Investigation of possibly “new magic” numbers in A≈110 r-process nuclei *

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The experiment 05028 was carried out at the National Superconducting Cyclotron Laboratory (NSCL) at the Michigan State University to measure $T_{1/2}$ and P_n –values of very neutron-rich isotopes in the ^{110}Zr-region. The goal was to obtain input parameters for r-process-calculations as well as to discover possibly new nuclear-structure properties of exotic nuclei in the investigated mass-region.
Nuclei around ^{110}Zr, especially the less neutron-rich Zr-isotopes, show an unusually large number of shapes, excitation modes and (sub-)shell closures within a small mass range, e.g. the local spherical $\nu d_{5/2}$ sub-shell at N=56 and the sudden onset of deformation at N=60, studied mainly at small ISOL-facilities (see [1,2]). Some theoretical predictions far from stability indicate new magic numbers (Z=40, N=70) caused by a large energy gap between the $\nu h_{11/2}$ and the $\nu g_{7/2}$-shell due to “quenching” of the classical N=82- shell. Thus, ^{110}Zr would be much less deformed in the ground state than predicted by mass-models which do not consider shell-quenching. According to the QRPA-calculations of the Mainz-group (Nilsson-potential, pairing included via BCS, ground-state deformations of FRDM), the β-decay pattern of this nucleus would change drastically [3]. In the strongly deformed case, the decay feeds a multitude of narrow-spaced 1^+-levels in the deformed daughter nucleus ^{110}Nb, resulting in $T_{1/2}\approx$ 88ms and $P_n\approx$ 8%. Assuming a strongly quenched N=82 shell for Z=40, the gross β-decay properties would be completely dominated by a single allowed transition to a 1^+-state at about 1.13 MeV. As a result, the $T_{1/2}$ would become shorter by about a factor of six, while the P_n would be even smaller by a factor of 10. Those differences in both gross β-decay properties should be detectable, also for the less neutron-rich Zr-isotopes.
The idea of a local non-quadrupole deformation of the ground state was also suggested by assuming a tetrahedral shape symmetry around ^{110}Zr [4]. This theoretical approach leads to the same “magic numbers” for neutron-rich nuclei (amongst others Z=40, N=70) as the quenching of the N=82-shell.

The investigated nuclei are also important for the understanding of the r-process. A doubly semi-magic, less deformed ^{110}Zr at N=70 would replace the classical N=82 neutron-magic isotope ^{122}Zr as a waiting-point. As a consequence, the r-process would enter the N=82-shell at a higher Z than predicted by mass models which do not contain shell-quenching. This may explain the “trough” prior the A=130-peak in the r-process abundance pattern which is obtained in a number of r- process calculations.

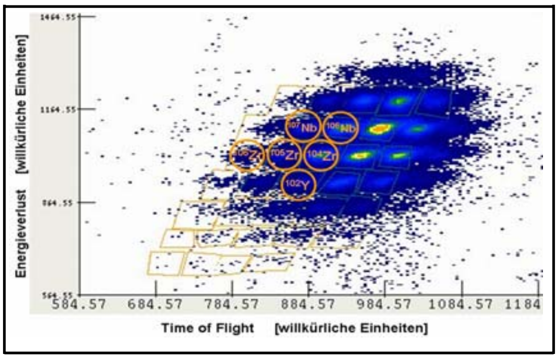

Figure 1: Particle-ID plot of 14 runs

To measure the gross β-decay properties of the nuclei in the ^{110}Zr-region, a 120 MeV/u ^{136}Xe-beam was fragmentated by a 235 mg/cm^2 Be-target at the coupled cyclotron facility of the NSCL. The secondary beam was separated by the A1900 fragment-separator, enhanced by an achromatic Al-degrader in the intermediate focus of A1900 to increase the separation. A position-sensitive plastic scintillator also at the dispersive intermediate focus was used to measure the momentum of the particles. Each nucleus of the secondary beam was identified in flight by time-of-flight and energy-loss measurements together with the A1900 momentum measurement. The beam particles were implanted in the Beta Counting System (BCS) of the NSCL. In the double-sided Si strip detector (DSSD) of the BCS, time and position of each ion and of any following β-decay was detected. The BCS was surrounded by the Neutron Emission Ratio Observer (NERO) to detect β-delayed neutrons. In addition, three detectors of the Segmented Germanium Array (SeGA) as well as a single Ge-detector were used to detect γ-rays of not yet known μs-isomers in the investigated mass-region.

The data analysis has just started; results will be presented in the future.

References

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