Eur. Phys. J. A **7**, 189–195 (2000)

THE EUROPEAN
PHYSICAL JOURNAL A

Study of the Mo-Ba partition in ^{252}Cf spontaneous fission

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Received: 21 July 1999 / Revised version: 19 November 1999
Communicated by D. Schwalm

Abstract. Measurements of fission fragment yields and neutron multiplicities have been carried out for the Mo-Ba fragment pairs in the spontaneous fission of ^{252}Cf, using the γ-ray spectroscopy technique to analyze γ-γ-γ coincidence data. Prompt γ-ray multiplicities were also measured as a function of the number of neutrons emitted in the fission process leading to the Mo-Ba partition. We do not observe the enhancement in the yields of events with high neutron emission multiplicity ($\nu_n \geq 7$) that has been associated to a second fission mode leading to the production of hyperdeformed Ba fragments, as reported in some earlier studies. The average γ-ray multiplicity is found to be rather weakly dependent on the number of neutrons emitted in the fission process.

PACS. 27.70.+q $150 \leq A \leq 189$ – 21.10.Re Collective levels – 25.70.Gh Compound nucleus

1 Introduction

Extensive investigations of fission fragment charge, mass and energy distributions in spontaneous fission of ^{252}Cf have been carried out in the past, providing valuable information on the dynamics of the fission process and, in particular, on the sharing of the total released energy among different degrees of freedom (thermal, deformation and total kinetic (TKE) energy) [1]. The excited fission fragments emit prompt neutrons and γ-rays which carry information on their structural properties and on the dynamics of the fission process. For a given TKE, the number of prompt neutrons emitted in a fission event is directly related to the thermal excitation energy of the fragments.

In some recent gamma-ray spectroscopy studies in ^{252}Cf spontaneous fission, enhanced cross-sections have been reported [2,3] for the production of Ba-Mo fragment pairs associated with high neutron emission multiplicities (ν_n) of 7 to 10 neutrons. To explain this observation, it was inferred that the ^{144,145,146}Ba fragments at scission exhibit an unusually large deformation characterized by a 3:1 axis ratio, while their Mo partners have a normal, only slightly deformed shape. Assuming that the two nuclei separate along their major axis, such a dinuclear configuration would be associated with a much lower total kinetic energy, as compared to the case corresponding to nearly spherical shapes. Consequently, the fission fragments would have unusually high excitation energies, thus evaporating a larger number of neutrons in their subsequent decay.

The enhanced yield corresponding to the events characterised by large neutron multiplicities ($\nu_n \geq 7$), was interpreted as due to a second fission mode leading to the population of hyperdeformed (HD) Ba nuclei. This interpretation was also substantiated by the measurement of the average fragment spin as a function of neutron multiplicity, where a strong correlation was observed between the average fragment spin and neutron multiplicity. The results reported in [2,3] stimulated wide interest from the experimental as well as theoretical point of view [4,5], since the search for HD structures in nuclei is at the forefront of the nuclear physics research. Indications for the population of HD structures were evidenced in the past in the actinide nuclei fission [6]. Furthermore, hyperdeformed rotational bands have also been investigated by using in-beam γ-ray techniques in the mass region of A=150-160, where they have been predicted [7,8] to occur at very high angular momenta (J$\geq$70 $\hbar$). The experiments performed so far in the Dy [9,10] as well as in the Gd [11,12] regions do not provide any conclusive evidence for hyperdeformed shapes produced in heavy ion induced reactions.

The occurrence of HD structures of fragments produced in the ^{252}Cf spontaneous fission is of great interest for the understanding of the fission dynamics as well as for nuclear structure studies. Therefore, any further attempt to extend the information presented in [2,3] on the fission products is worth pursuing. In the present work, we have carried out new measurements of the multiplicity distribution of the prompt neutrons emitted in the spontaneous fission of the ^{252}Cf by using the discrete γ-ray spectroscopy technique. Furthermore, the total γ-ray multiplicity has been measured for the first time as a function of the neutron multiplicity for the Ba-Mo fission fragment pairs.

2 Experimental Set-up

The experiment was performed at the GASP spectrometer [13], which consists of an array of 40 large volume Compton suppressed germanium detectors (HPGe) positioned in 7 rings at different angles with respect to the beam direction and an inner ball of 80 Bismuth Germanate (BGO) scintillators. A sealed weak ^{252}Cf source ($\sim 10^4$ fission$\times$s^{-1}) was placed at the center of the GASP array. The counting rate of the inner ball was 15 kHz for fold k$\geq$2 and the corresponding counting rate of each HPGe detector was $\sim$300 Hz. Data were collected during three weeks run with the condition of having fold k$\geq$2 in the inner ball elements in coincidence with at least one HPGe detector. This condition assures a good suppression of the γ-ray cascades originating from the released radioactivity in the source. Some of the results obtained in the present experiment for the production of energetic γ-rays in ^{252}Cf fission have already been published [14]. In the present paper, we discuss the results on the yields of specific Mo-Ba fragment pairs measured from the coincident γ-ray spectroscopic measurements.

