Structure of ^{155}Nd and ^{163}Gd from ^{252}Cf spontaneous fission

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(Received 29 April 2020; revised 1 July 2020; accepted 10 September 2020; published 26 October 2020)

Background: A puzzle has arisen recently caused by the apparent shift in maximum deformation from the expected ^{66}Dy isotopic chain to the $_{60}$Nd isotopic chain in the $82 < N < 126$ and $50 < Z < 82$ midshell region.
Purpose: This work provides data for two specific nuclei with odd neutron numbers, ^{155}Nd and ^{163}Gd, useful for constraining parameters in models that seek to answer the six proton shift in maximum deformation.
Method: Data from the spontaneous fission of ^{252}Cf were taken by the Gammasphere detector array at Lawrence Berkeley National Laboratory to observe the excited states of ^{155}Nd and ^{163}Gd.
Results: The structure of ^{163}Gd has been expanded with the addition of two new levels and three new γ rays, which are found to be consistent with previously published calculations and the structure of ^{165}Dy. In ^{155}Nd, nine new levels and 12 new γ rays are observed. The spins and parities of the previously known levels in ^{155}Nd have been reassigned from a $\nu3/2^-[521]$ ground state configuration to a $\nu5/2^+[642]$ isomeric configuration by comparison of these newly observed levels with levels in ^{153}Nd and ^{155}Sm.
Conclusion: Further experimentation is required to determine the energy of the newly reassigned $\nu5/2^+[642]$ level in ^{155}Nd with respect to the suspected $\nu3/2^-[521]$ ground state. Additionally, more experiments should be conducted to further determine the structure of neutron rich nuclei, rarely produced in the spontaneous fission of ^{252}Cf, such as ^{163}Gd.

DOI: 10.1103/PhysRevC.102.044323

I. INTRODUCTION

Between the spherical magic numbers of 82 and 126 for neutrons and 50 and 82 for protons, it was expected that $^{170}_{66}$Dy$_{104}$ would have the greatest deformation from spherical, as it lies at the exact center of this midshell region. Based on currently known first 2^+ excited state energies of even-even nuclei, it does appear that $N = 104$ correlates with maximum deformation in Dy-Hf. However, as shown in Fig. 1, $Z = 66$ does not correlate with the greatest deformation, as expected, but rather $Z = 60$, the Nd chain.

This puzzle has been discussed for many years in the literature [1–10], but as of yet no complete solution has been proposed to explain this six proton shift in maximum deformation. Some have proposed partial deformed shell closure at $N = 98$ to explain the local maximum visible in Fig. 1 at $N = 98$ for the $_{60}$Dy, $_{60}$Gd, and $_{60}$Sm chains [2–6]. Thus more data are needed for nuclei in this doubly midshell region.

This work seeks to provide data for several nuclei with at least one odd nucleon in this region. Specifically ^{155}Nd, ^{163}Gd, and the Eu isotopic chain have been examined by observation of the spontaneous fission (SF) of ^{252}Cf.

Previous work by Hwang *et al.* [11] established a $\nu3/2^-[521]$ band up to 1831.6 keV for ^{155}Nd. This work adds 12 new γ-ray transitions and nine new levels to the structure of ^{155}Nd, and reassigns the configuration of the levels observed by Hwang *et al.* [11] to $\nu5/2^+[642]$.

Until recently, very little was known about the structure of ^{163}Gd. Sato *et al.* [12] published five γ rays, but cited no level scheme. An 137.8 keV isomer was subsequently observed by Hayashi *et al.* [13] with $t_{1/2} = 23.5(10)$ s. Most recently, Zachary *et al.* [14] built a complex level scheme for ^{163}Gd from the β decay of ^{163}Eu. This work confirms six of the levels and seven of the γ rays placed into the level scheme of ^{163}Gd by Zachary *et al.* [14]. Beyond these, two new levels and three new γ rays have been added to the $\nu7/2^+[633]$ ground state band of ^{163}Gd.

II. EXPERIMENT AND METHODS

The experimental data examined in this work were collected by use of the Gammasphere detector array, which was

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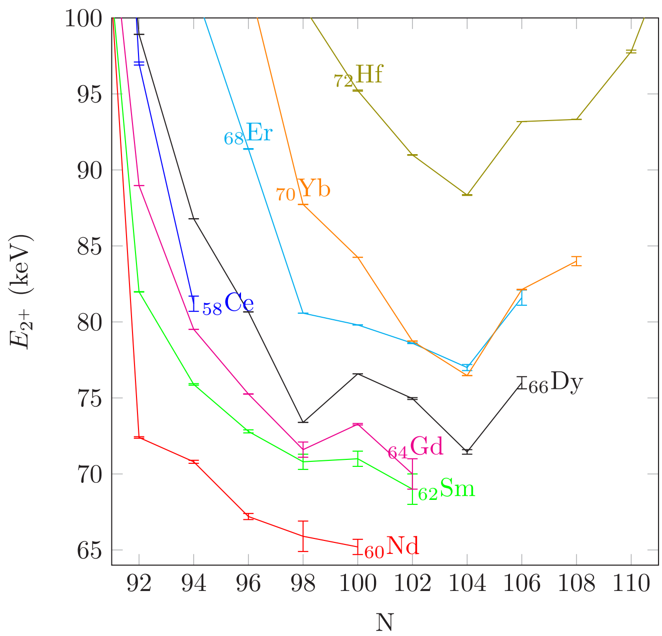

FIG. 1. Lowest first 2^+ energies in the $82 < N < 126$ and $50 < Z < 82$ midshell region. The data show in this figure are compiled from Refs. [6,15–35].

