SOME NEW RESULTS FROM GAMMASPHERE*

R.M. Diamond

Nuclear Science Division
Lawrence Berkeley National Laboratory
Berkeley, California 94720, USA

(Received December 8, 1995)

Several Gammasphere experiments of the past year are presented to illustrate advantages of the increased sensitivity of the new arrays. These involve lifetimes of superdeformed bands, their configurations, enlarging the superdeformed regions, and searching for hyperdeformation.

PACS numbers: 21.10.-k

Before discussing some recent experiments at Gammasphere, I should say a few words about the instrument itself. It was designed as an array of 110 Ge detectors, each individually suppressed by a BGO shield. The plan was to build it in two steps. First the Early Implementation (EI) mode, employing the existing HERA electronics with up to 30 of the new detectors as they arrived, so as to start experiments as soon as possible and to be able to test the prototype electronic modules in actual beam operations. This EI phase started taking data in March, 1993, and within a few months had its full complement of detectors, which then grew to 36: 15 forward at 17°–37°, 15 backward at the corresponding angles, and then 6 more at 90°. During the slightly less than two years that it existed, 60 experiments were performed with over 4200 hours of beam on target. Then a major change occurred; in October and November, 1994 the EI frame was replaced by two translatable and rotatable hemispheres. In December, 1994 we still used the old electronics, but in January and February the new VXI electronics was brought on. Another change that took place last Fall was the switch from the usual cylindrical Ge detectors to ones segmented into two halves lengthwise. This increase in granularity was to reduce the angular width of the detectors mounted between 50 and 130 degrees with respect

* Presented at the "High Angular Momentum Phenomena" Workshop in honour of Zdzisław Szymański, Piaski, Poland, August 23–26, 1995.

to the beam, so that the Doppler broadening of γ rays emitted by recoiling nuclei would reduced. We now have 23 of them and they are operating well. This (full implementation) mode of Gammasphere has been going since March, 1995, with 55–59 detectors. Through August there were 18 experiments performed, with 1829 hours on target, 101 hours of tuning, and 21 hours lost. A total of 73 users were involved, 74 % form U.S. National Labs, and U.S. universities, and 26 % from England, Canada, France, Korea and Sweden.

The experiments performed this past year can be grouped rather arbitrarily under seven headings: superdeformed (SD) bands, hyperdeformed (HD) bands, normal deformed (ND) bands, neutrino-rich nuclei, electroweak coupling constant, continuum region, shears bands. It is not possible to cover all these topics in a reasonable time, nor do I have the knowledge. Since most of the recent experiments involved superdeformation, that is what I shall discuss today. But tonight Prof. Fossan will give you examples of interesting intruder bands, and tomorrow Dr Winchell will tell you about a new region of superdeformation around mass 80 and I shall discuss some new experiments aimed at hyperdeformation.

The experiments on SD bands can also be broken into subtopics: identical bands, C_4 bands, linking transitions and decay modes, quadrupole moments (lifetimes), shell structure (configurations), expansion of the regions of SD. I shall give examples of the last three topics.

One of the most important parameters of a SD band is its deformation. This is usually derived from the quadrupole moment, which is determined by measuring the lifetimes of the states by Doppler-shift techniques. But now with the increased resolving power of the new arrays, several SD bands (yrast and excited) can be studied in a single nucleus or in neighboring nuclei in the same bombardment. This procedure eliminates errors (typically 10–20 %) from different treatments of stopping powers and side-feeding which characteristically occur when Doppler-shift experiments on different bands are studied by different groups using different programs, and are then compared. Also, if one obtains sufficient statistics, the nature of the side-feeding can be studied and its effect minimized by gating from above; up to now there has been little information on this subject. Finally, one can then make direct comparisons of the deformations of the different configurations in one nucleus, or in the bands of the different nuclei produced in the same bombardment, with errors as low as 5 %, although the absolute magnitude can still be wrong by 10–15 %. One can perhaps then answer questions such as: Does the addition of a high-j, low-Ω nucleon have a significant polarizing or shape-driving effect? How stable is the second minimum with respect to different particle configurations? Do identical bands in different nuclei have the same deformation?

