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Spectroscopy of Few-Particle Nuclei around Magic ^{132}Sn from Fission Product γ-Ray Studies

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We are studying the yrast structure of very neutron-rich nuclei around doubly magic ^{132}Sn by analyzing fission product γ-ray data from a ^{248}Cm source at Eurogam II. Yrast cascades in several few-valence-particle nuclei have been identified through $\gamma\gamma$ cross coincidences with their complementary fission partners. Results for two-valence-particle nuclei ^{132}Sb, ^{134}Te, ^{134}Sb and ^{134}Sn provide empirical nucleon-nucleon interactions which, combined with single-particle energies already known in the one-particle nuclei, are essential for shell-model analysis in this region. Findings for the $N = 82$ nuclei ^{134}Te and ^{135}I have now been extended to the four-proton nucleus ^{136}Xe. Results for the two-neutron nucleus ^{134}Sn and the $N = 83$ isotones ^{134}Sb, ^{135}Te and ^{136}I open up the spectroscopy of nuclei in the northeast quadrant above ^{132}Sn.

1 Introduction

The doubly magic nucleus ^{132}Sn and the few valence particle nuclei around it are neutron-rich species inaccessible for study by the common tools of nuclear reaction spectroscopy. The limited information available concerning the structure of these nuclei comes mostly from β^- decay studies of fission product radionuclides, supplemented in a few cases by γ-ray decay data for yrast isomers with μs half-lives. Blomqvist [1] has pointed out that there should be many points of resemblance between the spectroscopy of the ^{132}Sn region and the well studied nuclei around doubly-magic ^{208}Pb. The orbitals above and below the energy gaps in the two cases are similarly ordered, and every single particle state in the ^{132}Sn region has its counterpart around ^{208}Pb with the same radial quantum number n, and one unit larger in angular momenta l and j. One consequence with particular impact on the present work is that specific nucleon-nucleon interactions required for shell model calculations in the ^{132}Sn region may be estimated from the corresponding empirical interactions in ^{208}Pb region nuclei, which are known in some detail [2].

Recent investigations using multidetector Ge arrays to study fission product γ-rays from ^{252}Cf or ^{248}Cm sources have identified prompt and delayed γ-ray cascades from individual product nuclei in the ^{132}Sn neighborhood [3,4]. In the present measurements, the Eurogam II array consisting of 124 Ge detector elements and four LEPS spectrometers recorded 2x10^9 three-fold or higher-fold γ-ray coincidence events from a ^{248}Cm source delivering ~6x10^4 fissions/sec. Additional experimental details have been given in previous publications, which have presented results for the two- and three-proton $N = 82$ nuclei ^{134}Te and ^{135}I [4]. Here, we present first results for the four-valence-proton $N = 82$ nucleus ^{136}Xe. We then turn attention to $N = 83$ and $N = 84$ nuclei near ^{132}Sn, which should provide key information about em-

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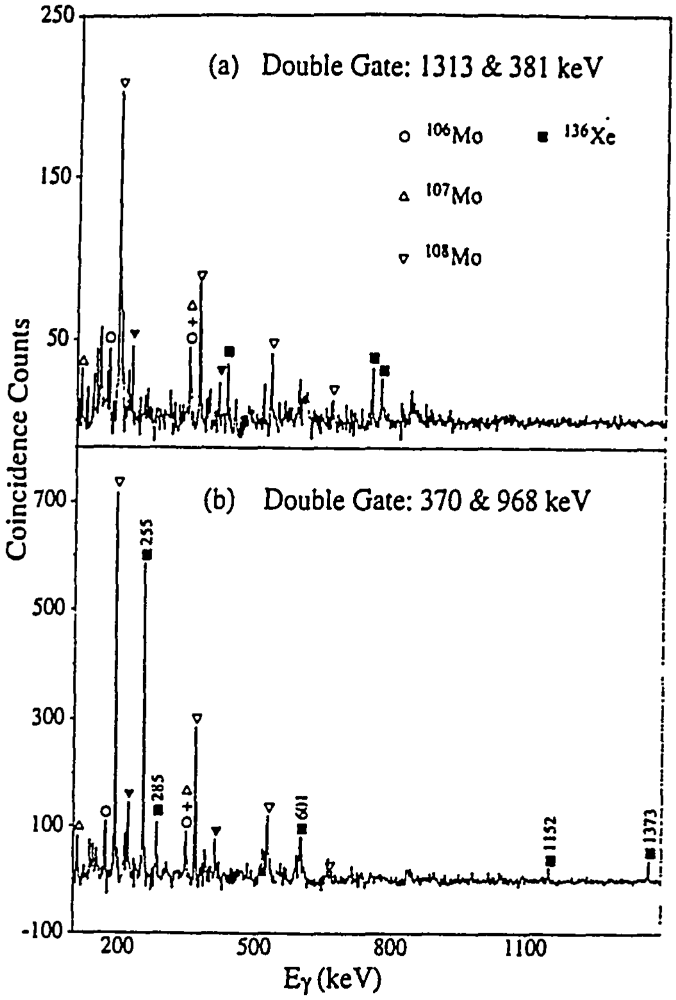

Figure 1: Key γ-ray coincidence spectrum of double gates on transitions above and below the yrast 6^+ isomer in ^{136}Xe. Isotopic assignments are indicated for all prominent γ-rays.

