Theme Meeting on Scientific Opportunities of ANURIB

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Variable Energy Cyclotron Centre, Kolkata

Book of Abstracts

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Atomic collisions using low and high energy ion beams at wider perturbation strengths

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Various features molecular collisions under swift ion collisions are of recent interest for its application towards radiobiology, radio sensitization, astrochemistry of intersteller medium as well as fundamental quantum mechanical issues. Particular interest is the collective plasmon resonance (GDPR and GQPR) which is common thread among the PAH molecules, nano-particles, halouracils, nanosensitizers, fullerenes etc. A novel idea is demonstrated i.e. use of highly charged ions to observe the giant dipole plasmon resonance in PAHs and C60 as well as the giant quadrupole plasmon resonsnce (GQPR) for C60. The dramatic enhancement of the double and triple ionizations he DI-to-SI ratios for PAHs upon HCI impact are again related to the multi-electron-correlation induced plasmon excitation. The high energy x-rays and Auger electron spectroscopy can be applied in case of high energy ion-atom, ion-solid collisions in order to investigate the ionization of strongly bound K-shell electrons which is highly influenced by the strong field and relativistic effects. The high energy collisions are also most suitable situation to study the radiative electron capture or di-electronic recombination processes. The wider range of energies offered by various accelerators such as ANURIB or other related machines can be suitably used to explore various facets of atomic molecular physics be it outer shell or inner shell processes. The present measurements are carried out using fast HCIs of energy a few MeV/u as well as 100s keV/u obtained from the Pelletron and ECR-based ion accelerator at TIFR.

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CERN-MEDICIS : a dedicated isotope mass separation facility for medical research

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We will provide in this presentation recent progresses made in the availability of radionuclides for medical application based on developments of the production methods using ion beam and separation technologies. MEDICIS is an extension of the ISOLDE class A laboratory at CERN. It is a facility dedicated to the production of radionuclides for research in the medical field. It comprises an irradiation station located in the beam dump of the HRS target station, a remote handling system, an isotope mass separation system and a simple radiochemistry laboratory (Fig 1) [1]. It receives on average 50% of the 1.4 GeV protons delivered by the Proton Synchrotron Booster (PSB). It was commissioned with Radioactive Ion Beams (RIBs) in 2017. MEDICIS has operated for the past 5 years in batch mode, with targets irradiated in a station located at the HRS beam dump, and with external sources

provided by MEDICIS cyclotrons and nuclear reactors partners, notably during the Long Shutdown (LS2). Additional features of the facility include the MELISSA laser ion source, radiochemistry on implanted radionuclides and an online gamma-ray spectroscopy implantation monitoring. In 2022, we introduced Key Performance Indicators (KPI) to monitor the operation of the facility for collected efficiencies, the optimization of the radiological risks and evaluate impact of possible modifications of the station, paralleling for instance LHC's integrated luminosity. Its scientific programme is defined with the MEDICIS Collaboration, has been focused on preclinical biomedical research, and has met with a recent highlights, notably with the elaboration of projects of clinical relevance exploring high molar activity grade radionuclides possibly translated in radiotherapeutics, notably in targeted radioligand theranostics [1,2]. It also recently triggered a new European network, PRISMAP, for the development of high purity grades radionuclides for medical research across Europe [3].
We acknowledge the financial support of the E.U. through the MEDICIS-Promed program (grant agreement No. 642889) and the PRISMAP program (grant agreement No. 101008571)

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Carbon ion radiotherapy (CIRT): A highly interdisciplinary approach can overcome the hurdles in cancer treatment

