PRESENT STATUS OF THE RIKEN RING CYCLOTRON

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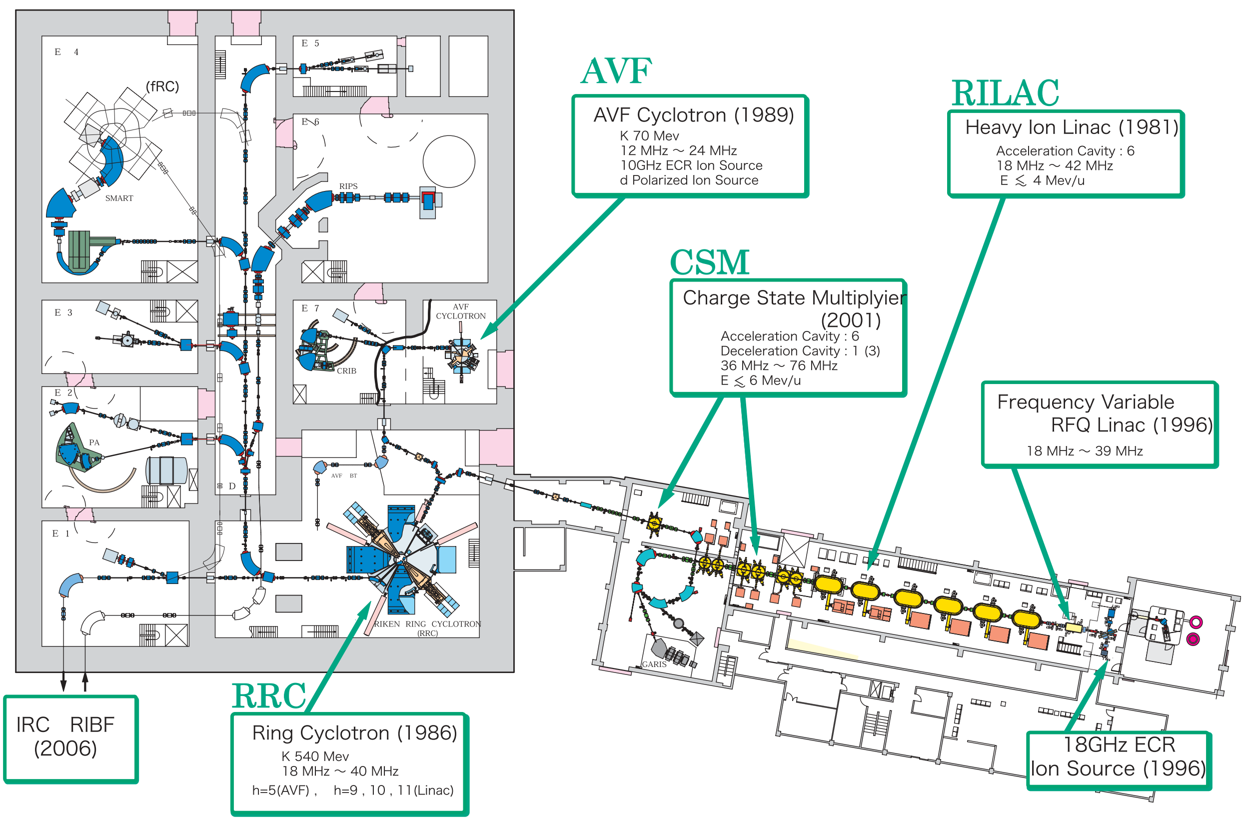

Figure 1: Layout of the RIKEN Accelerator Research Facility (RARF).

Abstract

The RIKEN Ring Cyclotron (RRC) has been in stable operation over seventeen years, and supplying many kinds of heavy-ion beams to experiments. The secondary beams produced in projectile fragmentation have been extensively used for experiments. The beam intensity of some heavy-ion beams has been drastically increased after the improvements done on RILAC. The RILAC-RRC will be an injector to the RIBF.

