

प्रस्तावित सुविधा

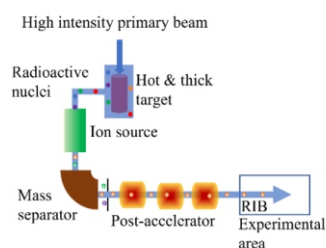
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वैज्ञाग में भारी आयन अन्वेषण हेतु स्थायी एवं अस्थायी समस्थानिक कणपुंज (सुभीर) सुविधा

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रेडियोसक्रिय आयन कणपुंज

(आरआईबी) उत्पादन की ऑनलाइन

रेडियोसक्रिय (आईएसओएल) विधि का

योजनाबद्ध प्रदर्शन।

सारांश

मौलिक अनुसंधान एवं अनुप्रयोगों के लिए 10 MeV/u तक ऊर्जा के स्थिर और अस्थिर आयनों के किरणों को तीव्र करने हेतु वैज्ञाग के त्वरक परिसर में एक बहुउद्देश्यीय भारी आयन त्वरक सुविधा का निर्माण प्रस्तावित है। 30 MeV इलेक्ट्रॉन और 40 MeV प्रोटॉन त्वरक का उपयोग करके रेडियोसक्रिय आयनों को चालक त्वरक के रूप में उत्पादित किया जाएगा। भारी आयन त्वरक में, दो अलग-अलग ईसीआर आयन स्रोतों को स्थिर और अस्थिर आयनों से अंतःक्षेपित करने का प्रस्ताव है, जो स्थिर भारी आयन (1 से 92 की सीमा के भीतर Z) और रेडियोधर्मी आयनों (~Z = 38 से 60, A = 90 से 170) दोनों की आपूर्ति में सक्षम हैं। यह सुविधा, न्यूट्रॉन, गामा किरणों और आवेशित कणों के मापन का पता लगाने की व्यवस्था के साथ अत्याधुनिक प्रयोगात्मक क्षेत्र हेतु अग्रणी अनुसंधान का कार्य करेगा।

Proposed Facility

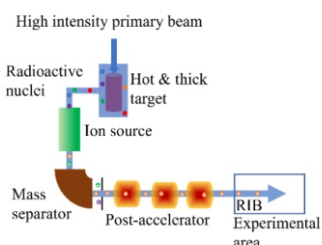
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Facility for Stable and Unstable isotopic Beam for Heavy Ion Research (SUBHIR) at Vizag

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Schematic representation of isotopes online (ISOL) method of Radioactive Ion Beam (RIB) Production.

ABSTRACT

It is proposed to construct a versatile heavy ion accelerator facility at the accelerator complex at Vizag for accelerating beams of stable and unstable ions of energy up to 10 MeV/u for basic research and applications. The radioactive ions will be generated using the proposed 30 MeV electron and 40 MeV proton accelerator as driver accelerators. Two separate ECR ion sources are proposed to inject stable and unstable ions to the heavy ion accelerator, capable of delivering both stable heavy ion (Z within the range of 1 to 92) and radioactive ions (~Z=38 to 60, A=90 to 170). The facility will have state-of-the-art experimental area with detection setup for measurement of neutrons, gamma rays and charged particles to perform frontline research.

KEYWORDS: Stable and radioactive ion beams, Electron accelerator, Proton accelerator, Heavy ion accelerator.

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Introduction

Ion accelerators are one of the primary tools for nuclear physics research which involves the transmutation of elements through fusion, fission, transfer, breakup, spallation and fragmentation reactions. Studies of static and dynamic properties of nuclei require accurate knowledge of nuclear structure and reaction mechanism. By accelerating and colliding ion beam with target nuclei, and observing the collision products, properties of the interacting nuclei and atoms can be studied. These studies can be performed at various energy regions starting from very low energies like few keV/nucleon (A) to GeV/A. The medium and high energy regions deal with nucleons and its internal structure. The low energy nuclear physics focuses on the fundamental issues related to the nature of strongly interacting matter in the universe, starting from its creation and more specifically the interaction between nucleons. Nuclear physics research has led to the basic understanding of the energy generation in sun and other stars, energy generation using nuclear fission and fusion reactions, nuclear medicine, etc. [1]. Most of the current knowledge on nuclear properties has been gained by performing experiments using stable ion beams or long lived naturally occurring isotopes from accelerator facilities that are restricted to about 300 nuclei mostly on stable elements or long lived naturally occurring isotopes as target.