In the off-line analysis, a total number of 0.8×10^9 5-fold events (2 γ-rays in the BGO inner ball and 3 γ-rays in the HPGe detectors) were considered. In this data set, prompt HPGe γ-ray events were selected by requiring a gate of 40 nsec in the TDC spectra started by the inner ball. The overall energy resolution in the total projection spectrum of the HPGe detectors was found to be about 1.8 keV at E_γ=331 keV. The HPGe prompt γ-γ-γ coincidences were used to build E_γ-E_γ matrices and E_γ-E_γ-E_γ cubes. To study the γ-ray multiplicities associated with different selections of final fission fragments, E_γ-E_γ-k cubes were used by gating on γ-ray transitions in specific fission products.

3 Method of data analysis

The triple γ-γ-γ coincidence data were analyzed to extract the relative production cross-section for a given pair of final fragments. A double gate on two coincident γ-rays in a given nucleus (A_1, Z_1) (usually the $2^+ \rightarrow 0^+$ and $4^+ \rightarrow 2^+$ transitions in case of an even-even product), was used to obtain a γ-ray spectrum where the transitions in the partner fragments were clearly identified. The intensities of the γ-ray transitions in the partners (usually the $2^+ \rightarrow 0^+$ lines in case of even-even nuclei) were corrected for the detection efficiencies of the γ-rays involved in the selection and used to extract the relative yields for the considered partitions.

For a given pair of fission products (A_1, Z_1) and (A_2, Z_2) with Z_1+Z_2=98, the number of emitted neutrons is uniquely defined as ν_n=252-(A_2+A_1). As a result, the partition yields uniquely determine the distributions of the neutron multiplicity associated with the nucleus (A_1, Z_1). The total neutron multiplicity distribution for the Ba-Mo fission channel was then obtained by summing the probabilities for the same number of emitted neutrons associated with the different (Ba or Mo) isotopes. The data were then normalized to the results presented in [3]. This procedure is based on the assumption that the intensity of the transition used to extract the production yield is proportional to the total yield of the fragment. Such an assumption is certainly justified for even-even nuclei. In case of odd nuclei, the decay paths are usually much more complicated and the complete spectroscopic informations are not available in some cases [15]. The reconstruction of the total production yield in the present analysis was obtained by using the two most intense lines to identify a particular odd nucleus.

In this work, the results on production yields and neutron multiplicity distribution for the Mo-Ba fission channel are reported. The Mo-Ba partition is the strongest channel in the ^{252}Cf spontaneous fission, accounting for $\sim$17% of the fission decay. In order to verify the extent to which the results are influenced by the chosen gating transitions and by the available spectroscopic information, the data analysis was performed in two ways by double gating on the Mo as well as on the Ba isotopes. As a further check, the transition energies used as first and second gates in the nucleus (A_1, Z_1) were in all cases interchanged.

It has to be stressed that, in this study, we consider events in which at least 5 γ-rays have been detected in the GASP array (2 in the BGO inner ball and 3 in the HPGe detectors). This condition minimizes the background due to radioactive decays of the fission products, which involve rather short γ-ray cascades, and allows to use 3 γ-ray transitions to tag any fission fragment pair. It is believed that the bias introduced by this selection in the prompt fission γ-ray data is rather small in the case of the Mo-Ba channel, since the associated average γ-ray fold measured with the above trigger conditions in the GASP inner ball is $<k>\sim 8$ for all fragment pairs, as it will be shown in Sect. 4.2.

4 Results and discussion

The γ-ray transitions used to select different final fission fragments (A_1, Z_1) in the Mo-Ba partition are listed in Table 1. In most cases, the double gated γ-ray spectrum with appropriate background subtraction shows clearly the absence of contributions from nuclei other than the tagged isotopes (A_1, Z_1) and the correlated fragments ($A_{2,\nu}$, Z_2), where $A_{2,\nu}$=252-A_1-ν, and Z_2=98-Z_1. As an example, we show in Fig. 1a the spectrum obtained with the double gate (E_γ=199 and 331 keV) on the ^{144}Ba nucleus. The γ-ray spectrum is seen to be dominated by transitions in the Mo isotopes corresponding to the emission of 2,4 neutrons.

