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FORMATION OF MIXED X,n-RADIATION FIELD AT AN ELECTRON ACCELERATOR

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For conducting photonuclear programs with the use of a high-intensity photon source the latter is ordinary obtained by transformation of an electron beam into X-ray radiation. Such a process is performed using an intermediate target-converter maid from a high-Z material. The (γ,n) reactions take place in the converter under the action of high-energy bremsstrahlung photons. As a result, a quasi-isotropic neutron flux escapes the converter jointly with the photon beam directed forward. The parameters of the both types of radiation, as well as the ratio of their intensities play the important role depending on a program under way. In work, the spatial radiant characteristics of the mixed X,n-radiation generated with the electron beam in the converter located together with an isotopic target in the middle of a neutron moderator in the electron energy range 40…95 MeV and various size of the moderator are studied by computer simulations with the use of a GEANT4 transport code.

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INTRODUCTION

Pulse neuron sources on the basis of electron accelerator provide the possibility to measure the cross section of the neutron-capture reactions at neutron energy in the range from thermal one until tens MeV using a time-of-flight technique. The most widespread way to obtain such radiation field is the neutron generation by (γ,sn) reaction in a converter of the bremsstrahlung (X-ray) radiation exposed to an electron beam. A specially developed moderator is commonly applied to increase the yield of the low-energy neutrons (see e.g. [1]).

A promise area of application of the mixed X,n-radiation with the thermalized spectrum of the neutron component is photonuclear technology of isotope production, in particular, of medical assignment [2]. In work, the possibility to control the radiation flux density and neutron spectrum at an isotopic target by moderator size and electron beam energy is studied by computer simulation on the basis of a GEANT4 code [3].

1. SIMULATION CONDITIONS

1.1. In the research of processes of the neutron generation and moderation, a device outlined in Fig. 1 was considered as the basis. It comprises a branch tube from aluminum 1, which axes coincides with the axes of the electron beam. At the tube centre, the bremsstrahlung converter K and isotopic target M are positioned. The converter consists of four tantalum plates each by 1mm in thickness separated with the same gaps for cooling. For measuring the isotope yield under joint acting of X-rays and thermalized neutrons, the tube with the converter and target were located in the middle of the moderator. Detail description of the latter is given in the work. A channel for placement of neutron activation detectors was preliminary maid in the moderator body.

1.2. At the beginning of the research, the data on the cross section of the $^{181}Ta(\gamma,sn)^{181-s}Ta$ reactions that provide the photoneutron generation in the Ta converter were checked. Their excitation functions calculated by a TALYS-1.95 package [4] and used in simulations were compared with those obtained experimentally (Fig. 2).

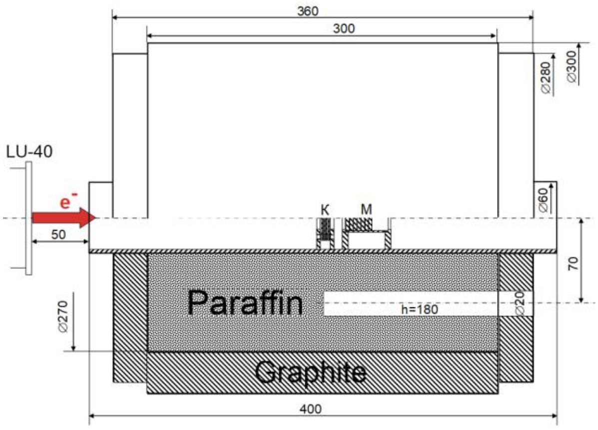


Fig. 1. Target station with the neutron moderator

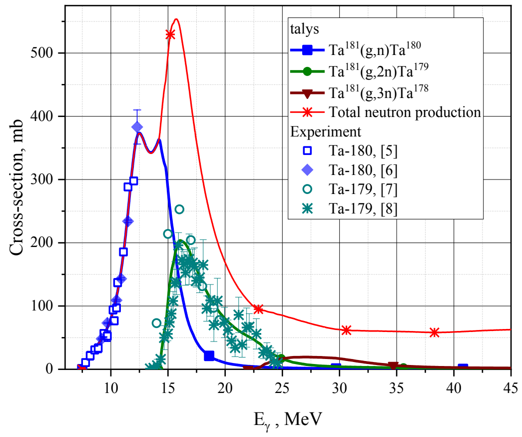


Fig. 2. Cross section of the $Ta^{181}(\gamma,sn)Ta^{181-s}$ reactions (TALYS + experiment)

For comparison the cross sections of the neutron photogeneration in tantalum computed by TALYS and GEANT4 codes respectively are represented in Fig. 3. It is seen that in the area of giant dipole resonance (GDR) both presentations of the excitation function are in good agreement. For calculation of the neutron yield from the converter into the front and back half-space relative to the electron beam, and also energy distribution of the neutrons, the circuit given in Fig. 4, was used.

