MATHEMATICAL MODELING OF A NEUTRON PRODUCTION TARGET OF AN ELECTRON ACCELERATOR DRIVEN SUBCRITICAL ASSEMBLY

M.I. Aizatskiy, A.M. Dovbnya, I.M. Prokhorets, S.I. Prokhorets, Y.V. Rudychev, M.A. Khazhmuradov
NSC KIPT, Kharkov, Ukraine
E-mail: khazhm@kipt.kharkov.ua

An electron-neutron converter was optimized to ensure effective usage of generated neutrons in a subcritical assembly.

PACS: 61.20.ja

1. INTRODUCTION

At present, neutron physics becomes a powerful tool for solving various applied and fundamental problems. Some fields of neutron application became classical. ear energetic is one of such applications. For example, new safe reactors based on fast neutrons are used, and nuclear facilities using spallation neutrons with external irradiation of an active zone by protons [1] are created. Element transmutation is also the classic field of neutron application. This field is directly connected with nuclear energetic because it becomes possible to load reactors with other kind of fuel. Neutrons are widely used in medicine, e.g., for cancer treatment [2]. Science progress in techniques, biochemistry and biology makes it necessary to use new physical methods which give possibility to obtain complex information about molecular structure and molecular dynamics of composite crystal and molecular-biology systems in natural conditions [3,4]. The modern methods in neutron physics are unique because information obtained by these methods could not be obtained by other methods. Application of the above-mentioned methods is limited because neutron sources with high intensity and required spectrum characteristics are not always available. Creation of a hybrid nuclear facility (accelerator – target – subcritical assembly) also known as Accelerator Driven Systems (ADS) is one of the ways to obtain neutron source with required characteristics [5]. Therefore, to develop such kind of facilities it is important and necessary to optimize parameters of all facility units.

The aim of this work is optimization of the parameters of the neutron source target for an electron accelerator driven assembly.

2. OPTIMIZATION OF THE ELECTRON-NEUTRON CONVERTER

Neutrons are generated as a result of so-called photonuclear reactions. Photonuclear reaction model must take into account the different nuclear reaction mechanisms involved in the initial photonuclear excitation process and subsequent decay of the excited nucleus by particle and gamma-ray emission. All these processes were taken into account for modeling of neutron generation by Monte-Carlo method. Detailed description of such processes can be found in [6]. The GEANT4 physical tools were used for numerical modeling.

The typical curves of neutron yield for several elements are shown in Fig.1 and Fig.2. [7].

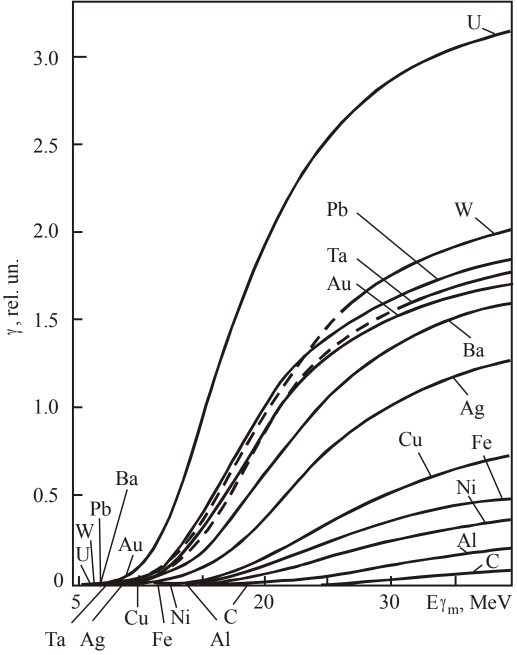

Fig. 1. Photonuclear reaction yields

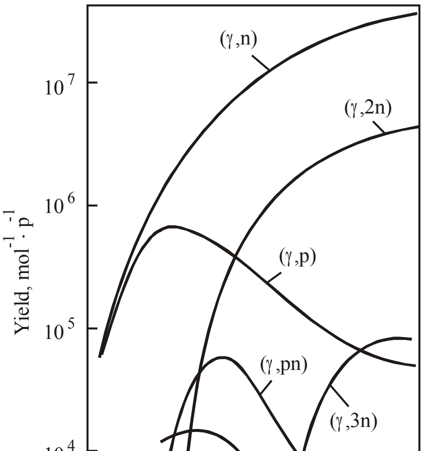

Fig. 2. Photonuclear reaction yields versus nucleus atomic numbers

These curves show that for obtaining high intensity neutron source it is necessary to choose target with high atomic number. Besides, a material for electron-neutron converter must be refractory and easy to treat. Tungsten meets all these requirements and it was chosen as the material for electron-neutron converter.

