Identification of high spin states in ^{134}I from ^{252}Cf fission

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High spin states in ^{134}I were identified for the first time based on measurements of prompt γ rays from the spontaneous fission of ^{252}Cf at Gammasphere. Five excited levels with five deexciting transitions were observed. The mass number was assigned based on the intensity of transitions in the complementary Rh fragments. Angular correlations for the first two transitions in ^{134}I and for high spin states in ^{133,135,136}I were performed, but were not sufficient to firmly assign the spins and parities in ^{134}I.

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Studies of the structure of neutron-rich nuclei near the double magic ^{132}Sn ($Z = 50$, $N = 82$) nucleus provide important tests for shell model calculations that utilize effective interactions. Therefore, with one neutron below the $N = 82$ major shell and a few valence protons outside the $Z = 50$ closed shell, the $N = 81$ isotones are good candidates for these calculations. Here, we report our identification of levels in ^{134}I ($N = 81$), with one neutron "hole" and three protons beyond the double magic ^{132}Sn core.

A level scheme of ^{133}I was constructed from the ^{133}Te β decay and the ^{133}I isomeric decay [1]. High spin states in $^{135-139}$I were examined from the spontaneous fission of ^{248}Cm [2–6]. Low-lying transitions in ^{134}I were observed from the ^{134}Te β decay [7,8]. A 3.8(2) min isomer at 316.3 keV was reported in ^{134}I and tentatively assigned as 8^-, either a $\pi(1g_{7/2})\nu(1h_{11/2})^{-1}$ or $\pi(2d_{5/2})\nu(1h_{11/2})^{-1}$ state [9]. However, no higher spin states in ^{134}I have been reported so far.

Here, we report the first identification of high spin states in ^{134}I, populated in the spontaneous fission (SF) of ^{252}Cf. Data for this work were obtained with the Gammasphere detector array at the Lawrence Berkeley National Laboratory in the year 2000. A total of 5.7×10^{11} triple and higher fold γ-ray coincidence events were recorded. The coincidence data were analyzed with the RADWARE software package [10]. Details of this experiment and data analysis procedure can be found in Ref. [11]. In the binary SF, a ^{252}Cf nucleus breaks up into two partner fragments where there are multiple pairs of related partners for a specific nucleus. By double gating on the previously known transitions in each of its partners, the transitions in a given nucleus can be identified. The fission partners of ^{134}I are Rh isotopes, such as $^{111-113}$Rh [12].

Coincidence spectra were obtained by double gating on the strong transitions in the I partner isotopes ^{113,112,111}Rh. The transition energies used for double gating in Rh isotopes are shown in Fig. 1. In Fig. 1, one sees a new 952.4 keV transition and the previously known strong transitions in ^{133}I [1], ^{135}I [2], ^{136}I [3], and ^{137}I [4]. By double gating on the new 952.4 keV transition observed in these spectra (Fig. 1) and on a strong transition in each of the $^{111-113}$Rh isotopes, several new transitions of energies 640.2, 244.3, 752.5, and 785.5 keV were observed. These new transitions are marked with an asterisk in Figs. 2(a) and 2(b). Figure 2(c) clearly demonstrates the coincidence relationship among the 940.4, 640.2, 244.3, 752.5, and 785.5 keV transitions as well as among transitions in the Rh isotopes. Careful cross-checking of numerous coincidence spectra confirmed that this cascade consisting of 952.4, 640.2, 244.3, 752.5, and 785.5 keV transitions exists and belongs to an iodine isotope.

Because the level schemes of $^{133,135-139}$I are well known, we propose that this cascade is in ^{134}I. A comparison of the relative intensities among the 952.4 keV transition, the 1133.8 keV transition in ^{135}I and the 1111.8 keV transition in ^{136}I in different Rh gates (see Fig. 1) supports such an assignment. The most crucial support is from the following measurement for the mass number assignment. In the 620.5/488.2 keV (^{137}I), 1111.8/260.7 keV (^{136}I), 1133.8/288.2 keV (^{135}I), and 952.4/640.3 keV double gates, fission yield ratios of the 232.3 keV transition in ^{113}Rh to the 183.0 keV transition in ^{112}Rh were measured, as shown in Fig. 3. The variation of these ratios follows that of similar ratios of ^{108}Tc to ^{107}Tc in $^{140-143}$Cs gates [13], which indicates that the mass number for the 640.3 → 952.4 cascade is below 135. However, the yrast level scheme of ^{133}I has been investigated very well [1] and most of the strongly populated transitions are also observed in our data. Moreover, the fission yield rate of ^{132}I is much less than that of ^{134}I to exclude that this cascade belongs to ^{132}I. Therefore, the level scheme of ^{134}I is built with five new transitions, as shown in Fig. 4.