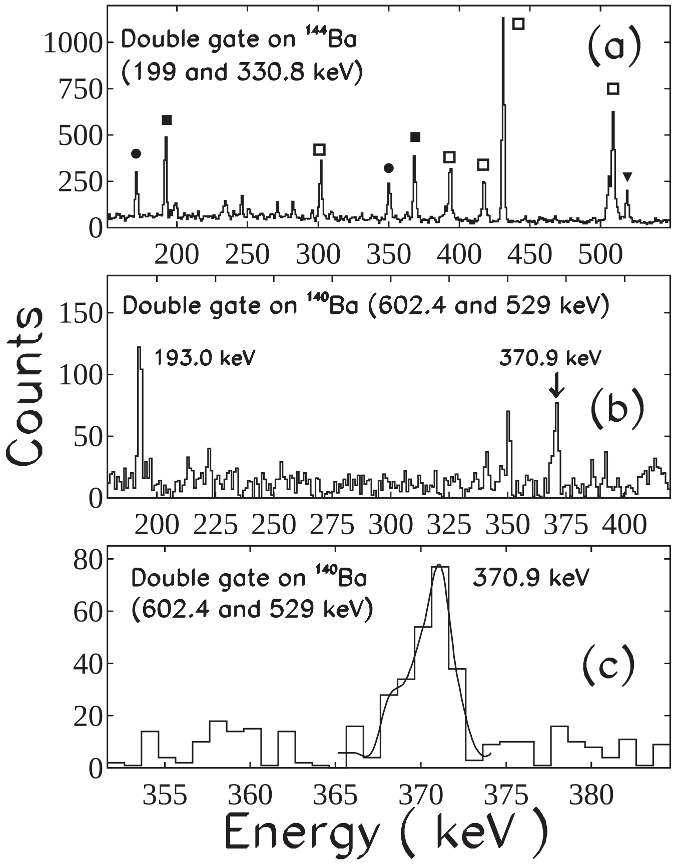


Fig. 1. γ-ray spectra obtained with a double gate, background subtracted, on transitions in ^{144}Ba (a) or ^{140}Ba (b and c). Marked transitions in (a) are from: ^{144}Ba (open squares), ^{106}Mo (full dots), ^{104}Mo and ^{108}Mo (full squares), ^{104}Mo only (full triangle). For further details see the text

Table 1. γ-ray transitions used to select the different final fission fragments in the Ba-Mo partition. For more details see the text

Nuclei	E^1_γ	E^2_γ
^{140}Ba	602.3	530
^{142}Ba	359.6	475
^{143}Ba	492.9	342.9
^{144}Ba	199.3	330.7
^{145}Ba	248.8	373.8
^{146}Ba	181.0	332.7
^{148}Ba	281.8	384.8
^{102}Mo	296.6	447.1
^{103}Mo	251.1	102.4
^{104}Mo	192.8	368.9
^{105}Mo	94.5	137.7
^{106}Mo	172.1	351.1
^{107}Mo	348.4	406.0
^{108}Mo	192.9	370.8

In some cases, however, the tagging of a given nucleus has to be performed with great care due to the presence of transitions having the same (or nearly the same) energy in two or more isotopes. An important example of this situation is the case of the ^{104}Mo and ^{108}Mo nuclei. The $2^+ \rightarrow 0^+$ transitions have, indeed, almost the same energy in the two nuclei: 192.8 keV and 192.9 keV for ^{104}Mo and ^{108}Mo respectively. In addition, the $4^+ \rightarrow 2^+$ transitions are also very close in energy: 368.9 keV and 370.8 keV for ^{104}Mo and ^{108}Mo respectively. In the present data analysis, it is of extreme importance to clearly distinguish the yields for partitions involving ^{104}Mo and ^{108}Mo fragments, since the ^{104}Mo-^{140}Ba and ^{104}Mo-^{138}Ba channels correspond to the rare ν_n=8 and ν_n=10 neutron multiplicity events, whereas the ^{108}Mo-^{140}Ba and ^{108}Mo-^{138}Ba partitions are associated with the more probable 4 and 6 neutron emission channels.