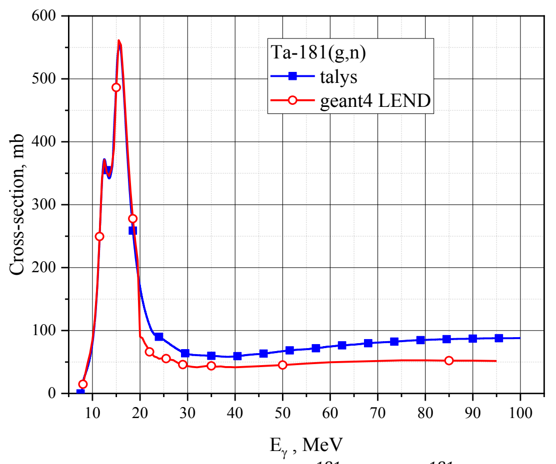


Fig. 3. Cross section of the $Ta^{181}(\gamma,sn)Ta^{181-s}$ reaction (TALYS + GEANT4 LEND)

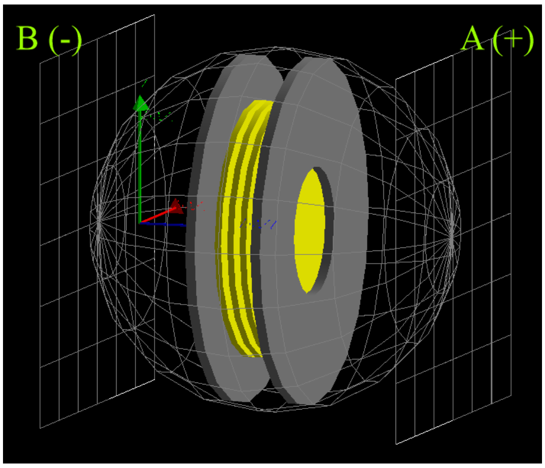


Fig. 4. Geometry of calculation of the photoneutron yield from the converter

2. RESULTS

2.1. In Figs. 5, 6 the results of modeling of the neutron reduced yield, spectrum and output angle from the converter at an electron beam energy of 40 MeV are given.

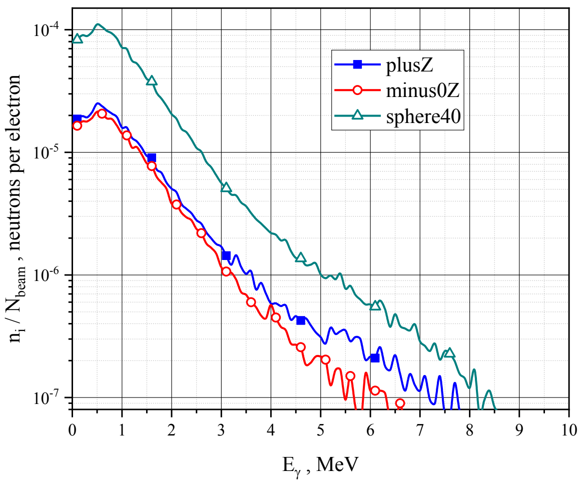


Fig. 5. Energy distribution of neutrons:
plusZ – towards Z axis (the plain A(+));
minus0Z – against Z axis (the plain B(–));
sphere40 – the total yield into sphere 4π

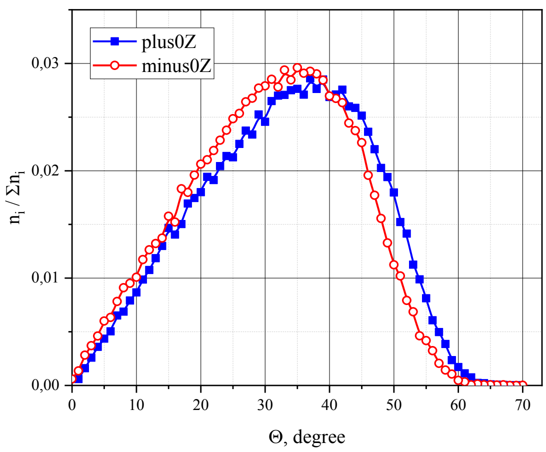


Fig. 6. Neutron distribution vs output angle from the converter

The results of simulation of the photoneutron spectra in the electron energy range that provides a LU-40m accelerator of NSC KIPT [9] are presented in Fig. 7 and Table 1. For speedup, the calculations were carried out with step 0.1 MeV. It is evident that the major part of neutrons has the energy less than 2.5 MeV.

