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Nuclear structure of heavy neutron rich systems: Fragmentation spectroscopy with a 1 GeV per nucleon ^{208}Pb beam*

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We present results on the isomer spectroscopy of a number of neutron-rich rare earth and transitional elements with A $\sim 190 - 200$, following the projectile fragmentation of a 1 GeV per nucleon ^{208}Pb beam. The technique was sensitive to decays from metastable states with lifetimes in the nano- to millisecond time range. The nuclei of interest were separated and unambiguously identified on an event-by-event basis using the Fragment Separator at GSI. The analysis allows a clear differentiation between ions of different charge states and places a new lower limit of ~15 ns, on the lifetimes of isomers which have been studied using this technique.

1. INTRODUCTION

The internal structure of heavy nuclei to the neutron rich side of the valley of stability is notoriously difficult to investigate using standard gamma-ray probes. This particularly applies to medium and high spin states, which have traditionally been investigated using fusion-evaporation and other Coulomb barrier energy reaction mechanisms. Recently however, radioactive beams of projectile fragments with relativistic energies, have opened up the possibility of studying heavy, neutron rich systems with A>180 [1,2] which are inaccessible using fusion barrier style reactions with stable beam target combinations. In particular, cold fragmentation reactions [2] have been used to synthesize neutron rich

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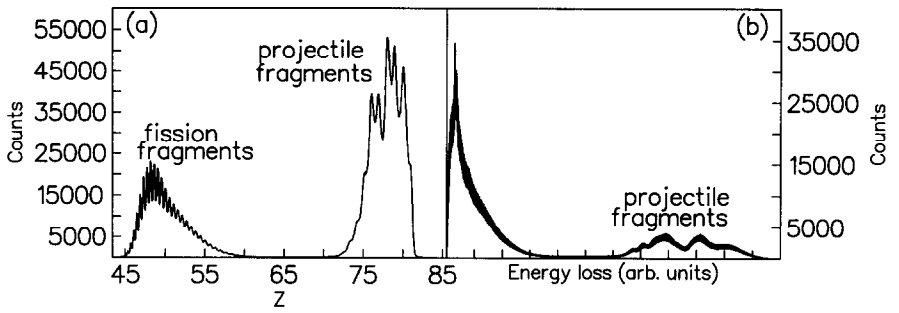

Figure 1. (a) Calibrated 'Z' spectra from the energy loss in the MUSIC for the FRS setting centred on fully stripped ^{191}W ions. (b) The energy loss signal from the plastic scintillation detector after the final degrader, but before the aluminum stopper.

nuclei via proton-only abrasion. This has led to the identification of a number of rather neutron rich, heavy nuclei, below the Z=82 shell gap for the first time. By identifying the projectile fragments on an event-by-event basis, gamma-rays depopulating isomeric states can be measured at the final focus of the fragment separator [1,3]. Such decays can be used to provide the first information on the internal structure of these exotic heavy systems. In this conference paper, we report on the initial analysis of our experiment to study isomeric decays in heavy, neutron rich nuclei between A $\sim 190 - 200$, following the projectile fragmentation of a ^{208}Pb beam.

2. EXPERIMENTAL DETAILS

The experiment was performed at the GSI facility, Darmstadt, Germany, and used a 1 GeV per nucleon ^{208}Pb primary beam impinging on a 1.6g/cm^2 natural beryllium target. The primary beam was provided by the SIS accelerator, with a typical on-target beam intensity of 2×10^8 lead ions over a 12 second beam spill. The fragments were identified and separated using the GSI FRagment Separator (FRS) [4]. Niobium foils (221 mg/cm^2) were placed after both the target and degrader to maximise the electron stripping, such that (typically) 90% of the ions for a given isotope were fully stripped.

