STUDIES OF ISOMERIC STATES AND LIMITS OF PARTICLE STABILITY AROUND N∼Z∼40 USING FRAGMENTATION REACTIONS* **

P.H. Regan [a], C. Chandler[a], C.J. Pearson[a], B. Blank[b], R. Grzywacz[c,d], M. Lewitowicz[d], A.M. Bruce[e], W.N. Catford[a], N. Curtis[a], S. Czajkowski[b], P. Dessagne[f] A. Fleury[b], W. Gelletly[a], J. Giovinazzo[f], Z. Janas[b,c], C. Longour[f], C. Marchand[b], C. Miehe[f], N.A. Orr[g], R.D. Page[h], M.S. Pravikoff[b], A.T. Reed[h], M.G. Saint-Laurent[d], S.M. Vincent[a], R. Wadsworth[i], D.D. Warner[j], J.S. Winfield[d]

[a] Dept. of Physics, University of Surrey, Guildford, GU2 5XH, UK
[b] CEN Bordeaux-Gradignan, Le Haut-Vigneau, F-33175 Gradignan cedex, France
[c] Inst. of Exp. Phys., Warsaw University, Hoża 69, 00-681 Warsaw, Poland
[d] GANIL, BP 5027, F-14021, Caen cedex, France
[e] Cockcroft Building, University of Brighton, Brighton, BN2 4GJ, UK
[f] CRN Strasbourg, IN2P3 and Université Louis Pasteur, Strasbourg, France
[g] LPC, Bld. du Marechal Juin, 14050, Caen cedex, France
[h] Oliver Lodge Laboratory, University of Liverpool, Liverpool, L69 3BX, UK
[i] Department of Physics, University of York, Helsington, York, Y01 4DD, UK
[j] CCLRC Daresbury Laboratory, Warrington, WA4 4AD, UK

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Fragmentation products from a ^{92}Mo beam on a natural nickel target have been used to study structural properties of the very neutron deficient nuclei around N∼Z∼40. We present the first observation of isomeric decays in the $T_z=1$ systems $^{74}_{36}$Kr, $^{80}_{39}$Y and $^{84}_{41}$Nb. The isomer in ^{74}Kr is interpreted as the hindered decay from an excited 0^+ state, confirming the prediction of prolate/oblate shape coexistence in this nucleus. Transitions from states below an isomer in the N=Z nucleus $^{86}_{43}$Tc have also been tentatively identified, making this the heaviest N=Z system for which decays from excited states have been observed. In addition, we have obtained the first conclusive evidence for the existence of the $T_z=-\frac{1}{2}$ isotopes $^{77}_{39}$Y, $^{79}_{40}$Zr and $^{83}_{42}$Mo. The data for $^{77}_{39}$Y is of particular interest in light of the reported instability in the lighter odd-Z, $T_z=-\frac{1}{2}$ systems ^{69}Br and ^{73}Rb.

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1. Introduction

The information gained from the observation of anomalously long lived, excited nuclear states or 'isomers', provides vital elements needed for the calibration and testing of nuclear mean field models. An isomer can be used to precisely define the relative excitation energy of intrinsic states and to infer the residual interactions between individual single particle orbitals. The lifetime of the isomer and the energy of the de-exciting gamma-ray transition can be used to infer the difference in spin and parity of the isomeric state and the states to which it decays. Such unambiguous structural information is, in general, rather hard to obtain in nuclei at the limits of particle stability.

In the current work we report on the identification of isomers in a number of very neutron deficient nuclei around N$\sim$Z$\sim$40, populated in heavy ion induced, fragmentation reactions. This is a region which is very rich in nuclear structure phenomena, where the relatively low level density means that large variations occur in the nuclear shape for small changes in nucleon number [1–6]. In addition to the observation of isomeric states, this work has also yielded new information on the limits of particle stability in very neutron deficient isotopes with Z=N+1.