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Cancer is one of the leading death-causing diseases worldwide. Despite advancements in surgery, chemotherapy, radiotherapy, radiochemotherapy, and immunotherapy, Carbon Ion Radiotherapy (CIRT) is becoming very promising for the treatment of cancers, especially certain unresectable, chemoresistant, and radioresistant hypoxic tumors. Being the particle nature the CIRT has several inherent advantages over photon therapy like excellent dose localization due to characteristic Bragg's peak, lesser lateral scattering, higher relative biological effectiveness (RBE) value, more effective in killing gamma/chemo resistant tumor, effective against hypoxic tumor etc. About 70% of cancer patients are treated with radiotherapy. Both photons and particles are used in radiotherapy. The quality and quantity of cellular damage by the particle are different from that of photon due to the difference in physical nature and the detailed mechanism of cellular signaling/response after exposure to the ion beam is largely unknown. To understand the cellular response and improve the CIRT a highly interdisciplinary approach is required. Precise detection of tumors is associated with the success of treatment in radiotherapy. Computed tomography (CT), magnetic resonance imaging (MRI), single-photon emission computed tomography (SPECT), positron emission tomography (PET) etc are used for 3-D location of the deep-seated tumor. Furthermore, tremendous advancements have been done to treat movable targets like tumors in lungs using the respiratory-gated carbon-ion scanning radiotherapy. So, expertise in Imaging Techniques, Medical Physics, and Nuclear Physics is extremely important for a successful CIRT. Lastly, understanding the biology of cancer is of utmost importance. The cancer cells are highly heterogeneous and the genetic setup varies from patient to

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Challenges and advantages of an e-LINAC based positron beam facility

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The Helmholtz-Center Dresden - Rossendorf operates the superconducting electron linear accelerator ELBE (short for Electron LINAC with high Brilliance low Emittance) as a high-power driver for various types of secondary radiation. Running in a 24/7 mode of operation, ELBE serves as user facility which attracts several hundreds of national and international users per year. Secondary beam lines focus on research in fundamental and applied nuclear physics with MeV X-rays from bremsstrahlung production for nuclear photon scattering, photo-activation, nuclear astrophysics, and energy-selective neutron interactions employing time-of-flight techniques. Electron beams are further used for secondary IR radiation by means of free-electron lasers and sub-ps superradiant THz radiation for materials research at high electric field strengths. Finally, intense secondary beams including hard X-ray production from electron-bremsstrahlung serve as an intense source of positrons by means of pair production. The Mono-energetic Positron Source MePS [1] utilizes positrons with variable kinetic energies for depth profiling of atomic defects and porosities on nm- to µm-scales in thin films. High timing resolutions ($\sigma_t \approx$100 ps) at high average rates ($10^5 s^{-1}$) and adjustable beam repetition rates allow performing high-throughput experiments.
In the presentation, special emphasis will be given on the challenges of this high power radiation source and the advantages for state-of-the-art materials research and other applications.
The MePS facility has partly been funded by the Federal Ministry of Education and Research (BMBF) with the grant PosiAnalyse (05K2013). AIDA was funded by the Impulse- und Networking fund of the Helmholtz-Association (FKZ VH-VI-442 Memriox) and by the Helmholtz Energy Materials Characterization Platform.
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Decay Spectroscopy of Neutron-rich Exotic Nuclei

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Decay spectroscopy is a powerful tool used to address the structure of exotic nuclei. Since the decay measurements happen far from the place where the nuclei are produced, the method is very sensitive, allowing the study of nuclei produced at rates below 1/minutes.
Examples of recent decay spectroscopy studies will be presented, aiming at introducing the technique and focusing on different physic cases investigated at GSI, RIKEN, ISOLDE.

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Detector Instrumentation activities for nuclear physics at IUAC

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Inter University Accelerator Centre (IUAC), New Delhi provides facilities for nuclear structure and reaction studies [1], focused at energies around Coulomb barrier, using the Pelletron-LINAC accelerator system. The Centre is equipped with the research facilities such as gamma detector array, recoil mass spectrometers, scattering chamber and neutron detector array. The heavy-ion induced reactions are characterized by performing measurements such as high spin gamma spectroscopy, Coulomb excitation, fission mass and angular distributions, fusion cross-section and barrier distributions, multi-nucleon transfer, neutron and charged particle multiplicity, etc. To execute these experiments, detector systems [2,3] based on proportional counters, particle identification telescopes, scintillators for light charged particle and neutron detection have been developed. New detector systems for the future facilities such as FAIR are also being planned. An overview of developments in detector instrumentation at IUAC will be presented.

