Neutron multiplicity at spontaneous fission of $^{246}$Fm

A.I. Svirikhin$^{1, a}$, V.N. Dushin$^2$, M.L. Chelnokov$^1$, V.I. Chepigin$^1$, I.N. Izosimov$^1$, D.E. Katrasev$^1$, O.N. Malyshev$^1$, A. Minkova$^3$, A.G. Popeko$^1$, E.A. Sokol$^1$, and A.V. Yeremin$^1$

$^1$ Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia
$^2$ V.G. Khlopin Radium Institute, 194021 St. Petersburg, Russia
$^3$ Institute for Nuclear Research and Nuclear Energy, 1784 Sofia, Bulgaria

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Abstract. The neutron-deficient isotope $^{246}$Fm, produced in the complete fusion reaction $^{40}$Ar$^+$+$^{208}$Pb, was investigated. 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. From the experimental data the average number of neutrons per spontaneous fission of $^{246}$Fm was determined ($\bar{\nu}=3.55\pm0.5$).

1 Introduction

Presently, the available experimental information on the spontaneous fission of transmutation 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) 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 most important characteristics of spontaneous fission. Experimental measurements of this parameter are very important for the theory, especially for the predictions of the spontaneous-fission properties of isotopes of elements close to the “island of stability”. For example, the predictions of the average number of prompt neutrons per fission $\bar{\nu}$ for the superheavy isotope $^{298}$Hg was estimated to be $\bar{\nu}=8$ [2], $\bar{\nu}=8-10$ [3] and $\bar{\nu}=5$ (in the case of symmetric fission) and $\bar{\nu}=12$ (in the case of asymmetric fission) [4].

In the past the multiplicity distribution of prompt neutrons emitted in spontaneous fission was measured for elements not heavier than fermium [5], and only one measurement was performed for the isotope $^{252}$No [6] (see fig. 1) with the use of the off-line and mechanical separation system. The mechanical experimental set-ups, used in these experiments had critical limitations in the half-life measurements, as well as in background conditions, due to rather low suppression factors of unwanted reaction products and the necessity to place detectors close to the target position.

In-flight recoil separators are now widely used for the synthesis and study of the decay properties of transmutation nuclei [7]. A high level of suppression of beam particles and unwanted reaction products, having high production rates in the region of charge and mass of target nuclei, has been achieved. The transportation time amounts to a few microseconds allowing the investigation of very short-lived isotopes. The focal-plane detector assemblies can have a well structure [8]. This provides the possibility to measure the energy of both fission fragments (TKE) from the spontaneous fission of the implanted evaporation residues (ERs), when one of the fission fragments is registered by the focal-plane detector and the second one by the side detector.

First measurements of the average number of prompt neutrons per fission at the focal-plane detector system of the recoil separator VASSILISSA [9] has been performed for $^{252}$No (see fig. 1), formed in the reaction $^{48}$Ca($^{206}$Pb, 2$n$) [10].

2 Experimental details

The $^{40}$Ar beam was delivered by the FLNR Dubna U400 cyclotron. The intensity of the beam passing through the separator target was typically $(2-3) \times 10^{12}$ s$^{-1}$. The projectile energy of $186 \pm 2$ MeV was chosen to be close...
The average number of neutrons per fission as a function of the atomic mass number $A$. The result for $^{252}\text{No}$ measured at VASSILISSA is shown by the star ($\bar{\nu} = 4.43 \pm 0.45$), the result of this work is shown by the black square ($\bar{\nu} = 3.55 \pm 0.5$).

to the maximum of the 2n evaporation channel excitation function (see fig. 2). The beam energy was determined by measuring the energy of the ions with a time-of-flight technique. The measured energy accuracy was about 1% (FWHM). Enriched lead material was used for the preparation of the target: $^{208}\text{Pb}$, 97.2% ($^{206}\text{Pb}$, 1.0% and $^{207}\text{Pb}$, 1.8%). Targets of $^{208}\text{Pb}$ with average thicknesses of 280 $\mu$g/cm$^2$ were fabricated by evaporation of the metal onto the 0.8 mg/cm$^2$ Al backing foils. The target segments were mounted on a disk rotating perpendicularly to the beam direction.

The produced evaporation residues were separated in flight by the VASSILISSA electrostatic separator [9]. The time of flight of the ERs through the separator, a new system with a 16-strip detector assembly, 60 x 60 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 position resolution along each strip was measured using the test $^{40}\text{Ar} + ^{176}\text{Yb}$ and $^{40}\text{Ar} + ^{164}\text{Dy}$ reactions. The value of 0.5 mm (FWHM) was obtained for sequential $\alpha$-$\alpha$ decays, 0.8 mm for ER-$\alpha$ and 1.0 mm for ER-SF events. 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 $\alpha$-particles in the energy range from 6 to 9 MeV. In the case of backward detectors, we obtained an energy resolution of about 150 keV. The reason for this degradation is the broad range of energy losses for escaping $\alpha$-particles that hit the backward detectors over a wide range of angles.

For the purpose of the study of spontaneous fission of the isotope $^{246}\text{Fm}$ in more detail a neutron detector consisting of 54 $^3\text{He}$-filled counters was mounted around the focal-plane detector chamber of the VASSILISSA separator. Neutron detectors with $^3\text{He}$-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 the $^3\text{He}$-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 of 120 mm in diameter. Neutron counters were placed around this chamber in three concentric rings (see fig. 3) 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. This allowed us to reduce the neutron background by one order of magnitude. When the $^{40}\text{Ar}$ beam intensity was about 0.5 $\mu$A on the