5. RESEARCH ACTIVITIES

5.1 NUCLEAR PHYSICS

R.K. Bhowmik and S.K. Datta

After the successful conclusion of INGA runs at the HIRA beam line, the electronics has been reassembled at the GDA beam line to resume gamma spectroscopy experiments at NSC. Primary emphasis this year has been on the measurement of transition probabilities of nuclear states by RDM and DSAM technique. Lifetime measurements have been carried out on the nuclei ^{81,83}Rb, ^{132,134}La, ^{139}Pm, ^{167}Lu, and ^{195,197}Pb. Perturbed Angular Distribution (PAD) setup has been used to measure the g-factor for the $31/2^+$ isomer in ^{153}Ho.

The experiments carried out using the INGA facility at NSC in 2003 have now been analysed. From the measurement of lifetime by DSAM technique, a ΔI=1 band observed in ^{112}Sb has been assigned to magnetic rotation. A search for band termination was carried out band in ^{113}Sb. A l number of rotational bands have been identified in the transitional nuclei ^{125}Cs and ^{137}Ce.

HIRA facility has been extensively used for studying fission hindrance in heavy ion induced fission. The BGO array has been used in this setup for gamma multiplicity measurements. Clean separation between the evaporation residues and beam-induced background was obtained by TOF measurement.

A number of experiments have been carried out using the GPSC facility to understand fission dynamics near the Coulomb barrier by measuring the fission fragment mass distribution. A large enhancement in the width of the mass distribution has been observed for deformed targets. This has been attributed to the role of quasi-fission processes near the barrier.

Entrance channel effects in fusion well above the barrier have been investigated by populating the compound nucleus ^{61}Cu at roughly the same excitation energy and angular momentum by both asymmetric and nearly symmetric reaction channels. There are systematic differences in the energy spectra for emitted alpha particles in the two reactions, which has been interpreted in terms of the larger equilibration time for the symmetric system.

5.1.1 Lifetime measurements in ^{112}Sb and ^{113}Sb

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Antimony isotopes show variety of phenomena and are of particular interest as they lie just beyond Z = 50 shell closure. The existence of low-lying single particle states with collective structures, at higher excitation energies, was first observed in the odd-mass antimony [1,2] and even-mass tin [3] nuclei. The collective structures result from proton particle-hole excitation across Z = 50 shell gap. These excitations primarily involve promotion of protons from the β-up-sloping $\pi g_{9/2}$ orbital into the β-down-sloping $\pi(g_{7/2}, d_{5/2})$ or $\pi h_{11/2}$ orbitals, for prolate deformations. Such bands in Sb isotopes are based on a 3p-2h structure. Another interesting aspect of this mass region is observation of smooth terminating bands. Such bands have been reported in some twenty nuclei with highest spins in the range of 40-50$\hbar$ (4 and references therein). The abundance of these bands can be attributed to (i) the limited number of valance nucleons outside the double shell closure at N = Z =50 and (ii) a specific configuration remains yrast over a wide spin range. Rotational-like M1 sequences now known as shears bands [5] in nearly spherical nuclei have also been focus of research interest ever since their discovery. These bands are based on the configurations involving high-Ω $g_{9/2}$ protons and low-Ω $h_{11/2}$ neutrons, in the A ≈ 110 region. At the bandhead, these angular momentum vectors are perpendicular to each other. Higher angular momentum states in the band result as these vectors align with the total angular momentum vector. This is reflected in the decrease in B(M1) values with increasing angular momentum [6].

High-spin states in ^{112}Sb and ^{113}Sb were populated using ^{89}Y(^{30}Si, α3n/α2n) fusion-evaporation reactions at 120 MeV. The ^{30}Si beam was delivered by the 15-UD pelletron at Nuclear Science Centre (NSC), New Delhi. The gamma-rays following the reaction were detected using an early implementation of Indian National Gamma Array (INGA) consisting of five clover detectors at the time of experiment. Out of five clovers three were situated at an angle 141^o and remaining two at 81^o with respect to the beam direction. About 500μg/cm^2 of yttrium was deposited on a gold foil of thickness 10mg/cm^2, which comprised the target. The data were acquired using CANDLE, an acquisition system developed at NSC. The other details about the experiment and the data analysis can be found elsewhere [7,8].

^{112}Sb:

The cross-section for ^{112}Sb was a small fraction of the total fusion cross-section. Therefore, the negative parity M1 band [9] that carries about 30% of total intensity could be studied. The band was predicted to exhibit the shears mechanism.

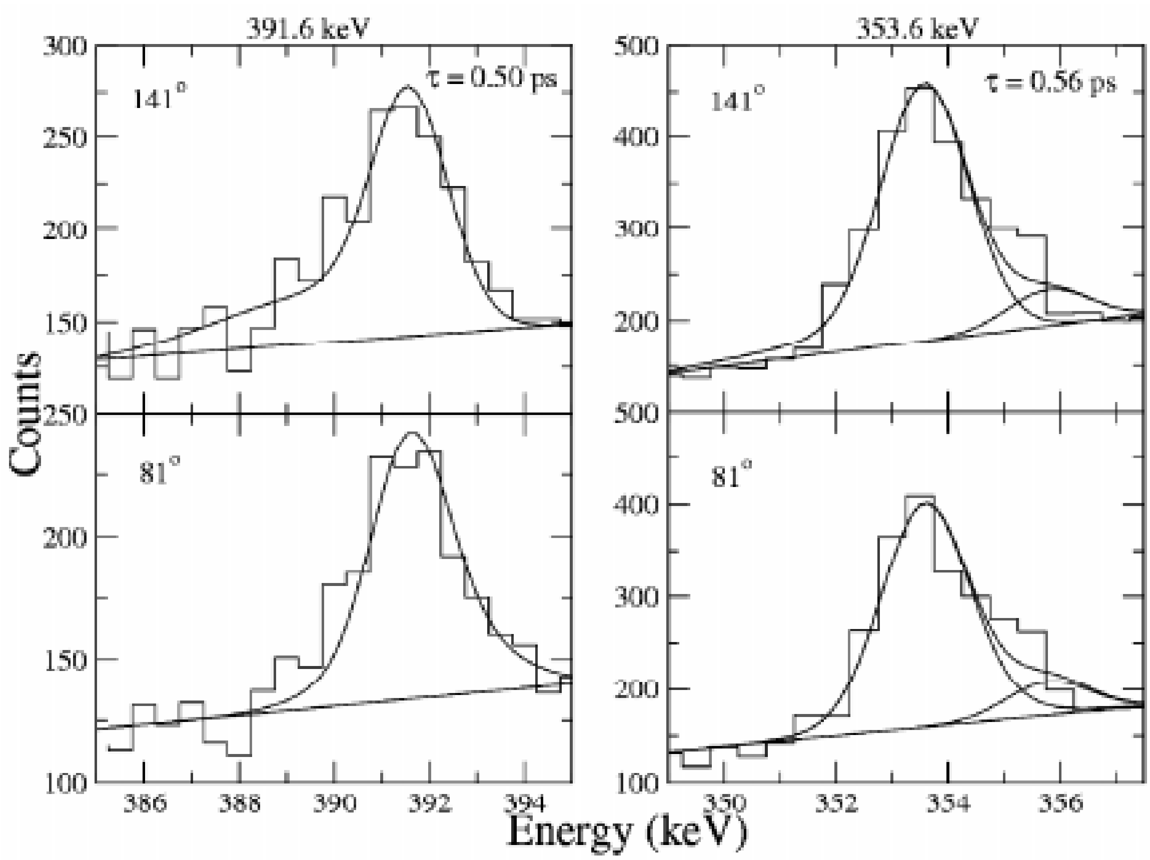

Fig. 1 : Experimental data and associated lineshapes for 353.6 and 391.6 keV transitions

Figure 1 shows the fits to the experimental data for 353.6 and 391.6 keV transitions obtained from LINESHAPE [10] analysis. The results are summarized in Table 1 which also gives estimated M1 and E2 transition rates. The quoted errors do not include systematic errors arising from uncertainties in the stopping powers and may be as large as 10-15%.

TABLE I

Measured lifetimes of states in M1 band, τ and corresponding B(M1) and B(E2) transition strengths.

***Eγ* (keV)**	***τ* (ps)**	***B(M1)* $(\mu_N)^2$**	***B(E2)* (eb)^2**
353.6	$0.56^{0.26}_{0.25}$	$2.28^{0.69}_{1.03}$	$1.00^{0.30}_{0.45}$
380.2	$0.51^{0.16}_{0.17}$	$2.04^{0.70}_{0.63}$	$0.74^{0.25}_{0.23}$
391.6	$0.56^{0.26}_{0.25}$	$1.90^{0.38}_{0.43}$	$0.59^{0.10}_{0.11}$

In order to confirm the nature of the band and to assign the configuration to the band we performed semiclassical tilted axis cranking (TAC) calculations using the hybrid version, which facilitates the use of realistic flat bottom potential. In the ^{112}Sb nucleus, there is a proton hole in $g_{9/2}$ orbital and the last neutron occupies the $h_{11/2}$ shell. Therefore, $\pi g_{9/2}^{-1} \otimes h_{11/2}$ configuration was chosen for the calculations. The decrease in B(M1) values is well accounted for within the framework of TAC model (Fig. 2). The results of the calculations are shown in Fig. 3. The similarity between the slopes of the two curves verifies our choice of the configuration.

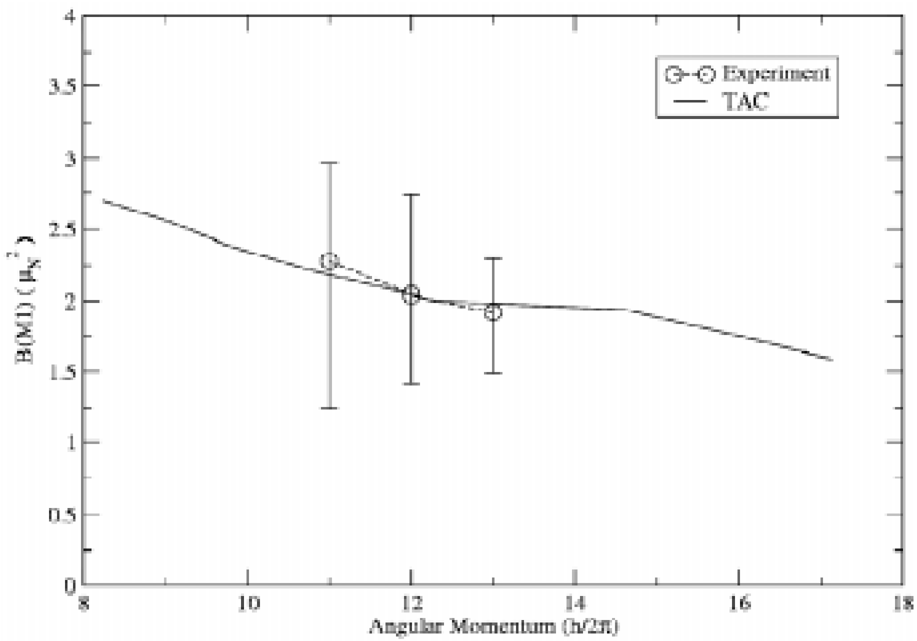

Fig. 2 : B(M1) values versus angular momentum for the band under study.

