RESEARCH HIGHLIGHTS FROM THE HOLIFIELD HEAVY ION RESEARCH FACILITY

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1. Introduction

The purpose of this paper is to present the scope of research carried out at the new Holifield Heavy Ion Research Facility (HHIRF) at Oak Ridge. This will be accomplished with reference to several research projects currently underway. The data that will be presented are preliminary and have been obtained by a number of different research groups at ORNL. Those involved directly with any given investigation are listed in the reference section. The areas of research represented are microscopic and macroscopic aspects of nuclear reactions and nuclear structure. In view of the scope of this conference, emphasis will be placed on nuclear reactions. All work presented involves the use of the new tandem electrostatic accelerator in either the stand-alone mode or coupled with the Oak Ridge Isochronous Cyclotron (ORIC).

In Section 2 a brief description of HHIRF will be given, together with its current status. Section 3 will be devoted to microscopic aspects of reactions between nuclei, with reference to the prospects for the study of giant resonances by means of heavy ions, and to studies of elastic and inelastic scattering of ^{60}Ni nuclei. Macroscopic aspects of nuclear reactions will be illustrated in Section 4 by means of the study of collisions between ^{58}Ni nuclei at 15.1 MeV/u and by means of Spin Spectrometer (crystal ball) studies of the $^{19}\text{F} + ^{159}\text{Tb}$ reaction. In Section 5 results will be presented for lifetime measurements of high-spin states in ytterbium nuclei.

2. Description and current status of HHIRF¹⁾

The HHIRF consists of a new "folded" electrostatic tandem accelerator designed for terminal voltages of 25 MV and an isochronous cyclotron, ORIC, which has been in operation since 1963. A key feature of the facility is the ability to operate the two machines in a coupled mode. Such operation results in the production of lighter heavy ions with energies of up to 25 MeV/u. A sectional elevation of the facility is shown in Fig. 1.

Construction of the tandem began in April 1976. The pressure vessel was completed in situ in January 1978, and the building was completed in November 1978. In May 1979 voltages in excess of 30 MV were reached in column tests prior to the installation of

Fig. 1. Sectional elevation of the HHIRF accelerators indicating the transfer line from the tandem to the cyclotron, together with one of the tandem experimental beam lines.

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the development of new beams and changes in energy proceed smoothly once the appropriate beam has been extracted from the tandem. In Fig. 3 the capability of the combined facility is indicated with the terminal potential constrained to 18 MV. It can be seen that for many ions the effects of this limitation are small. An additional feature of coupled operation is the good energy resolution of the beam that can be achieved. This is illustrated in Fig. 4 for the case of 400-MeV ^{16}O . The 115-keV FWHM resolution is not achieved routinely at the present time (200 keV is more typical). Due to experience obtained from beam extraction studies, however, it is anticipated that beam resolution of about 115 keV will be routinely available in the future.

Fig. 3. Comparison of maximum energy for ions from the coupled tandem and cyclotron accelerators for terminal voltages of 18 and 25 MV.

Fig. 4. Spectrum of ^{16}O particles from bombardment of ^{208}Pb with 400-MeV ^{16}O as taken with a position-sensitive Si detector at the focal plane of the broad-range magnetic spectrometer.

3. Microscopic aspects of nuclear reactions

3.1. STUDIES OF GIANT RESONANCES WITH HEAVY IONS²⁾

In principle, the excitation of giant resonances by means of heavy-ion reactions has the advantages that the resonance cross sections are expected to be large and that they are expected to increase with increasing bombarding energy. This point is illustrated in Fig. 5 where the calculated maximum cross sections at the grazing angle are shown, as a function of the incident energy, for the $L = 2$ and $L = 4$ excitations in the $^{208}\text{Pb}(^{16}\text{O}, ^{16}\text{O}')$ reaction. In this calculation, 100% of the energy-weighted sum rule was used at $Q = -12$ MeV. The expected GQR cross section of 40 mb/sr at 400 MeV is about four times larger than that obtained from the 200-MeV (p, p') reaction and about double that obtained with 150-MeV alpha particles.