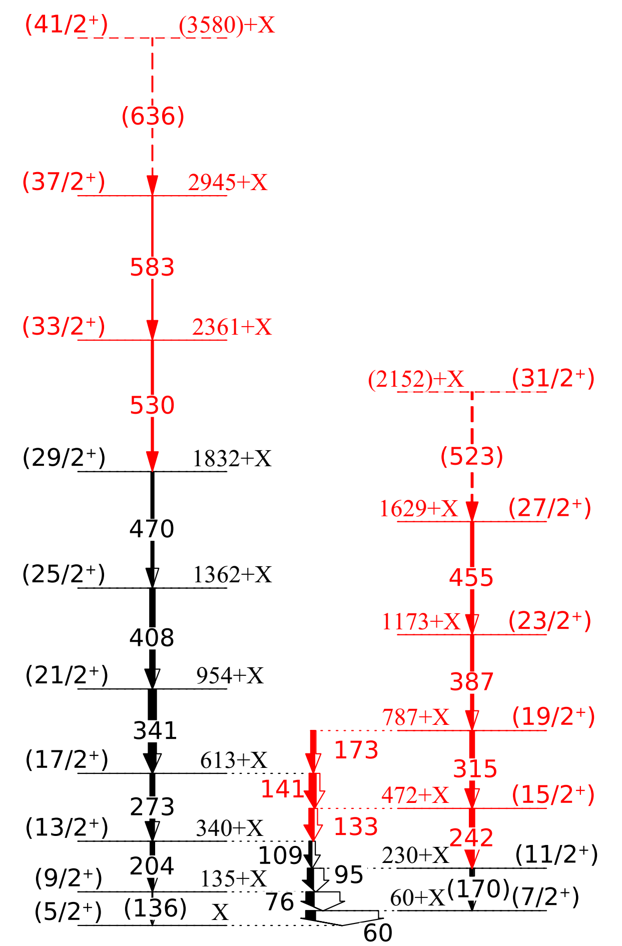

FIG. 2. The level scheme of ^{155}Nd as found in this work. All level and γ energies are in keV. Red transitions and levels are newly observed in this work. Table I has the precise energies for these levels and γ rays.

located at Lawrence Berkley National Laboratory at the time of the experiment. A 62 μCi source of ^{252}Cf was placed between iron foils inside Gammasphere yielding 5.7×10^{11} γ-γ-γ and higher coincidence events, including 1.9×10^{11} γ-γ-γ-γ events. Because the iron foils were thick enough to stop the fission fragments, no Doppler corrections were needed on the measurements. At the time of the experiment, 101 of Gammasphere's hyperpure germanium γ-ray detectors were working and were arranged spherically about the source. More details on this experimental setup can be found in Luo *et al.* [36].

III. RESULTS AND DISCUSSION

A. ^{155}Nd

By use of γ-γ-γ-γ coincidences, the level scheme of ^{155}Nd has been extended up to ≈3.5 MeV with 12 new γ rays and nine new levels. The newly developed level scheme of ^{155}Nd is shown in Fig. 2 and more details about the transitions and levels can be found in Table I.

Figure 3 shows a double gate on the first two yrast transitions of ^{94}Sr, the three neutron fission partner of ^{155}Nd. In that figure one can see transitions from $^{152-156}$Nd, including every transition from ^{155}Nd observed in this work. The primary difficulty in examining gates for ^{155}Nd, as shown in Fig. 3, is the similarity of energies across Nd isotopes. Fortunately, for identifying new transitions in ^{155}Nd, as typical for neighboring isotopes, this similarity diverges with increasing energy.

In Fig. 4 two triple gates are shown, demonstrating both the left and right half of the band shown in Fig. 2 for ^{155}Nd. The top of Fig. 4 shows a triple gate on three transitions in the left half of the band shown in Fig. 2. One can clearly see all the transitions in that half of the band (except those gated upon) including the two newly identified transitions. The ≈352 keV transition from ^{95}Sr is seen in this gate because it is the two neutron fission partner of ^{155}Nd.

The triple gate shown in Fig. 4(b) demonstrates the transitions in the right half of the band shown in Fig. 2. This gate consists of the ground state transition from ^{94}Sr (836.7 keV) and two from within the structure of ^{155}Nd (314.8 and 109.4 keV). In this gate, one can clearly see the transitions from the levels in the right half of the band shown in Fig. 2 up to and including the tentative 522.7 keV transition.

Unmarked peaks in Fig. 4 come from nuclei other than ^{155}Nd or an isotope of Sr. These background/contaminant peaks disappear in other gates which are not shown in Fig. 4 (such as Fig. 3), and thus can be clearly ruled out as not belonging to ^{155}Nd. All of the transitions identified in Fig. 2 and Table I are visible in more gates than those shown in Figs. 3 and 4. The net result of the preponderance of gates are shown in Fig. 2 and Table I, amounting to 12 new γ rays from nine new levels, as well as the new spin assignment of $\nu 5/2^+[642]$ for the lowest energy state observed, as described above.