2. Experimental details

The nuclei of interest were produced in the fragmentation of a 60 MeV/A ^{92}Mo beam provided by GANIL facility. The beam bombarded a selection of natural nickel targets with thicknesses between 50 and 100 μm, placed at the entrance of the LISE3 spectrometer [7, 8]. The primary beam intensities were typically 100 enA. The LISE3 spectrometer was used to separate the fragmentation products from the primary beam particles and allowed A and Z identification of each individual nucleus. Four silicon detectors were placed at the final focus of the LISE3 spectrometer. The first of these silicon detectors, which was 300 μm thick, acted as an energy loss, or ΔE counter, and enabled clean Z separation of the fragments which passed through it. The final three silicon detectors, in which the fragments were stopped, each had a thickness of 150 μm. Selection by mass over charge state ($\frac{A}{Q}$) was obtained using the time of flight for the fragments to pass through various sections of the spectrometer. Typically, the detected ions were fully stripped of electrons through the spectrometer due to their high velocities ($\frac{v}{c}$ $\sim$30%). Gamma-rays from the de-excitation of isomeric states and following the subsequent beta-decays of the fragmentation products, were measured with a high efficiency gamma-ray array of seven 70 % germanium detectors packed in close geometry to the silicon stack at the final focus of the LISE3 spectrometer. This array had an absolute photopeak efficiency of approximately 3% for a 1.33 MeV gamma-ray. Increased efficiency for low-energy gamma-ray decays was achieved using a four element (clover), germanium planar (LEPS) detector. Details of similar experiments using this technique can be found in references [9] and [10]

The master electronics trigger required the detection of an ion passing through the ΔE detector. The hardware master gate was then opened for 100 μs to allow detection of delayed gamma-ray events during this period. Information on the lifetimes of isomeric states was obtained by recording the time difference between a ΔE signal and the detection of a delayed gamma-ray. Two separate time ranges of 0$\rightarrow$600 ns and 0$\rightarrow$80 μs were recorded (using TDCs and TACs respectively). This allowed good resolution over a wide time range. A number of spectrometer settings were used to maximise the count rate for particular groups of nuclei.

3. Data analysis and experimental results

As figure 1 highlights, clean, particle identification spectra could be obtained by setting gates in software on ΔE spectra gated by specific time of flight conditions.

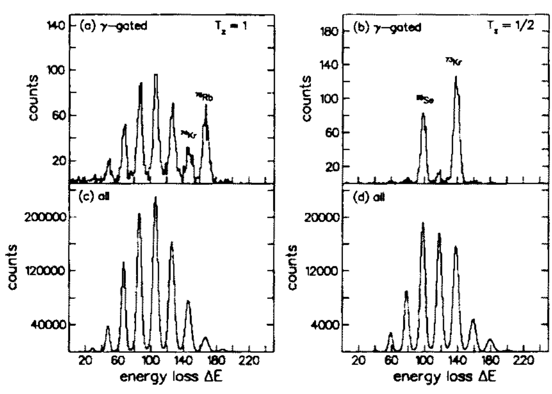

Fig. 1. Projections of time of flight versus ΔE spectra for $T_z = \frac{1}{2}$ and $T_z = 1$ nuclei. Note the dramatic change in the mass distributions of these spectra when the extra condition is applied, that a delayed gamma-ray is observed.

The time of flight condition separated nuclei by their mass to charged state ratio ($\frac{A}{Q}$). Since nuclei were, in general, fully stripped of their atomic electrons, this corresponded to separation in $\frac{A}{Z}$. Nuclei with isomeric decays were identified by the further condition that a delayed gamma-ray was detected in the same master-trigger period.

Using software gating on ions of a particular ion species as a particle identification, matrices of gamma-ray energy versus time could be contructed for specific nuclear species. By setting gates on particular time regions, transitions from decays of isomeric states could be highlighted. Similarly, by gating on specific gamma-ray energies, time spectra could be obtained from which the lifetime of the isomer was measured. As shown in figure 1, observation of previously reported isomeric states [11-13] in ^{69}Se, ^{73}Kr and ^{76}Rb could be used as consistency checks to ensure the validity of the experimental method and as internal timing calibrations for the TACS and TDCs.