The atomic number of each fragment was determined by: (a) measuring the energy loss in the MUSIC (Multi Sampling Ionisation Chamber) (see figure 1) and (b) from the position of the ions at the final focus, (see figure 2). The mass-to-charge ratio of the ions, A/Q, was determined from their time of flight through the second part of the FRS. The measured change of the magnetic rigidity of ions before and after they passed through a degrader placed at the intermediate dispersive focal plane of the FRS, was used to provide a charge state identification (see upper part of figure 2). Figure 2 shows the particle identification plots for fully stripped, hydrogen-like and helium-like fragments which were transmitted for the setting centred on fully stripped ^{191}W ions. The separation between three charge states and the clarity of the particle identification is clearly demonstrated.

The fragments passed through a series of detectors at the final focal plane of the FRS, before being implanted in a Z-shaped, aluminum stopper, which had an effective thickness of 4 mm. A variable thickness aluminum degrader was used to slow down the fragments

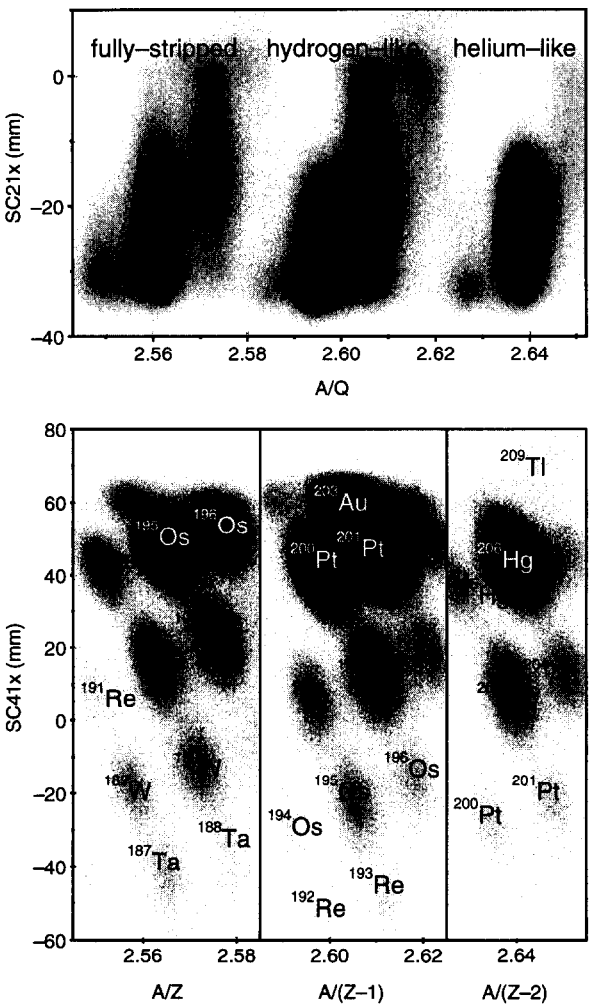

Figure 2. *Upper Portion:* Position versus time of flight spectrum for setting centered on fully stripped ^{191}W ions. Note, this spectrum highlights the separation between the different charge states through the FRS. *Lower Portion*: The associated particle identification spectra of position at the final focus (~Z), versus time of flight through the FRS ($\sim \frac{A}{Q}$) for fully stripped, hydrogen and helium-like nuclei.

of interest, and ensure their implantation in the Z-shaped catcher. Lighter, fission product fragments, which were not stopped in the catcher, were recorded in a 'veto' scintillator placed after the catcher. An array of 4 segmented germanium CLOVER detectors recorded gamma-rays emitted from isomeric decays from the implanted ions. The absolute photopeak efficiency of the gamma-ray array was measured with standard calibration sources to be approximately 8% at 661 keV. However, the effective detection efficiency was reduced due to the ions stopping in the catcher, which gave rise to a prompt burst of low energy x-rays and bremsstrahlung. For the ^{191}W FRS setting, this had the effect of "blinding" on average 10 of the total 16 detector elements in each event. Two time ranges (8 μs TDC and 80 μs TAC) were used to enable the measurement of both short and longer-lived isomers. In this way, time correlated, delayed gamma-ray spectra for previously inaccessible neutron rich nuclei could be obtained. The initial analysis of these data for a separate FRS setting, centred on ^{177}Ta, has shown the surprising result of the population of a number of known A$\sim$180, high-K isomers, with spins up to $\frac{35}{2}\hbar$ [5].