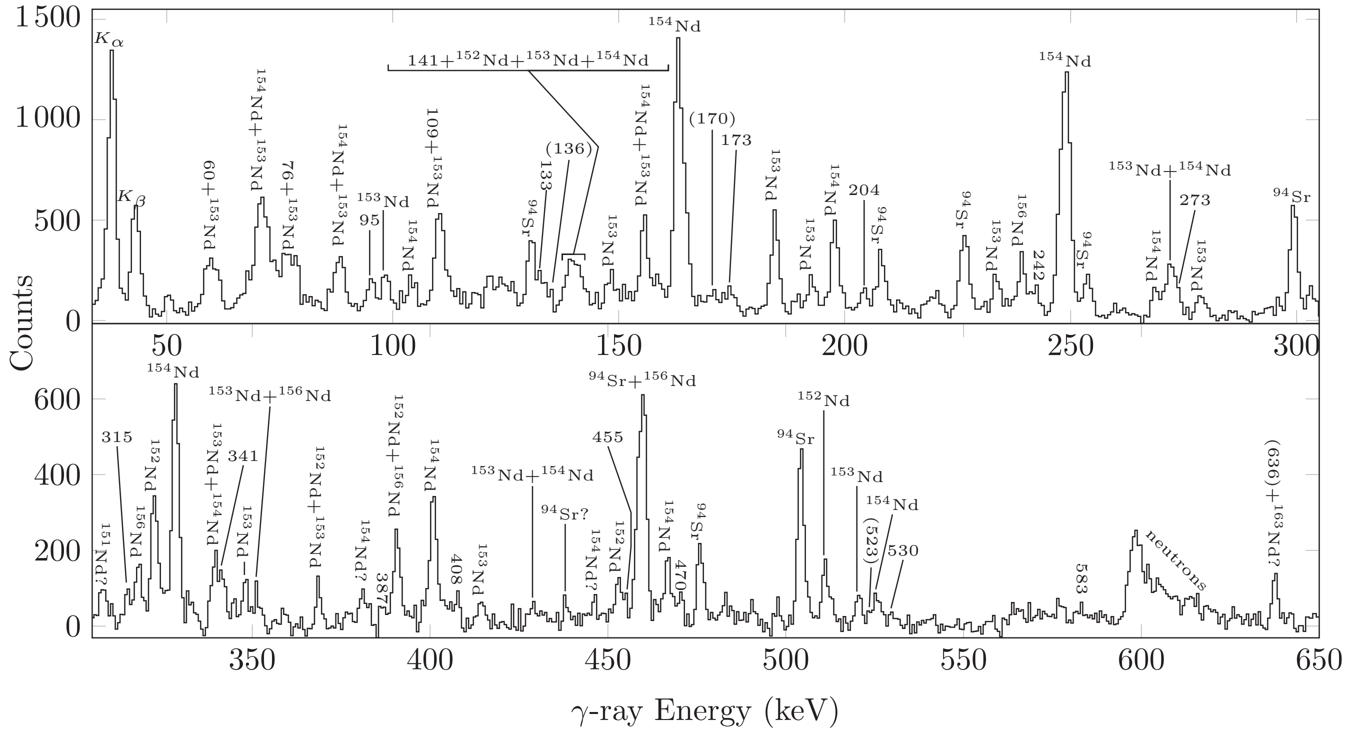

FIG. 3. A double gate on 836.7–1308.7 keV, the first two yrast transitions from ^{94}Sr, the three neutron fission partner of ^{155}Nd. Transitions from ^{155}Nd are labeled with their rounded energy. For peaks from other sources the source is given as the label. Labels ending in a question mark indicate that the transition is previously unidentified. Transitions with contributions from multiple sources are combined with plus (+) signs.