An experiment of this type was reported last year at the Berkeley Conference by Ward and collaborators [1]. They measured the lifetimes in the two yrast SD bands of ^{131,132}Ce in a single experiment, and obtained a β_2 difference of 8 ± 7 %, concluding that the addition of a second $i_{13/2}$ neutron had little effect. An Anglo–American collaboration [2] has extended this study of five bands in ^{131,132}Ce (two yrast and three excited), populated simultaneously in the reaction ^{100}Mo(^{36}S, xn) at 155 MeV. This experiment was the second run with the new Gammasphere frame and electronics, done in March, 1995. There were 55 detectors (18 forward, 30 backward, 7 at 90°). The target was a 0.60 mg/cm^2 foil on 12 mg/cm^2 Au backing. About 9×10^8 events were obtained after setting a prompt time gate, and the yields of the mass 132:131 channels were 3:2. An example of the forward and backward spectra obtained is given in Fig. 1, as well as intensity profile typical for these Ce SD bands (and most other SD bands, except ^{131}Ce EX1, see later) with little side-feeding below $\sim$1200 keV. So two sets of centroid analyses were done; one with gates set above $\sim$ 1150 keV to reduce the effect of side-feeding (eliminates side-feeding below each gate), and another with gates set below $\sim$ 1150 keV to include side-feeding. An example of the experimentally deduced curves of $(\langle v \rangle / v_i)$ or $T(\tau)$ *vs.* transition energy from the first type of analysis (gated high) is shown in Fig. 2 for the two yrast bands, along with two curves calculated using the stopping powers of Ziegler and Chu [3] for quadrupole moments of 8.4 and 6.4 eb that bracket the experimental ones. It can be seen that the experimental curves are very similar. The same is true for all three ^{132}Ce SD bands. The quadrupole moment, Q_t, that gives the best calculated fit to the experimental $F(\tau)$ curve is determined from a plot χ^2 *vs.* the Q_t used in the calculated curve (as illustrated in Fig. 3(b)). The resulting best-fit values are given in Table I. All are very similar and close to 7.4 eb except for ^{131}Ce Ex1. It has the higher value, 8.5 eb, and has the odd intensity profile of roughly constant intensity after the first transition observed, hence no side-feeding. We do dot understand the cause of either of these features. Now consider the effect of side-feeding in the other SD bands. Compare $F(\tau)$ curves gated high and gated low, Fig. 3(a). The low-gated curves (for all but ^{131}Ce Ex1) fall below the high-gated ones. So side-feeding is slower than the main feeding, as shown more clearly in Fig. 3(b). It turns out to be 3–4 times slower for the yrast band in ^{131}Ce (and the effect observed is a lower limit as there is still some side-feeding include above the individual gates). Finally, it remains to be seen whether the second minimum on other mass regions is as rigid, as little polarized by a high-j particle, as in these examples.

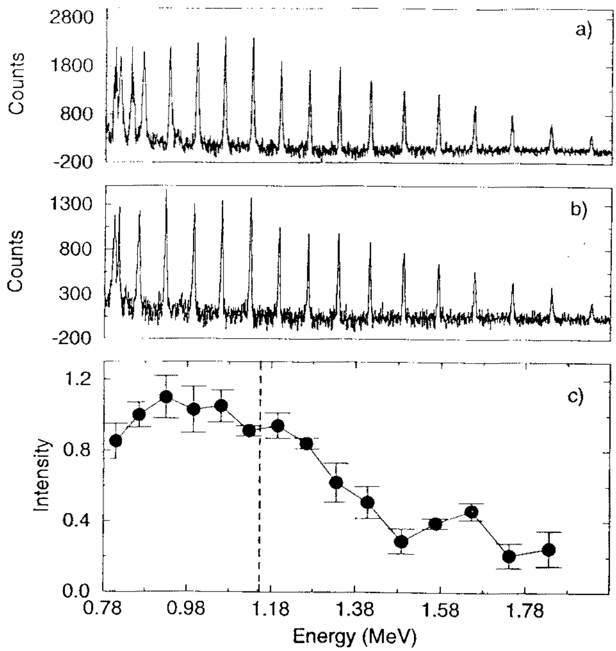

Fig. 1. a) Backward and b) forward spectra from sum of doubly-gated spectra for ^{132}Ce yrast; c) relative intensity profile for ^{132}Ce yrast band from doubly-gated triples cube; dashed line at 1150 keV indicates division into gated-high and gated-low regions.

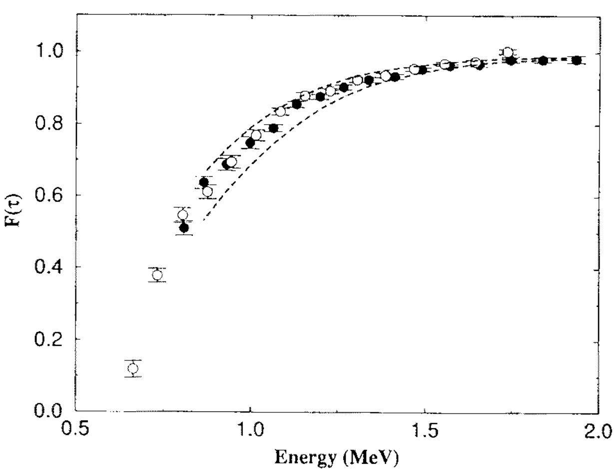

Fig. 2. Experimentally deduced (gated high) $F(\tau)$ or $\langle v \rangle / v_{\text{initial}}$ *vs.* E_γ curve for ^{131}Ce yrast band, ∘, and ^{132}Ce yrast, •. Dashed curves are calculated for $Q_t = 8.4$ and 6.4 eb, using [3].

