NEUTRON FLUXE MEASUREMENTS AT THE ELECTROSTATIC ELECTRON ACCELERATOR "ELIAS"

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Neutron fluxes were measured at an electron energy of 3 MeV, a current of 51 μA and a beryllium target thickness of 3 mm. Taking into account spare capacities for increasing the neutron flux, calculations were made of a maximum attainable thermal neutron fluence for a 3-hour exposure of the object, it was calculated to be ≅ 10^{10} n·cm^{-2}.

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A variety of applications, including the method of oncotherapy based on the principle of boron-neutron capture therapy (BNCT), call for the production of intense fluxes of thermal neutrons. Neutron sources can be provided by fission reactors or by electron accelerators (due to (γ,n) reactions).

However, in these cases, the neutron energy spectra have the maximum in the neutron energy range between 1 and 2 MeV, this involving special measure for neutron moderation.

This gives rise to the necessity of investigating the possibility of producing neutrons with an initial energy as low as possible. This can be attained through the use of the electron (γ-quantum) beam having the energy a little higher than the (γ,n) reaction threshold. The choice of beryllium as a neutron-generating target, with its (γ,n) reaction threshold equal to 1.66 MeV, permits the use of the 3 MeV electron accelerator "ELIAS" for neutron production.

Besides, low boundary energy of the electron beam substantially simplifies the problem of protection against the background γ-radiation of the object exposed to the neutron flux.

This factor is of great importance, because for providing the required neutron flux on the object, the latter is usually placed at the minimum distance from the neutron-producing target. The precision control of the upper boundary of the γ-quantum energy can be realized at the electron accelerator with a high energy resolution, as is the case with the Van de Graaff-type electrostatic electron generator "ELIAS" at the NSC KIPT. According to the recent data on the calibration of voltammeter (model KS/3000) of the ELIAS generator, the absolute accuracy of electron beam energy measurements at the ELIAS accelerator makes 0.05 keV [1]. This accuracy complied with the initial ideas of the authors about the precision control of the electron energy in the near-threshold region of neutron production.

At the first stage of the measurements, the reaction of radioactive neutron capture ^{107}Ag(n,γ)^{108}Ag was chosen as a technique for registering thermal neutrons. The half-life of the β-active isotope ^{108}Ag is 2.3 min., this being quite acceptable for measurements.

However, in the process of experiments it became clear that the above-mentioned technique failed to provide the required efficiency of neutron yield measurements versus electron energy because of the necessity of multiple turns-off of the accelerator (beam) for a quick delivery of the sample with the neutron-induced activity from the accelerator exit to the measuring bench.

The measuring technique with the use of the industrially manufactured neutron detector-dosimeter NKS-01R was chosen as more preferable. It provided neutron flux measurements in a wide neutron energy range (from thermal to fast). The measurements were remote, without attending the experimental halls of the accelerator. In addition to the rated values, we made an additional calibration of the neutron detector with the help of the plutonium-beryllium neutron source with the $1.13 \cdot 10^5$ n·s^{-1} fluency.

The neutron flux measurements were carried out for the following neutron energy ranges: < 0.025 eV (thermal), > 0.025 eV (intermediate+fast).

The measurements were done in the following geometry.

After passing through a thin exit foil of the accelerator, the electron beam was converted into gamma-quanta in the tantalum converter located immediately after the exit foil of the accelerator. A special design of the water-cooled tantalum converter provided the removal of thermal power ≅ 1.5 kW at a maximum beam current of 500 μA.

The gamma-quantum beam from the converter was incident on the neutron-producing target placed after the converter. The target was a 3 mm thick beryllium plate.

The neutron detector was set in the horizontal plane at an angle of 90° to the accelerator axis at a distance of 100 cm from the neutron-producing target. The solid angle of the detector was $d\Omega = 2\pi \cdot 10^{-2}$ sr.

The figure shows the thermal neutron flux (a) and the intermediate+fast neutron flux (b) as functions of the electron energy at an electron current of 51 μA. The characteristic increase in the neutron fluency with an increasing electron energy, seen in the two figures, demonstrates a successively increasing number of photons in the γ-spectrum, the photon energy exceeding the threshold of (γ,n) reaction on beryllium in the 1.66… 3 MeV range.

The data show that the practically significant flux values of both thermal and fast neutrons are attained at the maximum electron energy of the beam.

Assuming the spatial distribution of neutrons from the beryllium target to be isotropic, it is possible to estimate the total yield of neutrons.

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At E=3 MeV, the 3 mm thick neutron-producing target (as a source of neutrons to the solid angle 4π) provides the following fluencies:

thermal neutrons ……………..≅ 10^6 n·s^{-1},

intermediate+fast neutrons ……≅ $3\cdot10^7$n·s^{-1}.

