Status report of the RIKEN radioisotope beam factory (RIBF)

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Abstract

The operation of RIKEN Radioisotope Beam Factory (RIBF) was started at the end of 2006 with a heavy-ion injector linac (RILAC), an injector cyclotron (AVF), four ring cyclotrons (RRC, fRC, IRC and SRC), and projectile-fragment separators (RIPS and BigRIPS). After that, an additional new injector heavy-ion linac (RILAC-II) with a 28 GHz superconducting ECR ion source was completed in March, 2011. SRC is the final stage superconducting cyclotron and its maximum energy is 400 MeV/nucleon for lighter ions of hydrogen to Ar and 350 MeV/nucleon for heavier ions up to uranium. The achieved beam intensity is 1 pμA for ^{4}He and a few pnA for ^{238}U. A polarised deuteron beam is also available. New developed electron-nucleus scattering equipment is under construction. It is called SCRIT (self-confining radioisotope ion target), and consists of a 150-MeV microtron and a 700-MeV electron synchrotron storage-ring. Uranium photo-fission target system and an ISOL will be constructed for the unstable-nuclide supply. It will realise the electron scattering experiment with unstable nuclides for the first time.

Introduction

The construction of a facility expanding project, RIKEN Radioisotope Beam Factory (RIBF) [1], was completed and the first beam was accelerated at the end of 2006. The first experimental result was obtained [2] at the beginning of the following year. After the construction of the accelerators efforts were made to increase the variety of available beams and their intensities, and to construct detectors.

For the experiment of scattering between electron and unstable nuclide, a novel ion-trap target equipment was discovered with an electron storage ring. It is called SCRIT (self-confining radioisotope ion target), and its construction has started.

Heavy-ion accelerators

Figure 1 illustrates a bird's eye view of the RIBF accelerator complex.

The oldest accelerator of RIBF is the heavy-ion variable frequency linear accelerator, RILAC, which was built in 1980. It has been used as an injector for the RIKEN ring cyclotron, RRC, and has been used alone for the super-heavy element synthesis, such as an element of atomic number 113, and other experiments.

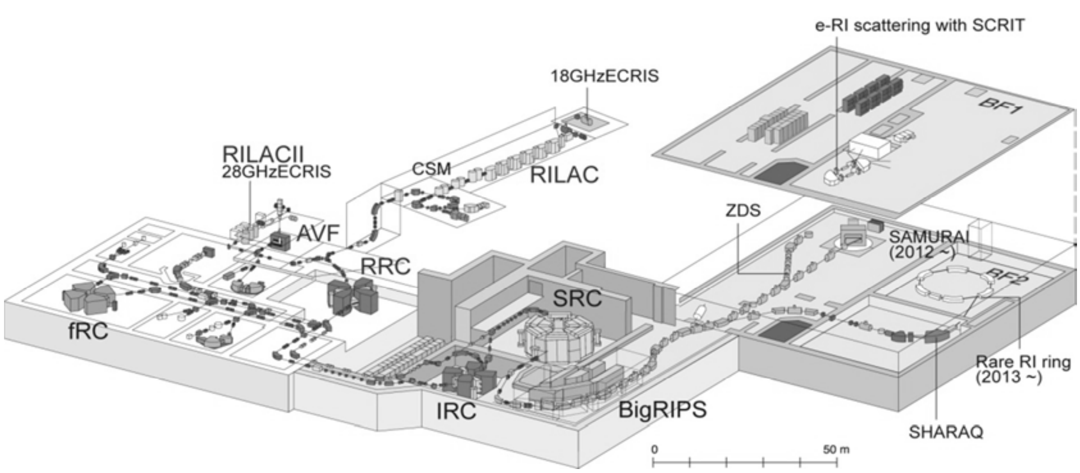
The AVF cyclotron is used for the injector of RRC for light heavy-ions up to nickel. This is also used alone for the production of commercially-distributing radioisotopes.

RRC has been the main accelerator for a long time. It achieved nuclear physics experiment of very short-lived lighter nuclides with the RIKEN projectile fragment separator, RIPS. Many biological and engineering experiments have also been carried out.

In the RIBF Project, three-ring cyclotrons of fRC (fixed-frequency ring cyclotron), IRC (intermediate-stage ring cyclotron) and SRC (superconducting ring cyclotron) [3] were constructed.

