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In-Beam Thin Target Fragmentation of ^{197}Au.

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Abstract. This paper reports on a test experiment to investigate the viability of using in-beam gamma-ray spectroscopy with projectile fragmentation reactions to explore the structure of heavy, neutron-rich nuclei. The experiment used a 'thin target' fragmentation reaction with a 30 MeV per nucleon ^{12}C beam on a 30 mg/cm^2 self-supporting gold target. The initial analysis has identified a number of previously known discrete cascades in a variety of in-beam reaction products. The decay of products has also been investigated and an initial comparison of their relative yields with predictions from the EPAX parameterisation begun. The relevance and future viability of this method as a complimentary technique to fragmentation-isomer studies to investigate the near-yrast properties of heavy, neutron-rich nuclei is discussed.

INTRODUCTION

The combination of high-efficiency arrays of hyperpure germanium detectors coupled with projectile fragment separators has led to a number of exciting new spectroscopic results following measurements of decays from isomeric states. Highlights of this type of work include (a) studies using intermediate energy (~60 MeV/u) beams at GANIL pushing out towards the proton drip line [1] and for neutron-rich nuclei approaching the doubly-magic nucleus $^{78}_{28}$Ni$_{50}$ [2]; and (b) work at GSI providing the first spectroscopy of heavy, neutron-rich nuclei between Erbium (Z=68) and Uranium (Z=92) following the fragmentation of relativistic (~1 GeV/u) beams of ^{238}U [3] and ^{208}Pb [4].

Although these experimental programs have been very successful in exploring new areas of the nuclear chart, the restriction of requiring an isomeric state that decays within a specific temporal range of tens of nanoseconds up to a few ms makes this technique somewhat restrictive. Coloumb excitation using secondary fragmentation beams has been pioneered by groups at both Riken and MSU [5]. More recently, there have been reports of 'in-beam' gamma-ray spectroscopic studies using both single and double-step fragmentation [6]. These experiments are however limited by the singles event rates in the gamma-ray detectors and current technology precludes investigations of nuclei with

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A>100 using this method.

This paper reports on the preliminary analysis of a 'thin-target fragmentation' experiment aimed at investigating the feasibility of performing in-beam fragmentation studies, *without* the use of a fragment separator. The ultimate aim of this work is to develop a technique which allows detailed spectroscopy of heavy, neutron-rich nuclei using specific experimental tags such as decays from isomeric states and/or characteristic X rays following internal conversion decay.

EXPERIMENTAL DETAILS, RESULTS AND FORWARD LOOK.

The philosophy behind the feasibility experiment was the use of a non-inverse reaction in which, assuming a simple two-body reaction for the fragmentation process (admittedly a rather gross assumption), the much heavier target-like fragmentation reaction products are emitted almost perpendicular to the beam direction in the laboratory frame. As such they should should stop in the target within a few picoseconds of the reaction and therefore, states populated with apparent lifetimes greater than this should be observed with no Doppler shift and associated loss in resolution due to Doppler broadening effects. (Note that a similar experiment to study decays in light, neutron-rich nuclei has recently been reported by the Berkeley group [7]).

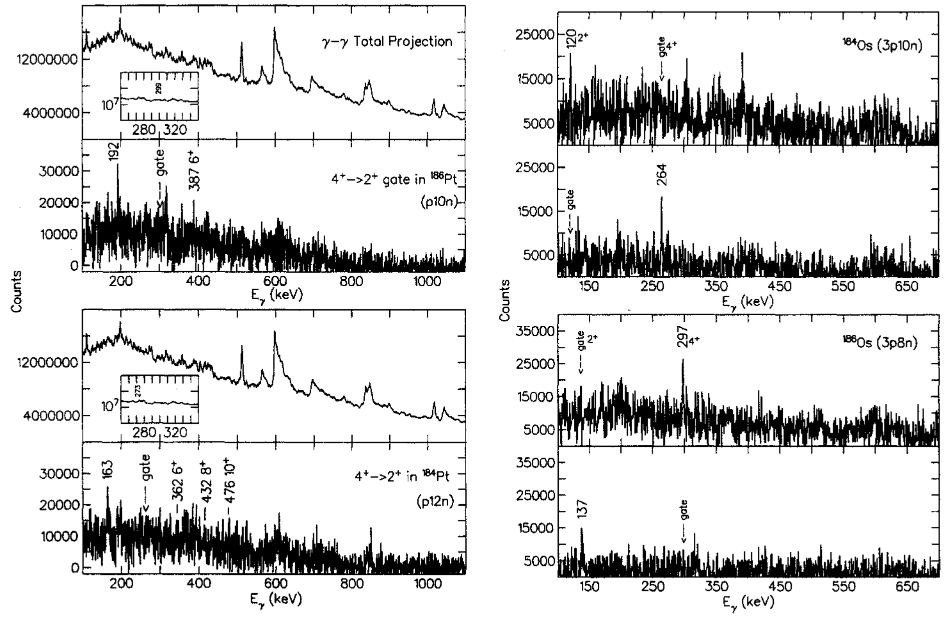

FIGURE 1. In-beam $\gamma-\gamma$ coincidence spectra from the current work.