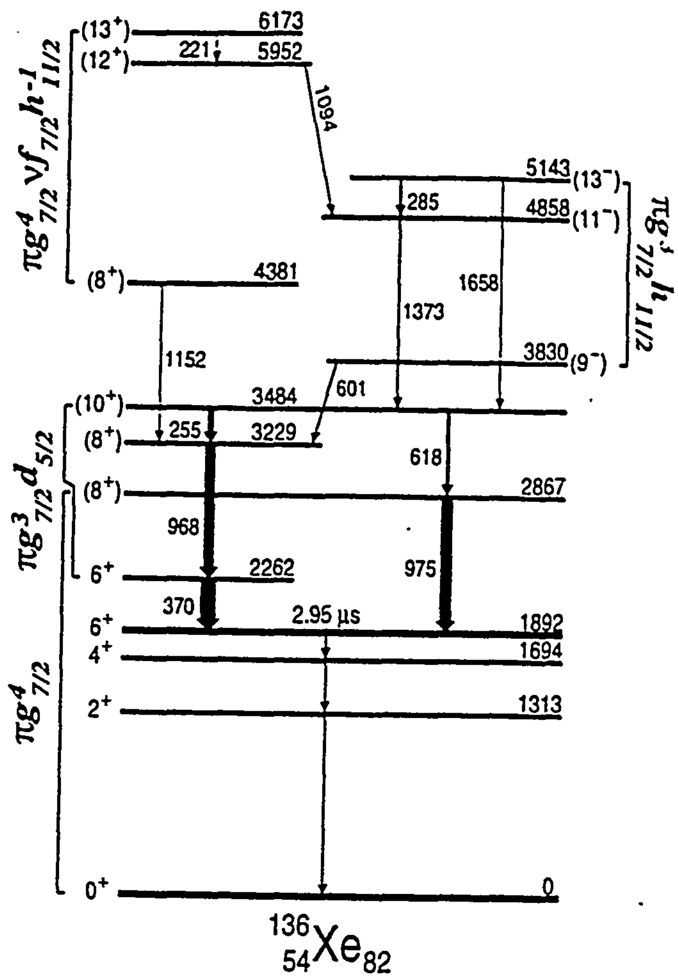

Figure 2: The ^{136}Xe level scheme showing proposed spin-parities, configuration assignments, and the isomeric half-life.

pirical proton-neutron and neutron-neutron interactions in the region. Although the fission yields for several of the interesting $N = 83$ products were predicted to be fairly large [5], one could anticipate that their unusually small neutron separation energies might result in drastically reduced γ-ray cascade intensities. (Indeed, no trace of the known [6] 1561 keV $\nu h_{9/2} \rightarrow \nu f_{7/2}$ γ-ray in ^{133}Sn could be detected in cross-coincidence with ^{110,111,112}Pd γ-rays even though the yrast γ-rays of neighboring ^{132}Sn and ^{134}Sn were clearly seen). we report results for the three $N = 83$ isotones ^{134}Sb, ^{135}Te and ^{136}I, and for the two-neutron nucleus ^{134}Sn.

2 The $N = 82$ Isotones ^{134}Te, ^{135}I, and ^{136}Xe

In our previous paper [4] on the two- and three-proton nuclei ^{134}Te and ^{135}I, empirical two-body interactions from the experiments $\pi g^2_{7/2}$, $\pi g_{7/2} d_{5/2}$, and $\pi g_{7/2} h_{11/2}$ multiplets in ^{134}Te were used in shell model calculations to characterize clearly the corresponding three-proton states in ^{135}I. In addition, the highest levels located in ^{134}Te and ^{135}I were shown to be core-excited states involving $\nu f_{7/2} h^{-1}_{11/2}$ particle-hole excitations. We also examined a shell model decomposition of the ^{135}I $(\pi g^3_{7/2})15/2^+$ state involving the ground state masses of the $N = 82$ isotones ^{132}Sn, ^{133}Sb, ^{134}Te, and ^{135}I, and we concluded that one or more of the accepted $N = 82$ masses [7,8] is inaccurate by much more than their estimated errors.

Very recently, Andreozzi et al.[9] presented results for shell model calculations for ^{134}Te and ^{135}I employing an effective interaction derived from the Bonn A free nucleon-nucleon interaction. The calculated level energies for both nuclei are in excellent agreement with experiment. These workers[9] also calculated ground state binding energies for ^{134}Te and ^{135}I that agree well with the accepted mass values [7]. In this respect their conclusions contradict ours, and they suggested [9] deficiencies in our analysis. In response, we have submitted a comment [10] clarifying the shell model decomposition method, and defending our contention that the accepted masses of ^{134}Te and/or ^{133}Sb must be inaccurate. Aside from this mass mini-controversy, it will be interesting to see whether the realistic interaction calculations also give good agreement with experimental level energies for $N = 82$ nuclei above ^{135}I.