In addition to these levels identified in the present work, many low-lying transitions seen from the ^{134}Te β decay are also observed in our data to provide an additional support for the identification of high spin states in ^{134}I.

The ground state of ^{134}I is mainly built on the configuration of $\pi(1g_{7/2})\nu(2d_{3/2})^{-1}$ with a tentative spin-parity

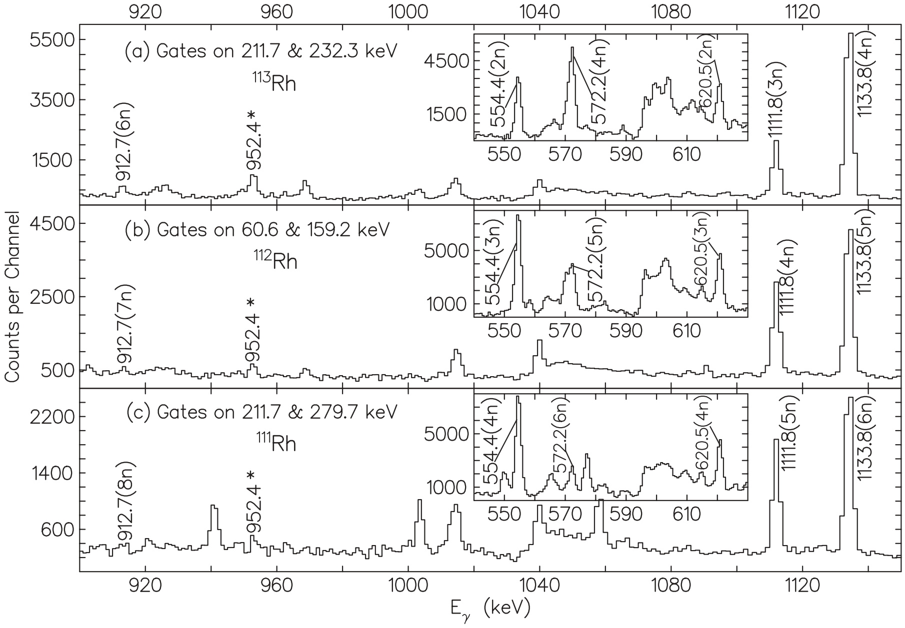

FIG. 1. Coincidence spectra double gated on transitions in $^{111-113}$Rh [12]. The xn labels indicate transitions from an I nucleus corresponding to the x neutron channel. A new transition of an energy of 952.4 keV is indicated in these spectra with an asterisk.

assignment of 4^+ [7]. A 3.8(2) min isomeric state at 316.3 keV was reported and tentatively assigned to be either a $(\pi(1g_{7/2})\nu(1h_{11/2})^{-1})_{8^-}$ or $(\pi(2d_{5/2})\nu(1h_{11/2})^{-1})_{8^-}$ state in ^{134}I [9]. The ground states of the $N = 81$ isotones ^{132}Sb ($Z = 51$) and ^{136}Cs ($Z = 55$) were reported to be $(\pi(1g_{7/2})\nu(2d_{3/2})^{-1})_{4^+}$ [1] and $(\pi(1g_{7/2})^{-3}\nu(2d_{3/2})^{-1})_{5^+}$ [14], respectively, and an 8^- isomeric state was found in both nuclei with the identical configuration of $\pi(1g_{7/2})\nu(1h_{11/2})^{-1}$ [1,15]. For ^{132}I, a 4^+ ground state and an 8^- isomeric state were reported [1]. For ^{136}I, a 1^- ground state and a 6^- isomeric state were reported [1,16] and high spin states were proposed to be built on the 7^- state [3] because the 6^- isomer is only 42.6 keV below the 7^- state [16]. Therefore, it is most likely that the observed yrast cascade in ^{134}I in the present work is built on the 316.3 keV 8^- isomeric state with a configuration of $\pi(1g_{7/2})\nu(1h_{11/2})^{-1}$. This configuration can be achieved by coupling a $\pi(1g_{7/2})$ proton from the ^{133}I ground state to a $\nu(1h_{11/2})^{-1}$ neutron from the ^{133}Te ground state. This is supported by the fact that the SF of ^{252}Cf mostly populates high spin states.