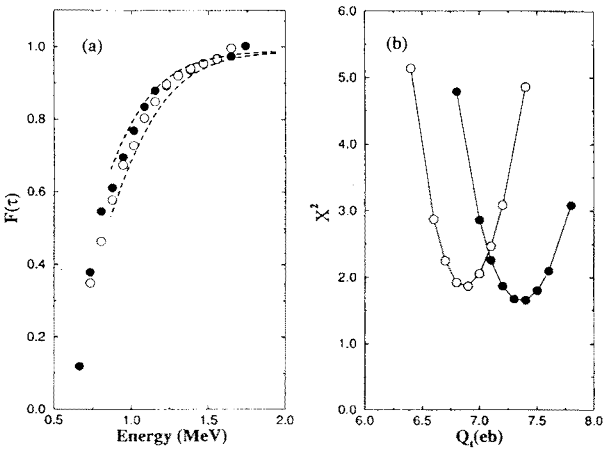

Fig. 3. (a) $F(\tau)$ *vs.* transition energy curves for ^{131}Ce yrast band gated high, •, and gated low, ∘. Dashed curves are calculated $Q_t = 8.4$ and 6.4 eb; (b) plots of χ^2 *vs.* Q_t for fits of the experimental $F(\tau)$ *vs.* E_γ curves calculated for the values of Q_t given as abscissa.

TABLE I

Experimental Quadrupole Moments

^{131}Ce Band	Q_t (eb)	^{132}Ce Band	Q_t (eb)
Yrast	7.4(3)	Yrast	7.4(3)
Ex1	7.3(4)	Ex1	8.5(4)
Ex2	76.(4)		

Another class of new results possible with the increased sensitivity of Gammasphere is the enlargement of the regions of superdeformation. An example is the discovery of a SD band in ^{154}Er [4]. No SD band in the mass-150 region had been observed previously with a Z greater than 66, Dy, although total Routhian surface (TRS) and cranked-Hartree–Fock calculations [5, 6] had predicted a well-developed second minimum for a number of such nuclei, including ^{154}Er, an isotone of ^{152}Dy, at or above a rotational frequency of 0.5 MeV and with a deformation of $\beta_2 \sim 0.61$. The experiment, a collaboration of LLNL, LBNL, and Rutgers U., was done during the EI stage of Gammasphere, with 36 Ge detectors. A target of two self-supporting 0.50 mg/cm^2 ^{118}Sn foils was bombarded with a 185-MeV ^{40}Ar beam. Of order 1.5×10^9 events were recorded on magnetic tape with a trigger condition of 3 or more suppressed, coincident Ge signals. The most intense evaporation residue was ^{154}Er. A band was found consisting of 13 mutually coincident transitions with dynamic moments of inertia, $J^{(2)}$, characteristic of the known SD bands in this mass region. A sum of spectra triple-gated on these lines is shown in Fig. 4, where the band is marked by asterisks. The lowest line is very weak and is only tentatively included. The assignment of the band to ^{154}Er is based on coincidences between the SD transitions and known ND lines in that nucleus [7]. All the major and moderately intense lines in the figure that are not SD ones are ND lines in ^{154}Er below spin 25 $\hbar$ and are marked by a Δ. Eight of the SD tarnsitions had their multipolarity determined as stretched quadrupoles by means of an empirical asymmetry ratio that was calibrated by known stretched quadrupole and dipole transitions in the nucleus.

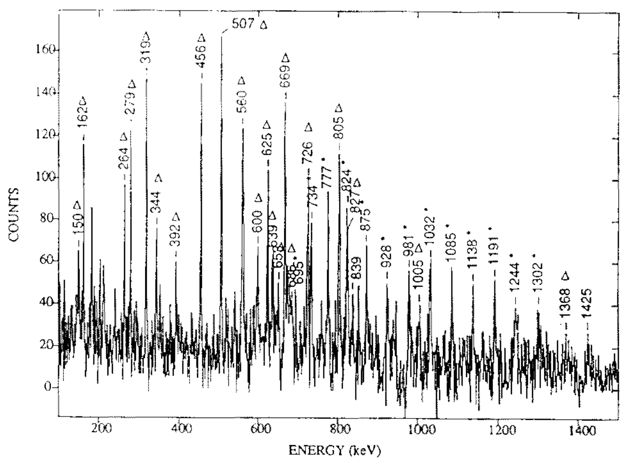

Fig. 4. Triple-gated spectrum of superdeformed band in ^{154}Er. Superdeformed band transitions are labeled with $*$ and ND lines with Δ.

The decay scheme is given in Fig. 5. The linking transitions between the SD and ND bands were not identified, but the approximate entry region into the yrast band can be determined as indicated in the figure. The SD band depopulates sharply with $\sim$80 % of the peak intensity leaving after the 734-keV tarnsition, and this all appears to flow into the 319-keV [$25^- \rightarrow 23^-$] ND band transition (The next higher ND transition, 772-keV [$27^- \rightarrow 25^-$] line, is either not in the spectrum or very weak.). The intensity of the SD band as a fraction of the reaction channel cross-section is difficult to determine because of its weakness, but an estimate is $\sim$0.4 %. This is weak compared with other yrast SD band in this region which are mostly 1–2 % of their reaction channel, and this weakness may be a sign that ^{154}Er is near the limiting edge of SD here.

