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# ISOMER SPECTROSCOPY IN THE NEUTRON-DEFICIENT LEAD REGION FOLLOWING PROJECTILE FRAGMENTATION *

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Projectile fragmentation of a 750 MeV/nucleon $^{238}$U beam was used to populate neutron-deficient nuclei around $A$ ∼190. Isomeric states in Hg, Tl, Pb, Bi, and Po isotopes were identified and their lifetimes determined, with the ultimate aim of measuring their isomeric ratios to provide information on the spin population in such reactions.

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## 1. Introduction

The neutron-deficient lead nuclei present a special case where three potential minima-spherical, oblate and prolate-are both predicted and observed and at relatively low excitation energies [1,2]. The primary aim of the present test experiment was to investigate this 'shape co-existence' phenomena using isomer tagged projectile fragmentation. The measurement of the decays of such isomers using conventional techniques becomes increasingly problematic as the production cross sections plummets with decreasing neutron number. Highly selective techniques are therefore essential and the efficiency of the relativistic-fragmentation, isomer tagging technique [3] makes it ideally suited for this application.

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## 2. Experimental details

The nuclei of interest were populated following the projectile fragmentation of a 750 MeV/nucleon $^{238}$U primary beam impinging on a 1.6 g/cm$^2$ natural beryllium target. The primary beam was provided by the SIS accelerator at GSI. The fragments were identified and separated using the GSI FRagment Separator (FRS) [4], operated in the standard achromatic mode with a wedge shaped degrader located at the intermediate focal plane. Niobium foils were placed after both the target and degrader to maximise the electron stripping.

The atomic number of each fragment was determined by measuring the energy loss in an ionisation chamber. The mass-to-charge ratio of the ions, A/q, was determined from the time of flight through the second part of the FRS and the magnetic rigidity of the dipole magnets. The fragments passed through a series of detectors at the final focal plane of the FRS, before being implanted in a $Z$-shaped, plastic catcher. An aluminium degrader of variable thickness was used to slow down the fragments of interest, and ensure their implantation in this catcher. Fission product fragments, which were not stopped in the catcher, were recorded in a 'veto' scintilator placed behind. Two segmented germanium Clover (VEGA) detectors recorded $\gamma$-rays emitted from isomeric decays from the implanted ions in a time window up to 80 $\mu$s after the implantation.

## 3. Results

Previously identified isomeric decays in $^{188}$Hg, $^{192}$Tl, $^{192,193,194,195,196}$Pb, $^{195,197,199}$Bi, and $^{198,200}$Po were observed in the present experiment. All these species were transmitted as fully stripped ions in the first half of the FRS and hydrogen-like in the second half (after the wedge-shaped degrader), in a single setting. Nuclei close to $^{186}$Pb were transmitted through the FRS as fully stripped ions in both sections of the FRS, but at much lower rate due to their reduced population cross section. No isomeric decays in the $^{186}$Pb region were observed in the current work. Examples of delayed $\gamma$-ray spectra are shown in figure 1.

The decays in Hg, Tl, Pb, Bi, and Po isotopes represent the first time these decays have been observed following production via projectile fragmentation. This region of nuclei is dominated by intrinsic states with spherical and oblate shapes [5]. The isomeric states identified in the present experiment are all spherical, with the exception of the $12^+$ isomer in $^{188}$Hg [6] and the $(8^-)$ in $^{192}$Tl [7], which are interpreted as originating from oblate configurations. In the lead isotopes oblate isomeric states with $I^\pi\!=\!11^-$ are known but are non-yrast. Their decays were not observed in this work.

The lifetimes of the isomers were determined. The obtained mean lives are consistent with the published results from previous experiments (see Table I).