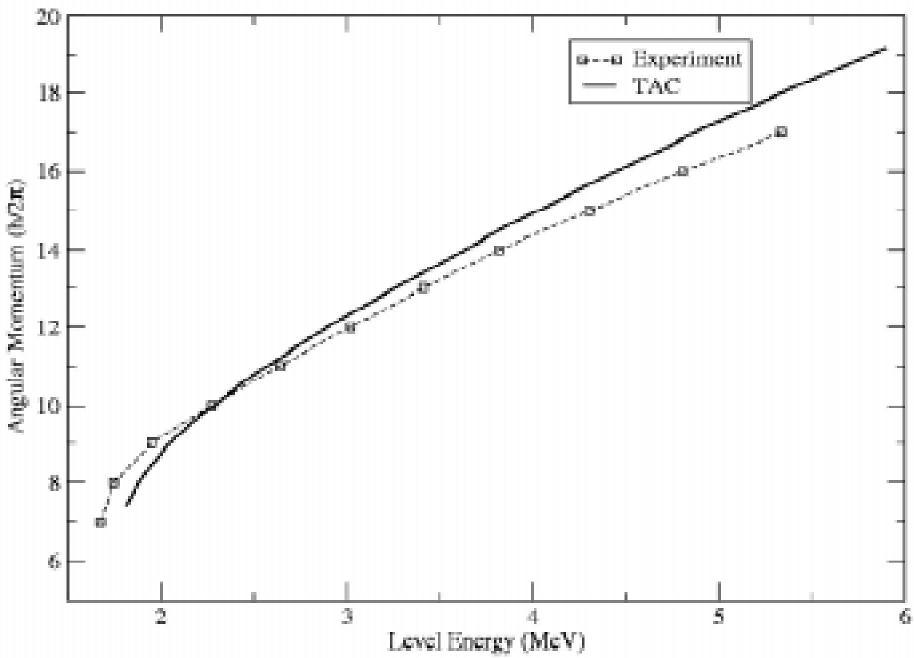

Fig. 3 : Angular momentum as a function of level energy.

To summarize, we determined lifetimes of three states in one of the M1 bands in 112Sb using Doppler-Shift Attenuation Method. Though derived B(M1) values do not show much decrease they are in good agreement with the TAC prediction based on $\pi g_{9/2}^{-1} \otimes h_{11/2}$ configuration. The B(E2) values are found to be considerably higher than those in the neighbouring nuclei which are known to exhibit shears mechanism.

^{113}Sb:

All isotopes of antimony from ^{107}Sb to ^{113}Sb are reported to exhibit smooth band termination (4 and references therein). The first conclusive evidence of smooth band termination as gradual transition from collective rotation to non-collective terminating states was reported in ^{108}Sn and ^{109}Sb by R. Wadsworth *et al.* [11]. They have determined lifetime of states in two bands in ^{108}Sn and one in ^{109}Sb using DSAM technique. V.P. Janzen *et al.* [12] measured lifetimes of the states in $\pi h_{11/2}$ band using Doppler-shift analysis of the gamma-ray centroid shifts in this nucleus. This has resulted in $Q_0 = 4.4 \pm 0.6$ eb.

We have attempted to measure lifetimes of the states in the band, which is already known to as a well deformed band, in search of band termination. Experimental lineshape along with lineshape fits, obtained by minimizing χ^2, for 854 and 986 keV transitions are shown in Fig. 4. Table II summarizes the results obtained from lineshape analysis. We have done the cranked Woods-Saxon calculations in order to understand the experimental results for the band. The results of these calculations indicate a prolate minimum with β_2 = 0.27 and a slightly negative γ-deformation across the range of rotational frequencies from 0.2 to 0.6 MeV (Fig. 5). A shape transition to a triaxial shape (with positive gamma) is seen to begin at 0.6 MeV. However, this frequency is beyond the experimental observations.

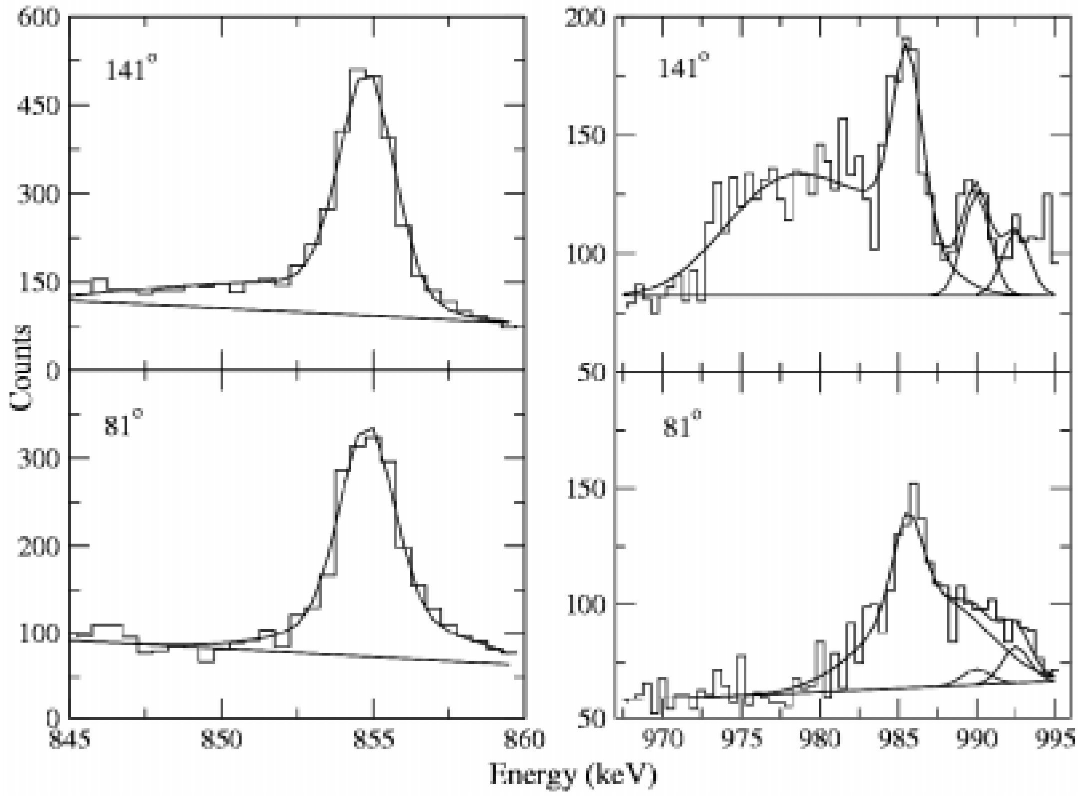

Fig. 4 : Experiment lineshapes along with fits obtained from LINESHAPE analysis for 854.8 and 985.6 keV transitions.

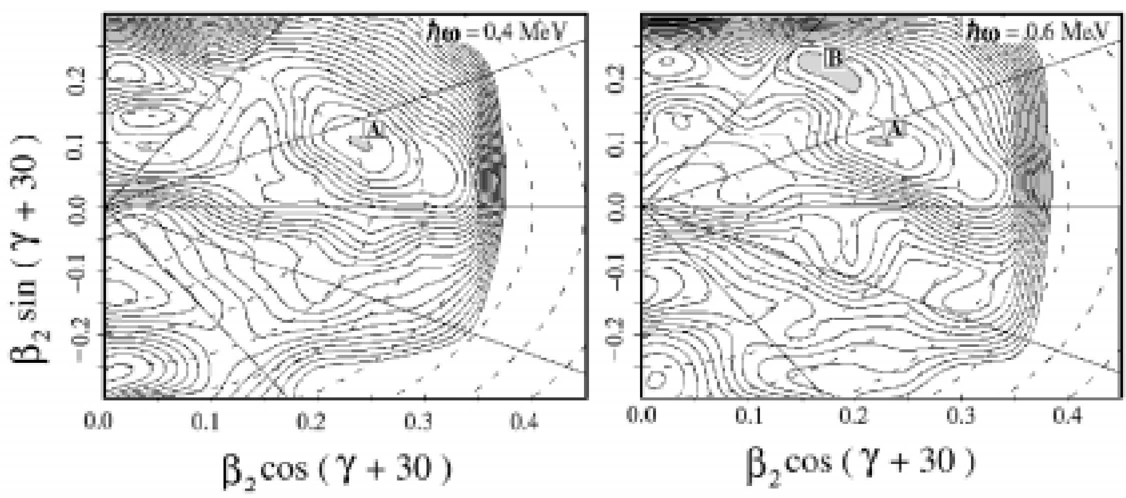

Fig. 5 : Total Routhian Surfaces for negative parity band in ^{113}Sb.

TABLE II

Lifetimes, quadrupole moments and B(E2) transition strengths for $\pi h_{11/2}$ band in ^{113}Sb.

***Eγ* (keV)**	***τ* (ps)**	***Q_t* (eb)**	***B(E2)* (eb)^2**
854.8	$0.32^{0.03}_{0.03}$	$4.91^{0.21}_{0.21}$	$0.56^{0.04}_{0.04}$
918.6	$0.21^{0.02}_{0.02}$	$4.83^{0.25}_{0.24}$	$0.59^{0.06}_{0.06}$
985.6	$0.16^{0.02}_{0.01}$	$4.48^{0.25}_{0.21}$	$0.55^{0.06}_{0.05}$

The values of deformation (β_2, γ) at a rotational frequency of 0.4 MeV are (0.27, -10^o). This corresponds to a transition quadrupole moment of 4.2 eb which is in reasonable agreement with the values of 4.4-4.9 eb those we have deduced from the DSAM measurements.

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5.1.2 In beam γ-ray spectroscopy of ^{125}Cs

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The $_{55}$Cs nuclei are expected to display a rich variety of band structures as the deformation remains well-developed across a large range of the neutron Fermi surface. For the odd-Z nuclei, the shape at low rotational frequencies is mainly influenced by the valence quasiproton. At higher frequencies, additional rotationally-aligned $\nu(h_{11/2})^2$ quasiparticles are expected to polarize the γ-soft core depending upon the position of the neutron Fermi surface in the $h_{11/2}$ shell. In continuation to our earlier investigations in this region [1,2], we have done experiment to study high spin states in ^{125}Cs nuclei.