Figure 6 gives the experimental $J^{(2)}$ values for the ^{154}Er SD band as a function of rotational frequency. At its start, around $\hbar\omega = 0.35$ MeV, $J^{(2)}$ decreases rapidly with increasing frequency, but becomes roughly constant

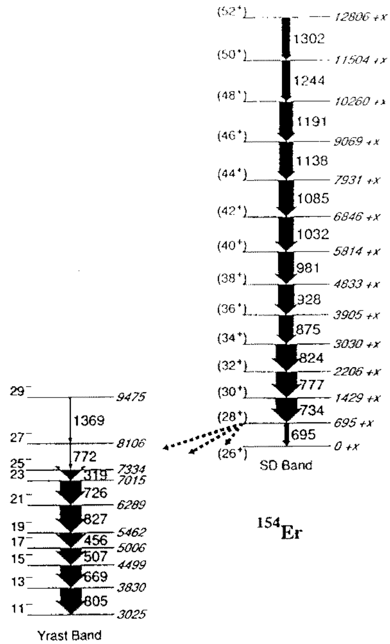

Fig. 5. Decay of the SD band of ^{154}Er into the high-spin ND states. The partial level scheme is from [7].

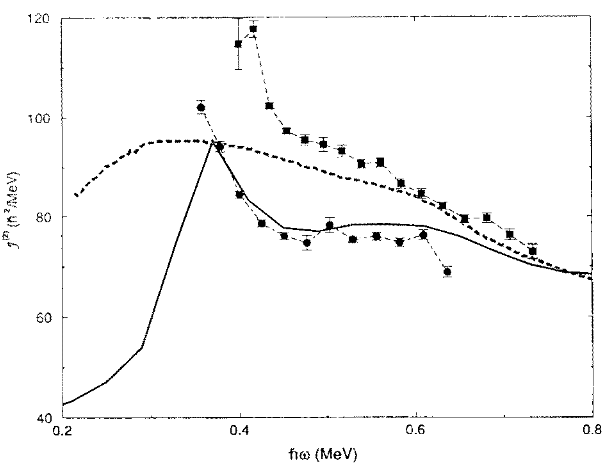

Fig. 6. Dynamic moments of inertia *vs.* $\hbar\omega$ for the yrast SD bands in ^{154}Er, •, and in ^{150}Gd, ■, from experiment. Calculated curves for ^{154}Er with $\beta_2 = 0.61$ (— — —) and $\beta_2 = 0.58$ (——).

above $\hbar\omega = 0.45$ with an average value of $\sim 75\ \hbar^2/\text{MeV}$. A change of this sort corresponds to the aftermath of a rapid gain in alignment spin) which usually occurs following the Coriolis-induced alignment of a pair of high-j, low-Ω particles. The (unseen) rapid rise, and subsequent observed fall of $J^{(2)}$ over only a few transitions implies a relatively weak interaction between the crossing orbitals. The nature of the alignment in ^{154}Er can be suggested by examining the behavior of $J^{(2)}$ in neighboring nuclei. Using a combination of TRS and cranked Woods-Saxon calculations, Nazarewicz and colleagues [8] have assigned intruder configurations to many SD bands in the mass-150 region. Their calculations have been remarkably successful in predicting $J^{(2)}$ for these bands, including the steep fall for the yrast SD band in ^{150}Gd above a rotational frequency of ~ 0.4 MeV, also shown in the figure. It should be noted that calculations that do not include (self-consistent) pairing do not show this effect, which is considered due to the alignment of a pair of [770]1/2 quasineutrons, brought on at a low frequency by the pairing. However, these same calculations do not predict similar behavior for ^{154}Er as is observed, but give a gently sloping curve lying 15–20 % higher than what is actually seen in the nearly constant region. This discrepancy between calculation and experiment may be due to the TRS calculations predicting too large a deformation for the yrast SD band in ^{154}Er, $\beta_2 = 0.61$, the same as that of the yrast band in ^{152}Dy. The size of the $N = 86$ SD shell gap is predicted to be sensitive to small changes in deformation, and to be a maximum around $\beta_2 = 0.61$. The deformation is calculated to be smaller, ~ 0.58, for the ^{150}Gd yrast band, and hence its $N = 86$ neutron shell gap is expected to be smaller. The reduced gap moves the [770]1/2 intruder orbital closer to the Fermi surface, which leads to a higher quasineutron level density and to larger pairing correlations. The result is an earlier lower frequency) weakly interacting [770]1/2 band-crossing or alignment in ^{150}Gd. Since ^{154}Er shows similar behavior, a cranked-shell-model calculation with self-consistent pairing and a smaller deformation, $\beta = 0.58$, was carried out. As can be seen in Fig. 7, this gives the observed rapid fall of $J^{(2)}$ at about the right frequency, and the right magnitude in the nearly constant region. In addition, the calculations give spin values consistent with those shown on the level scheme. Thus, it seems likely that the behavior of the ^{154}Er SD band is also due to a $j_{15/2}$ quasineutron band-crossing, but with a deformation of order $\beta_2 = 0.58$. As mentioned, such a value is not given by the TRS calculations, so again, not all the answers are in yet.

