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The Beijing ISOL initial conceptual design report

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ABSTRACT

Peking University (PKU) and China Institute of Atomic Energy (CIAE) are jointly proposing to construct a large science facility, temporarily called "Beijing ISOL". This facility aims at both basic science and application goals, and is based on the double driver system, namely reactor driving and intense deuteron-beam driving. On the basic science side, the radioactive ion beams produced from the isotope separation online (ISOL) device will be used to study the new physics and technologies at the limit of nuclear stability. On the other side regarding to the applications, the facility will be devoted to material research for the nuclear energy system by using typically the intense neutron and ion beams. In the whole process of design, construction and operation, an opening policy will be pursued, and the domestic and international cooperation will be emphasized. Through this project, a joint research and education mode will be established.

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1. Science background

There are only less than 300 stable nuclei in the universe, which compose the world where people live. But much more unstable nuclei (8000–10,000) have been predicted. At present, only about 1/3 of the unstable nuclei can be produced in laboratories and much less have been studied for their properties. Since 1980s, many new phenomena have been observed in the study of unstable nuclei, such as halo structure [1], cluster configuration, new magic numbers and so on. These phenomena reveal the systematic evolution of the nuclear structure across the area far from the stability-line and the emergence of new physics characterized by new degrees of freedoms and new effective interactions. At the meantime, studies in nuclear astrophysics have led to many new discoveries, including the star energy stability mechanism, the pathway to synthesis heavy elements and so on, which are closely related to the nuclear physics in the area of unstable nuclei [2].

On the high mass end of the nuclear chart, there is a predicted island of super-heavy nuclei. As we know, uranium ($Z = 92$) is the heaviest element in the nature, all the other heavier elements have to be synthesized in the laboratory and often have very short life-times due to large fission and α-decay probability [3]. A thorough understanding of the neutron-rich nuclei is indispensable in order to find new ways to reach the "super-heavy stable island", including fusion reaction with neutron-rich projectiles or large mass transfer reaction. Therefore, many RIB (Rare Ion Beam) facilities have been or are going to be constructed worldwide, such as RIBF-BigRIPS in Japan [4], GSI-SuperFRS in Germany [5], GANIL-SPIRAL2 in France [6] and MSU-FRIB in USA [7]. But when approaching the neutron drip line, the production of unstable nuclei is getting more and more difficult and the new generation of RIB facilities is still needed.

In addition, materials used in nuclear energy system must sustain severe conditions such as intense radiation, high temperature (close to 1000 °C), high pressure, and high erosion intensity and so on [8]. Material performance is one of the most important factors for the security of the nuclear energy system. The radiation damage, especially the neutron radiation damage, is the key problem for nuclear materials [9,10]. The damage level may increase from a few dpa (displacement per atom) to more than 100 dpa for the future fourth generation of fission reactors and the fusion reactors. Such a severe damage is not sustainable by any presently available materials. Therefore, research on the radiation damage is extremely important, and the strong neutron sources will provide necessary platforms for these kinds of studies.

Due to the exciting science and application goals, Peking University (PKU) and China Institute of Atomic Energy (CIAE) are jointly proposing to construct a large science facility, temporarily called "Beijing ISOL". Multi-beam, multi-energy and multi-terminal will be used to meet the users' requirements relating to the basic science research and urgent applications. A brief description of the facility conceptual design is given below.

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2. Initial conceptual design of Beijing ISOL

As shown in Fig. 1, there are two kinds of driven modes for Beijing ISOL. The first driver will be the CARR (Chinese Advanced Research Reactor). This approach relies on the large thermal neutron fission cross section for ^{235}U and high neutron flux in the reactor, which allow to deliver very high fission yield. The second driver is the high intensity deuteron linear accelerator (d-LINAC). It makes use of the (d, n) reaction to produce fast neutrons in the energy range of 1–20 MeV. The ^{238}U fission will be induced by the fast neutron, and become a strong source of fission beams. The d-LINAC can be operated independently for neutron beam applications. Both drivers are complementary to each other, and the basic science and application goals will be achieved under the effective operation. The summary of Beijing ISOL with regard to main characteristics and research fields is shown in Fig. 1.

