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A NEW NEUTRON SPECTROMETER WITH NARROW DIAGRAM OF ACCEPTANCE

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Abstract. The instrument for spectrometry of neutrons has been designed. The original design scheme which is distinct from the widely spread Bonner type neutron spectrometer is used. Main difference is in angular selectivity that is absent in the Bonner spectrometer. The helium counters of thermal neutrons SNM-18 surrounded by a screen and moderator layers for various ranges of neutron energy are used as detectors. The protection from thermal neutrons ensures the complete shielding of the counter from selected directions that has allowed creating of a spectrometer accepting radiation only from the given direction. The energy diapason of a spectrometer makes from a thermal range up to hundreds MeV. The important feature of the instrument is its angular directivity: the angle of acceptation does not exceed 30-40 degrees. Construction of a spectrometer (with the detailed representation of all materials which are included in it) has been simulated on GEANT-4 package. This has allowed us to investigate response of the instrument to neutrons and other particles of various energies from 0.1 eV up to 300 MeV. The working experimental sample of a spectrometer unit is manufactured and its calibration is carried out. Technical data of the instrument appeared in the consent with calculated. Measuring of the thermal neutron intensity at the ground has shown a significant anisotropy of neutron flux. Determination of a neutron spectrum over all the indicated energy diapason requires a solution of an inverse problem: deconvolution.

1. Construction of the spectrometer

The principle of operation of the spectrometer sets up on a phenomenon of an effective moderation and reflection of neutrons by the materials containing of many hydrogen atoms (polyethylene, paraffin etc.). Only neutrons with energy more than some threshold depending on width of substance can overcome a stratum of such substance. On this principle widely spread Bonner type spectrometers are made [1-3]. However, they have an essential shortage - they are omni-directional. On the basis of the detector of thermal neutrons SNM-18 the spectrometer with a directional diagram about 30-40 degrees has been designed. A core of the spectrometer unit is SNM-18. The counter tube SNM-18 represents the cylinder in diameter of 32 mm and length 300 mm filled by ^{3}He. The counter is protected from all directions, except for a rather narrow band along the cylinder (the reception window), a shield (the substance swallowing thermal neutrons with effectiveness more than 99 %). A thick stratum of polyethylene encloses the counter together with its shield. In such construction we have a narrow directed detector of thermal neutrons. As it will be said below the thick stratum of polyethylene is need to reflect neutrons totally. Both the stratum and protection from thermal neutron provide so good shield from backward neutrons. The operating unit of the spectrometer is shown on Fig.1. There is a petal directed detector of thermal neutrons in such construction. Direction sharpness is determined the reception window and equal ~ 40 degrees in petal cross-section; it is about 120-140 along the petal.

For measuring neutrons of high energies the reception window of a unit is covered by a particular thickness polyethylene moderator. Only neutrons with energy higher than a particular threshold pass through. The package of such units is the neutron spectrometer of wide energy diapason. The package of a spectrometer may consist of 5-7 such detectors. The window of each of them is covered by a polyethylene slab of the given thickness. Thus the detector appears sensitive to neutrons above a particular threshold of energy. The complete spectrum of neutrons is obtained via a numerical solution of an inverse problem: deconvolution of the all detectors data.

2. Modeling of the spectrometer with GEANT-4

2.1. *Geometry and the experiment concept*

The neutron spectrometer operation was modeled before manufacturing. To determine the detector response of the neutron spectrometer the geometry and material composition of it were implemented in GEANT-4 as real as possible. In the Fig. 1 visualization of a neutron spectrometer is presented. Fluxes of neutrons with energies over range 10^{-1}-10^{9} eV were used on each modeling pattern. The shield quality was checked (modeled) initially. It was found that the shield swallows all neutrons (effectiveness is more than 99 %). Than the counter tube was closed by polyethylene plates with various thickness (in figure these plates are not shown). In the first part of numerical experiments neutrons with a random initial position and angular distribution dropped on the detector surface bounded by sizes of the counter (model approximation). In the second part of numerical experiments neutrons were started with the given incident direction (from 0 up to 90 degrees relative to vertical incident direction).

2.2. *Methodology*

For the calculations presented in this work, the GEANT-4 simulation toolkit version 9.4 was used on openSuSe 11.2 operating system [4]. Additionally, the neutron data library G4NDL3.14 was installed, which includes cross sections for thermal scattering. In all calculations the neutron fluence in the detector volume (i.e. the actual proportional counter tube) was scored using a Sensitive Detector class. In order to determine the counter response, ^{3}He (n,p) ^{3}H + 0,764 MeV reaction was used.

For physics processes the built-in physics list QGSP_BERT_HP (recommended for such applications), which includes various interaction model was applied.

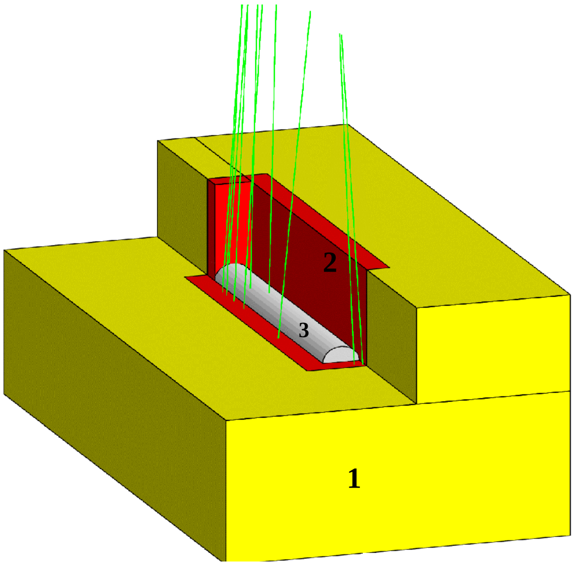

Fig. 1. A unit (one detector) of a neutron spectrometer is shown (in section). Polyethylene shield is marked 1, protection box from thermal neutron is marked 2, neutron detector SNM-18 (filled with He^{3} gas counter) is marked 3. This unit is shown without polyethylene moderator, which covers above the counter tube into gap of protection. Lines are neutron tracks in response modeling. Neutron initial position and angular distribution are random into some value limits to avoid "empty" tracks when neutrons pass by the box.

