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EFFICIENCY CALCULATION OF DETECTOR AND OPTIMIZATION OF ITS CONSTRUCTION FOR NERA SPECTOMETER BY USING GEANT4

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The efficiency calculation of different variants of assembly designs consisting of 3, 4 and 5 Helium-4-1 type counters are presented. Optimization of the geometric parameters of the assemblies has been carried out to increase the homogeneity of efficiency and to simplify the design of the detector system. The GEANT4 package has been used to simulate the operation of the modules designed to replace the old counters of the spectrometer NERA at the IBR-2 reactor. The calculation results have been compared with the experimental ones.

Keywords: thermal neutron, ^{3}He counters

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1. Introduction

Monte-Carlo simulations are very useful in development of neutron detectors. One of the best tools to simulate the passage of particles trough the matter is GEANT4 [1], which was originally developed for high energy physics applications. Recently, GEANT4 has been extended to include low energy application, namely, the thermal neutron scattering model and the corresponding data library [2]. Reasonable agreement in comparison with GEANT4 predictions and experimental data has been reported in [3, 4]. This fact suggests a high potential of GEANT4 in simulation of the response from low and thermal energy neutron detectors. The present paper reports on the results of efficiency optimization of thermal neutron detector modules for the NERA spectrometer [5] detector system. Based on these calculations, the detector system of NERA was upgraded in summer-autumn 2019.

2. Experiment

NERA is an indirect geometry spectrometer located at the Frank Laboratory of Neutron Physics of the Joint Institute for Nuclear Research. NERA is designed predominantly for the study of molecular dynamics. The scientific program on NERA includes the studies of hydrogen-bonded systems, biologically active materials, organic compounds, as well as the study of properties of dynamic complexes with transfer of electric charge, etc. The primary spectrometer defines the energies of the incident neutron and transports the neutron beam from the IBR-2 moderator to the sample position at L_1 = 109.05 m. The design features of the main part of the NERA spectrometer, which analyses and records the scattered neutrons, are presented in Fig. 1. The spectrometer consists of two symmetrical sections, A and B. One scattering chamber for neutron powder diffraction(NPD) and eight chambers for inelastic (INS) and quasielastic neutron scattering (QENS) measurements are located in each of them. Detector modules made of ^{3}He counters are used in the NPD, INS and QENS chambers. The detailed description of the spectrometer can be found in Ref [5].

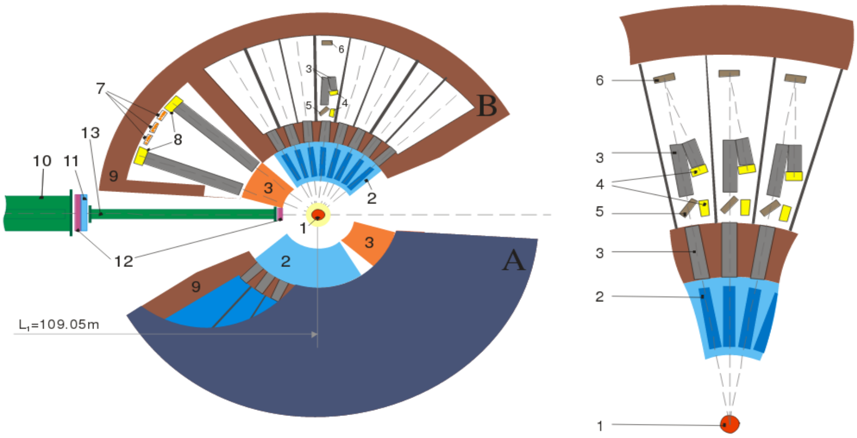
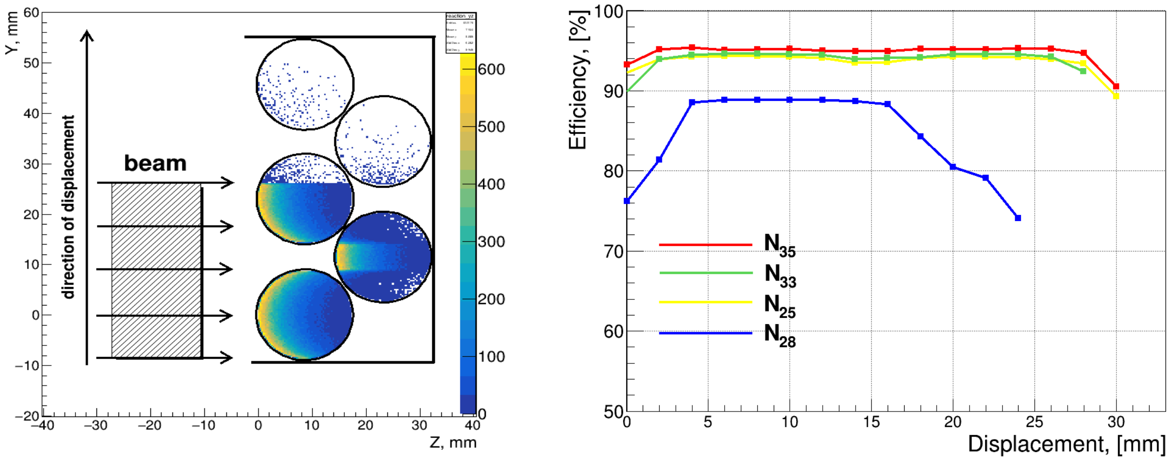