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Emulation of irradiation damage in reactor structural materials using ion beams at VECC

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World-wide, ion beams are being used as a surrogate of neutron irradiation in studying the damage in nuclear reactor structural materials. By using a judicious choice of ion, its energy, fluence, flux and irradiation temperature, one can span the neutron equivalent damage produced in the reactors [1].
The short-irradiation time and low induced activity caused in the materials due to the ion irradiation, enables one to carry out quick screening and bench-marking of new alloys. By characterising the ion irradiated materials, one can establish a structure-property correlation which helps in understanding the irradiation response of the material, which in turn helps in new alloy design.
In this talk, we will discuss, how the irradiation damage program in respect of the nuclear structural materials is being carried out at VECC using the different ion beams available in-house.

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Experimental Nuclear Physics research facility at VECC

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The experimental programme for nuclear physics at Variable Energy Cyclotron centre (VECC) is based on investigations of properties of nuclei under different conditions of temperature, angular momenta, deformation and isospin degrees of freedom, using the available accelerated ion beams from the cyclotron at VECC. Several state of the art detector facilities have been developed at VECC over the years to carry out exclusive multi-parameter experiments using light and heavy ion beams from the K-130 cyclotron, as well as the expected beams from superconducting cyclotron and radioactive ion beam facilities. The detector development and their use in various physics experiments, with some of the recent results will be discussed.

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Experiments using VECC Penning trap, cryogenic operation and future outlook

PARNIKA DAS[None]

The Penning trap has become an essential component of Radioactive Ion Beam facilities due to its potential to manipulate ions, resulting in high-resolution beam purification. It is an incredibly powerful tool for high-precision mass measurement and trap-assisted spectroscopy. The techniques employed in trap-assisted studies are highly efficient and sensitive, allowing for the separation and isolation of a small number of ions of interest for further study. In this context, a detailed understanding of the basic principles and techniques employed in trap-assisted studies will be presented.
A cryogenic (4K) Penning Trap is operational at VECC. Experiments performed with trapped electron cloud using Penning trap assembly at both room temperature and 4K will be presented. Indigenous developments and modifications have led to trapping of electron cloud upto 800 seconds at a pressure 5x 10-10 mbar in VECC Penning Trap. Spin-off from this developmental work and future steps to utilize exotic ions from ANURIB will be discussed.

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Exploring Nuclear Reaction Dynamics using Radioactive Ion Beams through α and ⍰-Decay Spectroscopy

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The investigation of nuclear reaction cross-sections for the creation of isotopes using radioactive ion beams (RIB) and studying their decay modes has been a critical source of understanding for nuclear reaction dynamics. While much of the experimental research on nuclear properties has focused on nuclei near the valley of stability, however, with the availability of RIBs, recent attention has turned to studying nuclei far from stability. Measuring systems at the limits may provide important information that, when contrasted with more stable systems, can shed light on the underlying physics and improve our understanding of the reaction dynamics. Some of the recent significant advancements include the discovery of additional heavy chemical elements, the observation of neutron halos in highly neutron-rich nuclei, and the experimental mapping of nuclear shell structures far from stability. We are an established group and have made significant contribution to the study of pre-compound emission and complete fusion (CF) / breakup fusion (BUF) reaction dynamics using stable beams obtained from the Variable Energy Cyclotron Centre (VECC), Kolkata and Pelletron Accelerator of the Inter University accelerator Centre (IUAC), New Delhi, India, respectively. With the availability of the ANURIB facility at VECC, it would be possible to produce exotic nuclei and study their properties, that are generally, not accessible using stable beams, by measuring their cross-sections over a range of energies through ⍰ and/or ⍰-decay spectroscopy. However, conducting experiments using RIBs requires special beam and detector technology development, crucial for these studies. Many neutron halos, of one neutron or two-neutron character, have been identified in the nuclear chart e.g., 11Be, 15C, and 19C for the former and 6He, 11Li, and 14Be for the latter. Some useful beams for the measurements from the point of view of reaction dynamics studies may also include 9Be, 14C, 15O, 18F, and many more. As soon as some of these beams are developed, the reaction dynamics studies using RIB's may be initiated. Comparing the cross-sections of populated residues with stable and unstable beams over a range of energies, may provide important information on the reaction dynamics that can help in developing and/or extending the systematics on BUF contributions as well. Further, the proposed proton and neutron beamlines at the facility may give additional advantage of studying the nuclear reactions and measuring cross-sections with better accuracies. This talk will present the details of some proposed experiments using radioactive ion beams.