We have now extended our fission product studies to the four-valence-proton $N = 82$ nucleus ^{136}Xe. Known high-spin excitations in this nucleus populated in the β-decay of 47 s ^{136}I included a $(\pi g^4_{7/2})_{v=2}$ 6^+ yrast isomer and a probable $(\pi g^3_{7/2}d_{5/2})6^+$ state that decays to it by a 370 keV $6^+ \rightarrow 6^+$ transition. Our study of ^{136}Xe faced initial difficulties since its predicted ^{248}Cm fission yield is only 0.4%. Moreover, the Eurogam II coincidence data were acquired with rather narrow TAC time ranges, not suited for investigating delayed coincidence relationships across μs isomers. Thus, the 3μs half-life of the yrast 6^+ isomer in ^{136}Xe ruled out possibilities of selecting higher-lying γ-rays through coincidences with known delayed γ-rays. The known 370 keV transition feeding the 6^+ isomer helped in the isotopic identification, and careful inspection of the cross-coincidences observed(Fig. 1) with known ^{106,107,108}Mo γ-rays led to firm identification of two strong γ-ray cascades. The subsequently constructed ^{136}Xe level scheme is shown in Fig. 2, where the tentative spin-parities and configuration assignments are mostly based on the four-valence-particle shell model calculations which will be discussed below. The highest levels located at 5952 and 6173 keV may be core-excited $\pi g^4_{7/2}\nu f_{7/2}h^{-1}_{11/2}$ states similar to the yrast 12^+, 13^+ states at 6 MeV in ^{134}Te.

One of the main aims in studying the spectroscopy of few-valence-particle nuclei around ^{132}Sn is to characterize the nucleon-nucleon interactions in this region. To perform shell model calculations for the $N = 82$ isotones, the simplest method is to adopt two-body interactions from the experimental level spectrum of the two-proton nucleus ^{134}Te. This approach, which takes account of diagonal matrix elements only, and thereby neglects configuration mixing, provided valuable guidance in the interpretation of the observed ^{136}Xe levels. (In Table 1, experimental and calculated energies are compared.) A few years ago, Wildenthal [12] performed comprehensive shell model calculations for all $N = 82$ nuclei then known, and used an iterative procedure to obtain a best fit set of 160 two-body matrix elements, both diagonal and off-diagonal. The ^{136}Xe level energies calculated using these parameters are shown also in Table 1. Since the results

Table 1: The experimental and theoretical level energies in ^{136}Xe The theoretical energies are calculated with diagonal matrix elements from ^{134}Te(DIAG), and with Wildenthal's and Blomqvist's best fit parameter sets(c.f. the text).

I^π	EXP	DIAG	WILD	BLOM
	(keV)	(keV)	(keV)	(keV)
0^+	0	0	0	0
2^+	1313	1279	1314	1372
4^+	1694	1577	1714	1717
6^+	1891	1691	1846	1858
6^+	2261	2097	2260	2236
8^+	2866	2666	2931	2862
8^+	3229	3200	3230	3242
10^+	3484	3499	3582	3484
(9^-)	3830	3666	3738	3836
(11^-)	4857	4783	4844	4923
(13^-)	5142	5057	5157	5138

for ^{135}I and ^{136}Xe obtained in our work are significant additions to the data base, Blomqvist [13] has now updated the $N = 82$ interaction parameterization, and has changed 54 of Wildenthal's matrix elements, mostly diagonal. As shown in Table 1, these changes improve the agreement between theory and experiment to a small extent. However, forthcoming results for the five-proton $N = 82$ nucleus ^{137}Cs [14] will provide a much more satisfying test of the rival interaction sets.

3 Yrast States of $N = 83$ ^{134}Sb, ^{135}Te, and ^{136}I

The occurrence of a 0.51 μs yrast isomer in the three valence particle nucleus ^{135}Te has long been known from fission fragment mass separator studies by Kawade et al. [15]. These workers showed that the isomer decays by a 50 keV E2 transition followed by 325 and 1180 keV γ-rays, and they proposed a ^{135}Te scheme consisting of $7/2^-$, $11/2^-$, $15/2^-$, and $19/2^-$ (isomeric) levels of mainly $\pi g^2_{7/2}\nu f_{7/2}$ character. This isomeric decay scheme provided a point of departure for the present study. With the Eurogam II data, the best sorting conditions that could be achieved for the ^{135}Te case preferentially selected prompt γ-rays in an 80-240 ns time interval preceding the 1180 and/or 325 keV γ-rays. The resulting spectrum of γ-rays preceding the 1180 keV transition (Fig. 3(a)) shows several low-energy Ru lines from cross coincidences, and four γ-

rays above 1 MeV that could be firmly assigned to ^{135}Te. The weak 1357 and 2407 keV γ-rays, barely visible in Fig. 3(a), are seen much more convincingly in prompt coincidence with the 1679 keV γ-ray, as shown in the Fig. 3(a) inset. No other transition appeared in prompt coincidence with the 1085 keV γ-ray, which must feed the 0.51 μs isomer in parallel with the stronger 1679 keV transition. The extended ^{135}Te level scheme is displayed in Fig. 4, and will be discussed below.

