Status Report on RIKEN Ring Cyclotron

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Abstract

It has already passed 10 years since the RIKEN Ring Cyclotron started to supply beams to its users. Since then, the RRC has been accelerating a variety of beams stably for a variety of experiments. Many improvements are being and will be made to upgrade the machine as an injector toward the future program, the RI beam factory [1].

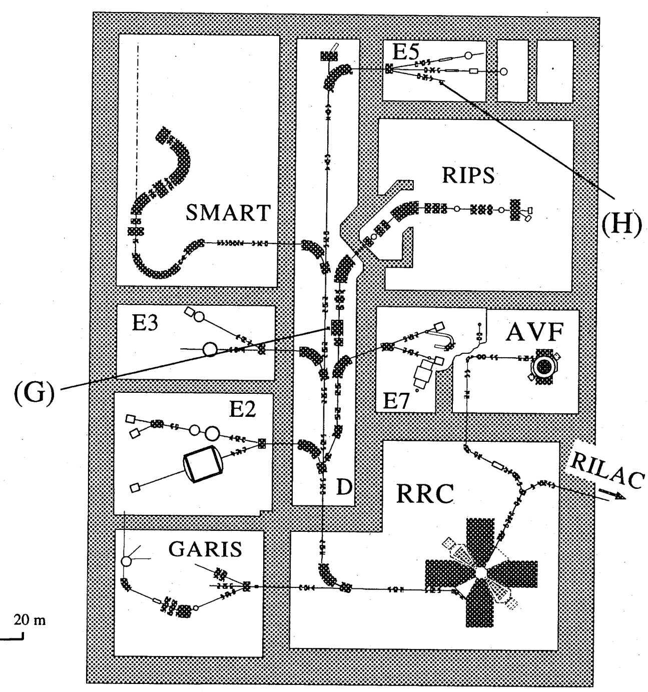
1 Introduction

The RIKEN Ring Cyclotron (RRC) was completed in 1986. The first beam of 26 MeV/u ^{40}Ar was extracted successfully from the RRC in the end of this year, when it was coupled with a injector of RIKEN heavy-ion linac (RILAC). The RRC began to work with the full performance in 1989, when the second injector, the AVF cyclotron with a 10GHz ECR ion source was completed. After the large-scaled experimental instruments such as RIPS, GARIS, and SMART were constructed, the RIKEN Accelerator Research Facility (RARF) was fully completed in 1990 as shown in Fig. 1.

Since then, RRC has been providing a variety of beams to users. A operation status of RRC will be reported together with some improvements which were and will be done so as to upgrade the machine for the future project[1].

2 Operation Statistics

A number of kinds of beams have been accelerated so far with the RIKEN Ring Cyclotron (RRC). Among them, typical beams are listed in table 1 together with their acceleration conditions and beam intensities. There are 25 kinds of elements and more than one hundred combinations of ion and energy. The numbers are still increasing. Their masses as well as their energies cover a very wide range as shown in Fig. 2, where the beams accelerated in the last ten years are plotted in the region of energy-mass space. Recently the heaviest ion ^{209}Bi in the case of RILAC-RRC