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Gamma spectroscopy with low-energy RIB: possibilities with ANURIB

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In the first stage of ANURIB, low-energy rare isotope "beams" will be available to the users, which are ideal for the study of decay gamma spectroscopy. The decay spectroscopy of the neutron-rich nuclei are very important not only for the better understanding of the nuclear structure physics but has its implication in the applied field as well. Two aspects of the gamma spectroscopy, the Discrete gamma spectroscopy (DGS) and Total absorption gamma spectroscopy (TAGS) measurements which are used in the decay studies will be discussed. The TAGS measurement has been established as one of the most useful technique for proper estimation of beta-decay feeding intensity. The determination of beta-feeding intensity of the fission products is useful in reactor application to estimate its decay heat [1]. The recently suggested priority nuclei has been given in Ref.[1] for this application. It includes the neutron rich isotopes of Zr (Z = 40) to La (Z = 57). On the other hand, some of these nuclei in the A ~ 140 - 150 region are also interesting to study from nuclear structure physics point of view to investigate certain higher order correlation. The DGS, along with lifetime measurements of excited states in the daughter nuclei will be useful for such measurements. In the similar context, the decay study of neutron rich nuclei around 78Ni are also of paramount interest.

At VECC, we have started a program of TAGS and DGS measurements of neutron rich nuclei. The TAGS and DGS measurements have been applied for initial studies of the decay of 43K [2] and 126Sb [3] at our centre. The measurements and the future possibilities with ANURIB will be presented.

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ISOLDE Facility, some highlights of recent work and plans for the future

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The ISOLDE Facility at CERN is the world's leading facility for the production of radioactive ion beams (RIBs) using the ISOL (Isotope Separation On-Line) method. Over 1000 isotopes of more than 70 elements have been produced by the impact of a 1.4 GeV proton beam on a variety of targets and using different ion sources for providing beams at 40-50 keV energy. Purified isotope/isomer beams can be further accelerated to about 10 MeV/u using the HIE-ISOLDE post-accelerator.

The low-energy and accelerated beams are used for a wide variety of experiments in nuclear structure research, but also for studying astrophysical processes, for materials properties research, for biochemical and biomedical research and for fundamental interaction studies.

This presentation will introduce the ISOLDE facility and RIB production, including some recent examples of experiments addressing open questions in nuclear physics.

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Ion beam interaction with Semiconductors and nano-scale materials

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While traveling through a material energetic ions lose energy by nuclear (Sn) and electronic (Se) energy loss. Sn is an elastic energy loss process that is well described by Rutherford scattering cross-section. This stochastic binary collision process produces vacancies and interstitials and their complexes. With increasing energy Se dominates over Sn and peaks at around 1 MeV/nucleon. This inelastic energy process generates energetic electrons through the Coulomb interaction of the nuclear charge of the projectile and the bound and free electrons in the material. These energetic electrons generate thermal spike along the ion path by interacting with the lattice. Beyond a material-dependent threshold, a collective atomic movement is possible leading to an ion track. In this talk, I shall discuss how thermal spike which is unique to swift heavy ions is used for the shaping of nano-particles. And to modify semiconductors, namely recrystallization of partially damaged semiconductors and controlled defect formation. Also, discuss the possible utilization of radioactive ions to study these effects.

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Ion irradiation on ZnO and other metal oxides: prospects, challenges and future directions