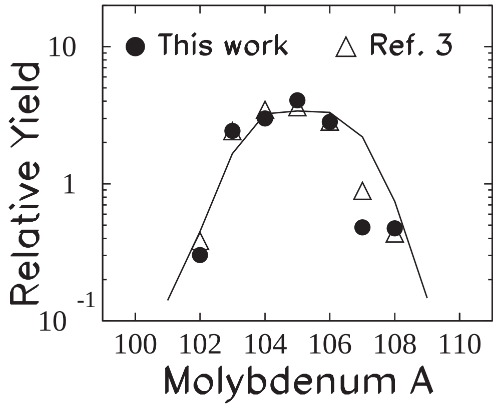
In these two cases, we have first gated on the Ba isotopes of interest. As an example, to obtain the yields of the ^{140}Ba-^{108}Mo (ν_n=4) and ^{140}Ba-^{104}Mo (ν_n=8) partitions, we tag the ^{140}Ba nucleus by the coincident 602 keV ($2^+ \rightarrow 0^+$) and 530 keV ($4^+ \rightarrow 2^+$) transitions. The associated double gated spectrum is shown in Fig. 1b. Since the contributions to the intensity of the 193 keV line from the two ^{104}Mo and ^{108}Mo partner nuclei could not be distinguished, we obtained the yield ratio for these products using the $4^+ \rightarrow 2^+$ γ-rays which are separated by 1.9 keV. In fact, in the expansion of the ^{140}Ba double gated spectrum as shown in Fig.1c, the line at 370 keV appears clearly to be a doublet. The yield ratio of ^{104}Mo and ^{108}Mo nuclei in coincidence with the ^{140}Ba nucleus was then calculated with a two-gaussian fit, as shown in the same figure (Fig. 1c). In this way, the yield for the ^{108}Mo-^{140}Ba partition (ν_n=4) was found to be 2.8 times larger than the ^{104}Mo-^{140}Ba channel (ν_n=8). This is also as per the expectations that the relative yields for many partitions in the ^{252}Cf fission exhibit a maximum at ν_n = 3 - 4 [16].

We note that this result is substantially different from the ratio 0.33 reported in [3] where the 8n channel yield is 3 times larger with respect to the 4n one. It has to be noted that in [3], the overestimation of the probability for this specific, i.e. the ^{104}Mo-^{140}Ba 8n channel strongly influences the total probability for the 8n emission. The ^{104}Mo-^{140}Ba partition accounts, in fact, for 2/3 of the total 8n channel strength reported in that work.

4.1 Fission fragment yields and neutron multiplicity

The total relative production yield of the Ba and the Mo isotopes was obtained by summing over the single partition yields. The yield distributions for Ba and Mo isotopes are shown in Fig. 2. The data are compared with results from [3] and with semi-empirical estimates of the ^{252}Cf fission product yields [17]. The results of the present study agree quite well with both these semi-empirical estimates and the experimental data from [3], demonstrating that our analysis reproduces the known gross features of the isotopic distributions.

In Fig. 3, we show the total neutron multiplicity distribution for the Mo-Ba partition. As discussed in Sect. 3, the two data sets presented here correspond to the choice of either Ba or Mo isotopes as (A_1, Z_1) tagged nuclei. The



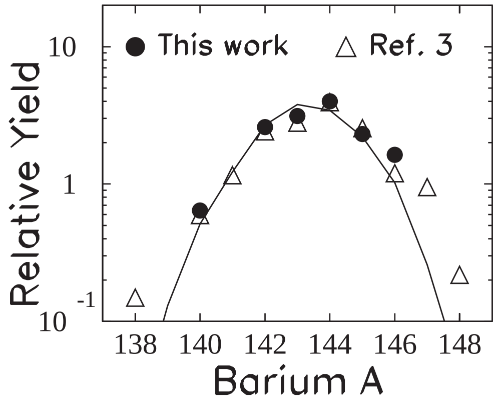


Fig. 2. Total relative yield of Ba and Mo isotopes compared with results from [3]. The solid line is a semiempirical evaluation from [16]

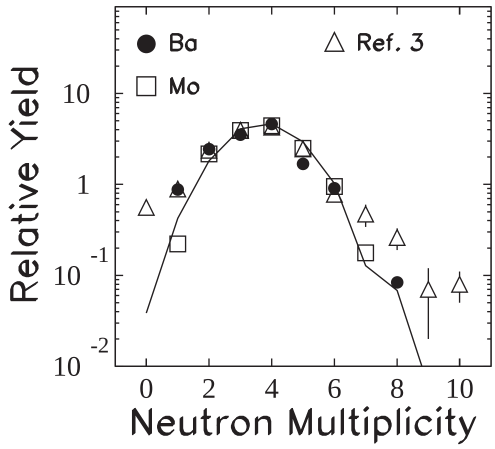


Fig. 3. Total neutron multiplicity distribution for the Mo-Ba partition from our experiment compared with the results from Tab. III of [3]. The solid line is the result of inclusive neutron mesurements from [17]

two exctracted neutron emission probability distributions are very similar, with the exception of the 1n channel, where the Mo-tagged data show a lower yield. The agreement between the two distributions demonstrates that, in general, the transitions used to tag the Ba-Mo pairs do not bias the results, and excludes the possibility of any contaminations from nuclei produced in other partitions. In Fig. 3, we also present the results from the γ-ray study of [3] and from inclusive neutron distribution measurements of [18]. It appears that a satisfactory agreement is achieved between the different data sets when neutron multiplicities between 1 and 7 are considered. On the contrary, our values are much lower when compared to the data from [3], for the ν_n=8 channel, which has been already discussed.

