STATUS OF THE RIKEN RIB FACTORY

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Abstract

The first outcome from a newly operational RI beam facility called the RIKEN RIB Factory was obtained in the first test experiment conducted in the last week of May 2007. A new very neutron-rich isotope, Pd-125 was discovered in the in-flight fission of U-238 isotopes accelerated up to 345 MeV/nucleon. Since 1997, RIKEN has been constructing this facility, where three new ring cyclotrons with K-values of 570 MeV, 980 MeV and 2600 MeV, respectively, boost energies of the output beams from the existing K540-MeV ring cyclotron up to 440 MeV/nucleon for light ions and 350 MeV/nucleon for very heavy ions. The K2600-MeV ring cyclotron is the world's first ring cyclotron with superconducting sector magnets. These energetic heavy-ion beams are converted into intense RI beams via projectile fragmentation of stable isotopes or in-flight fission of uranium isotopes by a superconducting fragment separator.

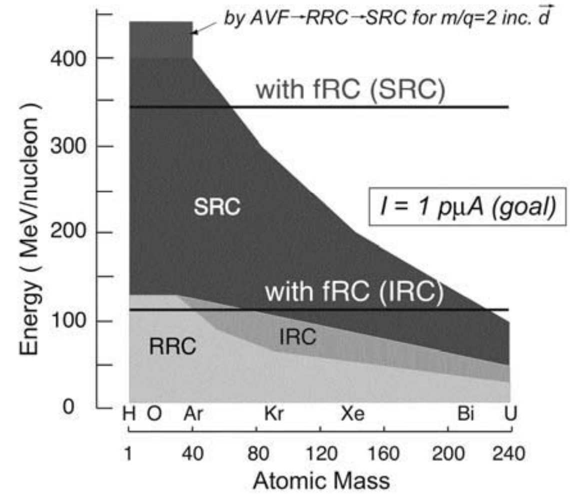

Figure 2: Acceleration performance of the RIB Factory.

OVERVIEW

RIKEN has been constructing a next-generation RI beam facility called "RI Beam Factory," or simply "RIB Factory" since April 1997 after a two-year R&D. The RIB Factory will be capable of providing RI beams of all elements, energies and intensities of which will reach several hundreds MeV/nucleon and will greatly exceed the current world standard.

Figure 1 shows a schematic layout of the RIKEN RIB Factory. Some details of this facility including its future upgrades are described in the recent publication [1]. A K540-MeV ring cyclotron (RRC) properly uses a couple of pre-accelerators: a 16-MV variable-frequency linac (RILAC) following an 8-MV fixed-frequency booster linac (CSM), and a K78-MeV AVF cyclotron (AVF). The RILAC has an injector of a variable-frequency RFQ linac (FCRFQ) equipped with two 18 GHz ECR ion sources.

A new high-power heavy-ion booster system consisting of three ring cyclotrons with K-values of 570 MeV (fixed frequency, fRC), 980 MeV (Intermediate stage, IRC) and 2600 MeV (Superconducting, SRC), respectively, will boost energies of the output beams from the RRC up to 440 MeV/nucleon for light ions and 350 MeV/nucleon for very heavy ions. An 880 MeV polarized deuteron beam will also be available. These primary heavy-ion beams will be converted into intense RI beams via the projectile fragmentation of stable isotopes or the in-flight fission of