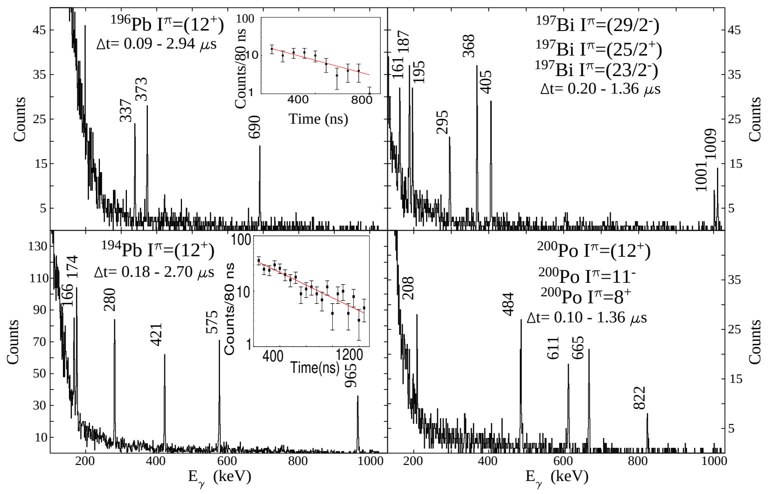


Fig. 1. Examples of $\gamma$-ray and time spectra from the present work.

TABLE I

Isomers observed in the present experiment. The extracted lifetimes are compared with the values in the Nuclear Data Sheets compilations.

| Isotope | $I^\pi$ | $\tau$ (present work) | $\tau$ (published value) | |
|---|---|---|---|---|
| $^{188}$Hg | $(12^+)$ | 270(51) ns | 193(22) ns | [6] |
| $^{192}$Tl | $(8^-)$ | 451(64) ns | 427(7) ns | [8] |
| $^{192}$Pb | $(12^+)$ | $2.1(^{+\infty}_{-1.1})$ $\mu$s | 1.59(7) $\mu$s | [8] |
| $^{192}$Pb | $(10)^+$ | | 134(16) ns | [8] |
| $^{193}$Pb | $(33/2^+)$ | $104(^{+370}_{-34})$ ns | $194(^{+36}_{-22})$ ns | [9] |
| $^{194}$Pb | $(12^+)$ | $469(^{+144}_{-66})$ ns | 505(14) ns | [10] |
| $^{195}$Pb | $21/2^-$ | $14.8(^{+130}_{-5.8})$ $\mu$s | 14.4(1) $\mu$s | [11] |
| $^{195}$Bi | $(29/2^-)$ | $0.9(^{+2.9}_{-0.3})$ $\mu$s | 1.08(7) $\mu$s | [11] |
| $^{195}$Bi | $(25/2^+)$ | | 115(14) ns | [11] |
| $^{196}$Pb | $(12^+)$ | 343(89) ns | 390(6) ns | [12] |
| $^{197}$Bi | $(29/2^-)$ | 326(194) ns | 379(19) ns | [13] |
| $^{197}$Bi | $(25/2^+)$ | | 87 (31) ns | [13] |
| $^{197}$Bi | $(23/2^-)$ | | 294(26) ns | [13] |
| $^{198}$Po | $12^+$ | $1.0(^{+11}_{-0.5})$ $\mu$s | 1.08(7) $\mu$s | [14] |
| $^{198}$Po | $11^-$ | | 288(29) ns | [14] |
| $^{199}$Bi | $(29/2^-)$ | 247(91) ns | 242(19) ns | [15] |
| $^{200}$Po | $(12^+)$ | 395(94) ns | 387(4) ns | [16] |
| $^{200}$Po | $11^-$ | | 151(11) ns | [16] |
| $^{200}$Po | $8^+$ | | 88(4) ns | [16] |

## 4. Conclusions

Nuclei in the $A = 188$–$200$, $Z = 80$–$84$ region have been populated following the projectile fragmentation of a $^{238}$U primary beam. Although several isomeric states are known in the region, only the decay out from yrast isomers was observed, suggesting a near-yrast population of angular momentum states in such reactions, as observed in our previous work [17].

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