PRESENT STATUS OF RIKEN RING CYCLOTRON

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Abstract

The RIKEN Ring Cyclotron (RRC) has been in stable operation over 25 years, and has been used for supplying many types of heavy-ion beams for various experiments. Since 2007, it has also been used for supplying beams to the four Ring Cyclotrons at the Radioactive Isotope Beam Factory (RIBF), including the Superconducting Ring Cyclotron (SRC). The RRC has three types of injectors: the AVF cyclotron for comparatively light ions, variable-frequency linac for heavy-ions (RILAC), and the RIKEN Heavy-ions Linac 2 (RILAC2) for using high-intensity very-heavy ions such as those of Uranium (U) and Xenon (Xe). Many accelerator combinations are possible, and the RRC should work as a first energy booster in any acceleration mode. The total operation time of the RRC is more than 4000 hours/year. The present status of the RRC operation is reported here.

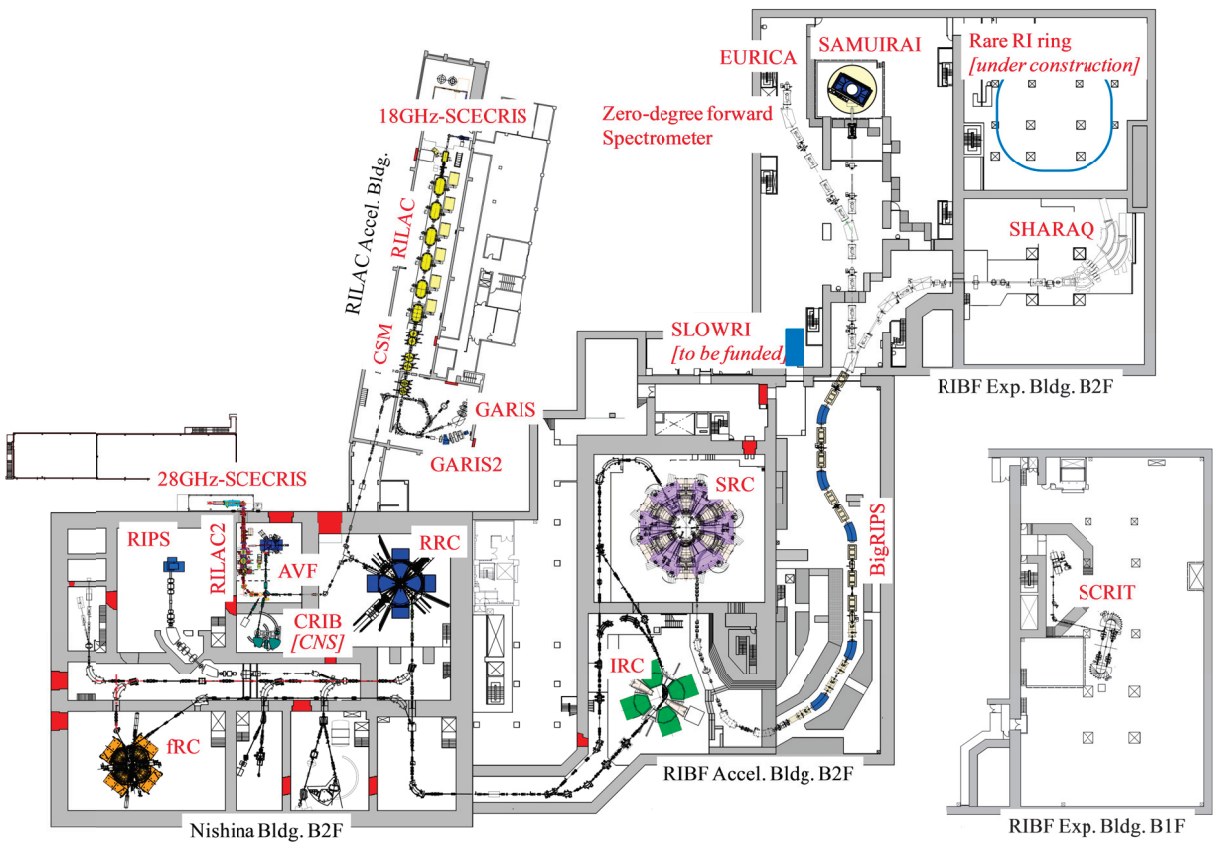

Figure 1: RIBF layout. Three types of injectors and four ring cyclotrons.

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INTRODUCTION

The Radioactive Isotope Beam Factory (RIBF) [1] was built for expanding the scope of our research on heavier nuclei, thus building upon our work on light unstable nuclei generated using a combination of RIKEN Ring Cyclotron (RRC, K=540 MeV), three new cyclotrons (fRC; fixed-frequency Ring Cyclotron K=570 MeV, IRC; Intermediate-stage Ring Cyclotron K=980 MeV and SRC; Super-conducting Ring Cyclotron K=2600 MeV) and the RIKEN projectile fragment separator. The layout of the RIBF is shown in Fig. 1. Using the RIBF, we aim to produce the most intense radioactive isotope (RI) beams in the world covering all atomic masses, and to operate a beam having an intensity of 1 pμA.

The RRC (Fig. 2) has three types of injectors: the AVF cyclotron (K=70 MeV) for comparatively light ions, variable-frequency linac for heavy-ions (RILAC) and the RIKEN Heavy-ions Linac 2 (RILAC2) [2] for using high-intensity very-heavy ions. The RRC has been in stable operation over 25 years, and has been used for supplying many types of heavy-ion beams as a first energy booster in any acceleration mode. The present status of the RRC operation is reported here.

