STATUS OF THE RARE ISOTOPE SCIENCE PROJECT IN KOREA*

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Abstract

A heavy-ion accelerator facility has been designed in Korea for the production of rare isotope beams under the rare isotope science project (RISP). The project is funded and officially started in the end of 2011. The accelerator complex is composed of three main accelerators: a superconducting linac to use the in-flight fragmentation (IF) method to generate isotope beams, a 70 MeV proton cyclotron for the ISOL method, and a superconducting post accelerator for re-acceleration of rare isotope beams produced by ISOL to the energy range of 18 MeV/u. Minimum energy of a U beam requested for the IF driver is 200 MeV/u at the beam power of 400 kW. This facility will be unique in the aspect that the IF and ISOL systems can be combined to produce extreme exotic beams. In addition, standalone operation of each accelerator will accommodate diverse users in the beam application fields as well as in nuclear physics.

INTRODUCTION

A heavy ion accelerator facility is being designed in Korea to produce rare isotope beams by using both in-flight fragmentation (IF) and ISOL methods. The project is named as rare isotope science project (RISP), and was started from the end of 2011 after a period of conceptual design [1]. A conceptual layout of the facility is shown in Fig. 1.

The main accelerator is a superconducting linac, which can accelerate a ^{238}U beam to 200 MeV/u and protons to 600 MeV. It is divided into two sections, SCL1 before charge stripping at the energy of 18.5 MeV/u and SCL2 after the stripping. These parameters of the primary beam are similar to those of the FRIB project in the US [2]. A major difference from the planned FRIB facility is the use of an independent ISOL driver. A 70-MeV H- cyclotron will be employed to drive a 70-kW ISOL target system. The radioisotope beam extracted from the target will be further ionized in EBIS [3] or ECR ion sources to achieve a higher charge state before beam injection to the post accelerator (SLC3), which is also a superconducting linac to accelerate a beam up to the energy of around 18 MeV/u. Furthermore this isotope beam produced by ISOL can be accelerated using the SCL2 for the IF system to produce more exotic isotope beams.

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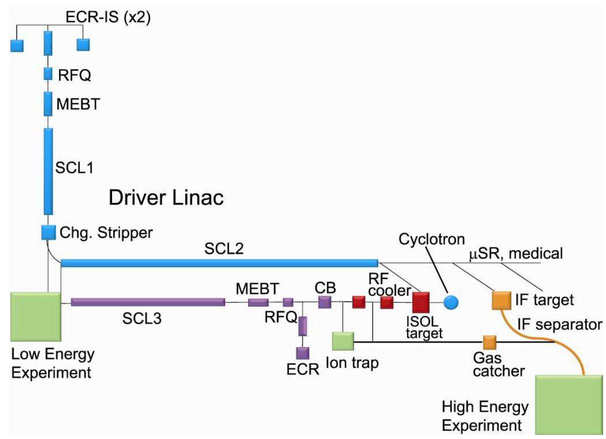

Figure 1: Conceptual layout of the heavy-ion accelerator complex of the RISP.

When the primary beam passes through a thin target, fast radioisotope beams are produced by the projectile fragmentation and fission mechanisms. Then the following isotope-beam selection system utilizes Bρ–energy loss–Bρ analysis to separate and identity an isotope beam of interest. This fast isotope beam can be stopped using a gas stopper, and the charge state of the beam extracted from the gas stopper can be boosted like in the ISOL method before being injected into the post accelerator. A main advantage of the IF method is that it is not subject to chemistry of the ions unlike in the ISOL. Hence rare isotope beams in a wider range can be produced.

The experimental areas are divided depending on the energy of the beam delivered as shown in Fig. 1. Different kinds of spectrometers are planned to be facilitated for nuclear reaction and structural studies [4]. In addition, the facility will accommodate beam users in various application fields including biomedical and material sciences using both stable and isotope beams. The stopping location of an isotope beam can be accurately traced by radiation measurement, which is a notable advantage of radioactive beam and is to be explored in some applications.

ACCELERATOR COMPLEX

To produce highly charged ion beams, a superconducting ECR ion source similar to the VENUS source of the LBL [5] is to be developed. To meet the goal of 400-kW beam power for U beam, envisioned scheme was to accelerate a beam in two charge states of 34+ and

35+ [6], but recent ECR test results showed that a single-charge-state U beam could be sufficient for the production of the full beam power.

The injection beam line is designed to accept a two-charge-state beam for very heavy ions such as U beam in case that higher beam power can be more easily achieved with a two-charge-state beam from the ECR. However, beam losses may be reduced for a singly charged beam especially in longitudinal phase space due to the mitigation of sensitivity to misalignment errors and so on.

To increase acceleration efficiency for a heavy ion beam, it is needed to strip electrons from the ions as the beam energy is increased. The charge stripping is set to be performed at the energy near 18 MeV/u to produce the charge state of around 78+ for the U beam. We plan to use a carbon foil for initial low-current beam testing, but not at the beam power over a kW because empirical results show that the lifetime of carbon foil is greatly shortened [7]. A liquid Li target is being studied as the stripper, which can handle the full power beam as has been developed by an ANL group [8]. A gas target is also a possibility. Higher pressure gas could be confined with plasma window to produce higher charge state beam. The equilibrium charge state by the gas stripper is significantly lower compared to that by a carbon foil, while liquid Li target is expected to produce higher charge states than by the gas.