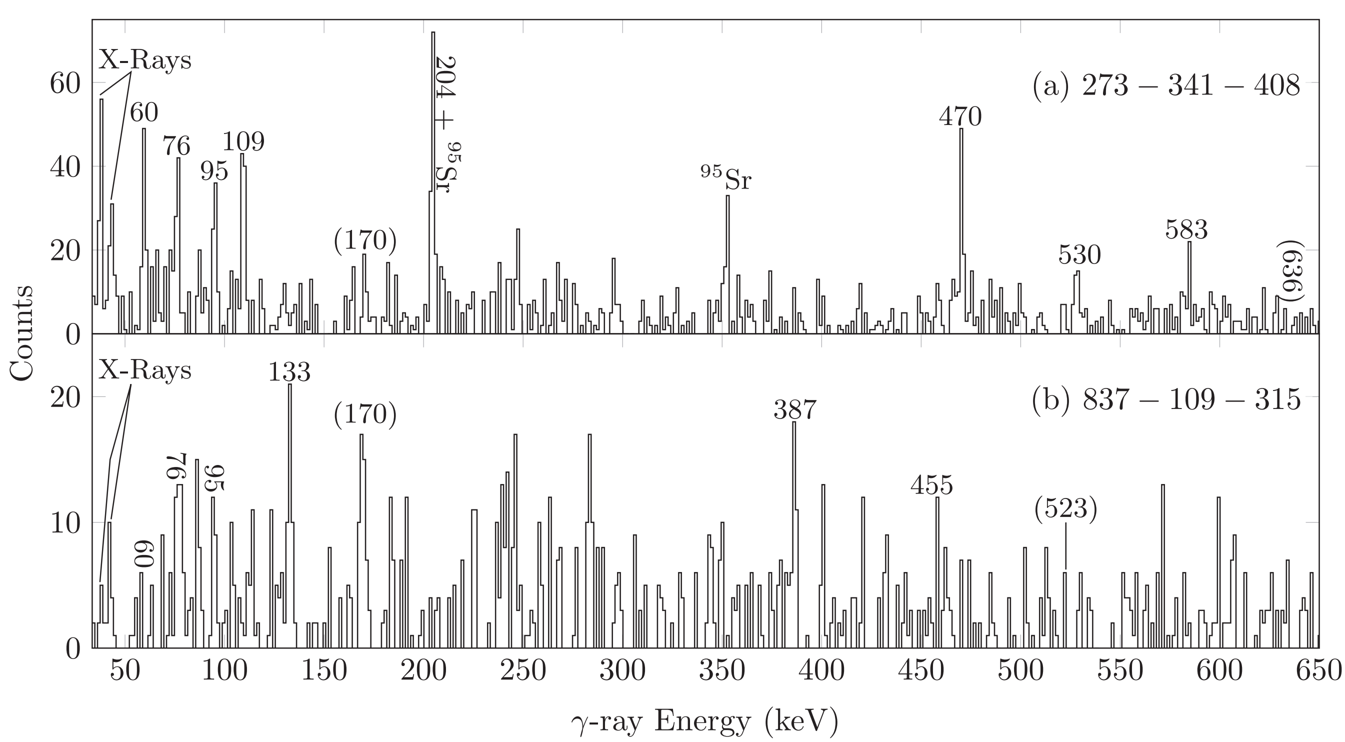

FIG. 4. Two triple gates showing transitions in the structure of ^{155}Nd. Transitions from ^{155}Nd are labeled with their rounded energy. For peaks from other sources the source is given as the label. (a) A triple gate on the 273.1–341.3–407.5 keV within the structure of ^{155}Nd. (b) A triple gate on 836.7 keV from ^{94}Sr and 109.4–314.8 keV from ^{155}Nd.

TABLE I. Levels and γ-ray transitions observed in this work for ^{155}Nd. The intensities shown have not been corrected for internal conversion. Transitions and levels marked with an asterisk (*) are newly observed in this work. Square brackets indicate that a transition or level is tentative.

E_γ (keV)	I_γ	$E_i - X$ (keV)	J_i^π	$E_f - X$ (keV)	J_f^π
59.6(5)	<316	59.6(5)	$(7/2^+)$	0	$(5/2^+)$
75.8(5)	<260	135.4(8)	$(9/2^+)$	59.6(5)	$(7/2^+)$
94.6(5)	100(8)	230.3(9)	$(11/2^+)$	135.4(8)	$(9/2^+)$
109.4(5)	<99	339.7(7)	$(13/2^+)$	230.3(9)	$(11/2^+)$
132.5(5)*	86(12)	472.2(7)*	$(15/2^+)$	339.7(7)	$(13/2^+)$
[135.5(7)]	<13	135.4(8)	$(9/2^+)$	0	$(5/2^+)$
141.2(6)*	112(19)	613.1(6)	$(17/2^+)$	472.2(7)*	$(15/2^+)$
[170.0(8)]	55(9)	230.3(9)	$(11/2^+)$	59.6(5)	$(7/2^+)$
173.4(6)*	65(10)	786.8(6)*	$(19/2^+)$	613.1(6)	$(17/2^+)$
204.2(5)	58(9)	339.7(7)	$(13/2^+)$	135.4(8)	$(9/2^+)$
241.9(5)*	76(12)	472.2(7)*	$(15/2^+)$	230.3(9)	$(11/2^+)$
273.1(5)	69(18)	613.1(6)	$(17/2^+)$	339.7(7)	$(13/2^+)$
314.8(5)*	70(10)	786.8(6)*	$(19/2^+)$	472.2(7)*	$(15/2^+)$
341.3(5)	123(17)	954.4(8)	$(21/2^+)$	613.1(6)	$(17/2^+)$
386.6(5)*	47(7)	1173.4(8)*	$(23/2^+)$	786.8(6)*	$(19/2^+)$
407.5(6)	83(12)	1361.9(10)	$(25/2^+)$	954.4(8)	$(21/2^+)$
455.4(5)*	49(9)	1628.8(9)*	$(27/2^+)$	1173.4(8)*	$(23/2^+)$
469.7(5)	43(15)	1831.6(11)	$(29/2^+)$	1361.9(10)	$(25/2^+)$
[522.7(5)]*	27(6)	[2151.5(11)]*	$(31/2^+)$	1628.8(9)*	$(27/2^+)$
529.6(6)*	29(4)	2361.2(13)*	$(33/2^+)$	1831.6(11)	$(29/2^+)$
583.3(7)*	17(4)	2944.5(15)*	$(37/2^+)$	2361.2(13)*	$(33/2^+)$
[635.6(5)]*	10(3)	[3580.1(15)]*	$(41/2^+)$	2944.5(15)*	$(37/2^+)$

While the tentative 170 keV transition is visible in both gates shown in Fig. 4, other gates not shown in Figs. 3 and 4 do not see the 170 keV transition when it should be visible based on the coincidence relationships. Furthermore, in gates that do see the 170 keV transition, its intensity and energy are inconsistent, leading to its tentative assignment and large energy uncertainty in Table I. The intensity discrepancy is clearly seen in Fig. 4 where Fig. 4 a shows the intensity of the 170 keV transition as about half of the intensity of the 95 keV transition, while this ratio is reversed in Fig. 4(b).

Now, Hwang *et al.* [11] used the same experimental data as described in this work. All discrepancies between Table I in this work and the work of Hwang *et al.* [11] are a combined result of two factors. First, at the time of the analysis presented in Hwang *et al.* [11], the data had not yet been compiled into a γ-γ-γ-γ coincidence matrix. Thus, Hwang *et al.* only had access to the γ-γ-γ coincidence matrix. The energies and intensities presented in Table I are combined from information derived from both γ-γ-γ and γ-γ-γ-γ coincidence spectra. Furthermore, the calibration of the data has been recalculated since the publication of Hwang *et al.* [11]. The combined results of these two changes should be less than the error bars on the γ-ray energies.

