THE INVESTIGATION OF PROPERTIES OF SHORT-LIVED SF ISOTOPES (Z > 100) AT THE FOCAL PLANE OF VASSILISSA SEPARATOR

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For the registration of heavy ER in the focal plane of the VASSILISSA recoil separator, a new system with a 16-strip detector assembly, 60x60 mm^2 in size, and surrounded by backward detectors was developed. For the purpose of the study of spontaneous fission of short-lived SF isotopes in more detail a neutron detector consisting of 54 ^{3}He filled counters was mounted around the focal plane detector chamber of the separator. In the last years we carried out several experiments aimed to investigate properties of short-lived SF isotopes. The neutron-deficient isotope ^{246}Fm, produced in the complete fusion reaction ^{40}Ar + ^{208}Pb, was investigated in the year 2008. In the year 2010 we carried out an experiment aimed at investigating the properties of spontaneous fission of neutron deficient isotopes of ^{252}No and ^{244}Fm produced in the reaction with ^{48}Ca, ^{40}Ar-beam and ^{206}Pb-target. The main goal of the experiment was to determine the neutron multiplicity at spontaneous fission of these isotopes. From the experimental data for the first time the average number of neutrons per spontaneous fission of $^{244,246}Fm$ was determined ($\nu = 3.3\pm0.3$ and $\nu = 3.6\pm0.5$ respectively). The average number of neutrons from spontaneous fission of ^{252}No was equal to 4.06±0.12. This value is in good agreement with that from literature (4.15±0.30).

1. Introduction

Presently the available experimental information on the spontaneous fission of transfermium elements mainly concerns partial half lives. For Fm and No isotopes and for a few Md, Lr and Rf isotopes the total kinetic energy (TKE)

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and mass distributions of fission fragments from spontaneous fission were also accurately measured [1].

It should be noted, that the multiplicity distribution of prompt neutrons is one of the important characteristics of spontaneous fission. The number of neutrons emitted during fission directly depends on the degree of excitation of fission fragments and thus plays an important role in the restoration of the reaction energy balance and aids in exploration of the nuclear properties. On the other hand, the mean number of neutrons per spontaneous fission is a unique characteristic of the nucleus. Studies of the dependence of this number on the nuclear mass can significantly facilitate the identification of super-heavy nuclei obtained both in off-line experiments, where chemically isolated samples are placed inside the detector [2], and in on-line heavy ion beams experiments with using kinematic separators.

2. Experimental setup

Recoil in – flight separator VASSILISSA [3] is widely used for the synthesis and study of decay properties of heavy and superheavy nuclei. The time of flight of the ERs through the separator is about 2 μs. For the registration of heavy ER in the focal plane of the separator, a new system with a 16-strip detector assembly, 60x60 mm^2 in size, and surrounded by backward detectors was developed. Each strip in the focal plane assembly is position sensitive in the longitudinal direction. The value of 0.5 mm (FWHM) was obtained for sequential α - α decays, 0.8 mm for ER - α and 1.0 mm for ER - SF events using test reactions with ^{40}Ar, ^{48}Ca-beam and ^{176}Yb,^{164}Dy-targets. These values were obtained for energies of the implanted ER in the range from 4 to 15 MeV. A typical energy resolution of about 25 keV for the focal plane detector was obtained for α - particles in the energy range from 6 to 9 MeV. In the case of backward detectors, we obtained the energy resolution of about 150 keV. The reason for this degradation is the broad range of energy losses for escaping α - particles that hit the backward detectors over a wide range of angles.

For the purpose of the study of spontaneous fission of short-lived SF isotopes in more detail a neutron detector consisting of 54 ^{3}He filled counters was mounted around the focal plane detector chamber of VASSILISSA separator. Neutron detectors with ^{3}He filled counters placed in a moderator are typically used for experimental studies of prompt spontaneous fission neutrons because of their constant high efficiency in a broad range of neutron energy (in thick detectors). The main advantages of ^{3}He-based neutron detector system are a practically zero energy threshold, the absence of cross-talk and a low sensitivity to gamma rays. They have stable parameters during long measurements with low intrinsic background. The geometry of the detectors can be easily chosen for various experimental demands. The focal plane detector assembly was housed in a cylindrical vacuum chamber 120 mm in diameter. Neutron counters were placed around this chamber in three concentric rings (see fig. 1). To measure the efficiency of detection of one neutron and better simulate of the experimental condition the thin Al-foil (1.2 micron) with small quantity of curium chloride was placed inside the focal plane detector (intensity of source was equal 3-4 SF-events per second). The efficiency of neutron detector measured using ^{248}Cm source was 40±1 %.

