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Experimental systems overview of the Rare Isotope Science Project in Korea

K. Tshoo, Y.K. Kim *, Y.K. Kwon, H.J. Woo, G.D. Kim, Y.J. Kim, B.H. Kang, S.J. Park, Y.-H. Park, J.W. Yoon, J.C. Kim, J.H. Lee, C.S. Seo, W. Hwang, C.C. Yun, D. Jeon, S.K. Kim

The Rare Isotope Science Project, Institute for Basic Science, Yuseong-gu, Daejeon 305-811, Republic of Korea

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A B S T R A C T

The Rare Isotope Science Project (RISP) was launched by the Institute for Basic Science (IBS) in December 2011 in Korea. The project aims to construct the new accelerator complex consisting of the Isotope Separation On-Line (ISOL) and the In-Flight Fragment (IF) facilities for the rare isotope science. The scientific programs and the experimental systems of RISP are briefly introduced with an overview of the complex.

1. Introduction

A construction of the accelerator complex for the rare isotope science was approved by the Korean government in 2009 as a major research facility of the International Science Business Belt (ISBB). The Institute for Basic Science (IBS) is the main institution of ISBB to host about 50 research centers and other affiliated institutes and the Rare Isotope Science Project (RISP) was launched in December 2011 in order to carry out the technical design and the construction of the accelerator complex named "RAON" which will be a major facility of IBS.

RAON is a rare isotope (RI) beam facility that aims to provide various RI beams of proton- and neutron-rich nuclei as well as variety of stable beams for the researches in basic science and application. RAON will provide not only the low energy RI beam ($E \leqslant 18.5$ MeV/nucleon), where would be for study of the nuclear astrophysics, the atomic physics, and the biological applications, but also the high energy RI beam ($E \leqslant 250$ MeV/nucleon), where would be for investigation of the nuclear structure of nuclei near the neutron drip line, the properties of exotic nuclei, the equation of state (EoS) of nuclear matter, and the nuclear reactions, as well as the material and the medical sciences. The research issues related to the rare isotope beams have been examined extensively in Refs. [1,2]. This report gives an overview of RAON, and briefly introduces the scientific programs and the experimental systems being considered in RISP.

2. General overview of RAON

In order to produce the RI beams of high purity and high intensity near the proton- and, in particularly, neutron-drip line, the two RI production methods [3] will be adopted at RAON, i.e., the ISOL (Isotope Separation On-Line) and the IF (In-Flight Fragment). RAON consists of proton cyclotron, post-accelerator, and heavy ion linear accelerator. The schematic diagram of RAON is shown in Fig. 1. A 70 MeV proton cyclotron is used as the driver for the ISOL facility. The RI beam produced from the ISOL target is accelerated by the post-accelerator up to 18.5 MeV/nucleon after charge breeding. The heavy ion linear accelerator (driver linac) is comprised of the injector, the low energy superconducting linac, the charge stripper station, the high energy superconducting linac, and the beam transport line. The driver linac for the IF facility delivers various ion beams from the proton to the uranium to IF target with a beam power greater than 400 kW. The uranium (proton) beam will be accelerated up to 200 MeV/nucleon (600 MeV) at the driver linac.

The IF method has an advantage of producing the short-lived rare isotopes due to the short flight time of the RI beam through the separator (less than a few hundreds of nsec). The production process of the IF method is independent to the chemical properties

* Corresponding author. Tel.: +82 42 878 8703.
E-mail address: ykkim@ibs.re.kr (Y.K. Kim).

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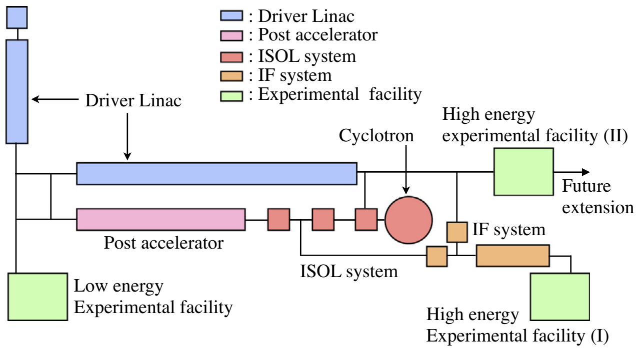

Fig. 1. Schematic diagram of RAON.

of the RI beam and target. The ISOL technique has an advantage in terms of the beam quality and intensity of the RI beam, comparing to the IF method. While the facilities RIBF and FRS are based on the IF method to produce fast RI beams, the ISOLDE and ISAC use the ISOL technique to provide intense RI beams.

