BRIEF REPORTS

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New $N = 84$ isotone: ^{136}Te

J. A. Cizewski
Department of Physics and Astronomy, Rutgers University, New Brunswick, New Jersey 08903 and Department of Physics, University of Manchester, Manchester, M13 9PL United Kingdom

M. A. C. Hotchkis, J. L. Durell, J. Copnell, A. S. Mowbray, J. Fitzgerald, and W. R. Phillips
Department of Physics, University of Manchester, Manchester, M13 9PL United Kingdom

I. Ahmad, M. P. Carpenter, R. V. F. Janssens, T. L. Khoo, E. F. Moore, and L. R. Morss
Argonne National Laboratory, Argonne, Illinois 60439

Ph. Benet
Purdue University, Lafayette, Indiana 47907

D. Ye
University of Notre Dame, Notre Dame, Indiana 46556
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We have assigned γ-ray transitions to ^{136}Te by examining the prompt gamma radiation following spontaneous fission of ^{248}Cm. The transitions were identified in spectra gated on the Ru complementary fragments, and confirmed by studying prompt γ rays following spontaneous fission of ^{252}Cf. The results are examined in terms of the systematics of other tellurium and $N = 84$ nuclei.

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The study of excitations in neutron-rich nuclei has traditionally been limited to γ-ray transitions following beta decay of fission fragments. Therefore, spectroscopy of moderate-spin excitations in these nuclei has been severely limited. However, measurements [1] of prompt γ radiation following spontaneous fission have allowed the study of moderate-spin excitations in neutron-rich nuclei, and have also helped to identify the most neutron-rich species of elements populated in spontaneous fission. Earlier studies have concentrated on the neutron-rich A=140 nuclei [1–3], where a new region of reflection asymmetric shapes has been identified, and the most deformed nuclei in the A=100 region [4]. This Brief Report discusses the assignment of γ-ray transitions to ^{136}Te, the lightest $N = 84$ isotone.

The measurements were made with the Argonne–Notre Dame BGO γ-ray facility, which consisted of 10 Compton-suppressed Ge (CSGe) detectors, 2 low-energy photon spectrometers (LEPS), and a 50-element inner array of BGO detectors, which served as a multiplicity filter. Data were recorded with the multiplicity requirement that at least two Ge detectors (CSGe or LEPS) and three BGO elements fired. This requirement enhanced the selection of prompt fission events with a γ-ray multiplicity of $\approx$7–8. For the present work only multiplicity-gated CSGe γ-γ coincidence data were analyzed. A ^{248}Cm spontaneous fission source, a pellet of 11 mm diameter containing 5 mg of material, was placed at the target position of the array. The target was made by mixing curium oxide with 150 mg of potassium chloride and compressing under a pressure of 600 MPa. The curium was separated from its fission products 2 days before the experiment started. The source dimensions were such that the absorption of x rays and low-energy γ rays was minimal, while the fission fragments were stopped quickly; no Doppler broadening was observed in the γ-ray spectra.

In spontaneous fission, the primary fragments are produced at a range of excitation energies such that a few neutrons may be evaporated from each fragment; the average number of neutrons evaporated per fission event is about $n = 3$. For a ^{248}Cm source, it is expected that candidate transitions in ^{136}Te would be in coincidence with transitions in the complementary fragments $^{108-110}$Ru, representing the total evaporation of four to two neutrons, respectively. The level spectra [5] of the even-mass ruthenium isotopes have recently been deduced. Except for the $10^+ \rightarrow 8^+$ transition, the yrast transitions in ^{108,110}Ru cannot be resolved in our Ge spectra, so that we cannot distinguish $n = 2$ from $n = 4$ fission events.