Until this year, no SD band with $Z > 82$ had been reported in nuclei of the mass-190 region, although theoretical calculations do predict second minima in Bi and Po nuclei [9–11]. But earlier this year, an American–French–English collaboration reported the observation of two SD bands in Bi [12], and a second EI experiment [13] added a third band and assigned one to each nucleus in ^{195,196,197}Bi. Two different reactions were used:

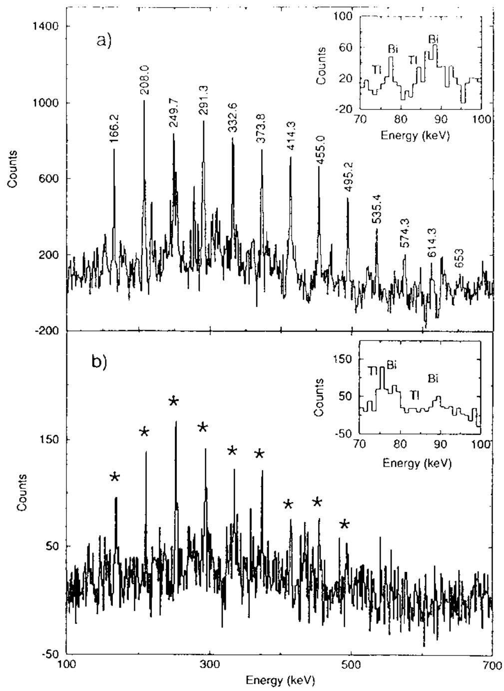

Fig. 7. a) Sum of doubly-gated spectra from three-fold data for band 2 from ^{183}W(^{19}F, xn) reaction at 108 MeV. b) Same, but from ^{181}Ta(^{20}Ne, xn) reaction at 123 MeV. Insets show the X-ray region.

(1) ^{183}W(^{19}F, xn) at 108 MeV and (2) ^{181}Ta(^{20}Ne, xn) at 123 MeV, which helped with the mass assignments as they produced mainly ^{197,196}Bi and ^{195,196}Bi, respectively. Both yielded just under 10^9 three- and higher-fold events. An example of a band spectrum formed from summing combinations of double gates on three-fold coincidence data is shown in Fig. 7. This is band 2 which was previously reported [12] and tentatively assigned to ^{197}Bi, but now must be assigned [13] to ^{196}Bi as that mass is the only one appreciably produced in both reactions. It is also the strongest of the bands, with an upper limit to the calculated channel intensity of 2%. As is true for all of the bands, consistent coincidences were found with Bi X-rays, which is shown in an insert to the figure. It can be noticed that the ratio of K_α to K_β lines is different in the two experiments because the Ta/Cu absorbers usually in front of the Ge detectors were removed in the second run to give a better yield of X-rays. Band 1 is the new one, seen only in the second experiment, and so assigned to ^{195}Bi. It is weak, with no more than 0.7 % the channel intensity. Band 3 was already tentatively assigned to ^{197}Bi, and this is supported by its non-appearance in reaction (2). The

intensity is estimated as 0.6 % or less of the $5n$ channel yield in reaction (1). For all three bands, strongly-coupled signature partners were looked for, but not found.

The behavior of a band in an odd-mass Bi isotope is greatly influenced by the nature of the state which contains the odd proton. A quasiproton Routhian diagram calculated with a BCS gap parameter held constant at the $\omega = 0$ value and with $\beta_2 = 0.48$, $\beta_4 = 0.07$, $\gamma = 0$ shows that the [514]9/2, [642]5/2, and [651]1/2 orbitals are all possible quasiproton states. But since no signature partner was found for any of the bands, and the first two configurations would be expected to have partners with little splitting and hence about the same intensities, they do not agree with what has been observed. So [651]1/2 is the most plausible orbital involved. It is expected to show large signature splitting, and the favored signature should be more strongly populated, thus explaining why only one band is seen with the current instrumental sensitivity. In addition, the alignment of the favored partner is similar to that of the [642]5/2 (hole) states, providing a qualitative explanation for the observed similarity in the magnitudes and slopes of the curves of $J^{(2)}$ for the bands in the odd-mass Bi and Tl isotones, Fig. 8.

In ^{196}Bi, presumably the proton occupies the same [651]1/2 orbital, but the nature of the odd neutron must be considered. Band 2 is the strongest of the three, and no unsplit signature partner was found, suggesting that band 2 involves a strongly aligned neutron orbital as well. A quasineutron Routhian plot suggests that possible states are the [512]5/2, [624]9/2, and [752]5/2 orbitals. But again the first two are expected to form strongly-coupled, signature-partner pairs of bands with little splitting and with some M1 cross talk. So neither can be involved in the ^{196}Bi and observed. But [752]5/2 fits the observations well. It is the lowest lying orbital and well split from its signature partner, so that it is expected to produce a relatively strong single band. Furthermore, the SD bands in ^{195}Pb based upon the $N = 7$ levels have rather flat dynamic moments of inertia just like ^{196}Bi, as shown in Fig. 8. This is due to the blocking of the important contribution of the $N = 7$ orbitals to the pairing correlations. A last comment to indicate that there are still problems. The magnitude of $J^{(2)}$ for the ^{196}Bi band is smaller than that for the favored $N = 7$ band of ^{195}Pb. The addition of a proton to the favored partner of the [651]1/2 orbital should cause the opposite effect, so that other factors such as differences in the deformation and/or pairing strengths must also be important.