3.1. Observation of new isomeric decays

3.1.1. The T_z=1 systems $^{80}_{39}$Y and $^{84}_{41}$Nb

Figure 2 shows the delayed gamma-ray energy spectra associated with ^{80}Y. The spectrum has the condition that the gamma-ray was detected between 0 and 20 μs after the ^{80}Y ion was implanted in the silicon stack. The 84 keV transition represents a decay from an isomeric state. The inset shows the time spectra gated by this 84 keV transition for ^{80}Y recoils which reveals a mean-life of 6.0±1.5 μs.

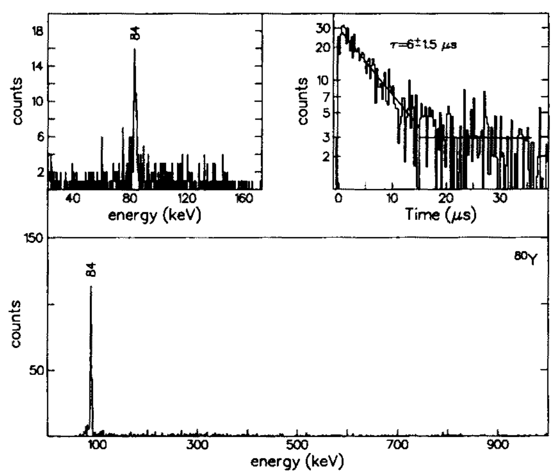

Fig. 2. Time and gamma-ray energy spectra showing the decay of the isomer in $^{80}_{39}$Y$_{41}$. The inset on the upper left is the low energy portion of the LEPS spectrum.

The lifetime of the isomeric state and energy of the de-exciting transition in ^{80}Y, restrict the likely decay modes to either an electric or magnetic quadrupole decay (ie. either E2 or M2). A lifetime of 6 μs for an 84 keV gamma-ray in ^{80}Y corresponds to approximately 1 Weisskopf unit for a pure

E2 decay and 10^{-2} Wu for an M2 decay. (Typical values for M2 decays in this region are between 10^{-2} and 10^{-1} Wu [14]).

The recent high-spin study on ^{80}Y by Bucurescu *et al.* [15] identified a number of high-spin, rotational structures, indicating a substantial nuclear deformation in this nucleus. This previous experiment used a thin target coupled to the Legnaro recoil mass separator and was insensitive to decays from isomeric states. Bucurescu *et al.* assigned the strongly populated yrast structure to a positive parity $\pi g_{\frac{9}{2}} \otimes \nu g_{\frac{7}{2}}$ configuration. Negative parity structures from a $\pi g_{\frac{9}{2}} \otimes \nu f_{\frac{5}{2}}$ configuration are also expected in this nucleus and candidates for such structures are identified in reference [15]. The bandhead of one of the structures observed in Ref. [15] could not be deduced in the high spin study and the isomer observed in the current work is possibly the decay of this bandhead via an M2 transition to the positive parity yrast bandhead.

Figure 3 shows the spectrum obtained using the condition that a gamma-ray was emitted within 600 ns after the implantation of a ^{84}Nb recoil in the stack of silicon detectors. Gamma-ray transitions at energies of 115, 133, 141, 175 and 206 keV are evident in this spectrum.