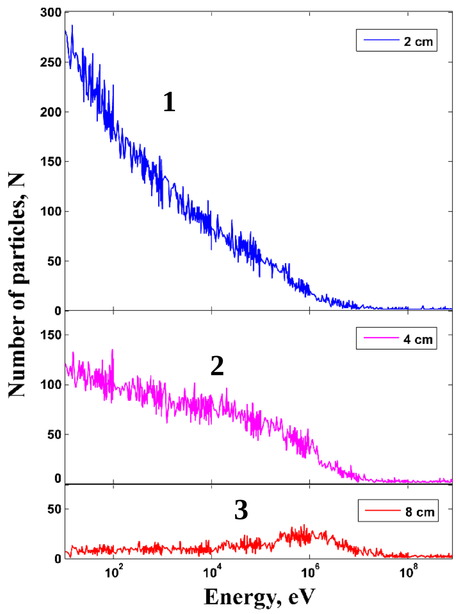

Fig. 2. A neutron detection efficiency depending on moderator thickness obtained as a result of first part of modeling. 1, 2, 3 lines represent efficiencies for moderator thickness of 2 cm, 4 cm and 8 cm respectively. Efficiency is given as N particle per 1000 initial ones.

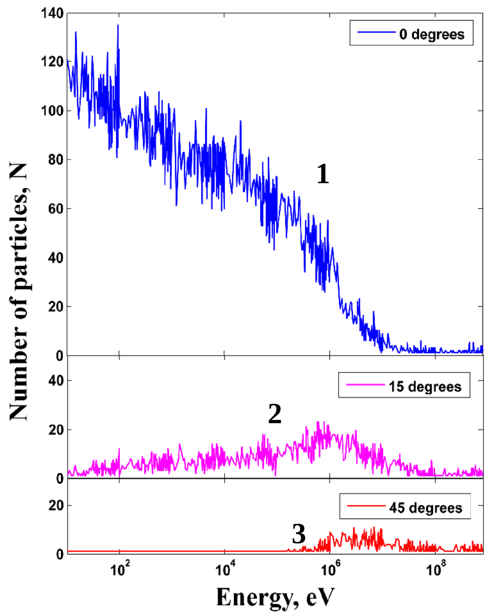

Fig. 3. A neutron detection efficiency depending on incident direction relative to vertical one obtained as a result of modeling. 1, 2, 3 lines represent efficiencies for incident direction with angles 0, 15 and 45 degrees respectively. Efficiency is given as N particle per 1000 initial ones.

As a result of modeling of neutron detection efficiency depending on thickness of the polyethylene plate closing an upper of the counter (polyethylene moderator) for the first experiment and depending on incident direction for the second experiment (Fig. 2, Fig. 3 respectively) were obtained. These results have good agreement with ones of real tests of a neutron spectrometer.

3. The first real measurement

Firstly in real measurement the spectrometer unit counter was totally covered neutron protection and proper count rate ("dark count") was carried out. It was less than 0.2 min^{-1}. Then thermal neutron anisotropy was found. The detector window was opened and turned to upward to measure a neutron downward flux. The count rate was equal ~1 min^{-1}. At last the detector window was turned to downward to measure a neutron upward flux. The count rate was equal ~ 0.5 min^{-1}. In Fig. 4 count rate registered by the detector of downward and upward fluxes of thermal neutrons is presented.

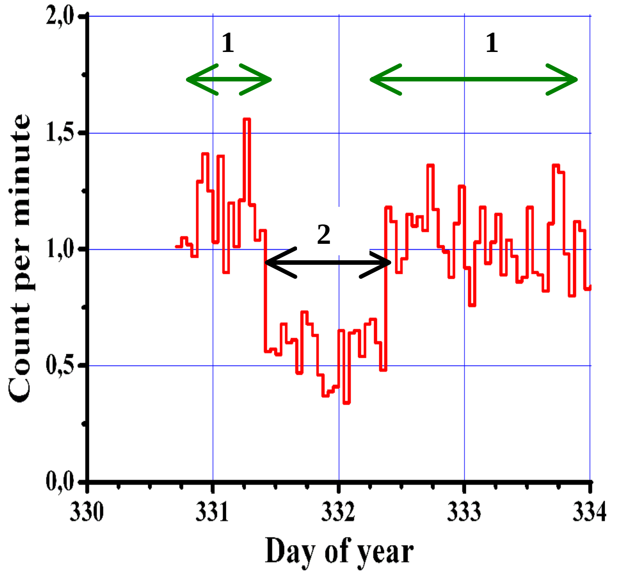

Fig. 4. Measurement of thermal neutron anisotropy. It is hour average. Downward and upward fluxes are marked 1 and 2 respectively. The fluxes are reduced to the dark count.

Conclusions

A new neutron spectrometer has been designed. The worth of it is in angular selectivity that is absent in a Bonner spectrometer. The important spectrometer features (as angular directivity, response function) have been simulated on GEANT-4 package. This has allowed investigating of the instrument response to neutrons and other particles of various energies from 0.1 eV up to 300 MeV. The working experimental model of a spectrometer is manufactured and its calibration is carried out. Measuring of the thermal neutron intensity at the ground has shown a significant anisotropy of neutron flux.

References

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