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ZnO is a well-known wide band gap (3.37 eV at room temperature), intrinsically n type and extremely radiation hard semiconductor [1]. The exciton binding energy of ZnO is ~ 60 meV. Intense luminescence in the ultra-violet region due to exciton recombination is seen from ZnO at room temperature [2]. Hole doping in ZnO (p type) is challenging, still there are reports [1]. Furthermore, undoped ZnO is diamagnetic but becomes ferromagnetic due to intrinsic or extrinsic defects. In brief, ZnO is a promising candidate for opto-electronic devices, particularly useful in high radiation environments as in spacecrafts.
On this regard, ion irradiation in ZnO is extremely important from several considerations. Defect accumulation in ZnO due to energetic particles is intensely investigated [3,4]. In fact, choice of ion, its energy, fluence, irradiation conditions etc. is important to achieve a purposeful defective/doped state of ZnO. Ion irradiation with suitable ions is beneficial to fabricate p type or ferromagnetic ZnO. Tuning of ZnO resistance up to 10 orders of magnitude can be done using ion irradiation. Knowledge on semiconductor-metal junction properties is necessary for ZnO based devices and irradiation technique has been found to be fruitful to tailor such junction properties.
Defect probing in ZnO is another interesting area of study. Positron annihilation, Raman, photoluminescence, Rutherford backscattering spectroscopy, several microscopic techniques and synchrotron based spectroscopic probes have been employed. Rich defect physics and chemistry of ZnO have been unearthed and yet to be explored fully.
Summary of our works based on H, C, N, O and Ar ion irradiations on ZnO will be discussed in the direction for strategic investigation on other metal oxides. Irradiation with few stable and radioisotopic beams on ZnO and their possible applications will also be mentioned.
Acknowledgements: Supports from Dr. A. Chakrabarti, Dr. S. Dechoudhuri and D. Bhowmick (VECC, Kolkata), Dr. D. Kanjilal, Dr. P. Kumar and Dr. S. A. Khan (IUAC, New Delhi) and Dr. C. Hugenschmidt (TU Munich) are gratefully acknowledged.
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Journey towards ANURIB – Applied & Nuclear Research using Rare Isotope Beams

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An ISOL post-accelerator type RIB facility has been developed in Variable Energy Cyclotron Centre (VECC). The RIBs are produced using alpha and proton beams from K130 cyclotron using multiple thin targets. The recoil products are transported using gas jet transport and ionized in a 2.4 GHz ECR ion source capable of handling dynamic gas loads. The charge state of the 1+ ions from the first ECR source are increased further using a 6.4 GHz second ECR source as charge breeder followed by an isotope separator. The RIBs are accelerated from 1.75 to 99 keV/u using a Heavy Ion Radio Frequency Quadrupole (RFQ). Further acceleration up to 1.04 MeV/u is done by five numbers of IH LINACS. In near future, four superconducting Quarter Wave Resonators will augment the energy to 1.5 MeV/u.

A few RIBs have been already developed using this facility. The present status of the facility

Based on the experience gathered in developing the present RIB facility, a dedicated RIB facil

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Journey towards the nuclear drip line

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In this presentation, I shall highlight recent advancement in understanding nucleon-nucleon interaction by studying the nuclei around the limits of existence using the state-of-the-art experimental techniques and its impact in explaining the cosmic events in explosive burning scenario.

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Nuclear fission studies using gas jet transport system

Rahul Tripathi[None]

Gas jet transport systems provide access to short-lived fission products and, thus, can help in detailed measurement of members of isobaric chains which is important for understanding the role of different neutron and proton shells in governing the fission mass distribution which has been recently an active area of investigation. Gamma-ray spectrometry after the gas-jet transport is a complementary technique to the on-line mass separation or gamma-gamma coincidence measurement to obtain the information about mass and charge of the fission products which is important for ascertaining the role of neutron and proton shells. In the last few years, experiments have been carried out to study the fission product mass distribution using the gas-jet transport facility at VECC, Kolkata and pneumatic carrier facility at Dhruva reactor, BARC. A detailed comparison of these results with the calculations by the GEF code has been carried out. In this presentation, results from these studies will be discussed. In addition, coupling of the gas-jet transport system with the radiochemical separation can help in the detection and quantification of low yield fission products and can also be useful for decay studies for some of the fission products. Some recent attempts in this direction will also be discussed.

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Nuclear physics of exotic nuclei and its implications in astrophysics

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The John D. Fox Accelerator Laboratory at Florida State University operates an accelerator system comprised of a 9 MV Tandem plus a 8 MV superconducting linac booster to provide light- and heavyion beams for nuclear structure and nuclear astrophysics research. The laboratory is operating an inflight radioactive beam facility called RESOLUT to produce radioactive beams one or two nucleons off stability. Exotic beams have been successfully used in projects of astrophysical interest, such as the excitation-function measurement for 18Ne(alpha,p), relevant for the breakout from the hot-CNO cycle, and 7Be+d, which is analyzed in its impact on the primordial lithium problem. Other recent projects include the study of a threshold-resonance in 11B, which had been hypothesized to play a role in the beta-delayed proton decay of 11Be. The laboratory also operates high-resolution stable-beam instruments, such as the SE-SPS large-acceptance magnetic spectrograph and the Clarion-2 gamma spectrometer, which create synergy towards common scientific goals pursued at the laboratory.