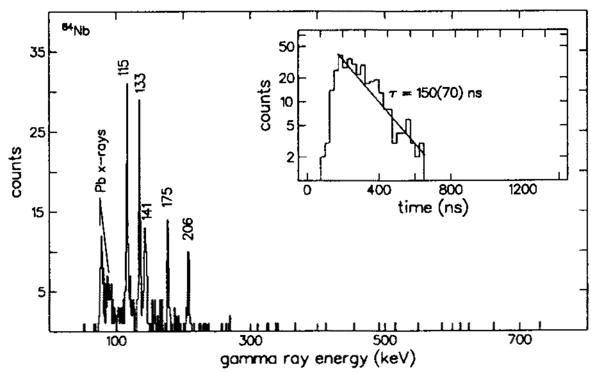

Fig. 3. Time and gamma-ray spectra for $^{84}_{41}$Nb$_{43}$. The time spectrum between t=0 and 40 ns is affected by software cuts to remove prompt gamma-rays.

None of these transitions have previously been associated with the decay of excited states in ^{84}Nb. The intensities of the transitions fall into two distinct groups, suggesting two separate cascades from the isomer into different configurations or the presence of two isomers with similar lifetimes. The 115 and 133 keV lines appear to have similar intensities (within the experimental uncertainties) as do the 141, 175 and 206 keV lines. The timing spectra of the individual lines are similar, consistent with the two cascades decaying from a common isomeric state with a mean life of 150±70 ns.

Excited states in ^{84}Nb have been identified by Gross *et al.* [16] using a fusion-evaporation reaction on the Daresbury Recoil separator, however this work was not sensitive to decays from isomeric states.

3.2. Evidence for shape coexistence in $^{74}_{36}Kr$, existence of a 0^+ isomer

Figure 4 shows the spectrum associated with ^{74}Kr, for gammas measured within 150 ns of the ion stopping in the silicon stack. The 456 keV decay from the yrast 2^+ state to the ground state is evident. The inset shows the time spectrum gated by this line (following the implanation of a ^{74}Kr fragment) and indicates an apparent mean-life for this state of 35±10 ns.

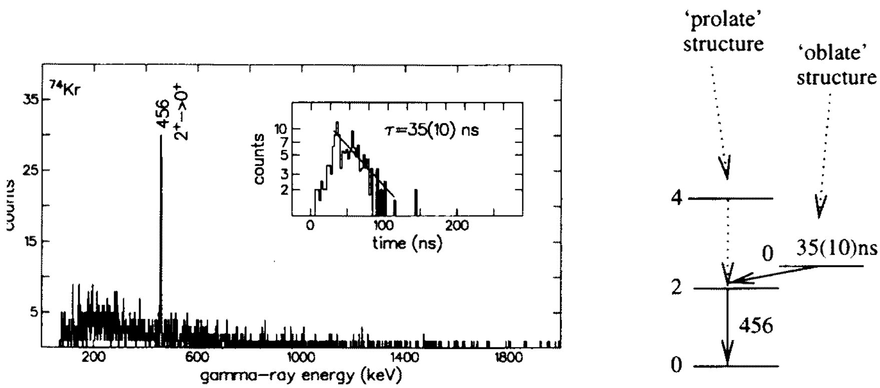

Fig. 4. Time and gamma-ray spectra for ^{74}Kr showing the decay from the proposed 0_2^+ isomer. The gamma-ray spectrum is gated by ^{74}Kr fragments and has the requirement that the delayed gamma-ray was detected less than 100 ns after the ion implanted in the silicon stack. The region within 40 ns of time zero in the time spectrum is affected by software cuts which remove prompt gamma-rays due to secondary reactions in the silicon detectors.

The lifetime of the 2^+ state has been measured by Roth *et al.* [17] and Tabor *et al.* [18] to be approximately 25 ps. Since the yrast $4^+ \rightarrow 2^+$ transition (558 keV) is not observed in the spectrum shown in figure 4 we conclude that the isomeric state decays directly into the yrast 2^+ state at 456 keV. The transition linking the isomer to the yrast 2^+ state must have an energy of less than 100 keV from the lack of observation of any other transition in the ^{74}Kr spectrum (see Fig. 4).