Angular correlations of the 640.2 and 952.4 keV transitions in ^{134}I were measured (see details in Ref. [17]). The measured values of A_2 and A_4 for the 640.2 → 952.4 keV cascade are −0.20(4) and −0.02(5), respectively, as shown Fig. 5. Theoretical A_2 and A_4 values of γ-γ angular correlations are $A_2 = 0.102$ and $A_4 = 0.009$ for a pure quadrupole-quadrupole cascade, $A_2 = -0.071$ and $A_4 = -0.0$ for a pure quadrupole-dipole cascade, and $A_2 = 0.05$ and $A_4 = 0.0$ for a

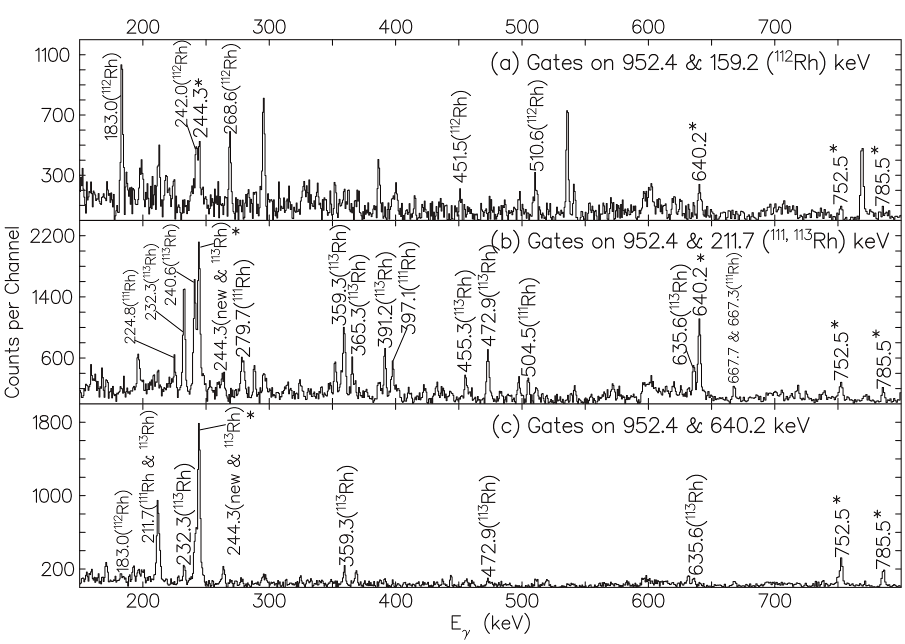

FIG. 2. Coincidence spectra double gated on the new 952.4 keV transition, on the 159.2 and 211.7 keV transitions in Rh nuclei, and on the new 640.2 keV transition. The transitions marked with an asterisk are newly identified in the present work.

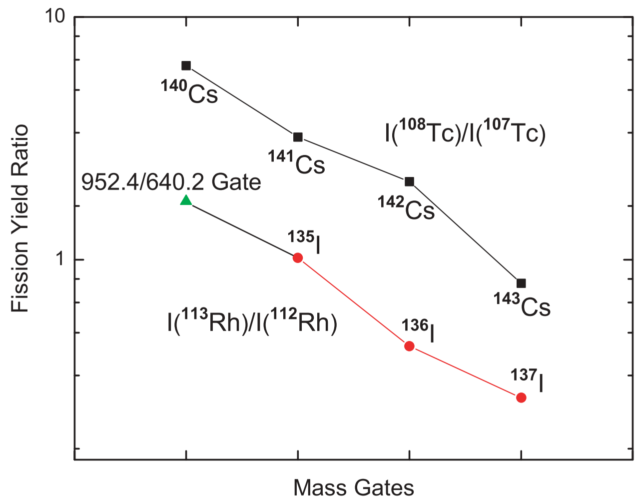

FIG. 3. (Color online) Fission yield ratios of ^{113}Rh to ^{112}Rh in $^{135-137}$I gates and in the 952.4/640.3 keV gate and those of ^{108}Tc to ^{107}Tc in $^{140-143}$Cs gates [13]. A logarithmic scale is used for the *y* axis.

pure dipole-dipole cascade [18]. Comparisons of experimental values of A_2 and A_4 for the 640.2 → 952.4 keV cascade in ^{134}I with theoretical ones listed above indicate that one or both of these two transitions are mixed.