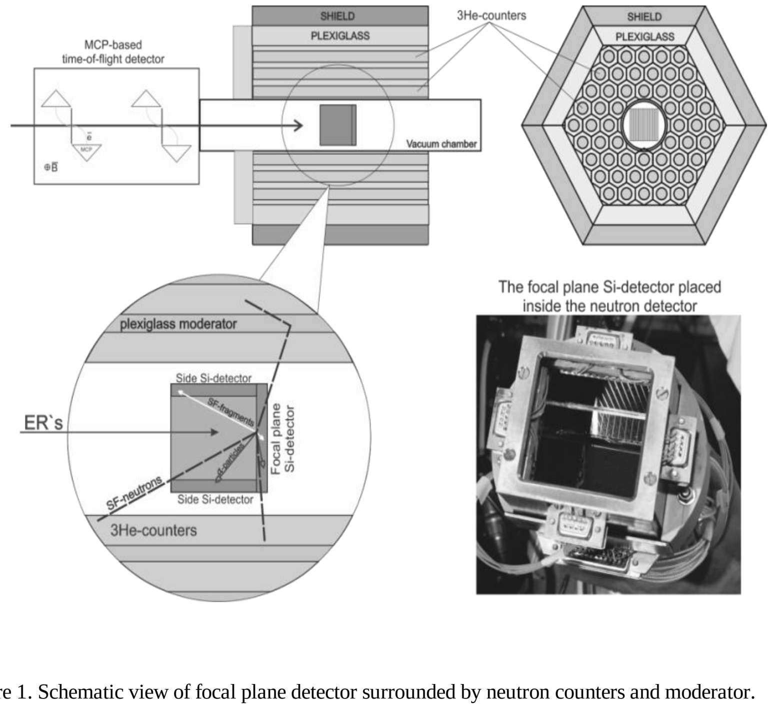

Figure 1. Schematic view of focal plane detector surrounded by neutron counters and moderator.

From the outside, neutron counters were covered by separate elements of organic glass and boron polyethylene, both of 5 cm in thickness, to slow down and capture background neutrons from the outside of the neutron counter. It allowed us to reduce the neutron background by one order of magnitude. When the ^{40}Ar beam intensity was about 0.5 pμA on the Faraday cup of experimental set up, the counting rate of background neutrons was equal to 100 Hz.

3. Experiments and future plans

In the last years we carried out several experiments aimed to investigate properties of short-lived SF isotopes.

Heavy-ion fusion reactions ^{48}Ca + ^{204}Pb and ^{44}Ca + ^{208}Pb leading to the same compound nucleus ^{252}No were run in attempts to produce new neutron-deficient spontaneous-fission isotopes of $^{249,250}No$ using the electrostatic separator VASSILISSA in the year 2002. Production cross-sections for the spontaneous fission activities with the half-lives 5.6 and 54 μs observed in these reactions are compared with the measured ones for the well-known isotopes of $^{251-255}No$ formed in the heavy-ion fusion reactions ^{48}Ca + ^{206}Pb and ^{48}Ca + ^{208}Pb [4].

In the year 2004 for experiments aimed at the study of spontaneous fission of transfermium nuclei improvements in the focal plane detector system of recoil separator VASSILISSA have been made. The first edition of neutron detector consisting of 72 ^{3}He filled counters has been mounted around the focal plane detector chamber. In the first experiment the multiplicity of prompt neutrons emitted in spontaneous fission of ^{252}No was measured [5]. The efficiency of detection of one neutron measured using a ^{248}Cm source, placed in the position of focal plane semiconductor detector, was 25%. A multiplicity distribution of prompt neutrons emitted in spontaneous fission of ^{252}No, formed in the reaction $^{48}Ca(^{206}Pb,2n)$, was measured in test experiments and was equal to 4.43± 0.45. This value is in good agreement with that from literature (4.15± 0.30) [6].