The flight time for fully stripped ^{74}Kr ions in the LISE3 spectrometer in the current work was 480 ns. If the isomer has a mean lifetime 35±10 ns, the fraction of ions which could be created in the isomeric state and reach the end of the LISE3 spectrometer is given by $\exp\left(-\frac{480\text{ns}}{35\pm10\text{ns}}\right)$. This puts a limit on the maximum value on the fraction of ions in the isomeric state which one would expect to survive transit through the separator of 2×10^{-5} or one in 40,000. The total number of $^{74}_{36}$Kr ions produced to form the spectrum shown in figure 4 was 1.34×10^{6}. There are approximately 120 counts in the full energy peak for the 456 keV line. For a measured, absolute total peak gamma-ray efficiency for measuring a 456 keV gamma-ray of approximately 5% this corresponds to at least 1 in 560 ^{74}Kr ions being in the isomeric state, far more than expected from the measured lifetime of the state. This anomaly can be explained if the decay of the isomer is hindered in flight. A likely explanation for the apparently anomalous lifetime for the isomer in ^{74}Kr is that the isomer has a 0^+ structure.

The direct decay from the excited 0_2^+ state to the 0_1^+ ground state can only proceed through E0 internal conversion. However, the high velocities of the ^{74}Kr ions through the spectrometer result in them being fully stripped of electrons. Therefore, in flight, the isomer can only decay via the E2 gamma-decay to the yrast 2^+ state (note that decay by electron conversion to this state is also not possible from the fully stripped ion in flight). This will increase the *effective* lifetime of the isomeric state. Once the ion is stopped in the silicon stack detector, it regains its atomic electrons and the E0 and E2 electron conversion partial decay widths take their usual values again. The isomer can then decay with its (shorter) 'atomic' rather than pure 'nuclear' lifetime.

The Weisskopf single particle estimate for the mean-life of a 100 keV E2 transition in ^{74}Kr (our upper limit for the linking transition) is approximately 4.3 μs, rising to 55 μs for a 60 keV decay. Since the flight path of the spectrometer is less than 0.5 μs this explains why the (fully stripped) isomeric state does not decay in flight through the LISE3 spectrometer. Note that we were only sensitive to decay branches of this isomer through the yrast 2^+ state. Under normal conditions, the isomer decays principally via E0 electron conversion directly to the 0^+ ground state.

We propose that the 0_2^+ isomeric state is the bandhead of the yrare, oblate deformed band in this nucleus. The nucleus ^{74}Kr has 36 protons and 38 neutrons and is a prime candidate for prolate/oblate shape coexistence. The relatively low level-density close to the proton and neutron Fermi surfaces in the N,Z$\sim$36-40 region gives rise to dramatic variations in the nuclear shape with the addition or removal of just one or two nucleons [2]. The sudden drop in the excitation energy of the first excited state in going from the N=Z=36 system $^{72}_{36}$Kr to the N=Z=38 nucleus $^{76}_{38}$Sr has been interpreted [1, 3, 4] as being due to a sudden alteration in the nuclear shape, going from a highly deformed oblate core in $^{72}_{36}$Kr to a highly deformed prolate core in $^{76}_{38}$Sr. The deformed single particle energy diagram for the Woods-Saxon potential (see Ref. [1]) shows a large oblate shell gap at Z=36 (krypton) and a large prolate deformed shell closure for N=38. Nazarewicz *et al.* [1] have suggested that an oblate 0^+ structure lies approximately 600 keV above the prolate ground state configuration in ^{74}Kr. A similar prediction regarding the presence of a low-lying oblate bandhead in this nucleus has recently been obtained by Petrovici *et al.* as described in references [19, 20].

3.3. Identification of an isomeric decay in the T_z=0 nucleus $^{86}_{43}Tc$

Prior to this work, the N=Z=42 system, ^{84}Mo was the heaviest self-conjugate nucleus where an excited state had been observed [3]. Figure 5 shows the gamma-ray and time spectra for $^{86}_{43}$Tc fragments and reveals the presence of an isomeric state with a mean-life of 2±1 μs.

