**LA-UR** -90-2594

Received by OSTI

AUG 06 1990

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--90-2594

DE90 014976

TITLE CLOSING COMMENTS ON THE WORKSHOP ON SHORT-LIVED NUCLEAR BEAMS

AUTHOR(S) Gerald T(homas) GARVEY

SUBMITTED TO Proceedings
Los Alamos Workshop on the Science of Intense
Radioactive Ion Beams
April 10-12, 1990

**DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

# CLOSING COMMENTS ON THE WORKSHOP ON SHORT-LIVED NUCLEAR BEAMS

GERALD T. GARVEY
*Los Alamos National Laboratory*
*Los Alamos, New Mexico 87545*

It was a great pleasure to have heard so many interesting and forward-looking talks at the plenary sessions and vigorous discussion within the working groups. One feels being in on the emergence of a new field, which is very exciting. As time is quite short my remarks will be by way of observations and comments rather than an attempt to summarize this stimulating and diversified conference.

First, there is clearly an ever increasing interest in this area of research. For example, note the recently expressed interest of Brookhaven National Laboratory (BNL) and the Rutherford Laboratory in using their proton beams to provide a basis for a radioactive beam facility. There is also, I can assure you, great interest at Los Alamos in studying how effectively LAMPF can provide an outstanding facility for this community. As you know, we have an 800-MeV, 1000-$\mu$A proton beam that might provide the very best source of short-lived nuclei in the world.

There seemed to be some initial feelings of competition between those advocating production of exotic beams by fragmentation and those who want to achieve it via spallation. I see no need for this apparent contest. The production of beams via fragmentation creates useful yields in the regime above 100 MeV/amu. To get high-quality beam at lower energy via this process requires collecting these fragments in a storage ring, cooling them, and then collecting and deaccelerating them, but that takes time and so the technique will not likely be profitable with nuclei whose lifetime is less than say a minute. It also seems unlikely that it would be profitable to accelerate radioactive beams generated via spallation from thermal energies to much above 10 MeV/amu. Thus, it appears that there is a natural separation in the field between high-energy beams from fragmentation and low-energy beams produced by acceleration following production via spallation. The physics in the two regimes is quite different as the lower energy focuses on issues of nuclear structure while the higher energies deal with nuclear properties such as the equation-of-state.

If you would allow me a moment to reminisce, I can tell you how I first got into the interesting business of exotic nuclei. At Lawrence Berkeley Laboratory (LBL) in the summer of 1965 there was great excitement as $^{8}$He had been discovered by Poskanzer 1) and collaborators and its mass had been measured 2) by Joe Cerny's group at the Lawrence Berkeley Laboratory (LBL) 88-inch cyclotron. The question of the moment was whether or not $^{10}$He was stable. In dealing with that question, the idea of employing mass difference equations 3) was developed. It is, of course, evident that large binding for $^{8}$He makes it easier for $^{10}$He to decay into $^{8}$He + $2n$. By way of a further remark, a few years later I realized that insofar as $^{10}$He is a doubly magic nucleus its mass could be directly predicted using the Cohen and Kurath [4]) matrix elements ($T$ = 1, 1$p$ shell).

$$\mathrm{BE}(^{10}\mathrm{He}) - \mathrm{BE}(^{4}\mathrm{He}) = 4\epsilon_{3/2} + 2\epsilon_{1/2} + \left(\frac{3^2}{2}\right)^{J=0} + 5\left(\frac{3^2}{2}\right)^{J=2}$$
$$+ \left(\frac{1^2}{2}\right)^{J=0} + 3\left(\frac{1}{2},\frac{3}{2}\right)^{J=1} + 5\left(\frac{1}{2},\frac{3}{2}\right)^{J=2} = -2.29\ \mathrm{MeV}$$

using their (6-16)2BME matrix elements. In the above expression $\epsilon j$ indicates the single particle energies while the other terms are the $(2J + 1)$ weighed values of the two-body $T = 1$ interaction energies. The fact that this procedure predicts $^{10}$He to be unbound against decay in $^4$He + 6$n$ was a further clear indication of its instability against strong decays. Of course, $^{10}$He has not been found to be stable. However, $^{11}$Li has been discovered and is a very interesting case. $^{11}$Li drew much attention at this conference. The talk by Ingamar Ragnusen [5]) was very informative in this regard. It is very interesting to understand the wave function of $^{11}$Li in shell model terms. Of course, the radial wave function of the last two neutrons will be unusual because of their very small separation energy $S_{2n}$ ($^{11}$Li) ~ 0.2 MeV, whatever their shell model configuration. The question is, "What is the orbital of the last two neutrons in $^{11}_{3}\mathrm{Li}_8$?" Are all the nucleons in the 1$p$ shell, or does the system take advantage of the possibility that both the last two neutrons and third proton can gain energy by taking on the prolate deformed orbits ($K^{\pi}$ = 1/2) as shown in Fig. 1? A similar argument could be made for $^{11}_{4}\mathrm{Be}_7$, which has a $J^{\pi}$ = $(1/2)^+$ ground state! In the discussion following Ragnusen's talk John Schiffer pointed out in experiments done at Argonne many years ago on the $^{10}$Be($d,p$)$^{11}$Be reaction the spectroscopic factor for the $^{11}$B ground state was found to be $S$ = 0.73 ± 0.06 [6]). Such a large value would not be compatible with a deformed $K^{\pi}$ = 1/2$^+$ Nilsson orbit, as one expects a value of $S \simeq 0.3$ for large deformation [7]). However, John has more faith than I do in our ability to extract absolute spectroscopic factors from these reactions. In a very deformed case the orbit could be appreciably larger than one generated in a spherical potential and might lead one to considerably overestimate the spectroscopic factor from the measured yield. Be that as it may, it remains a challenge to determine the nature of exotic light nuclei