Fig. 5. Grazing angle cross sections calculated for $L = 2$ and $L = 4$ excitations in the reaction $^{208}\text{Pb}(^{16}\text{O}, ^{16}\text{O}')$ plotted as a function of incident ^{16}O energy using the 100% energy-weighted sum rule.

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Measurements of inelastic excitations of giant resonances in ^{208}Pb have been made recently by means of the 400-MeV ^{16}O beam obtained from coupled machine operation.²⁾ The resulting spectrum is shown in Fig. 6. The peak at 10.9 MeV is due to the GQR. The structure at 13.7 MeV is due to the excitation of both the GMR and the GDR, as is substantiated by angular distribution data. The peak at 17.6 MeV is believed to be an excitation in ^{208}Pb and may be the $L = 3$ giant resonance as reported by Morsch et al.³⁾ in ^4He inelastic scattering. The peak at 24.8 MeV probably arises from decay following nucleon pickup, since results with 350-MeV ^{16}O projectiles show the peak to shift by 3 MeV. The solid curves represent fits to the peaks and to the underlying continuum.

In addition to the peaks clearly shown in Fig. 6, there is a very large peak at about 7 MeV. It is due to the excitation of states in the ^{16}O projectile and illustrates one of the disadvantages in the use of heavy ions for giant resonance studies. On the other hand, the primary advantage of heavy ions, the large peak-

to-continuum ratio for the GQR excitation, is stressed in Fig. 7. In this figure GQR data are shown for ^{208}Pb excited both by ^{16}O ions²⁾ and by 152-MeV alpha particles.⁴⁾ The data have been normalized to the same level of the continuum background. It can be seen that while the peak-to-continuum ratio is about 2.2:1 in the ^{16}O case, it is only 1:1 in the ^4He case. Thus it is anticipated that heavy-ion probes will be very useful in studies of the excitation and subsequent decay of giant multipole resonances. Future emphasis is expected to be placed on investigations of rare decay modes.

Fig. 6. Spectrum from ^{16}O bombardment of ^{208}Pb at 400 MeV. The solid curves are fits to the peaks and an estimate of the underlying continuum.²⁾

Fig. 7. Comparison of the GQR in ^{208}Pb excited by 400-MeV²⁾ ^{16}O and by 152-MeV⁴⁾ ^4He . The spectra have been normalized to the same estimated level of the underlying continuum.

3.2. ELASTIC AND INELASTIC SCATTERING OF ^{60}Ni NUCLEI⁵

The motivation for this study was provided in part by the fusion cross section results of Beckerman et al.⁶) who observed large differences between $^{60}\text{Ni} - ^{60}\text{Ni}$, $^{58}\text{Ni} + ^{60}\text{Ni}$, and $^{58}\text{Ni} + ^{58}\text{Ni}$ excitation functions in the barrier region. In the Oak Ridge work, elastic and inelastic scattering was investigated for the systems $^{60}\text{Ni} + ^{60}\text{Ni}$, $^{60}\text{Ni} + ^{58}\text{Fe}$, and $^{60}\text{Ni} + ^{58}\text{Ni}$. Data were obtained at three ^{60}Ni energies ranging from 176 MeV to 228 MeV, but results only from the highest energy case will be reported here.

The experimental technique made it possible to obtain reasonably good energy resolution, without the use of a magnetic spectrometer, by making use of the kinematic relationships between the scattered projectile and the recoiling target nuclei. Two position-sensitive silicon detectors operated in coincidence were placed 50 cm from the target. One of the detectors was covered by a slotted mask. Typical data are shown in Fig. 8 as a function of the laboratory angle. The effect of the slotted mask is clearly visible in the lowest portion of the figure. In the top portion of the figure, the reconstructed energy spectrum is shown. The technique makes use of the fact that the opening angle between the coincident nuclei depends on the reaction Q value. Since the angular resolution in these measurements was better than 0.1° , it was possible to deduce energy spectra with better energy resolution than could have been obtained from a direct energy measurement using a silicon detector.

