APPLYING OF THE PROGRAM CODES FOR MODELING THE ELECTRON ACCELERATOR DRIVEN SUBCRITICAL ASSEMBLY

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Some physical aspects of the electron accelerator driven subcritical nuclear assembly are considered. Results of calculations of some parameters of target and homogeneous subcritical assembly are presented.

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1. INTRODUCTION

Project of the new base facility of the Institute of High Energy Physics and Nuclear Physics – electron accelerator with energy up to several hundreds MeV – is being discussed now. One of the tasks that can be solved within this project is intense neutron source creation. This source may work in pulse or continuous regime. Great attention is paid to the creation of such sources in the world now. It is caused, first of all, with increasing neutron role as tool for solving of different scientific, technical and ecological problems. Reactor in subcritical mode and accelerator joint usage in one facility is characteristic feature of the facilities which were developed during last years. Such facility is used to obtain intense neutron fluxes. Neutrons from accelerator target are used for reactor switching to the subcritical mode. In such mode neutron multiplication factor K_{eff} nearly equals to one. Usually such subcritical assembly is either neutron target itself or includes a special target device converting charged particles to neutrons and fission provides further neutron multiplication. Therefore modeling of the electron accelerator driven subcritical system can be divided into two parts: modeling of the neutron production target and modeling of the subcritical assembly.

2. PHYSICAL PRINCIPLES OF NEUTRON GENERATION AT THE ELECTRON ACCELERATOR

On the base of the electron accelerators the neutrons can be obtained in result of the radiation double conversion: electrons → bremsstrahlung photons → neutrons from reactions (γ, *n*), (γ, 2*n*),…, (γ, *xn*) and at the heavy nuclei – (γ, *f*), where *f* – fission products. The neutron yield depends on many factors. Necessary condition of the photonuclear reaction is that interacting gamma-quantum energy and hence accelerated electron energy must be higher than the threshold energy for given reaction. Quantitatively the photonuclear reaction is characterized by its probability during the interaction between nucleus and gamma-quantum with defined energy, i.e. interaction cross-section. It was found that cross-sections of the gamma-quantum interaction with different chemical elements have the same shape: from the (γ, *n*) reaction threshold energy cross-section increases, reaches maximum and that decreases. This maximum is well-known from the literature as Giant Dipole Resonance (GDR) and has different values for different chemical elements. Photonuclear reaction cross-sections values and neutron yield at the area of GDR increase with increasing of the target atomic number *Z*.

The photonuclear reaction yield which is often used for reaction description, can be defined as number of interactions between photons of the given energy and element nuclei normalized by chemical element mass unit and gamma-radiation intensity. Typical curves of neutron yield from electron irradiated targets are shown at Fig. 1 [2].

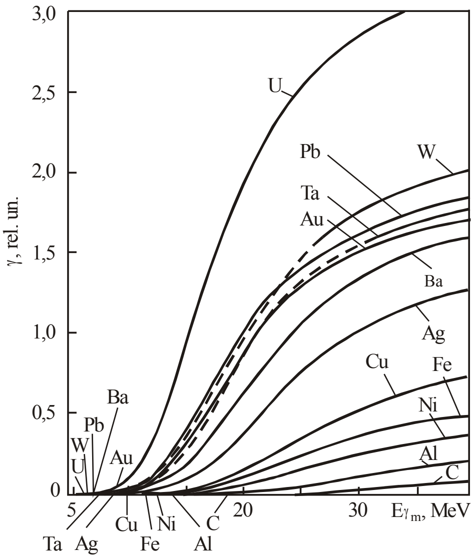

Fig. 1. *Curves of photonuclear reaction yields*

Yields from photonuclear reactions (γ, *n*), (γ, 2*n*), (γ , 3*n*)are shown at Fig. 2 [3]. From this figure it is clear that many-particle processes mainly contribute to the neutron yield reactions for the electron energy more then ≈ 25 MeV, especially for targets with large *Z*.

Besides dependences shown at the Fig. 1-2, other features that influence on the neutron production target design can be found in the literary sources on photonuclear reactions, namely:

- main part of the neutrons emerging from the target is the results of the evaporation process, so these neutrons have isotropic angular distribution;
- direct gamma-nuclear interaction process gives neutrons with anisotropic angular distribution.

According to available data such neutrons are 10…20 % from the total neutron yield from targets with high Z, e.g. lead, tungsten, tantalum;

- neutron yield depends on the target shape and dimensions. Optimal target thickness (i.e. thickness of the target with maximum neutron yield) equals to 10…20 radiation lengths (i.e. 5…10 cm of lead);
- maximum neutron yield can be obtained at the target from natural or enriched uranium.

