Production of medium-mass neutron-rich nuclei in ^{238}U fission

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Abstract.
The production cross sections of neutron-rich fission residues produced in reactions induced by a ^{238}U beam impinging onto Pb and Be targets were investigated at the Fragment Separator (FRS) at GSI. These data allowed us to discuss the optimum energies in fission for producing the most neutron-rich residues.

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INTRODUCTION

During the last years, medium-mass neutron-rich nuclei have shown important implications in nuclear structure (e.g. shell evolution with neutron excess) and nuclear astrophysics investigations (e.g. r-process in stellar nucleosynthesis). However, the experimental access to this region is limited because of the difficulties in producing radioactive beams of medium-mass nuclei around the $N = 82$ shell. Fission of actinides has been used successfully for producing a large variety of neutron-rich nuclei, both in in-flight [1, 2] and in ISOL facilities [3].

In order to produce medium-mass neutron-rich nuclei, two fission modes can be considered, depending on the excitation energy deposited in the system. Fission at low excitation energies produces a very asymmetric mass distribution of neutron-rich residues. At high excitation energies the distribution becomes more symmetric due to the damping of shell effects with temperature [4], while the average neutron excess decreases by neutron evaporation. However, larger fluctuations in N/Z caused by temperature compensate the evaporation process [5].

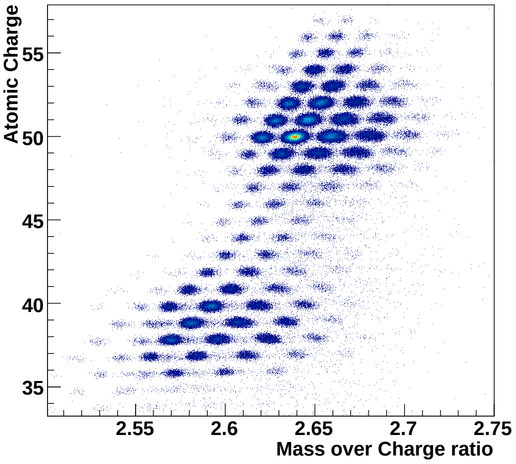

FIGURE 1. Two-dimensional scatter plot of the fission fragments energy loss versus their A/Q value isotopically identified at final focal plane of FRS

EXPERIMENTAL TECHNIQUE

Investigation of high and low energy fission have been performed in inverse kinematics at FRagment Separator (FRS) in GSI. The use of inverse kinematics at relativistic energies to induce fission in peripheral collisions provides three main advantages:

1. The fragments are focused into a narrow cone centered around the beam direction and their velocities are almost constant. Thus, fragments are efficiently transmitted through a spectrometer.
2. The fragments are fully stripped, i.e. their charge state equals their atomic number and ambiguities when dealing with different charge states are avoided.
3. At these high velocities, fission residues can be identified by $B\rho$-ΔE-ToF techniques.

The SIS18 synchrotron delivered a ^{238}U beam at 950 MeV/u with an average intensity of 10^8 particles per second. The beam intensity was measured with a secondary-electron current monitor SEETRAM [6]. The beam impinged onto a Be (1036 mg/cm^2) or Pb (650-1500 mg/cm^2) target located at the entrance of the FRS [7] to produce fission fragments, mainly by electromagnetic fission ($E^* \sim 12$ MeV) in the case of the Pb target, or fission induced by nuclear reactions ($E^* \sim 27$ MeV/u per abraded nucleon), in the case of Be, simulating low and high excitation energy.

Forward emitted fission fragments with trajectories inside the FRS acceptance were identified from their magnetic rigidity and velocity [1, 8, 9]. The magnetic rigidity was obtained from the measured positions at the intermediate and final focal planes using time projection chambers (TPCs) and the velocity was obtained from the time-of-flight. The atomic number of each fission residue was determined from its energy loss in a Multi Sampling Ionization Chamber (MUSIC).