Fig. 8. Elastic and inelastic scattering data from $^{60}\text{Ni} + ^{60}\text{Ni}$ at 227.7 MeV. In the two lower portions of the figure, yields of coincident products are shown as a function of their lab angle. The prominent structure in the lowest portion of the figure is due to a slotted mask placed in front of one of the detectors. In the top portion of the figure, a reconstructed energy spectrum is shown (see text).

Fig. 9. Elastic (top) and inelastic (bottom) scattering results from the reaction $^{60}\text{Ni} + ^{60}\text{Ni}$ at 228 MeV. Cross sections are given in mb/sr as a function of the c.m. angle. The strong oscillations in the elastic scattering case are due to the exchange symmetry in identical particle scattering. Solid curves depict coupled-channels calculations with $V = 40$ MeV, $W = 15$ MeV, $r = 1.20$ fm, and $a = 0.55$ fm.

Angular distributions obtained for the $^{60}\text{Ni} + ^{60}\text{Ni}$ reaction at 228 MeV are shown in Fig. 9. Strong oscillations arising from the exchange symmetry in identical particle scattering can be seen in the elastic scattering data. It was found that the elastic data can be represented adequately by a coupled-channels calculation using only a pure Coulomb interaction. This calculation, however, was not

able to reproduce the inelastic results, and the theoretical curves shown in Fig. 9 were obtained by means of a coupled-channels calculation in which a rather standard nuclear potential was included, together with the Coulomb potential. Although a systematic search for the potential that best describes the data has not as yet been carried out, it is clear that inelastic data are essential in defining the optical potential in any given case.

In Fig. 10 elastic scattering results are shown for the $^{60}\text{Ni} - ^{56}\text{Fe}$ reaction at 228 MeV, together with the appropriate theoretical curve from the coupled-channels calculation. This calculation was similar to that discussed above and was modified only to take into account the different Z and $B(E2)$ values of the target nucleus. As can be seen, the theoretical curve is an extremely poor representation of the experimental data. The origin of this dramatic discrepancy is not known.

Fig. 10. Angular distribution of ^{60}Ni nuclei elastically scattered from ^{56}Fe at 228 MeV. The cross section is in mb/sr, and the angle is in degrees in the c.m. system. The solid line indicates the same coupled-channels calculation as shown in Fig. 9, with only the Z and the $B(E2)$ values of the target adjusted to this case.

Elastic scattering of ^{60}Ni at 228 MeV is shown for targets of ^{58}Ni and ^{56}Fe in Fig. 11. Two interesting features are apparent. First, the $^{60}\text{Ni} - ^{58}\text{Ni}$ reaction seems to exhibit an oscillatory behavior at backward angles that may be indicative of the elastic transfer of two-neutron pairs. Second, there is a rather large and unexplained difference between the two reactions at angles greater than 80° in the center of mass. These results, together with those discussed above, open up a number of tantalizing questions which point to a rich field for future investigation. More data are needed for more systems, particularly at backward angles. Further effort is also needed in the coupled-channels analysis of the data.

Fig. 11. Elastic scattering results from the systems $^{60}\text{Ni} + ^{58}\text{Ni}$ (circles) and $^{60}\text{Ni} + ^{56}\text{Fe}$ (triangles) at 225 MeV.

