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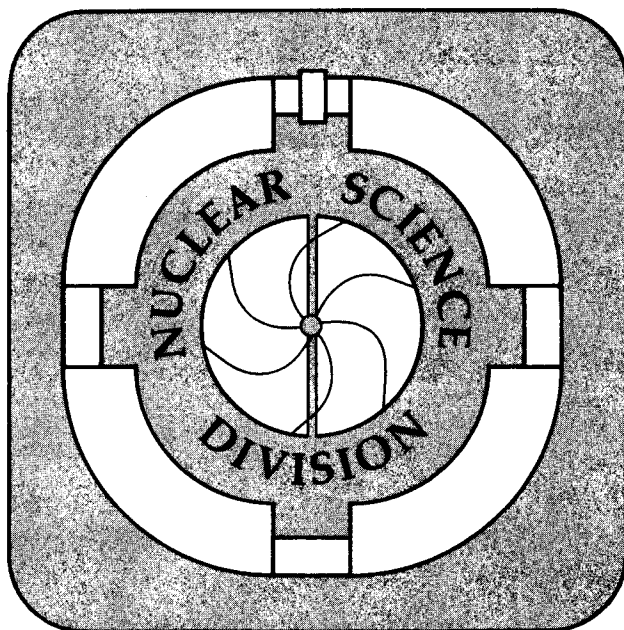
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Evidence for M1 Transitions Between Superdeformed States in ^{193}Hg

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ABSTRACT

Two-way decay has been observed between superdeformed bands in ^{193}Hg . It is proposed the decays have M1 multipolarity and connect signature partner bands. Candidates for the two-way gamma decays connecting superdeformed bands are observed for the first time.

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Superdeformed states are associated with extremely large quadrupole deformations, typically $\beta_2 \approx 0.6$ in the mass 150 region [1, 2] and $\beta_2 \approx 0.47$ in the mass 190 region [3-4]. The large quadrupole deformations enhance stretched E2 transition rates. Indeed both the mass 150 region and the mass 190 region have $B(E2)$ values [2-5] for superdeformed states which are three orders of magnitude larger than the corresponding single particle (Weisskopf) units. However, superdeformed bands around mass 190 extend to low frequencies ($\hbar\omega \sim 0.15$ MeV) and spins ($I_f \sim 8$) [6], much lower than for mass 150 nuclei. The large electron conversion coefficients associated with low energy M1 decays enhance the total M1 transition probability and the E2 transition probabilities decrease with decreasing transition energy ($B(E2) \propto E_\gamma^5$). Thus it is more likely for M1 decays to compete with stretched E2 decays, resulting in cross talk between superdeformed states.

The first evidence for transitions between superdeformed bands was in ^{193}Hg [7]. Four superdeformed bands were observed and they were assigned as, $[512]5/2$ $\alpha = -\frac{1}{2}$ (band 1), $[624]9/2$ $\alpha = \pm\frac{1}{2}$ (bands 2 and 3) and $j_{15/2}$ (band 4). Bands 1 and 3 ($\alpha = -\frac{1}{2}$) have identical transition energies at low spin. A fifth band was proposed (the 'missing' $[512]5/2$ $\alpha = +\frac{1}{2}$ band) to have identical transition energies to band 2 ($\alpha = +\frac{1}{2}$) and this will be referred to as band 2'. Band 2' would then be the signature partner to band 1. In order to clarify the ^{193}Hg superdeformed band assignments and to help prepare the way for the following discussion, a partial level scheme for bands 1, 2, 2' and 3 is shown in figure 1. In ref. [7] it was suggested that the decay proceeded from band 1 to band 3. The intensity of the cross talk was estimated to be of the order of 30% and it was proposed that the decays are E1.

In this paper we report on the first observation of two-way cross talk between superdeformed bands in ^{193}Hg . It is proposed that the cross talk comprises

of M1 transitions between superdeformed signature partner bands. In addition candidates for the M1 γ decays are presented for the first time.

