MULTIPLICITY OF PROMPT NEUTRONS FROM SPONTANEOUS FISSION OF THE ISOTOPE $^{252}102$

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The average number of prompt neutrons, $\bar{\nu}$, emitted in the spontaneous fission of the isotope of element 102 with mass number 252 and a half-life of 2.4 s has been measured to be 4.15±0.30 relative to $\bar{\nu}$ = 2.69±0.01 for spontaneous fission of ^{244}Cm.

Spontaneous fission, which is an extremely rare process for uranium nuclei, is one of the major modes of radioactive decay of nuclei with $Z \geqslant 100$. A large number of even-even isotopes of fermium and heavier elements decay solely by spontaneous fission. Even in the case of some odd heavy enough nuclei such as $^{261}105$ [1], $^{259}104$ [2] and $^{259}102$ [3] the spontaneous fission probability may be comparable with the probability for α-particle decay. However, except for the data on the partial half-lives, no experimental information is presently available about the spontaneous fission and low-energy fission as a whole for nuclei heavier than fermium. On the other hand, fission of fermium isotopes has just been the subject of extensive studies in recent years [4–12].

It is unlikely that such detailed information about the fission process in the transfermium region can be obtained in the near future because of the considerable experimental difficulties involved, e.g., the lifetimes of isotopes with $Z > 100$ lie within several seconds. This necessitates on-line measurements at a heavy ion beam, the latter being the only means of penetrating to the region of elements with $Z > 100$. In addition, the accessible quantities of nuclei under investigation decrease as sharply as their lifetimes do. At the same time, some average fission characteristics of a number of short-lived isotopes can be established rather accurately.

The present paper deals with the first attempt to obtain this kind of information. In particular, we tried to determine the multiplicity of prompt neutrons from spontaneous fission of the isotope of element 102 with mass number 252.

The $^{252}102$ isotope has a half-life of 2.4±0.2 s and a spontaneous fission branch of about 30% [1, 13]. This isotope was produced previously [1] by means of the ^{235}U(^{22}Ne, 5n)^{252}102 reaction, with a cross section which reaches a maximum value of 1.5×10^{-32} cm^2 for the spontaneous fission branch at an ion energy of 117 MeV. The overall effective cross section for the formation of fission fragments produced by background reactions does not exceed 10^{-34} cm^2 in this case [1].

The experiments were carried out using an external ion beam from the 310 cm cyclotron of the JINR Laboratory of Nuclear Reactions. An enriched ^{235}U target, 1 mg/cm^2 thick, was bombarded by a ^{22}Ne beam with an energy of 117 MeV and intensity of about 10^{12} particles per second. Recoil nuclei were collected on a thin aluminium catcher foil. The catcher foil was in shuttle motion between the target and the effective centre of a large fission neutron detector, where a surface-barrier Si(Au) detector with an active area of 12 cm^2 was placed to detect the $^{252}102$ fission fragments. Another Si(Au) detector was used for the continuous calibration of the neutron detector by means of a ^{244}cm source. The catcher foil was set in motion by a pneumatic system, which was capable of transporting it over a distance of 0.5 m in 0.2 s. In each of the extreme positions, i.e., in front of the target and in front of the Si(Au) detector, the catcher foil stopped for 3.6 s. Thus collecting recoil nuclei on the catcher foil alternated with the spontaneous fission detection. At the time of transport and detection the accelerator was switched off.

