PROCEEDINGS OF SCIENCE

β-decay and neutron emission studies of r-process nuclei near ^{137}Sb

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β-decay half-lives and neutron emission probabilities (P_n) play an important role in r-process nucleosynthesis. An experiment was performed at GSI to measure β-decay half-lives and P_n values in the A=130 region including the waiting point nuclei ^{136}Sn and ^{137}Sb. The experiment was performed with a stack of four 500 μm thick double sided silicon strip detectors along with the Mainz 4π neutron long counter detector. The system allows to time correlate ion implant and decay events and the detection of the neutrons emitted during the decay. We discuss the analysis approach and some preliminary results.

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1. Introduction

The rapid neutron capture process, r-process, differs from the slow neutron capture process, s-process, by capturing neutrons on a shorter timescale than the respective β-decay for the target nucleus. The r-process therefore involves formation of nuclei further away from the valley of stability. Since the β-decay timescale is large compared to the neutron capture timescale, the β-decay half-lives determine the speed of the process and the abundance pattern. [1][2][3]

Toward the end of the r-process the neutron abundance drops, and at this point the β-unstable nuclei begin to β-decay back toward stability. There is a finite probability, P_n, for neutron emission during β-decay if the neutron-separation energy is less than the decay Q-value. Neutron emission will modify the final abundances produced in the r-process by shifting the abundance from an isobar with mass A to one with mass A-1. Neutron emission also impacts the neutron abundance during freezeout. It has been pointed out that neutron emissions smooth out odd-even effects so that the final abundances more closely resemble observed solar r-process abundances [4], though other effects such as late time neutron capture have similar effects.

2. Experimental setup

An experiment to measure β-decay half-lives and neutron emission probabilities for nuclei near ^{137}Sb was performed at the Helmholtzzentrum für Schwerionenforschung (GSI) in Darmstadt, Germany. A primary beam of ^{238}U originating from the Heavy Ion Synchrotron (SIS) accelerator impinged upon a lead fission target to create a fragment beam of rare isotopes around ^{137}Sb. Detectors set at the dispersive and focal planes of the Fragment Separator (FRS) [5] were used to identify fragments by energy loss, magnetic rigidity, and time-of-flight. These included a set of Multiwire Proportional Counters (MWPC), a MUSIC detector and a scintillator where position, energy loss and time-of-flight were determined, respectively (Fig. 1).

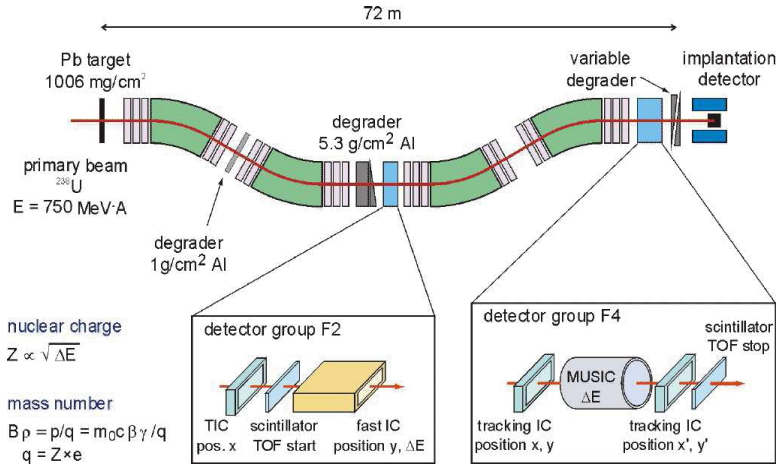

FIGURE 1: *Illustration of the Fragment Sperator (FRS) at GSI including detectors used for particle identifiaction.*

After identification of the isotopes the beam was further slowed using a variable degrader such that the isotopes of interest were implanted into a set of detectors used to determine β-decay half-lives and neutron emission probabilities (Fig. 2). The implantation and decay detector consisted of a stack of four double sided 500 μm thick silicon strip detectors (DSSDs). β-particles from the decay of the implanted isotopes were also detected. The Mainz neutron long counter surrounded the DSSD stack for determining the P_n values. The long counter consists of a set of ^{3}He gas proportional counters embedded in a polyethylene matrix to moderate the neutrons for increased detection efficiency.