As a postscript, a collaboration of several groups headed by one from Rutgers University has reported [14] a SD band in ^{198}Po from a run on Gammasphere in June. They used a 148-MeV beam of ^{29}Si to irradiate a target of 3×0.5–0.6 mg/cm^2 self -supporting foils of ^{174}Yb. They found a band with the characteristics of a SD one, and Fig. 9 is a preliminary

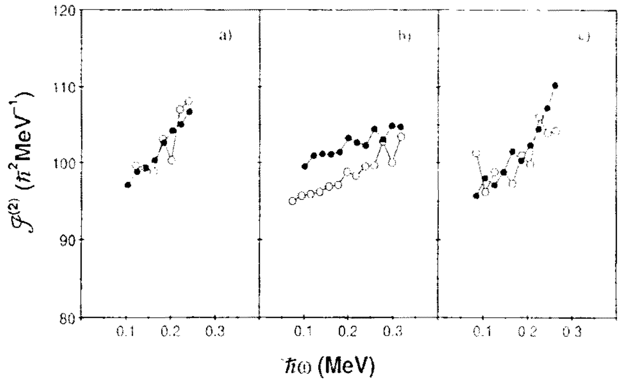

Fig. 8. Plot of the dynamic moment of inertia as function of $\hbar\omega$ for: a) ^{195}Bi, ∘, and ^{193}Tl(1), •; b) ^{196}Bi, ∘, and ^{195}Pb(1), •; c) ^{197}Bi, ∘, and ^{195}Tl(1), •.

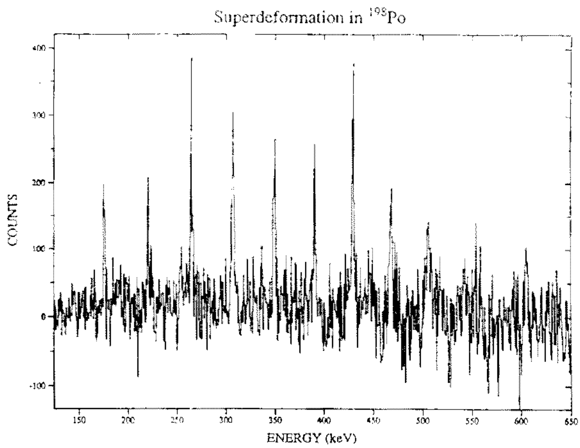

Fig. 9. Spectrum of SD band in ^{198}Po obtained as sum of all clean combinations of double gates.

spectrum, although the data are still being worked on.

The same ideas and theoretical calculations that predicted sperdeformation in about the mass regions in which it has now been observed predict states with still larger prolate deformation, *i.e.*, a 3 : 1 axis ratio, for some nuclei at very high spins. For example [15], such states, named hyperdeformed (HD), are predicted to become yrast at spins above 80 $\hbar$ in ^{152}Dy. Conventional fission barriers go to zero below such a spin in the rare-earth region [16], implying that the existence of such states is questionable or that we have more to learn about fission barriers. I believe conventional barriers do not include shell effects, and a strongly deformed shell gap of a few MeV at certain proton and neutron numbers may permit these nuclei to exist at higher spins than usually thought possible, although with increasingly weaker intensities. Experimentalists are always optimistic about seeing something new, so attempts have been made to find HD bands. In 1993 a Chalk River group reported [17] that using a ^{120}Sn(^{37}Cl,pxn) reaction and a CSI particle array inside the 8π Spectrometer, they had observed a ridge in the $E_\gamma - E_\gamma$ correlation matrix at transition energies of 1.2–1.5 MeV with about a 30-keV spacing and a weak discrete band with the same regular increase in transition energies. These were attributed to a HD band in either ^{152}Dy or ^{153}Dy. Assuming that at high spins and large deformation the nucleus approximates a rigid rotor, *i.e.*, $J^{(2)} = J^{(1)}$, gives, for the transition energies found, spins of 78–79 $\hbar$. The ridge was confirmed by Lunardon *et al.* [18] at GASP, but not the discrete band. And unsuccessful attempts to make the band by (HI,xn) reactions and in an additional (HI,pxn) experiment at GASP have left the matter somewhat up in the air. Also in 1993, Åberg suggested [19] that ^{146}Gd might be a better candidate nucleus for hyperdeformation as he calculated that HD band to become yrast about 10 $\hbar$ lower than in ^{152}Dy.

