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Nuclear level densities and gamma-ray strength functions of 180;181;182Ta and neutron capture cross sections

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Most stable and extremely low abundance proton-rich nuclei with <i>A</i»110 are thought to be produced by the photodisintegration of <i>s</i>- and <i>r</i>- process seed nuclei. However, this so-called <i>p</i>-process is insufficient to explain the observed low abundance (0.012%) of the ¹⁸⁰Ta isotope. Hence combinations of several processes are considered to reproduce the observed abundance of ¹⁸⁰Ta in the cosmos, provoking debates and making it a unique case study. Significant uncertainties in the predicted reaction rates in <sub>p</sup>-nuclei arise due to large uncertainties in nuclear properties such as the nuclear level densities (NLD) and gamma-ray strength functions (gamma;SF) [1], as well as the actual astrophysical environments. An experiment was performed in October 2014 to extract the NLD and gamma;SF below the neutron threshold in ^{180,181,182}Ta isotopes which provide important input parameters for nuclear reaction models. In the present case study, these parameters were measured using the ¹⁸¹Ta(³He, ³He') and ¹⁸¹Ta(³He, ⁴He) reactions with 34 MeV beam, ¹⁸¹Ta(d, d') and ¹⁸¹Ta(³He, t) reactions with 15 MeV beam , and ¹⁸¹Ta(d, d') and ¹⁸¹Ta(d, p) reactions with 12.5 MeV beam at the Oslo Cyclotron Laboratory. Using the SiRi array at backward angles (64 silicon particle telescopes) and the CACTUS array (26 NaI(Tl) detectors), the NLD and gamma;SF were simultaneously extracted below the neutron separation energy from particle-gamma; coincidence matrices through iterative procedures using the Oslo method [2]. The experimental results have been used to determine the corresponding neutron capture cross sections, which in turn were utilized to extract Maxwellian averaged cross sections. The latter can be used in astrophysical network calculations to investigate the galactic production mechanism of 180Ta. In this talk I will present results of this investigation of statistical properties for ^{180,181,182}Ta and the corresponding (n, gamma;) cross sections.

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1

Feasibility of Nuclear Plasma Interaction studies with the Activation Techniques

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Electron-mediated nuclear plasma interactions (NPIs), such as Nuclear Excitation by Electron Capture (NEEC) or Transition (NEET), may have signicant impact on nuclear cross sections in High Energy Density Plasmas (HEDPs). These HEDP environments are found in the cosmos where nucleosynthesis takes place. Attempts have failed so far in measuring the NEEC process [1], while NEET has recently been observed experimentally [2]. NEEC, NPIs have not been observed due to the narrowness of nuclear transitions (⊠ 1eV). The NPIs may occur on highly excited nuclear states in the quasi-continuum which is populated in nuclear reactions prior to their decay by spontaneous
-ray emis-
sion. Direct observation of NPIs are hindered by the lack of a clear signature of the eect in HEDP environments. Hence, a new signature [3] for NPIs on highly excited nuclei will be tested by investigating isomeric to ground state feeding from the quasi-continuum region. An experiment was performed using the reactions 197Au(13C, 12C)198Au and 197Au(13C, 12C2n)196Au at Lawrence Berkeley National Laboratory in inverse kinematics with a 197Au beam of 8.5 MeV/u energy. The activated foils were counted at the low-background counting facility of Lawrence Livermore National Laboratory. I will discuss several measurements with dierent target congurations to investigate the feasibility of NPI studies.

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PSF in 181,182Ta and the emergence of the scissors resonance

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Relatively small resonances on the low-energy tail of the giant electric dipole resonance such as the scissors or pygmy resonances can have significant impact on reaction rates. These rates are important input for modelling processes that take place in astrophysical environments and nuclear reactors. Recent results from the University of Oslo indicate the existence of a significant enhancement in the photon strength function for nuclei in the actinide region due to the scissors resonance [1]. Further, the M1 strength distribution of scissors resonances in rare earth nuclei has been studied extensively over the years [2]. In order to investigate the extent and persistence of the scissor resonance in other mass regions, an experiment was performed utilizing the NaI(Tl) gamma-ray detector array (CACTUS) and silicon particle telescopes (SiRi) at the cyclotron laboratory at the University of Oslo. Particle-γ coincidences from the ^{181}Ta(d,p)^{182}Ta reaction were used to measure the nuclear level density and photon strength function of the well-deformed ^{182}Ta system, to investigate the

existence of resonances below the neutron separation energy. In this talk I will present and discuss the final results of this investigation and place our findings in the context of previous work.