INTRODUCTION

The RIKEN Accelerator Research Facility (RARF) has three kinds of accelerators. The RIKEN linac (RILAC), which was constructed 1980, is a heavy-ion linac having six frequency-tunable cavities. The RIKEN Ring Cyclotron (RRC), which was completed in 1986 as the main accelerator in RARF, is a separated-sector cyclotron with a K-value of 540. The first beam of 26 MeV/u ^{40}Ar was successfully extracted from RRC in December 1986 with its first injector of RILAC. In 1987, RRC has begun to deliver beams for experiments and then the RARF officially started. The RRC reached to its full performance in 1989, when the second injector, the K70 AVF cyclotron (AVF), was completed. Since then, RRC has been delivering a various kinds of beams to experiments in many fields such as nuclear physics, biology [1], radiochemistry [2], and atomic physics. In special, most beam time has been devoted into experiments using RI beams produced in the RIKEN Projectile-fragment Separator (RIPS).

The project of RI beam factory (RIBF)[3] started in 1995, in order to extend the mass range of RI beams. It was decided that the RILAC-RRC would be the injector to the RIBF accelerators. Therefore improvements have been done around RILAC. The pre-injector of RILAC, which had been a 500kV high-voltage terminal, was exchanged into the combination of a frequency-tunable RFQ [5] and a high power 18GHz-ECRIS [4] in 1996. The charge-state multiplier (CSM) was proposed as beam-intensity breeder in RIBF and its six acceleration cavities of CSM [5] were installed in 2000.

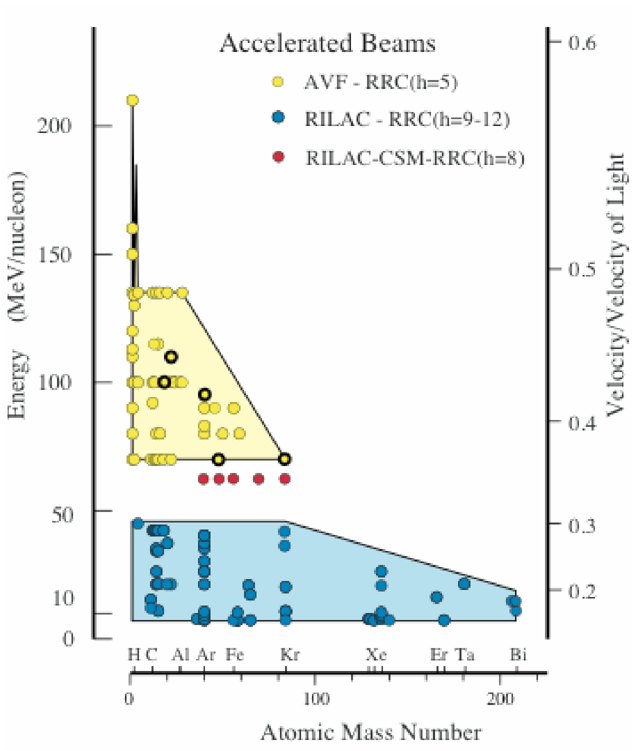

Figure 2: Performance of RIKEN Ring Cyclotron

RRC BEAM PERFORMACE

The RRC have been supplying a number of kinds of beams since1986. They are plotted in a mass-energy plane as shown in Fig. 2. The accelerated beams cover the all energy and mass ranges according to the initial design for both RILAC-RRC and AVF-RRC schemes.

About 80% of the total beam time was devoted into experiments using secondary beams (that is RI beams) produced at RIPS by the projectile fragmentations. For the efficient production of the RI beams, the intense primary beams of neutron-rich isotopes are frequently required, such as ^{18}O 110MeV/u, ^{22}Ne 100MeV/u, ^{48}Ca 70MeV/u, ^{86}Kr 70MeV/u. These beams are marked in terms of emphasized-circles in Fig.2. The AVF-RRC scheme supplies enough beam intensities (>100 pnA) for ^{18}O and ^{22}Ne, but poor intensities for beams heavier than ^{48}Ca (only several pnA).