The initial geometry was following: we used the cylindrical converter and parallel electron beam normal to the target face surface. The diameter of initial beam was 5 mm and energy was 100 MeV. It is also necessary to note that neutron generation reactions are threshold ones. It means that if the energy of gamma is less than given threshold energy, then all secondary particles can not be able to generate neutrons. The threshold energy value depends on a material. As it has been mentioned above, tungsten is the material for our converter. Then for this material all gammas with energy less than 6.19 MeV can not generate neutrons. Therefore, such gammas are background and have an influence only on converter temperature. Thus, in this case gammas with such energies are ignored under modeling.

Choosing a target thickness is the first step of optimization. Having analyzed the obtained data, the thickness of our converter was chosen as 6.5 cm.

About 99.84% of gammas created as a result of interaction between initial electron beam and converter material are adsorbed in the converter of such thickness. On the other hand, 99.98% of distributed gamma fluxes participate in process. So, nearly all gammas can generate neutrons.

The neutron energy spectrum is shown in Fig.3. This spectrum shows that most of neutrons have energies up to 6 MeV. These neutrons are conceivably generated as a result of (γ,n) and $(\gamma,2n)$ reactions in a Giant Dipole Resonance (GDR) region. Threshold energies for these reactions are 6.19 and 13.6 MeV, respectively.

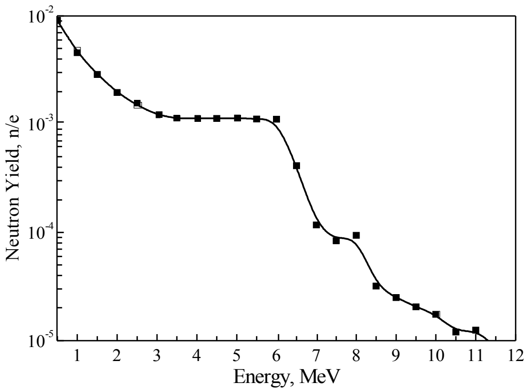

Fig. 3. Energy spectrum of neutrons generated by tungsten target irradiated with 100 MeV electrons

These reactions have a maximum cross-section in GDR region. At the higher neutrons energies the yield decreases more than order of the magnitude that corresponds to appropriate cross-sections. Besides, the number of gammas decreases exponentially with increasing of their energy.

Angular distribution of generated neutrons is shown in Fig.4. This distribution indicates that scattered neutron yield probability has a maximum at the angle more than 100°, i.e. in backward direction to the initial beam, as forward scattered neutrons is gone from large material thickness. This distribution has such shape as neutron yield is isotropic in any direction, and the maximum of generated neutrons lies in the thickness up to 3 cm.

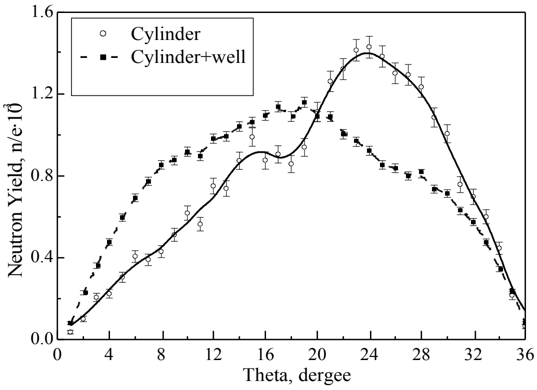

Fig. 4. Angular distributions of neutron yield for cylindrical target (cylinder, solid line) and for cylindrical target with channel (cylinder + well, dashed line)

It is obvious that the given configuration of the neutron fluxes is not optimized, as there is a probability to have a leakage of backward scattered neutrons because of the subcritical assembly construction,

To optimize our neutron yield, we modified the converter geometry by adding a small channel inside the cylinder, which is denoted as a "well" in our figures. The similar modification for spherical geometry was used by Kovalev [8].

Diameter of this channel is practically equal to the initial beam diameter; in our case it is equal to 5.1 mm.

The channel depth influence on neutron yields change was calculated. In particular, the dependence of neutron yields from lateral and face cylinder surfaces on channel depth was investigated. Results are shown in Fig.5.