The fusion reaction between two stable nuclei leads to the production of nuclei in the neutron deficient side of the nuclear chart while, the fission and fragmentation reactions in general produce nuclei in the neutron rich side. The nuclear collision between stable ion beam with stable target can produce only a limited number of unstable nuclei which have been thoroughly studied. By colliding stable ion beam on target made of stable isotopes one cannot reach a large fraction of nuclei which are among the around 7000 nuclei that are estimated to be lying between the proton and neutron drip-lines [2,3]. To produce most of the unstable nuclei away from the line of stability on the nuclear chart, radioactive ion beams and/or radioactive targets are required. To produce unstable/radioactive ion beam (RIB), stable ions need to be transmuted through nuclear reaction in reactors or accelerator facilities. Using accelerators, the unstable ion beam produced by bombarding high intensity stable ion beams on suitable target can either be directly used for experiments after purification if it has enough energy or after reacceleration for secondary reaction studies. Owing the nature of production of secondary radioactive ion beam, the beam current is typically very low compared to the stable ion beam. However, developments over the last few decades have resulted in mature techniques that allow to explore the properties of isotopes that have a neutron-to-proton ratio very different from the stable isotopes in an unprecedented way [3-8]. The present proposal is to build a world class National Radioactive Ion Beam (RIB) facility with moderate to low beam current at Vizag, to perform 'forefront research' in nuclear physics, and other branches of physics with capability to provide stable heavy ion beam across the periodic table at high intensities. Specifically, this facility will focus on the production of neutron rich nuclei which are less synthesized and studied.

Physics Interest

Radioactive ion beam facilities are transforming nuclear science by making beams of exotic nuclei with various properties, available for experiments. The study of novel nuclear structures and the decay modes associated with weak nucleon binding and isospin can be explored using the RIB. At present, the main excitement and thrust of work with unstable beams are given below.

Role of exotic shape, size and weak binding on reaction dynamics, and decay modes

Nuclei come in a variety of sizes and shapes, from spherical to deformed shapes, which can be prolate or oblate or triaxial. Experiments using RIB can produce and investigate static properties, structure and reaction dynamics of nuclei having exotic shape and structure like halo nuclei, Borromean nuclei, Bubble nuclei, nuclei with neutron skin, etc. For example, nuclei like ^{11}Li , which has only 11 nucleons (neutrons and protons) has a matter radius as big as a lead nucleus with 208 nucleons and hence higher reaction cross-section. These exotic nuclei near drip line have also demonstrated exotic decay modes like proton radioactivity which is not observed in nuclei close to the line of stability. Some of the exotic nuclei have also shown soft dipole resonance seen as the collective oscillation of tightly bound core against the loosely bound valency nucleons. Nuclear reaction and structure studies using exotic beams will be one of the main focuses of this facility. The high quality of the beam produced from Isotope Separation OnLine (ISOL) facility, with proton-to neutron numbers varying over a wide range, allows high-precision measurements of beta decay, particle correlations and atomic masses. These kinds of measurements will be a good testing ground for fundamental symmetries like isospin. Most of the nuclear models developed to describe the properties of stable nuclei fail to describe the nuclei at the extremes of neutron to proton ratio. The three body forces required to explain the halo nuclei and the new magic number are few of the examples. With further studies in the unexplored region, the surprises could be plenty.

Production of super heavy elements (SHE)

Like atoms, nuclei having 2, 8, 20, 28, 50, 82 protons and/or 2, 8, 20, 28, 50, 82, 128 neutrons show more stability compared to nearby mid shell nuclei. Beyond $Z=83$ and $N=128$ (^{209}Bi nuclei), no stable nuclei have been found even though the long living isotopes of thorium and uranium are found in nature. These heavy nuclei are unstable mostly against fission or alpha decay. However, the major shell closure beyond $Z=82$ and $N=126$ can stabilize nuclei and increase their half-life. There are predictions for stability of super heavy elements with $N=184$ and Z between 110 or 114 or 126 [10].

In addition, the stability can also be brought in by deformed shell closure. Recent calculations indicate that ^{270}Hs is a doubly magic deformed nucleus, with deformed magic numbers $Z = 108$ and $N = 162$ [11]. Apart from the production and identification of nuclei in super heavy island, studies using them are very important. On the other hand, recent calculation indicates the smearing of the electronic and nuclear shell structure of SHE due to the relativistic effects and other phenomena leading to no major distinction between the shells

[12]. The RIB facility with neutron rich isotopic beam will be required to study properties of such nuclei and atoms.