RAON uses both ISOL and IF techniques. The rare isotopes produced in the ISOL system would be injected into the driver linac for accelerating the RI beam even higher energies or for using in the IF facility to produce even more exotic rare isotopes. This is unique operation mode that nobody has tried before. In the future stage, the proton beam in the driver linac would be used for the ISOL system with higher power. Therefore, large number of rare isotopes with high intensity and with various beam energies will be available at RAON. More details of the accelerator systems are described in Ref. [4].

3. Scientific programs and experimental systems

3.1. Scientific programs

The production of the RIs near the drip line and their properties are still unexplored compared to basic elements and proton- or neutron-deficient RIs due to the difficulties of the RI production mechanism. As mentioned earlier briefly, the scientific programs of RISP include studies of the nuclear structure for very neutron-rich nuclei near the drip line, the properties of exotic nuclei and the equation of state (EoS) of nuclear matter, and the attempt to understand the origin of the universe and the process of nucleosynthesis under the various stellar environments. Furthermore, RISP aims to discover a new super-heavy element with $Z > 113$.

For the applied science, finding new material, mutating the cell or DNA, constructing nuclear data, and developing new medical heavy ion therapy would be fulfilled. The material science with the RI beams, whose scale is in femto meter, would give us chance to make new materials, to study their properties, and to see a dynamic image in the nano meter scale. For the medical and biological applications, there is a plan to develop the advanced treatment technology by using the energetic RI beams, and to study the mutation of DNA. A systematic nuclear data measurement using the fast neutrons has been planned for the future nuclear energy development and the radioactive waste transmutation research.

The various RI beams of proton- and neutron-rich nuclei which are demanded for research opportunities at RISP are summarized in Table 1 [5]. The required RI beams and the desired beam intensities are listed by the RISP user community with thorough consideration of perspective and analysis of current research trends in research fields of the RI science.

3.2. Recoil Spectrometer

Recoil Spectrometer (RS) has been proposed for nuclear physics and nuclear astrophysics experiments using the low energy (up to 18.5 MeV/nucleon) ion beams. Since the RI beams have rather low intensities in many cases, it is clear that the experiments by using RI beams requires not only high-quality beams of the short-lived nuclei but also detection systems with high-efficiencies, high-selectivity, and high-resolutions. Typical beam intensities available at the existing RI beam facilities in the world are 10^9–10^{11} particles/s or less. It is expected that recoil separators combined with appropriate detector systems provides highly selective and highly sensitive measurements for the study of unstable nuclei far from the stability. Main research topics and available experiments at the RS are briefly listed in Table 2.

The stable isotope beams up to the energy of 18.5 MeV/nucleon would be also delivered to RS from the main linac. We consider the low energy in-flight separation with stable isotope beams, and expect that the proton-rich RI beams which can be produced up to A$\sim$80 would be separated by RS. This system would give an opportunity to study various research topics related to the exotic nuclei of proton-rich side. Furthermore, the possibility of searching for the super heavy element ($Z > 113$) with hot fusion reaction, such as ^{232}Th + (^{58}Fe or ^{64}Ni), at RS is being considered. Fig. 2 shows the configuration of the Recoil Spectrometer with the result of the first order ion optics using the GICOSY code [6].

Table 2
Main research topics and available experiments at the Recoil Spectrometer (RS).

Physics topics	Measurements
rp-Process	Radioactive capture, transfer reaction, scattering
r-Process	Transfer reaction (d,p), decay measurement
Proton and neutron drip line studies, halo nuclei	Transfer reaction, scattering

Table 1
Selected RI beam requirements for the RISP research opportunities.

RI beam species	Energy range (MeV/u)	Desired intensity (particles/s)	Research fields
^{80}Ni, ^{76}Fe, ^{132}Sn, ^{144}Xe	5–20, >100	$>10^{8-9}$	Nuclear structure
^{14,15}O	<10 (and <30 keV)	$>10^{10-11}$ (and $>10^{8}$)	Nuclear astrophysics, material science
^{26m}Al	5–20	$>10^{7-8}$	Nuclear astrophysics
^{45}V	0.61–2.3	$>10^{7-9}$	Nuclear astrophysics
^{39}Si, ^{36}Mg	5–10	$>10^{7-9}$	Nuclear structure
^{68}Ni, ^{106,132}Sn, ^{140,142}Xe	10–250	$>10^{9}$	Symmetry energy
^{6,8}He, ^{12}Be, ^{24}O	50–100	$>10^{9}$	Nuclear study with polarized target
^{17}N, ^{12,14,15,17}B, ^{31,32}Al, ^{34}K	50–100	$>10^{9}$	Nuclear study with polarized RI beam
^{8}Li, ^{11}Be, ^{17}Ne	<30 keV	$>10^{8}$	Material science
$^{133-137}$Sn	<60 keV	>1	Atomic physics
^{8}B, ^{8}Li, ^{9,11}C, ^{15}O	>400	$>10^{7-9}$	Medical and bio sciences

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