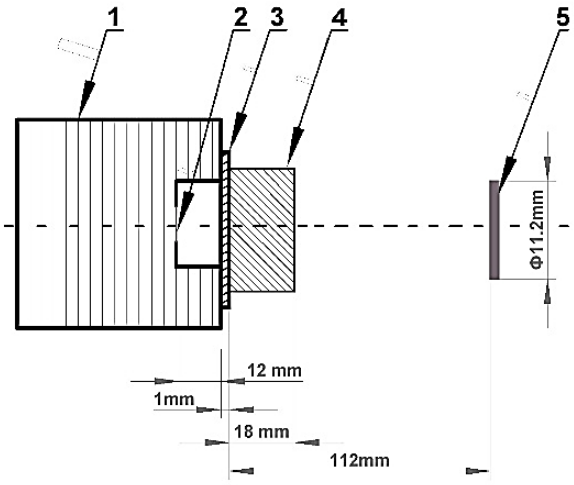


Fig. 1. Irradiation scheme for experimental samples

2. RESULTS

As a result of the simulations, the characteristics of the beam components (e, γ and n) generated by Ta and by double-layer targets (Ta + C, Ta + Al and Ta + Pb) were calculated in the plane of potential placement of the samples under study and on the samples themselves.

As an example, the panel plot in Fig. 2 presents the energy spectra of particles: a) electrons, b) bremsstrahlung photons, and c) neutrons in the plane of placement of the experimental samples.

The obtained energy spectra of particles in the plane of potential placement of the samples under study and on the samples themselves were used to determine their integral values (Tables 1 and 2, respectively).

Table 1

Integral values of electron, bremsstrahlung photon and neutron fluxes in the plane of placement of the samples under study

Particles	Ta	Ta + C	Ta + Al	Ta + Pb
e	0.945	0.761	0.4415	0.019
γ	1.304	1.738	2.04505	1.029
n	2.89E-5	2.19E-5	2.92E-5	4.18E-4

Table 2

Integral values of electron, bremsstrahlung photon and neutron fluxes that interacted with the samples under study

Particles	Ta	Ta + C	Ta + Al	Ta + Pb
e	7.75E-3	4.92E-3	2.08E-3	1,78E-4
γ	4.5E-2	4.04E-2	3.95E-2	3.11E-2

It should be noted that the calculation statistics for an initial flux of 10E8 electrons did not allow the values for photoneutrons on the samples themselves to be determined.

The obtained results reproduce the general patterns of bremsstrahlung photon (e→γ) and neutron (e→n; e→γ→n) generation by electrons in the indicated materials (Ta, Ta + C, Ta + Al and Ta + Pb), as well as the ranges of particles (e, γ, n) in them [7, 15, 16].

Based on the simulation results, profiles were obtained for electron fluxes (Fig. 3) and bremsstrahlung photons (Fig. 4) in a cross-section of the 1000x1000 mm plane at the potential location of the experimental samples formed by Ta and by the double-layer targets Ta + C, Ta + Al and Ta + Pb.

The panel plot in Fig. 5 presents the transverse distributions of a) electrons and b) photons in the plane of placement of the samples under study for Ta and the double-layer targets Ta + C, Ta + Al and Ta + Pb.

