ISOMERIC STATES IN THE LIGHT Tc ISOTOPES*

A.B. Garnsworthy[a,b], P.H. Regan[a], S. Pietri[a], D. Rudolph[c]
L. Cáceres[d,e], M. Górska[d], Zs. Podolyák[a], S.J. Steer[a]
A. Heinz[b], F. Becker[d], P. Bednarczyk[d,g], P. Doornenbal[d]
H. Geissel[d], J. Gerl[d], H. Grawe[d], J. Grębosz[g,d], A. Kelic[d]
I. Kojouharov[d], N. Kurz[d], F. Montes[d], W. Prokopwicz[d]
T. Saito[d], H. Schaffner[d], S. Tachenov[d], E. Werner-Malento[d,f]
H.J. Wollersheim[d], G. Benzoni[h], B. Blank[i], C. Brandau[a]
A.M. Bruce[j], F. Camera[h], W.N. Catford[a], I.J. Cullen[a]
Zs. Dombrádi[k], E. Estevez[l], W. Gelletly[a], R. Hoischen[c]
G. Ilie[m,n], J. Jolie[m], G.A. Jones[a], A. Jungclaus[e], M. Kmiecik[g]
F.G. Kondev[o], T. Kurtukian-Nieto[l], S. Lalkovski[p], Z. Liu[a]
A. Maj[g], S. Myalski[g], M. Pfützner[f], T. Shizuma[a,r], A.J. Simons[a]
S. Schwertel[s], P.M. Walker[a], O. Wieland[h]

[a]Department of Physics, University of Surrey, Guildford, GU2 7XH, UK
[b]WNSL, Yale University, 272 Whitney Avenue, New Haven, CT, 06520, USA
[c]Department of Physics, Lund University, 22100 Lund, Sweden
[d]GSI, Planckstrasse 1, 64291 Darmstadt, Germany
[e]Departmento di Teórica, Universidad Autonoma de Madrid, Madrid, Spain
[f]IEP, Warsaw University, Hoża 69, 00-681 Warszawa, Poland
[g]The Institute of Nuclear Physics, 31-342 Kraków, Poland
[h]Universitá degli Studi di Milano and INFN Milano, 20133 Milano, Italy
[i]CENBG, le Haut Vigneau, 33175 Gradignan Cedex, France
[j]School of Engineering, University of Brighton, Brighton, BN2 4GJ, UK
[k]Institute for Nuclear Research, 4001 Debrecen, Hungary
[l]Universidad de Santiago de Compostela, Santiago de Campostela, Spain
[m]IKP, Universität zu Köln, 50937 Köln, Germany
[n]National Institute of Physics and Nuclear Engineering, Bucharest, Romania
[o]Nuclear Engineering Division, Argonne National Laboratory, IL-60439, USA
[p]Faculty of Physics, University of Sofia "St. Kliment Ohridsk" Sofia, Bulgaria
[r]Japan Atomic Energy Research Institute, Kyoto, 619-0215, Japan
[s]Physik Department E12, Technische Universität München, Garching, Germany

(Received November 1, 2006)

* Presented at the Zakopane Conference on Nuclear Physics, September 4–10, 2006, Zakopane, Poland.

Preliminary results from the first experiment of the Stopped Beam RISING campaign are presented. The relativistic projectile fragmentation of a 750 MeV/u beam of ^{107}Ag populated isomeric states in very neutron deficient nuclei at the proton dripline around mass 80–90. Nuclei were unambiguously identified using the FRagment Separator (FRS) and its ancillary detectors located at GSI. The ions produced were slowed down from relativistic energies by means of an Al degrader and implanted in the centre of the high-efficiency Stopped RISING array. This allowed the identification of new excited states in the $N = Z = 43$ nucleus, ^{86}Tc, populated following the de-excitation of a microsecond isomer. Preliminary results of this analysis, as well as previously unobserved isomeric states in ^{87,88}Tc, are reported.

