Excitations of two- and three-valence-proton nuclei ^{134}Te and ^{135}I

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(Received 13 August 2001; published 6 December 2001)

Analyses of ^{248}Cm fission product γ-ray coincidence data recorded at Gammasphere have yielded additional information about γ-ray cascades in $N=82$ isotones ^{134}Te and ^{135}I. New-yrast and near-yrast states in both nuclei have been identified, and they are interpreted as specific shell model excitations.

DOI: 10.1103/PhysRevC.65.017302 PACS number(s): 23.20.Lv, 21.60.Cs, 25.85.Ca, 27.60.+j

There has been significant recent progress, both experimental [1–7] and theoretical [8–10], in the spectroscopy of the few-valence-proton $N=82$ isotones just above doubly magic ^{132}Sn. New experimental results have come from advanced β-decay studies of short-lived radionuclides produced in fission of actinides [1,2] and from detailed coincidence measurements of prompt and delayed γ-ray cascades in the fission product nuclei themselves [3–7]. In an earlier paper based on ^{248}Cm fission product γ-ray data recorded at Eurogam II, we reported [3] yrast states for the $N=82$ nuclei ^{134}Te and ^{135}I to above 5.5 MeV excitation energy, and interpreted them using empirical nucleon-nucleon interactions as valence-proton and particle-hole core excitations. In a related theoretical development, calculations by Andreozzi *et al.* [8] using an effective interaction derived from the Bonn A free nucleon-nucleon potential gave excellent agreement with experiment for the two- and three-proton states in ^{134}Te and ^{135}I. Subsequently, we have performed a new set of γ-ray measurements at Gammasphere, again using a ^{248}Cm fission source, but with more favorable control of timing conditions, and a total of about 1.8×10^9 fourfold and higher-fold coincidence events were collected. These data were generally better than those from the Eurogam II experiment, and they have yielded additional results for ^{134}Te and ^{135}I, which are reported here. More details about the Gammasphere measurements may be found in Ref. [11].

The isotopes ^{112}Ru, ^{111}Ru, and ^{110}Ru are the $2n$, $3n$, and $4n$ complementary partners of ^{134}Te in the fission of ^{248}Cm, and during analysis of the excellent $\gamma\gamma\gamma$ data from Gammasphere many double gates were set on pairs of γ rays in ^{134}Te and Ru partner nuclei. Samples of coincidence spectra acquired in this way are displayed in Figs. 1(a) and 1(b). Gating on the 1279 keV ^{134}Te $2^+\rightarrow0^+$ and ^{111}Ru 151 keV transitions showed in coincidence [Fig. 1(a)] a strong 1404 keV γ ray in addition to previously placed 979 and 1151 keV γ rays. The 1404 keV γ ray is not coincident with the 297 keV $4^+\rightarrow2^+$ transition in ^{134}Te, but feeds directly into the 1279 keV 2^+ state from a level at 2683 keV. Further analysis

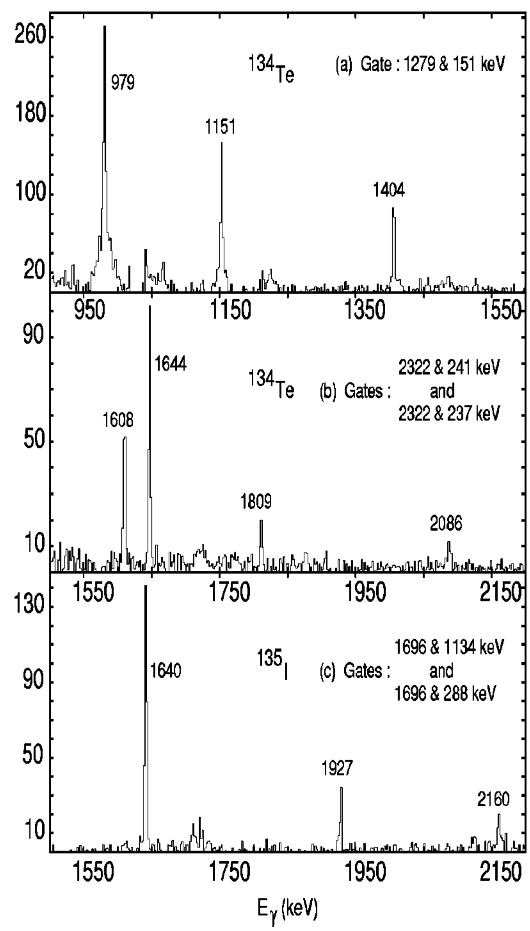

FIG. 1. (a)–(c) Key γ-ray coincidence spectra for ^{134}Te and ^{135}I. The 241-, 151-, and 237-keV γ rays are known transitions in ^{110}Ru, ^{111}Ru, and ^{112}Ru fission partners.