3. DATA ANALYSIS AND RESULTS

The upper part of figure 2 shows fully stripped, hydrogen and helium-like ions, as detected at the scintillator placed at the intermediate focal plane and the first scintillator after the last dipole magnet of the FRS. The different isotopes have been identified from the time of flight and magnetic rigidity calculation (which directly gives $\frac{A}{Q}$, where A is the atomic mass and Q is the charge state). The decays from the previously identified isomeric decays in ^{200}Pt [7] and ^{206}Hg [8] were used to confirm the isotopic identification technique and also acted as an internal check for the isomer decay half-life measurements.

Figure 3 shows a selection of the gamma-ray and associated time spectra for isomeric decays observed for the three charge states. The isomeric decays in $^{188}_{73}$Ta, $^{190}_{74}$W, $^{192}_{75}$Re, $^{193}_{75}$Re, $^{197}_{77}$Ir, $^{201}_{78}$Pt and $^{202}_{78}$Pt observed in this work are the first spectroscopic information obtained on the internal structure of these nuclei. Note in particular the spectra obtained for the hydrogen-like ions of ^{200}Pt and ^{201}Pt. The 7^- isomeric state in ^{200}Pt was reported by Yates *et al.* [7] to decay with a half-life of approximately 14 ns, however, the transition which directly depopulated the isomeric state was not observed. The time of flight for the fragments through the separator was measured to be approximately 300 ns. We propose that the isomeric state survives through the spectrometer due to the transition energy being less than the K-shell binding energy in platinum (78 keV). This effectively 'switches-off' this internal, electron conversion decay branch for the ion in flight and considerably extends the effective lifetime of the state through the separator. (Note a 50 keV E2 in ^{200}Pt has $\alpha_{\mathrm{tot}} = 117$). The data shows a similar effect for the previously unreported isomer in ^{201}Pt, which appears to have a decay lifetime similar to that of ^{200}Pt (see figure 3).

Figure 4 shows the results of a $\gamma - \gamma$ coincidence analysis on the delayed transitions associated with ^{200}Pt. The previously observed yrast cascade in ^{200}Pt [7] is clearly observed, showing that a gamma-gamma style analysis is possible for these types of data set.

Note, the lines in figure 4 at 319, 543 and 709 keV represent a cascade, which appears to decay from a previously unreported, higher lying isomer, with a similar half-life to the 7^- state observed by Yates et al. [7].