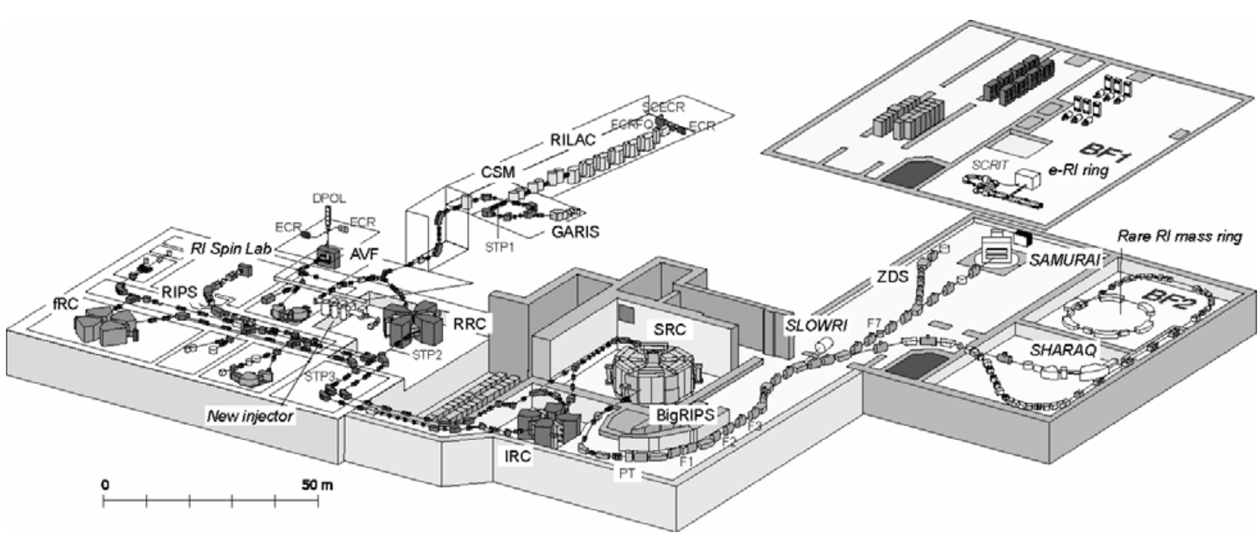

Figure 1: Schematic layout of the RIKEN RIB Factory.

uranium isotopes by a superconducting fragment separator, BigRIPS. The primary-beam intensity is targeted to be 1 particle micro amp. The combination of the SRC and the BigRIPS will greatly expand our knowledge of nuclear world into presently inaccessible region on the nuclear chart.

Several acceleration modes will be available. Mode (1): RILAC→(charge stripper1, STP1; this is used only for ions having their mass-to-charge ratio greater than 6.8)→ RRC→(STP2)→fRC→(STP3)→IRC→SRC is used for the RI-beam generation at 350 MeV/nucleon (fixed energy). Mode (2): RILAC→(STP1)→RRC→(STP3)→ IRC→SRC is used for variable energy experiments. In these two modes, a part of 115 MeV/nucleon output beams from the IRC may be transferred back to the RI Spin Lab of the existing RIPS (time sharing). Mode (3): AVF→RRC→SRC is used for providing an 880-MeV polarized deuteron beam. Figure 2 summarizes the acceleration performance of the RIB Factory.

COMMISSIONING

At 16:00 on December 28 2006, the first beam was successfully extracted from the SRC (Fig. 3): a 345 MeV/nucleon $^{27}Al^{10+}$ beam was extracted. Its mass to charge ratio is the same as that of a $^{238}U^{88+}$ beam. In this acceleration trial we skipped the fRC, because the vacuum leaking took place in this cyclotron. We could, however, confirm the acceleration performance of the SRC.

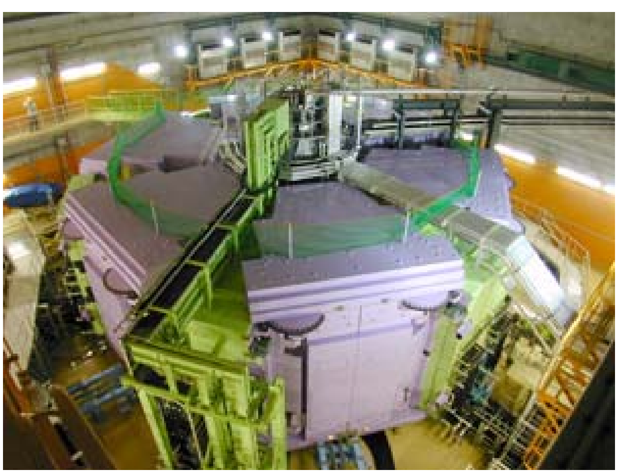

Figure 3: The K2,600MeV (8.2Tm) 6-sector superconducting ring cyclotron, SRC. This is the world's first separate sector cyclotron with superconducting sector magnets. A special feature of its design is that the whole valley regions between the sector magnets are covered with about 1 meter thick soft ion slabs to significantly reduce inverse-direction leakage magnetic flux coming from the 3.82T sector magnets to valley acceleration regions. Another merit of this design is its self-radiation shielding. The total weight amounts up to 8,300 tons.