High spin states in ^{125}Cs populated in the fusion-evaporation ^{100}Mo (^{28}Si, p2n) and ^{100}Mo (^{30}Si, p4n) reactions at E_{lab} = 130 and 138 MeV, respectively, have been investigated through in-beam γ-ray spectroscopic techniques. A total of 300 million events were collected for the reaction ^{100}Mo (^{30}Si, p4n). The data were subsequently sorted offline using INGASORT program to produce a symmetrized 4k x 4k matrix of $E\gamma$ vs $E\gamma$. The level scheme is shown in fig 1. It consists of rotational structures labelled “A-G”. The earlier level scheme of ^{125}Cs [2] has been extended substantially. Single quasiparticle

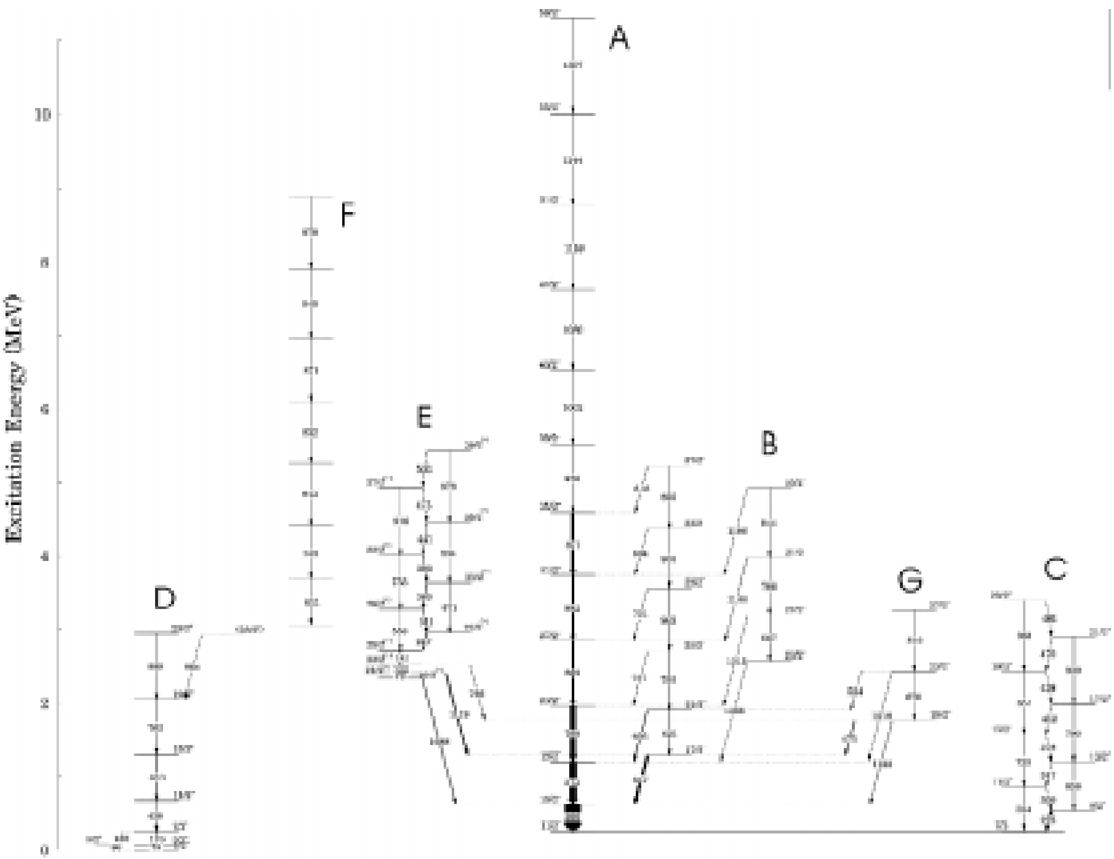

Fig. 1 : Level scheme of ^{125}Cs

bands are based on $\pi h_{11/2}$, $\pi g_{7/2}$ and $\pi(g_{9/2})^{-1}$ orbitals, respectively. The yrast band 'A' based on the $\pi h_{11/2}$ exhibits $\nu(h_{11/2})^2$ neutron pair alignment at $\hbar\omega$ = 0.43 MeV in both the signature partners. In addition, the earlier observed coupled band "E" has been reassigned high-K three-quasiparticle $\pi h_{11/2} \otimes \nu g_{7/2} \otimes \nu h_{11/2}$ configuration.. A new rotational band 'F' comprising of 611, 743, 832, 843, 865, 871, 949 and 979 keV transitions is found. This band is decaying mainly to the $\pi h_{11/2}$ band 'A' and also to the $\pi g_{7/2}$ band 'D'. Linking pattern is yet to be established. The observed part is likely to involve rotationally aligned $\nu(h_{11/2})^2$ and $\pi(h_{11/2})^2$ quasiparticles.

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5.1.3 Deformation Characteristics of Odd-Odd nuclei, ^{132}La and ^{134}La

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The odd-odd nuclei, ^{132}La and ^{134}La, have been the focus of our study in the recent past. The nuclei in the mass region ~ 130, specially the odd-odd ones, show a rich variety of nuclear structure properties e.g. the chirality in nuclear rotation, first observed in ^{132}La by Starosta et. al. [1]. Earlier we studied the level schemes of ^{132}La and ^{134}La by populating them via ^{122}Sn (^{14}N, 4n) ^{132}La and ^{124}Sn (^{14}N, 4n) ^{134}La reactions, respectively. In the case of ^{132}La, we made a definite spin assignment to the chiral band [2] by identifying a new transition of energy 351 keV decaying from the band head. In addition, an entirely new band, tentatively assigned as a 'doubly decoupled band' was found from our data. In order to confirm the nature of this band, we needed to determine its deformation characteristics by experimentally finding the life-times of its energy states. Since the life-times were expected to be in the picosecond range, we planned an experiment based on the Recoil Distance Method (RDM). Similarly, life-times of many low spin states in ^{134}La, either known [3] or found from our data [4] were predicted to have the life-times in the RDM range.

Two experiments were performed in September 2004, utilizing the plunger in the GDA set-up. The reaction used were (i) ^{124}Sn (^{15}N, 5n) ^{134}La at E_{lab} = 75 MeV and (ii) ^{122}Sn (^{15}N, 5n) ^{132}La at E_{lab} = 83 MeV. These experiments were done with ^{15}N beam instead of ^{14}N (used in earlier experiments, mentioned above) to get the maximum possible value of recoil velocity of the residues which is an important criteria for these experiments. This was achieved in two ways, firstly by increasing the mass of the projectile and secondly by increasing the beam energy for the 5n reaction channel. However, there were some experimental difficulties and shortcomings which are worth noting here. The TiN (enriched with ^{15}N) mixed with graphite, was used as cathode for the ion source of the Pelletron accelerator. While taking the ^{15}N (charge state: 5^+) beam, from the molecular beam the presence of ^{12}C (charge state: 4^+) could not be avoided. The beam current was good but the data suffered from the contaminated peaks coming from the reaction of ^{12}C on ^{124}Sn target (Fig. 1). To overcome this problem, the choice of beam with the charge state as 6^+ at higher beam energy, was preferred for experiment (ii). This data, however, was of poor statistical quality because of low beam current.

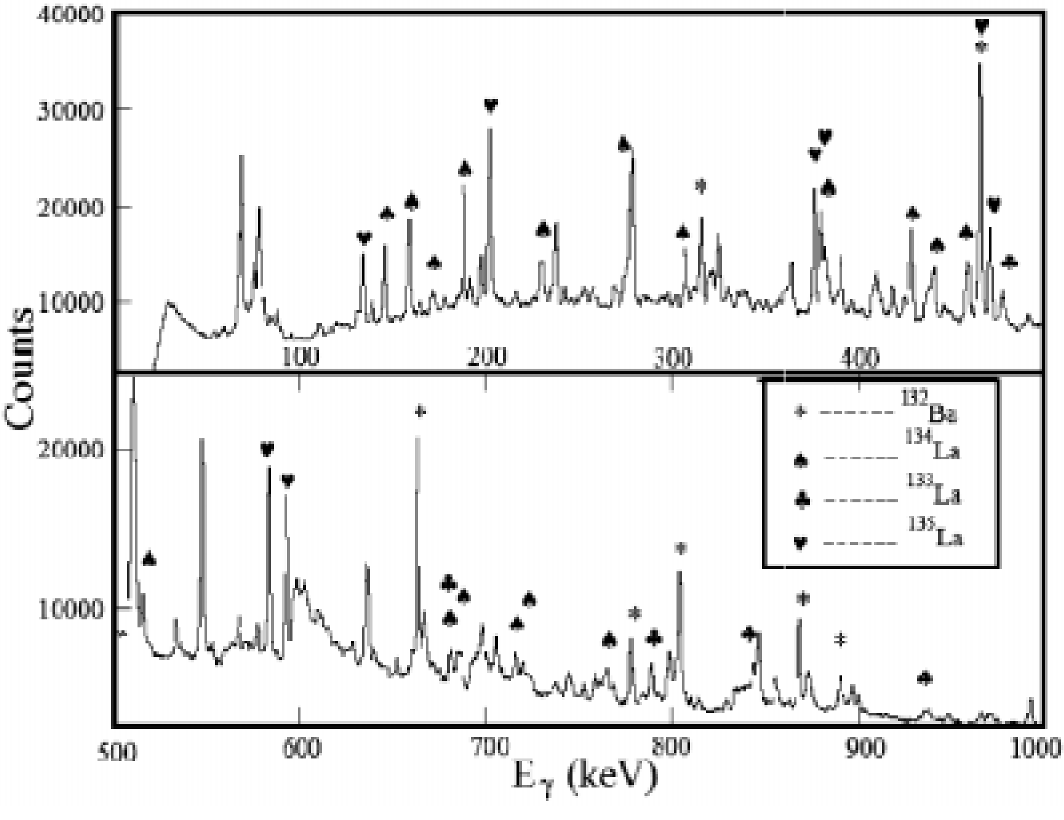

Fig. 1. Gamma energy spectrum for the reaction ^{15}N+ ^{124}Sn. The nucleus ^{132}Ba is formed because of the contamination of ^{12}C in the beam.

Preparing the good target was a challenge in these experiments. The lowest possible value of the measurable life-time depends on the minimum distance between the target and the stopper which in turn depends on the flatness of the target and stopper. By the capacitance measurement the minimum distance achieved was 15.7 μm as shown in the Fig. 2. We could further reduce the separation and collected the experimental data at two more distances. For these points (shown as the filled circle in Fig. 2) the micrometer

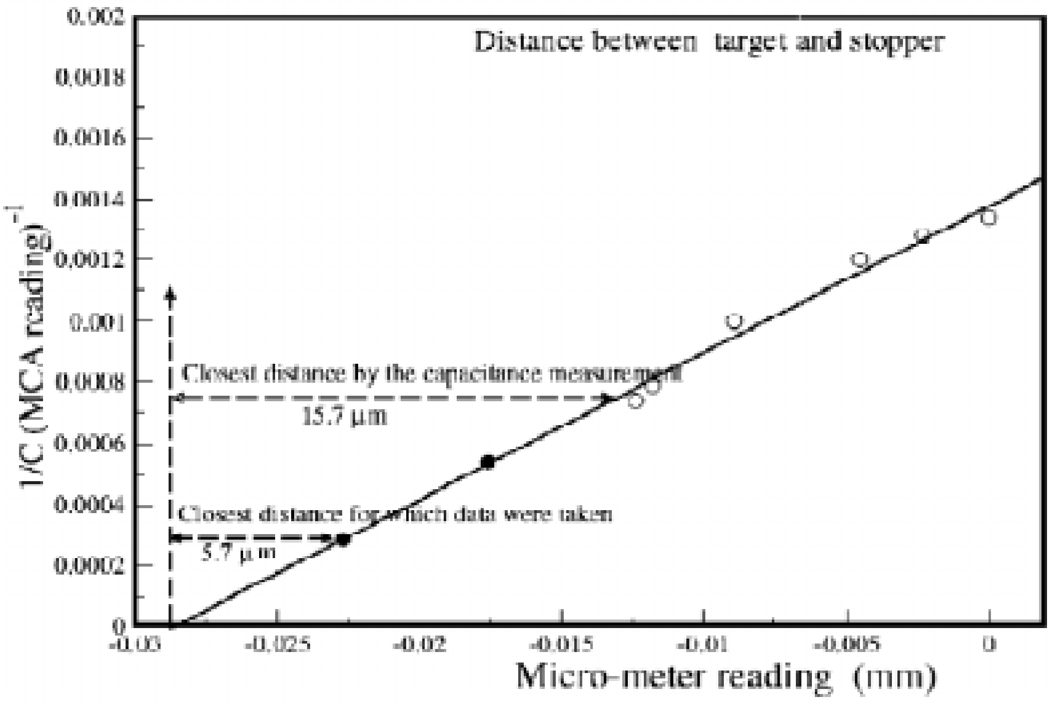

Fig. 2. Calibration of the target-stopper separation by the capacitance measurement.

readings were relied on for finding the separation. We finally collected the data for many distances 6 µm to 10044 µm.