Little was known up to now about high-spin states in $A > 135$ iodine nuclei. In the present work, detailed systematic examinations of $\gamma\gamma$ cross coincidence intensity patterns between complementary I and Tc fission fragments led to identification of yrast cascades in both ^{136}I and ^{137}I, as well as the $A = 108-111$ Tc isotopes(Fig. 3). For example, a double gate on γ-rays assigned to ^{109}Tc (Fig. 3(b)) shows in coincidence the yrast γ-ray cascades of ^{135}I, ^{136}I, and ^{137}I, the 4n, 3n, and 2n fission product partners of ^{109}Tc. The bottommost transitions placed in ^{135}I are 1134 and 288 keV, in ^{136}I are 1111 and 261 keV, and in ^{137}I are 554 and 400 keV. The literature provides substantial support for these isotopic assignments, since 1134 and 554 keV γ-rays are known strong ^{135}I and ^{137}I transitions observed in β-decay studies of ^{135}Te and ^{137}Te [16], while a 261 keV γ-ray de-exciting a $\sim$4 ns ^{136}I isomer populated in ^{252}Cf fission was reported by two groups many years ago [17,18].

Low-lying yrast transitions were previously known in ^{131}Sb and ^{133}Sb but not in the $N = 83$ nucleus ^{134}Sb. Here again, detailed study of $\gamma\gamma$ cross coincidence intensities, in this case between complementary Sb and Rh products, led to identification of yrast cascades in $A = 110-113$ Rh isotopes, and of 1053, 1073 and 2126 keV γ-rays in ^{134}Sb.

The two-particle nucleus ^{134}Sb has two β-decaying isomers with $I^\pi = 0^-$ and 7^-, both assigned the configuration $\pi g_{7/2}\nu f_{7/2}$ [19,20]. It is natural to identify the ^{134}Sb level populated by the 2126 keV γ-ray (Fig. 4) as the $(\pi g_{7/2}\nu f_{7/2})7^-$ state. In ^{133}Sb the $\pi d_{5/2}$ and $\pi h_{11/2}$ single particle states are located 962 and 2793 keV above the $\pi g_{7/2}$ ground state [1], and in ^{133}Sn the $\nu h_{9/2}$ and $\nu i_{13/2}$ states lie 1561 keV and $\sim$3 MeV, respectively, above the $\nu f_{7/2}$ ground state [6]. There are not many possibilities for yrast two-particle states in ^{134}Sb with I>7, and the most likely assignments appear to be $(\pi g_{7/2}\nu h_{9/2})8^-$ and $(\pi h_{11/2}\nu f_{7/2})9^+$ for the 1073 and 2126 keV levels. Approximate excitation energies for these states could be calculated using the single particle energies together with estimates of $(\pi g_{7/2}\nu f_{7/2})7^-$, $(\pi g_{7/2}\nu h_{9/2})8^-$, and $(\pi h_{11/2}\nu f_{7/2})9^+$ proton-neutron interaction energies obtained from the $\pi\nu$ interactions known in ^{210}Bi for the analogous $(\pi h_{9/2}\nu g_{9/2})9^-$, $(\pi h_{9/2}\nu i_{11/2})10^-$, and $(\pi i_{13/2}\nu g_{9/2})11^+$ states [2], with scaling as $A^{-1/3}$ to take