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[2] P. von-Neumann-Cosel, K. Heyde, and A. Richter, Rev. Mod. Phys., 82, 2365, (2010).

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4

SAIF - the South African Isotope Facility

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The iThemba LABS' Radioactive-Ion Beam project has evolved into SAIF - the South African Isotope Facility. It has two phases, the first of which comprises the Low-Energy Radioactive-Ion Beam (LERIB) project and ACE Isotopes (Accelerator Centre for Exotic Isotopes) project. ACE isotopes calls for the installation of a commercial, off-the-shelf 70 MeV cyclotron for radionuclide production. It will remove isotopes production from the existing SSC accelerator, freeing additional beam time for research. The LERIB project is an upgraded version of the RIB "demonstrator", capable of producing neutron-rich beams of high-intensity, due to the fissioning of natural uranium at a rate of up to 6 x 10¹³/s. The beams from LERIB will be of low-energy, 60 keV - suitable for decay studies and implantation in materials as radioactive probes. Phase 2 of the SAIF project is the Accelerator Centre for Exotic Beams (ACE Beams). It will see the addition of a post-accelerator, likely a LINAC, to take beams from the LERIB to high-energies for research into sub-atomic physics.

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TOWARDS IMPLEMENTATION/DEVELOPMENT OF STATE-OF-THE-ART ELECTRON SPECTROMETER CAPABILITY AT iThemba LABS

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An electron spectrometer that implements a Si(Li) detector for the detection of internal conversion electrons and a combination of LaBr3 detectors for the detection of coincident decays is undergoing development at iThemba LABS, South Africa. For optimization of measurements with the electron spectrometer, electron calibration sources (207Bi and 133Ba) are used in the measurements of energy and momentum resolution of the Si(Li) detectors. Other parameters such as transmission and efficiency which are used in describing the performance of electron spectrometer [1], are also determined during the characterization measurements. Lifetime measurements which provide crucial information needed for the measurement of E0 matrix elements will be performed using LaBr3 detectors. Electron energy versus magnet current calibration was done by varying the lens current repeatedly to ensure reproducibility. Characterization measurements are presented and discussed

for the purpose of commissioning the electron spectrometer for the study of 0+ states at iThemba LABS.

Keywords: Electron spectrometer, internal conversion electrons, coincident decays, electron energy, magnetic current.

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Hybrid potential analysis of clustering in heavy and superheavy nuclei

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Local core -cluster interaction of Saxon-Woods type functional form with parameters
derived from Michigan-3-Yukawa (M3Y) microscopic potential model have been used to investigate the decay properties of heavy and superheavy nuclei.
Further applications of the potential model to the low lying spectra of heavy nuclei reveals its inadequacy in the internal structure consistent with earlier works.
The geometry of the interior is taken to be influenced by the possible
core-cluster overlap.
An additional interaction in the interior
taken to mimic the nucleon distribution in the overlap region
is shown to improve the spectra.

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Pairing Isomers

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The concept of configuration dependent pairing does not usually appear in the textbooks and is rarely considered in the literature. The resulting lowering of excited 0n+ states into the pairing gap in even-even deformed nuclei accounts for many states that have traditionally been assumed to arise from time-dependent "β vibrations" of the nuclear shape along the symmetry axis. The experimental evidence that requires the low-lying 0n+ states to be re-evaluated will be reviewed from the early (p,t) work of Maher et al. [1] and Kolata and Oohoudt [2] to more recent γ-ray spectroscopy studies [3-5].