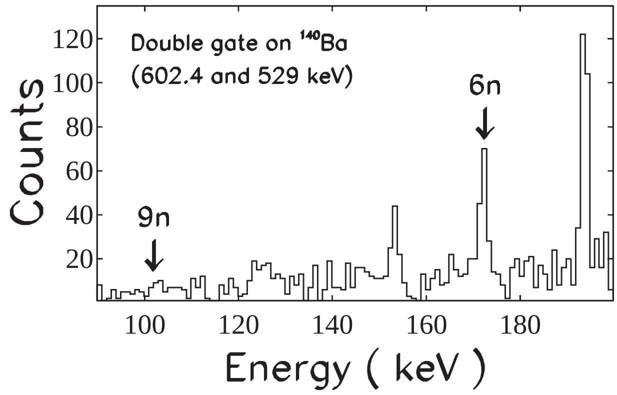


Fig. 4. γ-ray spectrum obtained by double gating on ^{140}Ba. The arrows indicate the transition energies 102.4 keV (^{103}Mo, ν_n=9) and 172.1 keV (^{106}Mo, ν_n=6)

Furthermore, the present measurement for the ν_n=9 channel yield was also much lower than that reported in [3]. In this reference it was reported that two partitions, i.e. ^{138}Ba-^{105}Mo (yield 0.02±0.02) and ^{140}Ba-^{103}Mo (yield 0.05±0.03) contribute to the 9n channel. As far as the ^{140}Ba-^{103}Mo partition is concerned, our results are illustrated in Fig. 4, where the spectrum gated on ^{140}Ba is expanded in the energy region where the 102.4 keV transition in ^{103}Mo is expected. The yield of this line appears to be very small, compared to the expectations based on [3] for which the ratio between the 102.4 keV and the 172.1 keV (^{106}Mo) lines is supposed to be about 1/2. In a further attempt to search for this channel we used the procedure of [2]. In that work two spectra were produced: the first one gating on the transitions 251 keV (^{103}Mo) and 602 keV (^{140}Ba) and the second one called “background spectrum” gating on energies 270 keV (background level) and 602 keV (^{140}Ba). In [2], the analysis of the 529 keV structure (^{103}Mo) showed a much lower yield in the “background spectrum” with respect to the first one. In our case, we found nearly the same counts for the 529 keV structure obtained in the two spectra. This confirms the very low yield associated to the ^{140}Ba-^{103}Mo as shown in Fig. 4. This smaller production rate for the ν_n=9 channel evidenced here agrees quite well with the results from the inclusive neutron measurements of [18]. The latter distribution, being not related to a specific partition in the spontaneous fission of ^{252}Cf exhibits the shape resulting from the dominant fission mode.

As far as the ν_n=10 channel is concerned, [3] attributes to this channel a yield of 0.08±0.03, which is only due to the ^{138}Ba-^{104}Mo partition. This yield is, in principle, well above our detection limit. In the present experiment, the ^{138}Ba-^{104}Mo was tagged by a preliminary double gate on ^{138}Ba. This choice is essentially due to the difficulties in the discrimination between the ^{104}Mo and the ^{108}Mo nuclei as discussed earlier. The ^{138}Ba is known to have a 6^+ isomeric level with 0.8 μs lifetime at 2091 keV excitation energy. This isomeric state decays to the ground state by a cascade of 3 γ-rays of energies 192 keV, 463 keV and 1435.8 keV, the latter transition being the connection between the first 2^+ and the $0^+_{g.s}$ levels. It is not known if the 4^+ level is fed only through the isomeric 6^+ state or there are some prompt side-feeding transitions which bypass the isomer. In any case, the presence of the isomer would reduce the tagging efficiency for the ^{138}Ba due to the triggering conditions of the present experiment. Furthermore, a strong production of 1435 keV γ-rays was found in the data due to the inelastic excitation of the first 2^+ level of the ^{52}Cr present in the stainless steel cointainer of the ^{252}Cf source. This fact creates an additional background problem when tagging the ^{138}Ba nucleus via its $2^+ \to 0^+$ transition. As a final result, it was not possible to detect a clear signature associated to the ^{138}Ba-^{104}Mo partition.