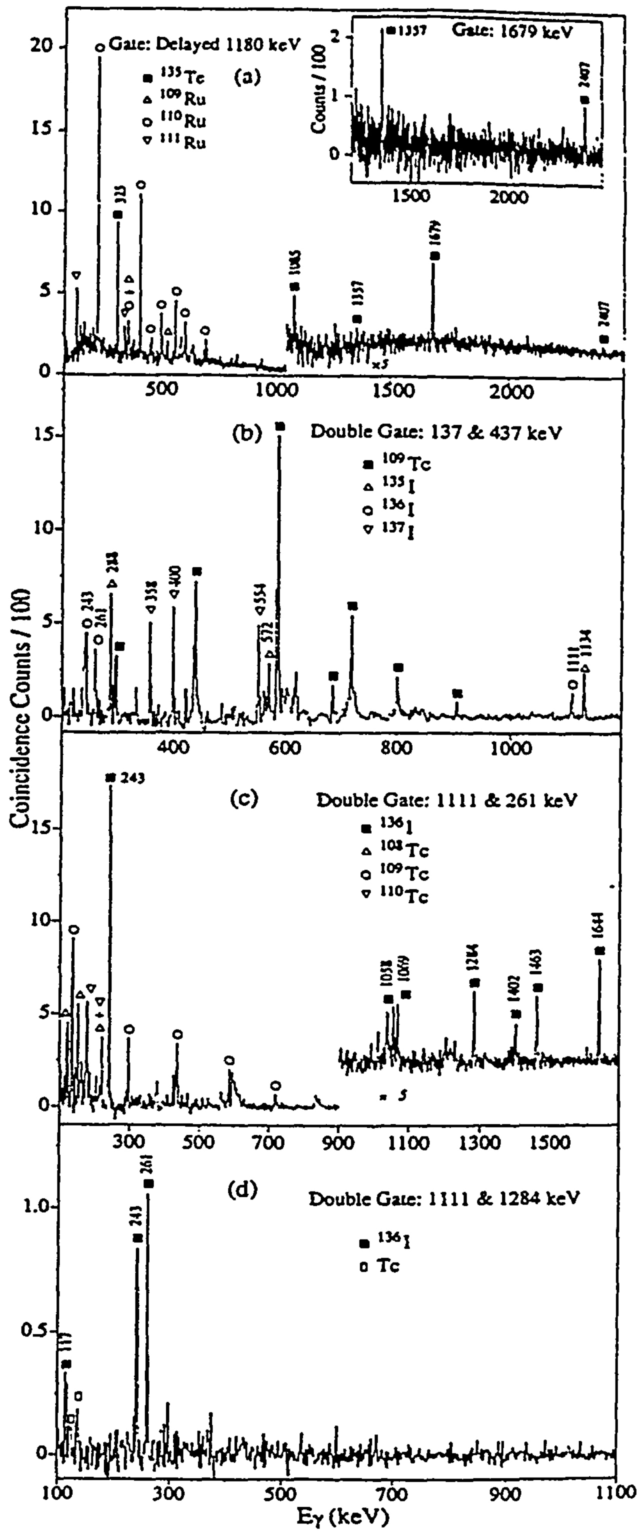

Figure 3: Key γ-ray coincidence spectra. Fig. 3(a) displays γ-rays preceding the 1180 keV ^{135}Te transition, while the inset shows γ-rays in prompt coincidence with the 1679 keV transition. Fig. 3(b) displays γ-rays coincident with 137 and 437 keV ^{109}Tc transitions. Fig. 3(c) and (d) show γ-rays coincident with double gates on the ^{136}I γ-rays specified.

account of the nuclear size variation [1,4]. The results, 1561-441 = 1120 keV for the $(\pi g \nu h)8^-$ excitation energy and 2793-653 = 2140 keV for the $(\pi h \nu f)9^+$ state, agree rather well with experiment, and lend forceful support to this interpretation of the sparse ^{134}Sb data. Moreover, they encouraged us to proceed with truncated shell model calculations for all three $N = 83$ nuclei using a single set of input parameters.

The shell model calculations for ^{134}Sb, ^{135}Te, and ^{136}I included the $\pi g_{7/2}$, $\pi d_{5/2}$, $\pi h_{11/2}$, $\nu f_{7/2}$, and $\nu h_{9/2}$ orbitals, and considered only yrast and near-yrast states having pure configurations. The input consisted of the single particle energies cited earlier, proton-proton interactions taken directly from the ^{134}Te level spectrum as in ref. [4], and the proton-neutron interactions specified in Table 2. These $\pi\nu$ matrix elements were estimated from known ^{210}Bi interactions in the manner described above, except for the three values marked with asterisks, which have been slightly modified (by 40 keV or less) to achieve near-perfect agreement with the ^{134}Sb data. Table 2 compares the experimental and calculated excitation energies for the three $N = 83$ nuclei. For the ^{135}Te levels up to and including the 0.51 μs isomeric state, the agreement between theory and experiment is fair. There is not much doubt that they are dominantly $\pi g^2_{7/2} \nu f_{7/2}$ states, but with appreciable admixed contributions from other configurations, especially $\pi g_{7/2} d_{5/2} \nu f_{7/2}$. The calculations support the interpretation of the 2641 and 3235 keV levels as $(\pi g^2_{7/2} \nu h_{9/2})21/2^-$ and $(\pi g_{7/2} h_{11/2} \nu f_{7/2})25/2^+$ states. This $25/2^+$ state is closely related to the $(\pi h_{11/2} \nu f_{7/2})9^+$ state in ^{134}Sb and the $(\pi g_{7/2} h_{11/2})9^-$ state in ^{134}Te [20], but the second much weaker E3 branch expected from the ^{135}Te 3235 keV level to a $(\pi g_{7/2} d_{5/2} \nu f_{7/2})19/2^-$ level at about 2100 keV could not be detected. The weakly fed level at 4592 keV may be either $(\pi g_{7/2} h_{11/2} \nu h_{9/2})27/2^+$ or $(\pi g^2_{7/2} \nu i_{13/2})25/2^+$, both of which are predicted around 4.6 MeV. The topmost level at 5642 keV is probably a state of $(\pi g^2_{7/2} \nu f_{27/2} h^{-1}_{11/2})$ type directly related to the core-excited states identified in ^{134}Te at similar excitation energy [4].

