Present Status of the RIKEN Accelerator Research Facility (RARF)

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1 Introduction

The RARF (RIKEN Accelerator Research Facility) has an accelerator complex consisting of the K540 RIKEN Ring Cyclotron (RRC) as a main accelerator and its two injectors; frequency-variable RIKEN heavy-ion linac (RILAC) and K70 AVF Cyclotron (AVF). A present layout of these accelerators and their beam lines are shown in Fig.1. The combination of RILAC-RRC, which started its operation in 1986, has provided ion beams with a relatively low energy (5~40MeV/u) but covering the almost full mass range (A=4~209). On the other hands, that of AVF-RRC, which started in 1989, can accelerate ion beams with high energies (70~135MeV/u) and with a mass number less than 86 (normally less than 40).

The construction RI beam factory (RIBF) project is now in progress[1] on a site adjacent to the RARF building. Since the RILAC-RRC configuration will play a important role as an injector to RIBF, many improvements should be done.

Also according to the agreement on the collaboration between RIKEN and Center of Nuclear Science (CNS) of Tokyo university, some other improvements have been done in the RARF. They are based upon (1) To keep research activities of RARF at a high level until the RIBF project is completed, and (2) to use the AVF efficiently after the RIBF is completed.

2. Operation

The RRC together with the AVF and the RILAC have provided routinely a beam time of more than 4400 hours through a year since 1993. In these two years, this value decreased by 10~15% due to the construction of RIBF or some machine improvements. More than fifty kinds of ion beams have been prepared every year. These beams have been delivered to experiments on a variety of fields, such as nuclear physics, atom and solid-state physics, radiochemistry, nuclear chemistry, and radiation biology. See caption of Fig.1 for details of these researches.

3. The Projects of RIKEN-CNS collaboration

Since the contract between RIKEN and CNS of Tokyo University was made in 1999, the following projects have been planed and carried out concerning the RARF.

1) The 14GHz ECR, which had been in Tanashi campus of CNS, was moved to RIKEN and installed the ion source room of AVF.
2) The two 45-deg dipole magnets between horizontal beam line from ion source and vertical injection line of AVF was replaced into a new horizontally-rotationable 90-deg dipole magnet. As the result, the switch of more than one ECR ion source became possible for short time, keeping the vertical injection line for the polarized ion source as before.
3) A flat top system was added to cavities of AVF. An efficient extraction of a high quality beam are expected at AVF[2].
4) A new beam transport line from AVF to present beam line of RRC was designed and was partially completed at present.
5) Two large scale apparatus of nuclear physics experiment were moved in RARF. The installations of CRIB and PA were completed in E7 and E2 respectively.
6) The maximum energy of RILAC was upgraded from 4 to 6MeV/u. Four linac cavities were added to the first unit of CSM (see the next chapter for the details) which had been completed in 1999.
7) A new beam line, which is used exclusively by CNS, was built in a target room of RILAC. The experiment for university students will be done using this beam course.