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Searching for the low-energy enhancement in 91-Zr

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The nuclear level density (NLD) and
-ray strength function (
SF) are quantities that give
essential information about the behaviour of a nucleus at high excitation energy. NLD is dened
as the number of levels per unit of excitation energy.
SF is dened as a measure of the average
reduced
decay probability of a nucleus. These concepts are useful at high excitation energies
where the spacing between the levels is small and gives information on degrees of freedom
and underlying nuclear dynamics. The evidence of the low-energy enhancement in the
SF for
energies less than 4 MeV has been discovered in several nuclei. Recently, a strong enhancement
of M1 transitions in 90Zr has been predicted for
-ray energies below 2 MeV in shell model
calculations. In this work we explored the existence of the low-energy enhancement in the
neighbouring 91Zr isotope with the assumption that neigbouring isotopes have similar
SF and
hence provided rst experimental NLD and
SF for this nucleus. The experiment 90Zr(d,p)91Zr
was conducted at the Oslo Cyclotron Laboratory (OCL). The SiRi (silicon telescope) array was
used to detect charged ejectiles from the reaction. The CACTUS (NaI(Tl) detectors) array
was utilized to detect
rays that were in coincidence with charged particles. The nuclear
level density and
SF were extracted with the Oslo method. The existence of the LEE was
observed, which agrees with the shell model calculations in 90Zr. The NLD and
SF quantities
were used to calculate (n,
) cross sections with the Talys reaction codes. These were compared
with experimental data from direct measurement to test the reliability of the approach used in
this work.

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Gamma-Ray Strength Function in 74Ge from the Ratio Method

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An increasing number of experiments reveal the presence of a low-energy enhancement in the gamma-ray strength function (GSF). The GSF, which is the ability of nuclei to absorb and emit γ rays, provides insight into the statistical properties of atomic nuclei. For this project the GSF was studied for 74Ge which was populated in the reaction 74Ge(p,p')74Ge at a beam energy of 18MeV. The data was collected with the STARS-LIBERACE array at Lawrence Berkeley National Laboratory. Silicon detector telescopes were used for particle identification and γ-rays in coincidence were detected with 5 Clover-type high-purity germanium detectors. Through the analysis particle-γ-γ coincidence events were constructed. These events, together with well-known energy levels, were used to identify primary γ-rays from the quasicontinuum. Primary γ-rays from a broad excitation energy region, which decay to two 0+ states, six 2+ states, two 3+ states, five 3- states, and four 4+ states, could be identified. These states and the associated primary γ-rays are used to measure the GSF for 74Ge with the Ratio Method [1], which entails taking ratios of efficiency corrected primary γ-ray intensities from the quasicontinuum. I will discuss the results from the analysis of the data from the above reaction and focus on the existence of the low-energy enhancement in 74Ge. The results are further discussed in the context of other work done in 74Ge using the (γ,γ') [2], (3He,3He') [3] and (α,α') [4] reactions.

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Coupling of single neutron and proton configurations to collective core excitations in ¹⁶²Yb.

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The excited states of ¹⁶²Yb have been studied at iThemba Laboratory for Accelerator Based Sciences (iThemba LABS), using the ¹⁵⁰Sm (¹⁶O, 4n) ¹⁶²Yb fusion-evaporation reaction. The beam of 83 MeV ¹⁶O was provided by the Separated-Sector Cyclotron (SSC) and used to bombard a 3 mg/cm² ¹⁵⁰Sm target. The gamma rays emitted from the reaction products were detected using the AFRODITE gamma-ray spectrometer, comprised of 8 Compton-suppressed clover detectors. Attempts have been made in identifying the low-lying positive parity bands in ¹⁶²Yb, particularly the beta and gamma vibrational bands, which are traditionally associated with the first excited K^π = 0⁺ and K^π = 2⁺ respectively. Many levels have been found. In particular the first excited 0⁺ band and the even and odd sequences of the gamma band have been firmly established. The 0⁺ band and the even spin members of the gamma band are observed to exhibit a Laundau-Zenner crossing. This crossing demonstrates that the signature splitting in gamma bands is mainly caused by band mixing. The data will be discussed in terms of the Triaxial Projected Shell Model and also with the predictions of the 5-Dimensional Collective Model (5-DCM).

13

Search for Charality in 193Tl

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Research conducted at iThemba LABS showed that chiral symmetry can develop in the thallium isotopes in the 190 mass region. In order to increase the knowledge about chirality in this mass region, a ɣ-spectroscopy study of 193Tl was performed at iThemba LABS. The previous level scheme of 193Tl was modified and extended. Spin and parity were assigned to most of the levels. Three negative parity bands showing similar properties were identified. These bands were associated with the same configuration which is suitable for chiral symmetry. The observed near-degeneracy is good and indicates the presence of chiral symmetry. Furthermore, two bands that could form a chiral pair were observed at higher spins. The results from theoretical calculations using the Cranked Nilsson-Strutinsky (CNS) codes and the multi-particle-plus-triaxial rotor (MPR) model of Carlsson and Ragnarsson are in agreement with the proposed observation of chiral symmetry. Possible multiplet of chiral systems will be discussed.

