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An experiment was performed to measure the lifetimes of the states in the superdeformed band reported in ^{192}Pb. No evidence for such a band was found, despite the fact that the experimental conditions were nearly identical to those of an earlier measurement where this band was proposed. The problems and questions encountered in the analysis are described. The arguments presented here indicate that further measurements are needed to establish the existence of a superdeformed band in this nucleus unambiguously.

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The discovery of superdeformation (SD) in ^{191}Hg [1] prompted extensive studies of this phenomenon in the mass region near $A=190$. SD bands have since been established in $^{189-194}$Hg [2], $^{191-195}$Tl [2–4], and ^{194,196,198}Pb [5–7]. The properties of these bands, such as the increase in the dynamic moment of inertia with spin, the collectivity of the states involved as deduced from the $E2$ transition moments, the occurrence of excited bands, and the presence of bands with identical transition energies in nuclei differing by 1 or 2 mass units, have been reviewed in Ref. [2] together with possible theoretical interpretations.

It is interesting to study the lighter isotopes to determine the behavior of the SD minimum as a function of neutron number for $Z>80$. To this end, Henry *et al.* [8] studied the nucleus ^{192}Pb and proposed a SD band which consists of 11 transitions with γ-ray energies as listed in Table I. In the experiment of Ref. [8], the ^{173}Yb(^{24}Mg,5n) reaction was used at beam energies of 128 and 132 MeV. The target consisted of a stack of three ^{173}Yb foils of approximately 0.5 mg/cm^2 thickness. The data were taken with the HERA array. Further details can be found in Ref. [8].

In this work, we present the results of an experiment performed at the superconducting linear accelerator facility, ATLAS, at the Argonne National Laboratory, with the intent to measure the lifetimes of the states of the proposed SD band in ^{192}Pb. The results presented in Ref. [8] could not be reproduced in the present experiment, raising questions about the existence of a SD band in ^{192}Pb.

The measurements described here were performed under essentially the same conditions as those used in Ref. [8] with the Argonne–Notre Dame BGO γ-ray facility consisting of 12 Compton-suppressed Ge (CSG) spec-

TABLE I. The transitions in the proposed superdeformed band [8] compared to close-lying transitions of ^{192,193}Pb and $^{189-191}$Hg (see text for details).

	Possible contaminants					
E_γ^{a} (keV)	E_γ (keV)	Nucleus[b]	$I_i\to I_f$	E_γ (keV)	Nucleus[b]	$I_i\to I_f$
262.6	260.2	^{189}Hg	$\frac{23}{2}^-\to\frac{21}{2}^-$	261.5	^{190}Hg	$10^+\to9^-$
	263.4	^{190}Hg	$16^-\to14^-$			
304.1	305.4	^{190}Hg	$7^-\to6^+$			
345.6						
385.6	381.7	^{193}Pb	$\frac{31}{2}\to\frac{29}{2}^-$	382.8	^{192}Pb	$8^+\to6^+$
	383.2	^{190}Hg	$19^-\to17^-$	383.8	^{192}Pb	$21\to20^{(+)}$
	388.6	^{190}Hg	$10^-\to9^-$			
424.4	416.5	^{190}Hg	$2^+\to0^+$	416.7	^{192}Pb	$20^+\to18^+$
	420.0	^{190}Hg	$14^+\to12^+$			
462.8	463.4	^{192}Pb	$7^-\to5^-$	465.6	^{189}Hg	$\frac{31}{2}^-\to\frac{27}{2}^-$
	466.2	^{191}Hg	$\frac{21}{2}^-\to\frac{19}{2}^+$			
500.0	500.9	^{191}Hg	$\frac{41}{2}^+\to\frac{37}{2}^+$	501.8	^{192}Pb	$4^+\to2^+$
535.1	530.0	^{190}Hg	$11^-\to9^-$	530.9	^{192}Pb	$12^{(+)}\to11^-$
	534.2	^{192}Pb	$13^-\to11^-$	535.5	^{191}Hg	$\frac{15}{2}^+\to\frac{13}{2}^+$
	537.0	^{192}Pb	$15^{(-)}\to14^+$	537.2	^{192}Pb	$14^{(-)}\to12^{(-)}$
570.6	565.3	^{192}Pb	$6^+\to4^+$	566.0	^{190}Hg	$22^+\to20^+$
	566.9	^{189}Hg	$\frac{33}{2}^-\to\frac{29}{2}^-$	569.9	^{192}Pb	$9^-\to7^-$
	572.1	^{192}Pb	$14^-\to12^-$			
604	599.3	^{192}Pb	$8^+\to6^+$			
636	633.9	^{190}Hg	$12^-\to10^-$	636.6	^{189}Hg	$\frac{19}{2}^+\to\frac{15}{2}^+$

[a]From Ref. [8].
[b]The transitions of $^{189-191}$Hg were obtained from Ref. [11], those of ^{192}Pb and ^{193}Pb are obtained from Refs. [10,12].