2.1. Reactor-driven radioactive ion beam

The concept of reactor driving RIB is the following. A target with a 5-g ^{235}U will be installed in the neutron tunnel of CARR reactor. Fission products induced by thermal neutrons of the reactor will be released and transported into the ion source at a temperature of about 2300 °C, which is maintained by the fission power. The fission products will be ionized and extracted from the ion source, and then the interesting ion spices will be selected from the fission products. The selected ions will be feed into a charge breeder to form ion beams with low mass to charge ratio, which are suitable for post acceleration by a LINAC. This system consists of reactor driven target/ion source, mass separator, charge breeder, lenses and steerers, beam diagnostic units, vacuum system, control system, radioactive handling system, exhaust gas collection system etc. A schematic view of the system is shown in Fig. 2. Thermal ionization surface ion source, laser ion source and plasma ion source techniques will be tested to meet the demands for dedicated elements [11].

The beam will be formed in the ion source at 30 kV. After extraction and acceleration, it will be transported out of the reactor. In the reactor hall, the beam will be filtered in a pre-separator. The passed ion beam will go into a separator system which consists of two electrostatic analyzer and two magnets. The resolution power of the system is 1000 with 100% transport efficiency.

2.2. High intensity deuteron driver accelerator

The driver accelerator should accelerate the deuteron beam up to 40 MeV with maximum beam current of 10 mA. For most of the intense neutron facilities currently under construction or design, such as SPIRAL2 [12], SARAF [13] and IFMIF [14], the 40 MeV deuteron beam is proposed. Proton beams up to 33 MeV can also be accelerated in this accelerator. The accelerator can be operated on either CW (continuous waveform) or pulse mode, and the ion energy can be adjusted in a wide range. Fig. 3 is the layout of the high intensity deuteron driver accelerator. It is composed of three main sections corresponding to low, medium and high energies, respectively.

The low energy section is composed of a high-current deuterium ion source (IS) followed by a low energy beam transport (LEBT) line. The PKU compact permanent magnet 2.45 GHz ECR (Electron Cyclotron Resonance) ion source will be used to produce the deuteron beam with energy up to 50 keV. LEBT will be used to match the beam from IS to the medium energy section.

The medium energy section is composed of a room temperature radio-frequency-quadrupole (RFQ) accelerator and a medium energy beam transport (MEBT) line. A room temperature four vane RFQ will be used, with a resonant frequency of 176 MHz. Deuteron energies at the entrance and exit of RFQ are 50 keV and 3 MeV respectively. The main function of MEBT is to match the beam into SC linac in both transverse and longitudinal directions.

The high-energy section is composed of a RF superconducting (SC) linac followed by the high energy beam transport (HEBT) lines connected to different targets. The SC linac includes two different families of cryomodules with the SC cavities of $\beta = 0.09$ and $\beta = 0.15$, respectively. Half wave resonance (HWR) cavities will be used. The operation frequency is 176 MHz. HEBT is used to transport the beam to experimental halls and match beams from linac to different targets for different applications.

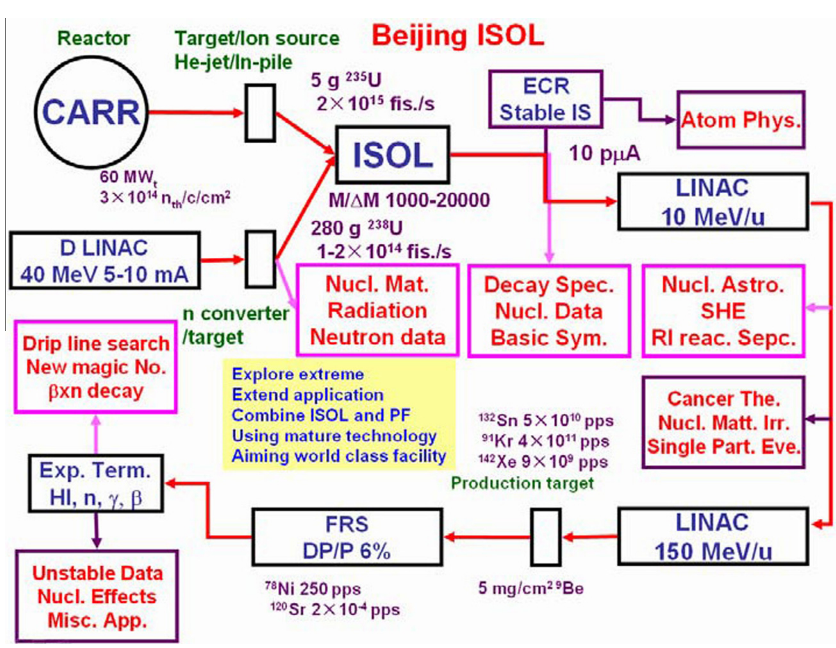

Fig. 1. Summary of Beijing ISOL with regard to main characteristics and research fields.

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