STUDY OF SPONTANEOUS FISSION USING THE SFiNx SYSTEM*

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A new detector system consisting of 116 ^{3}He neutron counters and a DSSSD array was created. This system can be used to study spontaneous fission properties of short-lived heavy isotopes. The single neutron registration efficiency of the counter assembly was measured as $54.7 \pm 0.1\%$ with the ^{248}Cm source. Using the setup, new data were obtained for prompt neutron yields of ^{252}No isotope.

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1. Introduction

The spontaneous fission process defines the boundaries of the existence of heavy elements. At present, there is no complete nuclear fission model, and new experimental data are needed more than ever to improve the theoretical approaches.

Our group has accumulated significant experience in the study of the decay properties of heavy isotopes using the VASSILISA [1] and SHELS [2] recoil separators. Important data were obtained for neutron deficient isotopes of Fm [3, 4], No [5, 6] and Rf [7, 8] using a detector [9].

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The detector consisted of 54 ^{3}He counters of neutrons and a silicon detector array with a 60×60 mm^2 focal plane detector. To increase the collection of recoil nuclei by a factor of 3, we decided to install a new DSSSD assembly [10] inside the neutron detector with a large 100×100 mm^2 focal plane detector. It was necessary to completely change the counter's geometry.

2. Detector

The new detection system was named SFiNx (**S**pontaneous **Fi**ssion, **N**eutrons and **x**-rays, Fig. 1). The system consists of 116 ^{3}He counters of neutrons that surround the vacuum chamber with DSSSD. The characteristics and the number of ^{3}He counters are given in Table I.

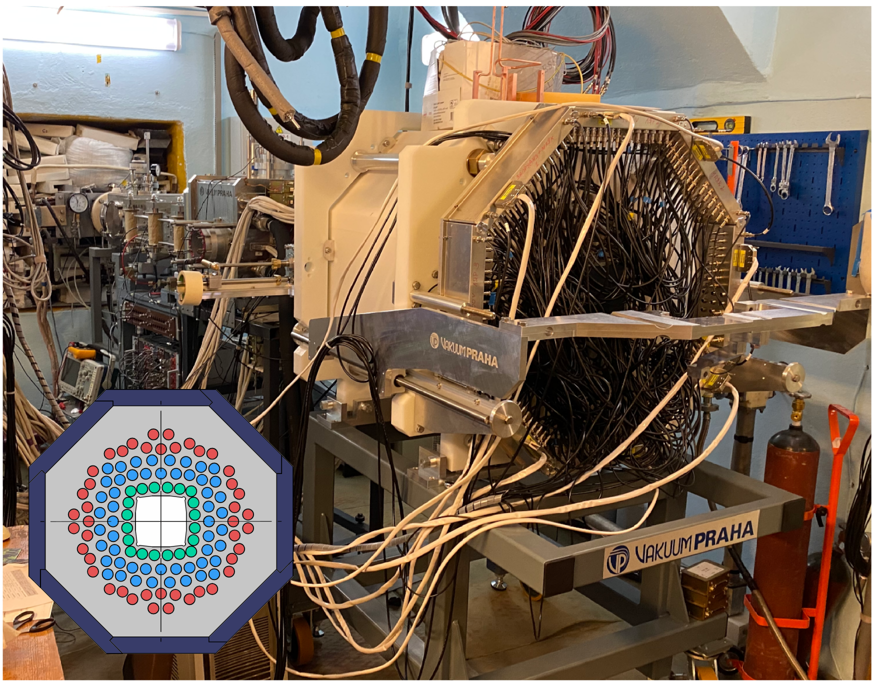

Fig. 1. Photograph of the SFiNx system. A schematic front view of the assembly is shown in the inset image.

The counters are placed in a polyethylene moderator in the form of a regular octagonal prism (height 630 mm, circumscribed circle diameter 762 mm). The outer side of the detector is covered with a 5%-borated polyethylene shield (thickness from 30 to 50 mm) to protect against background neutrons.

TABLE I

The main properties and the number of the different types of counters used in the detector. Layers are numbered relative to the central axis of the detector.

<table>
<tr><th>Layer</th><th>Number</th><th>Diameter [mm]</th><th>Active length [mm]</th><th>Operating voltage [V]</th><th>^{3}He pressure [atm]</th></tr>
<tr><td>1</td><td>20</td><td>32</td><td>530</td><td>1400</td><td rowspan="4">7</td></tr>
<tr><td>2</td><td>24</td><td rowspan="2">32</td><td rowspan="2">460</td><td rowspan="2">1775</td></tr>
<tr><td>3</td><td>28</td></tr>
<tr><td>4</td><td>44</td><td>30</td><td>585</td><td>1500</td></tr>
</table>

The single-neutron registration efficiency measured with ^{248}Cm source is $54.7 \pm 0.1\%$ (nonlinear least-squares method error). The average neutron lifetime in the setup is 18.4 ± 0.2 μs (exponent fitting error).