Just eight weeks before this Workshop, LaFosse *et al.* published [20] evidence for two bands in ^{147}Gd which, from their deduced properties, are suggested to be hyperdeformed. The experiment involved the first use of the Microball inside EI Gammasphere (actually the first use of an auxiliary detector with Gammasphere). The Microball, a beautiful device built by Prof. Sarantites and colleagues from Washington University, consists of 95 CsI(Tl) detectors with Si photodiode readout arranged in nine rings covering 4° to 172° in the laboratory frame, and has dimensions of roughly 18 by 10 cm. It nicely separated the protons and alphas observed in the reaction ^{100}Mo(^{51}V,$p3n$)^{147}Gd used with a 230-MeV beam from the 88-Inch Cyclotron. The event trigger was determined by the firing of three or more suppressed Ge detectors. And if one more Microball segments fired, their time, energy, and particle ID data (pulse heights of fast and sloe components of signal) were also recorded. About 1/4 of the events were in coincidence with protons, and gating additionally on them off-line improved the peak-to-background ratio by a factor of 4. The Microball caused significant absorption of γ rays only below 200 keV and a reduction of the peak-to-total ratio of the Ge detectors for 1.33-MeV γ rays from 0.54 to 0.49.

Two γ-ray sequences were found by both of two search programs, and gating on all possible double combinations but one in each sequence gave the two spectra shown in Fig. 10. The peaks have rather regular spacing, but not exactly so, which averages 28–29 keV, with a variation of ± 4 keV. These correspond to a very large and roughly constant dynamic moment of inertia, $J^{(2)}$, of $\sim 140\ \hbar^2$/MeV, which is consistent with a rigid prolate shape having a 3 : 1 axis ratio. In a later experiment without the Microball, but with 56 rather than 36 Ge detectors and the same reaction, ~ 5 times more events were produced with ~ 4 times poorer peak/background (other channels not eliminated) and several more members of both bands were found [21]. (And still a third run finished last week, mid-August, with the Microball inside Gammasphere will give 15–20 times the statistics of the first run.)

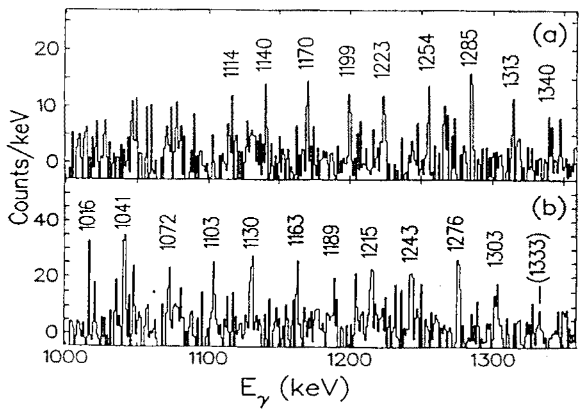

Fig. 10. Spectra of possible HD bands (a) A and (b) B from all the possible combinations of double gates on the indicated transitions except those at 1254 and 1189 keV. The energies of the peaks are given.

The assignment of the two bands to ^{147}Gd was made on the following basis. Gating on a proton produces a clean group of exit channels: ^{145,146,147}Gd. The ^{145}Gd channel involves 6 evaporated particles, and so is produced with the lowest spin distribution; this excludes it if the band is truly of high spin. Figure 11(a) shows the low-energy part of the double-gated spectrum that brings back HD band B (Fig. 10(b); the coincident normal deformed ^{147}Gd lines are marked by their energies. They are significantly enhanced relative to those from ^{146}Gd, indicated by asterisks, but the experimental channel cross-sections go the opposite way by a factor of over 4. If the gates are moved a few keV off the HD peaks, the lines of ^{146}Gd now dominate, as shown in Fig. 11(b). The same story is true for HD band A.

The HD bands A and B were estimated to be 5–6 times weaker than the SD bands in ^{146,147}Gd, and thus about 1/4 % of the ^{147}Gd channel. Estimates of their spins are difficult to make. If one assumes again that this nuclear rotation is rigid, then $J^{(2)} = J^{(1)}$ (as is also suggested by calculations the author have carried out using Åberg's deformation parameters