Based on systematics with ^{153}Nd [11,37], and ^{155}Sm [37,38] (see also Refs. [39–41]), we believe that the band described in [11] for ^{155}Nd is actually a $\nu 5/2^+[642]$ band instead of a $\nu 3/2^-[521]$ band. As shown in Fig. 5, the spacings of the only observed band in ^{155}Nd more closely

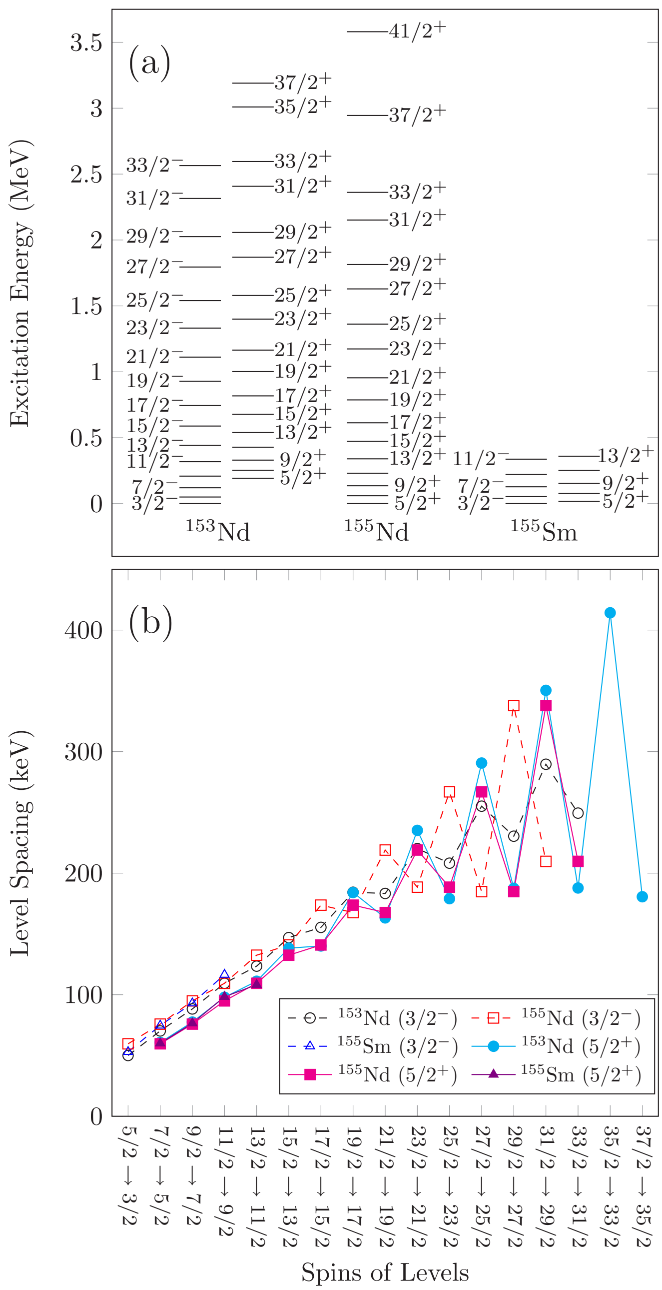

FIG. 5. Systematics of bands across ^{153,155}Nd, and ^{155}Sm. Data for ^{153}Nd are from [11] and ^{155}Sm come from [37,38]. Part (a) shows the $\nu 3/2^-[521]$ and $\nu 5/2^+[642]$ bands for each isotope, with the lowest energy level in ^{155}Nd set to zero to ensure that its levels fit in the plot better. Part (b) contains a plot of the spacing between any two levels whose spins differ by 1. The dashed lines indicate the $\nu 3/2^-[521]$ bands while the solid lines indicate the $\nu 5/2^+[642]$ bands. The line for the $\nu 3/2^-[521]$ band of ^{155}Nd is what the spins would be if the only observed band were that configuration, rather than the $\nu 5/2^+[642]$ configuration assumed by this work.

matches the spacings of the levels of the $\nu 5/2^+[642]$ bands in ^{153}Nd and ^{155}Sm. Figure 5(a) shows both the $\nu 5/2^+[642]$ and $\nu 3/2^-[521]$ bands for each of these three isotopes (except ^{155}Nd, which has only one band). Figure 5(b) shows the spacing between levels as a function of spin, where one can clearly see that an assignment of $\nu 5/2^+[642]$ for the observed levels in ^{155}Nd matches the spacing of the $\nu 5/2^+[642]$ bands of the other isotopes, especially ^{153}Nd, better than the spacing of the $\nu 3/2^-[521]$ bands. Of particular note is the signature splitting. If an assignment of $\nu 3/2^-[521]$ were given to the band observed in ^{155}Nd, then its signature splitting of levels would be opposite of the signature splitting in the spacing of the other bands observed of either configuration for ^{153}Nd or ^{155}Sm as clearly seen in Fig. 5(b). Because of these observations we propose a new assignment of a $\nu 5/2^+[642]$ configuration—in place of the previous $\nu 3/2^-[521]$—for the observed band in ^{155}Nd.

