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Spontaneous fission of rutherfordium isotopes - total kinetic energies

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Abstract. The isotopes ^{255,256,258}Rf were produced in the fusion-evaporation reactions ^{50}Ti + ^{207,208}Pb and ^{50}Ti + ^{209}Bi at GSI Darmstadt, using the velocity filter SHIP. Total kinetic energies of fragments from spontaneous fission for these isotopes were evaluated with a correction to pulse-height defect.

1 Introduction

Spontaneous fission (SF) is a decay mode with large impact on the stability of nuclei in the transfermium region. These isotopes are stabilized against SF mainly by microscopic shell effects [1]. Systematic studies of SF properties allow us to understand these effects and determine the production possibilities for the heaviest nuclei. Up to now, only a few results (often based on limited statistics of SF events) with measured total kinetic energy (TKE) were obtained for rutherfordium (Z = 104) isotopes [2–5].

2 Experiment

The experiment was performed at GSI Darmstadt in Germany. The heavy-ion ^{50}Ti beam with typical energies from 225 to 243 MeV was delivered by the UNILAC accelerator. The fusion-evaporation reactions ^{50}Ti + ^{207,208}Pb were used for production of the studied isotopes ^{255,256}Rf via xn evaporation channels from the compound nuclei ^{257}Rf and ^{258}Rf. The reaction ^{50}Ti + ^{209}Bi was used for indirect production of ^{258}Rf via EC decay of ^{258}Db.

Evaporation residues (ER) were separated from the beam and other undesired background using the velocity filter SHIP [6] and delivered to a detection setup. After passing through the time-of-flight system they were implanted $(6.5 - 6.8)\,\mu$m deep into the 16-strip position-sensitive STOP detector. The same-type detectors arranged in the "BOX" geometry were placed in front of the STOP detector to detect escaping particles. A clover detector with four Ge crystals was placed behind the STOP detector for γ- and X-ray detection.

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3 Results

In order to detect SF events from specific isotope, we used a time and position correlation search technique. In the case of ^{255}Rf, ^{256}Rf we searched for correlations between an ER implantation signal and a high-energy signal corresponding to SF. For ^{258}Rf instead of the ER implantation signal we used the low-energy signal corresponding to electrons originating from internal conversion process from de-excitation of levels populated after the EC decay $^{258}\text{Db} \xrightarrow{EC} {}^{258}\text{Rf}$. The time conditions were set to $\approx 5 \times$half-life between signals for each isotope (8500 ms for ^{255}Rf, 35 ms for ^{256}Rf and 60 ms for ^{258}Rf) and position window of 1 mm in the detector for ^{255}Rf and ^{256}Rf. As position condition for ^{258}Rf, we required only the same strip number since for many low-energy signals from electrons the position information was not registered. We collected several hundreds of SF events for ^{255}Rf, ^{256}Rf and ^{258}Rf. The TKE distributions of fission fragments for each isotope are shown in Fig. 1. The histograms contain all registered SF events - the cases when both fragments stayed in the STOP detector ($\approx$ 60%) as well as events when one fragment escaped the STOP detector and was either detected in the BOX detector ($\approx$ 30%) or escaped the detection setup completely ($\approx$ 10%).

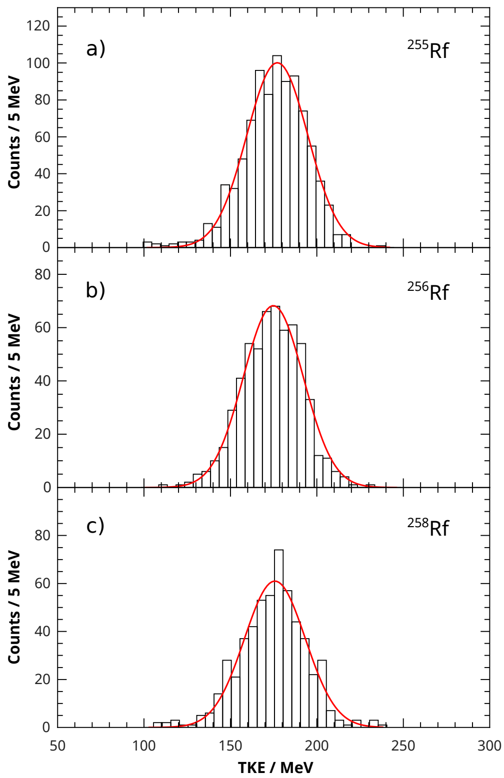

Figure 1. Total kinetic energies for ^{255}Rf, ^{256}Rf and ^{258}Rf from all observed SF events for each isotope. Due to the pulse-height defect, the positions of gaussians are shifted to lower values.

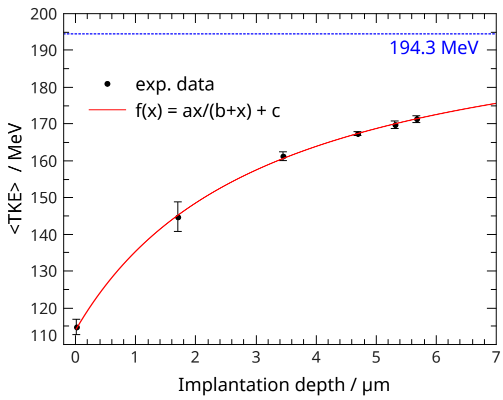

Figure 2. $\overline{TKE}$ from the SF of ^{252}No vs. implantation depth of ER in the detector. Blue dashed line: $\overline{TKE}$ = 194.3 MeV of ^{252}No from [3]. Red solid line: saturation-growth fit.

The crucial task for the evaluation of $\overline{TKE}$ using Si detectors is the correction of deficit in measured energies. There are two main effects influencing the TKE measurements, discussed in previous studies [7–9] performed at SHIP. First, the energy calibration based on α-decay energies is not valid for fission fragments due to the pulse-height defect (see e.g. [10]), resulting in a significant energy deficit. The second effect is a dependence of the detected TKE on the implantation depth of ER into the detector. In order to find the energy correction, we performed TKE measurements for ^{252}No with known $\overline{TKE}$ = 194.3 MeV [3] at six different implantation depths [8]. Our observations (shown in Fig. 2) proved the strong non-linear saturation-like dependence of detected TKE on implantation depth (see [11] for more details). The correction to the energy deficit at given implantation depth was determined as a difference of the reference $\overline{TKE}$ of 194.3 MeV and the value $\overline{TKE}_{fit}$ from saturation-growth model fit of the six points (blue dashed and red solid lines in Fig. 2) as $\Delta E = (194.3 - \overline{TKE}_{fit})$ MeV.

Table 1. In the table columns, from left to right, the isotope, $\overline{TKE}$ evaluated in this work, reference value of $\overline{TKE}$ and corresponding references are stated.

Isotope	$\overline{TKE}_{exp}$ [MeV]	$\overline{TKE}_{ref}$ [MeV]	Ref.
^{255}Rf	199.5 ± 2.7	199 ± 3	[4]
^{256}Rf	198.7 ± 2.8	198.9 ± 4.4	[2]
^{258}Rf	198.2 ± 3.0	197.6 ± 1.1	[2]

Considering the facts, that ^{252}No is close in Z, A and $\overline{TKE}$ to studied Rf isotopes, we applied this correction to $\overline{TKE}$ of ^{255}Rf, ^{256}Rf and ^{258}Rf. Corrected $\overline{TKE}$ values for each isotope are summarized in Table 1 and compared to values from previous studies. The results are in a good agreement, which supports the validity of our correction.

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