Nuclear astrophysics

Unlike the earth's composition where most of the elements are stable, stellar environment specifically during stellar explosion is expected to generate a lot of heavy radioactive nuclei. The nuclear reactions happening in this environment has led to the formation the elements from iron to uranium. Nuclear reactions occurring in such explosive stellar environments, such as novae, supernovae and X-ray bursters, are believed to play an important role in the synthesis of these heavier elements. The pathways of the reactions leading to them involve short-lived radioactive exotic nuclei, which can be studied using RIB.

Atomic and condensed matter physics

Collinear laser spectroscopy with radioactive ions can be performed to obtain information on hyperfine structure and isotope shift. Beta NMR spectroscopy which can be used to study the magnetic and electronic properties of ultrathin films, nanostructures and interfaces is possible only with radioactive ion beams. By implanting radioactive species inside the material, the surface and bulk properties of the solid and diffusion properties can be studied. Perturbed angular correlation to study the electric field gradient and magnetic field at implant site, emission channeling which uses the emitted radiation to measure the lattice position of the implanted ion in a crystalline host material, tracer diffusion studies and Mossbauer spectroscopy can be used to study various properties of the condensed matter.

Nuclear medicine

Radioisotopes can be used for medical diagnosis and treatment. Photofission and proton induced fission provides wide range of radioisotopes among them many of the isotopes can be of use for medical applications. One of the main advantages of RIB facility for production of radioisotopes for medical isotopes is due to the beam purification using high resolution mass spectrometers.

In addition, the high current stable heavy ion beam from the proposed accelerator will have uses in nuclear physics studies with many more projectile-target combinations at much larger beam energy and intensity allowing us to measure ultra-low cross-sections, SHE production, etc. It has uses in genetic modification of food grains, radiotracers, material surface corrosion studies, atomic physics, condensed matter physics studies, etc.

RIB Production Methods and Current Status

RIB can be produced majorly using two methods namely projectile fragmentation (PF) method and ISOL method [5]. In the projectile fragmentation method, the primary beam which is made up of very high energy heavy ions, on hitting a thin stable target, breaks into fragments through fragmentation, spallation and fission reactions. These fragments are forward focused and have high energy. Typically, mass separators are used to separate the species of interest from the rest of the beam and decelerated if required to reach suitable energy, focused and used as secondary radioactive ion beam for

experiments. Even though this method is good for accessing short lived isotopes, the purity and quality of the beam is of a major concern. In ISOL method, the primary beam which can be neutrons or electrons or protons or heavy ions (having very low energy to very high energy of the order of GeV) can be used to produce radioactive ions through various reaction processes like neutron/ proton/ deuteron/ heavy ion induced fission or photofission or spallation or nuclear fusion or transfer or breakup. The radioactive ions thus produced are stopped, extracted, separated and accelerated to form secondary radioactive ion beam. The beam quality of ISOL generated RIB is much better than the fragmentation method. However due to the delay in stopping, extraction and reacceleration, the short half-life radioactive nuclei decay before reaching the secondary target station limiting its usefulness for short lived isotope acceleration.

The ISOL facilities presently operating are ISOLDE, CERN at Switzerland, SPIRAL- GANIL at France, and upcoming facilities are SPES, LNL at Italy, TRIUMF at Canada, IThemba at South Africa and RAON at South Korea. Apart from the ISOL facilities listed above, FRIB at USA, Super-FRS, FAIR, GSI at Germany, RARF, RIKEN at Japan and FLNR, JINR at Russia are few of the important operating RIB facilities worldwide.

Currently India has only a few heavy ion accelerator facilities namely BARC-TIFR Pelletron-LINAC accelerator facility at Mumbai, IUAC Pelletron-LINAC accelerator Facility at Delhi, Variable energy cyclotron and Super Conducting Cyclotron (SCC) at VECC, Kolkata. Other than the recently commissioned K=500 cyclotron, other accelerator facilities do not have enough energy to cross the Coulomb barrier for most of the heavy projectile target combinations. VECC and SCC produce only a few species of beams. At VECC, ANURIB phase-I with very low energy and low current RIB using driver beam from VEC is operational.