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trometers and an inner array of 50 BGO elements. A notable exception is that a 0.9-mg/cm^2-thick ^{173}Yb target evaporated onto a 15-mg/cm^2-thick ^{nat}Pb backing was used to stop the recoiling nuclei. In principle, such a target allows the measurement of the lifetimes of SD states by means of the Doppler-shift attenuation method (DSAM), as has been demonstrated recently by Moore *et al.* [9] for ^{192}Hg. A beam energy of 132 MeV was chosen, since the production of ^{192}Pb was found to dominate at this energy [8]. Statistical model calculations indicate that with this reaction and beam energy the population of high-spin states in ^{192}Pb is enhanced. These calculations and other features of the experiment are described more completely in Ref. [10]. γ-ray events were recorded under the condition that at least two CSG spectrometers and two BGO elements fired in coincidence. In total 81×10^6 such events were recorded.

The statistical model calculations indicate also that the yield of the other evaporation products is spread over several channels, including some involving charged-particle emission. This feature is clearly corroborated by the data since the residual nuclei ^{189,190}Hg and ^{193}Pb are produced with significant strength via the reactions ^{173}Yb(^{24}Mg,α3,4n) and ^{173}Yb(^{24}Mg,4n), respectively. Most transitions placed [11,12] in the level schemes of these nuclei were identified in the present measurement.

The energies of the transitions in the proposed SD band [8] in ^{192}Pb are compared with possible "contaminant" γ rays originating from $^{189-191}$Hg [11], ^{193}Pb [12], and ^{192}Pb [10] in Table I. It is apparent from this table that all transitions of the band, with the exception of the 346-keV γ ray, have close-lying contaminants either at the nominal γ-ray energies or at the fully Doppler-shifted energies, i.e., at energies corresponding to γ rays emitted by residual nuclei in flight ($\beta_{recoil}=0.011$) and detected at backward angles (145.5°). This is especially noteworthy since the contaminant transitions belong mainly to the two strongest evaporation residues populated in this reaction, i.e., ^{192}Pb and ^{190}Hg.

The use of stringent windows on the prompt γ-ray fold measured in the inner BGO array was contemplated in order to remove as many unwanted contaminants as possible, particularly those belonging to the Hg isotopes. Unfortunately, the fold distributions of prompt γ rays measured in coincidence with known transitions in the nuclei of interest (cf. Fig. 1) reveal that little distinction is possible on this basis. This is mainly due to the fact that the presence of isomeric states in many of the nuclei produced in the reaction alters the expected multiplicity distributions and, in effect, squeezes them within a narrow set of values. For example, the fold distributions peak at 8 for ^{189}Hg [Fig. 1(a)] and 10 for ^{190}Hg [Fig. 1(b)]. The distribution for ^{192}Pb peaks around 8 when measured in coincidence with a transition below the yrast $J^\pi=10^+$ and 12^+ isomers [Fig. 1(c)], whereas it peaks around 10 when in coincidence with a transition bypassing these isomers [Fig. 1(d)]. Several E_γ-E_γ coincidence matrices were updated under the condition that the measured prompt fold be at least 8, 10, or 12. It should be noted that, in view of the distributions presented here, the selection of very high prompt folds as done in Ref. [8] would result in an enhanced yield of γ rays from ^{190}Hg relative to ^{192}Pb.

To illustrate the problems encountered in the search for the proposed SD band we present in Fig. 2(a) the spectrum obtained in coincidence with the 346-keV transition from the matrix updated under the condition of a minimum prompt fold of 8. Only γ rays detected in the Compton-suppressed germanium detectors located at backward angles contribute to this spectrum. The labels in this figure correspond to the γ-ray energies quoted in Ref. [8] for γ rays emitted from nuclei stopped in the target and for the corresponding γ rays emitted from nuclei with the full recoil momentum. In this spectrum there is no trace of a 263-keV γ ray, and the 304-keV line is very weak, if present. An indication for a coincident 386-keV γ ray is present, while the 424-keV line is, in comparison, rather strong. A transition can also be found at the posi-