SRC is the final stage accelerator, which is the world heaviest (more than 8 000 tonnes) and strongest magnetic-rigidity machine. The magnetic field is 3.8 tesla, and the stored energy is 240 MJ. While the main and the trim coils are superconducting, the iron pole is of room temperature. The valley parts are also covered with 80-cm-thick iron plates which work as an absorber of stray magnetic flux, a magnetic shield and also as a radiation shield.

Figure 1: A bird's-eye view of the RIBF accelerator complex



The accelerated beam is conducted into BigRIPS (big RIKEN projectile fragment separator) [4], where any nuclide lighter than uranium can be produced. The secondary unstable beam is delivered to the experimental area.

After the completion of the big project, a 2nd RIKEN linear accelerator, RILAC-II [5], with a 28 GHz superconducting ECR ion source was installed in 2011. RILAC-II supplies high-intensity heavy ion beams to RRC.

To meet the increase of the beam intensity, further improvements have been carried out for safety reasons.

Many superconducting quadrupole magnets are used in the BigRIPS tunnel, and a quench safety system has been installed. When it detects a quench signal or oxygen deficiency, ventilators are actuated and a warning siren goes off.

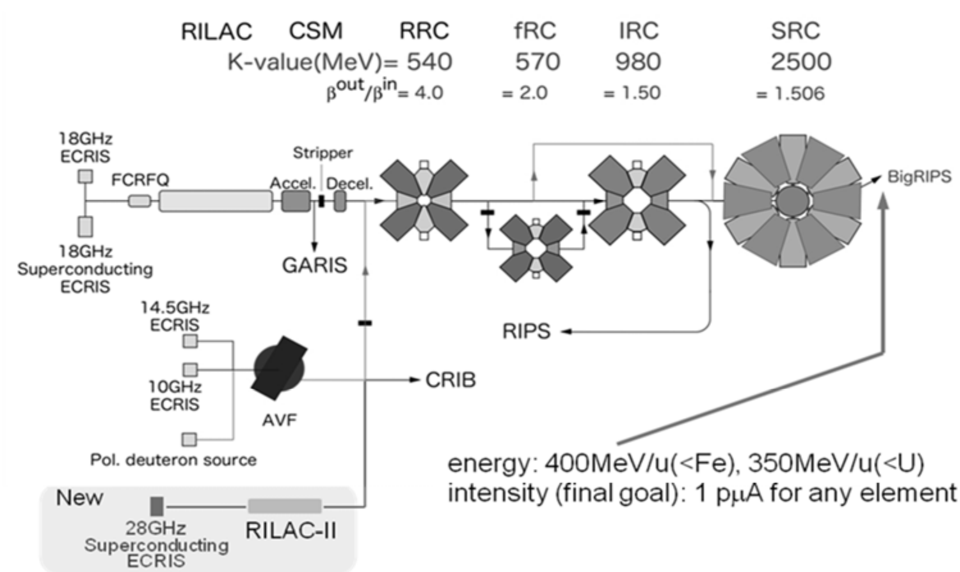
Since residual radiation level has become high around BigRIPS, pillow-seals that were originally developed at Paul Scherrer Institute in Villigen, Switzerland, have been installed. When the target or the magnets become damaged, the disabled equipment can be taken away without screwing work at vacuum connections.

The acceleration scheme is shown in Figure 2. When uranium or xenon ions are accelerated, RILAC-II, RRC, fRC, IRC and SRC are used. Light heavy-ions, such as deuteron, helium or nitrogen, are injected into RRC by AVF, and the beams are directly injected to SRC bypassing fRC and IRC.

It is possible to perform 3 experiments simultaneously, for example, a super-heavy element experiment with RILAC, radioisotope production with AVF and a high-energy unstable nuclide experiment with RILAC-II to SRC.

The beams listed in Table 1 have been already provided. The intensity of helium, for example, is limited by the license, and the beam loss at the SRC deflector, since a high beam-loss makes maintenance work difficult. The intensity of uranium is limited by the ion source and the damage on the charge stripper foils.

Figure 2: RIBF heavy-ion acceleration scheme



The condition of a stripper foil, which is placed immediately after RRC, is the severest, and a thin rotating carbon foil is used. Damage by the uranium beam is enormous: it may make a big hole after a several-hour operation. The carbon foil stripper was replaced by a helium gas stripping system at the beginning of 2012. The charge state was lowered by this replacement, and a minor alteration was done at fRC.