Angular correlation measurements were also performed for transitions in ^{133}I, ^{135}I, and ^{136}I for systematic comparisons. The angular correlations for the 260.7 → 1111.8 keV cascade in ^{136}I are shown in Fig. 6 as an example. Experimental values of A_2 and A_4 for the 647.5 → 912.7 keV cascade in ^{133}I, the 288.2 → 1133.8 keV cascade in ^{135}I, and the 260.7 → 1111.8 keV cascade in ^{136}I are 0.097(9) and 0.00(1), 0.102(4) and 0.004(7), and 0.101(6) and 0.01(1), respectively. They are consistent with theoretical $A_2 = 0.102$ and $A_4 = 0.009$ for a pure quadrupole-quadrupole cascade. These data establish that the 647.5, 912.7 keV transitions in ^{133}I, the 288.2, 1133.8 keV transitions in ^{135}I and the 260.7, 1111.8 keV transitions in ^{136}I are of pure quadrupole character. This conclusion confirms the

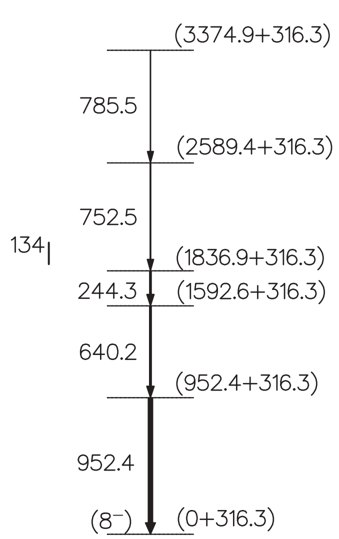

FIG. 4. New level scheme in ^{134}I identified here.

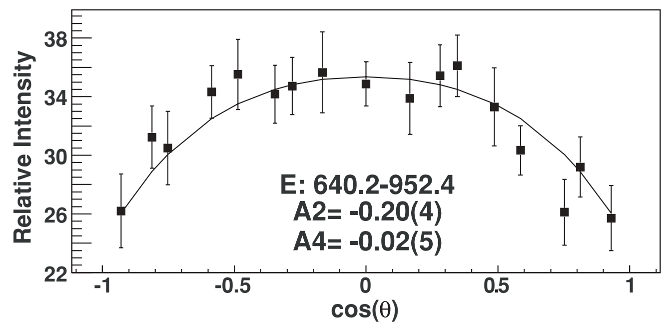

FIG. 5. Angular correlations for the 640.2 → 952.4 keV cascade in ^{134}I.

tentative spin assignments of $15/2^+ \to 11/2^+ \to 7/2^+$ to the 647.5 → 912.7 keV cascade in ^{133}I [1], $15/2^+ \to 11/2^+ \to 7/2^+$ to the 288.2 → 1133.8 keV cascade in ^{135}I [2], and $11^- \to 9^- \to 7^-$ to the 260.7 → 1111.8 keV cascade in ^{136}I [3]. However, the A_2 and A_4 values for the 640.2 → 952.4 keV cascade, and thus the multipolarities for these two transitions in ^{134}I, do not follow the trend shown in ^{133}I, ^{135}I, and ^{136}I.

To determine the spin sequence of the 640.2 → 952.4 keV cascade in ^{134}I, plots of A_2 vs A_4 using the mixing ratio δ as a parameter are shown in Fig. 7. Although the best fit for the spin sequence for the 640.2 → 952.4 keV cascade is 11 → 9 → 8 with the 952.4 keV transition mixed, 11 → 10 → 8 with the 640.2 keV transition mixed, and 10 → 9 → 8 with both the 640.2 and 952.4 keV transitions mixed, which occurs in ^{132}Sb [19], are allowed.

Since our work has been completed, we have learned that Covello and Gargano have prepared a paper on shell model calculations for ^{134}I [20]. Their results based on a realistic shell model calculation are 0 (8^-), 1022 (10^-), 1674 (11^-), 1905 (12^-), 2439 (13^-), and 3142 keV (14^-) for the level energies, which are in good agreement with all the level energies reported here with a root mean square deviation of about 100 keV. As regards the nature of the states, it turns out that they are dominated by either the proton $\pi(1g_{7/2})^3$ (8^-, 10^-, 13^-) or $\pi(1g_{7/2})^2(2d_{5/2})^1$ (11^-, 12^-, 14^-) configuration, with the neutron hole being instead stably located in the $\nu(1h_{11/2})$ orbital. So our data support their shell model calculations, which will be published elsewhere.