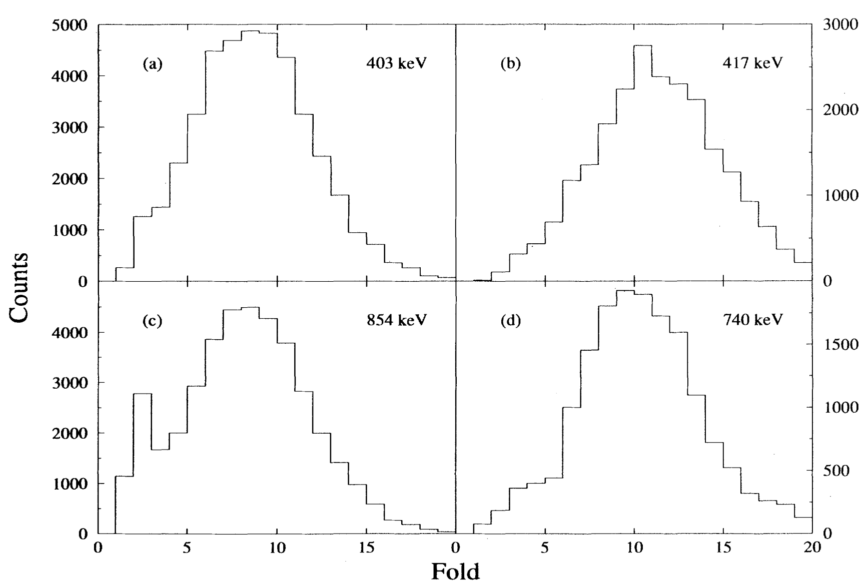

FIG. 1. Prompt-fold distributions observed in coincidence with (a) the 403.0-keV ($\frac{17}{2}^+\rightarrow\frac{13}{2}^+$ in ^{189}Hg), (b) the 416.5-keV ($2^+\rightarrow0^+$ in ^{190}Hg), (c) the 853.8-keV ($2^+\rightarrow0^+$ in ^{192}Pb), and (d) the 739.9-keV ($11_2^-\rightarrow9^-$ in ^{192}Pb) γ rays.

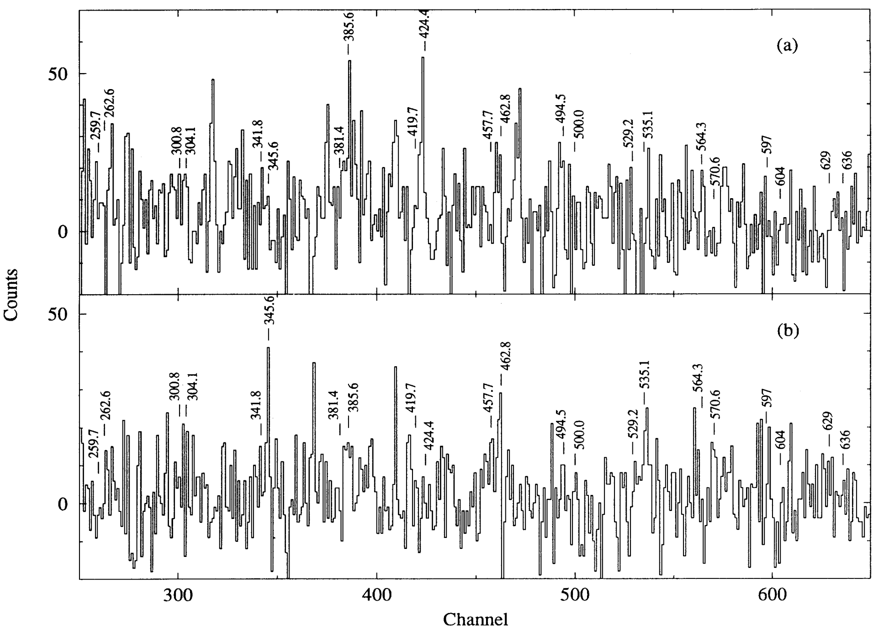

FIG. 2. Coincidence spectra generated for Compton-suppressed Ge spectrometers located at 145.5° by requiring a prompt fold of at least 8 and a coincidence with (a) the 346-keV and (b) the 424-keV transitions, respectively.

tion of the 463-keV γ ray emitted by a stopped nucleus. No evidence for a γ ray at 500 keV or at 535 keV, with or without a Doppler-broadened shape, could be obtained, nor is there any evidence for the lines with higher E_γ. A similar spectrum obtained by requiring a coincidence with the 424-keV line is shown in Fig. 2(b). Again, very weak coincident γ rays may be present at 263 and 304 keV, while a stronger peak is present at the next expected energy (346 keV). The 386-, 500-, 604-, and 636-keV transitions, however, either are very weak or are obscured by contaminants. The remaining evidence for possible members of this band consists of peaks at $E_\gamma = 535$ and 571 keV, assuming that the γ rays are emitted by a stopped nucleus. We note that the strongest peaks present in both spectra of Fig. 2 can be attributed to transitions in ^{190}Hg.