Figure 1. The layout of the NERA spectrometer: 1 – sample, 2 – Be-filters, 3 – collimators, 4 – ^{3}He detectors (INS and QENS), 5 – PG analyzers (INS), 6 – single crystal analyzers (QENS), 7 – detectors for high intensity diffraction, 8 – diffraction detectors with good collimation, 9 – spectrometer shielding, 10 – Ni-coated mirror neutron guide in a vacuum tube, 11 – incident-beam monitor, 12 – diaphragms, 13 – vacuum neutron guide

The detector systems of NERA need to upgrade the thermal neutron registration elements to increase the efficiency of the spectrometer. The cylindrical counter Helium-18/180-8.0 has been chosen as a base element for the detector module to construct assemblies from 3, 4 and 5 tubes. This type of counters is similar to the quite common and well-studied counter SNM-18, a standard instrument for neutron scattering research. To avoid global modification of the spectrometer and changes of the construction elements, the geometrical size of new modules has been chosen to the equal size of the old registration boxes. The arrangement of counters in modules affects on assembly efficiency and its uniformity in respect to the area of the detector illuminated by the neutron beam. To select the most suitable arrangement of tubes and their amount the simulation of detectors has been performed using GEANT4 [1].

3. Simulation

A cylindrical tube with technical characteristics corresponding to the Helium-18/180-8.0 counters has been used as a base element for modules in simulation. The homogeneous flux of neutrons with an energy of 4.65±0.36 meV has been used as a beam. This value corresponds to the most probable energy used at the NERA spectrometer. The maximum possible value of the transverse profile of the beam 180x35mm falling on the detector surface has been used in simulation. The falling angle of the beam was chosen to be 90 degrees, the maximum width of the simulated modules - 64mm in order to fit in the existing holders.



a) b)

Figure 2. a) – scheme of simulation to obtain the efficiency of assemblies as a function of displacement value; b) – efficiency of assemblies from 5(N_{35} - 64mm), 4(N_{33} - 62mm), 4(N_{25} - 64 mm) and 3(N_{28} - 50mm) standard ^{3}He counters

The efficiency of cylindrical counters can be calculated as a ratio of number of events where the neutron interacts with 3He to the total number of neutrons in the initial beam. The efficiency of assemblies has been obtained as a function of displacement value due to the fact that the area of the detector irradiated by neutrons is not known exactly. The 2mm step of displacement has been chosen along the axis corresponding to the side of the detector with a size of 64mm. The arrangement of cylindrical counters in the module composed from 5 items and the scheme of beam displacement are presented in Fig. 2, a. The 2mm step of displacement has been chosen along the axis corresponding to the side of the detector with a size of 64mm. The results of efficiency for 3- and 5-counter assemblies are shown in Fig. 2, b in blue and red lines. Green and yellow curves in Fig. 2, b present the efficiency for 4-counter assemblies with a width of 62 and 64 mm, respectively. The results have shown that a flat distribution of efficiency is observed for all assemblies. The sharp dips at the edges for the assembling from 3 and 4 (width 62mm) counters are a consequence of the fact that a part of the beam does not fall into the sensitive area of the module. The difference between the 5- and the 3-counter assemblies on the plateau is about 6% at a neutron energy of 4.65 meV. The difference in efficiency of the 5- and the 4-counter assemblies does not exceed 1% at a neutron energy of 4.65 meV and is about 7% at a neutron energy of 25 meV.