In the initial stage of data analysis, the calibrated E_γ - E_γ matrices were made for different detector angles. From the total projected spectra the intensities of Doppler shifted and unshifted peaks were determined for various values of target-stopper separation. Figure 3 shows an example of a long-lived decay (τ = 794 ± 25 ps) from the band-head of the chiral band belonging to the ^{132}La. An isomerism in the chiral band head is a new result [5] which should be understood from the theoretical framework.

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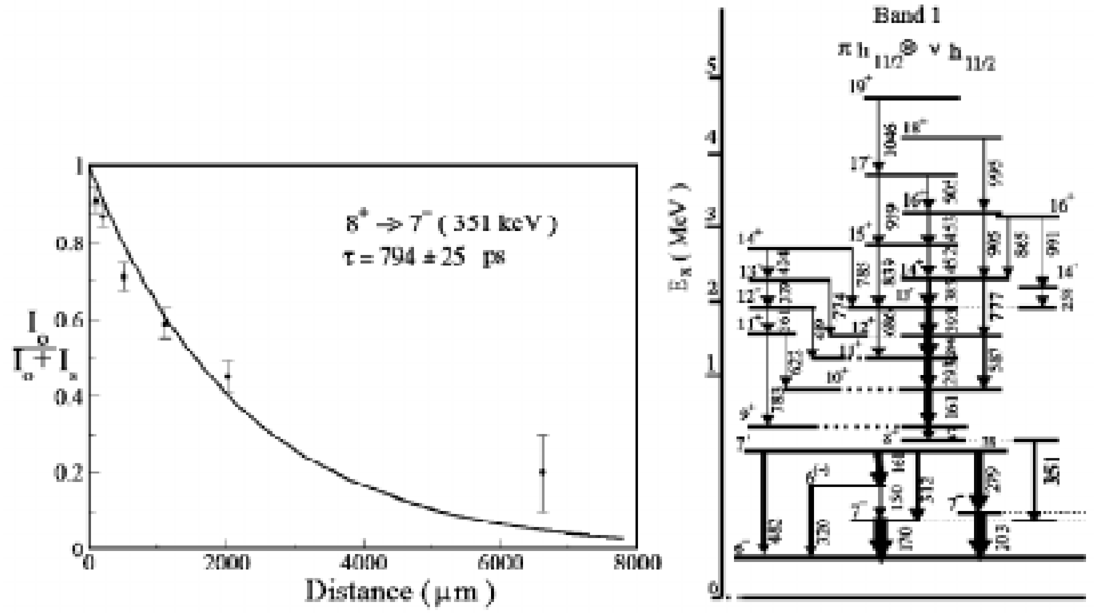

Fig. 3. A plot of the ratio of the unshifted (I_o) and total (I_o+ I_s) intensities for the 351 keV decay from the 8^+ state.

5.1.4 High spin study of N= 79 ^{137}Ce Nucleus

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The ^{137}Ce nucleus, one of the N = 79 transitional nuclei around A = 135, was populated along with ^{138}Ce via ^{130}Te (^{12}C, 5n) reaction using 65 MeV ^{12}C beam from the 15UD pelletron at NSC, New Delhi. The experiment was done using a modest γ array consisting of five Clover Ge detectors out of which two were kept at 81^o in the forward hemisphere and three were kept at 137^o in the backward hemisphere. Apart from these, there were two 23% single crystal HPGe detectors sitting at +10^o in the forward hemisphere. The target used was a 2.2mg/cm^2 enriched (99.9%) ^{130}Te, evaporated on a 2.0mg/cm^2 Au backing and was covered by a 50 μg/cm^2 thin Au film from top. The other details on the experimental set up are described in ref. [1].

The earlier studies [2,3,4] on this nucleus used mostly light ions and established a $(\pi h_{11/2})^{-2}$ decoupled band structure at low spin. Zhu et al [5] have studied the nucleus recently by ^{124}Sn (^{18}O, 5n) ^{137}Ce reaction and extended the level scheme up to 43/2$\hbar$. However, the authors could not establish the spin-parities of many of the newly proposed states unambiguously which warrant further investigation for a better understanding of the high spin structure.

In the present work, the DCO and the polarisation correlation analysis have been done using the upgraded version of INGASORT software package [6, 7]. A major account of the analysis has been reported recently [8]. The DCO ratio was estimated by the conventional method from the DCO matrix made with 137^o detectors along X-axis and the 81^o detectors along the Y-axis. The linear polarisation of a gamma ray of interest is estimated from the normalised difference between the Compton scattered gamma rays, in the plane parallel ($N_{||}$) and perpendicular ($N_{\perp}$) to the reaction plane, in the 81^o Clovers. From the projected spectra, the number of parallel ($N_{||}$) and perpendicular ($N_{\perp}$) scatters for a given gamma ray was determined. The polarisation asymmetry parameter is deduced from the expression

$$P = \{a(E\gamma)N_{\perp} - N_{||}\} / \{a(E\gamma)N_{\perp} + N_{||}\}$$

where the correction parameter $a(E\gamma) = N_{||}$ (unpolarised) / $N_{\perp}$ (unpolarised) comes from the asymmetry in the response of the clover segments. Figure 1 shows a plot of $a(E\gamma)$ versus γ ray energy which has been fitted by a straight line function. Using the fitted $a(E\gamma)$ parameter the polarisation correlation of all the γ rays in ^{137}Ce has been determined which is shown in figure 2.

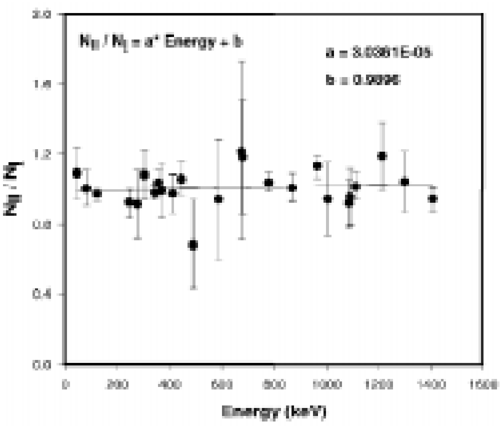

Fig 1. Polarization asymmetry for different transitions in ^{137}Ce

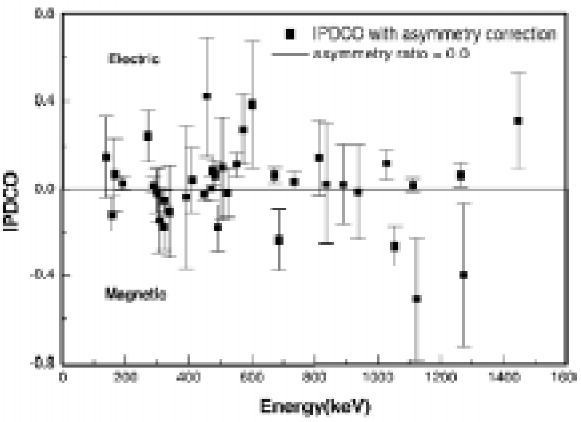

Fig 2. IPDCO ratio for different transitions in ^{137}Ce

Combining the DCO and the polarisation correlation information unique spin parity assignments of higher spin levels in ^{137}Ce have been made (figure 3) and the level scheme has been revised (figure 4). The authors are grateful to the NSC Pelletron operators for their helpful co-operation.

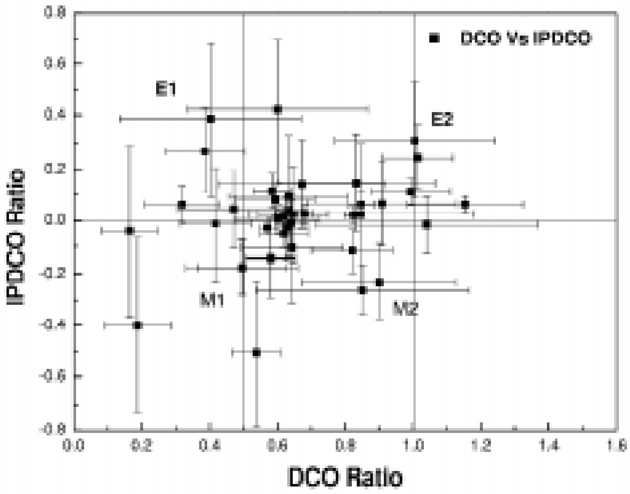

Fig 3. Comparison of Polarization correlation ratio with DCO

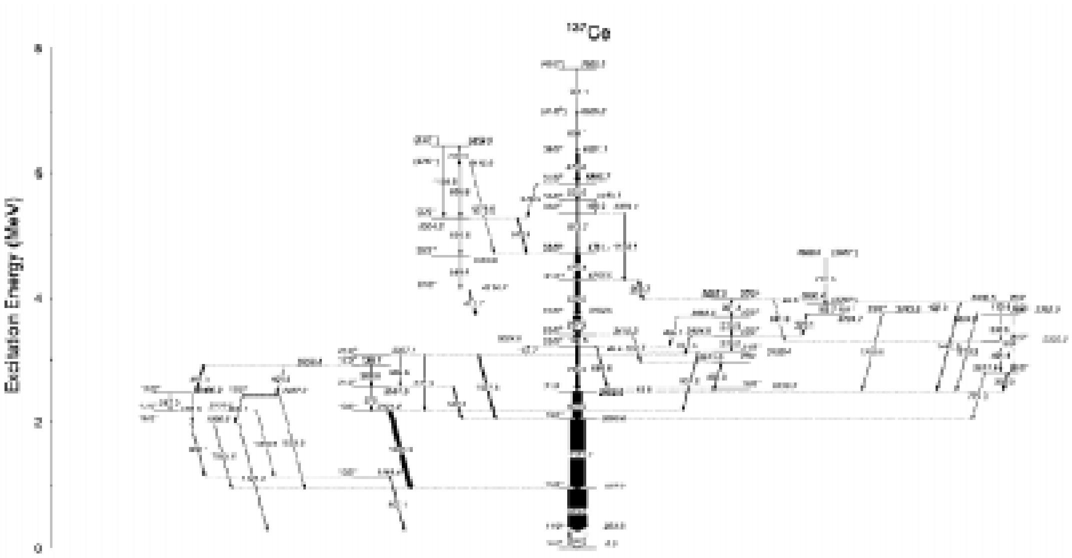

Fig 4. Level scheme of ^{137}Ce

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5.1.5 Study of Magnetic Rotation in odd-A Rb isotopes from Lifetime measurements

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Excited three quasiparticle ΔI=1 bands in several nuclei in the mass A=80 region have been identified as probable candidates for magnetic rotation [1,2]. Experimentally, such bands have been confirmed only in ^{79}Br [3] and $^{82,\,84}$Rb [4] on the basis of lifetime studies. The interpretation for the other nuclei with A~80 is based mostly on the *B(M1)/ B(E2)* ratios derived from γ-ray intensities. However, the predictions of the TAC model can be stringently tested only if the absolute *M1* and *E2* transition strengths are measured from lifetime studies. The present work was undertaken to study the lifetimes of states belonging to the ΔI=1 bands in the odd-A ^{81,83,85}Rb isotopes where magnetic rotation bands are predicted to exist from TAC calculations.