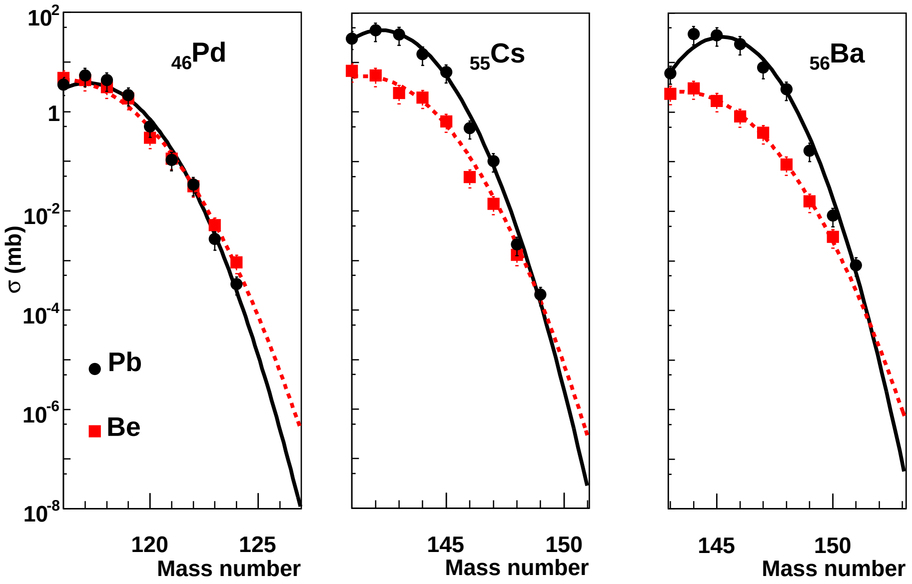

FIGURE 2. Production cross sections measured of palladium, cesium and barium with the lead (dots) and the beryllium target (squares) compared with a polinomial function in exponential scale (lines).

RESULTS

Figure 1 shows an identification matrix of the fission residues observed in a magnetic setting centered in ^{135}Sn with the lead target. The fragments are unambiguosly separated with a mass resolution of $\Delta A/A = 10^{-3}$. The figure also shows the typical asymmetric distribution of the fission at low excitation energies.

Figure 2 shows a sample of the isotopic distributions of production cross sections measured with both targets. It is clearly shown that in the case of asymmetric fission, the production cross sections are higher in the case of fission induced by the Pb target. We also see that the maximum of the distribution obtained with the Be target shifts to the neutron deficient side due to the fact that neutron evaporation channel is opened. In the case of symmetric fission, both production mechanisms have similar cross sections, as shown in the case of palladium. In order to investigate the behaviour of the cross sections for the most neutron-rich cases, we have extrapolated the experimental data using a polynomial function in exponential scale (lines). It is shown that in spite of the lower production cross sections in the case of the Be-induced fission and the average shift to the neutron deficient side, the extrapolated function for very neutron-rich nuclei presents larger values compared to the results obtained with the Pb target. Therefore, fission at moderate excitation energies enhances the production of the most neutron rich nuclei.

CONCLUSIONS

In the present work, we have investigated the production of medium-mass neutron-rich nuclei by fission. For this purpose, an experiment was performed at GSI to measure the production cross sections of neutron-rich fission fragments of ^{238}U using two targets (Pb and Be) enhancing low and high energy fission at 950 MeV/u in inverse kinematics. Using the high resolution magnetic spectrometer FRS, the yield distributions of fission fragments at different excitation energies has been investigated by using Be and Pb targets, providing a full identification of the final products. We have measured production cross sections of neutron-rich nuclei from Z=36 to Z=56 down to 100 pb for both targets. The experimental data were extrapolated in order to conclude about the fission mechanism enhancing the production of the most neutron-rich nuclei. The new data clearly indicates that fission at moderate excitation energies (20-50 MeV) increases the production of extremely neutron-rich nuclei, compared to the fission at lower excitation energy, even for asymmetric case.

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