PROGRESS OF RIKEN RI BEAM FACTORY PROJECT

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Abstract

The RARF (RIKEN Accelerator Research Facility) proposes "RIKEN RI Beam Factory" as a next facility-expanding project. In 1995, the budget for the three-year R&D has been partially approved. The factory is aimed at providing RI (Radioactive Isotope) beams over the whole atomic mass range with the world-highest level of intensity in a wide energy range up to several hundreds MeV/nucleon. A cascade of superconducting ring cyclotrons for an energy booster of the existing K540-MeV ring cyclotron are being investigated to provide primary heavy-ions, up to uranium ions, with the energies exceeding 100 MeV/nucleon. Multi-use experimental storage rings (MUSES) are also being studied as a new type of experimental installation.

1. INTRODUCTION

The RARF (RIKEN Accelerator Research Facility) houses a heavy-ion accelerator complex consisting of a K540-MeV ring cyclotron (RRC) as a main accelerator and two different types of injectors: a variable-frequency heavy-ion linac (RILAC) and a K70-MeV AVF cyclotron (AVF). The facility provides users covering a wide spectrum of research fields of nuclear physics, atomic physics, nuclear chemistry, materials science, radiobiology and others with various kinds of heavy-ion beams of a wide energy range from 0.6 MeV/nucleon to 135 MeV/nucleon. One of the remarkable features of this facility is capability of supplying light-atomic-mass RI (radioactive isotope) beams with the world-highest level of intensity produced by the projectile-fragment separator, RIPS [1]. In order to further promote research fields utilizing RI beams, the RARF proposes "RIKEN RI Beam Factory" as a next facility-expanding project. The factory takes the aim at providing RI beams covering over the whole atomic-mass range with very high intensity in a wide energy range up to several hundreds MeV/nucleon.

This paper describes an accelerator complex most suitable for realizing such factory. In adittion, the RILAC-upgrade program currently running relevantly to the project is reported. A new type of experimental installtion called MUSES (Multi-USe Experimental Storage rings) is described by T. Katayama et al. [2]

2. HEAVY-ION ACCELERATOR COMPLEX FOR HIGH-INTENSITY RI BEAM PRODUCTION

A preliminary plan of the factory is illustrated in Fig. 1. The existing facility will be expanded to the adjacent site where a two-story building will be constructed uderground.

The factory utilizes the "projectile fragmentation" to generate RI beams of intermediate energies. To enable the efficient generation are needed high-intensity primary heavy-ions of over 1 pμA, up to uranium ions, with the energies exceeding 100 MeV/nucleon. Such heavy ions are produced by a cascade of superconducting ring cyclotrons (SRC) which will be built as an energy booster of the RRC. RI beams are generated by the Big RIPS. The MUSES consists of an accumulator cooler ring (ACR), a booster synchrotron ring (BSR) and double storage rings (DSR). With the MUSES, various types of unique colliding experiments will become possible: ion-ion merging or head-on collisions; collisions of either electrons or X-rays with ion (stable isotope or RI) beams; internal target experiments; and atomic and molecular physics with cooler electron beams.

The RILAC serves as the initial-stage accelerator. We use the acceleration radio-frequency between 18 MHz and 38 MHz because this linac works stably in this frequency range. In order to upgrade the RILAC performance in the beam intensity by one or two orders of magnitude, its new pre-injector system consisting of a frequency-tunable folded-coaxial RFQ linac (FC-RFQ) equipped with an 18-GHz in source (ECRIS-18) has been developed[3]. In the recent test of this system, as for the FC-RFQ, the variability of the resonant frequency was measured to cover from 17.7 MHz to 39.2 MHz. In addition, the beam transmission efficiency of about 90 % at the maximum was obtained[4]. This efficiency agrees well with the value calculated by the computer code BEAMPATH[5]. High-intensity highly-charged ion beams have been obtained by the ECRIS-18. Some results are given in the report on this source[6]. The pre-injector is scheduled to be installed in due site in the summer of 1996. It will be used jointly with the existing 450-kV Cockcroft-Walton accelerator. The pre-injector beam is fully accepted and accelerated by the RILAC.