This reassignment of the spins and parities of the levels in ^{155}Nd comes with a few significant consequences. As Hwang *et al.* [11] states, the expected ground state of ^{155}Nd is a $\nu 3/2^-[521]$, especially since this is true of ^{153}Nd and ^{155}Sm. Thus, based on the present work, the band-head of the band observed in this work and in Hwang *et al.* [11] is likely not the expected $\nu 3/2^-[521]$ ground state of ^{155}Nd, but rather a $\nu 5/2^+[642]$ excited state. Since no alternative ground states are observed for ^{155}Nd, either (1) the $\nu 5/2^+[642]$ band head is an isomer, (2) the transition from the $\nu 5/2^+[642]$ band head to ground is less than 33 keV (the minimum detectable energy in our data), (3) the assignment of Hwang *et al.* [11] is correct and the assignment of this work is incorrect, or (4) the energies of the $\nu 5/2^+[642]$ and $\nu 3/2^-[521]$ bands are swapped for ^{155}Nd compared to its neighbors. Option (3) would be in direct contradiction with the observations of Fig. 5. While option (4) is not, strictly speaking, impossible concerning the observations in Fig. 5, it is unlikely, since ^{153}Nd and ^{155}Sm both have a $\nu 3/2^-[521]$ ground state and a $\nu 5/2^+[642]$ excited state. Furthermore, option (1) would be consistent with the observed 2.8(5) and 1.06(5) μs half-lives of the $\nu 5/2^+[642]$ states in ^{155}Sm and ^{153}Nd [37,41], respectively. Thus, based on the systematics shown in Fig. 5, this work favors a combination of options (1) and (2) to explain why the $\nu 3/2^-[521]$ state is not observed in this work.

The question is remains as to why the $\nu 3/2^-[521]$ band for ^{155}Nd is not observed by means other than decay from the $\nu 5/2^+[642]$ level. In both ^{155}Sm and ^{153}Nd, no linking transitions are observed between the $\nu 3/2^-[521]$ and $\nu 5/2^+[642]$ bands except for decay from the $\nu 5/2^+[642]$ isomers. Thus no linking transitions are expected in ^{155}Nd, and therefore can not be used to search for levels belonging to the $\nu 3/2^-[521]$ configuration in ^{155}Nd. Furthermore, as seen in Fig. 3, the energies of transitions in isotopes of ^{155}Nd are extremely similar. Thus, since no coincident relationships are observed (or expected except for isomeric decay) between the $\nu 5/2^+[642]$ and $\nu 3/2^-[521]$ bands, some prior knowledge at least one or two levels or transitions in the $\nu 3/2^-[521]$ would be required to uncover the energies of the transitions within the $\nu 3/2^-[521]$ that is likely available in our data.

By plotting the yields of Nd for each isotope of Sr as shown in Musangu *et al.* [42] (who worked from the level scheme provided by Hwang *et al.* [11]), one finds that ^{155}Nd has a slightly lower yield than the curve, in most cases, as shown in Fig. 6. However, this discrepancy is small. Thus, the yield curves of Nd-Sr reported in Musangu *et al.* [42], are inconclusive for determining whether or not the lowest level reported in Fig. 2 is the ground state of ^{155}Nd or not.

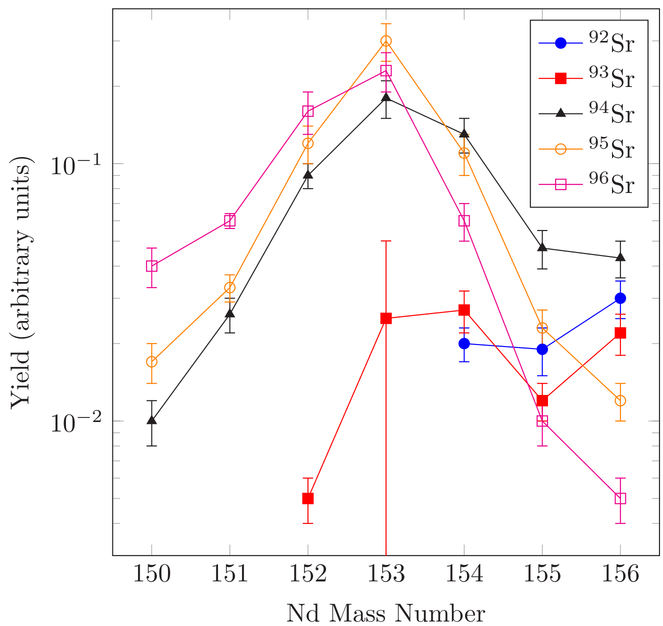

FIG. 6. Plots of the ^{252}Cf SF yields of Sr isotopes as function of Nd mass number (A) from Musangu *et al.* [42].

B. ^{163}Gd

By examining γ rays produced by the products of the SF of ^{252}Cf, this present work attempts to build on the level scheme for ^{163}Gd observed by Zachary *et al.* [14], as well as confirm the levels they observed. This analysis has resulted in three new transitions depopulating two new levels and the confirmation of seven transitions and seven excited states observed

TABLE II. A list of levels and γ rays observed for ^{163}Gd in the SF of ^{252}Cf. Transitions and levels marked with an asterisk (*) are newly observed in this work and square braces indicate that a transition or level is tentative.

E_γ (keV)	I_γ	E_i (keV)	J_i^π	E_f (keV)	J_f^π
[48.9(11)][a]	<70[b]	186.7(10)[a]	$3/2^-$	[137.8(5)][c,d]	$1/2^-$
[71.8(5)][c]	≪354[b]	209.6(7)[c]	$5/2^-$	[137.8(5)][c,d]	$1/2^-$
84.8(5)	94(9)	84.8(5)	$9/2^+$	0	$7/2^+$
103.8(5)	100(5)	188.6(7)	$11/2^+$	84.8(5)	$9/2^+$
115.1(5)	75(8)	324.7(9)	$7/2^-$	209.6(7)[c]	$5/2^-$
122.8(5)*	51(6)	311.4(9)*	$(13/2^+)$	188.6(7)	$11/2^+$
138.0(5)	67(7)	324.7(9)	$7/2^-$	186.7(10)[a]	$3/2^-$
142.6(5)*	<50	454.2(7)*	$(15/2^+)$	311.4(9)*	$(13/2^+)$
265.8(5)*	<18	454.2(7)*	$(15/2^+)$	188.6(7)	$11/2^+$
[453.8(6)]	<48	[453.8(6)]	$(5/2^-)$	0	$7/2^+$

[a]Not directly measured; calculated from level differences.
[b]Intensity upper limit obtained by ignoring contributions from known strong contaminants.
[c]Not directly measured; adopted from Zachary *et al.* [14].
[d]Known isomer with lifetime, 23.5(10) s [13].