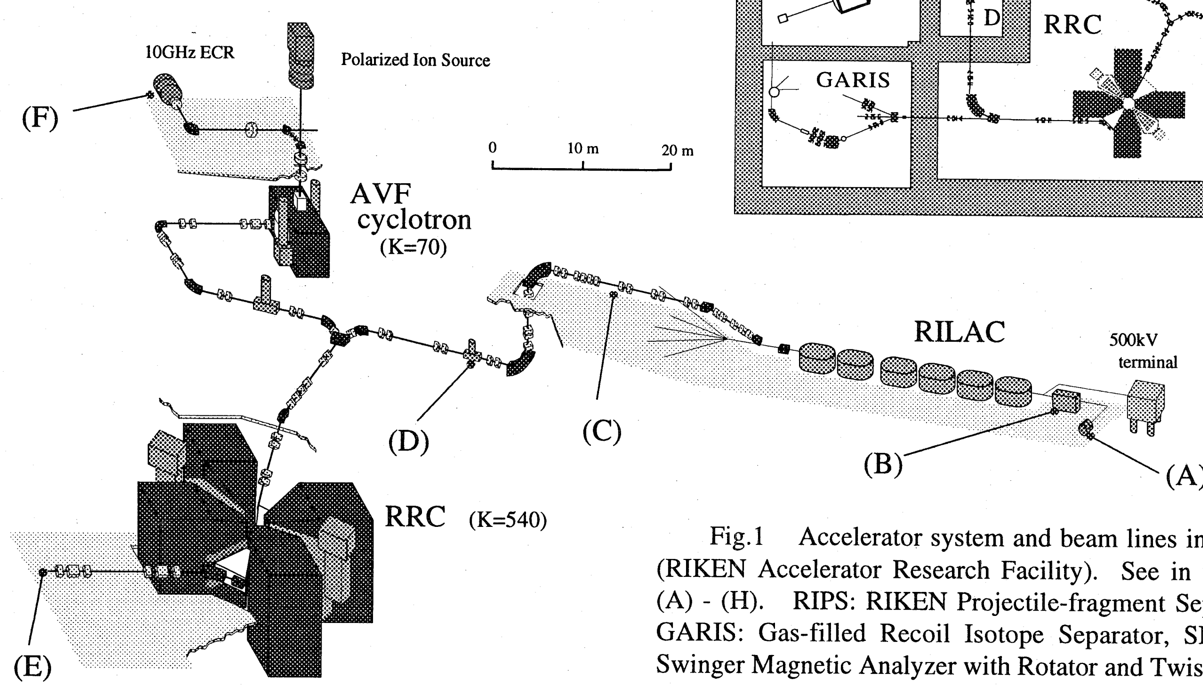


Fig.1 Accelerator system and beam lines in RARF (RIKEN Accelerator Research Facility). See in text for (A) - (H). RIPS: RIKEN Projectile-fragment Separator, GARIS: Gas-filled Recoil Isotope Separator, SMART: Swinger Magnetic Analyzer with Rotator and Twister.

Table 1 Typical beams accelerated by RRC

I ON	q	Energy (MeV/u)	RF (MHz)	h	Injector	Intensity (pnA)
p	1	210	39.0	5	AVF	1000
pol. d	1	134	32.6	5	AVF	280
α	2	135	32.6	5	AVF	50
^{11}B	2	15	24.0	10	RILAC	190
	5	70	25.0	5	AVF	200
^{12}C	6	135	32.6	5	AVF	500
^{14}N	7	135	32.6	5	AVF	230
^{15}N	7	115	31.0	5	AVF	30
^{16}O	8	135	32.6	5	AVF	300
^{18}O	8	100	29.0	5	AVF	380
^{20}Ne	10	135	32.6	5	AVF	70
^{22}Ne	10	110	30.0	5	AVF	150
^{24}Mg	12	100	29.0	5	AVF	50
^{27}Al	13	100	29.0	5	AVF	5
^{28}Si	13	100	29.0	5	AVF	46
	14	135	32.6	5	AVF	6
^{36}Ar	5	7.6	18.8	11	RILAC	1000
^{40}Ar	5	7.6	18.8	11	RILAC	500
^{40}Ar	17	95	28.0	5	AVF	70
^{48}Ca	18	70	25.0	5	AVF	4
^{48}Ti	7	7.6	18.8	11	RILAC	18
^{50}Ti	20	80	26	5	AVF	8
^{56}Fe	24	90	28.0	5	AVF	2
^{56}Fe	7	7.6	18.8	11	RILAC	200
^{58}Ni	8	7.6	18.8	11	RILAC	120
	25	95	28.0	5	AVF	4
^{59}Co	24	80	26.0	5	AVF	4
^{64}Zn	20	21	25.0	9	RILAC	0.5
^{65}Cu	8	7	18.0	11	RILAC	3
^{84}Kr	18	21	28.1	10	RILAC	33
^{128}Te	18	9	20.5	11	RILAC	3
^{136}Xe	19	9.5	19.1	10	RILAC	120
^{140}Ce	22	7	18	11	RILAC	2
^{166}Er	32	16	22	9	RILAC	2
^{181}Ta	37	21	25.4	9	RILAC	0.1
^{209}Bi	37	15	23.9	10	RILAC	1

