MODELLING THE CHARACTERISTICS OF e, γ, n PARTICLE FLUXES FORMED BY DOUBLE-LAYER TARGETS ON THE M-30 MICROTRON FOR NUCLEAR APPLICATIONS

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The paper presents the results of modelling the characteristics of particle fluxes (e, γ, n) formed by double-layer targets (Ta + C, Ta + Al, Ta + Pb) on the M-30 microtron electron accelerator, including energy spectra, integral values, and transverse distributions in the plane of potential sample placement perpendicular to the electron beam axis. Calculations performed using the GEANT4 toolkit took into account the technical characteristics of the M-30 microtron. The modelling results enable optimisation of radiation-resistance research on structural nuclear materials exposed to particle fluxes (e, γ, n) on the M-30 microtron. This approach may also 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) are widely used in the study of radiation phenomena in materials and of the effects of electron (e), photon (γ), and neutron (n) radiation on their properties [1–6]. Their use makes it possible to obtain mixed e, γ, n beams with continuous energy spectra and different particle ratios. For example, this allows one to simulate the radiation fields of nuclear reactors when studying the radiation resistance of structural materials to different types of particles (e, γ, n) [2, 3].

To form mixed-particle beams on electron accelerators with predetermined e, γ, n ratios that interact with the experimental samples under study, double-layer targets are used. These targets are composed of materials with differing nuclear-physical characteristics, such as tantalum (Ta), reactor graphite (C), aluminium (Al), and lead (Pb) [7]. When investigating the influence of mixed particle beams (e, γ, n) on the properties of the materials under study, as complete and reliable information as possible 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 electron accelerators, namely the design features of electron beam extraction units, which differ considerably for different accelerator types [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 of the component fluxes (energy spectra, their integral values, and transverse distributions in the plane of potential sample placement) of the beam constituents (e, γ, n) formed by double-layer targets (Ta + C, Ta + Al, Ta + Pb) on the electron accelerator of the Institute of Electron Physics of the NAS of Ukraine, namely the M-30 microtron, taking its technical characteristics into account.

1. MATERIALS AND METHODS

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

Calculations of the characteristics of particle fluxes (e, γ, and n) in the beam generated by tantalum and by three combinations of double-layer converter targets with 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 beam extraction unit; (2) titanium window of the extraction unit (shape: ellipse, dimensions 22 x 6 mm, thickness 50 μm); (3) Ta layer (plate dimensions 40 x 50 mm, thickness 1 mm); (4) C, Al, or Pb layer (discs 20 mm in diameter and 180 mm in height), (5) experimental sample.

During the simulations, all particles (e, γ, n) reaching the potential plane of placement of the experimental samples (1000 x 1000 mm), perpendicular to the axis of the primary electron beam, as well as the samples themselves (diameter 11.2 mm), were recorded. The calculated energy spectra of the particles (e, γ, n) and their integral values were normalised to one primary electron. On the basis of the modelling results, probability maps of the transverse distributions of photons and residual electrons in the planes where the experimental samples were placed were produced.

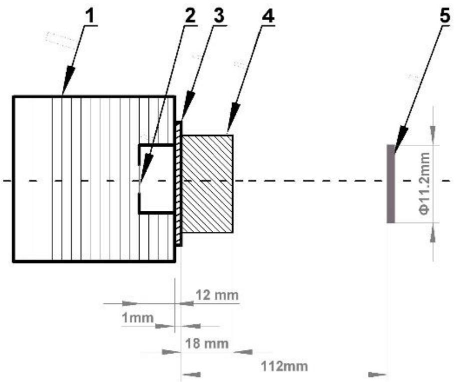


Fig. 1. Irradiation scheme for experimental samples

2. RESULTS

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

For illustration, Fig. 2 presents the energy spectra of particles in the sample-placement plane: (a) electrons, (b) bremsstrahlung photons, and (c) neutrons.

The obtained particle energy spectra in the plane of the potential placement of the samples under study and on the samples themselves were used to determine their integral values (Tables 1 and 2, respectively). It should be noted that the calculation statistics for an initial flux of 10E8 electrons did not make it possible to determine the values for photoneutrons on the samples themselves.

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

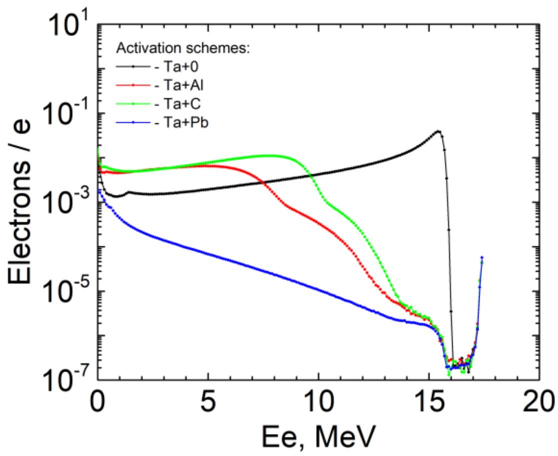
Integral values of electron, bremsstrahlung photon, and neutron fluxes that interacted with the samples under study