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Tape station for beta decay measurement

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The tape station system is used for collecting and counting of "mostly" short-lived radioactive nuclei and these kinds of systems are used at an on-line facility. Such devices allow measuring radioactive particle even if they cannot be seen by other instruments. A flexible tape transport system may be used to catch recoiling nuclei after they have been mass identied by high-resolution mass spectrometer.

Depending on the half-life of the element of interest, where the detection point can be
same as the implantation point or measuring at the dierent position, a tape has to be moved to a low background area where it will be observed by and detectors. After counting for a while, the tape is moved again to make sure that activity from the complete decay chain to stability is not observed.

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Coupling of single proton configurations to collective core excitations in ¹⁶²Yb: the nucleus ¹⁶¹Tm

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Over the past two decades there has been controversy as to whether deformed nuclei are subject to quadrupole vibrations (γ and β), particularly the β vibrations. Pertaining the gamma(K=2⁺) vibrations, experimental evidence has been more or less consistent, confirming they indeed exist. On the other hand the situation remains elusive for the β vibrations which are characterized by the first low lying 0+ excited state. The current study seeks to get more insight on the microscopic nature of the aforementioned by studying the nucleus 161 Tm, which was populate using the ¹⁵²Sm(¹⁴N,5n)¹⁶¹Tm reaction with the aid of the AFRODITE array at iThemba LABS. A level scheme was built for ¹⁶¹Tm by examining multiple gates using coincidence spectra. Transitions were confirmed with DCO (Direct Correlations for Oriented states) and/or polarization anisotropy measurements where applicable. Alignments and band crossings have been used to meaningfully describe the quantum behavior of the collective structures observed in this work. In addition systematic comparisons have also been used to further understand the structural behavior of band structures observed in the level scheme. Furthermore experimental B(M1)/B(E2) values for bands involving the [505]11/2⁻ orbital and other observed strong coupled bands
were obtained to confirm quasi-particle configurations.

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LOW SPIN STRUCTURE STUDIES OF EXOTIC STATES AND NUCLEI: NEW CAPABILITIES AT ITHEMBA LABS

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Excited 0+ states are the least understood of any low-energy degree of freedom in nuclei. E0 transition strengths are a measure of the off-diagonal matrix elements of the mean-square charge radius operator. Mixing of configurations with different mean-square charge radii produces E0 transition strength. The study of low-lying 0+ states has been a focus of attention in the last two decades because of their implications regarding shape coexistence in nuclei.

New capabilities are underway to be added to the arsenal of cutting-edge spectroscopy techniques at iThemba LABS. Through the application of electron and pair spectroscopy, and with the addition of magnetic spectrometers new avenues of nuclear structure will be opened and explored.

In addition, an array of LaBr3(Ce) detectors (2”x2”) for fast-timing measurements have been commissioned. With excellent timing resolution (<350ps) and good energy resolution these will be used to study the decays of the photon branch of these states. Measurements of lifetimes of these states, and their associated feeding/decaying states are also extremely important in understanding the associated wave functions and orbital assignments of states. With the combination of an array of fast-timing detectors, this enhances the motivation for these nuclear structure studies over a region of nuclear structure.

A review of these capabilities will be presented and commissioning experiments presented.

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The spectrosopy of ^{162}Hf at low and high spins