PACS numbers: 29.30.Kv, 23.20.Lv

1. Introduction

The Rare ISotope INversigation at GSI (RISING) project utilises relativistic projectile fragmentation reactions to investigate the nuclear structure properties of highly exotic nuclei. Primary beams of energies ranging between 500 and 1000 MeV per nucleon are provided by the SIS-18 synchrotron and following fragmentation (or fission) the reaction products are separated and identified by the FRagment Separator (FRS) [1]. The FRS has a range of ancillary detectors used in the unambiguous identification of each ion on an event-by-event basis. The detector set-up at the focus of the FRS incorporates fifteen Germanium Cluster detectors, each with seven large volume crystals, in various configurations designed to meet the requirements of investigating the physics involved in each experiment [2,3]. Experiments have recently been performed as part of the collaboration's 'Stopped Beam' campaign. Here the ions are slowed down by a variable thickness aluminium degrader and brought to rest in the centre of the RISING Germanium array, arranged in a high efficiency configuration, to observe γ rays emitted in the decay of nano-to-millisecond isomeric states in exotic nuclei. Details of the earlier 'Fast-Beam' campaign which identified radiation emitted in the prompt decay of highly exotic nuclei can be found in ref [4]. Results from the first experiment of the 'Stopped Beam' campaign are presented here and further details can be found in [2,3,5].

2. Experimental details and results

A beam of ^{107}Ag was accelerated to 750 MeV/u by the SIS-18 Synchrotron and impinged on a 4 g/cm^2 Be target. The spill structure of the beam was $1\rightarrow3\times10^9$ ions over $5\rightarrow6$ secs in a total cycle time of 10 secs. The

reaction products were transported to the focal plane of the FRS and identified by A/q and Z using measurements of magnetic rigidity, time-of-flight, position and energy loss. Details of the particle identification can be found in [2, 3]. The ions were brought to rest in a perspex block of 7 mm thickness at the centre of the Stopped RISING array after being slowed down in a 2 g/cm^2 Al degrader. Gamma rays emitted from isomeric states were detected in the array and correlated with the arrival of the associated ion.

This experiment confirmed the isomer in ^{86}Tc, previously reported by Chandler *et al.* [6] and enabled the identification of previously unreported decays in ^{87,88}Tc. Figure 1 shows projections of Z for nuclei of $T_z = 0$, $\frac{1}{2}$ and 1 for which delayed γ rays were detected in various timing regimes. The uppermost panel shows the Z projection with no additional timing condition. The central panel is gated on γ rays observed between 0.5 and 5 μs after implantation to identify isomers with μs half-lives, and the lower panel shows nuclei gated between 150 and 500 ns to indicate short-lived isomers. Evidence for isomeric states in ^{86,87,88}Tc can be seen in these plots as well as the previously reported isomer in ^{84}Nb [6]. Details of the short-lived isomeric state in the $T_z = 0$ nucleus, ^{82}Nb can be found in [5].

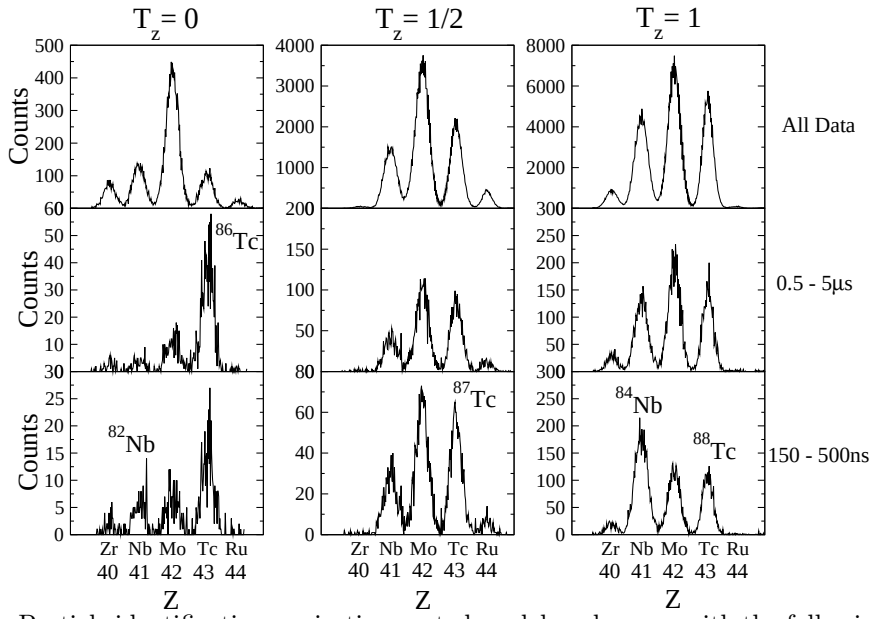

Fig. 1. Particle identification projections gated on delayed γ rays with the following time conditions: (Upper) No timing condition; (Centre) 0.5→5 μs; and (Lower) 150→500 ns after the time of implantation.