An array of DSSSD detectors inside the vacuum chamber is represented by a focal plane 128×128-strip detector (100×100 mm^2 area, 500 μm thickness) and 8 side 16×16-strip detectors (50×60 mm^2 area, 700 μm thickness) [10]. Silicon detectors allow for registering α-, β-particles, and fission fragments. Energy resolutions were measured using 8 MeV α-particles as 20 keV and 30 keV for the focal and side silicon detectors respectively.

3. Experiment

An experiment studying the ^{252}No spontaneous fission was carried out on a velocity filter SHELS [2]. The complete fusion reaction of accelerated ^{48}Ca^{18+} ions with the ^{206}Pb target nuclei was used. The thickness of the ^{206}PbS target was 350 μg/cm^2 (on 1.5 μm Ti backing) and the ^{206}Pb enrichment was about 97%. The beam energy in the middle of the target was about 215 ± 2 MeV ($2n$-evaporation channel maximum ~ 800 nb).

After passing through the separator, the recoil nuclei were implanted into the focal plane large DSSSD. The spontaneous fission branching fraction for ^{252}No is about 32%. When a fission fragment was detected in the focal DSSSD, the coincidence with the recoil nucleus that fell into the same pixel of the detector in the time window 1 ms–25 s ($\sim 10\ T_{1/2}$) was checked. After that, a search for neutrons was carried out in the time window of 128 μs. A total of 3260 reliable events of ^{252}No spontaneous fission were found.

The half-life of ^{252}No was determined as 2.44 ± 0.05 s (exponential fitting error) based on "recoil nucleus–fission fragment" correlations. The received half-life is in good agreement with the already measured values 2.44 ± 0.04 s [11] and 2.30 ± 0.22 s [12].

The prompt neutron multiplicity distribution of ^{252}No was measured and then the true distribution was restored by using the Tikhonov statistical regularisation method [13–15] (Fig. 2). The dispersion of the measured neutron multiplicity distribution is $\sigma_\nu^2 = 2.1$, whereas the dispersion of restored distribution is $\sigma_{\nu\mathrm{r}}^2 = 2.2$. The average number of neutrons per spontaneous fission act of ^{252}No was obtained as $\bar{\nu} = 4.25 \pm 0.09$ (contains the statistical error and the efficiency error of the neutron detector) and is in good agreement with previously measured values 4.15 ± 0.30 [16], 4.43 ± 0.45 [17], and 4.51 ± 0.25 [6]. The restored average number of neutrons per fission act is $\bar{\nu}_\mathrm{r} = 4.27 \pm 0.15$.

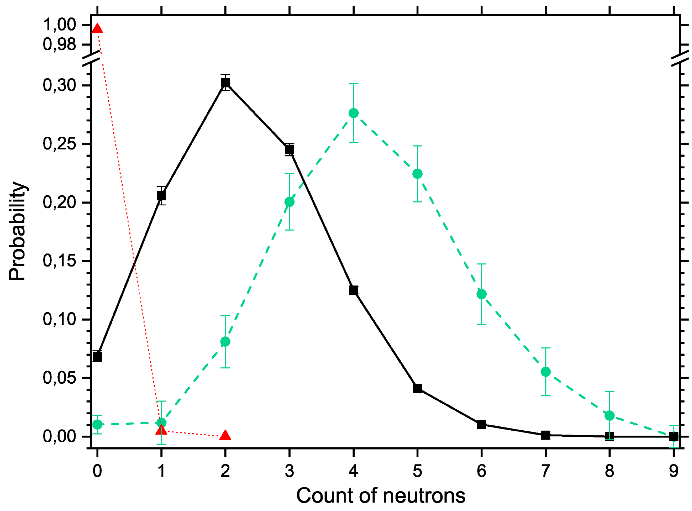

Fig. 2. Measured (squares) and restored (circles) prompt neutron multiplicity distributions of ^{252}No and background neutron spectra (triangles). Lines that connect the points have been added for clarity.

The background neutron multiplicity was estimated during the search for random coincidences of neutrons with ^{252}No α-particles in a time window of 128 μs.

4. Conclusion

The SFiNx setup contains 116 ^{3}He-filled proportional counters of neutrons and a DSSSD array has been created.

The new large focal plane DSSSD (100×100 mm^2) allowed to significantly increase the speed of statistics collection in comparison with our old neutron detector [9]. At the same time, the higher neutrons registration efficiency ($54.7 \pm 0.1\%$) of counter assembly allows us to better reconstruct the neutron multiplicity distributions by the statistical regularisation method.

As a result of the first experiment, new data were obtained on the prompt neutron yields from ^{252}No spontaneous fission.

The system currently has no analogs in the study of the spontaneous fission properties of short-lived heavy nuclei.

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