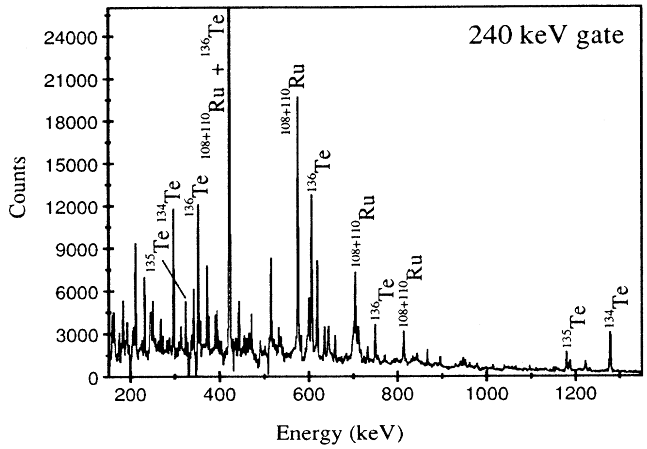

FIG. 1. Coincidence spectrum gated on the 240-keV line in the ^{248}Cm fission fragment data. Transitions in $^{108+110,109}$Ru and ^{134,135,136}Te are indicated. Energy assignments are taken from Refs. [5–8] and the present work.

In Fig. 1 we present a spectrum gated on the 240-keV line, the $2^+ \rightarrow 0^+$ transitions in ^{108,110}Ru. While the yrast transitions in these Ru isotopes are the strongest lines, we have also indicated known [7, 8] transitions in ^{134,135}Te and candidate lines for ^{136}Te. In Fig. 2(a) we present the spectrum gated on the 606-keV line. The ^{108,110}Ru transitions are clearly evident, as well as transitions in the $n = 3$ isotope ^{109}Ru. In Fig. 2(b) we display the spectrum gated on the 749-keV line. In all of these gated spectra, the 422-keV line is considerably more intense than the $2^+ \rightarrow 0^+$ transition in ^{108,110}Ru. We therefore have also placed this transition in ^{136}Te. Previously [6], a 1134-keV transition had been assigned as the $2^+ \rightarrow 0^+$ transition in ^{136}Te. We find no support for this assignment in our present ^{248}Cm study: Such a transition does not appear in coincidence with any strong transition in Ru fragments, and the 1134-keV line is not in coincidence with transitions in the Ru complementary fragments.

To provide further support for our assignment of a 422-keV transition to ^{136}Te, in Figs. 2(c) and 2(d) we present spectra gated on the 606- and 749-keV transitions, taken from our earlier ^{252}Cf data [1, 2]. With a ^{252}Cf source, the complementary fragments are Pd, rather than Ru, isotopes. In these spectra the candidate transitions in ^{136}Te are the strongest lines and transitions in the Pd complementary fragments are clearly evident.

In earlier work (e.g., Refs. [3, 4]) we used the average mass of the complementary fragments as a function of isotope to support new transitions. Such an analysis is not possible for the heaviest Te isotopes. First, the yrast transition energies in ^{108}Ru and ^{110}Ru cannot be resolved

