Applications of $^3$He Neutron Detectors

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Abstract—Neutron detectors with $^3$He-filled proportional counters are described. The use of these detectors in measuring the probability of neutron emission (in particular, multiparticle neutron emission) after the $\beta$ decay of neutron-rich nuclei and in studying rare events of spontaneous fission of superheavy nuclei is considered.

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INTRODUCTION

Experimental studies of the emission of delayed neutrons from neutron-rich nuclei and prompt neutrons from spontaneous fission require neutron detectors with a high efficiency that remains constant in a wide energy range. In addition, the detectors must be free of crosstalk, their parameters must be stable during long-term measurements, and the geometry of these detectors should be easy to change according to requirements of a particular experiment.

DESCRIPTION OF NEUTRON DETECTORS WITH HELIUM COUNTERS

Neutrons are detected in helium counters through the reaction $^3$He $+$ n $\rightarrow ^3$H $+$ p $+$ 780 keV, whose cross section for thermal neutrons is $\sigma_{th}$ $=$ 5320 b. Since thermal neutrons are to be detected, there is almost no energy threshold for this reaction. Each neutron can be detected only once, which makes crosstalk totally impossible. The counters in question are also only slightly sensitive to $\gamma$ rays.

Two types of neutron counters in the form of stainless steel pipes were used in our experiments. Counters of the first type, 50 cm long and 3.0 cm in diameter, were filled with $^3$He at a pressure of 7 bar. Counters of the second type, 30 cm long and 3.2 cm in diameter, had a pressure of 4 bar. All counters operated in the proportional mode.

Polyethylene was used as a moderator. The moderator layer between the counters was about 2 cm thick. The moderator either consisted of individual hexahedral prisms (the spacing between the parallel planes was 5 cm) or was a solid piece with channels for the counters and the source.

The detectors comprised several tens of counters arranged in several layers in the moderator around the neutron source (see Fig. 1a). Figure 1b schematically shows an assembly of charged-particle detectors arranged inside the neutron detector and used in correlation measurements.

The efficiency of the assemblies varied from 10 to 60%, depending on the geometry and the number of counters used. In many experiments, it was important that the sensitivity of the detector be constant in a wide range of neutron energies. In the experiment reported in [1], our group studied the response function for two assemblies of 39 proportional counters each for monoenergetic neutrons in the energy range 0.39–1.54 MeV. Experimental data on the sensitivity of neutron counting to variations in the neutron energy and moderator thickness led to the conclusion that constant efficiency of the detector at neutron energies up to 1.5 MeV could be maintained if the detector comprised at least four to five layers of modules consisting of a counter and a moderafor (the moderator surrounding the counter should be about 1 cm thick). The known spatial distribution of neutrons in systems with $^3$He counters in the moderator allows the average energy of neutrons from the source to be calculated [2] using the detector response functions obtained for monoenergetic sources.

The detector operates as follows: neutrons emitted from a source slow down to thermal energies and diffuse in the detector until they undergo absorption in the counters or the moderator or escape from the
The lifetime of neutrons in the detector is \( \tau = 15\text{–}25 \, \mu s \) for different configurations, being a combination of the moderation and diffusion times. The moderation time depends on the neutron energy and the detector configuration, while the diffusion time depends only on the detector geometry. Yet, the lifetime of neutrons in the detectors is virtually independent of the neutron energy since the contribution from the moderation time is small.

Neutron detectors with helium counters in the moderator allow angular correlations between neutrons to be measured despite the fact that it is thermal neutrons that are mainly detected. The angular resolution of the assembly schematically shown in Fig. 1 was experimentally measured for prompt neutrons from the spontaneous fission of \(^{248}\text{Cm}\) [3] and was found to be 20°.

**HELIUM-COUNTER NEUTRON DETECTORS USED TO STUDY DELAYED-NEUTRONS EMISSION**

The delayed-neutron-emission probability \((P_n)\) and the nuclear lifetime \((T_{1/2})\) are important measurable characteristics of the \(\beta\) decay of neutron-rich nuclei. Measurement of these quantities is important both for the investigation of nuclear structure and astrophysical processes and for applied research.

We carried out two experiments in the range of light nuclei using different neutron-counter assemblies. In one experiment [4], neutron emission was measured for the first time in \(^{26,27}\text{F}\) and \(^{29}\text{Ne}\) nuclei. Neutron-rich nuclei were produced by quasi-fragmentation of a beam of rare \(^{36}\text{S}^{16+}\) isotopes (0.5 \(\mu\)A, 2.8 GeV) on a tantalum target. The selected nuclei were implanted in a stack of silicon detectors placed in the focal plane of LISE3. These detectors were surrounded on three sides by 42 cylindrical proportional \(^{3}\text{He}\) counters, which were used to measure the probability of delayed-neutron emission. The total efficiency of this group of neutron counters was measured using the known \(^{30,31}\text{Na}\) sources of delayed neutrons and was found to be 14%.

In the other experiment [5] conducted at RIPS, \(T_{1/2}\) and \(P_n\) were measured for the neutron-rich Mg, Al, Si, and P isotopes. Neutron-rich nuclei were produced in the fragmentation of a \(^{48}\text{Ca}\) beam (70 \(A\) MeV) on \(^{9}\text{Be}\) and \(^{181}\text{Ta}\) targets. Measurement of delayed neutrons from \(^{15}\text{B}\) showed an efficiency of 11.4 ± 2.3% for the neutron detector with 42 proportional \(^{3}\text{He}\) counters placed in the moderator unit. Measurement of delayed neutrons from \(^{14}\text{B}\) with an energy (290 keV) smaller than that of neutrons from \(^{15}\text{B}\) (1.76, 2.81, 3.23, 4.32, and 4.75 MeV), showed a detector efficiency of 21.5 ± 4.2%. In further calcula-