Figure 2 shows the delayed γ singles data collected for ions identified as ^{86}Tc. In this experiment we identify for the first time γ decay from isomeric states in these nuclei. Figure 2 also shows the delayed singles spectra for ions identified as ^{87}Tc and ^{88}Tc respectively. Previous work on the ^{87,88}Tc isotopes identified prompt transitions [7] but were not sensitive to the decay of isomeric states of the nano-to few microsecond range.

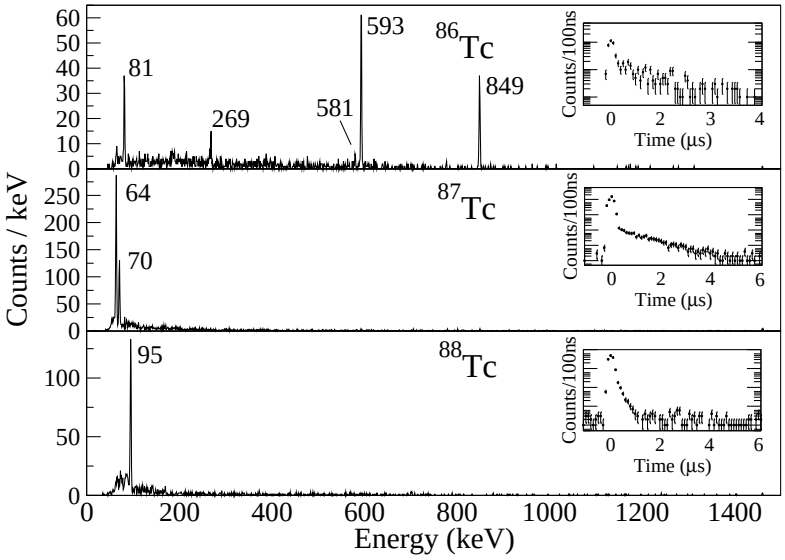

Fig. 2. Singles γ-ray spectra associated with ions identified as upper: ^{86}Tc, centre: ^{87}Tc, lower: ^{88}Tc. The insets show the time spectra produced by the signal from the DGF timing modules for each γ-ray event.

This work is sponsored by the EPSRC (UK), The Swedish Research Council, The Polish Ministry of Science and Higher Education (grants 1-P03B-030-30 and 620/E-77/SPB/GSI/P-03/DWM105/2004-2007), The Bulgarian Science Fund VUF06/05, The US Department of Energy (grants DE-FG02-91ER-40609, DE-AC02-06CH11357 and W-31-109-ENG-38), The Spanish Ministerio de Educación y Ciencia (Project number FPA2005-00696), The German Federal Ministry of Education and Research under grant 06KY205I and EURONS (European Commision contract number 506065). ABG would also like to thank Nexia Solutions Ltd for financial support.

REFERENCES

[1] H. Geissel, *Nucl. Instrum. Methods Phys. Res.* **B70**, 286 (1992).

[2] S. Pietri, accepted for *Nucl. Instrum. Methods Phys. Res.* **B**; *Acta Phys. Pol. B* **38**, 1255 (2007) these proceedings.

[3] P.H. Regan, *et al.*, *Nucl. Phys.* **A** in press.

[4] H.J. Wollersheim, *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A537**, 637 (2005).

[5] L. Cáceres, *Acta Phys. Pol. B* **38**, 1271 (2007) these proceedings.

[6] C. Chandler *et al.*, *Phys. Rev.* **C61**, 044309 (2000).

[7] D. Rudolph, *et al.*, *J. Phys. G: Nucl. Part. Phys.* **17**, L113 (1991).