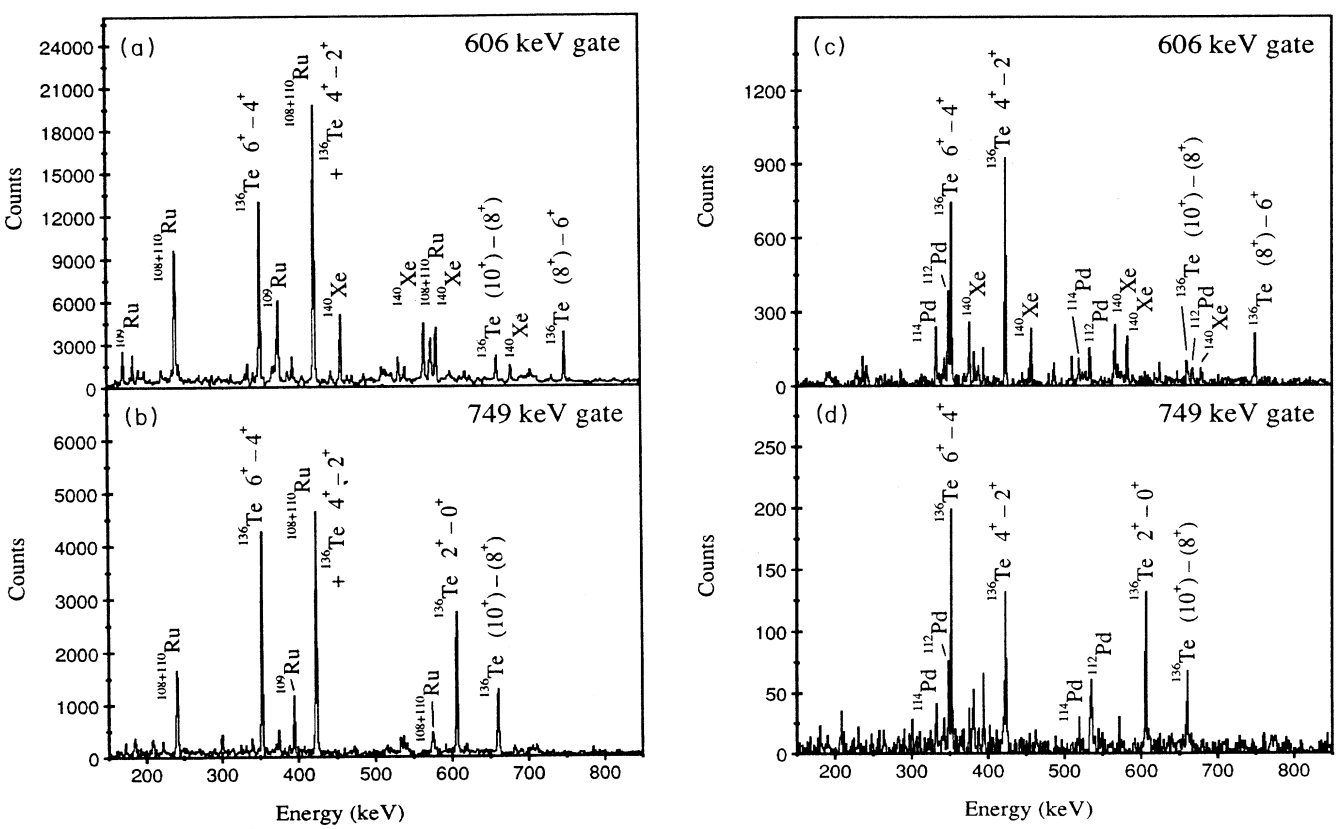

FIG. 2. Coincidence spectra gated on (a) the 606-keV line and (b) the 749-keV line in the ^{248}Cm fission fragment data. Transitions in $^{108+110,109}$Ru, ^{136}Te, and ^{140}Xe are indicated. The 606-keV line is also the $10^+ \rightarrow 8^+$ transition in ^{140}Xe. Coincidence spectra gated on the (c) 606-keV and (d) 749-keV lines in the ^{252}Cf fission fragment data. Transitions in ^{112,114}Pd, ^{136}Te, and ^{140}Xe are indicated. Energy assignments are taken from Refs. [5–8] and the present work.