4. Macroscopic aspects of heavy-ion reactions

4.1. PROJECTILE SPLITTING IN THE $^{88}\text{Ni} + ^{58}\text{Ni}$ REACTION AT 15.1 MeV/u⁷⁾

This study was motivated by the findings of two groups working at the Gesellschaft für Schwerionenforschung in Darmstadt, Germany.⁷⁻¹⁰⁾ Olmi et al.⁸⁾ found that when ^{88}Y was bombarded with ^{56}Kr ions at 12.1 MeV/u, events were observed which correspond to the fission of the projectile nuclei. These events were more probable than could be understood on the basis of the fission of an equilibrated system, and the authors concluded that they were due to a fast non-equilibrium process, which they called "projectile splitting." Two striking characteristics of this process were reported: relatively little energy loss appeared to be involved in the first step of the reaction, and little charge transfer was observed prior to fission. Unfortunately, the experimental configuration of Ref. 8 favored the observation of events with the above characteristics. The Heidelberg group studied the systems $^{84}\text{Kr} + ^{96}\text{Zr}$ and $^{84}\text{Kr} + ^{166}\text{Er}$ at 12.4 MeV/u and $^{129}\text{Xe} + ^{122}\text{Sn}$ at 12.5 MeV/u.^{9,10)} In this work all three partners of each detected three-body event were observed and were also shown to be due to a fast sequential fission mechanism. This conclusion was based on proximity effects in the outgoing three-body channel which made it possible to estimate the reaction time. In contrast to the finding of Olmi et al., however, it was found that the mass of the fissioning system was in the vicinity of 120-130 amu, which, in the case of krypton systems, implies a large mass (and charge) transfer prior to fission. Moreover, large energy losses were found to be involved in the first step of the reaction.

In the work reported here the goals were to determine if projectile splitting can be observed in a lighter system, and at a higher bombarding energy, than those discussed above and to establish the extent of charge transfer and energy loss in the first step of the reaction. Monte Carlo calculations were performed to determine the optimum experimental configuration for the detection of three-body events and to ascertain that the full range of energy loss was covered. The arrangement included a large-area ionization chamber capable of measuring the

energy, E , and the energy loss, ΔE , of reaction products as well as their in-plane and out-of-plane angles. A second detector was operated in coincidence on the other side of the beam. It consisted of an ionization ΔE section backed by a position-sensitive silicon counter. This detector covered a fixed in-plane angular range of -12° to -32° , while the large-area ionization chamber was operated at three angles, covering 4° to 30° lab. For every coincident event the quantities Z_1 , Z_2 , E_1 , E_2 , ϵ_1 , ϵ_2 , and ϵ were deduced from the recorded pulse heights. (Z refers to the nuclear charge; E to the kinetic energy; ϵ is the in-plane and ϵ the out-of-plane angle.) In the absence of light-particle emission, for a strictly three-body event, the above quantities are sufficient to fully determine the event. With increasing energy loss, the probability for significant light-particle emission increases, and conclusions based on measurements of the quantities listed above become more ambiguous.

Fig. 12. Distribution of single-fragment events detected in the large ionization chamber as a function of their nuclear charge, Z_1 , and their lab energy, $E_{1, \text{LAB}}$.

In Fig. 12 the distribution of single fragments is shown as a function of Z and E . The striking feature is that the distribution is dominated by the yield of products lighter than the projectile. Since a symmetric system is involved, there can be no potential energy driving force toward lower Z values. The effects that can contribute to the asymmetric nature of the distribution are: a) equilibrium charged-particle evaporation from the excited primary products; b) nonequilibrium charged-particle emission from either the reaction products or from the collision zone; and c) three-body events including projectile splitting. The question of

which of these effects dominates is a quantitative one which cannot be answered at the present stage of data analysis. Preliminary indications are, however, that if the primary charge-yield distribution is not very broad, equilibrium evaporation of charged particles from the highly excited and relatively light reaction products can account for the sparse yield of products with $Z > 25$.

Fig. 13. Distribution of coincident events as a function of the sum of the nuclear charges of the two detected partners, $Z_1 + Z_2$, and the sum of their lab energies, $E_{1,LAB} + E_{2,LAB}$. For a discussion of regions (a), (b), and (c), see the text and Fig. 14.