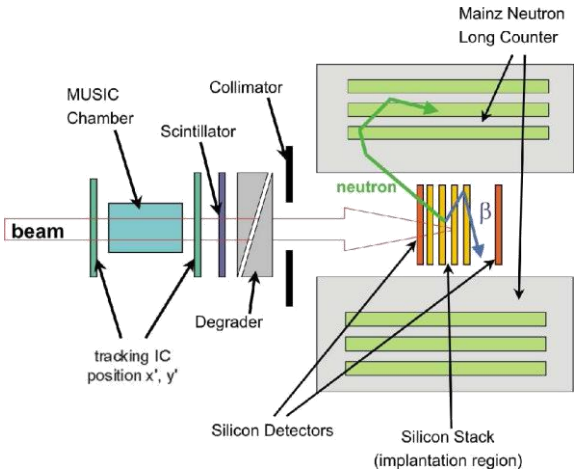

FIGURE 2: *Illustration of the implantation detectors at the final focal plane of the FRS. The incoming beam is slowed with a variable degrader and then implanted into a stack of silicon detectors. Neutrons emitted in coinidence with β-decays were detected in the surrounding long counter.*

Implantation events were correlated with decay events that occurred within ten seconds of each other and within a correlation volume around the location of the implantation. This volume may include β-decays on a detector adjacent to the DSSD in which the isotope was implanted. The volume was selected in such a way to maximize β detection efficiency and to minimize random background correlations.

3. Background Subtraction

The resulting decay-time histograms contain random background events. Some of this background is related to a light ion contamination in the secondary beam that deposits little energy when passing through the detector mimicking the behavior of β particles. Most of these light ions leave a straight track through the entire detector stack and can therefore easily be rejected, but owing to the finite detector efficiency some background remains that cannot be distinguished from β particles.

Another complication is that this beam related background has the time structure of the SIS beam, arriving at the detector in spills about one second wide with about a four second separation between spills. In addition, beam intensity during a spill varies as a function of time, and there are also variations from spill to spill. Therefore, the background at the implantation detector had a complex time structure that varied from event to event. [6]

For short half-lives, the decay occurs mostly within a spill, but not always as the implantation can occur towards the end of a spill. We solved this problem by taking advantage of the fact that the time dependence of the background is the same across the detector. For each implantation of the nucleus of interest, we create a virtual implant at another location to determine the background at the same time. The location of the virtual implant is chosen using the probability distribution of the actual implantation location. Therefore, the time structure of the background is accounted for exactly, while the position dependence of the background is accounted for in a statistical sense for the entire ensemble of implanted ions.

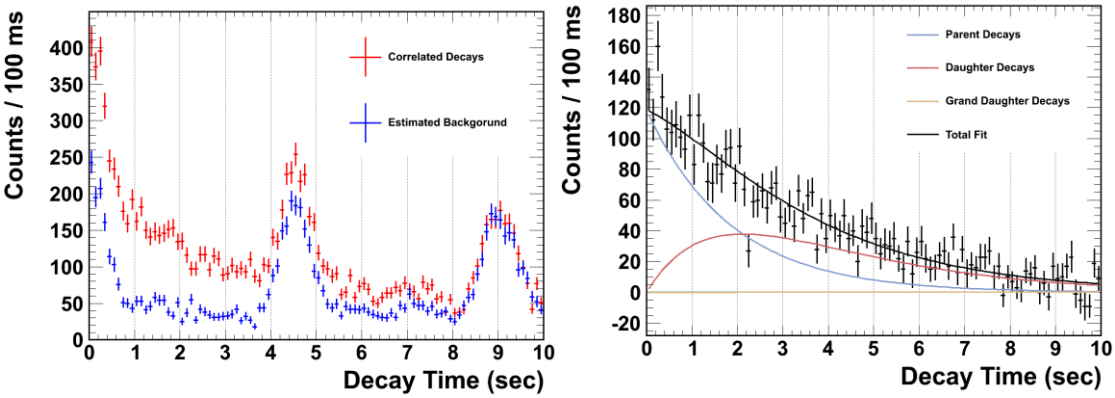

FIGURE 3: *Total β-decay curve for ^{142}Xe (left ,red) shows a dependence on the structure of the beam produced by the SIS. Spills have a width of about one second with a four second spill separation. The calculated background for ^{142}Xe (blue) is also shown. The right figures shows the background subtracted total β-decay curve for ^{142}Xe and the fit used to determine half-life and parent decays (parent decays in blue and daughter decays in red).*

The correlation that was used for the real implantations was then repeated using the virtual implant. The events correlated to the virtual implant must then be background events since they occured in another region of the DSSDs without a real implant associated with it. A background histogram was then created and subtracted from the histogram of the correlated decay times. The resulting decay curve is background free and was fitted with the parent half-life and the efficiency as free parameters. Error bars were determined by propagation taking into account the background subtraction procedure.

Neutron emission probabilities were determined by the ratio of all parent β-decay events as determined by the decay curve fit, and the subset of such events with a detection of a neutron. Preliminary results show antimony isotopes, ^{134}Sb[7][8][9], ^{135}Sb[8][10][11][12][13], ^{136}Sb[8], ^{137}Sb[13], agreeing with previosly published results. This work will include first time measurements of half-lives and P_n values for $^{138\text{-}139}$Sb, $^{139\text{-}141}$Te, and ^{143}I.

4. Acknowledgements

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