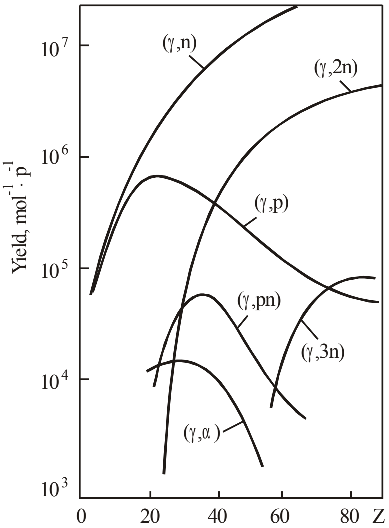

Fig. 2. *Photonuclear reaction yield versus atomic number Z*

From considered above it follows that during designing of the neutron production target at the electron accelerator neutron yield Y must be optimized as function of the target thickness T and its atomic number Z, i.e. we have to determine

$$\max Y = Y(T, Z, E_0),$$

where E_0 – accelerated neutron energy. For this purposes it is necessary to use program which is based on Monte-Carlo method and uses evaluated photonuclear data for (γ, n), (γ, 2n), (γ, f) processes.

3. BASE PROGRAMMING TOOLS FOR MODELING NEUTRON YIELD FROM NEUTRON PRODUCTION TARGET AND SUBCRITICAL NUCLEAR ASSEMBLY

Several programs are used now for $e^- \to \gamma + n$ and $e^- \to \gamma + 2n$ processes modeling. First, it is MCNP (Monte-Carlo N-particle) used together with Gamma Patch. This patch allows to generate neutrons after bremsstrahlung radiation or electron beam direct interaction with target. Further neutron histories are sampled in MCNP. In the existing works the combination MCNP4b+patch was used for targets from Al, Fe, Ta, W, Pb. Second, CALOR-95 can be used for neutron generation in the reactions with electrons and photons.

Besides that different versions of the MCNPX program can be used for calculations of the neutron yield from the $e \to \gamma + n(2n)$ reactions for neutron production targets from Pb, W, U etc. and for neutron transport through different materials (including fission ones). These codes allow completely calculation of the system from subcritical assembly and neutron target with incident neutron beam. Possibility to calculate criticality of the assembly with fission material, neutron fluxes and spectra at the assembly surface is the advantage of the MCNP-based (MCNP4b+patch, MCNPX etc.) program codes.

In this article neutron yields are also evaluated using one of the last versions of GEANT4 physical tools kit. Distinctive feature of GEANT4 is its free distribution and permanent updating.

4. ESTIMATION OF THE NEUTRON YIELD FROM NEUTRON PRODUCTION TARGET

The modeling results of the neutron production target irradiated by electron beam with energies 20…150 MeV are represented at Fig. 3-5. We used parallel electron beam with Gauss energy distribution normal to the target surface and uniformly distributed in the area on the target within diameter 10 mm.

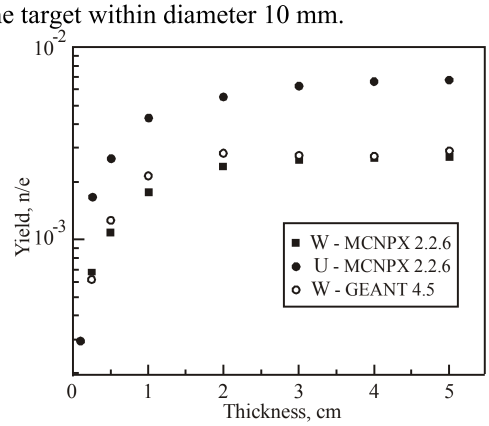

Fig. 3. *Neutron yield versus target thickness*

From Fig. 3 and 4 it is clear that neutron yield slightly depends on target thickness starting from 1.5 cm and on the electron beam energy starting from 30 MeV. Therefore it is possible to conclude that optimal target thickness is 3…3.5 cm.

From Fig. 5 it is clear that most of the neutrons from tungsten target have energies less than 7 MeV. The difference in the neutron spectra obtained from the target irradiated by electrons with energies 30 and 150 MeV can be explained by increasing influence of the direct neutrons knockout processes with electron energy increasing up to 150 MeV.