RRC OPERATION

The operations of the RRC in 2011, including the fRC, IRC, and SRC, have been reported [1, 3]. A list of the beams accelerated by these cyclotrons is presented in Table 1. The yearly beam tuning and experiment durations of these cyclotrons, which are used in six acceleration modes, were 1357 hours and 2149 hours, respectively, in 2011. The total RRC operation time was slightly lower than the average annual operation time (3961 hours in 2008, 4359 hours in 2009, and 4069 hours in 2010), because the operation time was limited due to the following three reasons.

The first is that experiments could not be arranged in the RIBF building from January to March 2011 owing to construction of the SAMURAI.

The second reason was the earthquake in the eastern part of Japan on March 11, 2011. Although direct damage due to the earthquake was apparently small, accelerator operation was limited until September 2011 owing to the shortage of electric power. In June and July 2011, only a 345 MeV/nucleon ^{18}O beam was accelerated and delivered to the BigRIPS and the SHARAQ in order to ensure that the performance of the RIBF was the same as before.

The third reason was that the AVF was not functional from April to September 2011. This was due to a vacuum leak from the copper cooling-water pipe inside the AVF-Dee electrode. Therefore, standalone operation of the RRC for ordinary experiments in the Nishina Building was very limited, and the seasonal biology experiment was only carried out in the RILAC-RRC (h = 7) mode, yielding an 85 MeV/ nucleon ^{12}C beam. The AVF-Dee electrodes were replaced in September 2011.

The RILAC2, a new linac injector, was constructed at the RIBF in 2010 for increasing the intensity of beams comprising very heavy ions such as those of U and Xe. The first beam acceleration was achieved in December 2010. To supply beams for the RIBF experiments, we extracted the Xe beam in the RILAC2-RRC-fRC-IRC-SRC acceleration mode in May 2011. The RILAC2 system together with a gyrotron-driven, 28-GHz ECR ion source was ready in the summer of 2011, and was used for producing a $^{238}U^{35+}$ beam with an intensity of 20-30 eμA. In November-December 2011, U and Xe beams were accelerated for the first time in the RILAC2-RRC-fRC-IRC-SRC mode. A 345 MeV/nucleon ^{238}U beam with an intensity of 3.7 pnA at FC-G01 and a 345MeV/nucleon ^{124}Xe beam with an intensity of 7.7 pnA were obtained.

Figure 2: RRC overview. The main coil of the East-sector magnet will be replaced with a newly fabricated coil in the summer of 2012.

TROUBLES

Main coils

In May 2011, it was found that the main coil of the RRC East-sector magnet (Fig. 2) has a sign of layer short and was causing the RRC magnetic field to fluctuate by as much as ±20ppm. The main coil was investigated between April and August of 2011. However, we found that it would be nearly impossible to repair the coil and decided to fabricate a new RRC main coil. In the summer of 2012, the main coil will be replaced with a new coil that was fabricated in FY2011. Because this is the first time that the RRC main coil is being replaced, the task has been scheduled over a period of three weeks.

Table 1: Beams accelerated using the RRC, fRC, IRC, and SRC in 2011

Accelerators	Particle	Experiment course	Energy (MeV/u)	Beam intensity (pnA)	Beam tuning (hr)	Experiment (hr)	Allocation frequency
AVF-RRC	^{12}C	E5B	135	< 1	67	46	3
	^{14}N	E3B	135	486	25	50	1
	^{22}Ne	RIPS	110	310	79	117	3
	^{22}Ne	E5B	135	< 1	13	6	1
	^{40}Ar	E5B	95	< 1	22	9	3
	^{56}Fe	E5B	90	< 1	22	12	1
RILAC-RRC	^{12}C	E5B	85	<1, (112)	18	11	1
	^{23}Na	RIPS	63	1050	14	60	1
	^{70}Zn	RIPS	63	94	21	166	1
RILAC2-RRC	^{238}U	E5A	10.8	< 2 (10)	35	12	1
RILAC-RRC-IRC-SRC	^{18}O	SHARAQ	250	181	146	303	1
RILAC2-RRC -fRC-IRC-SRC	^{124}Xe	BigRIPS	345	7.7	96	166	1
	^{238}U	BigRIPS	345	3.5	271	1191	1
	^{124}Xe	MS	345	–	51	0	1
RILAC2-RRC-(fRC)	^{124}Xe	MS	10.8	–	40	0	1
	^{238}U	MS	51	–	346	0	1
	^{238}U	MS	10.8	–	91	0	2

Magnetic Deflection Channel #2

Recently, a vacuum leak occurred in the RRC due to beam-loss damage to its extraction device, MDC2 (Magnetic Deflection Channel #2). Because this is not a hazardous vacuum leak, the MDC2 is still being used. However, we have been designing a new MDC2 for high-intensity heavy-ion beams such as those of U and Xe.

RF coaxial feeder

For the uranium acceleration, the rf cavity of the RRC operates at the frequency of 18.25 MHz which is the lowest end of the frequency range. Due to the severe multipacting, conditioning of the cavity by the rf power. In April 2012, during the preparation of the uranium acceleration, the ceramic insulator of the coaxial feeder damaged by spark with the rf power and the vacuum leak was occurred. The damaged parts were replaced and it took two days until a several hours elapsed before normalcy is restored.

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