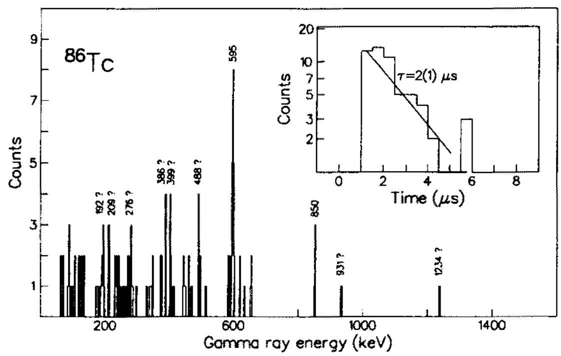

Fig. 5. Time and gamma-ray spectra for the N=Z nucleus ^{86}Tc.

Spectroscopic information on excited states of the odd-odd, N=Z nuclei in this region is of particular interest in terms of the significance of the isospin quantum number, T and proton-neutron pairing correlations. Fermi superallowed, ground state β decays have been observed in the N=Z systems, $^{62}_{31}$Ga, $^{66}_{33}$As, $^{70}_{35}$Br and $^{74}_{37}$Rb [21–23] suggesting 0^+ ground states for these nuclei. (This implies that the $T = 1$ states lie lower in energy than the $T = 0$ levels in these $T_z = 0$ nuclei). The observation of a proposed odd-odd 'pair-gap' in $^{74}_{37}$Rb [24] has also been the subject of much recent discussion.

Although the statistics of the spectrum shown in figure 5 represent the limit of our sensitivity, we can clearly identify the presence of a 595 keV transition in $^{86}_{43}$Tc. Prior to the current work, no experimental data had been reported on excited states in this nucleus. There are other tentative candidates for transitions in this nucleus at 192, 209, 385, 401, 487, 850 and 1235 keV. While the current data do not reveal a significant amount about the structure of ^{86}Tc, they are important for two reasons. Firstly, the presence of an isomeric state provides a direct observable with which to test mean field model predictions for this nucleus. Secondly, any future in-beam study of this very neutron deficient, N=Z nucleus using a recoil mass separator, would be insensitive to decays from isomeric states. The identification of a long-lived, metastable state, allows the transitions below the isomer to be used as clean experimental 'tags' (out of beam), for the prompt, high spin transitions in this nucleus.

3.4. New isotopes

In addition to the investigation of excited states in exotic nuclei via the detection of isomeric decays, we have identifed for the first time the $T_z = -\frac{1}{2}$ isotopes $^{77}_{39}$Y, $^{79}_{40}$Zr and $^{83}_{42}$Mo. Figure 6 shows the particle identification spectrum for the spectrometer setting aimed at maximising the transmission of nuclei with N=Z≈40.

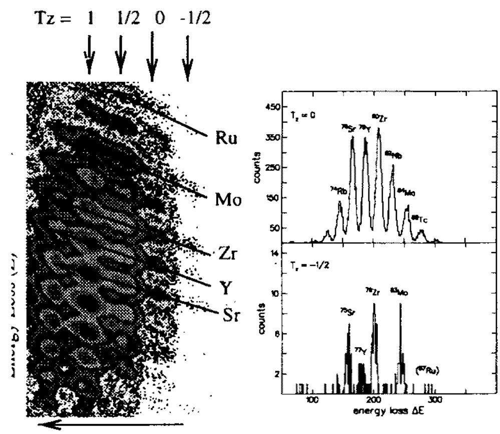

Fig. 6. Particle identificaton spectra for the $T_z = -\frac{1}{2}$ isotopes, $^{77}_{39}$Y, $^{79}_{40}$Zr and $^{83}_{42}$Mo.