The known 47 s β-decaying isomer of the odd-odd nucleus ^{136}I has been assigned $I^\pi = (6^-)$ [21], but the $(\pi g^3_{7/2} \nu f_{7/2})7^-$ state must be low-lying; here we make the assumption that the yrast γ-ray cascade in ^{136}I feeds this 7^- state, which subsequently de-excites by a low-energy transition. (The 6^- state is calculated 57 keV below the 7^-.) Accordingly, the ^{136}I excitation energies in Fig. 4 and Table 2 are expressed relative to zero for the 7^- state. The calculations support the interpretation of the ^{136}I levels up to 1615 keV as members of the $\pi g^3_{7/2} \nu f_{7/2}$ and $\pi g^2_{7/2} d_{5/2} \nu f_{7/2}$ multiplets. Associating the ~4 ns half-life with the 1372 keV level leads to a B(E2; $11^- - 9^-$) of about 4 W.u., which is in good accord with the B(E2) val-

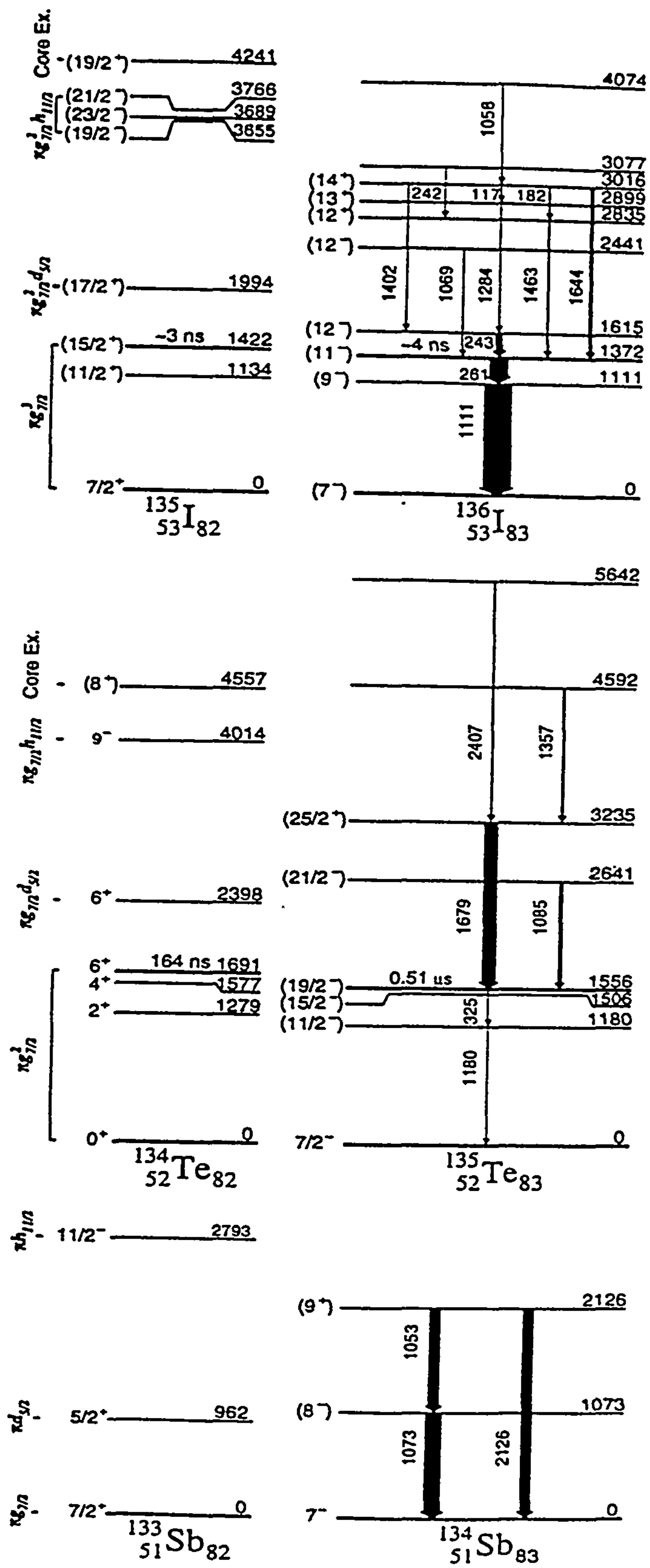

Figure 4: The proposed level schemes for $N = 83$ nuclei ^{134}Sb, ^{135}Te and ^{136}I. Main yrast excitations of the $N = 82$ neighbors ^{133}Sb, ^{134}Te, and ^{135}I are shown to the left.

Table 2: The shell model calculations for N=83 isotones. Empirical proton-proton interactions were adopted from the ^{134}Te spectrum, ar the proton-neutron interactions used are given below. Level energies calculated for the specified states are compared with the experiment energies.