As a final point, we would like to briefly discuss the ν_n=0 case. A special interest is set on this channel because the ν_n=0 events indicate that large amplitude motion in nuclei takes place as cold rearrangement of a large number of nucleons, in which very low thermal excitation energies are transferred to the fission fragments. In the present work, we have clearly identified two partitions contributing to the ν_n=0 channel, i.e. the ^{146}Ba-^{106}Mo and the ^{144}Ba-^{108}Mo. An example of this identification is given in Fig. 5 for the spectrum with the double gate on ^{146}Ba. The yield of the first partition was obtained by tagging the ^{146}Ba as well as the ^{106}Mo. Our estimates of the relative yield is 0.05±0.01, which is somewhat in agreement with the value reported in [3] (0.08±0.05). Furthermore, we also determined the yield of the second partition by only tagging the ^{144}Ba nucleus. Our value for this second partition is 0.05±0.01, to be compared with 0.06±0.05 quoted in [3]. Our data, therefore, confirm the findings of previous works for the yields of the $\nu_n = 0$ channel.

The results reported in this section demonstrate that we are not able to confirm the enhancement in the ν_n≥7 channels in the Mo-Ba partition, interpreted in earlier experiments as due to the presence of a second fission mode. We stress that our analysis was performed on the γ-γ-γ data where contaminations from beta decay or neutron induced events are strongly suppressed by the requirement of two additional gamma ray hits in the inner ball.

4.2 γ-ray multiplicity distributions

The mechanism of spin generation in spontaneous fission products has been investigated in the past [19-22] and it was found to be associated with the excitation of various angular momentum bearing modes, such as wriggling, bending and twisting in the nascent fragments [23,24].

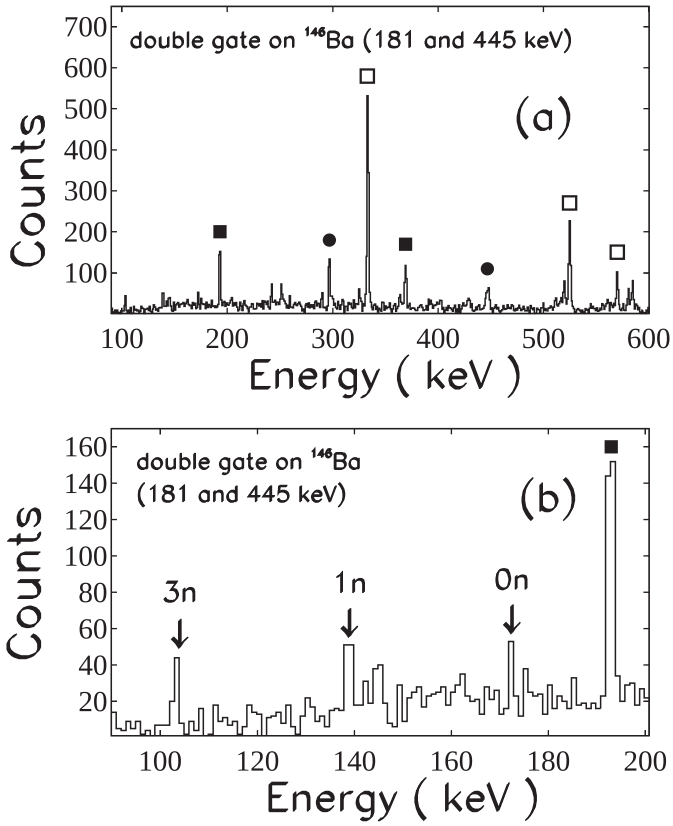


Fig. 5. γ-ray spectrum obtained by double gating on ^{146}Ba. In (a) the strongest transitions from ^{146}Ba (open squares), ^{104}Mo (full squares) and ^{102}Mo (full circles) are marked. In (b) the arrows indicate the transition energies 102.4 keV (^{103}Mo, ν_n=3), 137.7 keV (^{105}Mo, ν_n=1) and 172.1 keV (^{106}Mo, ν_n=0)

The present study offers a unique possibility for a detailed analysis of the γ-ray multiplicity associated with specific pairs of fission fragments. Furthermore, the γ-ray multiplicity as a function of the neutron multiplicity in the Mo-Ba partition has a specific interest when the ν_n≥8 channels are considered. In [3], the average angular momenta for individual fission fragments were derived from the measured populations of different spin levels. The average angular momentum for Ba fragments exhibited a sudden decrease in case of ν_n=8,10 channels which was assumed to be correlated with the second fission mode. It is, therefore, quite interesting to verify if such an effect is also seen in the γ-ray multiplicity measured with the GASP inner ball.