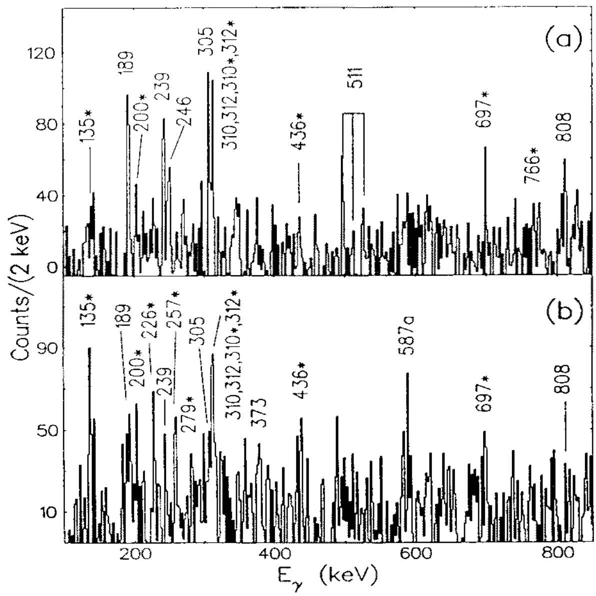

Fig. 11. (a) Low-energy part of spectrum in Fig. 11(b) that brings back HD band B, produced by double gating on all combinations of the band transitions except those at 1041, 1072, and 1333 keV. The ^{147}Gd lines are marked in keV, those from ^{146}Gd by an asterisk. Despite the greater than four times yield of the mass 146 channel over that mass 147, the strongest lines are ND transitions in ^{147}Gd. (b) Spectrum created with the gates moved off the HD peaks by about 5 keV; the ^{146}Gd lines now dominate. A ^{145}Gd peak is marked with an a. An enhancement of a factor of ~ 4 of the ^{147}Gd lines relative to those from ^{146}Gd is seen in panel (a) compared to (b).

[19] but cranking a Woods–Saxon potential), and from the experimental transition energies observed in the two bands a spin range of about 70–90 $\hbar$ is obtained. However, using conventional statistical model calculations gives for the 230-MeV ^{51}V reaction an l_{critical} of 84 $\hbar$, and fission lowers the sharp cut-off spin value for evaporation residues to ~ 71 $\hbar$. These values are obviously conflicting, and pose a serious problem. Perhaps deformed shell gaps could stabilize the HD nucleus against fission, but it would seem to take rather large values. Perhaps these are very strange dipole bands, as they have not yet been shown to be stretched quadrupole transitions, and that would halve the spins but cause other problems. Or perhaps the nucleus is not a rigid rotor but is making use of another degree of freedom to minimize its total energy, playing off changes in its potential energy against changes in its kinematic moment of inertia, as has been suggested very recently [22]. And beyond the all-important questions as to the multipolarity

of the band transitions and their true spin range if hyperdeformed, there are others, such as does proton emission play any role in observing the HD band beyond improving the peak/background ratio when gated upon, and where are other hyperdeformed nuclei, and is there a range of axis ratios to be found with change in proton and neutron number as is observed with superdeformation?

These questions and those posed about the other experiments discussed are only a small sample of the many that can be asked with a good chance of being answered by the new breed of arrays, and their successors.

I am very grateful for those listed below who communicated with me their unpublished results and/or sent pre- or post-publication drafts of their studies, even when knowing that I would not be able to use all of them due to limitations of time. My thanks go to C. Baktash, L.A. Bernstein, J. Cizewski, R.M. Clark, R.V.F. Janssens, H.-Q. Jin, D. LaFosse, I.-Y. Lee, D. McNabb, J.O. Rasmussen, J.X. Saladin, D. Sarantites, and W. Swiatecki. This work was supported in part by the U.S. Department of Energy through Contract No. DE-AC03-76SF00098.

REFERENCES

[1] D.Ward *et al.*, Conference on Physics from Large γ-Ray Detector Arrays, National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, Virginia 1994, p.4.
[2] R.M. Clark *et al.*, private communication, August 1995.
[3] J.F. Ziegler, J.P. Biersack, U. Littmark, *The Stopping and Ranges of Ions in Matter*, Vol. 1, Pergamon Press, New York 1985.
[4] L.A. Bernstein *et al.*, to be published, *Phys. Rev.* **C**, September (1995).
[5] P.H. Heenen, private communication to L.A. Bernstein, July 1995.
[6] P. Bonche, private communication to L.A. Bernstein, July 1995.
[7] C. Schuck *et al.*, *Nucl. Phys.* **A496**, 385 (1989).
[8] W. Nazarewicz, R. Wyss, A. Johnson, *Nucl. Phys.* **A503**, 285 (1989).
[9] R.R. Chasman *et al.*, *Phys. Lett.* **B219**, 308 (1989).
[10] W. Satula *et al.*, *Nucl. Phys.* **A529**, 289 (1991).
[11] S.J. Krieger *et al.*, *Nucl. Phys.* **A542**, 43 (1992).
[12] R.M. Clark *et al.*, *Phys. Rev.* **C51**, R1052 (1995).
[13] R.M. Clark *et al.*, submitted to *Phys. Rev.* **C**, and private communication, August 1995.
[14] D. McNabb *et al.*, *Bull. Am. Phys. Soc.* **29**, 1430 (1994), and private communication, August 1995.
[15] J. Dudek *et al.*, *Phys. Lett.* **B211**, 252 (1988).
[16] A.J. Sierk, *Phys. Rev.* **C33**, 2039 (1986).
[17] A. Galindo-Uribarri *et al.*, *Phys. Rev. Lett.* **71**, 231 (1993).

[18] M. Lunardon *et al.*, *Nucl. Phys.* **A583**, 215c (1995).
[19] S. Åberg, *Nucl. Phys.* **A557**, 17c (1993).
[20] D.R. LaFosse *et al.*, *Phys. Rev. Lett.* **74**, 5186 (1995).
[21] D. Sarantites, private communication, August 1995.
[22] W.J. Swiatecki, private communication, August 1995, and W.D. Myers, W.J. Swiatecki, this Proceedings.