4. Experimental results

To validate the simulation results, the two sets of measurements with a point source and at the NERA spectrometer have been performed. In the first case, the 5- and the 4-counter assemblies have been placed in a casing located at a fixed distance from the point source of thermal neutrons. The measurements have shown that the assembly from 5 counters has approximately 14% more efficiency than the assemblies from 4 counters (with 64 and 62 mm width respectively). These results are in reasonable agreement with simulation due to the fact that the point source produces neutrons with an energy of not only equal to 25 meV but also larger or less values. The results of measurements performed at NERA are presented in Fig. 3. Red, gray, blue, turquoise and black points correspond to the results obtained with the old detector, 5-(N_{35} - 64mm), 4-(N_{33} - 62mm), 4-(N_{25} - 64 mm) and 3-counter (N_{28} - 50mm) assemblies, respectively. All the results were normalized by the time of measurements.

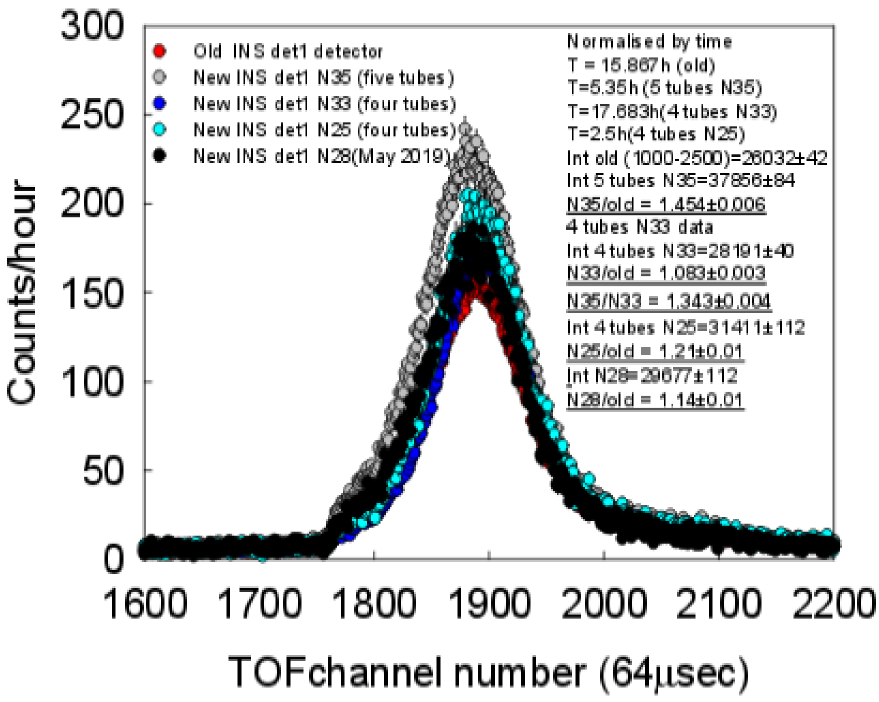


Figure 3. Experimental results obtained at the NERA spectrometer. Red, gray, blue, turquoise and black points correspond to the results obtained with the old detector, 5-(N_{35} - 64mm), 4-(N_{33} - 62mm), 4-(N_{25} - 64 mm) and 3- counter (N_{28} - 50mm) assemblies, respectively

The values of Nxx/old ratios in Fig. 3 show the difference in the number of samples for new and old assemblies. The assemblies from 5(N35 - 64mm), 4(N33 - 62mm), 4(N25 - 64 mm) and 3(N28 – 50mm) counters increase in the efficiency of 45%, 8%, 21% and 14% respectively, in comparison with the old detection element. These values disagree with simulation results which do not predict a significant difference in efficiency between 5-(64mm) and 4-(64, 62 mm) counter assemblies. A possible reason of difference between the experimental and simulation values is uncertainty of the neutron beam profile and its position on the detector module surface. Namely, the spatial and angular distribution of the neutron beam is not known exactly and may be strictly non-uniform. In some cases, a lot of neutrons may slide between counters in 3- and 4-counter assemblies, resulting in the decrease of efficiency as compared to calculations. An important experimental result is observed for the assembly from 3 counters. The efficiency of this assembly is better in comparison with the assembly from 4 counters for experimental conditions of NERA. This fact shows clearly that it is possible to decrease the cost of the detection part of the spectrometer using less number of standard counters.

5. Conclusion

According to the obtained experimental and simulation results, the 5-counter assembly is the most suitable solution for the modernization of the NERA spectrometer. This assembly possesses the best characteristics in comparison to the other assemblies and is not sensitive to the errors associated with the positioning of the detector and spatial characteristics of the beam. However, the optimization of counters' arrangement in assembly for future instruments is necessary, because the detector cost can decrease significantly with slight decrease of efficiency. It is the most important methodological result from the point of view of the production of large area detectors.

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