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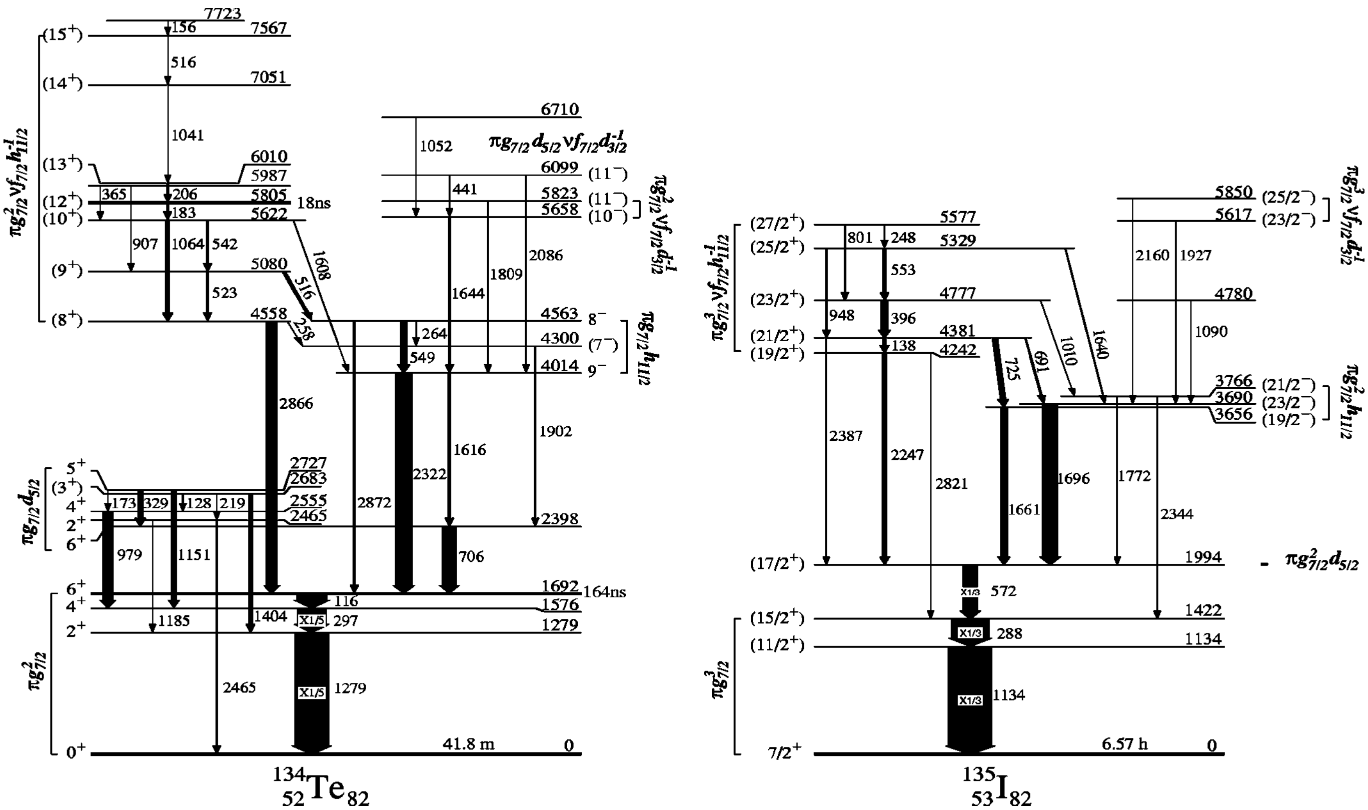

FIG. 2. Proposed ^{134}Te and ^{135}I level schemes. Arrow widths are proportional to the observed γ ray intensities. Dominant configurations proposed for most of the levels are shown.

showed that this new level also deexcites by 219 and 128 keV transitions to the known 2^+ and 4^+ $\pi g_{7/2}d_{5/2}$ states, and there is little doubt that this level must be the missing 3^+ member of the $\pi g_{7/2}d_{5/2}$ multiplet. All the other multiplet members have previously been located in β decay, and the calculations [8] have given rather good agreement with the experimental energies. This agreement is here seen to extend to the $(\pi g_{7/2}d_{5/2})3^+$ state, which was predicted 26 keV below the 5^+ multiplet member, and is now found at 2683 keV, which is 44 keV below the experimental 5^+ level.