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The search for triaxial strongly deformed (TSD) structures in the rare earth region of the nuclear chart has been of interest recently. These structures have been predicted to occur for over 35 years [1]. The main aim of this project is to comprehensively study the nuclear spectroscopy of ^{162}Hf at low and high spins and to search for TSD structures. The research is also part of an investigation into the systematic behaviour of the N=90 nuclei. Our interest is in the systematics of the positive parity excited bands in N=90 nuclei and the behaviour of the negative parity bands as the proton number Z is increased leading to a reduction in the deformation of the ground state structure. A number of high spin structures with high dynamic moments of inertia have been observed in the heavy Hafnium isotopes [2-7]. Cranked Nilsson Strutinsky calculations predict that such bands are most likely associated with TSD structures originating from a positive-γ energy minimum which dominates at ultrahigh spins. The data was collected using the world class multi-detector gamma-ray spectrometers namely the AFRODITE (South Africa) and JUROGAM at Jyvaskyla (Finland). The high spin states were populated in the ^{110}Pd(^{56}Fe, 4n) reaction at a beam energy of 270 MeV at Jyvaskyla and the medium and low spin states at iThemba LABS using the ^{144}Sm(^{22}Ne, 4n) reaction at a beam energy of 110 MeV. The collected data was sorted using MTSort and was analyzed using RADWARE [8]. Results from both data sets will be presented.

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A review of nuclear cluster models

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The nuclear cluster models has extensively been used to understand some of the structural properties of nuclear matter. A number of theoretical models have been developed since the discovery that alpha decay could be conceptually understood as the expulsion of a correlated subset of four nucleons from the parent nucleus. This presentation will give a brief overview of the most popular nuclear cluster model descriptions in nuclear physics, and will highlight some of the strengths and weaknesses of each of the models.

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Study of the low-lying states in $superscript^{26}$ Mg nuclei.

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The study of ^{26} Mg level structure is of particular importance in nuclear structure physics because of its impact in the slow neutron capture process (s-process) for the nucleosynthesis of heavy elements up to lead. In fact, the ^{26}Mg is the compound nucleus for the s-process neutron source ^{22}Ne (☒, n)^{22}Mg that is one of the dominant reaction in the s-process. Since it is an endothermic reaction it competes directly with the ^{22}Ne (☒, ☒)^{26} Mg radiative capture. Understanding the rate of both of these reactions is crucial for linking the observational evidence of s-process abundance with the internal structure of the stars. The uncertainties in the energy of the ^{26} Mg states and the inconclusive spin-parity assessments still lead in large error bars in these reaction rates.

In this work, the low-energy states in ^{26} Mg were populated using the inelastic scattering of alpha particles with beam energy of 120 MeV. The ^{26} Mg (☒, ☒′☒)
^{26} Mg measurements can be useful to improve the uncertainties in these rates by studying and extracting the characteristics of the excited states of ^{26} Mg. The experiment was performed at iThemba LABS research facility using a new designed experimental set-up: the K600 magnetic spectrometer coupled to the BaGeL array (Ball of Germanium and LaBr detectors). This combination was used to perform the coincidence measurements between charged particles and gamma rays. The excitation and the subsequent gamma decay of the ^{26} Mg states of interest will be investigated. Preliminary results on the analysis will be presented.

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Measurements of natural radioactivity in sands using an array of lanthanum -bromide scintillator detectors

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LaBr3:Ce detectors have been shown to be 1.2–1.65 times more efficient than NaI:Tl detectors above 350 keV, for 3.8 cm×3.8 cm (1.5 in.×1.5 in.) detectors and have an energy resolution of 2.5–3% at the 662 keV gamma-line of 137Cs, compared to 6–7% for NaI:Tl detectors[1]. The detector crystal has other advantages such as a high scintillation light output with a fast decay time[2]. An array of 8 2in x 2in LaBr3(Ce) scintillators with an XIA PIXIE-16 Digital Signal Processing system data acquisition system will be used to measure sands placed in the centre (17.5 cm from each detector) of the array (with all detectors lying in the horizontal plane) for 12 hours. The gamma-gamma coincidence method has the advantage of virtually eliminating all background peaks that do not exist in coincidence with other peaks, significantly improving detection limits of useful radionuclides[3][4]. By employing a gamma-gamma coincidence condition, the background from the radioisotopes in the LaBr3:Ce scintillator is eliminated, providing a means for improving detection limits[5]. The absolute gamma–ray energy detection efficiency of each detector will be determined and compared. Data from each detector will be analyzed. The activity concentration of 238U, 232Th and 40K in the sands will be determined and compared to certified values. Radiation hazard indices will be calculated for the soil samples and compared to certified values.