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

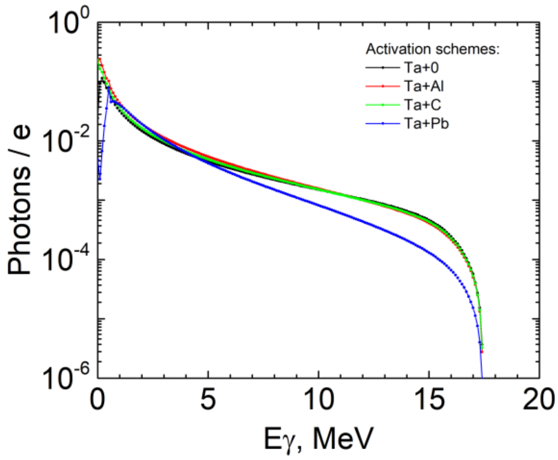
The obtained results reproduce the general regularities of bremsstrahlung photon (e → γ) and neutron (e → n; e → γ → n) generation by electrons in the specified materials (Ta, Ta + C, Ta + Al, Ta + Pb), as well as the transport of particles (e, γ, n) within them [7, 15, 16].

Fig. 3 presents the transverse distributions of (a) electrons and (b) photons in the plane of placement of the samples under study for Ta and for the double-layer targets Ta + C, Ta + Al, and Ta + Pb.

The total number of electrons reaching the sample-placement plane for the above target combinations is 7.77E5, 5.22E5, 2.45E5, and 7.04E3, respectively. Of their total number, 19.8, 18.4, 16.6, and 15.4% reach the sample, respectively. Similarly, the total number of photons reaching the sample-placement plane for the above target combinations is 1.89E6, 1.99E6, 2.09E6, and 8.26E5, respectively. Of their total number, 55.82, 48.89, 45.92, and 41.42% reach the sample, respectively. The modelling results indicate that using these target combinations enables beams with different particle ratios. In addition, the results obtained are required to optimise the dimensions of the samples under study in the plane of placement.



a



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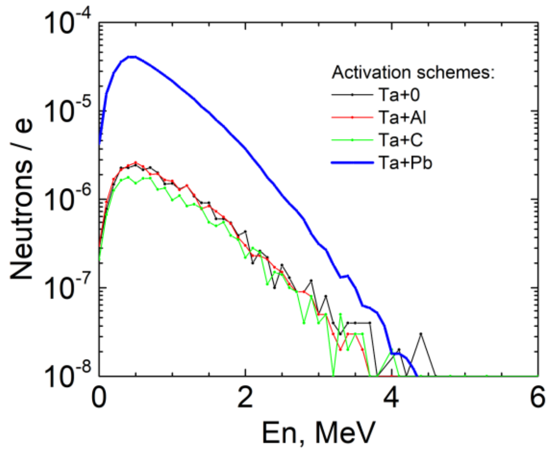
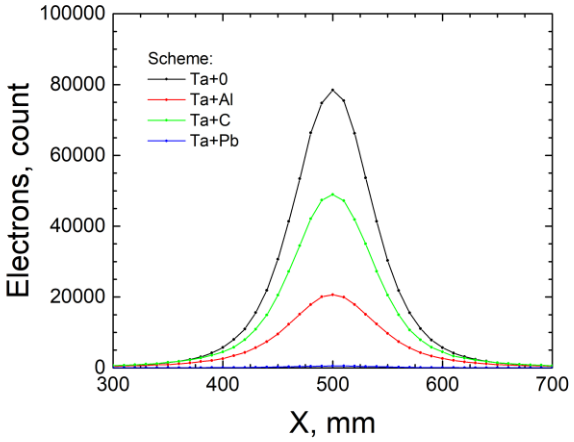


c

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



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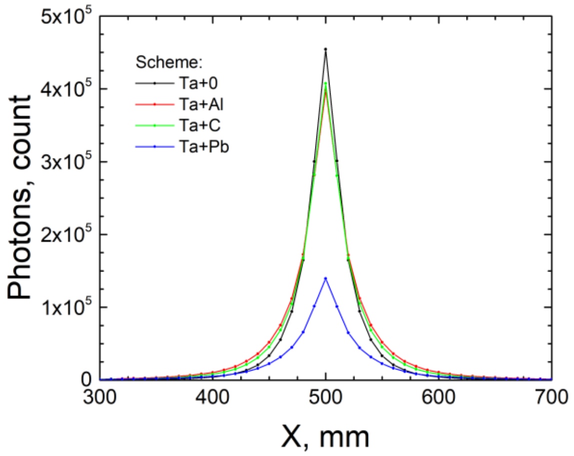

b

Fig. 3. Transverse distributions of electrons and bremsstrahlung photons in the plane of placement of the samples under study

CONCLUSIONS

The obtained results are required to form mixed particle fluxes (e, γ, n) with predetermined beam parameters using double-layer targets on the M-30 microtron when conducting experimental studies of radiation phenomena in materials and investigating the influence of radiation fields on their characteristics.

This approach may be used to develop irradiation schemes for materials across different types of electron accelerators and to predict the characteristics of mixed-particle beams.

The present work was carried out within the framework of the topic “Modelling the characteristics of mixed gamma-neutron fields for studying the parameters of radiation resistance of structural nuclear materials”, state registration No. 0126U002294.

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

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 інструмента GEANT4 враховувалися технічні характеристики мікротрона М-30. Результати моделювання дозволяють оптимізувати процес дослідження радіаційної стійкості конструктивних 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.