The gamma ray multiplicity distributions were obtained from the measured gamma ray fold spectra corresponding to a fragment pair by using the same technique of double gates set on transitions in one fragment and a third gate on a γ-ray from its partner nuclei. Such data analysis was performed for the most intense channels of the Mo-Ba partition, employing the gates reported in Table 1. Furthermore, the analysis was repeated by interchanging the double gates on Mo as well as the Ba isotopes, as was done for the production yield and neutron multiplicity measurements.

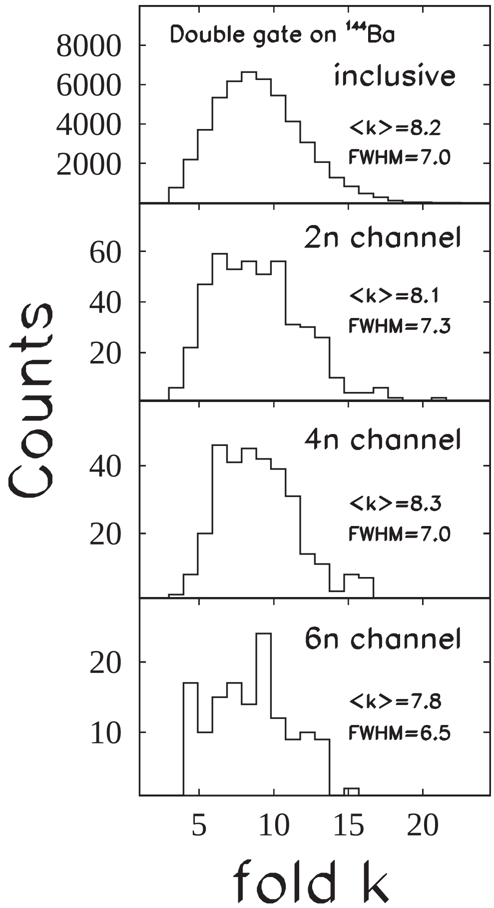


Fig. 6. The experimental raw fold distributions in coincidence with the ^{144}Ba nucleus (upper panel) and with the additional selection of different partner Mo nuclei

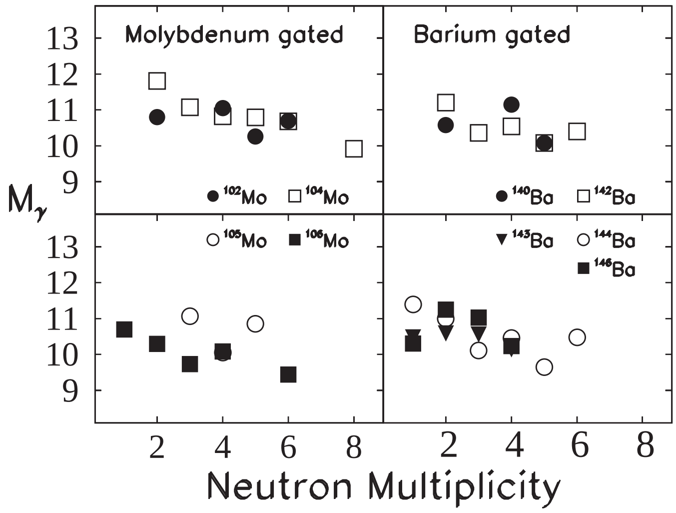


Fig. 7. Average γ-ray multiplicities obtained with a double gate on specific Mo and Ba isotopes and with a third gate on partner nuclei corresponding to a different multiplicity of emitted neutrons

An example of the measured raw fold distributions is shown in Fig. 6. The spectra shown are related to a double gate on the ^{144}Ba nucleus and the ν_n=2, 4 and 6 channels were selected by a third gate on the corresponding Mo isotopes. In all the pairs considered in this work, the width of the experimental fold distribution was found to be remarkably constant at around a value of Δk$\sim$6-7 (FWHM), which is larger than that due only to the response function of the GASP inner ball. This demonstrates that the intrinsic width of the spin distribution in the spontaneous fission is not negligible, as discussed in [19].

