# PRODUCTION OF MEDIUM-MASS NEUTRON RICH NUCLEI FROM FRAGMENTATION OF FISSION RESIDUES AROUND Sn*

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*(Received October 29, 2008; revised version received December 18, 2008)*

The fragmentation of neutron-rich Sn isotopes obtained from the fission of $^{238}$U projectiles at 950 MeV/$u$ has been investigated at the FRagment Separator (FRS) at GSI. In order to study the feasibility of a two-step reaction scheme for the production of medium-mass neutron-rich nuclei, fragments with masses $A \approx 130$ have been isotopically resolved in the first part of FRS and their fragmentation residues identified in the second part.

PACS numbers: 27.60.+j, 29.38.Db

## 1. 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

* Presented at the Zakopane Conference on Nuclear Physics, September 1–7, 2008, Zakopane, Poland.

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]. However, the production yields of nuclei around $N = 82$ with $Z < 50$ are very low. Moreover, due to their refractory nature, they have very poor extraction efficiencies in ISOL sources.

A new idea is to use a two step reaction scheme. Medium-mass neutron-rich isotopes are produced with high intensities as fission fragments. Then, they are used as projectiles in a second step to produce even more neutron-rich nuclei by cold fragmentation. In fact, this two step reaction might be a tool for producing beams of extremely neutron rich isotopes of refractory elements and short lived nuclei in future ISOL facilities [4].

In a recent work [5] the feasibility of the two step reaction scheme was investigated by calculating the production cross-sections of residual nuclei in this kind of reactions. Two different model calculations were used, EPAX [6], the semiempirical parameterisation for fragmentation cross-sections, and the cold fragmentation code COFRA, described in detail in Ref. [7]. It can be shown that the predictions of both model calculations applied for fragmentation of neutron-rich projectiles differ considerably.

## 2. The experiment

In order to obtain a clear answer for these discrepancies, an experiment was performed at the GSI facilities in Darmstadt, Germany. The SIS18 synchrotron delivered a $^{238}$U beam at 950 MeV/$u$ with an average intensity of $10^8$ particles per second. The beam impinged onto a 650 mg/cm$^2$ Pb target located at the entrance of the FRagment Separator (FRS) [8] to produce fission fragments. The FRS is a zero-degree magnetic spectrometer with a resolving power of $B\rho/\Delta B\rho \approx 1500$, a momentum acceptance $\Delta p/p \approx 3\%$ and an angular acceptance around the central trajectory of 15 mrad. Fig. 1 shows the FRS magnetic elements and the detection system used in both sections of the spectrometer.

Forward emitted fission fragments with trajectories inside the FRS acceptance were identified in the first section of the spectrometer from their magnetic rigidity and velocity. The magnetic rigidity was obtained from the measured positions at the intermediate image plane using time projection chambers (TPCs) and the velocity was obtained from the time-of-flight. An improved time-of-flight system, and the use of TPCs, whose position resolution was $\sigma \approx 200$ $\mu$m, for tracking corrections allowed, for the first time, to isotopically separate at the FRS fragments in the mass region $A \approx 130$ with a limited flight path (20 m). The atomic number of each fission residue was determined from its energy loss in a Multi Sampling Ionization Chamber (MUSIC). These fully identified fission residues impinged onto a secondary

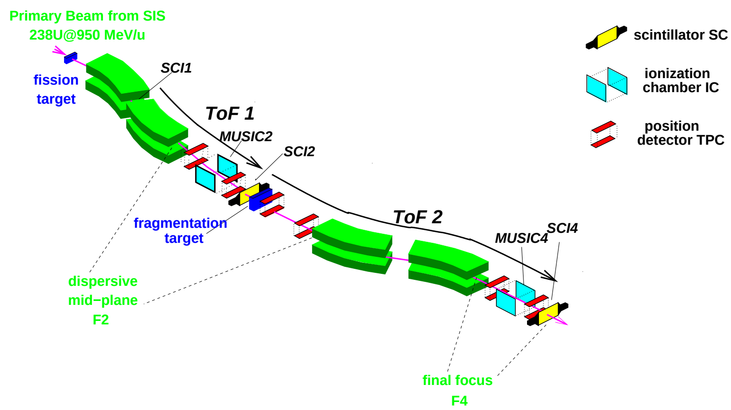


Fig. 1. Schematic layout of the FRS showing the dipole magnetic elements and the detection system used in the experiment.

beryllium target (2.6 g/cm$^2$) located at the intermediate dispersive focal plane. The fragmentation residues were then isotopically identified in the second section of the spectrometer using a similar technique.

## 3. Experimental results

Left panel of Fig. 2 presents the identification matrix obtained at the intermediate focal plane of the FRS in the form of a two-dimensional scatter plot of the energy loss in the MUSIC chamber, which is proportional to $Z^2$, and the mass over charge ratio obtained from magnetic rigidity. This plot also shows the excellent mass resolution obtained, $\Delta A/A \approx 1.4\times 10^{-3}$, using only the first part of the spectrometer.

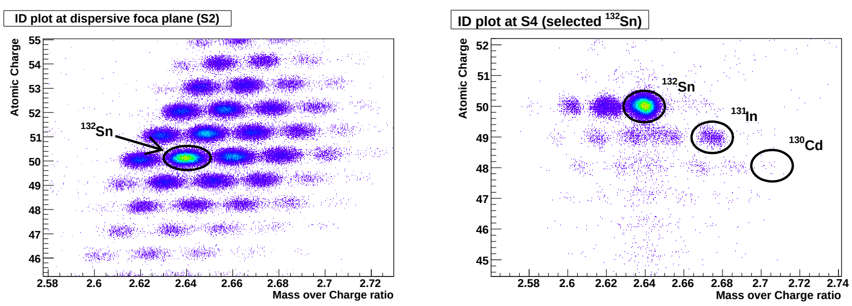


Fig. 2. Left panel: two-dimensional scatter plot of the fission fragments energy loss versus their $A/Q$ value isotopically identified in the first section of the FRS. The $^{132}$Sn is indicated. Right panel: Identification matrix of the fragmentation residues of $^{132}$Sn at the final focal plane of the FRS. $^{132}$Sn and the one-proton ($^{131}$In) and two-proton ($^{130}$Cd) removal channels are indicated.

The atomic number was determined using the charge distribution of the fission fragments at low excitation energy [9], identifying the symmetric fission, corresponding to Pd.

The right panel shows the identification matrix of the fragmentation residues of $^{132}$Sn produced in the beryllium target located at the intermediate focal plane of the FRS. In particular, in this figure, we can identify the two first proton removal channels ($^{131}$In and $^{130}$Cd). It is also seen that the mass resolution was improved ($\Delta A/A \approx 10^{-3}$) compared to the identification in the first part of FRS, due to the longer flight path (36 m). This plot also shows that the reaction products of $^{132}$Sn in the layers of matter of the final focal plane contaminates the fragmentation residues in the region with similar mass-over-charge ratio than $^{132}$Sn. We expect to improve the separation by means of conditions in the final focal plane positions.

The measured yields can be transformed into production cross-sections by normalizing to the number of secondary projectiles and fragmentation target thickness.

## 4. Conclusions

The experiment was performed at GSI, where the fragmentation of neutron-rich fission residues was investigated for the first time. An improved detection system at the FRS allowed the identification of the fission residues in the first part of the FRS and their fragmentation residues in the second half. Production cross-sections are being obtained.

This work was partially funded by the EC under the EURISOL-DS contract No. 515768 RIDS and by the Spanish Ministry of Education and Science under grant FPA2007-6252.

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