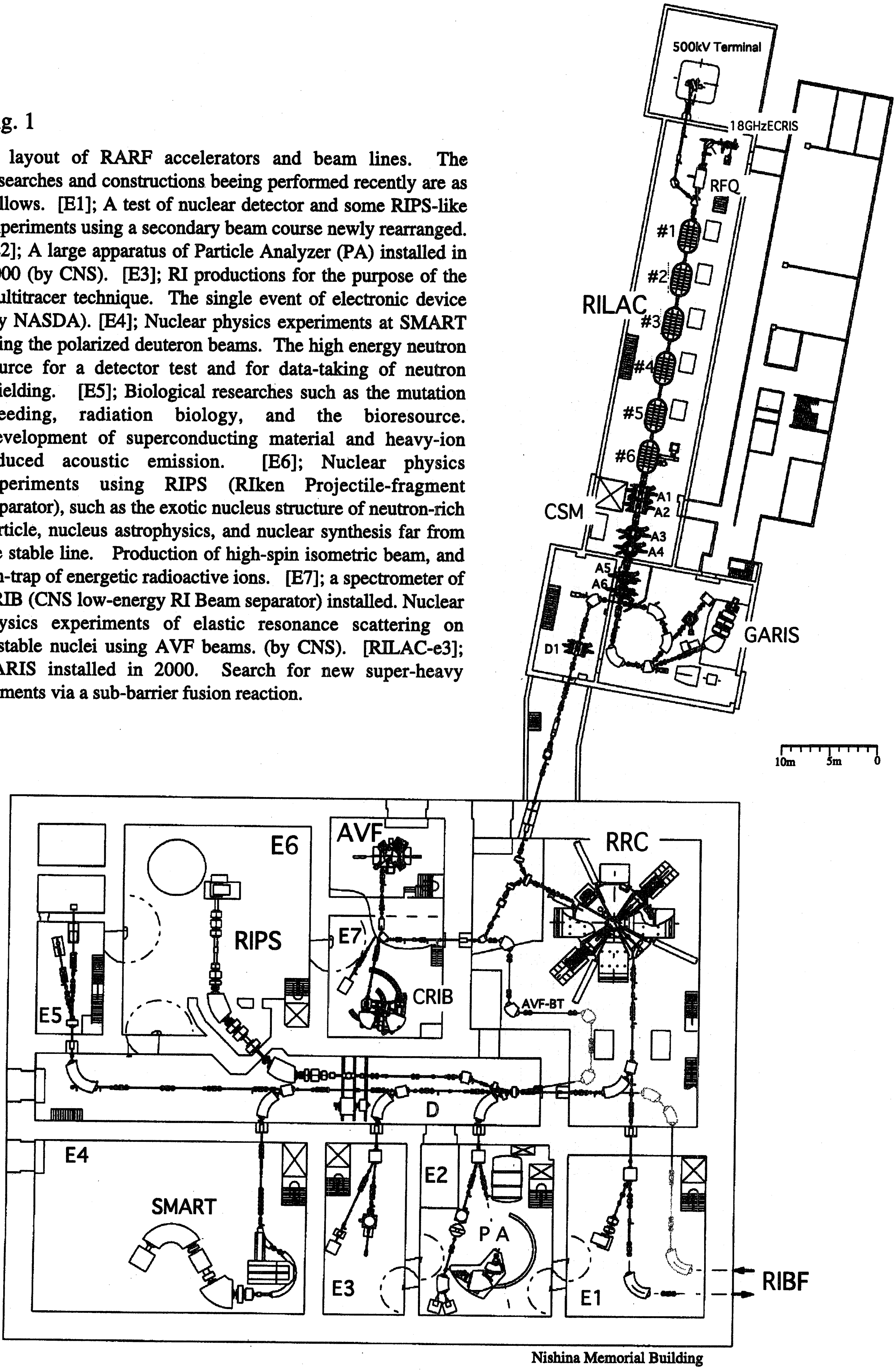
4. CSM and Energy Upgrade of RILAC

The Charge State Multiplier (CSM) has been proposed in order to increase the charge state of the ions that are injected into RRC[3]. At the final stage, it will become a combination of six acceleration cavities, a charge stripper, and three deceleration cavities. In 1999, the first unit of CSM, consisting of two acceleration cavities and one deceleration cavity, has been constructed[4]. These cavities are frequency-variable between 36 to 76 MHz, being operated the second harmonic of RILAC frequency.

In 2000, in collaboration with CNS of Tokyo University, the rest of four acceleration cavities were constructed. These cavities are operated at the fixed frequency of 75.5 MHz. The six cavities are installed just after RILAC as a booster of RILAC[5]. As the result these six cavities can

Fig. 1

A layout of RARF accelerators and beam lines. The researches and constructions beeing performed recently are as follows. [E1]; A test of nuclear detector and some RIPS-like experiments using a secondary beam course newly rearranged. [E2]; A large apparatus of Particle Analyzer (PA) installed in 2000 (by CNS). [E3]; RI productions for the purpose of the multitracer technique. The single event of electronic device (by NASDA). [E4]; Nuclear physics experiments at SMART using the polarized deuteron beams. The high energy neutron source for a detector test and for data-taking of neutron shielding. [E5]; Biological researches such as the mutation breeding, radiation biology, and the bioresource. Development of superconducting material and heavy-ion induced acoustic emission. [E6]; Nuclear physics experiments using RIPS (RIken Projectile-fragment Separator), such as the exotic nucleus structure of neutron-rich particle, nucleus astrophysics, and nuclear synthesis far from the stable line. Production of high-spin isometric beam, and Ion-trap of energetic radioactive ions. [E7]; a spectrometer of CRIB (CNS low-energy RI Beam separator) installed. Nuclear physics experiments of elastic resonance scattering on unstable nuclei using AVF beams. (by CNS). [RILAC-e3]; GARIS installed in 2000. Search for new super-heavy elements via a sub-barrier fusion reaction.



accelerate ions with mass-to-charge ratio of less than 5.6 up to the energy of 5.85MeV/u. The total voltage-gain of the booster is 16 MV, which is the same as that of the RILAC.

