A state of the RIKEN radioisotope beam factory

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Received 20 April 2012; accepted 10 May 2012

RIKEN Radioisotope Beam Factory (RIBF) consisted of a heavy ion linac (RILAC), a small cyclotron (AVF), four ring cyclotrons (RRC, IRC, IRC and SRC), and projectile-fragment separators (RIPS and BigRIPS) when its operation was started at the end of 2006. 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. A new injector linac (RILAC-II) with a 28 GHz superconducting ECR ion source was completed in March, 2011 and beam intensities of 1 p\(\mu\)A for \(^{4}\text{He}\) and 3 pnA for \(^{238}\text{U}\) were achieved. Polarized 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 synchrotron storage-ring. It will realize the electron scattering experiment with unstable nuclides for the first time. In spite of the big earthquake on March 11, 2011, damages on the accelerators were quite small, that is, vacuum leaks were found at two points in the transport lines. They were repaired, and the experiment was started in June, 2011.

Keywords: RIBF, Heavy ion, Superconducting ring cyclotron, Unstable nuclide beam, SCRIT, Electron scattering with unstable nuclide

1 Introduction

The construction of a facility expanding project, RIKEN Radioisotope Beam Factory (RIBF), was completed and the first beam was accelerated at the end of 2006. First experimental result was obtained in the next year. After the construction of the accelerators we have been making effort to increase the variety of available beams and their intensities, and to construct detectors.

When we started the RIBF project, we had a plan to construct an electron-unstable-nuclide-ion collider, however, the expecting luminosity was not enough, and the constructing cost and the electric consumption were expected huge. To obtain more reliable results with much lower cost a novel ion-trap target apparatus was discovered with an electron storage ring only. It is called SCRIT (Self-Confining Radioisotope Ion Target), and the construction is started.

2 Heavy Ion Accelerators

A bird’s eye view of the RIBF accelerator complex is shown in Fig. 1. 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 used alone for the super-heavy element synthesis, such as 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 was the main accelerator for a long time. It enabled nuclear physics experiment of very short-lived lighter nuclides with the RIKEN projectile fragment separator, RIPS. Many biological and engineering experiments also have been done.

In the RIBF project, three ring cyclotrons of RRC (fixed-frequency ring cyclotron), IRC (intermediate-stage ring cyclotron) and SRC (superconducting ring cyclotron) were constructed3.

SRC is the final stage accelerator, which is the world heaviest (more than 8 kilo tons) 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 a magnetic shield and also as a radiation shield.

The accelerated beam4 is conducted into BigRIPS, 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, 2nd RIKEN linear accelerator5, RILAC-II, with a 28 GHz superconducting ECR ion source was installed in
2011. RILAC-II supplies high intensity heavy ion beams to RRC.

To meet with the increase of the beam intensity, following improvement was done for safety. Many superconducting quadrupole magnets are used in the BigRIPS tunnel, and a quench safety system was installed. When it detects a quench signal or oxygen deficiency, ventilators are actuated and a warning siren goes off.

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

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

Now we can perform 3 experiments simultaneously, for example, super heavy element experiment with RILAC, radioisotope production with AVF and high-energy unstable nuclide experiment with RILAC-II to SRC.

We have provided the beams listed in Table 1. The intensity of helium, for example, is limited by the license, and the beam loss at the SRC deflector. If the beam loss is large, the maintenance work becomes difficult. The intensity of uranium is limited by the ion source and the charge stripper foils.
Table 1 — Available beam intensities at present

<table>
<thead>
<tr>
<th>Ion</th>
<th>Energy</th>
<th>Intensity</th>
</tr>
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<tbody>
<tr>
<td>polarized $d$</td>
<td>$250\text{ MeV/u}$</td>
<td>$120\text{ pnA}$</td>
</tr>
<tr>
<td>$^4\text{He}$</td>
<td>320</td>
<td>1000</td>
</tr>
<tr>
<td>$^{14}\text{N}$</td>
<td>250</td>
<td>80</td>
</tr>
<tr>
<td>$^{48}\text{Ca}$</td>
<td>345</td>
<td>200</td>
</tr>
<tr>
<td>$^{86}\text{Kr}$</td>
<td>345</td>
<td>30</td>
</tr>
<tr>
<td>$^{120}\text{Xe}$</td>
<td>345</td>
<td>10</td>
</tr>
<tr>
<td>$^{238}\text{U}$</td>
<td>345</td>
<td>5</td>
</tr>
</tbody>
</table>

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

3 Detectors

Three major detectors have been constructed. In 2007 the zero-degree spectrometer (ZDS) was completed, and the SHARAQ spectrometer (Spectroscopy with High-resolution Analyzer and Radio-Active Quantum beams) was finished in 2009. The SAMURAI spectrometer (Superconducting Analyzer for Multi-particles with Radio-Isotope beams) is under construction, and will be finished in March, 2012.

When SAMURAI is completed, three types of spectrometers are available, that is, zero-degree, small-angle high-resolution, and multi-particle (heavy ions, protons and neutrons).

The EURICA project (EUroball RIKen Cluster Array) proceeds now, that is, a high-efficiency gamma-ray spectrometer based on the former Euroball germanium cluster detectors is used at RIBF. It will be set in early 2012.

4 SCRIT

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

The concept of the SCRIT is shown in Fig. 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 of which characteristics are measured are supplied by the ISOL (Isotope Separator On Line) connected to the uranium carbide target as shown in Fig. 4.

The experimental scheme is as the following. Firstly, electrons from the 150-MeV racetrack microtron (RTM) are injected into the synchrotron storage ring (SR2), and accelerated up to 700 MeV. After storage is finished, the electron beam course is changed to the 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.

5 Effect of the Big Earthquake on RIBF

The earthquake and the following tsunami attacked east Japan on March 11, 2011, and about 20000 people were dead or missing.

Fortunately, the site of RIBF is not close to the hypocenter and the machines are in large massive buildings. The damage on RIBF was only 2 cracks in the beam lines. One was in the RILAC beam line, and
another was in the RRC beam line before the RIPS target. These damages were already repaired, and an experiment using BigRIPS was done in June, 2011.

By the accident of Fukushima nuclear power plant caused by the tsunami, radioactive iodine and cesium were scattered. However, the amount was small at Kanto area. The dose rate rose as 1.1 $\mu$Sv/h on March 15 at RIKEN campus, but it came down as about 0.1 $\mu$Sv/h (excluding natural background) at the beginning of April.

Due to the stops of nuclear power plants, we met electricity deficiency. However, our gas-cogeneration system of 6.5 MW-electric sustained the accelerator operation.

6 Summary
RIBF accelerators were almost completed. 28-GHz superconducting ECR ion source and RILAC-II were installed in 2011. Three major detectors will soon be finished. “Rare-RI ring” for accurate mass spectrometry and “SLOWRI” for slow radioisotope beam experiment are still waiting for budget. Further improvement is necessary for charge stripping. Electron and unstable-nuclide scattering experiment will be started with SCRIT. Effect of the big earthquake was limited.

References