In the detailed analysis, the coincidence spectra were gain matched on transitions emitted from stopped nuclei before being inspected carefully for every proposed transition. This was done for spectra recorded at forward and backward angles with the three conditions on the fold distribution mentioned above. Furthermore, to obtain the maximum statistical accuracy, these gain-matched spectra were added. Although the lowest six transitions in the proposed superdeformed band should appear at the position corresponding to emission from stopped nuclei, none were observed. Attempts were also made to enhance the possible signal of a SD band by subtracting spectra registered at forward and backward angles from each other. This method, introduced in Ref. [13], has been applied successfully in the case of the SD band of ^{152}Dy [14]. The results of all these efforts can be summarized as follows.

(1) Despite extensive analysis, no sequence of transitions could be identified that can be associated with the SD band reported in Ref. [8]. While some of the reported transitions seem to be present in some of the coincidence spectra, none of them appear consistently in all spectra. When transitions are present they can usually be understood as resulting from coincidence relationships expected from contaminant transitions in ^{190}Hg and/or ^{192}Pb (see Table I).

(2) When present, the reported transitions mostly appear to have energies corresponding to emission from stopped nuclei. Furthermore, no evidence for Doppler-broadened line shapes could be found.

(3) All spectra contain numerous other peaks, which again can be understood on the basis of coincidence relationships expected from the contaminants listed in Table I.

It must, therefore, be concluded that the presence of the reported SD band for ^{192}Pb cannot be confirmed from the present analysis.

Despite the above, we can generate a sum spectrum in which all the transitions of interest appear (together with much stronger contaminant peaks), but again with the γ-ray energies, corresponding to emission from a stopped nucleus. It is even possible to derive an intensity pattern similar to the one presented in Ref. [8]. This illustrates that the complexity of the spectra can inadvertently lead to a coincidence spectrum with a fairly regular intensity pattern.

To summarize, the present data provide no consistent evidence for the presence of the SD band in ^{192}Pb proposed in Ref. [8] even though the experimental conditions are essentially identical in the two experiments. It is conceivable that the use of a thick target in the present work has contributed to the negative result. Indeed, in the thin target experiment most isomeric decays occur outside the focus of the germanium detectors. This results in γ-ray spectra with fewer lines and possibly with a reduced number of contaminants. It is also possible that the capability of double gating in the experiment performed in Ref. [8] with the HERA array results in a gain in detection sensitivity. The latter gain is offset, however, to a large degree by the better Compton suppression achieved with the Argonne–Notre Dame BGO γ-ray facility. In fact, the two instruments have been found to have comparable capabilities in many other experiments (e.g., Refs. [15,16]). Furthermore, some of the problems uncovered in the present analysis must have been present in the work of Ref. [8] as well. For example, the Hg isotopes, which appear to play a rather significant role in the thick target experiment, must have been equally bothersome in the thin target data since long-lived isomeric states play only a minor role for these nuclei. Furthermore, as indicated in Table I, some of the proposed transitions of the SD band are very close in energy to transitions between normal states in ^{192}Pb. The presence of some yrast transitions in ^{192}Pb in the spectrum in coincidence with the proposed SD transitions in Ref. [8], therefore, cannot be regarded as a proof *per se* that the proposed band has to be assigned to ^{192}Pb. The present data show that the population of a possible SD band in ^{192}Pb with the transition energies of Ref. [8] must be extremely small (an upper bound of 0.2% of the $2^+ \rightarrow 0^+$ transition of ^{192}Pb is derived from our experiment). It is doubtful that a band with such a weak intensity can be observed with present-day detection systems. The arguments presented here indicate that further measurements are needed to establish the existence of a superdeformed band in this nucleus unambiguously. Further such searches may have to await more powerful instruments such as EUROGAM [17], GASP [18], or GAMMASPHERE [19]. It is felt that the use of the reported SD band in ^{192}Pb for the study of systematics concerning superdeformation in this mass region is somewhat premature.

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