The experiment was carried out using the GDA set up consisting of 12 Compton suppressed HPGe detectors (~25% efficiency). Isotopically enriched (>99%) targets of ^{68}Zn and ^{76}Ge were bombarded with 80 MeV ^{19}F and 50 MeV ^{11}B projectiles, respectively, to populate the excited states of ^{81,83}Rb. The data obtained on ^{83}Rb, produced in ^{76}Ge(^{11}B, 4nγ) at E=50 MeV, is reported here.

Most of the excited states of ^{83}Rb, reported in the literature [5] have been observed in the present work. The ΔI=1 band built on the $13/2^-$, 2313.8 keV state, and reported previously up to $19/2^-$, 2959.2 keV, has been extended to $23/2^-$, 4687 keV. In addition, seven new transitions have been placed in the level scheme, connecting states of the ΔI=1 band to other states. Doppler broadened lineshapes have been observed for the 362.2, 600.3 and 1127 keV transitions belonging to this band. Lineshapes have also been observed for transitions belonging to the $g_{9/2}$ yrast band. The analyses of the data is in progress and the results are expected to yield significant new information on the structures of both the ΔI=1 band and the positive-parity yrast band. The experimental R_{DCO} ratios, obtained in this work, will help in the assignment of firm spins to most of the high spin states.

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5.1.6 The lifetime measurement of MR Band head in ^{197}Pb using Pulsed Beam Method

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More than a decade ago, H.Hubel in Germany and later R.M Clark in U.K., observed rotational like band structures in the nearly spherical ^{198}Pb and ^{199}Pb nuclei. After several studies, it was concluded that the most intense intra band transitions in these bands are not electric quadrupole (E2) in nature, but of magnetic dipole (M1) type. Such bands are termed as Magnetic Rotational (MR) Bands or Magnetic Dipole Bands and subsequently also as Shears Bands [1]. A large transverse magnetic dipole moment is generated, when high-j protons are coupled to high-j neutrons holes or vice versa. The particle-hole coupling gives the lowest energy for a perpendicular orientation of the particle and hole angular momenta [2].

In the odd-lead isotopes, the $(h_{9/2}\, i_{13/2})11^-$ proton excitation across the Z=82 shell gap has particle character, while the neutron contribution is essentially a hole in the $i_{13/2}$ subshell. The perpendicular coupling of $\pi(h_{9/2}\, i_{13/2})11^-$ proton particles and $\nu i_{13/2}^{-1}$ neutron holes results in Magnetic Rotation bands in these odd-lead isotopes. First evidence on perpendicular coupling was reported by a measurement of the g-factor of the 2584-keV band head of the M1 band in ^{193}Pb [3]. The same experiment also confirmed that the band has $[\pi(h_{9/2}\, i_{13/2})_{11}^- \otimes \nu i_{13/2}^{-1}]$ $29/2^-$ structure. In the ^{197}Pb nucleus, similar type of band structure exits at 3283-keV. In order to confirm the perpendicular coupling and the configuration for this band structure in ^{197}Pb nucleus, an experiment has been planned to investigate the lifetime and the g-factor of lowest band head state (isomeric state with one of the de-exciting transition of 432 keV of E1 type) using the Pulsed beam method. In the first stage, we have carried out the lifetime measurement of this band head. The ^{197}Pb nucleus was populated using the reaction ^{186}W (^{16}O, 4n) ^{197}Pb at 97 MeV. The ^{16}O pulsed beam with pulse width 1.2 ns and period 250 ns was delivered by 15-UD Pelletron accelerator at Nuclear Science Centre, New Delhi. Self-supporting enriched ^{186}W target of thickness 1.5 mg/cm^2 was used. The emitted gamma rays were detected using 12 HPGe detectors GDA facility. In order to stop TAC out put, 4 MHz r .f. signal was used. A BaF_2 detector was also used to get fast timing information. A total of 240 million γ–γ events were collected in the list mode. The data has been sorted by using the INGASORT program. In the offline analysis, the data was sorted in to $E\gamma$-$E\gamma$ (4K $\times$ 4K) matrices. The de-exciting 432 KeV transition from the isomeric state of interest is seen in the gated spectrum (fig.1). Further analysis is in progress.

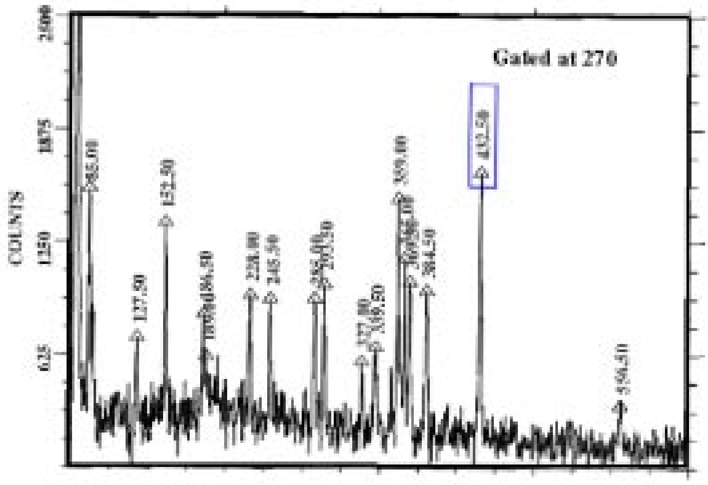

Fig. 1 : Gated γ-ray spectrum in ^{197}Pb

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5.1.7 Lifetime Measurements in ^{139}Pm

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An experiment was performed to study the high spin states in ^{139}Pm [1] and to measure the lifetimes of the nuclear levels of the Yrast band through Doppler Shift Attenuation Method (DSAM). The high spin states in ^{139}Pm were populated using the reaction ^{116}Cd (^{27}Al, 4n) ^{139}Pm at 120 MeV of beam energy delivered by the 15-UD Pelletron accelerator facility at the Nuclear Science Centre (NSC), New Delhi. At this beam energy ^{138}Pm [2] and ^{138}Nd [3] were also populated substantially through the 5n and p4n channels respectively. The target used was enriched ^{116}Cd of thickness 1.75 mg/cm^2 with a backing of Pb of thickness 90 mg/cm^2. The γ-rays were detected using the Gamma Detector Array (GDA) consisting of 12 CS-HPGe detectors with multiplicity filters. In the experimental setup, the detectors were placed at angles of 143°, 50° and 98° respectively with respect to the beam direction. A total of 643 million gamma-gamma coincidence events were collected in the experiment.

The data was sorted out off-line using the INGASORT programme. A number of 4K × 4K matrices were formed with all possible combination of detectors with a dispersion of 0.5 keV/channel. Fig. 1 shows the prominent transitions of the three nuclei in the projected spectrum in all vs all matrix and fig. 2 shows the gated sum spectrum of the Yrast band of ^{139}Pm. Fig. 3 shows the line shape of the 947 keV transition in this band of ^{139}Pm in backward and forward direction.

Analysis of the data is underway to determine the level lifetimes for the rotational bands mentioned above and for the high spin states.