Table 1: Available beam intensities at present

Ion	Energy (MeV/nucleon)	Intensity (particle-nA)
polarised d	250	120
He-4	320	1000
N-14	250	80
Ca-48	345	200
Kr-86	345	30
Xe-124	345	10
U-238	345	5

Detectors for heavy-ion experiment

Three major detectors have been constructed. In 2007 the zero-degree spectrometer (ZDS) was completed, and the SHARAQ spectrometer (spectroscopy with high-resolution analyser and radio-active quantum beams) was completed in 2009. The construction of SAMURAI spectrometer (superconducting analyser for multi-particles with radio-isotope beams) was completed in March, 2012.

Now, three types of spectrometers are available; zero-degree type (ZDS), small-angle high-resolution type (SHARAQ), and multi-particle (heavy ions, protons and neutrons) type (SAMURAI).

The EURICA (EUroball RIken Cluster Array) detector, which is a high-efficiency gamma-ray spectrometer based on the former Euroball germanium cluster detectors, was installed at ZDS, and major beam time is allocated for the experiment with it.

Electron accelerator facility, SCRIT

The SCRIT facility is under construction [6]. It consists of a 150-MeV microtron and a 700-MeV synchrotron storage-ring. It will realise an electron scattering experiment with unstable nuclides for the first time.

The concept of the SCRIT is shown in Figure 3. Ions are trapped by the electric fields made by the 700-MeV circulating electron bunches and the longitudinal electrodes. Electrons scattered by the trapped nuclides are detected.

The radionuclides whose characteristics are measured are supplied by the ISOL (isotope separator on line) connected to the uranium carbide target as shown in Figure 4.

Figure 3: Principle of the ion trapping in an electron storage ring

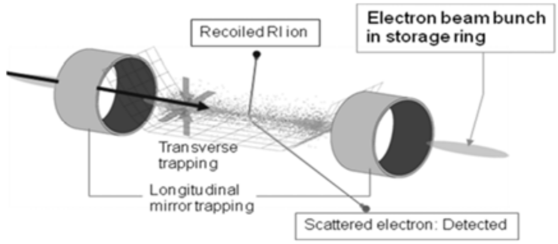
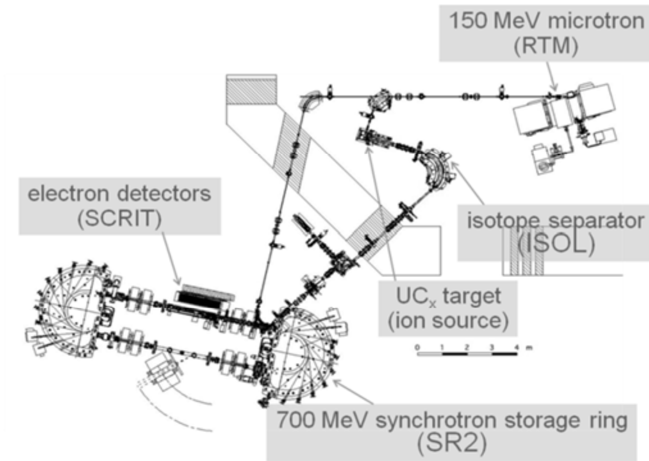


Figure 4: Layout of the SCRIT facility



The experimental scheme is as follows: Firstly, electrons from the 150-MeV racetrack microtron (RTM) are injected into the synchrotron storage ring (SR2), and accelerated up to 700 MeV. After the storage is finished, the electron beam course is changed to the uranium carbide (UCx) target. A 1-kW electron beam produces intense bremsstrahlung, which causes uranium fission. Fission fragment is extracted from the heated uranium target, separated with the ISOL, and conducted to the SCRIT trapping area.

Summary

RIBF accelerators were almost completed; 28-GHz superconducting ECR ion source and RILAC-II were installed in 2011. Three major detectors were already installed. "Rare-RI ring" for accurate mass spectrometry is under construction, and "SLOWRI" for slow radioisotope beam experiment is still waiting for budget. Improvements on charge stripping are under progress. An electron and unstable-nuclide scattering experiment will start with SCRIT within a year.

References

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