In addition to extending the limits of the nuclear landscape, the data on the odd-Z system $^{77}_{39}$Y is of particular interest in light of the particle instability of the lighter odd-Z, $T_z = -\frac{1}{2}$ systems $^{69}_{35}$Br [25] and $^{73}_{37}$Rb [27–29]. The observation (or lack thereof) of a particular nucleus close to the proton drip-line has important consequences for the path of the rapid-proton, or 'rp' process and the formation of elements heavier than iron [30]. Both Mohar *et al.* [27] and Hencheck *et al.* [28] have suggested that ^{69}Br is the heaviest $T_z = -\frac{1}{2}$ system which is particle stable. The recent work by Blank et al. [25] however, indicate that $^{69}_{35}$Br is in fact not bound. Rykaczewski *et al.* [26] have recently reported the observation of the heavy $T_z = -\frac{1}{2}$ nuclei, $^{89}_{45}$Rh and $^{93}_{47}$Ag. As figure 6 shows, our current data provide convincing evidence that $^{77}_{39}$Y is particle bound with a lifetime of at least the order the flight path in the LISE3 spectrometer (~480 ns).

An interesting question arises as to why, when $^{69}_{35}$Br [25] and $^{73}_{37}$Rb [27–29] appear to be particle unstable, the higher Z nucleus $^{77}_{39}$Y exists with a meanlife of greater than order 0.5 μs. $^{78}_{39}$Y has been predicted to be the last yttrium isotope which is stable against proton decay [31, 32] but these calculations are dependent on a number of model parameters which are extrapolated from neighbouring nuclei. One possible explanation for the existence of $^{77}_{38}$Y could lie in the shape polarising effect of the deformed shell gaps in this region. As mentioned earlier in the disussion regarding the excited 0^+ isomer in ^{74}Kr, in the region around N,Z~36–40 the presence of energetically favoured, deformed shell gaps can have a large influence on the shape of the nuclear mean field [1–3]. From a simple point of view, the shape of the mean field will affect the total binding energy of the system via the change in the surface energy. Also, a change in shape will cause the population of quite different single particle orbitals. In very neutron deficient nuclei, the odd-proton can remain quasi-bound by the effect of the centrifugal barrier which will increase for protons occupying higher–l orbitals (see for example Ref. [33]). We note that in this highly prolate deformed region, the proton Fermi surface resides in the low-Ω portion of the $g_{\frac{9}{2}}$ shell. The centrifugal barrier experienced by a proton in one of these $g_{\frac{9}{2}}$ orbitals will be substantially higher than for one occupying an orbital from the fp shell, as might be expected for the final proton in $^{69}_{35}$Br and $^{73}_{37}$Rb. This may qualitatively explain the increase in the proton binding energy for ^{77}Y compared to the lighter, odd-Z, $T_z=-\frac{1}{2}$ isotopes. One might thus expect ^{77}Y to be a good candidate for direct proton decay and possible study of the excited states may be viable using the the recoil decay tagging technique [34].

4. Summary and future directions

We have used fragmentation reactions to identify previously unobserved isomeric decays in the $T_z=1$ systems, $^{74}_{36}$Kr, $^{80}_{39}$Y and $^{84}_{41}$Nb and the N=Z nucleus $^{86}_{43}$Tc. The data on $^{74}_{36}$Kr isomer is of particular interest in the light of the prediction of prolate/oblate shape coexistence in this nucleus. We have also obtained convincing evidence for the particle stability of the $T_z = -\frac{1}{2}$ nuclei, $^{77}_{39}$Y, $^{79}_{40}$Zr and $^{83}_{42}$Mo. The particle stability of $^{77}_{39}$Y is somewhat suprising in view of the instability of the lighter, odd-Z $T_z = -\frac{1}{2}$ systems $^{69}_{35}$Br and $^{73}_{37}$Rb. This change in particle stability may be due to a nuclear structure effect, with the last proton occupying a higher–l orbital in ^{77}Y compared to $^{69}_{35}$Br and $^{73}_{37}$Rb.