$\pi\nu$ interaction energies (keV)	$\pi g_{7/2}\nu f_{7/2}$		$\pi g_{7/2}\nu h_{9/2}$		$\pi d_{5/2}\nu f_{7/2}$		$\pi h_{11/2}\nu f_{7/2}$	
	7^-	-420*	8^-	-910*	6^-	-760	9^+	-1090*
	6^-	-100	7^-	+ 40			8^+	0
	5^-	-300	6^-	-300			7^+	-150
	4^-	-140					6^+	- 20
	3^-	-300						
	2^-	-400						
	1^-	-680						
	0^-	-720						

Results

$^{135}_{52}Te_{83}$	I^π	config.	exp. (keV)	theor. (keV)
	7/2$^-$	$\pi g2\nu f$	0	0
	11/2$^-$	$\pi g^2\nu f$	1180	1341
	15/2$^-$	$\pi g^2\nu f$	1505	1626
	19/2$^-$	$\pi g^2\nu f$	1555	1684
	21/2$^-$	$\pi g^2\nu h$	2641	2640
	25/2$^+$	$\pi gh\nu f$	3234	3176

$^{136}_{53}I_{83}$	I^π	config.	exp. (keV)	theor. (keV)
	7^-	$\pi g^3\nu f$	0	0
	9^-	$\pi g^3\nu f$	1111	1162
	11^-	$\pi g^3\nu f$	1372	1472
	12^-	$\pi g^2 d\nu f$	1615	1607
	12^-	$\pi g^3\nu h$	2441	2413
	15^+	$\pi g^2 h\nu f$	-	2875
	12^+	$\pi g^2 h\nu f$	2835	2889
	13^+	$\pi g^2 h\nu f$	2899	2941
	14^+	$\pi g^2 h\nu f$	3016	2981

ues determined for the $\pi g^3_{7/2}$ $15/2^- \to 11/2^-$ transition in ^{135}I, and for the analogous $15^- \to 13^-$ E2 transition in the counterpart nucleus ^{212}At [22,23]. The cluster of ^{136}I levels around 2.9 MeV lies in an energy region where $\pi g^2_{7/2}h_{11/2}\nu f_{7/2}$ yrast states are expected, and the low-energy transitions between them suggest that they are structurally related. The observed decay properties of the 2835, 2899, and 3016 keV levels are consistent with I^π assignments of 12^+, 13^+ and 14^+, respectively, and the calculated energies fully support these assignments. There remains a question about the aligned 15^+ multiplet member, which is calculated to be lowest. The 2899 keV level might be considered an $I^\pi = 15^+$ candidate, with the 1284 keV an E3 transition to the yrast 12^- level. However, even though the $\pi h_{11/2} \to \pi d_{5/2}$ E3 involved is fast, the half-life of the parent level would be around 25 ns. The data on the other hand indicate that none of the excited states in Fig. 4 can have $t_{1/2}$ >10 ns. We conclude that the 15^+ state must be weakly populated in ^{248}Cm fission, and that it is not placed in the present work.

4 The Two-Valence-Neutron Nucleus ^{134}Sn

As expected, known ^{128}Sn, ^{130}Sn, and ^{132}Sn γ-rays appeared in coincidence with γ-rays from several Pd isotopes, but in addition gates on ^{112}Pd transitions showed also new 347.3 and 725.4 keV γ-rays which seemed to be prime candidates for placement in the N = 84 nucleus ^{134}Sn. Double gating on these two γ-rays revealed a 173.7 keV transition in the same cascade (Fig. 5), with all other peaks in the spectrum identified as known ^{110,111,112}Pd γ-rays. Pursuing a strong suspicion that the 174, 347, and 725 keV γ-rays belonged to ^{134}Sn, we applied a well tested method developed in earlier fission product γ-ray studies [24,25]. For each Sn fission product of mass A_1(Sn), the mean mass $\bar{A}_2$(Pd) of the complementary Pd fragments was determined from the Pd γ-ray intensities measured in coincidence with the γ-rays of that particular Sn isotope. The results are illustrated

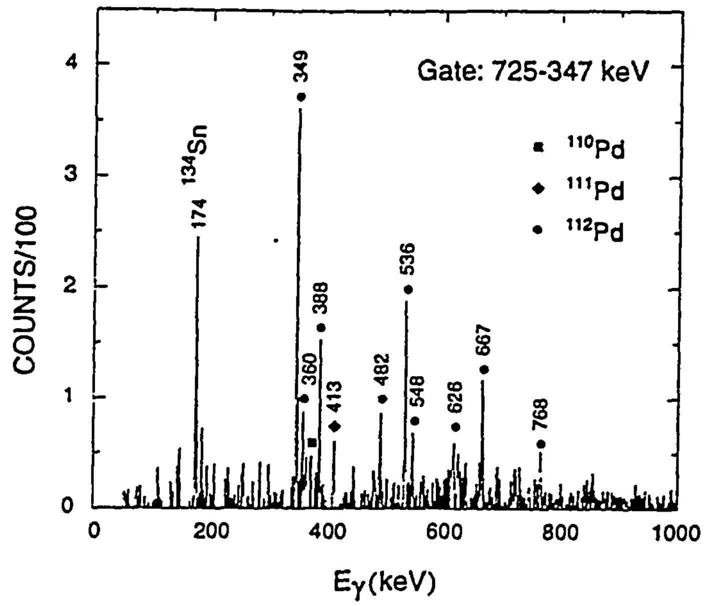

Figure 5: Key γ-ray coincidence spectrum recorded with a double gate on 347 and 725 keV transitions. Isotopic assignments are indicated for all prominent γ-rays.