Excited states in ^{193}Hg were populated by the reaction $^{176}\text{Yb}(^{22}\text{Ne},5n)^{193}\text{Hg}$ at a beam energy of 116 MeV. The gamma decay was detected using the HERA Ge detector array at the Lawrence Berkeley Laboratory 88-Inch Cyclotron. The data were sorted into an $E_\gamma - E_\gamma$ correlation matrix with the condition that at least two suppressed Ge detectors were in coincidence with a total γ ray fold of 14 and higher. Approximately 680 million events were contained in this matrix of which $\sim 60\%$ belonged to ^{193}Hg .

Figure 2a shows a γ ray spectrum in coincidence with the 353 and 391 keV transitions in bands 1 and 3.* In addition to these bands, low lying transitions (254, 295 and 334 keV) in band 2 are seen to be in coincidence with the gating transitions. It is estimated that approximately 25% of the intensity from band 1 and/or band 3 goes over to band 2 (at spin $I \approx \frac{31}{2}$).

A spectrum of superdeformed γ rays in coincidence with the 451 keV γ ray in band 2 is shown in figure 2b. Other members of band 2 can be clearly seen. However this spectrum also contains transitions with energies of 233, 274, 314 and possibly 353 keV. These transition energies correspond to known γ rays in the superdeformed bands 1 and 3. The intensity of the cross talk is of the order of 30% relative to the inband decay (at spin $I \sim \frac{29}{2}$). Furthermore, a spectrum (figure 2c) gated by the 274 keV γ ray in bands 1 and 3 not only contains all transitions from bands 1 and 3 but also contains all transitions from band 2 starting from the 334 keV γ ray and indicated in figure 2c by '*'. Note that the spectrum contains no evidence for a 254 or 294 keV superdeformed transition (band 2). This is consistent with bands 1 and 2' and/or bands 3 and 2 being

*It is not possible to say whether the decay is from band 1, band 3 or both since the γ rays from these bands are identical (to within 0.5 keV) below 430 keV.

strongly coupled signature partner bands (figure 1). These observations (figures 2a-c) suggest that not only is there evidence for decays from the $\alpha=-\frac{1}{2}$ to the $\alpha=+\frac{1}{2}$ structure (as observed by Cullen *et al.* [7]), but also from the $\alpha=+\frac{1}{2}$ to the $\alpha=-\frac{1}{2}$ structure. This is the first time that two-way cross talk has been reported between superdeformed bands.

Two-way cross talk, as observed in these data, implies little or no energy splitting between the connecting bands. Since it is proposed [7] that both positive and negative parity superdeformed bands exist, it is possible the decay may be either E1 or M1. Collective low energy E1 transitions between rotational bands of alternating parity may occur [8-10] in the presence of stable octupole deformations. However, ^{193}Hg is not expected [7] to exhibit stable octupole deformations. It is therefore suggested that in this case (^{193}Hg) two-way cross talk would most likely indicate the presence of M1 decays.

Calculations [11], specific to ^{193}Hg , have shown that M1 cross talk of the order of 25% is not unreasonable for the proposed configurations (namely [512]5/2 and [624]9/2). The possibility that the one-way cross talk observed [7] in ^{193}Hg was more likely to be M1 than E1 was first mentioned in ref. [12].

Assuming bands 1 and 2' and/or bands 3 and 2 are strongly coupled [7], it is possible to predict the transition energies expected for M1 decays between the signature partner bands. For superdeformed states in the spin range $\frac{21}{2} - \frac{37}{2}$ the M1 energies range from 111 to 192 keV and are separated by approximately 10 keV (figure 1). Figure 3 is a sum of gates on the 254 and 451 keV transitions in band 2 and the 353 and 391 keV transitions in bands 1 and 3. The known superdeformed γ rays from bands 1, 2 and 3 are indicated. In addition, at low frequencies there is evidence for a series of very weak γ rays at the energies one calculates for M1 transitions (the 162 keV γ ray is missing and this may be due

to a large γ ray at 160 keV causing this region of the spectrum to go negative following background subtraction). The average γ ray intensity for these low energy transitions is 14(4)% of the 413 keV γ ray intensity (100% of band 2). It is clear the sequence of transitions from 140 to 181 keV (and possibly 192 keV)[†] are very weak. However, two-way cross talk is observed between bands (figures 2a-c) and the energies of the transitions indicated in figure 3 are, within errors, exactly those one would expect for M1 decays (figure 1). Therefore, we propose these γ rays correspond to M1 decays between superdeformed signature partner bands. In addition, the intensity for the proposed γ decay, compared with the total cross talk intensity, is consistent with M1 decay. That is, the ratio of the measured γ ray intensity to the total M1 decay intensity is approximately $\frac{1}{3}$ (due to ce^- decay) whereas the ratio of γ ray to total E1 decay intensity would be closer to 1 (very little ce^- decay).