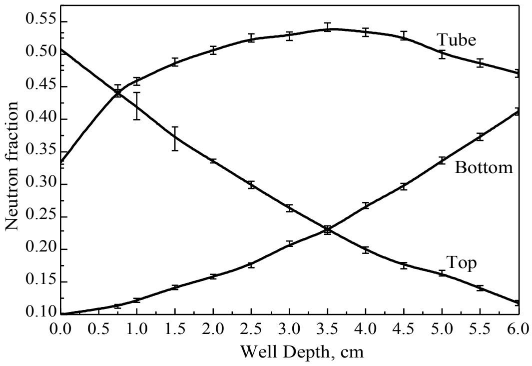

Fig. 5. Neutron yields versus channel depth for lateral and face cylinder surfaces normalized by total neutron yield from converter surface

From the obtained data we can conclude that the maximal neutron yield lies at the 3.5 mm of the channel depth. Also dependence of the neutron flux angular distribution has been obtained for given geometry as it is shown in Fig.4 (cylinder + well, dashed line). The maximum of the angular distribution lies near 90°. Thus, the optimized converter geometry ensures more effective neutrons yield. In our case the maximum of neutron yield from the neutron source target lateral surface is an optimization criterion.

After optimization procedure the geometrical configuration of electron-neutron, converter was following: cylinder of 10 cm thickness with channel of 3.5 cm depth.

So, it can be concluded that this optimized configuration of electron-neutron converter ensures effective usage of the generated neutrons for neutron multiplication in the subcritical assembly.

3. CONCLUSION

The electron-neutron converter irradiated with electrons with energy 100 MeV was simulated by using Monte-Carlo method based on the GEANT4 physical tools. It is necessary to note, that in the GEANT4, it is possible to use different physical models depending on the problem solved. Also the usage of the quark-level model ensured in our case more accurate description of energy and angular neutron distributions both at high and low energies. All models in the GEANT4 were verified by experimental data.

The converter geometry and material was optimized to obtain maximum neutron yield with the assumption of converter using together with the subcritical assembly.

Obtained results allowed defining the optimal geometry of the electron-neutron converter with taking into account the converter material. It was shown that after converter geometry modification from cylindrical shape to the cylinder with a channel, the neutron yield fraction from cylinder lateral surface increased from 35% up to 53%. This fact ensures more effective usage of the generated neutrons in the subcritical assembly. The angular and energy neutron flux distributions were simulated and optimized according to the listed above conditions.

REFERENCES

1. Yu.M. Ado. *NPP operating at the subcritical reactor with external neutron irradiation (impossibility of the reactor runaway):* Preprint IPHE 93-24 OKU. Protvino: 1993 (in Russian).
2. B.F. Bayanov et al. Accelerator-based neutron source for the neutron-capture and fast neutron therapy at hospital // *Nucl. Instrum. and Methods.* 1998, A413, p. 397-426.
3. G.E. Bacon. *Neutron Diffraction.* “Clarendon Press”, 1975.
4. Yu.A. Alexandrov et al.: Preprint JINR P-14-5358. Dubna, 1970.
5. M. Prome. *Major project for the Use of High Power Linac*. Proc. of Linac96. 1996, v.1, p.9-11.
6. *GEANT4 Physics Reference Manual.* GEANT4 Working Group CERN. June 21, 2004.
7. W.P. Swanson Calculation of neutron yields released by electron incident on selected materials // *Health Physics*. 1978, v.35, p.353-367.
8. V.P. Kovalev. *Secondary radiation of the electron accelerators*. M:. “Atomizdat”, 1979 (in Russian).

МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ НЕЙТРОНОПРОИЗВОДЯЩЕЙ МИШЕНИ ПОДКРИТИЧЕСКОЙ ЯДЕРНОЙ СБОРКИ, УПРАВЛЯЕМОЙ УСКОРИТЕЛЕМ ЭЛЕКТРОНОВ

Н.И. Айзацкий, А.Н. Довбня, И.М. Прохорец, С.И. Прохорец, Е.В. Рудычев, М.А. Хажмурадов

Проведена оптимизация нейтронно-производящей мишени с целью максимально эффективного использования произведенных нейтронов в подкритической ядерной сборке.

МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ НЕЙТРОНОУТВОРЮЮЧОЇ МІШЕНІ ПІДКРИТИЧНОЇ ЯДЕРНОЇ ЗБОРКИ, КЕРОВАНОЇ ПРИСКОРЮВАЧЕМ ЕЛЕКТРОНІВ

М.І. Айзацький, А.М. Довбня, І.М. Прохорець, С.І. Прохорець, Є.В. Рудичев, М.А. Хажмурадов

Проведено оптимізацію нейтроноутворюючої мішені з метою максимально ефективного використання нейтронів в підкритичній ядерній зборці.