Proposed Stable and Unstable isotopic Beam for Heavy Ion Research (SUBHIR) Facility at Vizag

This facility is proposed to deliver radioactive ion beam as well as intense stable ion beam across the periodic table from Hydrogen to Uranium at energies exceeding the Coulomb barrier. Thus, it will significantly surpass those achievable with the existing BARC-TIFR Pelletron-LINAC facility, which is the current workhorse for the nuclear physics community at Trombay. The short-lived nuclear reaction products mainly the unstable fission fragments, produced in proton induced fission and photo fission of actinide targets, will be the source of radioactive ions. The schematic layout of the proposed SUBHIR facility at Vizag is shown in Fig.1. The 40 MeV high intensity (2mA average beam current) proton beam extracted from the first stage of the MEHIPA (Medium Energy Heavy Ion Proton Accelerator), the 30 MeV 0.6mA (average) electron beam from the room temperature (RT) electron LINAC and in future the 50 MeV 2mA (ave) electron beam from the superconducting eLINAC proposed at the same accelerator complex will be used for producing unstable nuclei. The proton beam is expected to directly collide with the actinide target to produce radioactive ion (RI) inside a vacuum chamber. The electron beam from the eLINAC is expected to fall on a conversion target made of high atomic number, high melting point metal like tungsten to

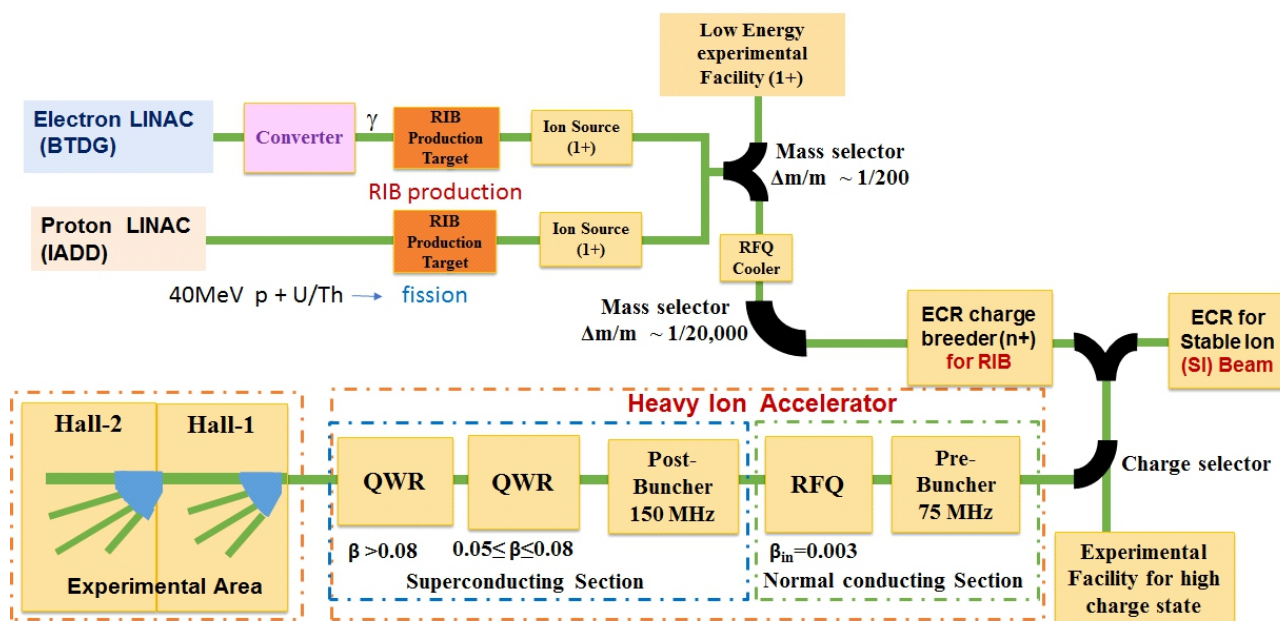


Fig.1: Schematic Layout of SUBHIR at Vizag.

produce forward focused bremsstrahlung photons which in turn upon interaction with actinide target (^{238}U or ^{232}Th) inside a vacuum chamber will produce fission fragments. Proton induced fission can provide neutron rich (via fission) as well as proton rich RIB (using (p,xn) reactions), while electron driver can provide neutron rich RIB (via photo fission). In case of electron driver, photo-fission involves low excitation energy and hence less neutron emission from fission fragments, yielding more neutron rich RIB relative to proton-induced fission. This facility is proposed to be constructed at the accelerator complex at BARC, Vizag.