If it is assumed that ^{193}Hg has the same quadrupole moment as ^{192}Hg (20eb), then from the measured branching ratios ($\frac{\Delta I=1}{\Delta I=2}$) one estimates the B(M1) strength to be of the order of $0.5\mu_N^2$ (for the [512]5/2 and the [624]9/2 levels, ref. [11] calculates B(M1) values of 0.5 and $1.0\mu_N^2$ respectively). Furthermore from the measured branching ratios it is also possible to calculate the expected K_α X ray yield due to ce^- decays. For M1 transitions in the energy range 111 to 181 keV, one obtains a K_α X ray yield of approximately 0.8 ± 0.2 per cascade (for E1 decays this value drops to 0.2 ± 0.06). In ref. [13] a K_α X ray yield of (1.3 ± 0.4) was measured for band 1 in ^{193}Hg . It is clear that any significant difference between our calculated value (0.8), based on the measured branching ratios, and the measured value (1.3) could easily be due to M1 decays between superdeformed transitions which we do not observe.

[†]A superdeformed γ ray at 193 keV has been assigned [7] as the lowest transition in band 1. The transition at 192 keV, if M1, would correspond to the de-excitation of the $\frac{37}{2}$ state in band 2.

Due to the very small intensity of the superdeformed bands (1-2% of the ^{193}Hg channel [7]) it was not possible to decompose the cross talk into contributions from either pair of assumed signature partner bands ($[512]5/2$ or $[624]9/2$). Neither was it possible to rule out the hypothesis that one-way E1 cross talk may also proceed from band 1 ($[512]5/2$ $\alpha=-\frac{1}{2}$) to band 2 ($[624]9/2$ $\alpha=+\frac{1}{2}$) as proposed by Cullen *et al.* [7].

In summary, the data presented here confirm the existence of cross talk between superdeformed bands. Unlike previous experiments the decay is observed both ways, indicating the presence of M1 transitions. Furthermore, a series of low energy γ ray transitions has been identified and it is suggested that these correspond to the M1 decays between superdeformed bands.

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Figure Captions.

Figure 1. Schematic partial level scheme for the proposed signature partner bands in ^{193}Hg . Following ref. [7] we assume that there are two pairs of strongly coupled bands based on the two configurations, $[512]5/2$ and $[624]9/2$. The two pairs of bands are 'identical' up to the spins shown. Note that bands 2 and 2' are not resolved and the single rotational sequence observed experimentally is assumed to be two bands. Also shown are M1 decays which may be expected to connect the signature partner bands. The M1 energies are calculated in the limit that the bands are strongly coupled. The spin assignments were derived from a fitting procedure and taken from ref. [6].

Figure 2. (a) Spectrum of superdeformed transitions in coincidence with the 353 and 391 keV γ rays in bands 1 and 3. Transitions in bands 1 and 3 are labeled by energy and band assignment. Below 392 keV bands 1 and 3 are identical, at higher energies the bands diverge and they are easily resolved. The γ rays marked with '*' correspond to known transitions in band 2. The insert is a section of the same spectrum expanded. (b) Spectrum of superdeformed transitions in coincidence with the 451 keV γ ray in band 2. Transitions in band 2 are labeled by energy. The γ rays marked with '*' correspond to known transitions in bands 1 and 3. The insert is a section of the same spectrum expanded. (c) Same as 2a, except the gating transition is now the 274 keV γ ray in bands 1 and 3. Transitions in bands 1 and 3 are labeled by energy and band assignment. The γ rays marked with '*' correspond to transitions in band 2. The lowest γ ray in band 2 ('*') is at 334 keV and the highest at 661 keV.