Some yrast excitations in $^{133-136}$I, which are near the $Z = 50$, $N = 82$ major shell closure, are presented in

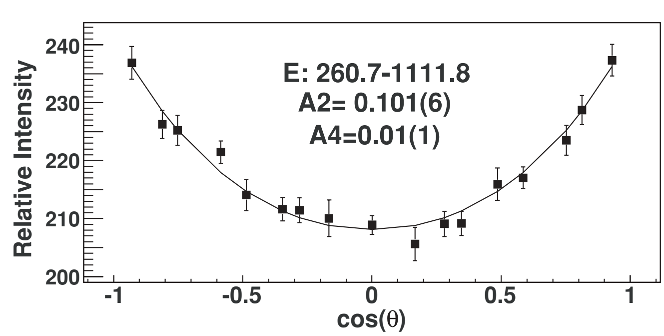

FIG. 6. Angular correlations for the 260.7 → 1111.8 keV cascade in ^{136}I.

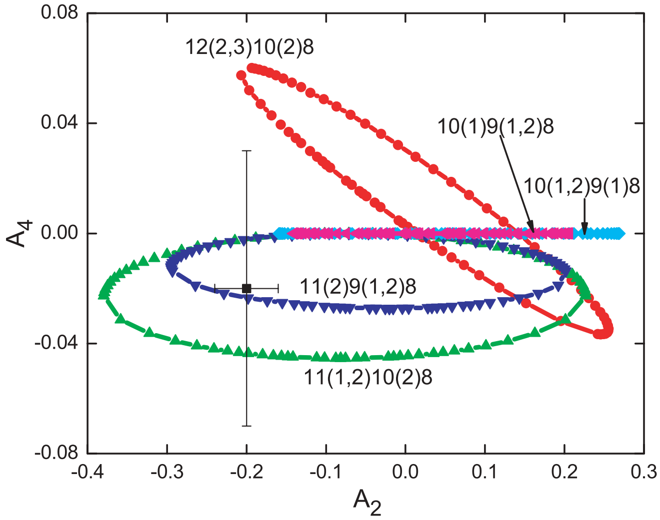

FIG. 7. (Color online) A_2 vs A_4 for selected spin sequences using the mixing ratio δ as a parameter. The experimental A_2 and A_4 values for the 640.2 → 952.4 keV cascade in ^{134}I are shown.

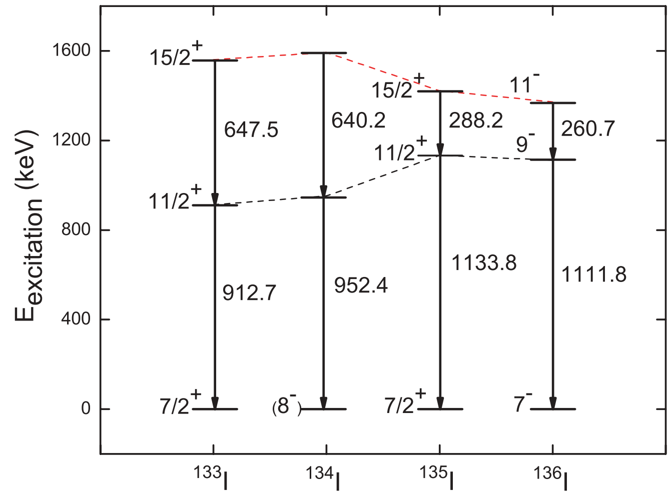

FIG. 8. (Color online) Some yrast states in $^{133-136}$I. Data are taken from Refs. [1–3] and the present work. Energies of the excited states in ^{134}I and ^{136}I are relative to the (8^-) state and the 7^- state, respectively.

Fig. 8. Their level spacings exhibit strong shell effects of the $N = 82$ neutron major shell. The systematics also supports the mass number assignment of ^{134}I and its level order.

In conclusion, from the spontaneous fission of ^{252}Cf, high spin states in ^{134}I were identified for the first time. Five levels and five deexciting transitions were observed to allow us to build the level scheme of ^{134}I up to $(3374.9 + 316.3)$ keV. The systematics of the ground and isomeric states in ^{132}I, ^{136}I, ^{132}Sb, and ^{136}Cs supports our assignment that the high spin states in ^{134}I are built on the 316.3 keV 8^- isomeric state with a configuration of $\pi(1g_{7/2})\nu(1h_{11/2})^{-1}$. Angular correlations for the 640.2 → 952.4 keV cascade in ^{134}I show a dipole-quadrupole mixture for one or both of these two transitions. The possible spin sequences for the 640.2 → 952.4 keV cascade were discussed.

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