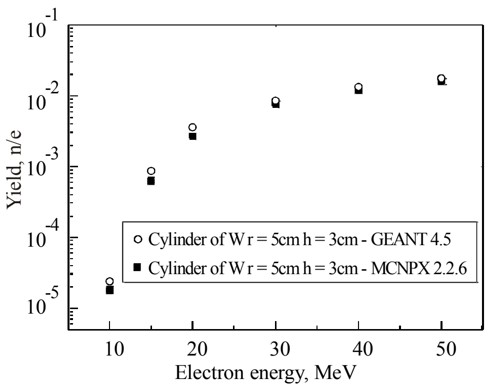

Fig. 4. Neutron yield versus electron energy

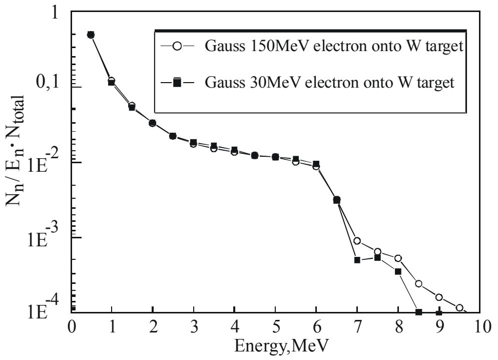

Fig. 5. *Spectral neutron energy distribution at the electron energies 30 and 150 MeV*

5. THE ASSEMBLY K_{eff} ESTIMATION

The programs developed on the basis of MCNP4C [5] were used for calculation of the basic characteristic of the subcritical assembly nuclei fission chain process – neutron multiplication factor K_{eff} and total neutron flux on the assembly surface. At the first stage of calculations we considered subcritical assembly with height *H* and diameter *D* filled with fission material UO_2 in aluminum matrix. Point neutron source was placed in the assembly center and was considered to have Watt fission spectrum. Calculations were done for 90%(HEU) and 20%(LEU) enrichments of ^{235}U. The results are presented in the Tables 1 and 2. Neutron fluxes are given per one source neutron.

Table 1

Parameters	HEU					UO_2
Density U, g/cm^3	1.0	2.0	5.0	7.0	9.0	
K_{eff}	0.9759	0.9799	0.9771	0.9766	0.9763	0.9741
Neutron flux, n/см^2	1.47e^{-3}	1.13e^{-3}	3.46e^{-4}	6.41e^{-4}	3.97e^{-4}	5.06e^{-4}
H/*D*	1	1	1	0.815	0.815	0.778

Table 2

Parameters	LEU			UO_2
Density U, g/cm^3	2.0	3.0	7.0	
K_{eff}	0.9769	0.9753	0.9741	0.9779
Neutron flux, n/см^2	8.78e^{-4}	1.08e^{-3}	3.67e^{-4}	1.07e^{-3}
H/*D*	1.286	1.186	1.56	1

6. CONCLUSION

Neutron yield from tungsten target obtained using GEANT4 well agrees with those one calculated using MCNPX. This agreement proves that we used GEANT4 tool in a proper way. GEANT4 may be used in future for optimization of the neutron production target in the subcritical assembly. Obtained neutron spectra can be used as input file for modeling of the subcritical assembly main parameters.

From results of the homogenous subcritical assembly modeling we can conclude that criticality and total neutron yield depend on many parameters such as fission material density, reflector and moderator sizes, etc. These parameters have to be taken into account to obtain optimal fast or thermal neutron fluxes. It is shown that nuclear fuel with different enrichment may be used for creation of the neutron source at the future basis NSC KIPT electron accelerator.

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ИСПОЛЬЗОВАНИЕ ПРОГРАММНЫХ КОДОВ ДЛЯ РАСЧЕТА ПОДКРИТИЧЕСКОЙ СБОРКИ, УПРАВЛЯЕМОЙ УСКОРИТЕЛЕМ ЭЛЕКТРОНОВ

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Рассмотрены некоторые физические аспекты работы подкритической реакторной сборки, управляемой пучком ускорителя электронов. Приведены результаты расчета отдельных параметров мишенного устройства и гомогенной подкритической сборки.

ВИКОРИСТАННЯ ПРОГРАМНИХ КОДІВ ДЛЯ РОЗРАХУНКІВ ПІДКРИТИЧНОЇ РЕАКТОРНОЇ ЗБІРКИ, КЕРОВАНОЇ ПРИСКОРЮВАЧЕМ ЕЛЕКТРОНІВ

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Розглянуто деякі фізичні аспекти роботи підкритичної реакторної збірки, керованої пучком прискорювача електронів. Наведено результати розрахунків окремих параметрів мішенного пристрою та гомогенної підкритичної збірки.