STATUS REPORT OF THE OPERATION OF THE RIKEN AVF CYCLOTRON

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Abstract

The RIKEN AVF cyclotron has been operating 26 years as an injector for the RIKEN ring cyclotron. The AVF cyclotron also provides low energy ion beams for the CNS Radio-Isotope Beam separator (CRIB) of the Center for Nuclear Study (CNS), the University of Tokyo, as well as to produce RIs for commercial use. The operating time is more than 2,000 hours per year.

INTRODUCTION

The RIKEN AVF cyclotron (AVF, K=70 MeV) [1] was constructed as an injector for the RIKEN Ring Cyclotron (RRC, K=540 MeV) [2]. In the AVF-RRC acceleration mode, ions from H^{2+} to ^{87}Rb are accelerated by AVF up to 3.78 to 7 MeV/u, and are further accelerated by RRC up to 65 to 135 MeV/u. They are provided to experimental course of RIKEN Accelerator Research Facility (RARF).

Since 1991, it was started to provide low energy heavy ion beams as a stand alone accelerator (AVF standalone mode). In the AVF standalone mode, various ions from proton (A/Q=1) to ^{42}Ca (A/Q=3.5) are accelerated up to 3.41 to 12.5 MeV/u (14 MeV for proton). The beams are provided for experiments of nuclear physics with CRIB (E7A course) [3], for student experiments (E7B course) and for production of Radioactive Isotopes (C03 course), as shown in Fig 1.

Since 2009, the AVF was started to be used as an injector of light ions for the RI-Beam Factory (RIBF) [4, 5]. In the light-ion mode of RIBF, the AVF Cyclotron has provided polarized deuteron, ^{14}N, ^{18}O, etc., so far. The beams further accelerated by RRC and Superconducting Ring Cyclotron (SRC, K=2600 MeV) [6] are provided for experiments of RIBF.

Three external ion sources (HYPER-ECR, SC-ECR, and Polarized deuteron) are available. One of the ion sources are selected to be used depending on the requirement of nuclear species (metal, gas). The beam time schedule is decided by considering the development and preparing time of ion

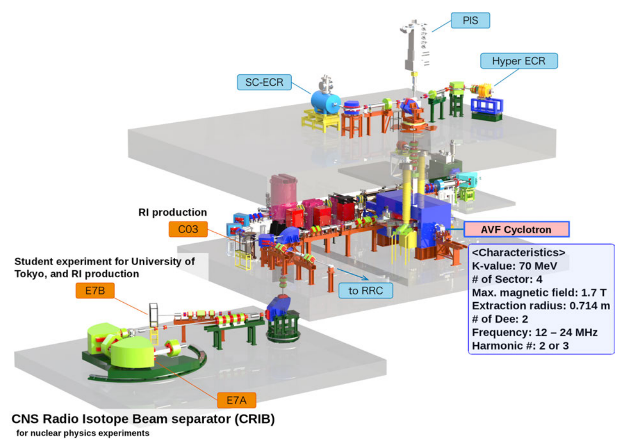

Figure 1: Overall view of the RIKEN AVF cyclotron with ion sources, and beam courses of the AVF standalone operation.

sources, so that the nuclear species can be changed in a short time as much as possible.

We will report the operating status of AVF (beam energies and species, operation statistics, troubles, and maintenance work) for the period from August 2014 to July 2015.

ACCELERATED BEAMS

Figure 2 shows energy per nucleon versus mass number for all kinds of beams accelerated by the AVF cyclotron. The species accelerated before August 2014 are shown by open solid circles. In this period, in the AVF standalone mode, two kinds of beams ($^4He^{2+}$ at 7.5 and 10.0 MeV/u) were extracted for the first time (red solid circles). The other eight beams in this mode are shown by red open circles. In the AVF-RRC mode, $^{40}Ar^{11+}$ accelerated up to 3.78 MeV/u was extracted for the first time (blue solid circles). The other six beams in this mode are shown by blue open circles. In the RIBF mode, polarized deuteron at 3.97 MeV/u was extracted (a green open circle). Accelerated beams in this period for these acceleration modes are summarized in Table 1.

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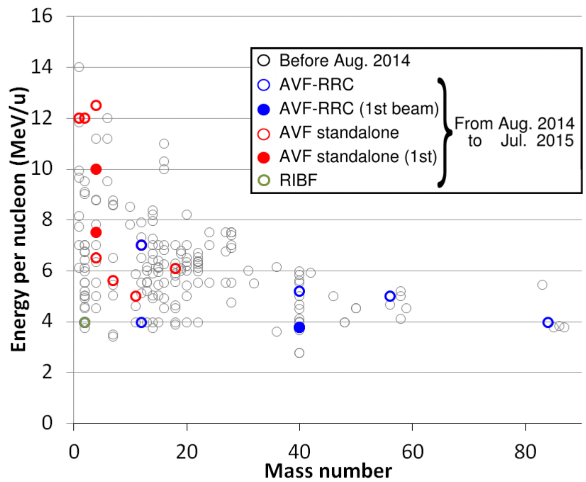

Figure 2: Energy per nucleon versus mass number of ions extracted from the AVF cyclotron.