A charge-state multiplier (CSM) consists of an accelerator, a charge stripper and a decelerator. Its functions are to produce higher charge state of ion beams by further increasing the stripping energy and to reduce their magnetic rigidity by decelerating them to the initial energy. With this device the magnetic rigidity of a most-probable value can be reduced to the acceptable value of the RRC even when the injection velocity into the RRC is increased. The accelerator and decelerator are of a type of frequency-tunable IH linac, whose operational radio-frequencies are twice as that of the RILAC to double an acceleration gradient. Maximum gap voltages are set to be 350 kV for 62 cells of the accelerator and for 28 cells in the decelerator, and their total lengths are 12.4 m and 5.5 m, respectively. Transmission efficiency through the CSM depends only on charge state distribution behind the charge stripper foil. We estimate the yield of a given charge state in terms of Shima's formula[7]. A preliminary design of the CSM is given in the report by M. Tomizawa et al[8].

In the former design, a very large single SRC has been studied as a post-accelerator of the RRC. As the result of this study, recently, we have modified the design so that the SRC is splitted into two stages: a 4-sector SRC (SRC-4) for the first stage and a 6-sector SRC (SRC-6) for the second. This two-stage scheme has several advantages: One is that the simultaneous utilization of the SRC-4 beams can be dine in both the existing experimental facility and the new facility when a part of the beams are charge-stripped and are returned back to the existing facility. An example is: a 135 MeV/nucleon $^{16}O^{7+}$ beam from the SRC-4, a main part of which is injected to the SRC-6, is partially charge-stripped and the O^{8+} beam is delivered to the existing facility (the magnetic rigidity of the beam can be accepted). Another advantage is that the difficulty of fabrication due to huge electromagnetic force is eased compared to single-stage scheme.

The maximum beam energy of the SRC-6 is set to be 400 MeV/nucleon and this energy is achieved at 38 MHz of the maximum rf frequency of the RILAC. This means that a velocity of RRC output beam is to be amplified by a factor of 2.26. To this end, the mean extraction radius of the SRC-6 is taken to be 2.26 times the mean injection radius of the SRC-4. We set this mean injection radius to be 2/3 times the mean extraction radius of the RRC; accordingly the mean injection radius of the SRC-4 and the extraction radius of the SRC-6 are 2.37 m and 5.36 m, respectively. The mean extraction radius and the mean injection radius is taken to be the same as the mean extraction radius of the RRC (3.56 m). Then the velocity gain factors of the SRC-4 and the SRC-6 are then 1.50 and 1.506, respectively. To meet a good matching condition, harmonic numbers in both the SRC-4 and the SRC-6 become 6 as that in the RRC is 9. The radio-frequency of the SRC-4 and the SRC-6 ranges from 18 MHz and 38 MHz, which is the same as that of the RRC. The maximum magnetic fields of the SRC-4 and the SRC-6 are required to be 2.5 T and 4.5 T, respectively. This cascade of the SRC’s boost energies of heavy ion beams up to: e.g. 400 MeV/nucleon for light heavy ions like carbon, 300 MeV/nucleon for krypton ions, and 150 MeV/nucleon for uranium ions.

The SRC-6 with the sector angle of 25 degrees has been investigated. The design details are described in the reports by T. Mitsumoto et al.[9], by T. Kawaguchi et al.[10] and H. Okuno et al.[11]

We estimate the beam intensity expected to obtain from the SRC-6 for some typical gaseous elements and uranium ions, on the basis of the following conditions: (1) the transmission efficiency through the FC-RFQ is 85 % irrespective of kinds of ion beams; and (2) from the exit of the FC-RFQ to the extraction beam line of the SRC's, the beam loss occurs only in the stripping process, i.e. this means that the transmission efficiency of both of the RRC and the SRC's is 100 % (this can be achieved by the off-centering acceleration technique which is routinely used for the RRC). In Table 1 is given comparison of the ECR beam intensity (I^{ECR}) of a given charge state (q^{ECR}) required to obtain an ion beam of the energy (E^{SRC}) with the intensity (I^{SRC}) to the present performance of the ECRIS-18 and the 14.5 GHz CAPRICE[12]. Quite high beam intensity is expected to be provided especially for light ions, but use of such primary beams is not realistic from a viewpoint of the radiation-shielding-problem. We consider that primary-beam intensity of 1 pμA is sufficient to generate RI beams with desirable intensity in the whole mass region: These primary beams will give us a possibility to create and identify as many as one thousand kinds of new isotopes. High current beams are used with a low duty factor of nearly 0.01 % for the MUSES.