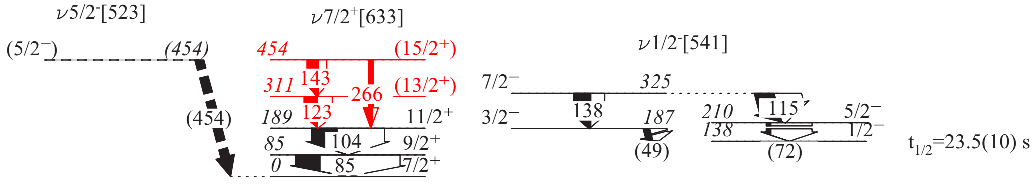

FIG. 7. The level scheme of ^{163}Gd as observed in this work. The width of the arrows indicates intensity (white is theoretical internal conversion). In red are the new transitions and levels newly observed in this work. The half-life of the ≈138 keV isomer is taken from [13]. The precise level and γ-ray energies are shown in Table II.

by Zachary *et al.* [14]. All of these transitions and levels are tabulated in Table II, while the level scheme of ^{163}Gd is shown in Fig. 7.

The only gate that clearly showed transitions from ^{163}Gd is a double gate on 704.1/863.6 keV from ^{86}Se, the three neutron fission partner of ^{163}Gd. Furthermore, all the intensities shown in Table II were measured using this double gate. This gate is shown in Fig. 8. In general, the statistics for triple gates were too low for any conclusions, though results in those gates were not contradictory with the structure shown.

Two major sources of contamination are seen in Fig. 8. First, two ≈704 keV transitions are known in the yrast band of ^{110}Ru at 705.3 keV ($8^+ \rightarrow 6^+$) and 703.9 keV ($14^+ \rightarrow 12^+$). When these transitions are combined with the two (albeit weak) ≈864 keV (861.5 and 863 keV) transitions in ^{139}Xe, the three neutron fission partner of ^{110}Ru, they produce two contaminant peaks in the spectrum shown in Fig. 8. Additionally, in the yrast band of ^{114}Pd one finds the $16^+ \overset{863.5}{\rightarrow} 14^+ \overset{703.9}{\rightarrow} 12^+$ cascade. Thus the $2^+ \overset{322.8}{\rightarrow} 0^+$ transition from ^{114}Pd can be seen in Fig. 8, as well as two other peaks generated by isotopes of Te, the fission partner of Pd.

The yrast band displayed in Fig. 7 agrees well with the theoretical calculations presented in Zachary *et al.* [14]. Furthermore, as also discussed in Zachary *et al.*, the new levels found for ^{163}Gd continue to closely match the structure of ^{165}Dy (see Refs. [43–45]), which is believed to have the same ground state configuration as ^{163}Gd ($\nu 7/2^+[633]$), since both nuclides have 99 neutrons. Thus, though the coincident evidence for the ^{163}Gd level scheme from the SF of ^{252}Cf is low, we have strong confidence in the structure presented in Fig. 7 and Table II for ^{163}Gd.

C. Isotopes of $_{63}$Eu

Only four isotopes of Eu produced by the SF of ^{252}Cf have any levels or γ rays known in the literature. Burke *et al.* [46],