Figure 3. Spectrum in coincidence with the 254 and 451 keV transitions in band 2 and the 353 and 391 keV transitions in bands 1 and 3. Transitions in bands

1, 2 and 3 are labeled by energy and band assignment. The γ rays marked with '*' correspond to energies where one would expect to see M1 γ rays decaying between the two pairs of strongly coupled superdeformed signature partner bands (assumed to be based on the [512]5/2 and [624]9/2 orbitals). The insert shows the total projection spectrum. The positions of the proposed M1 decays are indicated (*').

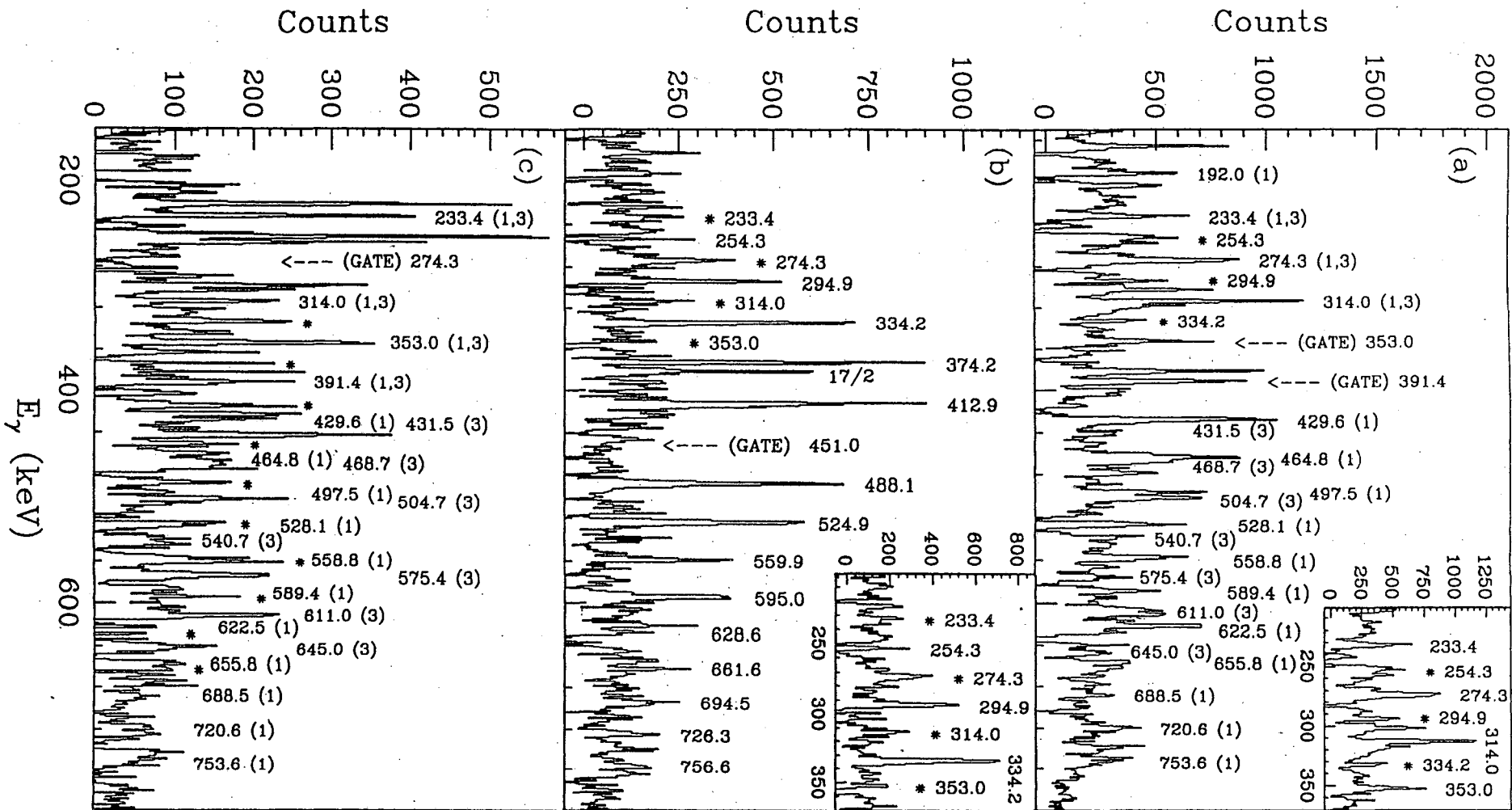
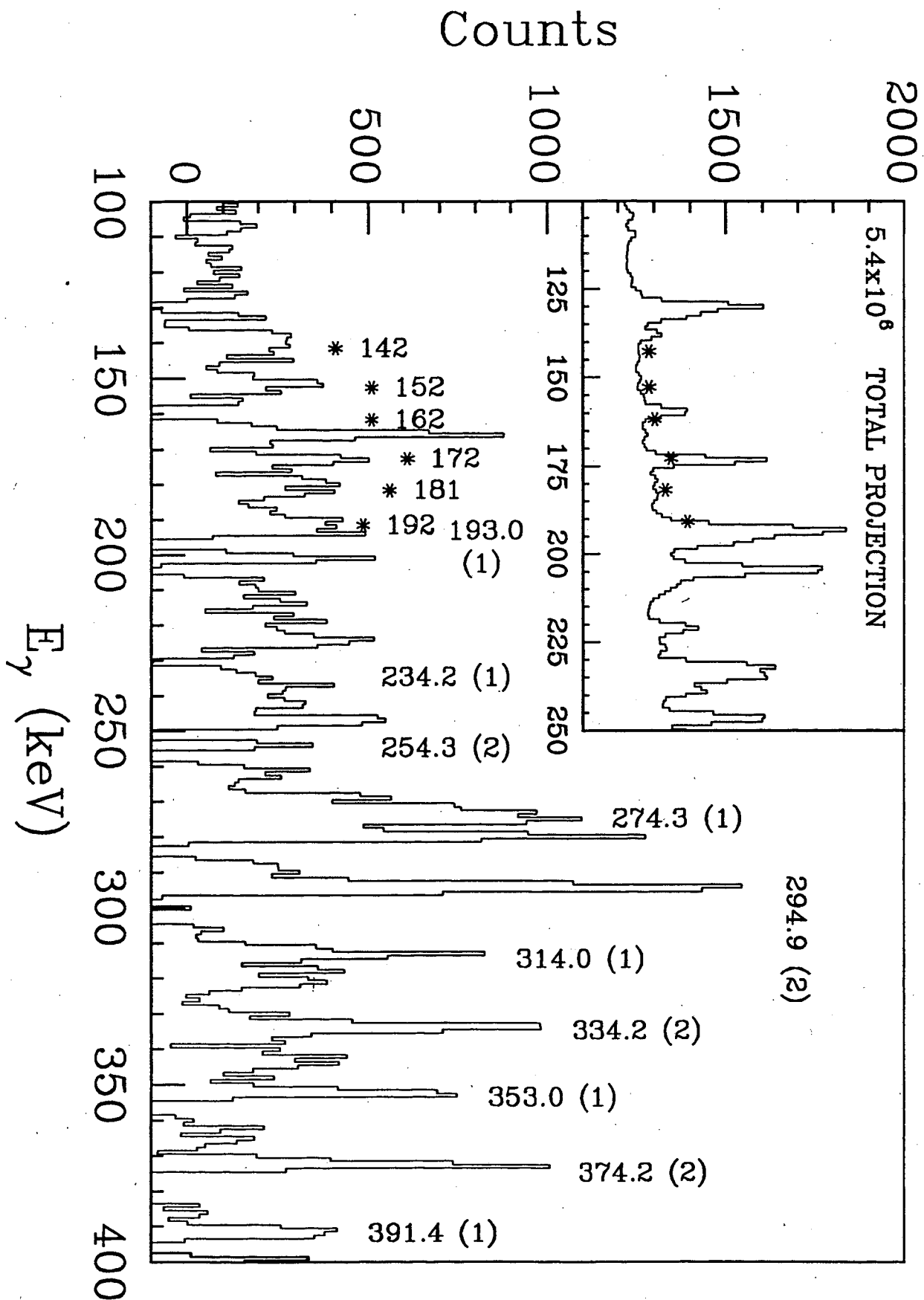


FIGURE 2



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