

Operation report on the ring-cyclotrons in the RIBF accelerator complex

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The operation of ring-cyclotrons (RRC, fRC, IRC, and SRC) in the RIBF accelerator complex in 2014 is reported. Table 1 summarizes the accelerated beams provided for users. The scheduled beam service time was 3192.3 h. The delivered beam service time was 2967.1 h. Note that 82% of the beam service time was distributed to the experiments that utilize beams accelerated by SRC and the remaining 18% was distributed to the experiments in which the beams extracted from RRC are used by the users. Beam availability, which is the most important parameter indicating the stability of operation, was 92.9%.

In March 2014, the campaign-type experiments utilizing the ²³⁸U 345 MeV/u beam were performed. In the beginning of the beam tuning procedure, we experienced a hardware fault related to the main differential probe (MDP) of the fRC twice, which resulted in 4.5-day delay of the beam start time. Once the beam service started on March 27, five experiment programs were performed without any issue with accelerators. After an 8.3-day break of the IRC and SRC operations scheduled for the 28-GHz ECR ion source, the beam service of uranium ions was resumed and it finished on May 13. Three experimental programs were performed after the break.

From May 16, we started a beam service of a 345-MeV/u ⁷⁰Zn beam. During the beam service, a hardware fault with the control system of the gas cogeneration system that supplies backup electricity to the helium refrigerator used for SRC occurred, which resulted in an 8-day beam service interruption in total.

After the problem was fixed, the beam was stably delivered until June 7. Owing to the beam current upgrade in the 18-GHz ECR ion source, the beam intensity increased to

123 particle nA, which corresponds to 120% of the intensity recorded during the beam service performed in 2012.

Since June 9, deuteron and ¹⁸O beams (250 MeV/u) are provided for RIBF experiments. In these beam services, low-emittance high beams with stability were strongly required by the users to realize high resolution measurements. The operation parameters of the accelerators used were finely tuned and the purity of single-turn extraction was 0.2%. This high-quality operation was maintained by fine tuning as necessary throughout these beam services.

After a shutdown scheduled for a routine maintenance in summer, the ²³⁸U (345 MeV/u) beams were delivered for six RIBF experiments from October 20 to November 18. The maximum beam intensity of 27.9 particle nA was recorded during this beam service.

Next, from November 18 to December 11, ⁴⁸Ca (345 MeV/u) beams were delivered for four RIBF experiments. During these beam services, the operational total acceleration voltage of the SRC RF system was upgraded to 2.4 MV/turn and a voltage applied to the electric deflection channel of SRC was 128 kV. These parameters are close to their maximum capability and essential in producing a low-beam-loss operation required for high-power beams. In addition to an ion-source improvement, the maximum beam intensity recorded in the beam service, 0.53 particle μ A, was obtained. This corresponds to the beam power of 8.8 kW which is the power record of the beams obtained in RIBF.

In addition to the biological experiments at E5B, the beam services of ⁴⁸Ca for RIPS (E6) and ¹³⁶Xe for KISS (E2B) were performed.

Table 1. Summary of the accelerated beams in 2014

Ions	Energy (MeV/u)	Accelerators	Beam Course	Beam Current (particle nA)		Scheduled time (h)	Delivered time (h)*	Downtime (h)**	Total time (h)	Availability (%)***
				requested	Max					
¹² C	135	AVF-RRC	E5B(Biology+MS)	1	393	71	71	0	71	100
⁴⁰ Ar	95		E5B(Biology)	1	91.2	32	32	0	32	100
⁵⁶ Fe	90		E5B(Biology)	1	2.8	20	20	0	20	100
⁴⁸ Ca	63	RILAC-RRC	E6(RIPS)	200	235.3	108	103.1	1.2	104.3	95.4
⁸⁴ Kr	70	RILAC2-RRC	E5B(Industry)	1	0.1	85	72.9	9.8	82.8	85.8
¹³⁶ Xe	10.75		E2B(KEK/KISS)	10	405	96	100.5	2.8	103.4	104.7
²³⁸ (235)U	10.75		A02.D(MS)	N/A	1428	121	121	0	121	100
²³⁸ U	50	RILAC2-RRC-IRC	H course(MS)	N/A	125	15	15	0	15	100
d	250	AVF-RRC-SRC	BigRIPS	10	510	252	268.1	42.7	310.8	106.4
¹⁶ O	250		SHARAQ(CNS)	10	41.8	108	125.4	18.6	144	116.1
⁴⁸ Ca	345	RILAC-RRC-IRC-SRC	BigRIPS, ZDS SAMURAI	500	530	492.2	474.1	18.1	492.2	96.3
⁷⁰ Zn(1st)	345		SHARAQ(CNS)	75	123	216	200.2	39.1	239.3	92.7
⁷⁰ Zn(2nd)	345		SHARAQ(CNS)	75	116.6	96	93.1	2.9	96	97
²³⁸ U(1st)	345	RILAC2-RRC-IRC-SRC	BigRIPS, ZDS, SAMURAI	10	22.1	540	384.4	159.6	544.1	71.2
²³⁸ U(2nd)	345		BigRIPS, ZDS	10	25	408	385.2	94.8	480.1	94.4
²³⁸ U(3rd)	345		BigRIPS, ZDS, SAMURAI, EURICA	15	27.9	532.1	501	31.1	532.1	94.2

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*Delivered time = Supply time for Beam users.

**Down time = Supply stop time caused by accelerator issues.

***Availability = Delivered time/scheduled time.