The RRC had been designed to operate with a harmonics of 9 in the case of the RILAC-RRC scheme. Using a part of energy booster of the CSM, the RRC operation with a harmonics of 8 was tried and successfully done in 2002. The beam data accumulated so far are listed in table 1 as for several beams. In the all cases, the beam intensities are drastically increased nevertheless their energies are somewhat lower (63MeV/u) compared with those in the AVF-RRC scheme. As the beam intensity is sometimes more important than these energy-degradations for the RI beams production, this new scheme has been frequently used for RIPS experiments recently. If the rebuncher between RILAC and RRC is more powerful, this scheme can be applied to the RRC with a harmonics of 7 or 6. The intensities for ^{18}O to ^{40}Ar are also improved without degrading energy.

In these operations, a thin carbon foil (80 μg/cm^2) is very important as a charge stripper after CSM boosters. The specially prepared carbon foil has been used [6], showing a very long life-time.

Ion	AVF → RRC: E_{RRC}, (h_{RRC}) MeV/n	Stripping after AVF: Qi / Qf	E_{AVF} MeV/n	effi. %	Beam intens. pnA		RILAC → CSM → RRC: E_{RRC}, (h_{RRC}) MeV/n	Stripping after CSM: Qi / Qf	E_{CSM} MeV/n	effi. %	Beam intens. pnA	
^{40}Ar	95 (5)	11 / 17	5.2	32(32)	90	AVF+RRC(28.1MHz)	63 (8)	11 → 15	3.6	26 (37)	1000	RILAC(37.8MHz)+A1+A2+RRC
^{48}Ca	70 (5)	11 / 18	4.0	26(28)	7	AVF+RRC(24.6MHz)	63 (8)	11 / 17	3.6	29 (37)	150	RILAC(37.8MHz)+A1+A2+RRC
^{58}Fe	90 (5)	13 / 24	5.0	14(15)	4	^{56}Fe data; AVF+RRC(27.6MHz)	63 (8)	13 / 21	3.6	32 (29)	80	RILAC(37.8MHz)+A1+A2+RRC
^{70}Zn							63 (8)	16 / 25	3.6	21 (25)	120	RILAC(37.8MHz)+A1+A2+RRC
^{86}Kr	70 (5)	20 / 31	4.0	27(9)	4	^{84}Kr data; AVF+RRC(24.6MHz)	63 (8)	16 / 30	3.6	11 (14)	90	RILAC(37.8MHz)+A1+A2+RRC

Table 1: Upgrade of beam intensities with CSM.

RILAC & AVF BEAMS

After the RILAC improvements, a high intensity beam with energy up to 6MeV/u became available at RILAC. A super-heavy element research has begun extensively at RILAC beam course. And then a new element of Z=113 was found in July 2004[7] using a ^{70}Zn 5.1MeV/u beam.

The upgrade of the AVF has been in progress with the cooperation of CNS; Univ. of Tokyo. The flattop acceleration system[8] was added to AVF cavities in 2002. The power supplies will be improved in order to increase the maximum energy of light ions beam.

OPERATION

Figure 3 shows the statistics of the RRC operation since 1987. A total of the operation hours per year is gradually but steadily increasing and in 1990 reaching to 6800 hr in a year, which is considered to be a practical limit. After that, the operation time decreased slightly due to the RIBF construction work and slight reduction of the operation budget.

In 2004 fiscal year, 310Myen (2.8MUS$) was approved for the operation and maintenance of the RARF accelerators, including the manpower cost of fifteen operators and upgrade and/or renewal of old parts. In addition, 320Myen was for power costs not electric but gas fuel for the Co-generation system (CGS)[9], which will be used as UPS for liquefied helium system of RIBF. The CGS can supply a power of 6.5MW at maximum, which is enough to cover the power consumption of existing accelerators.