The Phase-wise development of the proposed proton accelerator has already started for the 1GeV Accelerator Driven Subcritical Reactor System (ADSS) project that will be constructed at Vizag by Ion Accelerator Development Division (IADD), Multidisciplinary Research Group (MRG). IADD has already achieved acceleration of proton beam upto 20 MeV energy at Low Energy High Intensity Proton Accelerator (LEHIPA) facility, BARC, Trombay. The proton accelerator for ADSS at Vizag is planned to be used as the driver accelerator for RIB, when it reaches ~ 40 MeV of proton energy. Beam Technology Development Group (BTDG) has already obtained the financial approval for the development of a 30 MeV RT electron accelerator in the same accelerator complex for producing RIB via photo-fission. Two highly shielded RIB production caves, one each for electron and proton accelerator, will be used to produce, extract and transport radioactive ions. The RIB production targets technology is one of the most challenging parts of this project. It should be able to handle high beam power in small volume. It should be porous enough to release unstable ions produced inside. The production target R&D has already started at BARC. Efficient extraction of the radioactive ions produced is another crucial step. There are mainly two methods of radioactive ion (RI) extraction and transport from the production target namely diffusion-effusion method and gas jet method. Both the

methods are proposed for the future RIB facility.

The extracted radioactive ions will be converted into singly charged ions for further transportation. An RFQ beam cooler will be used to reduce the emittance of RIB before sending it through high resolution mass selector for purification of the beam. After mass selection, the singly charged radioactive ions will be stripped of many electrons to form highly charged positive ions using charge breeding ion source. An Electron Cyclotron Resonance (ECR) ion source is proposed to be used for this purpose.

For further accelerating, it is proposed to construct a heavy ion accelerator facility comprising of room temperature Radio Frequency Quadrupole (RFQ), and superconducting Nb cavities to accelerate even the heavy ions like ^{238}U upto 10MeV/u. For lighter ions the accelerator should be able to accelerate the beam to even higher energies per nucleon. The focus of the RIB facility is to produce, extract and accelerate unstable neutron rich fission fragments with $Z=38$ to 60 and $A=90$ to 170. A separate ECR ion source capable of delivering beams across the periodic table from ^1H – ^{238}U with high beam current (upto 100pA) is proposed to inject beam into the heavy ion accelerator. Further, advanced experimental facilities are planned in experimental halls for research purposes. This facility requires 8700 m² of space at the accelerator complex BARC, Vizag.

This state-of-the-art facility involves advanced scientific and technical know-hows where some of the technologies do not exist in the country at this moment. The project is planned in a phased manner. Work has already started for the construction of the 30 MeV electron accelerator at Vizag. The first phase of the MEHIPA accelerator for energies upto 40MeV is expected to start soon. R&D on the RIB production target-ion source system, prototyping of RFQ and SRF cavities are also ongoing. During the phase-I, medium energy RIB facility will be built utilizing the technologies currently under development. In

phase-II, additional high beta SRF cavities along with enhanced user facilities are proposed to be developed.

Phase I: Construction, installation and commissioning of heavy ion accelerator at BARC-Vizag

- Civil construction of the accelerator hall and beam line caves, beam halls will be taken up during this phase. All the laboratories required for this facility will also be built during this phase.
- Commissioning of RIB Target Ion Source and getting very low energy RIB with electron and proton accelerators
- Utilization of very low energy RIB for research and applications
- Fabrication, installation and commissioning of stable ion ECR ion source
- Development of radiofrequency (RF) power supplies, power amplifiers, LLRF systems and accelerator control system by Accelerator Power Control Section and Advanced Electronics Application Section.
- Fabrication, installation and commissioning of RFQ
- Fabrication, installation and commissioning of cryogenic plant for liquid helium production for this facility by Cryo-Technology Development Division (CrTDD), MRG, BARC.
- Fabrication, installation and commissioning of low beta and medium beta niobium superconducting quarter wave resonating radiofrequency (SRF) cavities.
- Integration, testing, beam trials, commissioning and utilization of phase-1 heavy ion accelerator.

Phase II: Enhancement in beam energy, and user facilities

- Fabrication, installation and commissioning of RFQ beam cooler for RIB
- Fabrication, installation and commissioning of charge breeding ECR ion source for RIB
- Installation and commissioning of high-resolution mass separator
- Integration of charge breeder with HIA
- Fabrication, installation and commissioning of medium beta SRF cavities.
- Development of beam lines and experimental facilities.
- Commissioning and utilization of full scope SUBHIR facility.

Conclusion

During the last 30 years, a lot of leading research activities have been performed using the stable ions from BARC-TIFR Pelletron LINAC accelerator Facility (PLF), Mumbai and now it is time for us to take our scientific endeavor to the level of current international pursuits and build a green field facility. This facility can provide much larger species of stable ion beams with much higher energy, intensity. The unstable ion beam from this facility with moderate intensity and medium energy is going to be something very new in India.

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