In Fig. 13 the distribution of coincident events is shown as a function of $Z_1 + Z_2$ and of $E_1 + E_2$. A strong peak appears centered at $Z_1 + Z_2 \approx 40$ and $E_1 + E_2 \approx 440$ MeV. Events in this peak are believed to originate from binary events which involve large energy losses and, therefore, large amounts of charged-particle emission. The peak represents only a small portion of all binary events due to phase-space restrictions resulting from our experimental geometry and from energy thresholds. The above interpretation of the origin of the peak is supported by the velocity plot of Fig. 14(a). The events comprising the peak are shown to have a velocity in the beam direction similar to the velocity of the center of mass. (The shift toward somewhat higher velocities is believed to be due to the phase-space bias discussed above.)

Ternary projectile-splitting events with a low to moderate energy loss in the first step of the reaction are shown in region (b) of Fig. 13. There are no obvious alternative explanations available for the origin of these events. The fast fission interpretation is given support by the velocity plot of Fig. 14(b) in which events from the (b) region of Fig. 13 are shown. The velocities involved are only slightly less than the beam velocity. For these events the relatively low energy loss, the high velocity in the beam direction, and the low value of $Z_1 + Z_2$ centered near $Z = 28$, all point to the projectile-splitting interpretation. Also shown in Fig. 14 are events of region (c) of Fig. 13. Their velocities can be seen to be intermediate between those of region (a) and those of region

(b) of Fig. 13. It is probable that both binary and ternary events contribute to the events found in this region. In summary, the preliminary conclusion from this study is that in the case of $^{58}\text{Ni} - ^{58}\text{Ni}$ at 15.1 MeV/u, fast fission of the projectile-like products is observed over an extended range of energy loss.

Fig. 14. Distributions of velocities, v , of the center of mass of the 1-2 systems. ($v = [m_1 v_1 + m_2 v_2] / [m_1 + m_2]$, where m and v refer to the masses and velocities of the two detected products.) The velocities are shown in terms of their components along the beam direction, v_x , and perpendicular to it, v_y . The solid line depicts the velocity of the center of mass of the total system. The combined length of the solid line and dashed line indicates the beam velocity. Events in parts (a), (b), and (c) are taken from the regions with the corresponding labels in Fig. 13.

4.2. SPIN SPECTROMETER STUDY OF THE $^{19}\text{F} + ^{159}\text{Tb}$ REACTION¹¹⁾

The ORNL Spin Spectrometer ("crystal ball") consists of an array of 72 sodium iodide crystals arranged in a 4π geometry about a thin-walled spherical reaction chamber. It has been used in a number of investigations ranging from nuclear structure studies to studies of equilibrium (compound nucleus) processes.¹²⁾ The purpose of the work presented here was to study various nonequilibrium features of the $^{19}\text{F} + ^{159}\text{Tb}$ reaction at 180 MeV. Eleven silicon counter telescopes were installed inside the reaction chamber at angles ranging from 15° to 150° . All telescopes detected α particles and protons, and four of them (located at 20° , 30° , 40° , and 50°) also detected products from Li through Mg. Only preliminary results obtained from a limited portion of the data will be discussed here.

Various reaction mechanisms give rise to the observed projectile-like fragments ($3 \leq Z \leq 12$). Two limiting processes are frequently considered: incomplete fusion (also referred to as massive transfer or breakup fusion) and deeply inelastic reactions (also known as damped events). In the former case, the projectile splits during the early stage of the interaction. One portion of it fuses with the target nucleus, while the other continues to travel with approximately the beam velocity. It was found¹³⁾ earlier that the average γ multiplicity, $\langle M_\gamma \rangle$, for such partially fused systems varies linearly with the captured mass. It follows that the angular momentum carried off by the escaping particle is proportional to its mass. The energies of these particles are expected¹⁴⁾ to correspond closely to the optimum Q value for particle transfer, which is determined by the conservation of linear and angular momentum along classical trajectories. In deeply inelastic collisions, on the other hand, the projectile and target nuclei remain in contact for a longer time, during which their relative kinetic energy is converted to rotational energy and to internal excitation. The angular momentum deposited in the target-like reaction product tends to be larger in this case than in the incomplete-fusion case. In the limit of complete energy damping, the observed kinetic energies of the deeply inelastic products reflect the mutual Coulomb repulsion of the fragments at scission.