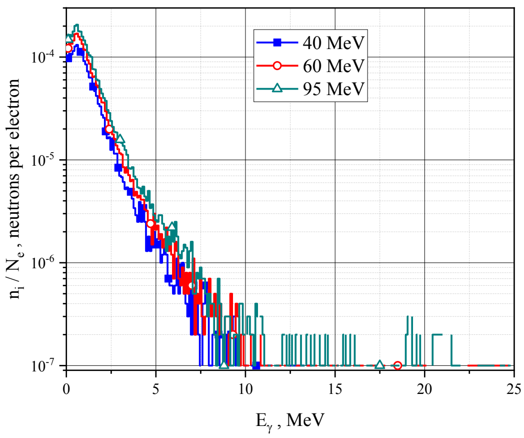


Fig. 7. Photoneutron spectra at various electron beam energy

Table 1

Asymmetry of the neutron escape from the converter when the simulation geometry given in Fig. 4

E, MeV	*nA(+)/nB(–)**
40	1.170
60	1.167
95	1.168

**nA(+)/nB(–)* – is the asymmetry coefficient (the ratio of the neutron yield into the A plain to their yield into the B plain).

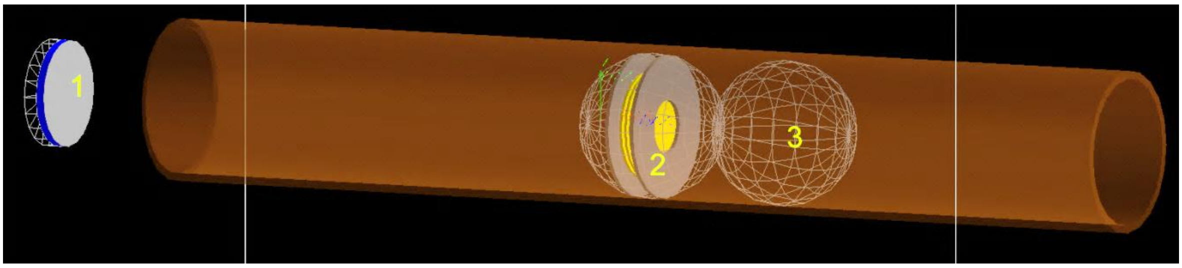
2.2. For the study of the moderator size impact on the spectrum and flux of the photoneutrons at the target, the devices were used, which layout is given in Fig. 8. In particular a moderator measuring 20×20, 30×30, and 40×40 cm was considered. The results of simulations are presented in Tabs. 2–6 and in Figs. 9–11. The obtained characteristics of the X-ray flux on the target as well as the data on the relative yield of the photons and photoneutrons are displayed in Figs. 12–14.

Table 2

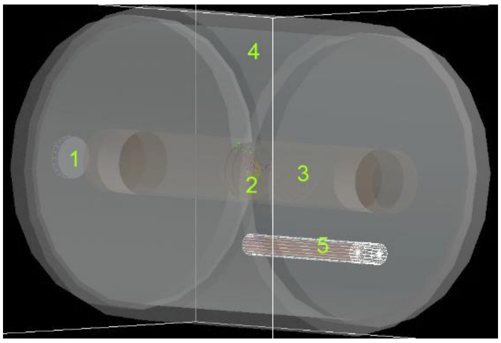
Characteristics of the total neutron yield from the converter at various electron beam energy

Ee, MeV	Simulated tracks	Neutron yield	Neutron per electron (n/e)	nS/e/cm^2 *	nS/100 μA
40	1.67E+08	250588	1.50E-03	1.49E-05	9.27E+09
60	1.64E+08	309814	1.89E-03	1.87E-05	1.17E+10
95	1.58E+08	346973	2.20E-03	2.17E-05	1.36E+10

*Mean density of the neutron flux on a sphere by 2.835 cm in radius, nS – reduced total neutron yield



a



b

Fig. 8. Geometry of simulation of the neutron flux in region of the isotopic target: a – without moderator (1 – accelerator's exit window; 2 – tantalum converter with the virtual spherical neutron counter 3); b – with moderator (4 – paraffin-graphite moderator; 5 – channel for the neutron activation detectors (the virtual spherical neutron counter is placed in the depth of the channel))