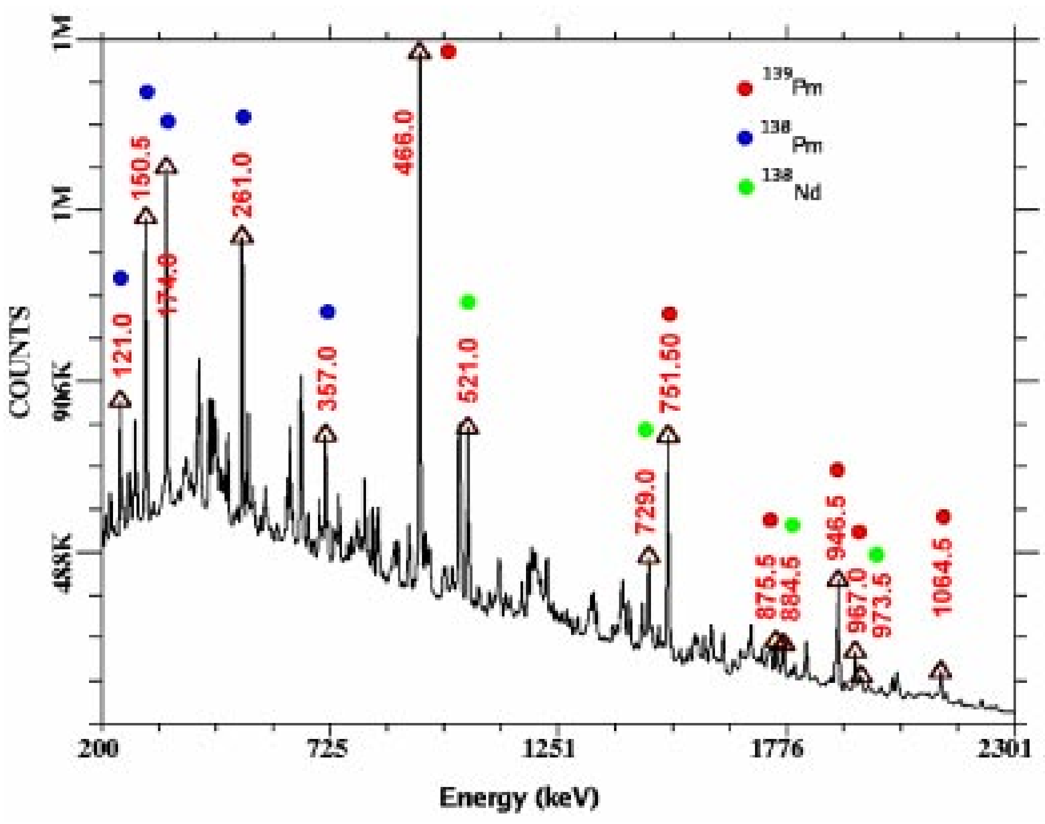

Fig. 1 : Projected spectrum

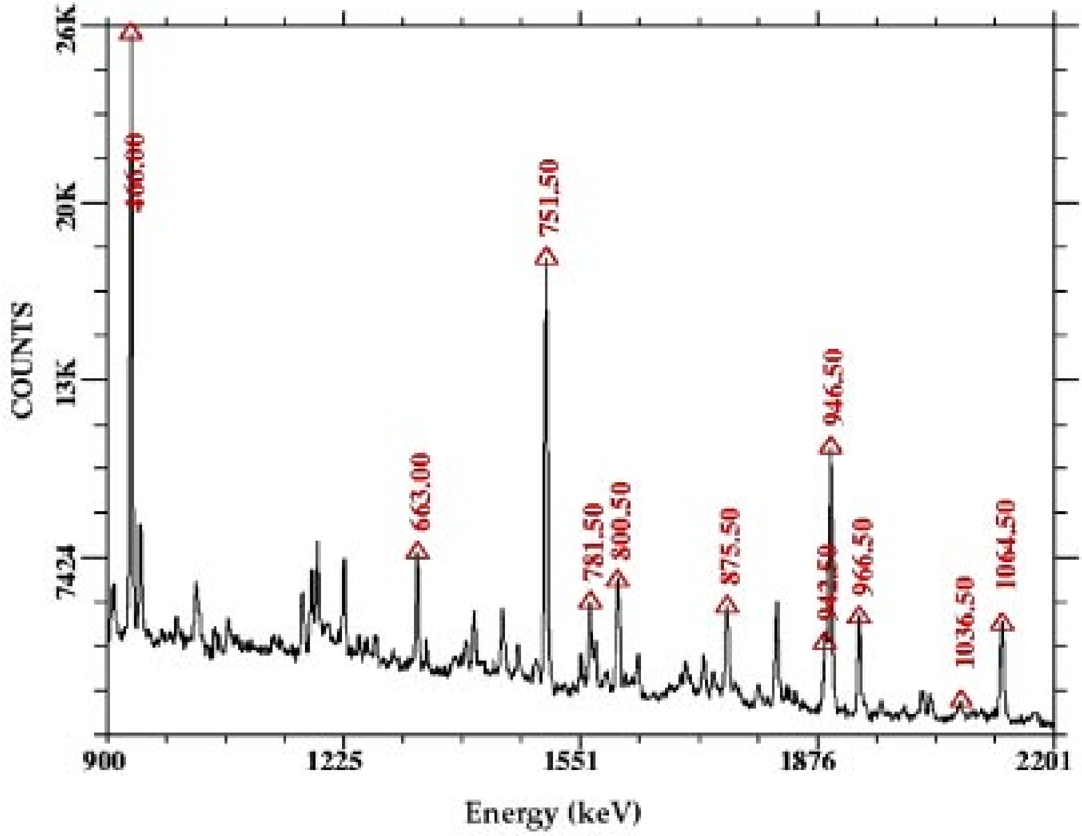

Fig. 2 : Gated sum spectrum of the Yrast band of ^{139}Pm

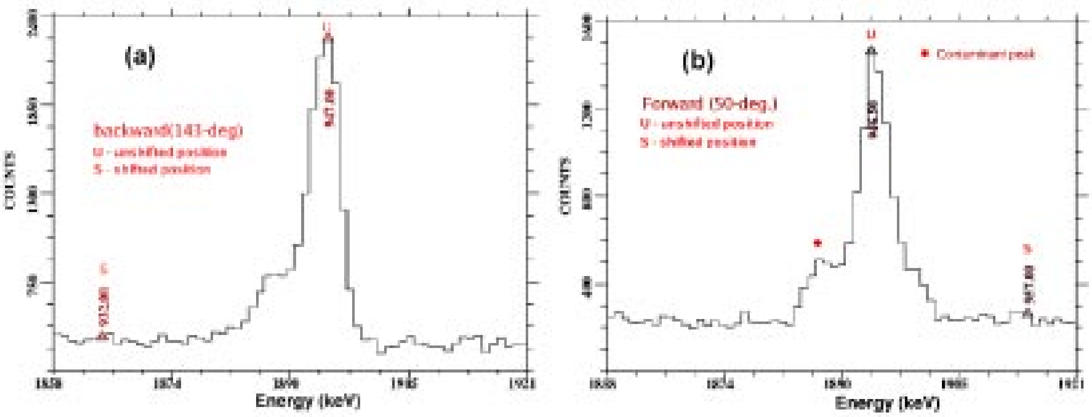

Fig. 3 : Lineshape in 946 keV transition of ^{139}Pm

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5.1.8 Lifetime measurements in ^{167}Lu

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The deformation measurements in the odd – Z nuclei with A ~ 170 are necessary for understanding the variety of nuclear structure phenomena observed in them. These nuclei are normally found to have well deformed prolate structures in their ground state, but when excited, they assume different shapes depending upon the type of orbital occupied by the valence nucleons. Even in the ground state also, a shift from their normal deformed structure is expected if the nuclear mean field in them is not stable. The $_{71}$Lu nuclei fall into this category, which being on the upper edge of the well deformed rare earth region has soft nuclear core. In this mass region the low Ω (= ½) $\pi h_{9/2}$ intruder orbital come down heavily as a function of energy and is therefore populated with enough intensity in these nuclei. When the odd proton is in this highly down sloping orbits, it has a strong polarizing effect on the even-even nuclear core. When the nuclear core is soft, the core polarization effect can give rise to any nuclear shape varying from the normal deformed to rather superdeformed nuclear structure. Such superdeformed nuclear structure has infact being seen in ^{171}Lu [1]. To see the influence of odd proton orbit on the equilibrium nuclear shape and also to study the change in the nuclear structure as a function of spin and excitation energy, we have performed the lifetime measurements for different quasi-proton bands in ^{171}Lu through the recoil distance Doppler shift method (RDM). The extensive level scheme relevant to this work already exists in the literature [2].

The high spins states of ^{167}Lu were populated using the fusion evaporation reaction ^{159}Tb (^{12}C, 4n) ^{167}Lu at a beam energy of E_{lab} = 72 MeV, provided by the 14 UD Pelletron at the Nuclear Science Center (NSC) New Delhi. The minimum distance between the target and the stopper (distance calibration) in the RDM plunger device at NSC was measured with the capacitance method [3]. The data was taken for 16 different target – stopper distances ranging from 20 – 5,000 μm, The emitted gamma rays were collected with the Gamma Detector Array (GDA) setup at NSC, consisting of 12 Compton suppressed HPGe detectors and the 14 element BGO multiplicity filter array. The HPGe detectors in the GDA array are arranged in three different concentric rings of four detectors each, making an angle of 50°, 98° and 144° with the direction of the beam. The data was collected in the singles mode with BGO multiplicity condition M = 2, and also in the List mode (γ -γ) with the with Ge multiplicity condition M = 2. For the analysis purpose, the data of all the four detectors at one angle, after proper gain matching, are added together to form the raw spectrum. The detailed data analysis is in progress.

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5.1.9 Nuclear g-factor measurement of $31/2^+$ isomer in ^{153}Ho

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The $31/2^+$ isomeric state ($T_{1/2}$ = 229 ns) is observed in ^{153}Ho [1], which is a neighbouring isotone of ^{152}Dy and ^{154}Er. It is considered as arising from the coupling of the 11^- isomer in the neighbouring even-even isotope ^{152}Dy [2] to the $h_{11/2}$ proton. The magnetic moment measurement can help to identify its configuration. The TDPAD measurements were performed at 15UD pelletron accelerator facility at Nuclear Science Centre (New Delhi). The $31/2^+$ (E = 2773 keV, $T_{1/2}$ = 229 ns) isomeric state in ^{153}Ho has been populated by the reaction ^{141}Pr (^{16}O, 4nγ) ^{153}Ho using 88 MeV pulsed ^{16}O ion beam (repetition period 1μs). The external magnetic field of 8.66(5) kG perpendicular to the beam-detector plane was provided by C–type electromagnet [3]. The target consisted of

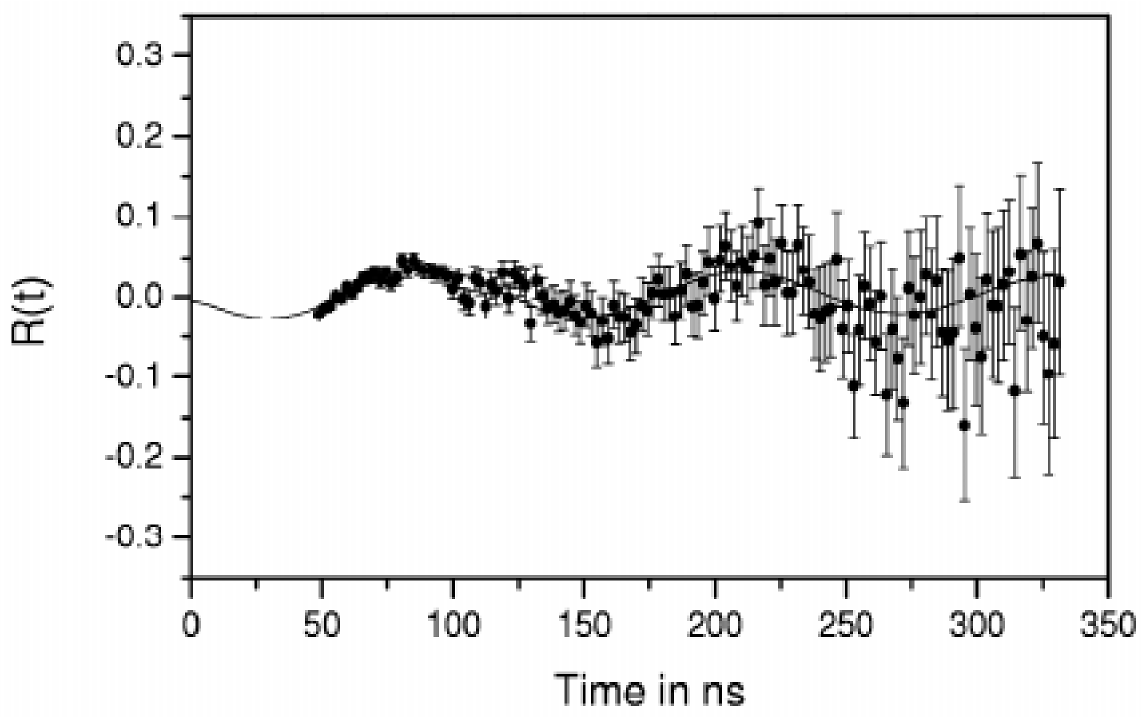

Fig. 1 : Spin rotation spectrum of $31/2^+$ state in ^{153}Ho.

800 μg/cm^2 natural ^{141}Pr sandwiched between gold backing (20 mg/cm^2) and 150 μg/cm^2 of gold. The data were collected in LIST mode with four parameters: the energy and time signals using two NaI(Tl) detectors at ± 45° to the beam. The amplitude of the modulation is determined by the effective anisotropy contribution of 287, 439, 475, 633 keV γ-ray transitions from 31/2$^+$ state. From the preliminary analysis of the data, we obtained the value of g-factor for 31/2$^+$ state as 0.086 from the fitted value of the Larmor precession frequency (ω_L) = 25.9 Mrad/s & by using the paramagnetic enhancement factor (β) = 7.24.