Fig. 15. Distribution of nitrogen products at 40° from reactions between 180-MeV ^{19}F and ^{159}Tb as a function of their energy and of the associated γ -ray coincidence fold, k . One of the arrows on the abscissa indicates the location of the energy corresponding to the optimum Q value for ^{15}N products, and the other arrow gives the Coulomb barrier in the exit channel.

As a result of the different characteristics described above, it should be possible to distinguish incomplete-fusion events from deeply inelastic events on the basis of the energies of projectile-like particles and of angular momenta of target-like products. These angular momenta are reflected in the associated γ multiplicities which are, in turn, derived from the measured γ -coincidence fold, k . In Fig. 15 the distribution of nitrogen events measured at 40° is shown as a function of k and of the energies of the nitrogen products. Energies corresponding to the optimum Q value and to Coulomb repulsion in the exit channel are indicated. Three distinct regions of events are visible. These correspond to incomplete fusion, to strongly damped collisions, and to events from reactions with target contaminants (low k and low energy).

In Fig. 16 similar density maps are shown for a number of nitrogen isotopes at the lab grazing angle of 30° . At this angle, the deeply inelastic component is relatively weak and no longer stands out. In addition to the groups of events discussed above, a new group appears in the case of ^{15}N and ^{14}N products at very low k values and at energies corresponding to the optimum Q value. In this case,

the heavy product is evidently left with very little excitation energy. It is possible that these events are due to the breakup of the projectile, without the subsequent capture of one of its portions. This mechanism would thus result in a three-body final state with little energy transfer to the target nucleus. This situation is reminiscent of earlier results obtained with a ^{16}O beam in which very low-lying states of target nuclei were observed in coincidence with ^{12}C fragments.¹⁵⁾

The above qualitative discussion has been restricted to only one limited aspect of the data. More results are already available,^{11,16)} such as the confirmation that $\langle M_Y \rangle$ decreases with increasing mass of the projectile-like product. An interesting and unexpected correlation has also been observed between $\langle M_Y \rangle$ and the Z of these products.

Fig. 16. Distributions similar to these of Fig. 15 for various nitrogen isotopes at 30° .

5. Lifetime measurements of high-spin states in $^{160}\text{Yb}^{17,22}$

The decay scheme of the 90-neutron nucleus ^{160}Yb has been studied extensively by several groups. A recent version of the level scheme is given in Ref. 18. It exhibits an yrast sequence extending to spin 34^- with two backbends (near spins 12^+ and 28^+), as well as five well-developed side bands with their own associated backbends. The location of the various backbends, as well as the general features of the decay scheme, are consistent with predictions of the cranked shell model.¹⁹) The purpose of the work presented here was to obtain transition matrix elements for as many of the states as possible in order to indicate any possible model deficiencies and to evaluate the need for self-consistent theoretical approaches such as Hartree-Fock-Bogoliubov (HFB) calculations.

Lifetime measurements of states in unstable nuclei can be made by means of the Doppler-shift recoil-distance method applied to compound nucleus reactions. In order to pursue such studies, a high-precision Doppler-shift recoil-distance device ("plunger") has been constructed at ORNL. It was designed to fit inside a 7-cm diameter annular opening of a 25-cm x 25-cm NaI detector. Appropriate gates on the total energy signal from this NaI detector were used to provide various degrees of selectivity of reaction exit channels.