Figure 4: The superconducting RI beam separator, BigRIPS. The separator consists of two stages: the first stage (in the cave of an upper-left corner of this photo) serves to produce and separate RI beam, while the second stage (a central part) to identify RI beam species in an event by event mode. The angular acceptances of the BigRIPS are designed to be 80 mrad horizontally and 100 mrad vertically, while the momentum acceptance to be 6 %. The maximum bending power is 9 Tm. The total length is 77 m. Now 5,000 tons concrete shielding blocks are piled up over the first stage.

At 3:00 on March 15 2007, the first RI beams were generated and identified by the BigRIPS (Fig. 4). A 345 MeV/nucleon $^{86}Kr^{31+}$ beam, mass to charge ratio of which is the same as that of a $^{238}U^{86+}$ beam, was projectile-fragmented. In this test run, we succeeded in operating the full cyclotron cascade including the fRC for the first time. After the first beam run, we accelerated a uranium beam with the fRC, and we observed that the most probable charge state after the stripping (STP3) at 51 MeV/nucleon is 86+ in stead of 88+ originally expected.

At 21:00 on March 23 2007 we succeeded in accelerating a $^{238}U^{86+}$ beam up to 345 MeV/ nucleon.

And eventually, at 6:40 on March 27 we successfully identified a large variety of RI beams produced via the in-flight fission of the 345 MeV/nucleon uranium beam.

THE FIRST TEST EXPERIMENT

In order to deliver a flash report on the first outcome from the RIB Factory during the International Nuclear Physics Conference 2007 (INPC07) which was held at Tokyo Japan on June 3-8 2007, the first test experiment was conducted by a Japanese, German, American and French joint international team in the last week of May 2007, just before the conference. This flash report was successfully presented in the plenary session in the middle of the conference. The outcome was the discovery of a new very neutron-rich isotope, Pd-125.

A 345 MeV/nucleon $^{238}U^{86+}$ beam was provided to the production target of 7 mm thick Be plate. An average beam current on the target was 2 enA (1.4×10^8 particles/sec.), while an average analyzed beam current of

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U^{35+} from the ECRIS-18 of the RILAC was 2,000 enA ($3,400\times10^8$ particles/sec.)

Charge stripping processes to breed 35+ to 71+ and to 71+ to 86+ were applied at 11 MeV/nucleon (STP2, between the fRC and the RRC) and at 51 MeV/nucleon (STP3, between the fRC and the IRC), respectively. In these processes the yield fractions of 71+ and that of 86+ were 15% by a 0.3 mg/cm^2 thick carbon foil and 25% by a 17 mg/cm^2 thick carbon foil, respectively. This means that the net beam transmission efficiency through the accelerators and the beam lines was only 1% ($0.01= 1.4\times10^8/3,400\times10^8/0.15/0.25$).

In addition, the beam was on the production target for only about 1 day in total during a one-week run to be actually provided for the experiment.

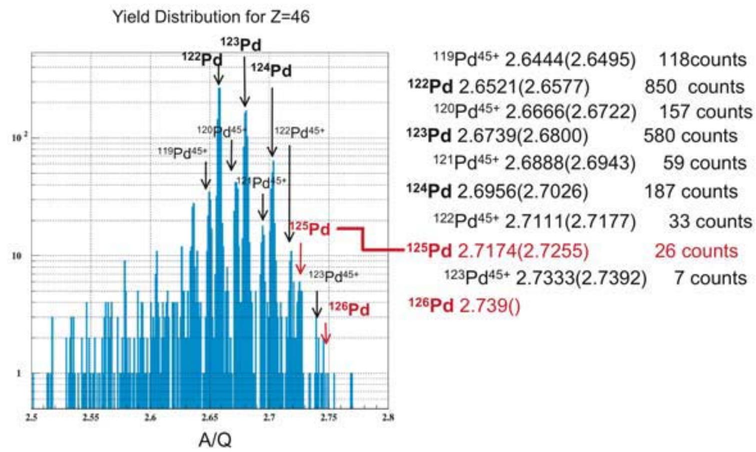

Figure 6: Yields at different A/Q values of Z=46 isotopes produced. The peak corresponding to the new isotope, Pd-125 is clearly isolated. Peaks of Q=45 (not fully stripped) for different isotopes are also seen.