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Neutrons from both the $^{252}102$ isotope being studied and the calibrating ^{244}Cm isotope were detected alternatively in coincidence with the fission fragments. The neutron detector [14] consisted of 36 proportional ^{3}He-filled high-pressure counters inserted in a plexiglas moderator. The Si(Au) detector pulses due to fission fragments escaping from the investigated or calibrating nucleus triggered a 130 μs gate and neutrons were counted during this gating time. The 130 μs gate was also triggered by a slow-rate pulser imitating fission fragments, to obtain the distribution of the multiplicities of background neutrons escaping from the delayed neutron emitters. The latter may be produced in both nucleon transfer reactions and fission of ^{235}U induced by ^{22}Ne ions. For each spontaneous fission event attributed to $^{252}102$, we determined the amplitude of one of the fission fragments, the time of the occurrence of the fission fragment as counted from the moment when the catcher foil stopped in front of the Si(Au) detector, and the number of neutrons detected. For spontaneous fission of ^{244}Cm, the amplitude of the fission fragment and the neutron number were determined, while only the latter was determined for background events. The registering electronics was connected on line via a program-controlled channel to the mini-computer TPA-1001 which provided for the accumulation and preliminary handling of the information [14]. Although the accelerator was switched off during the acceleration cycle, the background rate was fairly high; on the average 0.66 background neutrons per fission were detected. The main sources of background are the neutron-rich isotopes of light elements, which may be delayed neutron emitters, in particular ^{17}N ($T_{1/2}$ = 4.15 s). These nuclei are produced in nucleon transfer reactions on any material surrounding the target with a cross section of about 10^{-26} cm^2. In order to reduce the background, the neutron detector was separated from the reaction chamber by a paraffin-boron layer and surrounded by cadmium layers. Since the production cross section for ^{17}N on carbon is comparatively small, graphite was extensively used in the design of the reaction chamber.

In accordance with expectations, we observed about 10 spontaneous fissions per hour at the catcher foil. The total number of fissions detected was 178. Their time distribution corresponds to the half-life of $^{252}102$.

The experimental data obtained are presented in fig. 1. The histogram shows the distribution of the 178 spontaneous fission events over the number of neutrons detected, n. Fig. 1 also shows the normalized distribution of the multiplicities of neutrons detected at spontaneous fission of $^{252}102$ (before subtracting the background), (F'_n), and the distribution of the multiplicities of background neutrons, (B_n). These data indicate that on the average 2.37 neutrons were detected per spontaneous fission event, of which 0.66 should be attributed to the background. The neutron detection efficiency ϵ, determined from the known value of $\bar{\nu}$ = 2.69±0.01 for spontaneous fission of ^{244}Cm, was 41.4% to an accuracy of 1.5%. Since the fission neutron spectrum for $^{252}102$ is unknown, and the efficiency of this kind of detectors very weakly depends on neutron energy, the ϵ value for $^{252}102$ was also taken to be equal to 41.4%. After introducing a small correction for loss due to the finite electronics resolving time, the average number of prompt neutrons per spontaneous fission event was determined to be

$$\bar{\nu}(^{252}102) = 4.15 \pm 0.30.$$

In an attempt to establish which place this result occupies in the systematics of $\bar{\nu}$ numbers for spontaneous fission [15], one should note the following. In going from ^{252}Cf, for which $\bar{\nu}$ = 3.735±0.014, to the heavy fermium isotopes ^{256}Fm ($\bar{\nu}$ = 3.73±0.18) [8] and ^{257}Fm ($\bar{\nu}$ = 3.77±0.02) [6, 9] the average number of neutrons remains practically constant, the increase in Z by 4 units leading to the comparatively light isotope of element 102 apparently results in a noticeable increase in $\bar{\nu}$.

The experimental data also permit a determination of the distribution of neutron numbers, (P_ν). For this purpose one should first take the background into account very thoroughly and obtain the distribution (F_n) giving the detected multiplicity of only fission neutrons. This problem, in principle, reduces to the solution of the following system of equations

$$\sum_{i=0}^{n} B_i F_{n-i} = F'_n, \qquad n = 0, 1, 2, \dots, n_{\max},$$

where F'_n is the directly observed probability for detecting n neutrons per fission event, and B_i is the probability for detecting i background neutrons. Fur-