Beams listed here were accelerated from 1987 to Aug. of 1997. As for mass and energy, only typical ones are listed here.

operation was accelerated and the heaviest ion ^{84}Kr in the case of AVF-RRC operation will be accelerated soon. The plots in Fig. 2 are covering almost full of the available regions for the two injectors.

Figure 3 shows the statistics of the RRC operation during these 10 years. A total of the operation hours per year is gradually but steadily increasing after the RARF was completely constructed in 1990 and recently reaching to 6800 hr in a year, which is considered to be a practical limit if holidays and maintenance time are taken into account.

The beam service time for the last one year amounted to be about 5000 hr. Most of the beam time (86.7%) was devoted to nuclear physics experiments. A high intense beam of intermediate mass (up to ^{48}Ca) with the energies more than 100MeV/u is requested for RI beam production, and, one the other hand, a wide mass range of beam with energies smaller than 10MeV/u for experiment using fusion reactions.

The rest (13.3%) of the the beam time was devoted to other field experiments, such as medical science, radio-chemistry, health physics, material science, biology, atomic physics. The number of users for biologic research is increasing in recent years.

3 New Topics

3.1 Achievement of 1pμA beam

At the present, we need to increase a beam intensity beyond 1pμA to meet the requirement of a nuclear physics

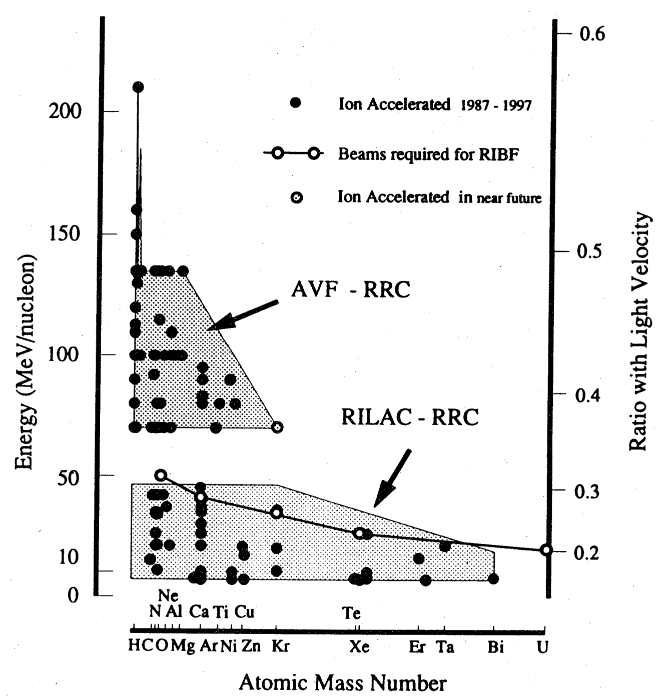


Fig. 2 The parformance of RIKEN Ring Cyclotron (RRC). The all beams which has ever been accelerated are shwon as solid circles on an energy-mass space.