Double gating on the 2322 keV $9^- \to 6^+$ transition in ^{134}Te and on ^{110,112}Ru partner γ rays showed coincident high energy lines of 1608, 1644, 1809, and 2086 keV [Fig. 1(b)]. Of these, the 1608 keV γ ray was already placed deexciting the 5622 keV (10^+) state. The 1644, 1809, and 2086 keV transitions must feed the 4014 keV 9^- state from parent levels at 5658, 5823, and 6099 keV. Gating on 2322 and 1644 keV γ rays further established that 441 and 1052 keV transitions populate the 5658 keV level (Fig. 2). The four new levels at 5658, 5823, 6099, and 6710 keV must all involve core excitations, and their decays suggest that their parity is negative. In the ^{132}Sn core nucleus, $\nu f_{7/2}h_{11/2}^{-1}$ and $\nu f_{7/2}d_{3/2}^{-1}$ states with excitation energies between 4 and 5 MeV are the lowest particle-hole excitations [12], and related $\pi g_{7/2}^2 \nu f_{7/2}h_{11/2}^{-1}$ yrast states have already been identified in the ^{134}Te nucleus [3]. Near-yrast states of $\pi g_{7/2}^2 \nu f_{7/2}d_{3/2}^{-1}$ and $\pi g_{7/2}d_{5/2}\nu f_{7/2}d_{3/2}^{-1}$ character are also to be expected in ^{134}Te, and we have calculated their energies with the OXBASH code using empirical interactions from both the ^{132}Sn and ^{208}Pb regions, following procedures similar to those described in Ref. [3]. Results of the calculations strongly support an interpretation of the 5658 and 5823 keV levels as 10^- and 11^- states of mainly $\pi g_{7/2}^2 \nu f_{7/2}d_{3/2}^{-1}$ character, while the aligned configuration $(\pi g_{7/2}d_{5/2}\nu f_{7/2}d_{3/2}^{-1})$ 11^- is indicated for the 6099-keV level; the energies calculated for these three states are 5818, 6031, and 6203 keV, respectively.

A weakly populated level at 5987 keV decays by 365 and 907 keV γ rays to the 10^+ and 9^+ $\nu g^2 \nu f h^{-1}$ states, suggesting that it could be another member of the same multiplet. However, its energy does not match well the calculated energy of the missing $(\pi g^2 \nu f h^{-1})11^+$ yrast state, which is predicted to be almost degenerate with the 12^+ state located at 5805 keV. The half-life of this 5805-keV level has been determined to be 18 ± 2 ns, giving for the 183-keV transition probability,

$$B(E2;12^+ \to 10^+) = 3.2(3) \quad \text{W.u.}$$

This value is slightly larger than the $B(E2)$ of 2.1 W.u. for the $6^+ \to 4^+$ transition between $\pi g_{7/2}^2$ states in ^{134}Te, but is much larger than the value of 0.11 W.u. obtained for the $8^+ \to 6^+$ transition between $\nu f_{7/2}h_{11/2}^{-1}$ states in ^{132}Sn [12].

Analysis of the Gammasphere data identified several other weak ^{134}Te transitions, most of which have been placed connecting previously located levels. All the γ rays assigned to ^{134}Te are listed in Table I, together with their placements, and they are included in the ^{134}Te level scheme (Fig. 2).

TABLE I. Energies and relative intensities of ^{134}Te γ rays observed following ^{248}Cm fission. For all but the weakest lines, energy errors are estimated to be about 0.2 keV, and the intensities should be accurate to within 20%.