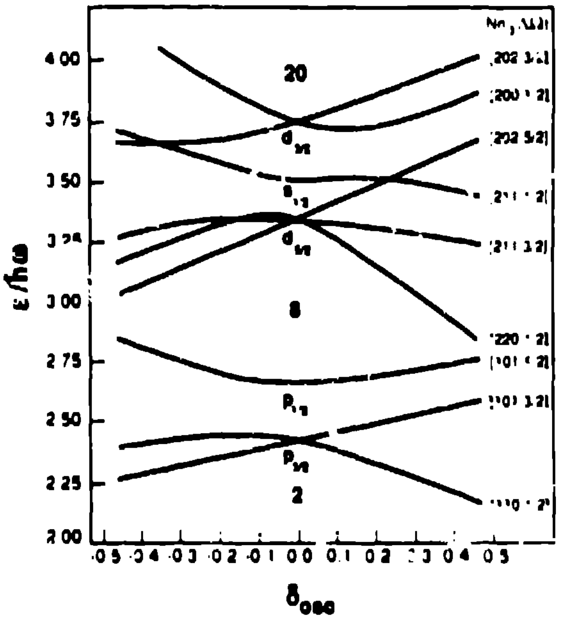

Fig. 1. Figure showing the energies of single-particle orbits as a function of deformation parameters for the anisotropic oscillator. The orbits are labeled by the asymptotic quantum numbers [$Nn_z\Lambda\Omega$] for large prolate deformation.

that may be undergoing deformation in those cases where both the last *protons* and *neutrons* have the possibility to lower their energy by assuming deformed orbits.

Another remark that caught my attention was Frank Stephen's observation that because the Coulomb interaction tends to induce fission the formation of high-spin systems that are richer in neutrons might let experimenters reach even larger angular momenta. At present, high-spin studies are of necessity carried out on the proton-rich side of the valley of stability. A rule-of-thumb appears to be that for each neutron supplanting a proton about one unit of angular momentum can be picked up without danger of fission. This gain in angular momentum before fission may be all that is needed to make ultra-deformed states (ratio of major to minor axis of 3/1) observable. This shape should come down to the yrast line at sufficiently high spin both because its moment of inertia is larger and certain single particle states will benefit from the large Coriolis interaction. The production of neutron-rich beams of medium-$A$ nuclei to use as projectiles in formation of high-spin levels should let one gain the order of five units in $N - Z$ and hence in angular momentum of the decaying systems. The unambiguous discovery of physical states with a (3/1) deformation would be most exciting.

One cannot fail to be impressed with the power of the nuclear models developed by Bohr-Mottelson, Nilsson, and further elaborated by Strutinsky. They have provided uncanny direction in understanding the behavior of nuclei at high spin. These models work so well that there really needs to be some careful study to determine how well these models of nuclear spectra should work. Only with a sharper understanding of the limits of this family of models can one effectively pursue this subject at greater depth. The experimental apparatus has become so powerful that researchers can comb through data and reject "uninteresting" decays to get at the specific type of system that one wants to examine. While very beautiful, and at some level very satisfying, what are we learning that would alter our view of the nature of nuclear excitations? With respect to the yrast line, the lowest lying ultra-deformed states will very likely have very small matrix elements coupling them to the neighboring levels. This is because it will have an intrinsic state made up of several high angular momentum single particle states. A glance at a Nilsson diagram for this large deformation and high rotation shows many crossings of single particle states. Each of these crossings requires a two-body interaction to rescatter the particles; hence the mixing matrix elements are small and the ultra-deformed states near the yrast line will appear to be very pure. One needs carefully formulated questions to investigate this matter at a depth that will reveal new information about nuclear behavior.

Attention should also be paid to investigating appropriate detector schemes for exotic beam research. The low intensities necessarily associated with exotic beams will require and allow detection systems of much greater acceptance than are now employed. There may be some very interesting and profitable trade-offs to be made between efficient detection systems and heroic efforts to increase the beam intensity. Once the beam drops below $10^5$ s$^{-1}$, it should be easy to observe and analyze each incident particle.

This has been an excellent and pleasurable workshop, and one readily sees the community of nuclear structure physicists rallying around a new and exciting possibility to expand our understanding of the atomic nucleus in its more exotic, quantum states. Your idea to organize a steering committee that is not site nor technology specific is an excellent idea at this time. I don't think there is a single idea or system yet so compelling that the entire nuclear physics community will rally behind it. However, I believe that by working hard on the scientific opportunities provided by exotic beams and the means of producing them, you will develop an irresistible plan. It is exciting seeing this process in motion!

## References

1) A. M. Poskanzer, R. A. Esterlund, and R. McPherson, Phys. Rev. Lett. **15** (1965) 1030.

2) J. Cerny, S. W. Cosper, G. W. Butler, R. H. Pehl, E. S. Goulding, D. A. Landis, and C. Detraz, Phys. Rev. Lett. **16** (1966) 469.

3) G. T. Garvey and I. Kelson, Phys. Rev. Lett. **16** (1966) 197.

4) S. Cohen and D. Kurath, Nucl. Phys. **73** (1965) 1.

5) Ingamar Ragnusen (this conference).

6) F. Ajzenberg-Selove and C. L. Busch, Nucl. Phys. **A336** (1980) 1.

7) A. Bohr and B. Mottelson, *Nuclear Structure*, Vol. II (W. A. Benjamin, Inc., Reading, Massachusetts, 1975), p. 290.