To obtain the average γ-ray multiplicity, the values of the first moment (i.e. the average value) of the raw fold distributions have to be corrected for the inner ball efficiency as well as for the effects of neutrons. The neutron induced events could not be suppressed experimentally, since the flight path in the inner ball was too short (17 cm) to reject them by the time of flight technique. We have, therefore, investigated the neutron-to-gamma event ratio in the BGO inner ball detectors by performing the n-γ discrimination by the time-of-flight technique in an independent measurement, where the flight path for one of the BGO detector was increased up to 70 cm. The measured ratio between the counts due to neutrons and γ-rays emitted from the ^{252}Cf source was used to determine a neutron multiplicity dependent correction to the γ-ray fold data.

The average γ-ray multiplicity as a function of the neutron multiplicity is shown in Fig. 7 for different fragment partitions. Two sets of data are reported in which the double gate selection is set on either Mo or Ba isotopes. The data show two important features. The bulk of the measured multiplicity data is in the range M_γ=10-11. This result is well in agreement with the value M_γ=10.5$\pm$0.6 obtained in a coincidence measurement with Ba X-rays [19]. Secondly, several data points are corresponding to the same neutron multiplicity. As an example, the four partitions ^{102}Mo-^{146}Ba, ^{104}Mo-^{144}Ba, ^{106}Mo-^{142}Ba and ^{105}Mo-^{143}Ba reported in Fig. 7 are all 4n channels. Multiplicity data have been obtained for those partitions by double gating on Mo as well as on Ba isotopes, providing a set of 8 different values. A remarkably good agreement is found among the measured γ-ray multiplicity values corresponding to different partitions leading to the 4n channel, the average dispersion of the data from the mean value being less than 5 %. Following this observation, the average values of the γ-ray multiplicity are plotted in Fig. 8 as a function of the neutron multiplicity. The interest in the correlation between number of emitted neutrons and γ-rays explored in past experiments [21,22] lies in the fact that the number of emitted neutrons reflects the thermal excitation energy of the fission fragments and the number of the emitted γ-rays is proportional to the total angular momentum built into the fragments. The present measurements show that the average gamma ray multiplicities have very weak dependence on the number of emitted neutrons. This is somewhat in contrast to the results reported in [3], where the total spin of the fragments showed a rather strong dependence on the number of emitted neutrons, particularly for $\nu_n\geq$8, which was considered as an

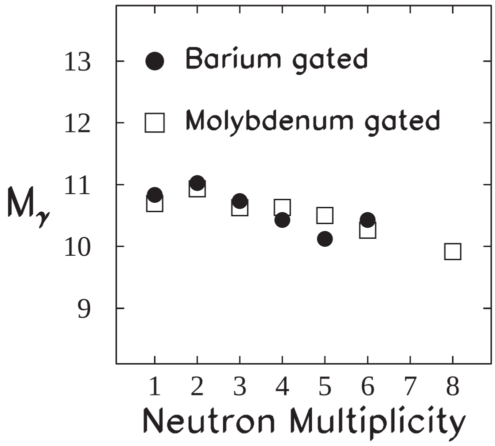


Fig. 8. Averaged gamma-ray multiplicity versus the number of the emitted neutrons

additional support for the occurrence of the second fission mode.

5 Summary

In the present work, we have measured the yields for the correlated Mo-Ba product pairs in ^{252}Cf spontaneous fission in a γ-ray coincidence experiment using the GASP array. The measured isotopic yields were used to derive the relative probability distribution of the number of evaporated neutrons in the Mo-Ba fission channel. The neutron multiplicity distribution was found to agree well with the results of a similar measurement [2,3] for multiplicities ν_n between 1 and 7. On the contrary, the yield for ν_n=8 channel resulted to be much lower than previously reported. A very low yield for the ν_n=9 events was also observed, whereas the ν_n=10 channel was not seen in the present experiment.

Prompt γ-ray coincidences between the HPGe detectors and the inner ball provided a measurement of the γ-ray fold distributions for a number of specific Mo-Ba fragments pairs. The derived average γ-multiplicities were found to be in agreement with earlier exclusive experiments in which the Ba X-rays were used to tag the Ba-Mo partition [19]. The average γ-ray multiplicity shows a rather weak dependence on the number of emitted neutrons.

In conclusion, the results of the present experiment do not show evidence for the proposed second fission mode suggested in [2,3] as being responsible for the enhanced production cross sections of the $\nu_n \geq 7$ fission channels and for the strong decrease of the fragment spin in the ν_n=8,10 channels. The major experimental difference between our work and the previous experiments of [2] and [3] is the γ-ray fold considered in the data analysis (triple γ coincidences with k$\geq$2 in this experiment and double γ coincidences in [2,3]). Further improved experimental data would be of help to map out the distributions in neutron multiplicity using different fold selections. This will allow the direct detection of possible influences due to the used fold on the apparent production yield for the rare channels and further verify the presence of the second fission mode.

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