We were confronted with a variety of machine troubles in this first long run. The troubles were as follows: a flat-top cavity of the IRC could not be excited because its high-power leakage rf electromagnetic wave damaged discharge damper resistors of electrostatic inflector and deflector placed nearby this cavity; the deflector channel for the beam extraction with a curvature of 90 m was incorrectly manufactured to have inverse curvature against the beam trajectories; in the SRC, one rf cavity among four rf cavities and a flat-top cavity could not be excited due to burn out of the contact fingers and the oscillator trouble; even in the operational three rf cavities, enough acceleration voltages could not be generated due to the lack of enough conditioning time. These troubles brought about miserable beam transmission efficiency and experimental duty factor. This test experiment run was carried out for machine debugging and conditioning, and operator training, as well.

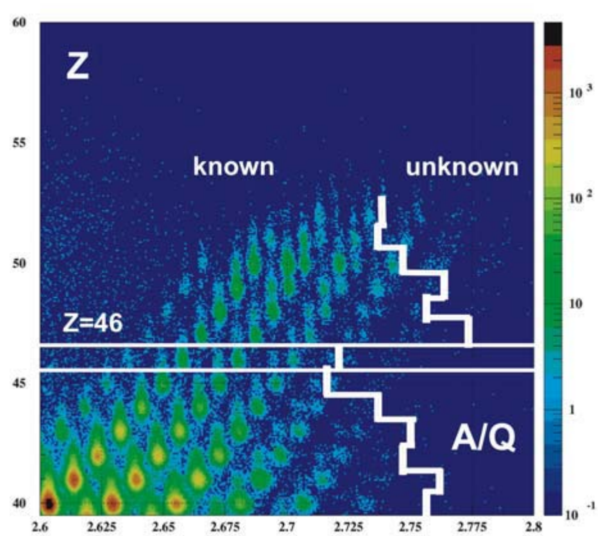

Figure 5: The results (preliminary) obtained in the first test experiment in the RIKEN RIB Factory aiming at producing new isotopes. A variety of isotopes which are produced by fission of uranium-238 of 345 MeV/nucleon are seen in the Z (atomic number, vertical) vs. A/Q (mass to charge ratio, horizontal) plot.

In spite of such bad accelerator condition, the first outcome was obtained. This achievement is attributed to much higher RI productivity of the uranium fission as compared to the projectile fragmentation as well as the very large acceptance of the BigRIPS to efficiently collect low-quality fission-fragment beams. Figure 5 shows the preliminary results. In this Z (atomic number) vs. A/Q (mass to charge state) plot, a variety of isotopes produced via the uranium fission appear. This plot has been created based on the data of the energy loss, time-of-flight and magnetic rigidity measured for each isotope in the second stage of the BigRIPS. The total dose and the total time duration for the measurement were 1.08×10^{13} particles and 25.4 hours, respectively. The white zigzag line indicates the limit of known isotopes discovered in GSI [2]. Several candidates of new isotopes are seen beyond this limit (larger A/Q values). When we select isotopes on Z=46 line, the yield distribution for Z=46 vs. each A/Q value is obtained as shown in Fig. 6. At A/Q=2.7174, a clearly isolated peak is seen which corresponds to the new isotope of Pd-125. The A/Q resolution was 0.07% (r.m.s.) at Z=40. Its yield totalled 26. In this test experiment, we have successfully demonstrated the potentiality and the possibility that the new facility possesses. Exploration of nuclear world inaccessible up to now has been launched.

REFERENCES

[1] Y. Yano, “The RIKEN RI Beam Factory Project: A status report”: Nucl. Instr. Meth.B (2007), doi:10.1016/j.nimb.2007.04.174. (in press)

[2] M. Bernas et al.: PLB 331(1994)19; PLB 415(1997) 111.