

Operation report on ring cyclotrons in the RIBF accelerator complex

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This paper presents an operation report on the ring cyclotrons in the RIBF accelerator complex from January to December 2021. Table 1 presents a summary of the beams accelerated by these cyclotrons. Availability can be defined as the ratio of the actual beam service time to the scheduled beam service time, which is an index of stable operation of accelerators. When calculating each availability for the beam service times completed earlier than scheduled, the scheduled times were identified with the actual times. Further, multiple experiments performed with identical beams were treated as one and presented in a row. The total actual beam service time was 2198.3 h. The ratio of beam service time between the experiments conducted in the old (RARF) and new (RIBF) facilities was 32 : 68.

In the RARF, the actual beam service time was 702.5 h, with an availability of 113.8%.

In the RIBF, five beam services were conducted; the actual beam service time was 1495.8 h with an availability of 98.3%. Accelerations in the light-ion mode were conducted using the AVF as an injector for the first time in three years. Three types of beams of ²H, ⁴He, and ¹²C were supplied. A ⁴He beam with an energy of 200 MeV/nucleon was delivered for the first time; the ¹²C beam was delivered for the first time as well. Despite the difficulties in transporting the first beams (new ions or energies), higher transport efficiencies were achieved from the RRC to SRC in comparison to those of similar light ions or energies, and high-quality single-turn-

extracted beams could be supplied. In ⁴He beam supply, we recorded the highest ever beam intensity of 1000 particle nA. In the final phase of the experiment, the apparatus malfunctioned, which can be attributed to radiation. The availability of ²H and ⁴He was 100.7% and 104.7%, respectively, because the beam services could be started ahead of schedule owing to smooth beam tuning. The beam service of ¹²C was interrupted for approximately 26 h owing to issues in the SRC helium refrigerator. However, it exhibited an availability of 102.3% because the beam service began ahead of schedule and the beam service time was extended by 8 h.

The beam services of ²³⁸U 345 MeV/nucleon were conducted twice. In the first U-beam service held in April 2021, discharges were frequently observed in SRC resonator 3 (SRC-RES3). An internal inspection was performed on SRC-RES3 and the burned-out RF contact fingers were replaced. In addition, the steering electromagnets installed at the exit of fRC (fRC-SH3, SV3) tripped owing to thermal anomaly. In the aftermath, a beam changed its trajectory to hit a bellow upstream a gas stripper installed in the E1 hall, thus leading to vacuum leakage; the availability was 94.2%. In the second U-beam service held in November 2021, no serious issues were observed in the accelerators. However, the beam supply was suspended earlier than scheduled owing to issues in the compressor of the BigRIPS helium refrigerator; the availability was 98.9%.

The total availability in the RARF and RIBF reached a record high of 102.8%.

Table 1. Summary of accelerated beams in 2021.

Beam particle	Energy (MeV/nucleon)	Acceleration mode	Beam course	Beam intensity (particle nA)		Beam service time (h)		Availability (%)		
				Requested	Actual	Scheduled	Actual			
RARF	¹² C	AVF-RRC	E5B (Biology)	2	541.7	33.0	13.0	100.0		
			E5A (Industry)	2	183.3	10.0	10.9	109.2		
	E3B (RI Production)		200	320.0	6.0	6.5	108.3			
	¹⁴ N		100							
	²⁰ Ne		135	E5B (Biology)	2	120.0	3.0	1.9	100.0	
	⁴⁰ Ar		95	E5A (Industry)	1	82.4	48.0	80.6	167.8	
	⁵⁶ Fe		90	E5B (Biology)	2	9.2	9.0	2.8	100.0	
	⁸⁴ Kr		70	E5A (Industry)	2	10.5	161.0	212.4	131.9	
				E3A (JAXA)	2	8.1	18.0	18.5	103.0	
	⁵¹ V		6	E6 (KEK/MRTOF)	2000	3576.9	126.0	125.8	99.8	
RARF	⁸⁶ Kr	RILAC2-RRC	E2B (KEK/KISS)	500	555.6	48.0	47.4	98.8		
			E2B (KEK/KISS)	100	140.0	120.0	120.4	100.3		
	E3A (JAXA)		1	100.0	18.0	17.3	100.0			
	²³⁸ U		10.75	E5A (Material)	2	214.3	48.0	37.4	100.0	
	⁴⁰ Ar		160	AVF-RRC-IRC	E5B (Biology)	2	30.3	18.0	7.7	100.0
RIBF	² H	AVF-RRC-SRC	BigRIPS	200	220.0	180.0	181.3	100.7		
			BigRIPS/SHARAQ	> 500	1000.0	197.0	206.2	104.7		
	⁴ He		250	BigRIPS/ZDS	500	500.0	192.0	196.5	102.3	
	¹² C		200	BigRIPS/ZDS/Rare RI Ring	70	89.5	648.0	610.6	94.2	
	²³⁸ U (1st)		345	RILAC2-RRC-IRC-IRC-SRC	BigRIPS/ZDS/Rare RI Ring/PALIS	120	73.0	304.5	301.2	98.9
	²³⁸ U (2nd)									
				Total	2187.5	2198.3	102.8			

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