In 1995 fiscal year, the budget for the three-year R&D to design the details of the factory has been partially approved. We plan to build a full-scale model of the sector magnet of the SRC-6 so that its design can be made sure under the condition as close to the real one as possible[13]. This would be particularly important to see if the huge magnetic force due to the high magnetic field and current density can be properly supported. The model magnet is aimed at generating stably a magnetic field higher than 4.2 T that is required in the current design of the SRC-6. We also plan to install and test a prototype of superconducting magnetic channel which will be used for the beam injection or extraction. Fabrication of the model magnet is scheduled to start early next year and completed by its end.

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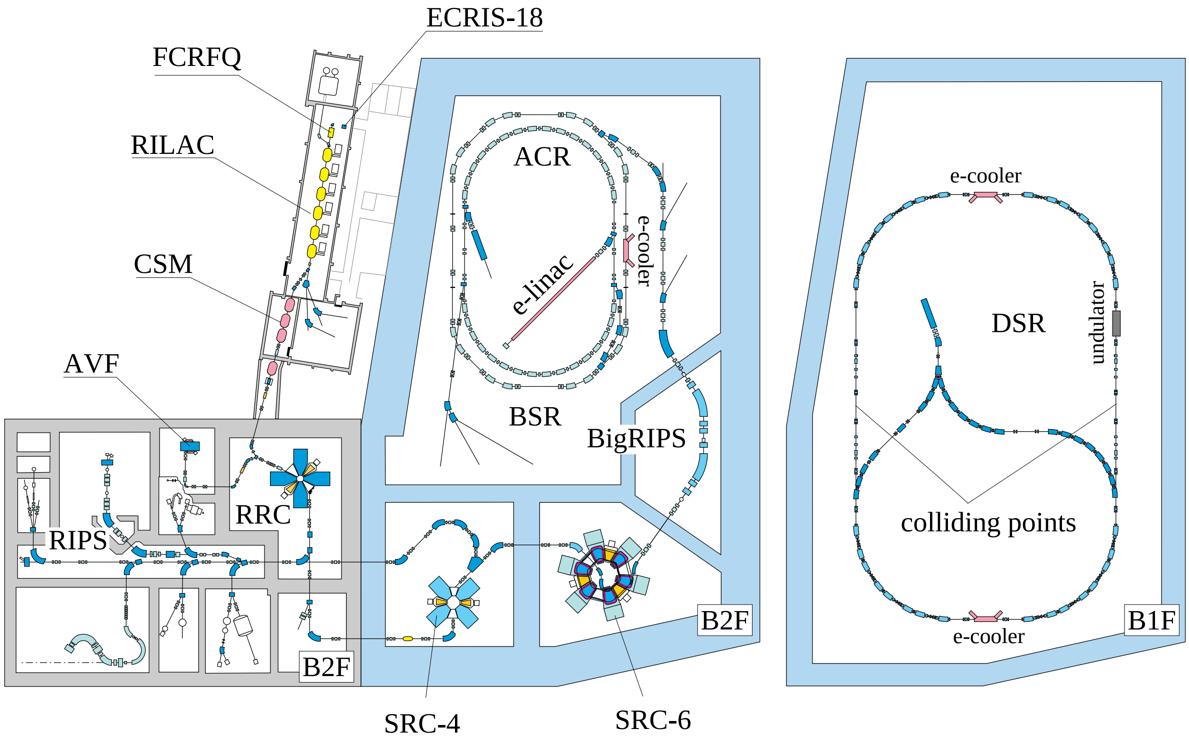

Fig. 1. Preliminary layout of the RIKEN RI Beam Factory. The SRC's and the MUSES are housed in a two-story building underground. Experimental setups are not depicted.

Table 1. Comparison of the required beam intensity to the performance of the ECRIS-18 and the 14.5 GHz CAPRICE.

Ion	E^{SRC} (MeV/u)	I^{SRC} (pmA)	q^{ECR}	I^{ECR} (emA)	$I^{ECRIS18}$ (emA) ext. voltage 10 kV	15 kV	$I^{CAPRICE14.5}$ (emA) ext. voltage 20kV
$^{16}O^{8}$	400	100	6	700	550	610	800
$^{16}O^{7}$	400	100	7	820	110		100
$^{40}Ar^{17}$	20	20	7	410			
			8	470	330	410	500
$^{84}Kr^{30}$	300	2	14	120	90	110	120
$^{129}Xe^{38}$	200	1	15	100			80
$^{238}U^{85}$	200	0.02	28	16			25
$^{238}U^{58}$	150	0.2	22	75			
$^{238}U^{49}$	100	1	16	110			