Table 3

Characteristics of the neutron flux in the target region (without converter)

E_e, MeV	N_{beam}	n converter	n target	target/conv	n_{targ}/e	n_{targ}/e/cm^2
40	1.14×10^{8}	164301	17923	0.109	1.57×10^{-4}	1.68×10^{-6}

Table 4

Characteristics of the neutron flux in the target region (with converter)

E_e, MeV	N_{beam}	n converter	n target	target/conv	n_{targ}/e	n_{targ}/e/cm^2
∅20×20 cm						
40	1.31×10^{8}	189928	41403	0.218	3.16×10^{-4}	3.38×10^{-6}
∅30×30 cm						
40	2.3×10^{8}	334008	76540	0.229	3.33×10^{-4}	3.56×10^{-6}
∅40×40 cm						
40	1.27×10^{8}	184742	42682	0.231	3.36×10^{-4}	3.6×10^{-6}

Table 5

Characteristics of the neutron flux in the activation detectors region

E_e, MeV	N_{beam}	n converter	n detect	detect/conv	n_{det}/e	n_{det}/e/cm^2	n_{det}/s/cm^2 for 100 μA
∅20×20 cm							
40	1.31×10^{8}	189928	1955	0.01	1.49×10^{-5}	2.11×10^{-6}	1.32×10^{9}
∅30×30 cm							
40	2.3×10^{8}	334008	4118	0.012	1.79×10^{-5}	2.54×10^{-6}	1.58×10^{9}
∅40×40 cm							
40	1.27×10^{8}	184742	2341	0.013	1.84×10^{-5}	2.61×10^{-6}	1.63×10^{9}

Table 6

Yield of neutrons with energy less than 100 keV (without moderator and at its different size)

E_e, MeV	N_{beam}	n (E_n < 0.1 MeV)	n0.1/N_{beam}
No moderator			
40	1.14×10^{8}	1308	8.72×10^{-6}
∅20×20 cm			
40	1.31×10^{8}	19692	1.50×10^{-4}
∅30×30 cm			
40	2.3×10^{8}	38259	1.66×10^{-4}
∅40×40 cm			
40	1.27×10^{8}	21720	1.71×10^{-4}

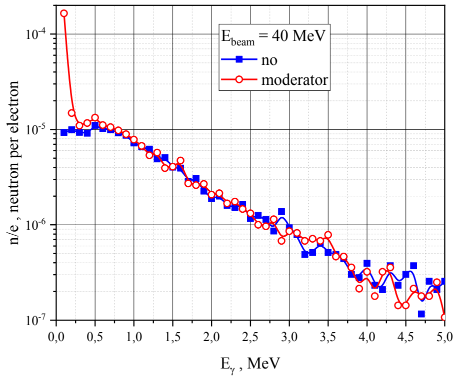


Fig. 9. Photoneutron spectrum in the target region depending on presence of the 30×30 cm moderator (40 MeV beam energy)

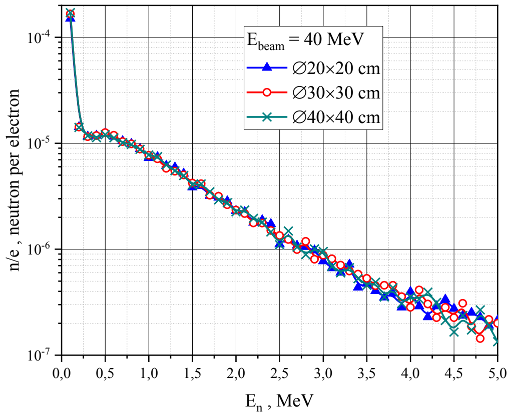


Fig. 10. Photoneutron spectra in the target region depending on moderator size (40 MeV beam energy)