The experiment was performed at the iThemba LABS, South Africa using a 30 MeV per nucleon ^{12}C beam incident on a self-supporting 30 mg/cm^2 ^{197}Au target. At this energy, the beam loses approximately 1 MeV/*u* through the target. In-beam reaction gamma rays were detected using the AFRODITE gamma-ray spectrometer [8] comprising 7, four-element clover germanium detectors and 8, four-way segmented planar 'LEPS' detectors (which provided enhanced sensitivity for low-energy decays). The experimental master-trigger condition was set such that a valid event required at least three detectors to fire within approximately 200 ns of each other, at least two of which were independent clover modules. Typical beam currents for the one day, in-beam test run were ~50 ppA, corresponding to a typical master-gate event rate of 2 kHz.

Figure 1 shows the gamma-gamma total projection for this work. Note the broadened lines at 596 keV and 691 keV associated with neutron scattering on the ^{74}Ge and ^{72}Ge isotopes in AFRODITE, highlighting the large neutron flux. The main path of the fragmentation 'corridor' flows primarily towards neutron-deficient nuclei and the subsequent cooling of the initial, hot fragmentation products gives rise to significant neutron evaporation. As figure 1 shows however, even with the poor signal to background ratio associated with simple gamma-gamma gating due to the very large number of reaction channels which are open, discrete yrast cascades can be identified. Specifically, figure 1 shows the yrast cascades in ^{184,6}Pt and ^{184,6}Os.

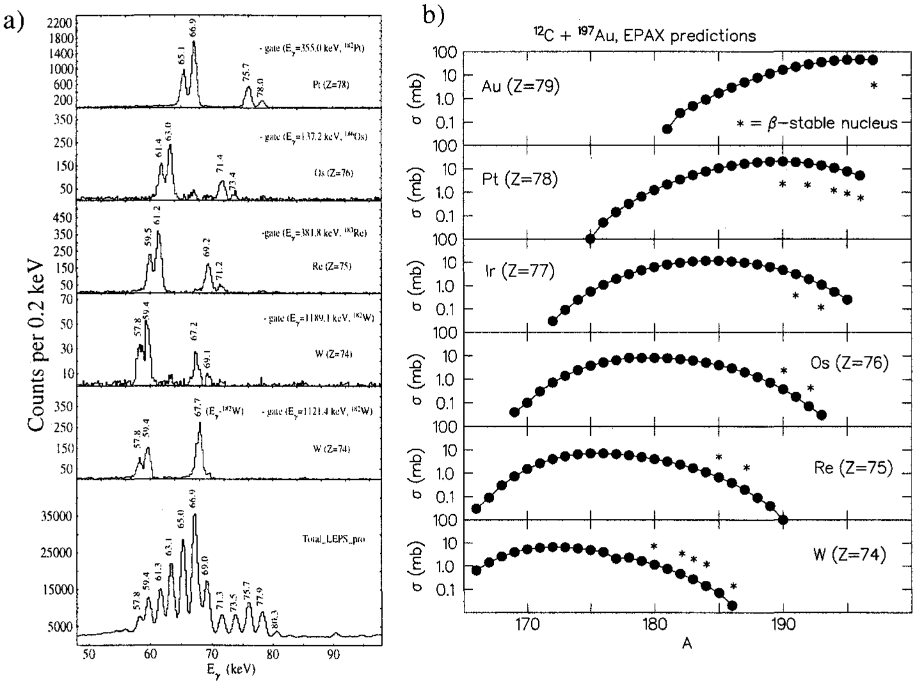

FIGURE 2. (a) Gamma gated LEPS spectra showing characteristic x rays from some of the strongly populated decay products. (b) EPAX calculations [9] for ^{12}C+^{197}Au.

Following the in-beam experiment the ^{197}Au target was left inside the AFRODITE array for four days and the data acquistion master condition set to singles. In this way the activity from the β-decaying target-like reaction products and their daughters could be measured. This data could then be used to provide a clearer picture of which reaction products were formed in-beam. A LEPS-clover coincidence matrix was sorted for the decay data which allow gating on characteristic K_α and K_β X-rays in elements ranging from W (Z=74) to Au (Z=79). Figure 2 highlights the clear separation of the different elements achieved by gating on decay transitions from known elements.