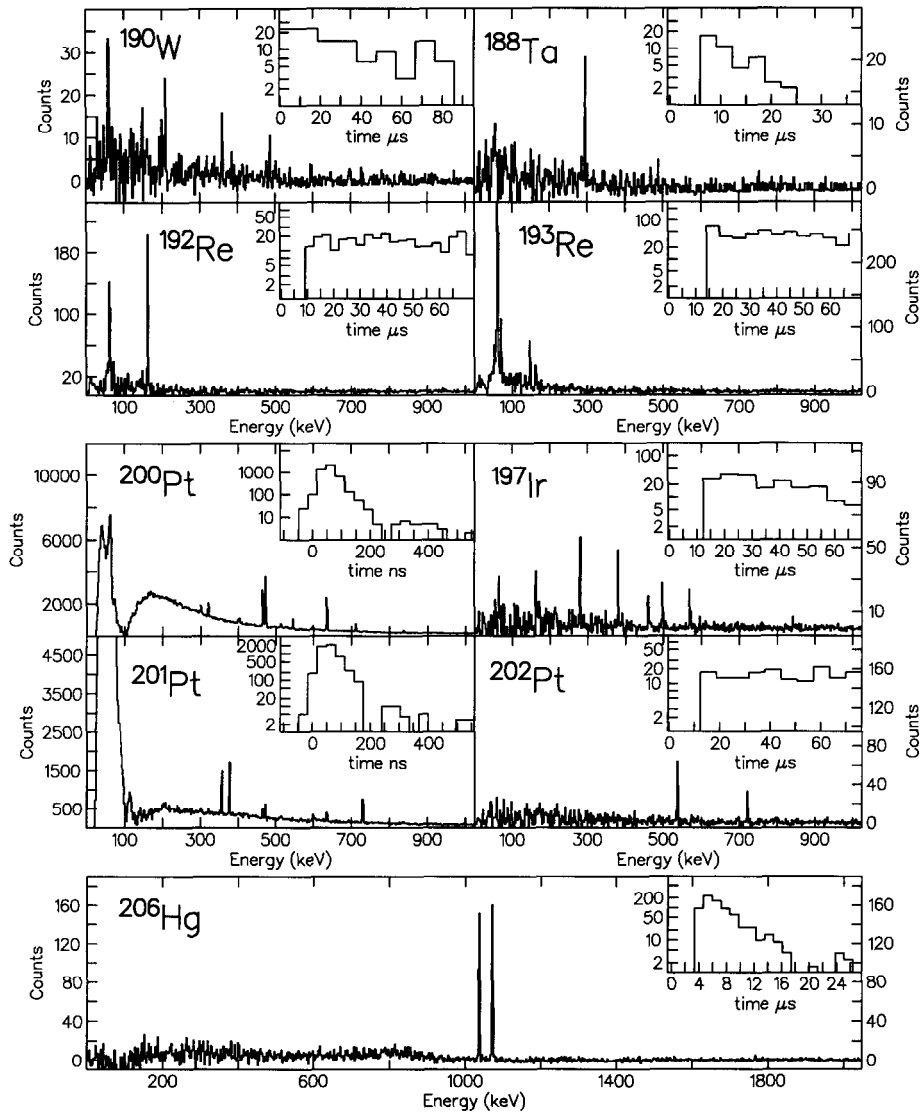

Figure 3. Gamma ray and time spectra for isomeric decays observed in fully-stripped (upper box), hydrogen-like (middle box) and helium-like (lower box) charge states. The spectra have all had a normalised, random spectrum subtracted, with the exception of the shorter-lived isomers in ^{200,201}Pt. In these cases, a normalised portion of the prompt gated gamma-rays associated with the specific ion of interest was subtracted. The non-zero starting time associated with some of these time spectra arises due to software cuts made in the off-line analysis.

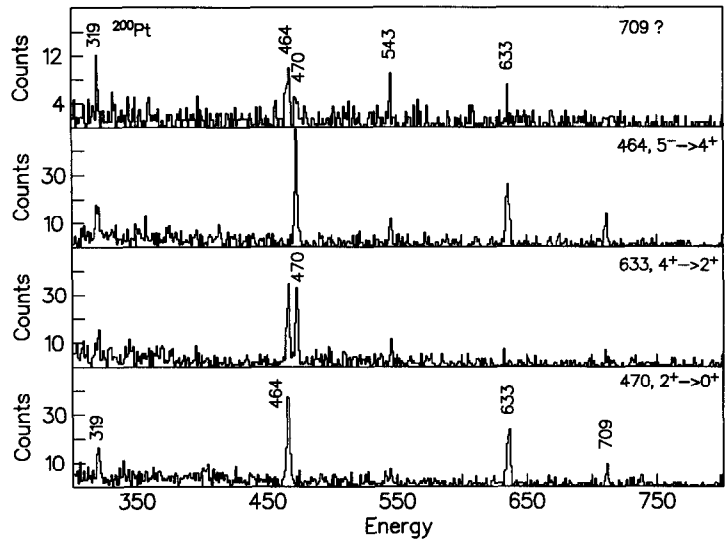

Figure 4. Gamma-gamma coincidence spectra for ^{200}Pt obtained in the present work. Note, the spin and parity of the state decaying via the previously unreported 709 keV transition are not known.

4. SUMMARY

The isomeric decays observed in the current work can throw light on a number of nuclear structure phenomena in this spectroscopically virginal region, including an increased importance of the triaxial degree of freedom and the related demise of the K-quantum number. Future plans for an extension of this technique include using an active stopper for conversion electron spectroscopy, fast lifetime measurements between transitions fed by an isomer and magnetic moment studies [6]. Taken together, these new techniques should allow future exploration of currently inaccessible regions of the Segré chart.

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