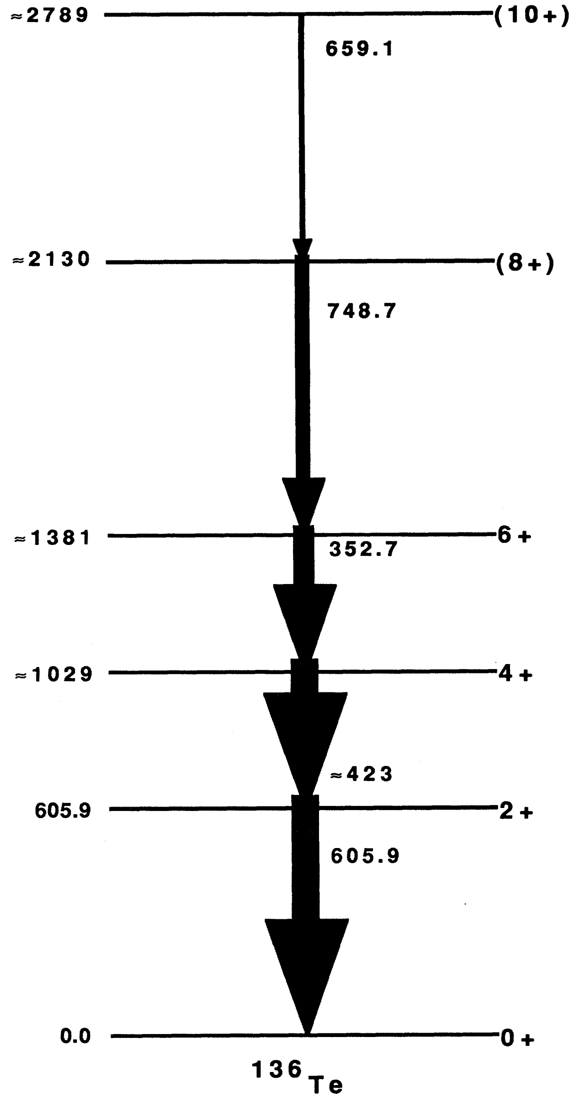

FIG. 3. Proposed level spectrum of ^{136}Te. Spin-parity assignments are based on expected systematical behavior.

TABLE I. Prompt gamma rays in ^{136}Te following spontaneous ^{248}Cm fission.

E_γ [a]	I_γ [b]	Placement
352.20(10)	79(2)	$(6^+) \rightarrow (4^+)$
$\approx$ 423	$\approx$ 94(10)	$(4^+) \rightarrow (2^+)$
605.91(10)	$\equiv$100	$(2^+) \rightarrow 0^+$
659.1(3)	19(2)	$((10^+))\rightarrow((8^+))$
748.70(15)	37(4)	$((8^+)) \rightarrow (6^+)$

[a] Energies of γ rays in keV. Errors in parentheses are on the last digit(s).

[b] Relative γ-ray intensities, normalized to the 606-keV transition. Errors in parentheses include statistical errors and those associated with uncertainties in the efficiency calibration.

in our Ge spectra, so that a distinction between $n = 4$ and $n = 2$ evaporation channels cannot be made. (The earlier ^{252}Cf fission measurements did not have sufficient statistics for such an analysis.) Second, the spectrum gated on the $2^+ \rightarrow 0^+$ transition in ^{134}Te only yields transitions below the 165-ns 6^+ isomer [7], and so shows no prompt transitions in complementary fragments.

The transitions we have assigned to ^{136}Te are summarized in Table I, and a level spectrum is displayed in Fig. 3. We have not been able to assign multipolarities to these transitions; spin-parity assignments are based on expected systematical behavior.

The systematics of tellurium isotopes is presented in Fig. 4(a). The ratio $R(4/2) = E(4^+)/E(2^+)$ for ^{136}Te is similar to that of ^{132}Te, both with two valence neutrons. However, the level spacings are quite different, which is clearly evident in the $R(6/4)$ values of 1.06 for ^{132}Te compared to 1.34 for ^{136}Te, which is closer to the vibrational