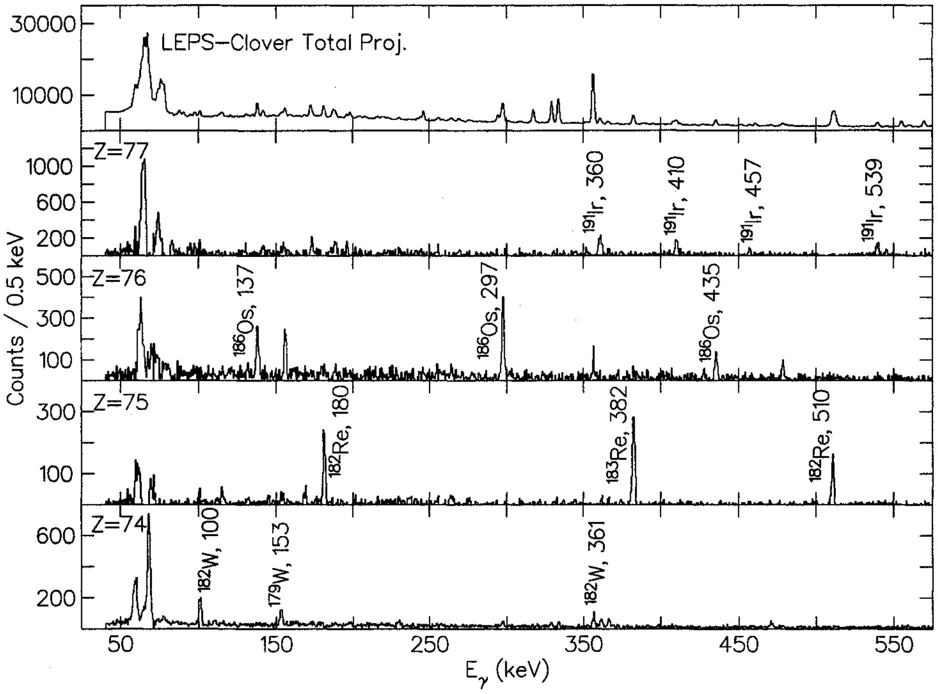

FIGURE 3. Examples of X-ray gated gamma-ray spectra for the decay products.

Elementally pure decay spectra were obtained by gating on characteristic X rays and subtracting a normalised portion of the neighboring element gate due to the usual energy overlap of the $K_{\alpha_1}(Z)$ and $K_{\alpha_2}(Z+1)$ peaks in neighboring elements (see fig. 3). The decay measurements will allow isobaric and elemental [10] yields to be determined.

The initial data suggest that the technique of in-beam, thin-target fragmentation may be a viable mechanism for studying heavy, neutron-rich nuclei. Although only proton-rich nuclei have been identified the current data, the EPAX calculations suggest that neutron-rich nuclei were also populated. Clearly in order to study these nuclei in-beam using this method, a significant increase in experimental sensitivity is required. In nuclei where the yrast cascade is known, this should be achievable by taking higher-fold gamma-ray gates (a gamma-triples analysis of the current data is underway). A major increase in selectivity could also be obtained by gating on transitions depopulating ns→ μs decays between the beam pulses. This would allow correlations above and below the metatable states providing a complementarity between the fragment separator based isomer studies and this type of 'prompt', in-beam work. Other experimental ancillary detectors which may improve sensitivity include the use of a multi-element neutron wall, since the more neutron-rich nuclei (by definition) emitted fewer neutrons than the more populous proton-rich systems.

The use of X-ray gating for in-beam decays to provide elemental selection is also clearly of significant benefit to these types of studies. Ideas being investigated in this area include the development of a LEPS-Clover hybrid detector, which would allow the *simultaneous* detection of both X-rays and gamma-rays. Linked to this is the development of the future generation of gamma-ray tracking arrays such as GRETA and AGATA. Such methods will lead to the possibility of much faster data rates which will be important in obtaining information on the more weakly populated neutron-rich nuclei. To this end significant developments are already taking place on the use of digital electronics for pulse shape analysis, which will soon usurp standard analogue amplifiers (see eg. reference [11]).

On the physics side, advances in this technique will enable a number of questions to be attacked. Currently, isomeric ratio measurements are the main method which has been used to obtain information in the angular momentum distribution of residual nuclei produced in such reactions [12]. However, the selection of discrete, in-beam cascades will provide a much clearer picture of this question over a very wide range of nuclei.

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