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Nuclear solid state techniques at VECC

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Gamma ray spectroscopy is a well known technique in nuclear physics research. Based on gamma ray spectroscopy, a number of nuclear solid state techniques, e.g., positron annihilation techniques, Mossbauer spectroscopy, perturbed angular correlation technique, etc., are widely used in the area of solid state physics / materials science research since last several decades. These facilities have huge potentials in characterizing different materials in future also. In the presentation, the basic principles of these nuclear solid state techniques and its unique characterization ability will be covered. The radioactive isotopes available from the upcoming ANURIB facility and the e-LINAC based positron beam facility will provide new opportunities with the nuclear solid state techniques for materials science research.

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Nuclei away from stability and the r-process

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Nuclei away from the "valley of stability," typically near the "drip lines", have challenged our understanding of nuclear structure. Some have a "long tail" in their matter density distribution – popularly known as a "halo," as in 11Be, 19C, in the light mass region or 34Na, 37Mg, in the deformed medium mass region. Another exciting development is the existence of "bubble nuclei" as in 20N, 22O, and 24Si, which have a marked depression in their central densities and are shaped as a biconcave spheroid – more like a human red blood cell. Naturally, some of the tenets of nuclear structure

physics, like the concept of magic numbers, are not sacrosanct anymore as one travels far from stability. Therefore, we ask what effect they have on crucial nuclear physics inputs, like reaction rates, in explosive nucleosynthesis, especially in forming heavy elements via the r-process.

To this effect, we consider two limited networks of C-N-O and Na-Mg-Al isotopes and study their final abundances, in an explosive scenario, for various nuclear physics inputs – some in which their exotic structures are accounted for and others with statistical inputs. Finally, we plan to show some of our recent results on what effect, even these limited data, can have on the full r-process network.

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Positron emitting Radioactive ion beams for simultaneous treatment and imaging

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Heavy ion particle therapy is a rapidly growing and potentially the most effective and precise radiotherapy technique. However, the sharp dose gradients in the distal ends make it extremely sensitive to range uncertainties, which remain one of its main limitations. In clinical practice, wide margins extending into the normal tissue are commonly used to guarantee tumor coverage, thus jeopardizing the benefits of the sharp Bragg peak. Online range verification techniques could potentially help to overcome this limitation. PET (positron emitting tomography) is one of the most established methods to verify the beam range. However, 12C-ion therapy, the physical shift in the β+ activity and dose peak, the low statistics compared to the delivered dose, and the long half-life of the most abundantly produced projectile fragment (11C) limits the PET-based range verification accuracy to approximately 2–5 mm. Direct use of β+ radioactive ion beams (RIB) for both treatment and imaging could help overcome this limitation by increasing the signal/noise ratio, mitigating the washout blur of the image, and reducing the shift between measured activity and dose. In this context, the BARB (Biomedical Applications of Radioactive Ion Beams) project was initiated at GSI aiming to assess the technical feasibility and investigate possible advantages of RIBs in preclinical studies. During the first year of experiments within this project, radioactive Carbon and Oxygen beams (10,11C and 15O) were produced by isotopic separation with the fragment separator and transported to the medical vault of GSI. Thanks to the upgrade of the SIS-18 in the FAIR in Darmstadt, it was possible to achieve RIB intensities sufficient to treat a small animal tumor. Besides showing the potential of RIB in a treatment planning study to estimate the magnitude of possible range margin reduction and its impact on the doses to organs at risk and on the normal tissue complication probability, the vast experimental campaign, including research ranging from basic nuclear physics and PET detectors developments to animal treatments, foreseen in this project will be presented.

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Possibilities and challenges with ion-beam modification of materials

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In this talk, we shall discuss the possibilities and challenges with ion-beam modification of materials in a few important areas which are related to some new and existing areas of research having high societal impacts. In doing so, we will discuss several experimental results based on different ion energies and species which may have direct relevance to ANURIB.

