Operation report on the RIKEN AVF cyclotron for 2022

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The annual report on the operation of the RIKEN AVF cyclotron (hereafter denoted as AVF) for the period January-December 2022 is presented.

AVF delivers beams to the following experimental courses as a stand-alone operation: C01 (machine study; MS), C03 (RI production), E7V (CNS experiments and RI production), E7A (CRIB experiments), and E7B (student experiments and RI production). In addition, AVF is operated as an injector of RIKEN ring cyclotron (RRC).

The yearly changes in operation statistics since 2019, and the beams accelerated using AVF in the period are summarized in Tables 1 and 2. The operation times for stand-alone operation and injection to RRC in the period were 2287 hours and 1574 hours, respectively. The beam service interrupt time caused by trouble of AVF was 0.7 hours. Because the RIBF experiments using light-ion beams were not scheduled, AVF-RRC-SRC experiments were not performed.

Table 1. Comparison of AVF operation statistics with that in the previous years.

AVF stand-alone operation	Year	2019	2020	2021	2022
Tuning of AVF	[h]	1314	744	1149	1212
Trouble of AVF	[h]	0	1	5	0
C01 MS	[h]	0	12	35	32
C03 Exp.	[h]	873	631	672	491
E7V Exp.	[h]	36	18	95	94
E7A Exp.	[h]	790	12	48	302
E7B Exp.	[h]	153	101	96	155
Sub total	[h]	3166	1519	2100	2287
AVF operation as injector of RRC	**Year**	**2019**	**2020**	**2021**	**2022**
Tuning of AVF	[h]	118	178	214	273
Trouble of AVF	[h]	0	5	1	1
RRC Exp. & RRC-IRC Exp.	[h]	320	999	834	1300
RRC-SRC Exp.	[h]	0	0	767	0
Sub total	[h]	438	1182	1816	1574
Total	[h]	3604	2702	3916	3860

Development of Xe beam with an energy of approximately 36 MeV/nucleon is now in progress. Although the Xe beam accelerated using RILAC2-RRC mode so far (∼10 MeV/nucleon at the exit of RRC) has already been supplied to the industrial application experiments, we aim to supply Xe beam with higher energy using AVF-RRC mode, which is frequency-variable. Required beam current is small, 20 nA or more. As part of the beam development, the tests of the acceleration harmonics $H = 3$ using $^{84}Kr^{14+}$ at 2 MeV/nucleon and $^{84}Kr^{17+}$ at 2.4 MeV/nucleon, and the extraction of Xe beams from the 18-GHz ECR ion source were performed. Furthermore, the change of operation permission for radiation safety was required to accelerate Xe beam. After those preparations, we successfully extracted 900 nA of $^{136}Xe^{27+}$ at 2.4 MeV/nucleon. However, the beam current of $^{136}Xe^{37+}$ after charge-stripping, which is required to accelerate at the RRC, was too low to extract from the RRC. Therefore, in the next machine study, we plan to use $^{129}Xe^{35+}$ instead of $^{136}Xe^{37+}$ with the same energy because an ion yield after charge-stripping is expected to be nearly an order of magnitude higher.

To improve equipment, an upgrade of phase probe (AVF-PP) used for isochronous tuning was performed. A channel switch of the AVF-PP malfunctioned possibly due to age deterioration. The channel switch was upgraded to a newer model because we have a policy to replace CIM/DIM system[1)] to N-DIM[2)] as an aging management.

Table 2. AVF beam list in 2022.

AVF stand-alone operation

Particle		Energy [MeV/nucleon]	Experimental Course
$^{1}H^{+}$		19	E7V
		30	C03
$^{2}H^{+}$		12	C03, E7B
$^{4}He^{2+}$		6.5	E7B
		7.25	C03, E7B
		12.5	C03
$^{7}Li^{2+}$		6	C03
$^{7}Li^{3+}$		8.3	E7A
	1st beam	10	C03
$^{12}C^{4+}$		7.3	C03
$^{18}O^{6+}$		7	E7V
$^{24}Mg^{8+}$		7.25	E7A
$^{84}Kr^{14+}$	1st beam	2	C01
$^{84}Kr^{17+}$	1st beam	2.4	C01

AVF operation as injector of RRC

Particle		Energy [MeV/nucleon]	Experimental Course
$^{12}C^{4+}$		7	RRC-RARF
$^{14}N^{4+}$		4	RRC-RARF
$^{20}Ne^{7+}$		7	RRC-RARF
$^{22}Ne^{6+}$		4	RRC-RARF
$^{40}Ar^{11+}$		3.8	RRC-IRC-E5B
		5.2	RRC-RARF
$^{56}Fe^{15+}$		5.01	RRC-RARF
$^{84}Kr^{20+}$		3.97	RRC-RARF
$^{136}Xe^{27+}$	1st beam	2.4	RRC-RARF

References

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