To increase the neutron flux, the following reserve factors can be used: (i) a 10-fold increase in the electron current, (ii) a ≅ 30-fold increase in the thickness of the beryllium target (the total increase ratio being 300). Then, with the accelerator ELIAS operating at an energy of 3 MeV and a current of 500 μA, the fluxes of neutrons to the solid angle 4 π will be as follows:

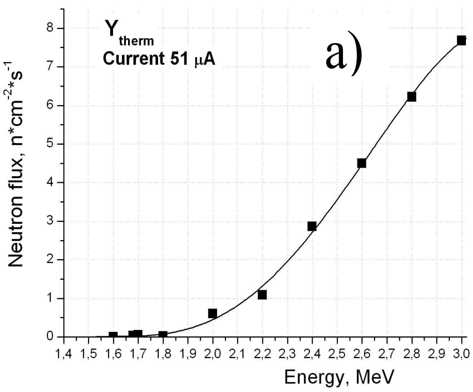
thermal neutrons ……………..≅ $3\cdot10^8$ n·s^{-1},

intermediate+fast neutrons ……≅ 10^{10}n·s^{-1}.

With the polyethylene moderator measuring 60×60×60 cm, in the space with a volume of up to 10^3 cm^3 near the neutron-producing target, a thermal neutron flux of practically uniform density can be produced [2]. As applied to our case, with due regard for the fact that the distance, within which photoneutrons are thermalized in the hydrogen-containing moderator, makes only ≅ 5 cm, the thermal flux density in the 200…300 cm^3 space in the neighborhood of the target is estimated to be ≅ $2\cdot10^6$ n·cm^{-2}·s^{-1}.

In a period of a few hours, the mentioned neutron flux density may provide a fluency of ≅ 10^{10} n·cm^{-2}·s^{-1}.

Thus, the thermal neutron source with the accelerator "ELIAS" as the basis may be used, for example, as a test bench for verifying the efficiency of boron-containing pharmaceutical preparations (aimed for the BNCT) introduced into small-size biological objects.



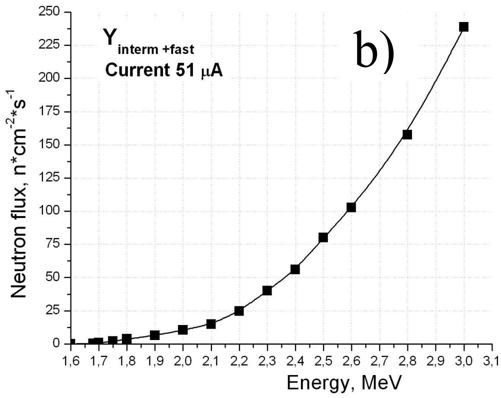


Fig.1. Neutron fluence versus electron energy: a) thermal neutrons (<0.025 eV), b) intermediate+fast neutrons (>0.025 eV)

The results obtained and the estimates based on them show that the electrostatic accelerator "ELIAS" can provide conditions for performing various programs with the use of thermal neutrons, where no high neutron flux values are needed.

REFERENCES

1. A.M. Astakhov, D.Yu. Barankov, V.N. Borisenko et al. Calibration of a rotary voltmeter at the electrostatic generator "ELIAS" // *Problems of Atomic Science and Technology. Series: Fiz. Rad. Povrezhdenij i Rad. Materialoved*. 2003, №6(84), p.127-128 (In Russian).
2. Yu.M. Tsipenyuk, V.I. Firsov. Microtron-based neutron source for activation analysis of liquid and large-volume samples // *Journal of Radioanalytical and Nuclear Chemistry*. 1997, v.216, №1, p.47-50.

ИЗМЕРЕНИЕ ПОТОКА НЕЙТРОНОВ НА ЭЛЕКТРОСТАТИЧЕСКОМ УСКОРИТЕЛЕ ЭЛЕКТРОНОВ "ELIAS"

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Измерены потоки нейтронов при энергии электронов 3 МэВ, токе 51 мкА и толщине нейтронопроизводящей мишени из бериллия 3 мм. С учетом имеющихся факторов увеличения потока нейтронов сделаны оценки максимально достижимого флюэнса тепловых нейтронов (за 3 часа экспозиции объекта), который составил ≅10^{10} н·см$^{-2}$.

ВИМІРЮВАННЯ ПОТОКУ НЕЙТРОНІВ НА ЕЛЕКТРОСТАТИЧНОМУ ПРИСКОРЮВАЧІ ЕЛЕКТРОНІВ "ELIAS"

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Виміряно потоки нейтронів при енергії електронів 3 МеВ, струмі 51 мкА та товщині нейтроногенеруючої мішені з берилію 3 мм. З урахуванням можливих факторів підвищення потоку нейтронів зроблено оцінки максимально досяжного флюенса теплових нейтронів (за 3 години експозиції об'єкта), що становить ≅10^{10} н·см$^{-2}$.