Fig. 17. Sections of the γ -ray spectra recorded at target-stopper separations of (a) 25 μm , (b) 100 μm , and (c) 2 mm. Only the members of the yrast sequence are labeled.

In order to produce the high-spin states in ^{160}Yb together with a suitable recoil velocity, the reaction $^{116}\text{Cd}(^{48}\text{Ti}, 4n)$ was used. The 205-MeV ^{48}Ti projectile imparted a recoil velocity of 6.9 $\mu\text{m}/\text{psec}$ to the resulting ^{160}Yb products. Spectra were measured at 11 target-stopper separations ranging from 25 μm to 2 mm. In Fig. 17 limited energy regions of the Ge(Li) spectra are shown for three target-stopper distances. Due to the complexity of the spectra, it was not possible to deduce the areas of both the shifted and the unshifted peaks of all transitions. Furthermore, data analysis was complicated by the problem of side-feeding from unobserved levels, and the lifetimes of some levels were too short to be determined in this experiment. The lifetimes and deduced $B(E2)$ values of some of the members of the yrast sequence are given in Table 1. The indicated uncertainties take into account not only the usual uncertainties in the decay curves but also the problems associated with side-feeding.

Table 1. Lifetimes of some yrast states of ^{166}Yb

State (J^π)	Lifetime (ps)	$B(E2)_{\text{exp}}/B(E2)_{\text{rot}}$
2^-	164 ± 9	1.00
4^-	11.7 ± 2.0	0.87 ± 0.15
14^-	10.9 ± 1.0	0.68 ± 0.06
16^-	2.8 ± 0.3	1.07 ± 0.11
18^-	3.0 ± 0.3	0.41 ± 0.04
20^-	1.7 ± 0.2	0.42 ± 0.04
22^-	1.3 ± 0.2	0.28 ± 0.04

The striking feature of Table 1 is the definite drop-off in collectivity with increasing spin. This result and also the deduced values of the transition quadrupole moments, Q_t , have been compared¹⁸⁾ with recent HFB calculations²⁰⁾ which indicate that, in the ground band, ^{166}Yb stretches with increasing rotational frequency. Unfortunately, reliable lifetime values could not be determined for the higher spin states of the ground band, and thus a comparison of experiment and theory is not possible here. However, the Q_t values in the s band fall off with increasing rotational frequency, ω , and this behavior is well accounted for in the calculations through an increase in the γ degree of deformation. Furthermore, plots of Q_t values versus ω indicate that there is a decrease of Q_t with increasing ω , not only in the case of the s band, but also in the case of the side bands. Similar behavior is observed in ^{164}Yb and ^{154}Dy , and the trend, therefore, appears to be independent of the quasi-particle configuration in the case of these nuclei at or near the 90-neutron transition boundary. One possible explanation of this effect is that, in this transition region, the collectivity of the states built on various quasi-particle configurations is governed by the γ degree of freedom, while ϵ_2 remains essentially constant.

As pointed out above, it was not possible to obtain reliable lifetime results for all members of the ground band because of the side-feeding and the short lifetimes involved. In future experiments a unique feature of HHIRF will be exploited, and inverse kinematics will be applied to the reaction under investigation. The heavy ^{116}Cd beam is able to impart a larger velocity to the recoiling system, resulting in a greater sensitivity of the measurements to short lifetimes. Results from such an experiment may provide a direct confirmation of the above picture.

6. Conclusion and acknowledgements

Preliminary results have been presented from five different research projects underway at HHIRF. This represents only a small fraction of the total research effort. No attempt was made to give a balanced representation of all research areas. For example, due to the nature of this conference, reaction studies were emphasized. The omission of the work from UNISOR, currently celebrating its tenth anniversary, is particularly regrettable, as is the failure to discuss (with one exception) some of the numerous collaborations between the in-house staff and the various outside groups.

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