E_γ (keV)	I_γ	Initial level	E_γ (keV)	I_γ	Initial level
115.7	196	1692	907.4	2	5987
128.4	6	2683	978.5	64	2555
156.1	1	7723	1040.6	3	7051
172.7	3	2727	1051.7	1	6710
182.6	14	5805	1064.4	24	5622
205.7	13	6010	1150.8	37	2727
218.5	1	2683	1185.9	1	2465
257.4	2	4558	1279.3	1000	1279
263.7	2	4563	1403.8	21	2683
297.1	884	1576	1607.9	4	5622
329.3	33	2727	1615.6	18	4014
365.1	1	5987	1644.3	12	5658
441.1	2	6099	1808.7	3	5823
516.0	1	7567	1901.7	6	4300
516.3	20	5080	2085.5	2	6099
522.5	13	5080	2322.0	104	4014
542.1	15	5622	2465.3	11	2465
549.3	40	4563	2865.6	69	4558
706.3	92	2398	2871.8	17	4563

We turn now to the three-valence-proton nucleus ^{135}I, for which the available information about yrast excitations all comes from the Eurogam II fission product study [3]. In the present analysis, double gating on 1696 and 1134 or 288 keV lines showed in coincidence 1640, 1927, and 2160 keV γ rays [Fig. 1(c)]. The 1640-keV transition was placed previously, but the other two γ rays are new, and they establish new ^{135}I levels at 5617 and 5850 keV that deexcite to the $(\pi g^2_{7/2}h_{11/2})23/2^-$ state at 3690 keV. The 5617 and 5850 keV levels are interpreted as $\pi g^3_{7/2}\nu f_{7/2}d^{-1}_{3/2}$ $23/2^-$ and $25/2^-$ states, calculated at 5618 and 5733 keV, respectively; these ^{135}I states are closely linked to the $\pi g^2_{7/2}\nu f_{7/2}d^{-1}_{3/2}$ 10^- and 11^- states at 5658 and 5823 keV in ^{134}Te. The ^{135}I 3690 keV level is also fed by a 1090 keV γ ray from a level of unknown structure at 4780 keV.

Many new γ rays feeding the 1134- and 1422-keV levels of ^{135}I were found, including high energy lines of 2344 and 2821 keV, which connect previously known high-spin states. The branching ratio for the transitions deexciting the 3766-keV $(21/2^-)$ level was determined to be I(2344)/I(1772) $=2.0(7)$ giving a $B(E3)/B(M2)$ ratio similar to that observed in deexcitation of the $11/2^-$ single particle state in ^{133}Sb [2]. Five other new ^{135}I γ rays of 523, 929, 1000, 1288, and 1452 keV establish levels at 2351, 2422, and 2874 keV, which are not included in the ^{135}I level scheme (Fig. 2) to minimize clutter, but which are clearly nonyrast states of $\pi g^2_{7/2}d_{5/2}$ and/or $\pi g_{7/2}d^2_{5/2}$ character, corresponding to the $\pi g_{7/2}d_{5/2}$ states located at similar energies in ^{134}Te. Finally, for the 3690-keV $(23/2^-)$ state in ^{135}I, the present measurements gave a half-life less than 5 ns, much shorter than a previous estimate [13]. This limit implies that the $B(E3;23/2^-\rightarrow 17/2^+)$ in ^{135}I is larger than 5.4 W.u., consistent with the $B(E3)$ of 8.0 W.u. reported for the fast $(\pi g_{7/2}h_{11/2})9^-\rightarrow(\pi g_{7/2}d_{5/2})6^+$ transition in ^{134}Te [1]. All the γ rays assigned to ^{135}I are listed, together with their placements, in Table II.

TABLE II. Energies and relative intensities of ^{135}I γ rays following ^{248}Cm fission. For all but the weakest lines, energy errors are estimated to be about 0.2 keV, and the intensities should be accurate to within 20%.

E_γ (keV)	I_γ	Initial level	E_γ (keV)	I_γ	Initial level
138.5	28	4381	1089.5	3	4780
248.4	6	5577	1134.0	1000	1134
288.1	872	1422	1288.0	4	2422
395.9	50	4777	1452.0	8	2874
523.1	1	2874	1639.5	8	5329
552.5	20	5329	1661.4	50	3656
572.3	339	1994	1695.8	118	3690
690.7	14	4381	1771.9	4	3766
725.1	41	4381	1926.5	3	5617
801.2	10	5577	2159.5	2	5850
928.7	8	2351	2247.8	31	4242
947.5	14	5329	2344.2	8	3766
1000.0	5	2422	2386.8	5	4381
1010.5	3	4777	2821.2	2	4242

We thank Jan Blomqvist for fruitful discussions. This work was supported by the U.S. Department of Energy under Contract Nos. DE-FG02-87ER40346 and W-31-109-ENG-38, and by Polish Scientific Committee Grant No. 2PO3B-074-18. The authors are indebted for the use of ^{248}Cm to the Office of Basic Energy Sciences, U.S. Department of Energy through the transplutonium element production facilities at the Oak Ridge National Laboratory.

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