5. GARIS experiment and H8 RRC acceleration.

The energy upgrade of RILAC permits the two new schemes at the RARF, even if the CSM is not fully completed.

One is that a search for superheavy elements with the GARIS (GAs-filled Recoil Isotope Separator) become available at RILAC, which had been done at E1 target room of RRC beam line. A very intense beam with a energy around 5.2MeV/u are required on this experiment. In summer of 2000, the GARIS apparatus (a total weight is 65 t) was moved from E1 and installed in a target room of RILAC. Compared with the before, more intense beam will be expected, and more beam time can be shared for this research.

The other is that a new configuration of RILAC-CSM-RRC becomes useful to improve a beam intensity. The RRC was designed to operate with a harmonic number of 9 in the case of RILAC-RRC. Due to the energy-variability of RILAC, the RRC has been operated with a higher harmonics such as 10, 11, and 12 as well as the designed one. In the RILAC-CSM-RRC, the RRC can be operated with a harmonics of 8, 7 and 6. Some beams, which had been obtained only in the AVF-RRC, can be accelerated in the new scheme of RILAC-CSM-RRC with a much more intensity, because lower-charge-state ions can be taken at the ion source of RILAC and also because a transmission efficiency of RILAC is better than AVF. Such beams, some of which are very important for nuclear phyics experiments, are listed table 1. A test of the RILAC-CSM-RRC with h=8 will be tried soon.

6. Developments and improvements

Because the RILAC-RRC will be an injector to RIBF, some developments and improvements have been done continuously. A superconducting ECR has been developed and its beam test is now in progress[6]. As the method to insert a solid element to ECR plasma, a micro-oven system was installed to the 18GHz ECR at RILAC. A beam intensity of some solid ions will be expected to increase.

A charge stripping of ions after RILAC will be a very essential mater for the RIBF. Recently a long-lived carbon foil has been successfully produced[7]. Also liquid type stripper has been developed[8].

A control system has been replaced by the new one using EPICS[9]. The low-level interfaces (CAMAC-CIM-DIM, GPIB) were kept as before. The new control system covers not only the whole accelerator but also experimental apparatus such as RIPS and SMART. A new interface, which had been developed for power supplies in RIBF, is also included to the new system and tested in a routine operation.

RF amplifiers for cavities #5, #6 were replaced into new ones. The new amplifiers are almost same as those of ring cyclotrons (IRC&SRC) in RIBF and analogous to those of RRC. The spared parts for these amplifiers can be commonly used.

References

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Table 1. Upgrade of Beam intensities with CSM

(Present Data) AVF → RRC

Ion	E_{RRC}, (h_{RRC}) (MeV/n)	Stripping after AVF Q_i	Q_f	E_{AVF} (MeV/n)	effi. (%)	Beam intens. (pnA)
^{28}Si	135 (5)	10+	→ 14+	7.0	50	50
^{18}O	100 (5)	6+	→ 8+	5.5	90	250
^{40}Ar	95 (5)	11+	→ 17+	5.2	42	90
^{48}Ca	70 (5)	11+	→ 18+	4.0	33	4
^{86}Kr	70 (5)	20+	→ 31+	4.0	8	1

(Expected Data) RILAC → CSM → RRC

Ion	E_{RRC}, (h_{RRC}) (MeV/n)	Stripping after CSM Q_i	Q_f	E_{CSM} (MeV/n)	effi. (%)	Beam intens. (pnA)
^{28}Si	124 (6)	6+	→ 14+	6.5	40	700
	RILAC(37.8MHz)+A1+A2+A3+A4+A5+A6+RRC					
^{18}O	86 (7)	4+	→ 8+	4.7	85	>1000
	RILAC(37.8MHz)+A1+A2+A3+A4+RRC					
^{40}Ar	86 (7)	8+	→ 17+	5.7	45	>1000
	RILAC(37.8MHz)+A1+A2+A3+A4+A5+(A6)+D1+RRC					
^{48}Ca	86 (7)	9+	→ 20+	5.7	15	800
	RILAC(37.8MHz)+A1+A2+A3+A4+A5+(A6)+D1+RRC					
^{86}Kr	66 (8)	16+	→ 31+	3.9	7	100
	RILAC(38.2MHz)+A1+A2+D1+RRC					