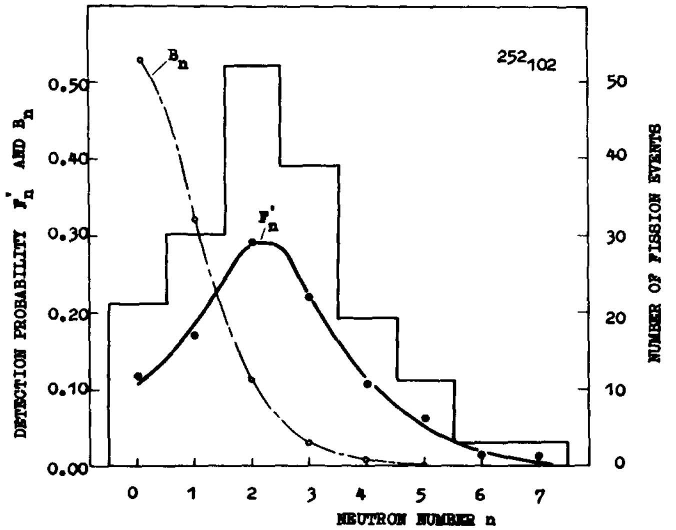

Fig. 1. Distribution of $^{252}102$ spontaneous fission events over the number of neutrons detected (histogram, the right-hand scale). The normalized multiplicity distributions of the detected neutrons for $^{252}102$ (solid curve) and of the background (dash-dotted curve).

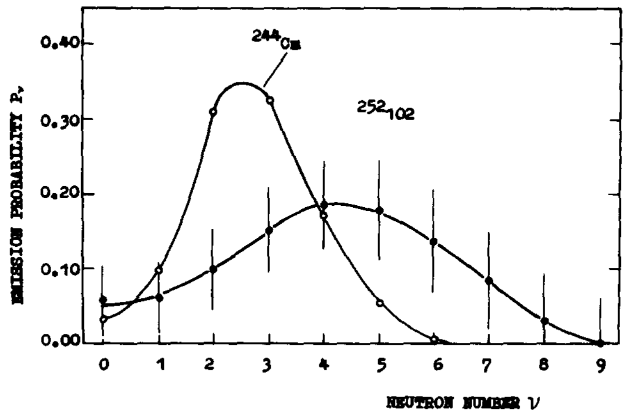

Fig. 2. Multiplicity distributions of prompt neutrons emitted in spontaneous fission of $^{252}102$ and ^{244}Cm.

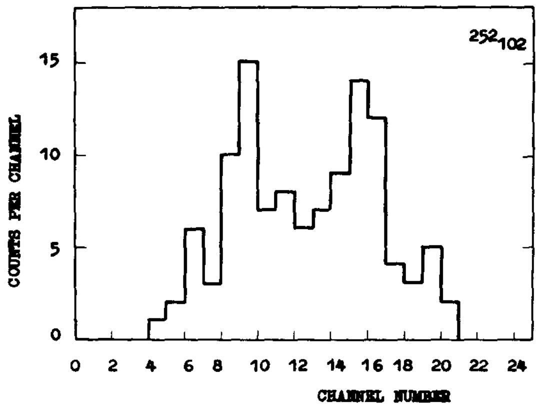

Fig. 3. Amplitude spectrum of spontaneous fission fragments from $^{252}102$.

ther, by taking the detector efficiency ϵ into account by the statistical regularization method [16], one can establish the real distribution of neutron number ν, emitted by the fissioning nucleus. The distribution (P_ν) obtained for spontaneous fission of $^{252}102$ in this manner is presented in fig. 2. The variance of this distribution is estimated to be $\sigma_\nu^2 \approx 4$. For comparison, fig. 2 shows the distribution of fission neutron numbers for ^{244}Cm, as determined in a previous paper [15]. It follows from fig. 2 that the distribution of neutron number for $^{252}102$ is much wider than that for ^{244}Cm. Unfortunately low statistics and difficulties involved in taking account of significant background do not allow to make more definite quantitative conclusions about the width of this distribution.

It is interesting to note that the amplitude spectrum of the detected fragments from spontaneous fission of $^{252}102$ (fig. 3) exhibits two fairly distinct groups of amplitudes in spite of the fact that the effective thickness of the target determined by the range of recoil nuclei in the catcher foil was 0.4–0.5 mg/cm^2, while the geometric efficiency for detecting fission fragments was close to 2π. It is not excluded that this shape of the amplitude spectrum of fission fragments may be due to the noticeable asymmetry in spontaneous fission of $^{252}102$.

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