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Spectroscopy of quadrupole excitations at low spin in even-even N~90 nuclei

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Vibrational levels are well known in atomic nuclei but despite many decades of research, some of their properties still remain elusive. In particular, low-lying rotational bands based on the first excited 0+ state, which are traditionally understood as β vibrational bands nevertheless show properties at odds with this interpretation, more especially in the transitional rare earth region with N~90 [Gar01]. An alternative is that they can be better be described as a "second vacuum", or coexisting minimum in the pairing degree of freedom [Sch11a]. In order to produce a complete and definitive microscopic picture of the so-called β and γ bands, an extensive systematic review is performed for nuclides in the 160 mass region, between N = 88 and 92 and Sm to Yb. The data are explained using a five dimensional collective Hamiltonian for quadrupole rotational and vibrational degrees of freedom [Li09, Nik09]. A good qualitative agreement is obtained between measured energies and electromagnetic transition rates across the entire A ~ 160 mass region. The implication of these findings on the interpretation the first excited 0+ states is there from discussed.

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Multiple many-particle chiral systems described within the particle-rotor model

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A nuclear chiral system is formed when the total angular momentum of the nucleus is aplanar, i.e. when it has significant projections along all three nuclear axes [1]. Most important for the identification of chiral bands is to establish a pair of ΔI = 1 bands that are near-degenerate in energy, but also in B(M1) and B(E2) transition probabilities [1]. Up to date, chiral candidates showing two- or multi-quasiparticle partner bands have been observed in several nuclei in A ~ 80, 100, 130 and 190 mass regions. It was suggested that multiple chiral partner bands (MXD) with the same two-quasiparticle nucleon configuration may exist in a single nucleus [1-3]. The first multiplet of chiral bands built on the same multi-quasiparticle configuration was observed in 103Rh [4]. Such a scenario was also considered recently for 194Tl [5].

In this work the multi-particle-plus-triaxial-rotor (MPR) [6] model calculations were performed for multiple chiral systems associated with the same multi-quasiparticle configurations in the 100, 130 and 190 mass regions described with a realistically large configuration space for the odd proton(s) and the odd neutron(s). The main objective was to study the properties of the excited chiral systems associated with the same nucleon configuration. In particular we were interested in whether the excited chiral systems might show better near-degeneracy than the yrast one.

Multiple chiral systems associated with many-particle nucleon configurations were found, but they may not necessarily form pairs of near-degenerate bands in an obvious way. Our calculations showed that in order to search for the best chiral symmetry, one needs to study not only the two lowest-energy bands, but also as many excited bands as possible. It is quite possible that the excited bands will couple into pairs with more similar geometry of the intrinsic angular momenta as a function of spin, and show closer intrinsic structure, than the two lowest-energy bands. It is also concluded that to couple chiral bands into pairs with a similar nature one needs to consider the projections of the angular momenta along the nuclear axes. Part of the results from this work has been published in Ref. [7]. The results from these calculations will be presented and discussed.

This work is based upon research supported by the National Research Foundation, South Africa, with grant numbers 75357, 76632, 91446, 93531, and 103478. We thank B.G. Carlsson and I. Ragnarsson for making available the multi-particle-plus-triaxial-rotor model codes and for numerous fruitful discussions.

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Nuclear structure studies relevant to double beta decay of 136Xe

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In addition to establishing the Majorana nature of neutrinos, obtaining the absolute neutrino mass scale is now the focus of several large-scale neutrinoless double beta decay experiments.
The current challenge in determining the neutrino mass accurately depends of calculation of nuclear matrix elements (NME's) in the select nuclei where these decays can take place. It is well known

that the dominating uncertainties in the calculated NME values arise from the model dependence of these calculations.
In this talk we will present some recent experimental results using high resolution spectroscopy from 136,138Ba(p,t) and 138Ba(d,a) reactions that will be useful for future NME calculations for the double beta decay of $^{136}Xe \rightarrow ^{136} Ba$

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Radiation Safety Calculations for iThemba LABS ACE Isotopes facility design - Faraday Cups

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The design of iThemba LABS Accelerator Centre for Exotic (ACE) Isotopes facility was proposed to have four beam-lines feeding the beam to two production vaults, with each vault having two production stations. The plan is to simultaneously operate one production station in both production vaults, meaning that only two opposite beam-lines will be delivering the beam at a time, with each of the two beam-lines feeding 70 MeV energy proton-beam of up to 350 µA current.

Two Faraday cups will be simultaneously used to stop 50 µA (standard beam current) proton beams during the optimization of beam-lines parameters.