In the early years, the vacuum/water leaks frequently happened to cooling-pipe connections in the RRC cavities or trim coils. After they were settled down, two serious troubles have ever occurred to the RRC. First a short circuit between layers inside main coil occurred to one of sector magnets in 1999. Second the contact fingers in rf cavity were breakdown due to the control-sequence problem. As shown in Fig.3, in the both cases, these could be repaired after about one month shut down.

SCHEDULE TOWARD RIBF

As the RIBF project is approaching to the commissioning, the RARF needs to start its preparations as follows. The production of uranium ion at RILAC ion source will begin in June 2005, and its acceleration test will start in summer 2005. To realize these, the ion source area was separated in summer 2004 from other accelerator space into an independent room for the treatment of uranium material. In autumn 2004, we will offer the government the acceleration of uranium ion beam in order to obtain the official permission. The developments of charge-stripper for the uranium beams are on progress. [6,10,11]

Since the construction of the fixed-frequency Ring Cyclotron (fRC) will be started in May 2005 in the E4 target room as shown Fig. 1, the spectrometer SMART will be shutdown at the beginning of May 2005. The some magnets in SMART will be transferred to new building of RIBF experimental hall, and used there as a part of new apparatus. The extraction beam lines of fRC will appear in the D room, the RRC room and the E1 room as shown in Fig.1 in terms of thin lines. The operation of RRC will be interrupted due to the construction of these beam lines from April to June 2006. In autumn 2006, the RILAC and RRC will begin to provide beams into the RIBF accelerators (fRC, IRC and SRC.)

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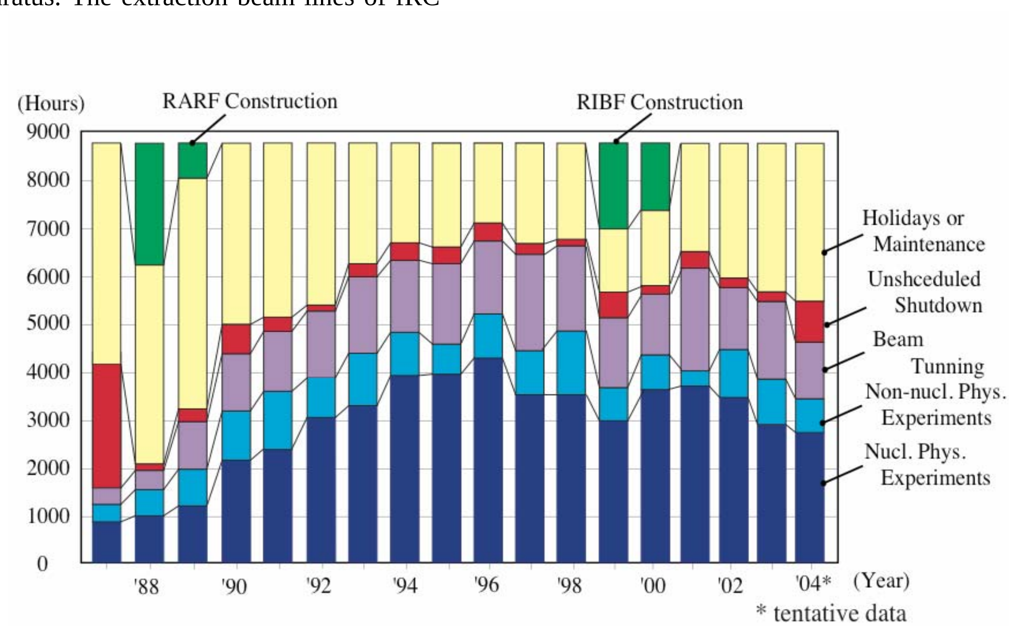

Figure 3: The RRC Operation Statistics since 1987.