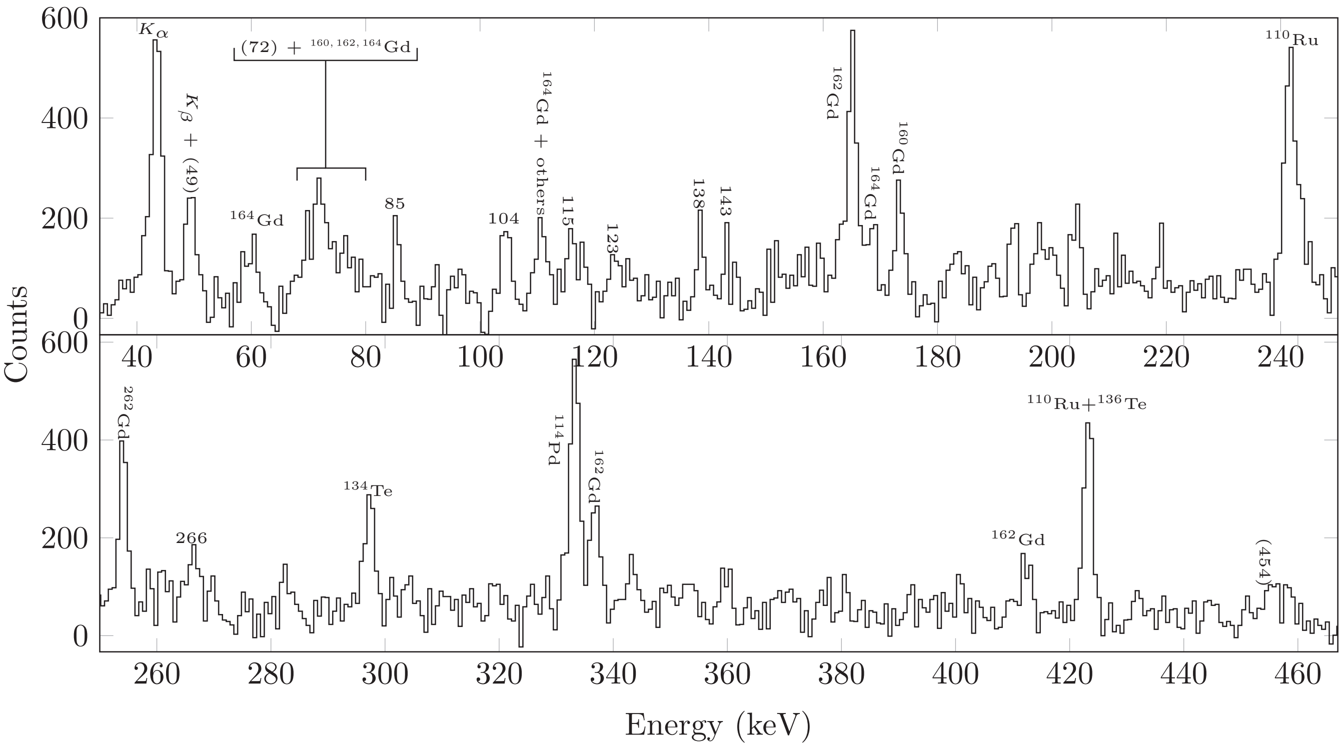

FIG. 8. A double gate on 704.1–863.6 keV, the first two yrast transitions in ^{86}Se, in which all the transitions observed in this work for ^{163}Gd, its three neutron fission partner, are visible. Transitions from ^{163}Gd are labeled with their rounded energy. For peaks from other sources the source is given as the label. Transitions with contributions from multiple sources are combined with plus (+) signs.

using the ^{158,160}Gd(t,α)^{157,159}Eu reactions, with polarized tritons, uncovered many levels in ^{157,159}Eu. Later, Willmes *et al.* [47] and Greenwood *et al.* [44] studied the β decay of ^{159}Sm and ^{157}Sm, respectively, observing γ rays and more precise values of some of the levels observed by Burke *et al.* [46] for ^{157,159}Eu. The isotope, ^{156}Eu has been studied by the ^{154}Eu(t,p)^{156}Eu [48] and ^{155}Eu(n,γ)^{156}Eu [49] reactions. Finally, ^{164}Eu has only four tentative γ rays known [6], but no excited states.

Unfortunately, due to a combination of a lack of statistics in our ^{252}Cf SF data, and a lack of previously known γ rays in the isotopes of Eu and its fission partners, no level schemes could be established in this work for isotopes of Eu. These issues are greatly compounded by the propensity of low energy γ rays known (and unknown) from many nuclei present in our data. For ^{155}Nd and ^{163}Gd, gates on fission partner energies were used to isolate transitions in those nuclei since their fission partners, being near the spherical magic number 50 for protons, have strong γ rays commonly well in excess of 500 keV. However, no excited states or transitions are known for isotopes of Br more neutron rich than ^{88}Br, making setting gates on their energies impossible for isolating transitions in isotopes of Eu. We are relatively confident, however, that, if more data were available in the literature concerning γ rays and excited states for neutron-rich isotopes of Br, that new γ rays and excited states would be observable for ^{156,157,159}Eu in our ^{252}Cf SF data. Furthermore, it is likely that, were another experiment to uncover a few excited states in isotopes of Eu which currently have no known excited states, and were some data known concerning their Br fission partners, that more levels and γ rays could be observed in our data.

IV. CONCLUSION

The level schemes of ^{155}Nd and ^{163}Gd have been studied following the SF of ^{252}Cf. The structure of ^{163}Gd has been expanded with two new levels and three new γ rays in the ground state band. The newly observed levels in ^{163}Gd are consistent with the theoretical calculations discussed in Zachary *et al.* [14] and the level scheme of ^{165}Dy [43–45].

For ^{155}Nd, nine new levels and 12 new γ rays have been observed. This has enabled a deeper comparison between level spacing between ^{155}Nd and its neighbors, ^{153}Nd and ^{155}Sm, resulting a reassignment the spins and parities of observed levels in ^{155}Nd. It is now believed that the lowest observed level in the structure of ^{155}Nd is actually a $\nu 5/2^+[642]$ (probably excited) state, rather than the previously assigned $\nu 3/2^-[521]$ configuration. An experiment more capable of examining isomers, or seeing transitions below $\approx$40 keV, would be required to determine whether the $\nu 5/2^+[642]$ level observed in this work is an excited state, or the order $\nu 3/2^-[521]$ and $\nu 5/2^+[642]$ configurations is reversed for ^{155}Nd, compared to its neighbors.

ACKNOWLEDGMENTS

The work at Vanderbilt University is supported by The United States Department of Energy under Grant No. DE-FG05-88ER40407. The work at Lawrence Berkeley National Laboratory is supported by the United States Department of Energy under Grants No. DE-AC07-761DO1570 and No. DE-AC03-76SF00098. The work at JINR was supported by the Russian Foundation for Basic Research Grant No. 08-02-00089 and by the INTAS Grant No. 03-51-4496. The work at Tsinghua University was supported by the National Natural Science Foundation of China under Grant No. 11175095. A special thanks also to the faculty and staff of Lawrence Berkley National Laboratory who facilitated the collection of the data discussed here.

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