The whole ACE operating system will be accompanied by an interlock system that will switch off the parameters of the cyclotron, e.g. the RF, and insert a Faraday cup in the axial injection line in case the beam is accidentally stopped in the beam-line. Moreover, less than 5% beam loss is expected to occur in the cyclotron. Beam-pipes of 150 mm diameter were proposed, therefore, the beam losses in beam-lines are not expected to be significant. Radiation resulting from beam loss in the cyclotron (35 µA at most) will, to a large extent, be shielded by the magnet of the cyclotron. The magnet shielding of the radiation caused by beam loss inside the cyclotron is better in the vertical direction. Therefore, radiation that will make it through the cyclotron vault floor to the basement is not expected to be significant.

Consequently, for the shielding of the cyclotron, the main source of radiation to consider was the beams on Faraday ups; Hence, this study was looking at the optimal shielding design especially when the proton beams hit the Faraday cups during optimization of the cyclotron beam-line parameters. This study was conducted using the FLUKA Monte-Carlo transport code.

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New developments in the nuclear binary cluster-Core in the Super-Heavy Nuclear region

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The atomic nucleus is a complex many-body interacting system, which exhibits a underlying correlated set of nucleon states. The clustering model is one of the most reliable models that predicts the strongly correlated subsystem of nucleons closed to the threshold decay of nuclei. The binary-cluster model describes the structure and decay properties of super-heavy nuclei.

The phenomenological Cubic Woods-Saxon potential, developed by Buck, Merchant and Perez, has successfully predicted a number of experimental observables associated with clustering phenomenon. The recently developed microscopic double folded M3Y potential results in the inverted spectra for the positive parity excited cluster states, but successfully predicts the decay half-life for alpha-Pb system. These shortcomings of the M3Y based microscopic binary cluster model lead to the newly developed hybrid code-cluster potential, obtained by fitting the Phenomenological Woods-Saxon Cube and the M3Y double folding at the surface region where the two potential coalesce.

The project presented will give an overview of the nuclear cluster models available. Furthermore the recently developed self-consistent relativistic mean-field cluster-core description will be presented.

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Coulomb-excitation programme at UWC

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The Coulomb-excitation process with the combination of highly-efficient γ and particle detector systems present a great tool to study quadrupole collectivity in nuclei and probing
nuclear-structure properties. This process employs the well-known Coulomb interaction and selectively excites collective nuclear states which decay back to the ground state through
γ-ray transitions. Coulomb-excitation measurements have been carried out by the UWC Coulex group, where various reorientation-effect Coulomb-excitation measurements (RECE) have recently been carried out f
or a systematic study throughout nuclei in the sd shell. This work reports on our new measurements on $Q_S(2_1^+)$ values at iThemba LABS and TRIUMF on $(^{12}C,^{20}Ne,^{32}S,^{36}Ar \quad and \quad ^{40}Ar)$, which will be presented during this conference. In particular, a solution is proposed for the
striking zig-zag pattern of $Q_S(2_1^+)$ values observed at the end of the sd shell.

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Spectroscopy of Exotic Lambda-hypernuclei within Covariant Density Functional Theory

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Covariant density functional theory can well describe the bulk and single-particle
properties of nuclei in a self-consistent way. Typical neutron-rich Lambda-hypernuclei 12Be and 16C are investigated within covariant density functional theory. The bulk properties of mean field, meson-nucleon tensor coupling, spin-orbit term, behaviors of neutrons are focused.

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Multiple Chiral Doublet Bands in ^{126}Cs

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Following the previously observed chiral doublet bands in ^{126}Cs, a new pair of chiral doublet bands has been proposed. Both two pairs are based on the identical configuration $\pi h_{11/2} \otimes \nu h_{11/2}$ and may be another candidate of novel type of multiple chiral doublets (“yrast” and “excited” MχD) first observed in ^{103}Rh. Theoretical calculations within covariant density functional theory and particle rotor model are also performed.