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Precision mass measurements for nuclear and neutrino physics studies as well as for tests of fundamental symmetries

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This review provides an overview on the latest achievements and future perspectives of Penning-trap mass spectrometry on short-lived radioactive as well as stable nuclides with applications in nuclear structure, neutrino physics, and most recently even in dark matter searches where relative mass uncertainties at the level of 10-11 and below are required. Rapidly developing neutrino physics has found in Penning-trap mass spectrometry a staunch ally in investigating and contributing to a variety of fundamental problems. The most familiar are the absolute neutrino mass and the possible existence of resonant neutrinoless double-electron capture / double-beta dacay. In addition, the most stringent test of CPT symmetry in the baryonic sector by mass comparison of the antiproton with H- will be presented.

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Proposed fast neutron beam facility at VECC and its possible applications

Kaushik Banerjee[1]

[1] *VECC*

Quasi-monoenergetic neutrons can be produced using (p, n) reactions in light mass target nuclei. In particular metallic 7Li and 9Be targets can be used as they are easy to handle compared to the gaseous targets. VECC medical Cyclotron provides the proton beam of energy 15 to 30 MeV and current of a few hundreds μA. This machine can be used to produce quasi-monoenergetic neutrons. Available neutron energy in this case would be in the range of 13 to 28 MeV and neutron flux of the order of 1010 n/cm2 (for 50 μA proton) can be produced. Neutron beams can also be produced using primary electron beams. Here the process is two steps; first the production of bremsstrahlung photons using (e, γ) reaction followed by (γ, n) reaction in a suitable target. For photo-neutron reaction 9Be target can be used as it has low threshold (1.66 MeV). Electron Linac is being developed as part of the ANURIB project. This can be utilized to generate secondary neutrons for different experiments. Finally I shall discuss a few key nuclear physics experiments that can be performed using the fast neutron beam facility.

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Radioactive ion beam in nuclear astrophysics

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Nuclear astrophysics is concerned with the nuclear reactions that occur in astrophysical sites as well as explaining the observed abundance of elements. A number of reactions occur in the interior of stars and other such sites that are diÓcult to study in terrestrial laboratories. Indirect methods have been devised to extract the cross sections for these reactions. The availability of radioactive ion beams in the last few decades has also contributed signiÑcantly to our knowl edge in this respect.

After a very brief introduction to the reactions in possible astrophysical processes, some representative experiments using radioactive ions will be discussed and their importance in understanding stellar structure, stellar evolution and nucleosynthesis will be highlighted.

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Research using BARC positron beam facility

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Positron annihilation spectroscopy (PAS) is an efficient nuclear-probe technique to study microstructural aspects in materials: for example, crystal defects in metals, alloys & semiconductors, molecular free-volumes in polymers and micro- & meso-pores in porous materials. In Radiochemistry Division, BARC variable energy slow positron dc beam facility has been developed and utilized since more than a decade to study depth profile of vacancy-like defects in multilayered system of metals & semiconductors, and free-volumes in polymer thin films. Recently, a pulsed slow positron beam facility is developed in Radiochemistry Division for quantitative estimation of molecular free-volumes in polymers and other porous thin films. An intense positron beam facility using Dhruva research reactor has been proposed, where thermal neutrons and high energy gamma rays will be used for the production of intense positron flux. The intense positron beam facility will be used for research on defect evolution in nanosecond time scale via single-shot spectroscopy techniques and positronium molecular spectroscopy.

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Spectroscopy of Exotic Isotopes and Possibilities at ANURIB

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We will present some of our selected results associated with the low-lying collectivity in atomic nuclei using the hybrid array of Compton suppressed Clover HPGe detectors and LaBr3(Ce) scintillator detectors. Related physics proposals for the ANURIB facility will be discussed. The need to develop a next generation gamma detection facility coupled to different ancillary detector systems for the decay spectroscopy will be discussed. In this connection, our involvement in the DEGAS project for DESPEC experiments at NUSTAR/FAIR will be presented.

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Status update on the ANURIB project

Vaishali Naik[1]

[1] *VECC Kolkata*

We have built an ISOL type Rare Isotope Beam (RIB) facility at VECC using the K130 cyclotron as driver accelerator. So far ion beams have been accelerated up to around 415 keV/u using a combination of Radio Frequency Quadrupole (RFQ) linac and three IH-Linacs. Two more IH Linac modules and inter-connecting beam-line have been added in a new Annex building to increase the energy to 1.0 MeV/u. Rare isotope beams of 14^O, 42^K, 43^K, 41^Ar and 111^In have been accelerated with typical intensities of 10^3 to 10^4 pps to demonstrate commissioning of the facility. Ion beams of stable isotopes are also accelerated and utilized by users for material science studies.