The primary accelerator is a superconducting linac composed of two sections SCL1 and SCL2. Four different types of superconducting cavities are planned to be developed. In SCL1 quarter-wave resonators with the geometrical β of 0.047 operating at 81.25 MHz will accelerate a beam from the RFQ. Another type is a half-wave resonator operating at 162.5 MHz with β of 0.12. After the charge stripping, spoke-type cavities will be used in SCL2, which operate at 325 MHz. Two types of single-spoke cavity with β of 0.3 and 0.53 will be developed. Operating temperature of all the cavities is 2 K. Cryogenic system for the entire facility will have refrigeration capacity of around 15 kW at 4 K. The total number of cavities including the cavities in SCL3 is over 500, and the number of cryomodule is around 150.

Transverse focusing for the superconducting linac will be made by quadrupole magnet doublets in between the cryostat. A similar focusing lattice has been used for SPIRAL2 [9]. It is expected that alignment errors of the focusing elements can be corrected more easily when they are located in the room temperature. The steering coils will be incorporated together with the quadrupole magnets.

The post accelerator SLC3 shown in Fig. 1 will use the same kinds of sc-cavities and focusing elements of the driver linac SCL1. Main differences would stem from the lower beam current of rare isotope beam and the beam charge state depending on the performance of charge breeding in the EBIS or ECR source. The beam diagnostic elements in wide dynamic range will be placed to measure and transport very low-current isotope beams. A standard technology is to use a stable beam with similar q/A first to tune the beam line and then to transport rare isotope beam to the downstream target or detector.

An H- cyclotron of 70 MeV is to be used as a driver for the ISOL system. The maximum beam current is specified as 1 mA. We plan to purchase a commercial unit as similar energy cyclotrons have been developed for the production of medical isotopes and as an ISOL driver [10]. The beam current of 1 mA is higher than that of existent commercial cyclotrons, which is around 700 μA. However, the increase to 1 mA is foreseen to be not technically very challenging. In fact, there is a concern in the lifetime of carbon foil for electron stripping extraction of 1 mA beam. However, the use of carousel containing several units should allow the foil exchange period to be acceptable.

As the cyclotron can be procured and installed more readily compared to the planned superconducting linac, isotope beams produced by the cyclotron will be available earlier by the end of 2016 in the current project schedule, while the beam from the linac is expected by the end of 2017.

RARE ISOTOPE BEAM PRODUCTION

Both methods of in-flight fragment separation and ISOL will be used to produce rare isotope beams. In the present work plan, ISOL facility belongs to the experimental user group, while the IF separator is being designed by the accelerator group. Some details of the beam characteristics by the ISOL are described in Ref. [4].

The in-flight fragmentation method has been developed in major nuclear physics laboratories at the beam energy higher than tens of MeV per nucleon [11]. But the intensity of isotope beams was limited by the beam power available from the primary accelerator. The next generation IF facility requests the beam power of a few hundred kW to produce high intensity rare isotope beams. As a result of this high beam power, the high-power target and removal of the primary beam in the process of isotope beam separation using a beam dump have become technical challenges.

The in-flight isotope beam separation system can be largely divided into pre and main stages. In the pre-separator, the primary beam is separated by momentum dispersion, and a beam dump is used to remove the separated primary beam in the localized area. This pre-separator area has the high-level of radiation, and radiation heating on the magnetic elements is high [12]. A remote handling system based on servo-motor controlled crane is being considered. The design of beam dump is in fact complicated because the system needs to separate different kinds of rare isotope beam from the primary beam in different beam energies, also considering that the range of the primary heavy-ion beam is short. A rotating water drum, which can be displaced along the axis, is being considered.

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The main separator is designed to identify the isotope beam of interest and to purify it by using the time of flight method and other nuclear physics techniques. The beam from the pre-separator is mixed with different kinds of isotope beams having similar q/A ratio. The use of a wedge-shaped degrader can remove some interfering isotope beams utilizing energy loss mechanism inside material at the cost of inducing additional nuclear reaction and beam energy straggling. The unwanted isotope beams identified by the time of flight method can be removed by an rf deflector located at the end of separator before the beam is delivered to the downstream experimental area. The rf deflector can be more effectively used to purify the isotope beam in the proton rich side.

SUMMARY

The rare isotope science project in Korea is in progress, which was started from the end of 2011. The high current heavy ion linear accelerator is a primary driver to produce rare isotope beams using the IF method. A 70-MeV cyclotron will be used to produce isotope beams using the ISOL method. A plan is that radio-isotope beam produced by ISOL can be further accelerated using the primary accelerator to a higher energy so as to utilize the IF method. This two-stage process is expected to produce more exotic isotope beams.

In the current schedule, the first proton beam from the cyclotron will be delivered to the target in the end of 2016, and the first IF beam by the end of 2017. This is very aggressive schedule to carry out, and the schedule is also subject to the construction of the building complex for the accelerators and experimental equipments. Achieving the permission to operate the high-level radiation facility from the Korea Institute of Nuclear Safety is also expected to be a tough task.

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