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Multipole Response of Hypernuclei within Skyrme Energy Density Functional

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We have extended the Hartree-Fock and Random Phase Approximation method to calculate the multipole giant resonances of hypernuclei within the Skyrme energy density functional self-consistently. This means that the same Skyrme interactions, including the nucleon-nucleon, nucleon-hyperon as well as hyperon-hyperon interaction, are adopted in the calculation of the properties of ground states and collective states in hypernuclei. In the calculations we use SKM* Skyrme interaction for the nucleon-nucleon interaction and Yamamoto nucleon-hyperon interaction as well as the Lanskoy SΛΛ1 parameter set for hyperon-hyperon interaction. We have systematically investigated the multipole response of double-Λ hypernuclei 18OΛΛ, 42CaΛΛ, 92ZrΛΛ, 122SnΛΛ and 210PbΛΛ. The effect of hyperon interaction on response function, the transition density, the low-lying states are analyzed in more details, the role of hyperon interaction depends on the type of the collective excitations, in some case it gives attractive effect, in another case, it is repulsive.

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Exploration of direct neutron capture with covariant density functional theory inputs

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Predictions of direct neutron capture are of vital importance for simulations of nucleosynthesis in supernovae, merging neutron stars, and other astrophysical environments. We calculated direct capture cross sections using nuclear structure information obtained from a covariant density functional theory as input for the FRESCO coupled reaction channels code. We investigated the impact of pairing, spectroscopic factors, and optical potentials on our results to determine a robust method to calculate cross sections of direct neutron capture on exotic nuclei. Our predictions agree reasonably

well with experimental cross section data for the closed shell nuclei 16O and
48Ca, and for the exotic nucleus 36S. We then used this approach to calculate the direct neutron capture cross sections on Sn isotopes which are of interest for the astrophysical r-process.

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Improving of the injection line transmission through the SPC2 cyclotron at iThemba LABS

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iThemba LABS has recently engaged in a journey of producing metal ion beams to use for nuclear physics experiments. In order to successfully deliver these beams, it is important that the transmission of the injection beamline through the injector cyclotron (SPC2) is of high quality. In order to achieve this, efforts are being made to improve the transmission. One of the concepts being investigated is how adding a second buncher, operating in second harmonic will improve the transmission. This is done using different simulation programs. In this talk preliminary results of the simulations will be presented.

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Measurement of beam characteristics of Low-Energy Accelerators

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China JinPing underground Laboratory (CJPL) was established inside the tunnels piercing Jinping Mountain in Sichuan Province, China, which can provide an ideal environment for low background experiment. A new 400 kV accelerator, with high current based on an ECR source, will be placed at this underground laboratory for nuclear astrophysics experiment (JUNA). Due to the new accelerator still being under construction, the resonance reactions, like ^{27}Al(p, γ)^{28}Si and ^{24}Mg(p, γ)^{25}Al, and non-resonance ^{12}C(p, γ)^{13}N was studied at 320 kV high-voltage platform at IMP to estimate the proton beam characteristics, like absolute energy, energy spread, and long-term energy stability. The results of experiment and current state of new 400 kV accelerator will be given.

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Possible umbrella-like antimagnetic rotation (UAMR) mode in Pd isotopes

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The tilted axis cranking model based on covariant density functional theory is used to study the $\pi g_{9/2}^{-4} \nu h_{11/2}$ bands in odd-A ^{101,103}Pd and the $\pi g_{9/2}^{-4} \nu h_{11/2}^{2}$ bands in even-even ^{102,104}Pd. The experimental energy spectra and B(E2) values are reproduced well in the self-consistent and microscopic calculations. By investigating microscopically the composition and orientation of angular momentum, an umbrella-like antimagnetic rotation (UAMR) mode resulting from the coupling of four $g_{9/2}$ proton holes to one or two aligned $h_{11/2}^{2}$ neutron particles is clearly illustrated for the first time.

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Chiral bands in ^{82}Br

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High spin states of ^{82}Br were studied by using the fusion-evaporation reaction ^{82}Se (^{4}He, 1p4n) at beam energies of 65 and 68 MeV. 26 new transitions and 13 new levels were added into the previous level scheme, including a positive-parity band. With the earlier configuration assignment $\pi 9/2 \otimes \nu 9/2$ to band 1 and the similar experimental features to the chiral doublet bands observed in ^{78}Br and ^{80}Br, the positive-parity doublet bands 1 and 2 in ^{82}Br are therefore suggested as chiral doublet bands with the $\pi 9/2 \otimes \pi 9/2$ configuration. The interpretation was supported by the relativistic mean field theory and triaxial particle rotor model calculations.