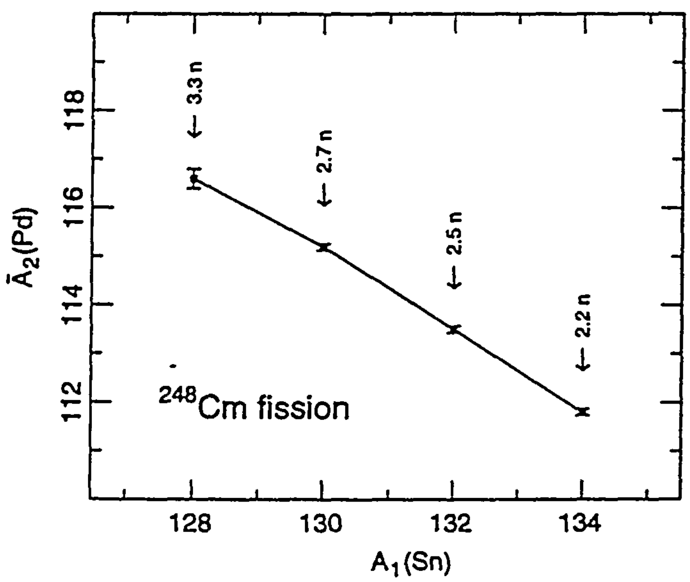

Figure 6: With the new γ-ray cascade tentatively assigned to ^{134}Sn, the Sn fragment mass A_1(Sn) is plotted against the average mass $\bar{A}_2$(Pd) of complementary Pd fragments deduced from γ-ray coincidence intensities. The average number of neutrons emitted in each case is also indicated.

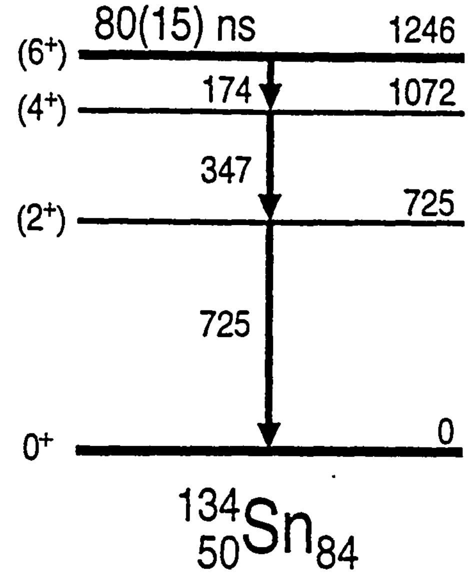

Figure 7: The ^{134}Sn level scheme showing proposed spin-parity assignments and the isomeric half-life.

in Fig. 6, where the smooth correlation observed between A_1(Sn) and $\bar{A}_2$(Pd) provides persuasive support for assignment of the 174, 347, 725 keV γ-ray cascade to the ^{134}Sn nucleus. The relative yields of ^{134}Sn and of its isotone ^{136}Te were estimated from the observed γ-ray coincidence intensities, and were found to agree well with the ^{134}Sn/^{136}Te yield ratio of 1/30 predicted for the fission of ^{248}Cm [5].

As is evident from the single particle level spectrum of $N = 83$ ^{133}Sn [6], the neutron $f_{7/2}$ state lies lowest above the $N = 82$ energy gap, where it is well separated from other single-neutron states. Accordingly, the ^{134}Sn levels located in the present work are naturally interpreted as the complete $(\nu f_{7/2})^2$ level spectrum up to the maximally aligned 6^+ state at 1246 keV; these levels furnish empirical two nucleon interactions between $f_{7/2}$ neutrons for use in shell model calculations. The $\gamma\gamma$ coincidence data indicated that the 174 keV transition de-excites an isomeric state, and the half-life of the 1246 keV level was determined from the measured $t_{\gamma\gamma}$ time distributions of delayed 725 keV γ-rays with respect to the prompt γ-ray bursts accompanying the fission events. The value $t_{1/2} = 80\pm15$ ns obtained gives the transition probability

$$B(E2;\, 6^+ \rightarrow 4^+,\, ^{134}\text{Sn}) = 36\pm7\ e^2\text{fm}^4$$
$$= 0.88\pm0.17\ \text{W.u.}$$

With the radial matrix element $\langle r^2 \rangle$ taken [26] as 32 fm^2, the E2 effective charge is then determined to be

$e_{eff}/e = 1.01 \pm 0.10$ $(\nu f_{7/2})^2$ in ^{134}Sn.

This result, which represents the $\nu f_{7/2}$ polarization charge, is similar to the value 0.88±0.05 reported [27] for $\nu g_{9/2}$ in ^{210}Pb, another two-neutron nucleus. Further discussion is postponed to a later paper, where the present result will be compared with the effective charges determined for $\nu h_{11/2}$ in the two-neutron hole nucleus ^{130}Sn [28], for $\pi g_{7/2}$ in the two-proton nucleus ^{134}Te [20], and for the counterpart valence particles in the nuclei around ^{208}Pb.

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