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5.1.10 Evidence of microscopic effects in fragment mass distribution in heavy ion induced reactions

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The dynamics of fusion of two heavy nuclei is to be well understood in order to obtain optimum entrance channel selection for the production of super heavy elements. It is proposed [1] and established [2] that precise measurement of exit channel mass distribution is a good probe to study the dynamics of fusion-fission process. We have determined the fission fragment mass distributions in reactions of light projectiles of ^{19}F, ^{16}O and ^{12}C on spherical ^{209}Bi and deformed ^{232}Th targets in near and below Coulomb barrier energies. In all the cases, the macroscopic theory (e.g. SSPM) predicts a smooth variation of the width of the fragment mass distribution with excitation energy of the equilibrated fused system.

The experiments were carried out in the General Purpose Scattering Chamber of Nuclear Science Centre Pelletron, New Delhi, using pulsed beams. Two MWPCs (24 cm x 10 cm), developed [3] in our laboratory at SINP, were kept at the folding angle to catch the complementary fission fragments (FF). The masses of the fission fragments were determined event by event from precise measurements of flight paths and flight time difference of the complimentary fission fragment. The mass resolution of the set-up was found typically 3 amu. Details of the experimental procedure and data analysis have been reported in ref [3].

The measured mass distributions at all energies are well fitted with single Gaussian distributions around the symmetric mass spilt for the target plus projectile systems. The variation of the square of the variance of the fission fragment mass distributions (σ_m^2) is shown in the Fig 1 for ^{16}O projectiles on spherical ^{209}Bi and ^{232}Th nuclei. It has been observed that the mass variance (σ_m^2) shows a smooth variation with beam energy of the fused system across the Coulomb barrier for the system ^{16}O + ^{209}Bi. Similar behaviour has also been observed for the ^{19}F + ^{209}Bi system [4]. This is in qualitative agreement with the predictions of statistical theory.

The variances of the mass distributions (σ_m^2) for reactions ^{16}O + ^{232}Th are shown in Fig 1(a). As the beam energy (excitation energy) is decreased, σ_m^2 value decreased monotonically, but shows a sudden upward trend approximately at the Coulomb barrier

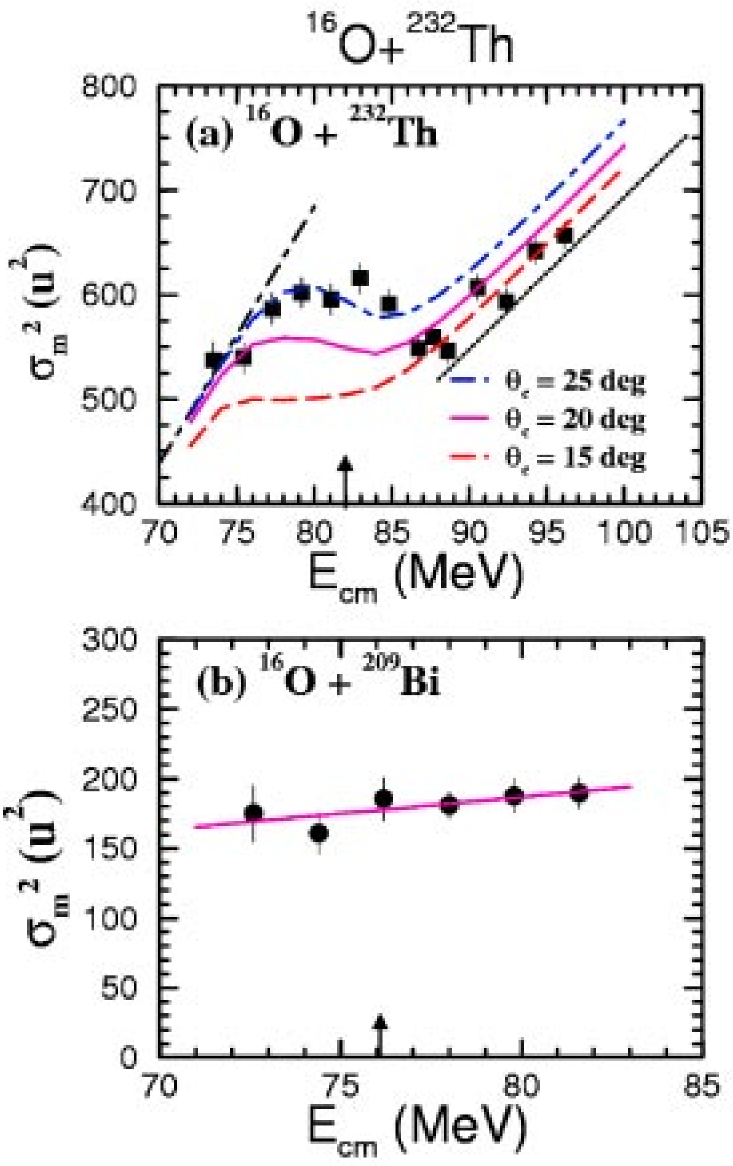

Fig. 1 : Variation σ_m^2 with beam energy.

(indicated by an arrow) energies. This is once again followed by a smooth decrease in energy as energy is further decreased. The sudden increase in σ_m^2 value is most prominent (~ 50 %) in case of ^{19}F + ^{232}Th and decreases to ~15% in ^{16}O+^{232}Th and to ~10% in ^{12}C+^{232}Th system [4]. It is interesting to note that anomalous increase in angular anisotropy of fission fragments were observed in almost at the same beam energies at which anomalous increase in variance of mass distributions are observed in all systems.

The calculated σ_m^2 values quantitatively explained the observed increase in widths of the mass distribution. The exact mechanism for the departure from the normal fusion-fission path is not known accurately. However, macroscopic effects such as the direction of mass flow or the mass relaxation time being too prolonged may not be the cause. Following the quantum mechanical effects favouring similar shapes in entrance and exit channel [5] we modify the simple postulation of the microscopic effects of the relative orientation of the projectile to the nuclear symmetry axis of the deformed target [6]. We assume that for the non-compact entrance channel shape, the impact of the projectile in the polar region of the ^{232}Th target drives the system to an almost mass symmetric saddle shape, rather than a compact equilibrated fused system. The observed fragment mass widths can be quantitatively explained under such assumption.

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5.1.11 Fission Hindrance Studies: Evaporation Residue and Gamma Measurements

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Study of fusion-fission reaction in the mass region 200 amu has been an area of great interest. Decay process in this mass region is more complicated due to the appearance of fission channels. Recent experiments show that the fission process is somewhat delayed compared to statistical model prediction. This phenomenon is known as **“Fission Hindrance”**. The compound nucleus (CN) decaying into evaporation residues (ERs) is a rare process at high excitation energy in heavy systems but gives valuable information on fission hindrance [1]. $^{200}Pb^*$ CN with different entrance channels has been studied by different methods (n, p, α, GDR-γ, FFs) [2-3] and fission hindrance has been reported. Experimentally an energy threshold is observed from where the onset of dissipation takes place resulting in deviation from the standard statistical model prediction. This energy threshold is not unique, rather it is different for different probes, especially in 200 mass region [4]. This discrepancy demands further accurate measurements involving different probes for better understanding of the physics of fusion-fission process. The combined study of spin distribution (gamma fold) and ERs has been carried out for the system $^{16}O + ^{184}W \rightarrow ^{200}Pb^*$.

The experiment was carried out using Heavy Ion Reaction Analyzer (HIRA) [5] and BGO ball (Multiplicity filter) (fig.1) at Nuclear Science Centre, New Delhi. ERs are always forward focused and swarmed by elastic beam like particles and hence HIRA (i.e. RMS) is required. ^{16}O pulsed beam with the pulse separation of 4 μsec was taken from 15UD Pelletron at Nuclear Science Centre. The measurements were carried out in the energy range 84 MeV to 124 MeV. Enriched isotopic tungsten target of thickness 200 $\mu g/cm^2$ with carbon backing of 100 $\mu g/cm^2$ was used [6]. A carbon foil of thickness 40 $\mu g/cm^2$ was placed 10 cm downstream from the target to reset the charge states of ERs

Fig. (1) Experimental setup

to statistical distribution after internal conversion processes. Two monitor detectors were placed symmetrically at ± 25° with respect to the beam direction for normalization purposes. The 14 element BGO multiplicity filter was used at the target chamber to record the gamma fold in coincidence with evaporation residues detected at the focal plane of HIRA using a 2D position sensitive resistive sillicon detector (50 X 50 mm^2). The TOF setup was useful in rejecting the beam-like particles at the focal plane. Start signal of the TAC was from focal plane detector and stop signal of the TAC was from RF (TWD signal) of pulsing system. Individual BGO signals were given to TDC to correct, in software, for background in each BGO signal while constructing the gamma multiplicity. Typical spectra of TOF Vs Energy and raw multiplicity is shown in fig. (2) and fig. (3) respectively. The offline analysis is carried out using CANDLE software [7]. Bitpattern was generated using the CANDLE software for extracting fold distribution. Extracted fold distribution was in turn gated with TOF spectra. The fold distribution extracted is shown in fig. (4). Further analysis is in progress.

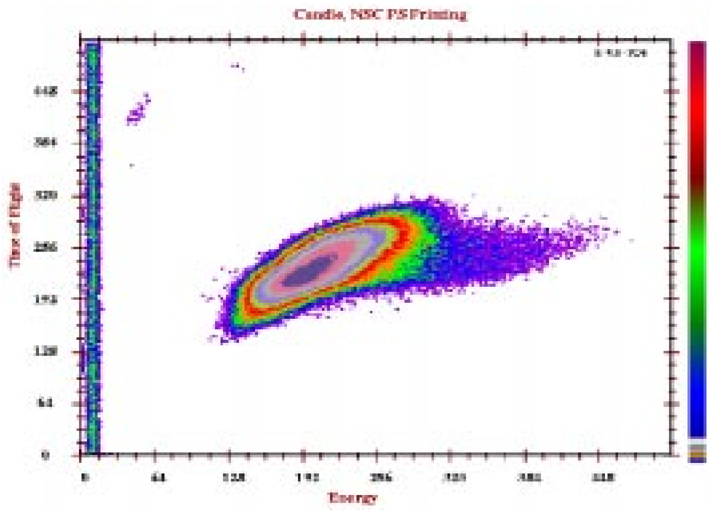

Fig. (2) TOF Vs Energy

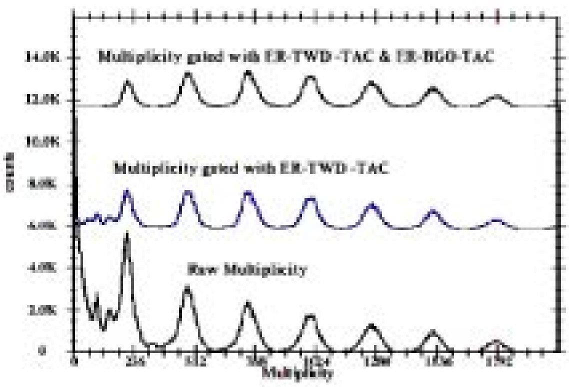

Fig. (3) Raw Multiplicity

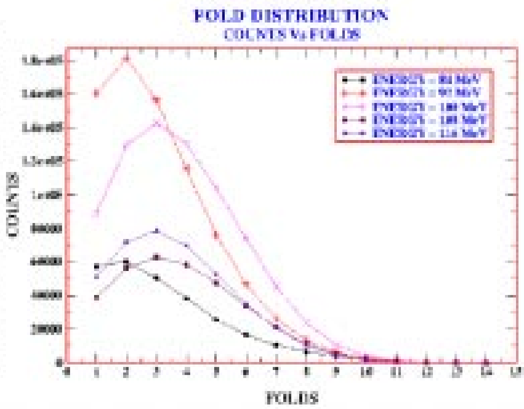

Fig. (4) Fold Distribution

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5.1.12 Entrance channel effects in the decay of the compound nucleus $^{61}Cu^*$