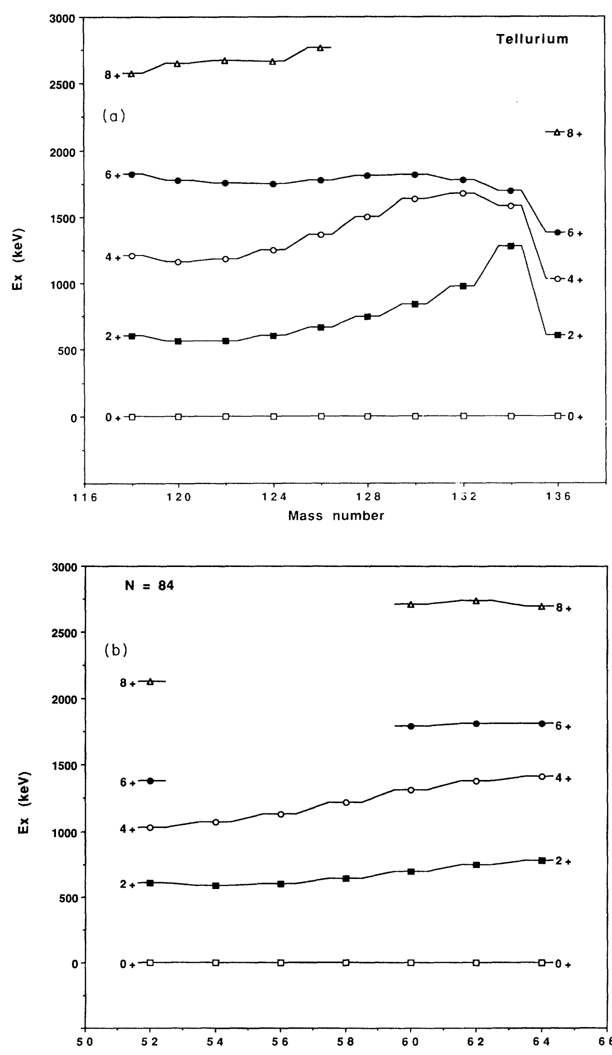

FIG. 4. (a) Energy level systematics for N=66–84 Te isotopes. Data are taken from Ref. [6] and the present work. (b) Energy level systematics for N=84 isotones with Z=52–64. Data are taken from Ref. [6] and the present work.

value of 1.50. The level spectrum of ^{136}Te appears more collective, although the level spacings are only *approaching* the expectations of a spherical harmonic vibrator.

The systematics of the other N=84 isotones is shown in Fig. 4(b). The $R(4/2)$ ratio in ^{136}Te is less than the average of ≈1.85 for the other N=84 isotones, again supporting a structure for ^{136}Te that is not very collective. The other N=84 isotones have been studied [9] in terms of two neutron quasiparticles coupled to proton-phonon excitations. The agreement between theory and experiment for the heavier isotones was quite good, in particular, for ^{144}Nd. Extrapolating these calculations to Z=52 gives an energy for the 2_1^+ state considerably depressed compared to our present results for ^{136}Te. However, with only two valence protons, any collectivity, or lack thereof, should come equally from neutron and proton motions in ^{136}Te.

It is not surprising that ^{136}Te with two valence neutron particles above N=82 is more collective than ^{132}Te with two valence neutron holes below N=82. The proton excitations in Z=52 Te are dominated by two-proton $(1g_{7/2})^2$ configurations. The valence neutron holes in ^{132}Te are predominantly [10] in the $2d_{3/2}$ orbital, which at best can give rise to a 2^+ two-neutron state. Therefore, in ^{132}Te only the ground and 2^+ states may have components which involve low-lying valence proton *and* neutron configurations. On the other hand, in ^{136}Te the lowest neutron orbital [9] is $2f_{7/2}$, with which two-neutron states up to 6^+ can be generated. The two-neutron $j = 7/2$ configurations have a large radial overlap [10] with the two-proton j=7/2 configurations, which enhances the collective motion.

In summary, we have made the initial identification of γ-ray transitions in ^{136}Te and obtained a deexcitation spectrum based on γ-γ coincidence measurements of prompt radiations from fission fragments. These results suggest that the low-lying excitations in ^{136}Te are predominantly two-neutron $2f_{7/2}$ and two-proton $1g_{7/2}$ in character. While more collective in nature than ^{132}Te, ^{136}Te is the least collective of the N=84 isotones.

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