MODELING OF THE TRANSFORMABLE NEUTRON SKIN OF THE FOBOS SETUP BASED ON THE $^3$HE-FILLED PROPORTIONAL COUNTERS

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A neutron detector utilizing $^3$He-filled proportional neutron counters has been applied in the numerous experiments in FLNR for measuring the multiplicities and angular distributions of low energy neutrons originated in the decays of nuclei\textsuperscript{1}). Absence both of the energy threshold for neutrons and of the cross-talk effect as well as high registration efficiency made it a useful tool for variety of studies requiring detection of neutrons. In a sense that the set of these counters has been used in the different geometrical configurations it is called “the transformable neutron skin (TNS).

The TNS generally consists of the separate hexagonal modules comprising a $^3$He-filled proportional counter, a polyethylene moderator, a high-voltage input and a preamplifier (Fig. 1, left). The most of the counters operate under a gas pressure of 7 bar, being 50 cm in length and 3.2 cm in diameter. The spacing between the parallel planes of the moderator in a detector unit amounts to 5 cm. The typically used configuration of the TNS turned to be a “barrel” (Fig. 1, right), therefore the properties of the detector in this shape are well known from the experimental data.

In the recent experiments at the FOBOS setup the TNS has been reconfigured to the “neutron belt”\textsuperscript{2)} consisting of 140 counters and covering effectively 19% of the complete solid angle of $4\pi$ (Fig. 2).

Processing of the neutron data obtained and the planning of the further experiments required to build up a numerical model of the TNS. The well known MCNP code has been chosen for modelling because it is supplied by any libraries needed and potenitates complicated geometrical lay-outs in a three-dimensional space; also it runs fast enough even at the low-power PC.

The TNS model has been checked for the “barrel” by simulating the dependence of the registration efficiency on the position of the source on the barrel’s axis (Fig. 3).

As one can see from the Fig. 3 the experimental efficiency is well reproduced by our calculations. The little discrepancy occurs because the detector of different individual properties (e.g. gas pressure) were used and so far the precise description of the barrel configuration for the further simulations was not considered; we were also not able to take this into account correctly. Hence, in our model of the barrel all the detectors were supposed to be identical. The latter seems to be quite adequate approximation. Indeed, the count rate ratio of the inner- to the middle layers derived from the experiment (1.059) perfectly coincides with the calculated one (1.052).

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The next very important parameter of the TNS for tuning of an experiment is the “life-time” of a neutron in an arrangement. The simulated distribution of the registration times is given in Fig. 4. The calculated life-time of a neutron in the barrel of 27 $\mu$s perfectly coincide with that of 25 $\mu$s reported in Ref.\textsuperscript{1)}

Our simulations have been proved also at the FOBOS detector with the TNS in a form of a “belt” consisting of the monotype counters arranged mostly by the groups of 16 counters each. The life-time of a neutron amounted to 20 $\mu$s also has been reproduced rather well\textsuperscript{2).} The smaller life-time in the belt compared to that in the barrel is due to a larger surface-to-volume ratio leading to the increased neutron escape probability from the belt, respectively.

The experimentally obtained ratio of the count rates between the inner and the outer layers of an arrangement turned to be 1.3. Simulated values amounted to 1.25 and 1.35 for the arrangements placed at 79$^\circ$ and 101$^\circ$ relative to the fission axis, respectively, and their mean value of 1.3 excellently agrees with the experimental one.
The capabilities of the TNS model in the calculation of such essential values like the registration efficiency and the life-time have been already successfully applied in the modeling of the measured neutron multiplicity in the experiments on search for collinear cluster tripartition (CCT).

Summarizing, our MCNP model of the TNS seems to reproduce the properties of the neutron counters adequately and, hence, could be useful in the further planning of the proper configuration of the TNS for the certain experimental needs.

The TNS is planned to be used in the forthcoming measurement at the mini-FOBOS setup. The neutron counters are combined into packs like that one shown in Fig. 5. Four of such arrangements mounted tightly around the reaction chamber at a distance of 25 cm form a square “neutron well” whose efficiency amounts to 18.4%. The detailed information on an influence of scattering of neutrons on the mini-FOBOS constructions including parts of the neutron well and also on a concrete of the cave is given in Table 1.

Fig. 5. The block of 16 counters at the experiments with mini-FOBOS.
Table 1. Study of the registration efficiency of the TNS in the experiments with mini-FOBOS.

<table>
<thead>
<tr>
<th>source</th>
<th>single 16-counters block</th>
<th>two adjacent blocks</th>
<th>4-blocks well</th>
</tr>
</thead>
<tbody>
<tr>
<td>just neutron counters, no matter around</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>isotropic</td>
<td>3.2 %</td>
<td>3.5 %</td>
<td>15.2 %</td>
</tr>
<tr>
<td>moving FF</td>
<td>1.4 %</td>
<td>1.6 %</td>
<td>7.2 %</td>
</tr>
<tr>
<td>neutron counters with mini-FOBOS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>isotropic</td>
<td>3.3%</td>
<td>3.6%</td>
<td>15.6%</td>
</tr>
<tr>
<td>moving FF</td>
<td>1.9%</td>
<td>2.1%</td>
<td>9.2%</td>
</tr>
<tr>
<td>the same in a concrete cave</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>isotropic</td>
<td>4.0%</td>
<td>4.3%</td>
<td>18.4%</td>
</tr>
<tr>
<td>moving FF</td>
<td>2.4%</td>
<td>2.6%</td>
<td>11.2%</td>
</tr>
</tbody>
</table>

The detailed study of the angular distribution of the neutrons with such a configuration of TNS at mini-FOBOS is impossible, however, our simulations (Fig. 6) leave some chance to distinguish between focused and unfocused neutrons. The latter could turn to be important for the further study of CCT.

Fig. 6. The angular response of the 16-counters pack to the neutrons focused perpendicular to the spectrometer axis (solid line) and to the isotropic emitted neutrons (dash-dotted line). Thin dashed line represents pure effect of the solid angle for the isotropic source. Inset explains detector numbering.

References

3. A.N. Tjukavkin et al., “Mathematical model...” Contribution to this report.

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