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The measured light charged particle spectra from the heavy ion induced fusion reactions have been found to have serious discrepancies from the predictions of the standard statistical model [1,2,3]. Measured spectra have been characterised as having lower energy than predicted. However the deviations from the predictions have been found to depend on the symmetry of the entrance channel [4,5]. We have planned a systematic study of the entrance channel effects. Here we report our results for the compound nucleus $^{61}Cu^*$ formed through the asymmetric reaction $^{16}O+^{45}Sc$ at 92 MeV and the relatively symmetric reaction $^{34}S+^{27}Al$ at 140 MeV. Both of these systems lead to the same compound nucleus $^{61}Cu^*$ with the same value of $l_{max}= 39\ \hbar$.

The alpha spectra from the $^{16}O+^{45}Sc$ reaction, as shown in Fig.1, are in agreement with the predictions of the statistical model using rotating liquid drop model values of moment of inertia and optical model transmission coefficients for the respective inverse absorption channels. However the alpha particle spectra in the case of $^{34}S+^{27}Al$ reaction, as shown in the dashed curve in fig.2, are not in agreement with such calculations. In order to explain the experimental spectra in case of the symmetric $^{34}S+^{27}Al$ system, we need to use the HICOL predicted value for $l=30\hbar$ (solid curves in fig 2). It seems as the symmetry of the system increases, the upper limit of the effective l-values contributing to the fusion is lowered. For the symmetric systems, the formation time is larger as compared to the decay time; hence the higher l values may decay before the compound nucleus is formed. The present study shows that the statistical model, which assumes the formation time to be much smaller than the decay time predicts the evaporation spectra for the asymmetric systems reasonably well, but in the case of the symmetric systems having longer formation times the dynamical effects seem to play an important role in the decay of the compound nucleus.

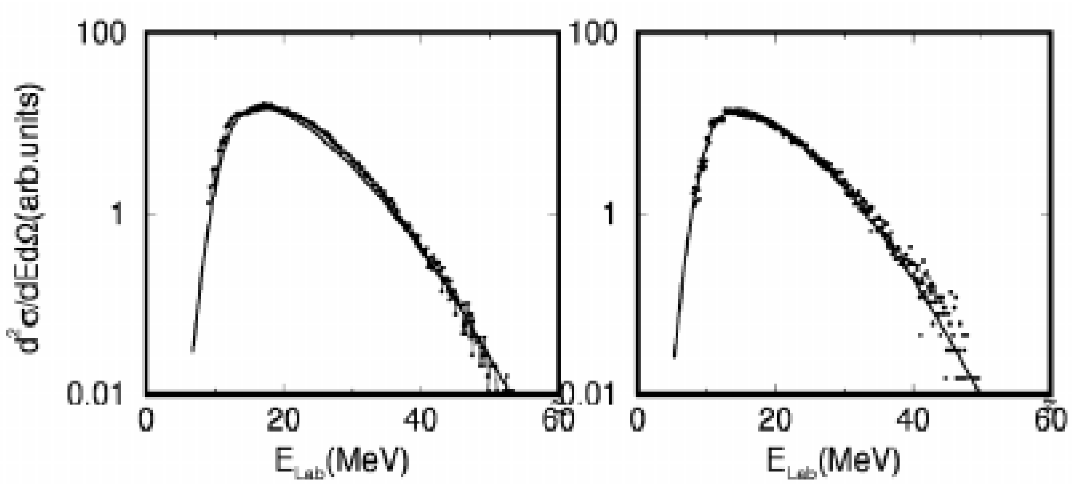

Fig. 1 : α-spectra from the $^{16}O+^{45}Sc$ reaction at 92 MeV. Solid curves are statistical model predictions with l_{max}= 39 ħ

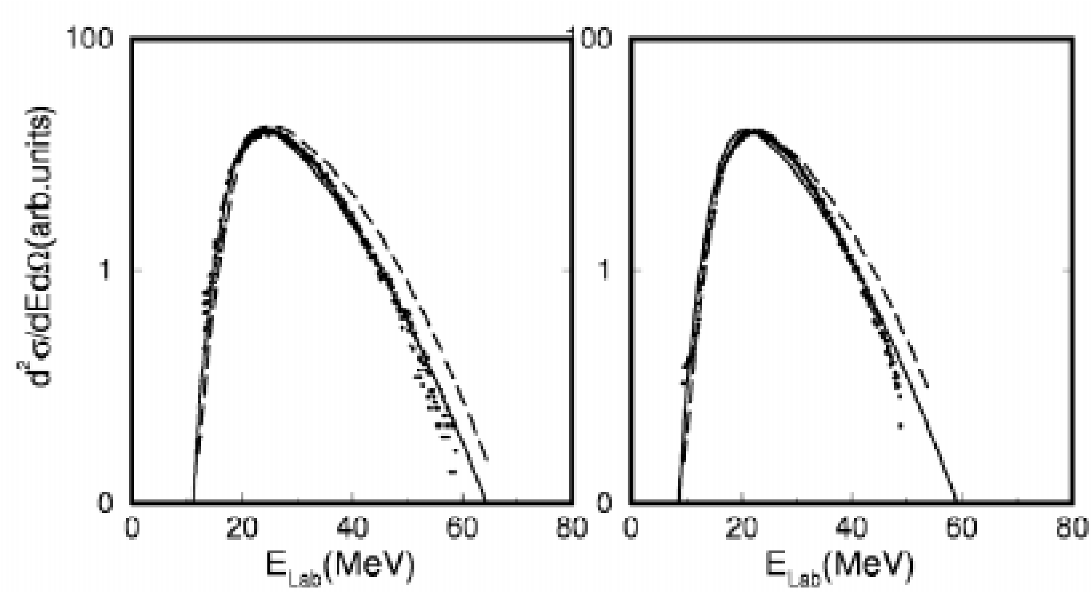

Fig. 2 : α-spectra from the reaction $^{34}S+^{27}Al$ at 140 MeV. Dashed curves are statistical model predictions with l_{max}= 39 ħ. Solid curves are statistical model predictions with a reduced value of l_{max}= 30 ħ as per HICOL calculations.

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5.1.13 Reaction mechanism studies in some medium mass nuclei below 7 MeV/ nucleon

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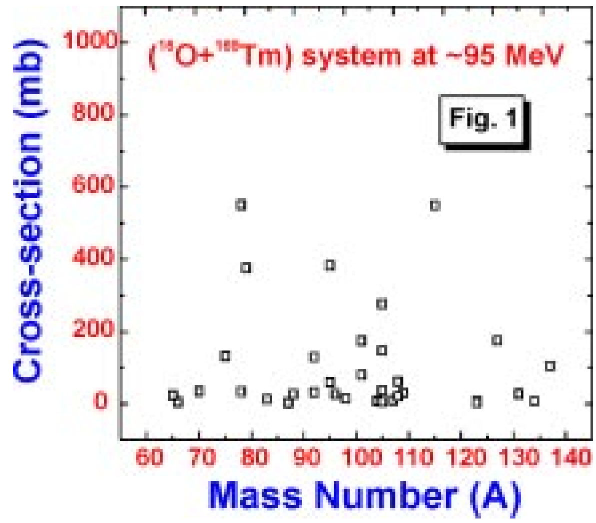
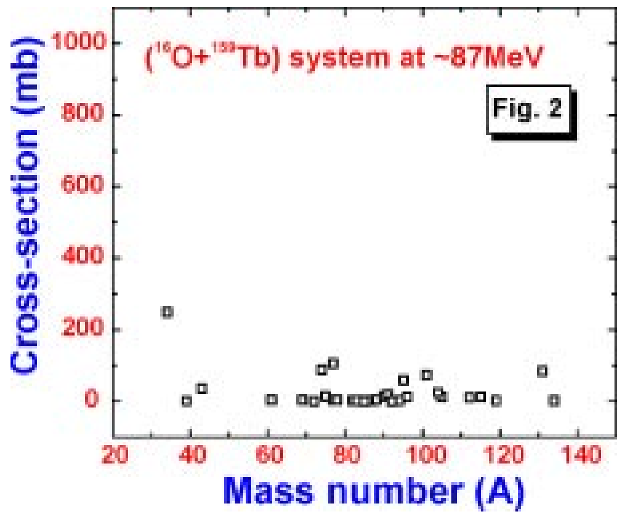
Recently, there has been a renewed interest in the study of heavy ion (HI) reaction mechanism. Recent literature indicates that HI reactions at energies just above the Coulomb barrier proceed through the complete fusion (CF) and incomplete fusion (ICF) processes. In some of our earlier measurements [1-4], CF and ICF processes have been found to play an important role in reaction mechanism. Relative contribution of CF and ICF processes have been studied in the several target-projectile combinations from the analysis of excitation functions (EFs), recoil range distributions (RRDs) and angular distribution of residues. During our previous run experiments have been carried out to measure excitation functions (EFs) for several reactions in $^{16}O+^{103}Rh$, $^{14}N+^{128}Te$ and $^{16}O+^{130}Te$ systems. EFs for a large number of reactions have been measured and analyzed employing different statistical model codes. The discrepancy between experimental and theoretical data has been attributed to the contribution coming from ICF. Further, recoil range distributions (RRDs) and angular distributions have also been measured for $^{16}O+^{169}Tm$ system. In order to confirm the above, more detailed experiments are required.

Further, during the analysis of γ-ray spectra of various samples it was observed that, there is a large number of γ-peaks, which could not be assigned to the residues populated via CF and/or ICF processes. As such, an attempt has been made to assign the γ-lines to various residues by analyzing the γ-ray spectra on the basis of characteristic γ-ray energies and half-lives of the residues. Interestingly, several γ-lines were assigned to the residues having the masses, which are characteristic of fission fragments. Cross-sections for the production of such residues ($34<A<134$) in the systems $^{16}O+^{169}Tm$ at ≈95 MeV and $^{16}O+^{159}Tb$ at ≈87 MeV have been determined. The measured production cross-sections for various fission like residues are shown in Figs.1 & 2, for both these systems.

Preliminary analysis of the data indicates that these residues may be populated via the fission of composite system formed via CF and/or ICF. In order to confirm this and in view of further study of fission mechanism more detailed analysis and experiments are needed.





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