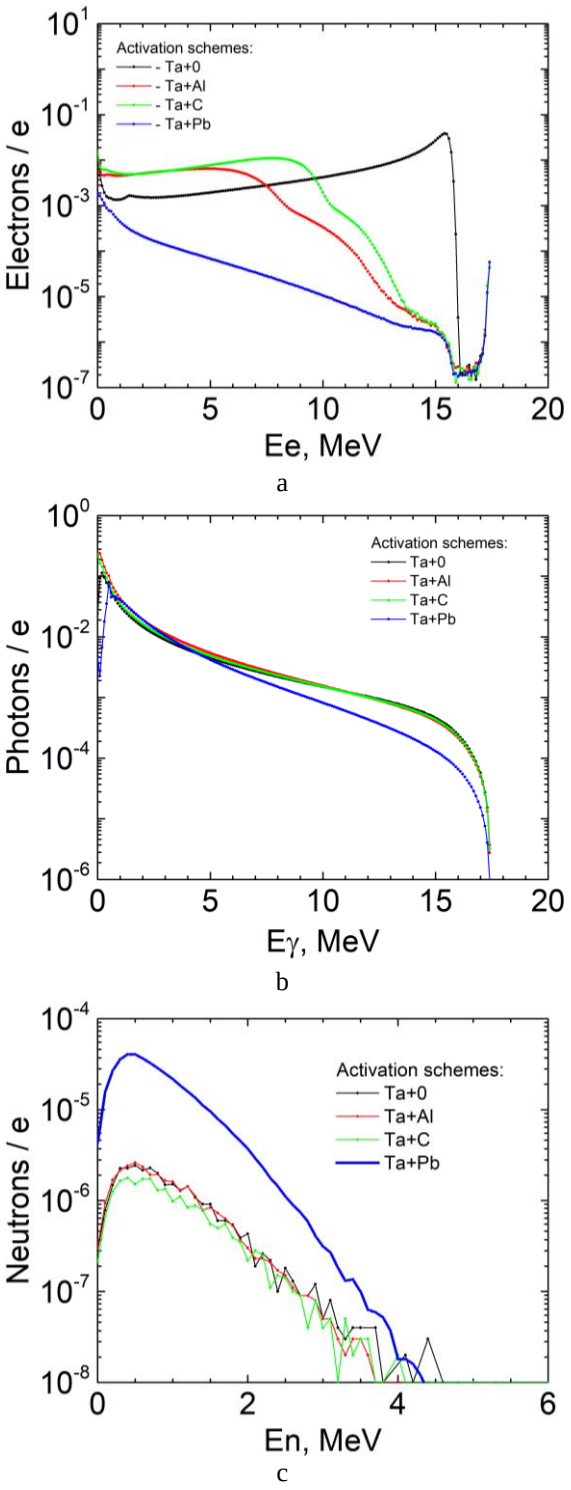


Fig. 2. Energy spectra of particles in the plane of potential placement of the samples under study

The total number of electrons reaching the plane of placement of the sample under study for the above target combinations is 7.77E5, 5.22E5, 2.45E5 and 7.04E3, respectively. The fractions reaching the sample under

study are 19.8, 18.4, 16.6, and 15.4% of their total number. Similarly, the total number of photons reaching the plane of placement of the sample under study for the above target combinations is 1.89E6, 1.99E6, 2.09E6 and 8.26E5, respectively. The fractions reaching the sample under study are 55.82, 48.89, 45.92, and 41.42% of their total number.

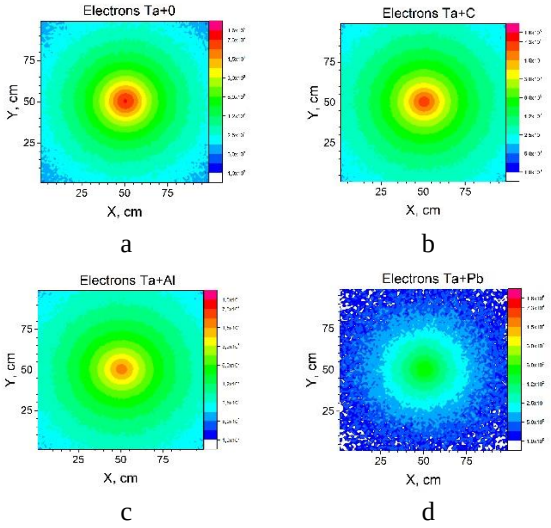


Fig. 3. Profiles of electron fluxes in the plane of potential placement of the samples under study

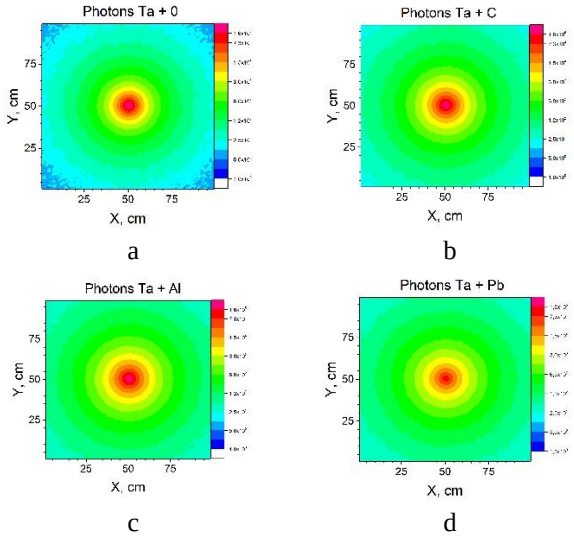


Fig. 4. Profiles of bremsstrahlung photons in the plane of potential placement of the samples under study

The simulation results indicate that the use of the indicated target combinations makes it possible to obtain beams with different particle ratios. In addition, the obtained results are necessary for optimising the dimensions of the samples under study within their plane of placement.