The future directions that this type of work may take could include the spectroscopy of decays from isomeric states in nuclei across the N=Z line, with studies of isomeric states in mirror nuclei becoming a real possibility. The identification of isomeric states can be useful as an experimental 'tag' for future in-beam experiments, where the delayed gamma-rays from decays via an isomer can be correlated with prompt, in-beam decays. Using a high-granularity, high-efficiency gamma-ray array such as EUROBALL, detailed spectroscopy in very neutron deficient systems should be possible.

REFERENCES

[1] W. Nazarewicz *et al.*, *Nucl. Phys.* **A435**, 397 (1985).
[2] W. Gelletly, *Acta Phys. Pol.* **B26**, 323 (1995).
[3] W. Gelletly *et al.*, *Phys. Lett.* **253B**, 287 (1991).
[4] C.J. Lister *et al.*, *Phys. Rev.* **C42**, R1191 (1990).
[5] C.J. Lister *et al.*, *Phys. Rev. Lett.* **59**, 1270 (1987).
[6] P.J. Ennis *et al.*, *Nucl. Phys.* **A535**, 392 (1991).
[7] A.C. Mueller, R. Anne, *Nucl. Inst. Meth. Phys. Res.* **B56/57**, 559 (1991).
[8] A.C. Mueller, B. Sheryl, *Ann. Rev. Nucl. Part. Sci.* **43**, 529 (1993).
[9] R. Grzywacz *et al.*, *Phys. Lett.* **355B**, 439 (1995).
[10] M. Robinson *et al.*, *Phys. Rev.* **C53**, R1465 (1996).
[11] M.R. Bhat *Nucl. Data. Sheets* **58**, 1 (1989).
[12] M.R. Bhat *Nucl. Data. Sheets* **68**, 579 (1993).
[13] S. Hofman *et al.*, *Z. Phys.* **A325**, 37 (1986).
[14] P.M. Endt, *At. Data. Nucl. Data Tab.* **23**, 547 (1979).
[15] D. Bucurescu *et al.*, *Z. Phys.* **A352**, 361 (1995).
[16] C.J. Gross *et al.*, *Nucl. Phys.* **A535**, 203 (1991).
[17] J. Roth *et al.*, *J. Phys.* **G10**, L25 (1984).
[18] S.L. Tabor *et al.*, *Phys. Rev.* **C41**, 2658 (1990).
[19] A. Petrovici *et al.*, *Nucl. Phys.* **A605**, 290 (1996).
[20] A. Petrovici *et al.*, Proceeding of the School on 4π Gamma-Ray Spectroscopy and Nuclear Structure, Erice, 16-24 Sicily Sept. 1996.
[21] D. Alburger *et al.*, *Phys. Rev.* **C18**, 1875 (1978).
[22] R.H. Burch Jnr. *et al.*, *Phys. Rev.* **C38**, 1365 (1988).
[23] A. Harder *et al.*, *Phys. Rev.* **C51**, 2932 (1995).
[24] D. Rudolph *et al.*, *Phys. Rev. Lett.* **76**, 376 (1996).
[25] B. Blank *et al.*, *Phys. Rev. Lett.* **74**, 4611 (1995).
[26] K. Rykaczewski *et al.*, *Phys. Rev.* **C52**, R2310 (1995).
[27] M.F. Mohar *et al.*, *Phys. Rev. Lett.* **66**, 1571 (1991).
[28] M. Henncheck *et al.*, *Phys. Rev.* **C50**, 2214 (1994).

[29] J.M. D'Auria *et al.*, *Phys. Lett.* **B66**, 233 (1977).
[30] A.E. Champagne, M. Wiescher, *Ann. Rev. Nucl. Part. Sci.* **42**, 39 (1992).
[31] S.J. Yenello *et al.*, *Phys. Rev.* **C46**, 2620 (1992).
[32] J. Jänecke, C.J. Mason *At. Data. Nucl. Data. Tab.* **39**, 265 (1988).
[33] C.N. Davids *et al.*, *Phys. Rev. Lett.* **76**, 592 (1996).
[34] E.S. Paul *et al.*, *Phys. Rev.* **C51**, 78 (1995).