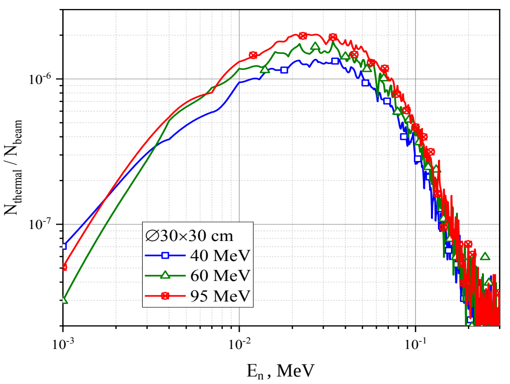


Fig. 11. Spectra of the thermalized neutrons at the target region

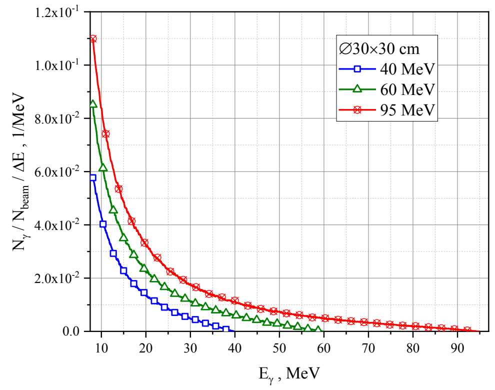


Fig. 12. Spectrum of the bremsstrahlung photons on the target

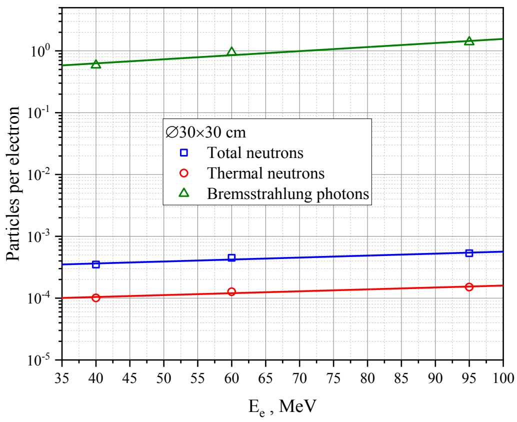


Fig. 13. Comparative yield of photoneutrons and bremsstrahlung photons

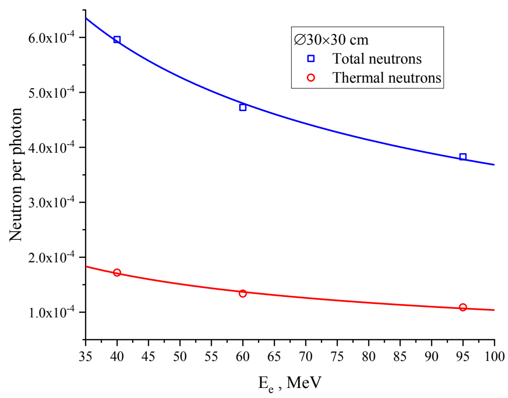


Fig. 14. Photoneutron yield per one above-threshold photon (E_{th} = 8.02 MeV)

CONCLUSIONS

1. The obtained results of the simulations on the yield of photoneutrons from the tantalum converter at the presence of the neutron moderator and without it are in satisfactory agreement with the data of measurements conducted earlier with the use of rhenium neutron detectors activated by the reaction ^{187}Re (n,γ) ^{188}Re [10].

2. The neutron distribution over the output angle from the converter is characterized by asymmetry with preference along the electron beam direction. The asymmetry coefficient is about 1.17 and doesn't depend on the electron energy in range 40…95 MeV.

3. The size of paraffin-graphite moderator of 30×30 cm seems being close to optimal as its expansion to 40×40 cm provides the gain in the thermalized neutron yield not higher than 1%.

4. The total yield of photoneutrons from the bremsstrahlung converter makes about of 10^{-4} of the yield of the above-threshold photons. The latter doesn't depend virtually on the presence of a moderator.

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ФОРМУВАННЯ ПОЛЯ МІШАНОГО X,n-ВИПРОМІНЕННЯ НА ПРИСКОРЮВАЧІ ЕЛЕКТРОНІВ

О.О. Захарченко, В.Л. Уваров, Ю.В. Малец

Для виконання фотоядерних програм з використанням джерела фотонів великої інтенсивності останнє зазвичай одержують шляхом трансформації пучка електронів у гальмівне випромінення. Цей процес здійснюють за допомогою проміжної мішені-конвертера, який виготовляють з матеріалу з великим Z. Під дією високоенергетичних гальмівних фотонів у конвертері відбуваються (γ,n)-реакції. Як результат, з нього, крім спрямованого уперед потоку фотонів, виходить також квазіізоторопний потік нейтронів. Параметри обох видів випромінення, так само як і співвідношення їх інтенсивностей, грають важливу роль залежно від програми, що виконується. У роботі методом комп´ютерного моделювання з використанням транспортного коду GEANT4 досліджено просторово-енергетичні характеристики мішаного X,n-випромінення, яке генерується електронним пучком у конвертері з танталу, що розміщений разом з ізотопною мішенню у середині модератора нейтронів, при енергії електронів у діапазоні 40…95 МеВ і різному розмірі модератора.