Our focus so far has been to complete R&D and construction of individual building blocks from ion-source to linear accelerators in preparation for the next generation facility called ANURIB - a facility for applied and nuclear research with rare isotope beams. Pre-project activity for ANURIB is funded and work is ongoing for filling R&D gaps in remaining three major areas namely super-conducting electron linac photo-fission driver, super-conducting heavy-ion linac and high power actinide target module which are being pursued jointly with TRIUMF lab in Canada.

Present status and future plans for the ANURIB project will be discussed.

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Study of neutron-rich nuclei at RIKEN RI Beam Factory

H. Sakurai[1]

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An overview on experimental activities about neutron-rich nuclei produced with the "Radioactive Isotope Beam Facility" (RIBF) would be given.
Since 2007, the RIBF facility has been aiming (1) to discover new quantum phenomena in a large isospin symmetry through investigating the nuclear structure in very neutron-rich, (2) to study correlation and condensation of loosely bound neutrons, (3)to elucidate the r-process path by giving a benchmark to astrophysical scenarios, and (4) to obtain the information on the equation-of-state in asymmetric nuclear matter.
In this talk, special emphasis would be given to selected recent highlights obtained at RIBF. A facility upgrade plan of RIBF would be introduced, too.

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Surface and nanoscience research prospects using ANURIB

Prasanta Karmakar[None]

Interactions of energetic ions with solid surfaces and interfaces have been the subject of active research for fundamental interest as well as technological applications. Further, radioactive ion implantation on surface and nano-structures adds exciting possibilities of modification and characterization in sub atomic scale. Spectroscopic study of the emitted radiations from the implanted exotic nuclei is fascinating for probing the host material as well as to explore the properties of exotic nuclei. We intensely use the beams of existing Radioactive Ion Beam Facility (RIBF) at VECC and propose to explore the research possibilities in surface and nano-science using the upcoming ANURIB facility. ANURIB is a unique facility, which will provide stable and radioactive beams of energy from few keV to MeV. Low energy and very low energy stable ion beams can be used for shallow implantation, which is very important for modern electronic and optoelectronic device realization, while low energy radioactive probe atoms can be used to study the local structural and magnetic properties. Intermediate energy can be used for synthesis of SOI structure (silicon on insulator), and interface mixing. Similarly, depth control implantation of RIB probes can be used for the detection of defects and magnetic structures. Higher energy stable ions can also be used for ion scattering (MEIS, RBS) and ion induce X-ray/ Gama ray emission studies. Emission channeling, photoluminescence and beta NMR are also possible using the radioactive ion beams. Research opportunities for surface and nano science using stable and radioactive beams of ANURIB will be discussed in the talk.

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Theoretical perspectives of exotic nuclei

Jhilam Sadhukhan[1]

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Depending on the mass regions, different predictive theories are employed to explore the properties of exotic systems such as superheavy nuclei and nuclei away from the \beta stability line. Mainly, ab initio theories are applied for relatively lighter nuclei, whereas nuclear energy density functional-based self-consistent theories are the most promising tool for heavy and superheavy nuclei. In the case of light neutron-rich systems, I will present crucial predictions from the chiral effective field theories. Then, emphasis will be given to the applications of energy density functional-based approaches. Implications to nuclear astrophysics and superheavy element research will be elaborated. Possible future perspectives will also be discussed.

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Total Absorption Gamma-ray Spectroscopy of Exotic Nuclei

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The total absorption gamma spectroscopy technique (TAGS) is one of few methods available that provide beta decay data free from the systematic error called Pandemonium effect. The technique is relevant for nuclear structure, in cases where a proper determination of the beta decay strength in the daughter nucleus is necessary. Beta decay data is also of great interest for practical applications in particular for those related to reactor applications like the determination the reactor antineutrino spectrum in reactors and the estimation of the decay heat after reactor shutdown.

In this talk, I will present the technique, and present some examples of recent measurements of relevance for reactor applications and nuclear structure.