Furthermore, the obtained data are necessary for predicting personnel shielding [17] during experimental work on the M-30 microtron electron accelerator.

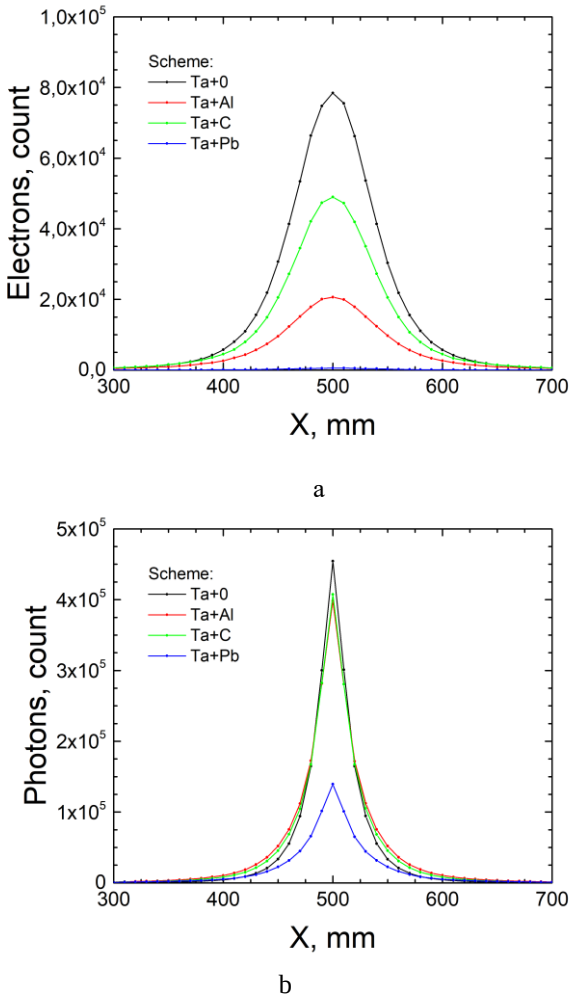


Fig. 5. Transverse distributions of electrons and bremsstrahlung photons in the plane of placement of the samples under study

CONCLUSIONS

The obtained results are necessary for forming mixed particle fluxes (e, γ, n) using double-layer targets on the M-30 microtron with predetermined beam parameters when conducting experimental studies of the radiation resistance of structural nuclear materials and examining the influence of radiation fields on their characteristics.

This approach can be used to develop material irradiation schemes on different types of electron accelerators and to predict the characteristics of beams of mixed particle fluxes.

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МОДЕЛЮВАННЯ ХАРАКТЕРИСТИК ПОТОКІВ e, γ, n-ЧАСТИНОК, СФОРМОВАНИХ ДВОШАРОВИМИ МІШЕНЯМИ НА МІКРОТРОНІ М-30

І.В. Пилипчинець, Є.В. Олейніков, В.В. Пискач, П.В. Яворський, Г.М. Гомонай, О.О. Парлаг

Представлено результати моделювання характеристик (енергетичні спектри, інтегральні значення, поперечні розподіли у площині потенційного встановлення зразків перпендикулярній осі пучка електронів) потоків частинок (e, γ, n), сформованих двошаровими мішенями (Ta + C, Ta + Al, Ta + Pb) на електронному прискорювачі – мікротроні М-30. При проведенні розрахунків за допомогою інструменту GEANT4 враховувалися технічні характеристики мікротрона М-30. Результати моделювань дозволяють оптимізувати процес дослідження радіаційної стійкості конструкційних ядерних матеріалів до потоків частинок (e, γ, n) на мікротроні М-30. Такий підхід може бути використаний для прогнозування характеристик потоків частинок (e, γ, n) на різних типах електронних прискорювачів та оптимізації схем опромінення експериментальних зразків.