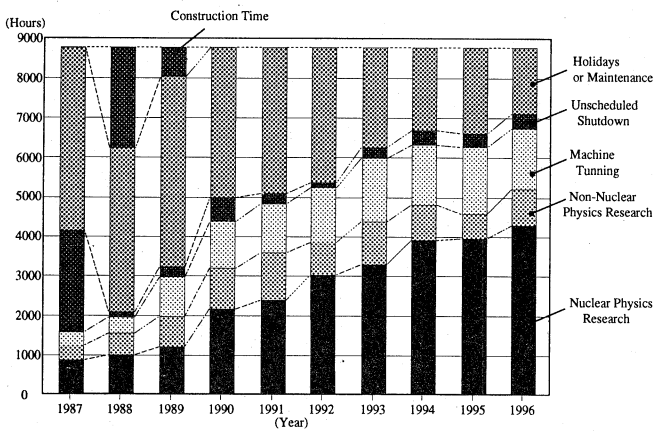


Fig. 3 The statistics of RRC operation in these 10 years (1987-1996).

experiment especially on super-heavy element research. Moreover, in the future, much more beam intensities will be required as an injector of ' RI beam factory '[1].

After installation of 18GHz ECR and RFQ in 1996 as a pre-injector to RILAC[2] (denoded as A and B in Fig.1), we tried to accelerate a 7.6MeV/u ^{36}Ar beam using the new pre-injector. As the result, a beam with more than 1pμA became available on the target. This intensity is upper limit value which is officially permitted in RARF. We are now offering the raise of this value up to 10 pμA for low energy beams.

Recently, the extraction voltage of 18GHz ECR ion source is raised by a factor of two and the four vanes of RFQ are converted correspondingly. It is expected that the beam intensity at the ECR is increased by a factor of two and the transmission efficiency of RFQ-RILAC is improved. Moreover, with the energy stabilization of RILAC (described in 3.2), the transmission efficiency through RRC will be 100%. A total efficiency from the ion source to a target is expected to be more than 40 %. In this way, a beam intensity of several pμA will be available soon for some beams with low energies less than 10MeV/u.

3.2 Phase stabilization of RILAC beam

In the RILAC-RRC operation, the beam transmission efficiency through RRC is 60 - 95%, depending on rf conditions of RILAC. The beam phase measured at beam transport line between RILAC and RRC (C in Fig.1) has a fluctuation corresponding to instability of rf voltages of some cavities of RILAC. We tried to stabilize the beam phase by a feedback loop to the final cavity of RILAC. As the result, we could improve the beam transmission efficiency through RRC[3].

3.3 ECR ion source

For the production of metallic-ion beams by ECR ion source (Aand F in Fig.1), the method of so-called MIVOC (Metal Ion by VOlatile Compounds) has been tried. The organic metallic compounds whose vapor pressure are high (10^{-3} mbar) at room temperature are used instead of metallic or metal-oxide rod. Charging metal to ECR plasma is done very easily and stably like gaseous material. We have already done for several kinds of compounds. Among them, beams of Fe^{+7} and Ni^{+8} were accelerated by RRC using compounds of $Fe(C_5H_5)_2$ and $Ni(C_5H_5)_2$, respectively. We obtained ten times more intensities than those by the previous method. (see table 1)

3.4 PPAC Emittance monitor

A new emittance monitor[4] has been developed with a two sets of position-sensitive gas counter (PPAC; parallel plate avalanche counter). It was designed for the precise measurement of beam emittance about a high-energy beam from the RIKEN Ring Cyclotron (E in Fig.1). A preliminary test was done.

3.5 Micro-beam course

A new focusing element (super-conducting solenoid, 6.8 T·m) was installed in just front of a production target of RIPS, in the last winter.(G in Fig.1) Using this, a beam size on the target could be reduced as small as 400 μmϕ with full intensity.

To meet the requirement from bioscience, a micro-beam course[5] will be built in the present beam line(H in Fig.1). Because the required beam intensity is very low, we will make a thin beam by inserting the thin collimator (50 μmϕ) on a parallel beam.

4 Conclusion

After 10-year operation, RRC provides a variety of beams with its full performance. To upgrade the present machine for the future project, many improvements will be made soon, especially in increasing a beam intensity.

References

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