Operation report on the ring cyclotrons in the RIBF accelerator complex

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Table 1. Summary of the accelerated beams in 2016

Beam particle	Energy (MeV/u)	Acceleration mode	Beam course	Beam current(particle nA)		Beam time(h)		Down time (h)	Availability (%)
				Requested	Actual	Scheduled	Actual		
^{4}He	7.3	RILAC2-RRC	A02(MS)	N/A	47.5	24.0	39.1	0.0	162.8
^{12}C	135	AVF-RRC	E5B(Biology)	1.0	583.3	41.5	47.0	0.0	113.3
^{22}Ne	70		E6(RIPS)	250.0	167.0	114.0	112.1	7.6	91.7
^{40}Ar	66		E5A(MS)	N/A	8.2	36.0	42.6	0.0	118.2
^{40}Ar	95		E5B(Biology)	1.0	91.2	28.0	28.3	0.0	100.9
^{40}Ar	95		E5A(Industry)	0.1	91.2	48.0	45.6	0.0	95.0
^{40}Ar	160	AVF-RRC-IRC	E5B(Biology)	1.0	55.5	8.0	8.2	0.0	102.5
^{48}Ca	63	RILAC-RRC	E6(RIPS)	150.0	352.9	120.0	127.2	1.0	105.1
^{51}V	6	RILAC2-RRC	A02(MS)	N/A	150.0	84.0	114.2	0.0	136.0
^{56}Fe	90	AVF-RRC	E5B(Biology)	1.0	6.3	25.0	27.2	0.0	108.8
^{58}Ni	63	RILAC-RRC	E6(RIPS)	200.0	97.8	63.0	75.1	0.0	119.2
^{84}Kr	70	AVF-RRC	E5A(Industry)	0.1	7.8	72.0	75.3	1.1	103.0
^{85}Rb	66		E6(RIPS)	1.0	0.7	48.0	56.3	0.2	117.0
^{86}Kr	36	RILAC-RRC	E3A(JAXA)	1.0	5.1	24.0	21.9	0.0	91.3
^{86}Kr	66	AVF-RRC		1.0	5.8	24.0	23.9	0.0	99.5
^{136}Xe	10.75	RILAC2-RRC	E2B(KEK/KISS)	50.0	47.5	147.0	149.0	4.1	98.6
^{238}U	10.75			140.0	4.9	48.0	46.6	0.0	97.0
^{18}O	230	AVF-RRC-SRC	BigRIPS/SAMURAI/SHARAQ	>650	838.0	336.0	351.0	18.4	99.0
^{48}Ca	345	RILAC2-RRC-IRC-SRC	BigRIPS/SAMURAI/ZDS/Rare-RI Ring	500.0	738.0	492.0	504.1	29.4	96.5
^{124}Xe	345	RILAC2-RRC-fRC-IRC-SRC	BigRIPS/SAMURAI/ZDS/F12	>10	102.0	168.0	180.0	3.5	105.1
^{238}U(1st)	345		BigRIPS/SAMURAI/ZDS/F12	5~60	37.0	372.0	384.0	56.9	87.9
^{238}U(2nd)	345		BigRIPS/SAMURAI/ZDS/F12	5~60	39.0	612.0	665.6	97.8	86.9
^{238}U(3rd)	345		BigRIPS/SAMURAI/ZDS/Rare-RI Ring	>35	41.0	600.0	600.0	88.8	85.2
					total	3534.5	3724.2	344.8	95.61

In this report, the operation of the ring cyclotrons in the RIBF from January to December 2016 is presented. Table 1 presents a summary of the beams accelerated by these cyclotrons (the upper part until ^{238}U at 10.75 MeV/u is for the old facility, and the lower part from ^{18}O at 230 MeV/u for the new facility). The availability in the table is defined by the ratio of actual beam time to scheduled beam time, which is an index of the reliability. The total beam supply time in 2016 was 3724.2 h. In the old facility, the actual beam time was 1025.4 h, and the availability was 107.4 %. In the new facility, the total beam supply time was 2580.0 h, and the availability was 91.2%.

For the experiments at the old facility, ^{22}Ne, ^{58}Ni, ^{48}Ca and ^{85}Rb for RIPS group, ^{40}Ar and ^{84}Kr for the industrial use (E5A), ^{86}Kr for JAXA group (E3A), and ^{136}Xe and ^{238}U for KEK/KISS group (E2B) were supplied. In addition, biological experiments (E5B) were conducted as usual.

The ^{18}O (230 MeV/u) beam was supplied to two experiments (Jun. 16th to 30th). The maximum intensity was 838 particle nA achieved by using the ion source SCECR.[1)] The intensity was two times that in the previous operation (March 2012)[2)]. The availability was 99.0% including the extension time of 15 h. The major troubles were caused by radiation: the failures of EIC / EDC and the main power supply for RRC, and a malfunction of the filament power supply for SRC-RES1.

The ^{48}Ca beam was supplied to six experiments (Nov. 15th to Dec. 6th). The maximum intensity was 738 particle nA. The availability was 96.5 % and the down time was 29.4 h. Most of the down time was due to the replacement of the charge stripper foils.

The ^{124}Xe beam was supplied to one experiment (Apr. 28th to May 6th). The maximum intensity was 102 particle nA. Owing to the improvement in transmission efficiencies, the intensity was increased by a factor of 2.7 compared with that in the previous experiment of June 2013. Since the tuning time was shortened, the beam was supplied for a duration 12 h longer than scheduled. Consequently, the availability became 105%.

The ^{238}U beam was supplied for three periods as follows: 1) Apr. 6th to Apr. 22nd for two experiments, 2) May 16th to Jun. 13th for five experiments, and 3) Oct. 17th to Nov. 12th for four experiments. The maximum beam intensity was 41 particle nA. The beam was supplied for 1370.1 h in total, and the availability was 86.5%. The reason that the availability became relatively low was that it took time to deal with several failures which frequently occurred. The major troubles were 1) the failure of output capacitors of the amplifier for RRC RF No. 1, 2) an interlock system of SRC He-refrigerator, 3) the power feeder of the S6 rebuncher, and 4) damages of the power feeder lines and directional couplers caused by a high-power operation of the acceleration resonators for SRC.

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References

1) T. Nakagawa et al.: RSI **75,** 1394 (2004).

2) M. Kase et al.: Proc. PASJ9, WEPS004, p. 350.