Table 1: Beams Extracted from the AVF in this Period

Mode	Ions	Energy [MeV/u]
AVF standalone	$^{1}H^{+}$	12
	$^{2}H^{+}$	12
	$^{4}He^{2+}$	6.5, 7.5*, 10.0*, 12.5
	$^{7}Li^{2+}$	5.6
	$^{11}B^{3+}$	5.0
	$^{12}C^{4+}$	7.0
	$^{18}O^{6+}$	6.07
AVF-RRC	$^{2}H^{+}$	12
	$^{12}C^{4+}$	3.97, 7.0
	$^{40}Ar^{11+}$	3.78*, 5.2
	$^{56}Fe^{15+}$	5.0
	$^{84}Kr^{20+}$	3.97
RIBF	Polarized $^{2}H^{+}$	3.97

*First beam

OPERATING STATISTICS

Figures 3 and 4 show the operation time for the AVF standalone mode, and the AVF-RRC and RIBF modes, respectively. The tuning time is a sum of periods from a start

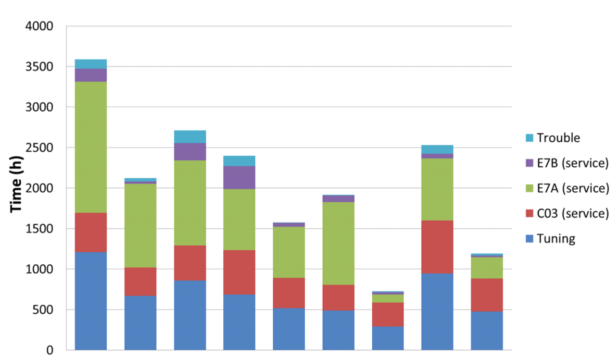

Figure 3: Operation time for AVF standalone mode.

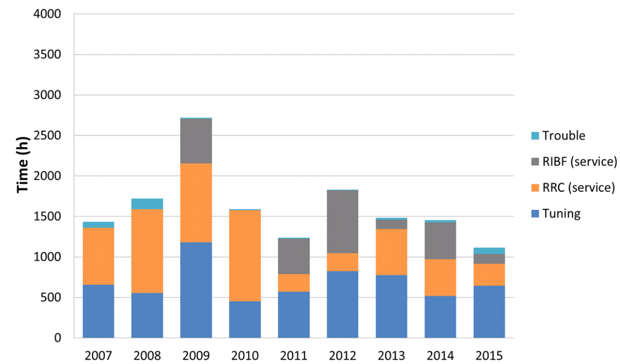

Figure 4: Aeration time for AVF-RRC and RIBF modes.

of the cycling of AVF main magnet to a finish of the spot tuning on a target. In the case of the AVF-RRC and RIBF modes, the tuning time for accelerators other than AVF is also included. The beam service time for each course (C03, E7A, E7B, RRC, RIBF) is defined as a sum of the period from the finish of spot tuning to the end of the experiment. The statistics for each year from August 2006 to July 2015 are presented.

In the latest period (2015), for the AVF standalone mode, beam service time for C03, E7A, and E7B were 478, 261, and 22 h, respectively. The total operation time was 1169 h, which was decreased by 52% from 2423 h in the previous period. Most troubles occurred during beam tuning at a magnetic channel, and they were fixed during that time. The total failure time was 26 h. All the beam service scheduled was completed.

For the AVF-RRC and RIBF modes, total operation time was 1036 h, which was decreased by 27% from 1426 h. This was because the operation time of other injectors RILAC [7] and RILAC2 [8] was increased. There was almost no trouble for the AVF cyclotron, however, the total failure time including RRC was 79 h, which was increased by 52 h compared with the previous period.

TROUBLES

Major troubles occurred at a magnetic channel (one of beam extraction devices), which was used since 2007 (Fig. 5). In September 2014, during beam tuning of the AVF, a leakage of cooling water occurred at one of hollow conductors due to a pinhole (Fig. 6). We closed the hole with paste. In July 2015, during a startup of the AVF, no electric current was observed in coils of the magnetic channel. The coils became open circuited because fixing bolts of electrodes which connects two hollow-conductors were loosened and melted (Fig 7). The bolts and electrodes were replaced with spare parts.

NEW MAGNETIC CHANNEL

To improve reliability, we replaced the old magnetic channel with a newly fabricated one in this summer (Fig. 8). The exchange operation was started at the end of July 2015, and finished in August 2015. Beam test was successfully performed on the middle of August.

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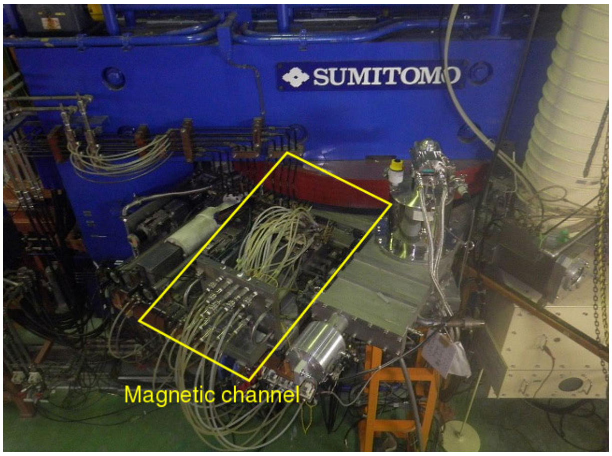

Figure 5: Magnetic channel of the AVF cyclotron.

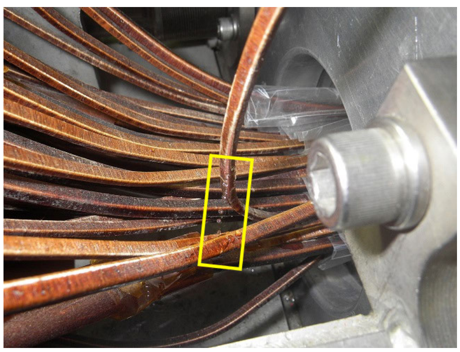

Figure 6: A leakage of cooling water at a hollow conductor of the magnetic channel.

Figure 7: Normal connection between two hollow-conductors with electrodes (left), and damaged electrodes (right).

Figure 8: A new magnetic channel.

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