The neutron-deficient isotope ^{246}Fm, produced in the complete fusion reaction ^{40}Ar + ^{208}Pb, was investigated in the year 2008. The main goal of the experiment was to determine the neutron multiplicity at spontaneous fission of this isotope. For experiments aimed at the study of spontaneous fission of transfermium nuclei improvements in the focal plane detector system of recoil separator VASSILISSA have been made. A neutron detector consisting of 54

^{3}He-filled counters has been mounted around the focal plane detector chamber (Fig. 1). From the experimental data the average number of neutrons per spontaneous fission of ^{246}Fm was determined (ν = 3.6 ± 0.5) [7].

In the year 2010, we carried out an experiment aimed at investigating the properties of spontaneous fission of neutron deficient isotopes of ^{252}No and ^{244}Fm produced in the reaction with ^{48}Ca, ^{40}Ar-beams and ^{206}Pb-target. In the first experiment, 1700 events of ^{252}No spontaneous fission were detected over a 24h exposure, which allowed us to measure the multiplicity distributions of neutrons with a high degree of accuracy and to test operation of the entire detector system. The average number of neutrons per one SF of ^{252}No was determined to be ν = 4.06 ± 0.12. The determined value is in good agreement with the earlier results [5,6].

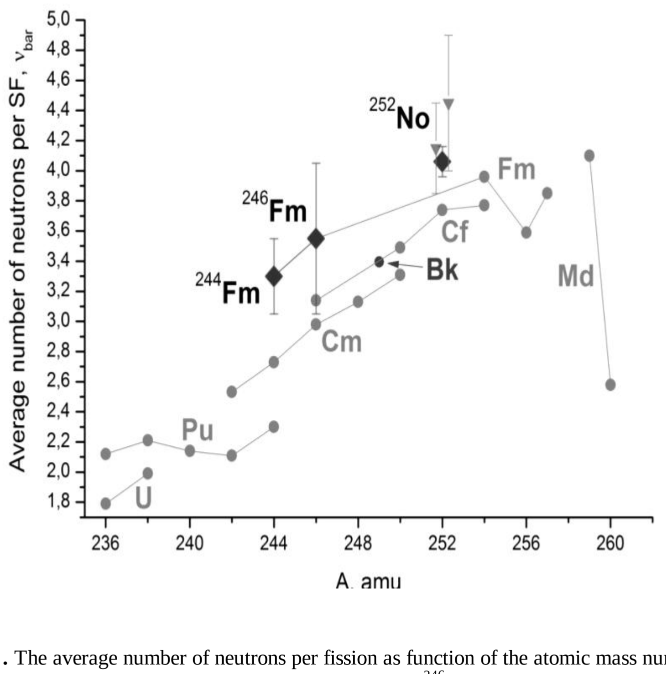

Figure 2. . The average number of neutrons per fission as function of the atomic mass number. The last results measured at VASSILISSA is shown as “diamonds”. ^{246}Fm (ν = 3.6 ± 0.5) – work [7], ^{252}No (ν = 4.06 ± 0.12) and ^{244}Fm (ν = 3.3 ± 0.3) – this work.

The next experiment was done to study the properties of ^{244}Fm formed in the 2*n* channel of the complete fusion reaction ^{40}Ar + ^{206}Pb. The cross section of the recoil nucleus production reaction is about 3 nb ($E_{1/2}$ = 186 MeV). The experiment lasted for 7 days, 212 events pertaining to ^{244}Fm spontaneous fission were registered. The average number of neutrons was determined as ν = 3.3 ± 0.3. The systematic of average neutron numbers per SF is presented in the Fig. 2.

We propose to undertake a comprehensive study of SF in heavy short lived neutron deficient isotopes is planned including in the lighter Cf –No region. In the near future, these experiments can be carried out at Dubna after the modernization of VASSILISSA.

Acknowledgments

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References

1. Hulet E K *Sov. Journ. of Nucl. Phys.* **57** 1165, (1994).
2. Oganessian Yu Ts et al., *Phys. Rev.* **B72** 034611, (2005).
3. Yeremin A V et. al, *Phys. At. Nucl.* **66** 1042, (2003).
4. Belozerov A V et. al,. *Eur. Phys. J.,* **A16** 447, (2003).
5. Yeremin A V et. al., *Nucl. Instr. Meth.* **A539** 441, (2005).
6. Lazarev Yu A et. al., *Phys. Lett.,* **B52** 321, (1974).
7. Svirikhin A I et, al,. *Eur. Phys. J.,* **A44** 393, (2010).