9. RI Spin Laboratory

(*Abstract*)

We propose to equip the present fragment separator RIPS at the E6 experimental room with a beam line that delivers beams of 115 *A* MeV heavy ions up to Z ~ 76 from the IRC cyclotron. Radioactive nuclei produced by the primary beams of such an intermediate energy are suitably low in energy to be stopped in a sample material of limited thicknesses and also allow for a scheme to polarize their spins, thus enabling a number of stopped-RI type experiments to be conveniently performed. The researches done here include nuclear structure studies through electromagnetic moments, β-decay and β-γ spectroscopy, and also materials science studies, placing the main focus on several spin-related research techniques such as the β-NMR, γ-PAD, γ-PAC, laser, low-temperature nuclear orientation, and in-beam Mössbauer methods.

In order to enhance and fully capitalize the unique and valuable experimental opportunity provided by this IRC-RIPS configuration, two schemes of time-sharing beam delivery to BigRIPS and RIPS are proposed. In the first one, a pulsing magnet is used to change the beam path within a switching time of 10 ms. The other uses an RF beam splitter, which can provide DC-like beams to both BigRIPS and RIPS.

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II. OUTLINE

In the RIBF project intense beams can be provided over the whole range in the atomic number at the energy E=350 AMeV for heavier mass ions after the final acceleration by Superconducting Ring Cyclotron (SRC) in the cyclotron cascade. By using Big-RIPS, large variety of radioactive isotope beams (RIBs) can be produced. In this configuration, beams can be accelerated up to the energy of E = 115 A MeV with Intermediate-Stage Ring Cyclotron (IRC). These beams have sufficiently high energy to produce RI beams via projectile-fragmentation reaction. If a beam-transport line from IRC to RIPS in the existing facility is constructed, intense beams with a wide range of atomic number can be also provided to RIPS as well as BigRIPS. Compared with presently obtained RIB intensities with the AVF-RRC acceleration, their intensities are drastically increased as shown in Fig. 1.

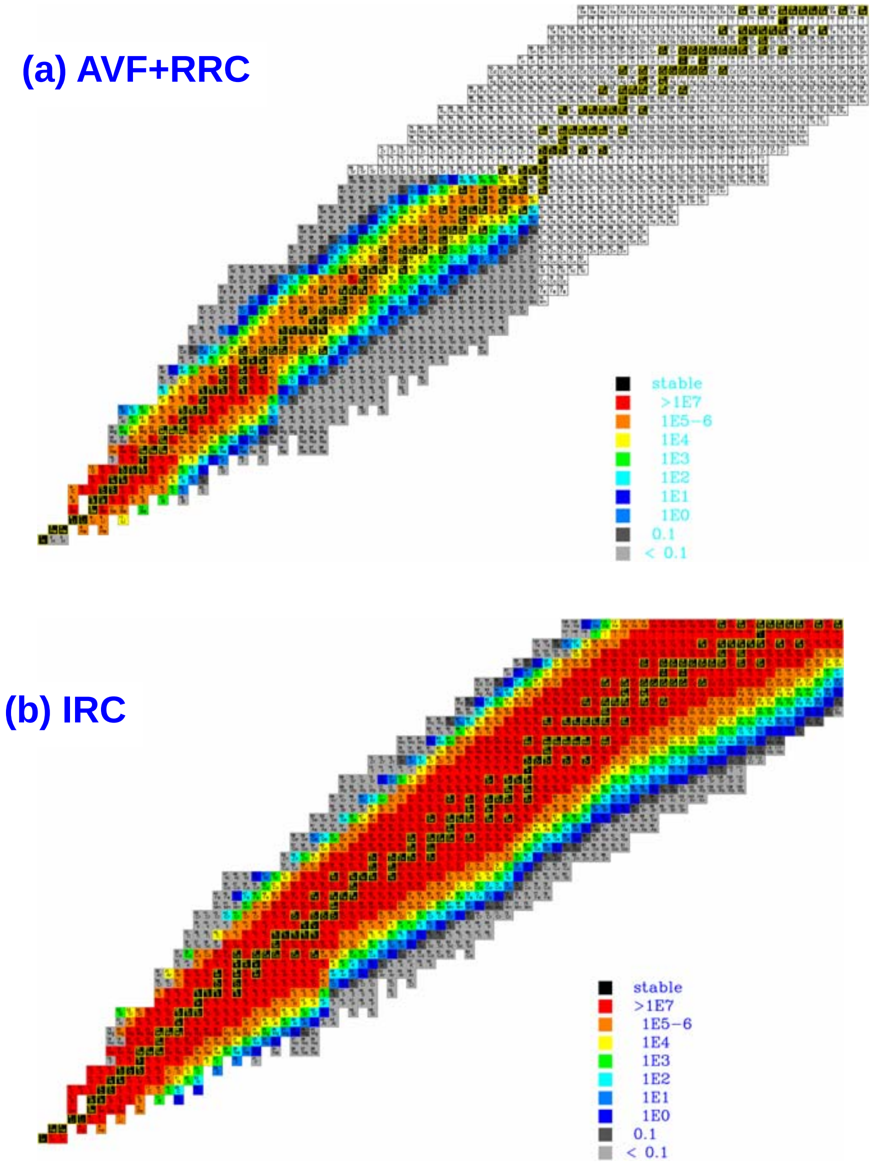

FIG. 1. Comparison of RIB production rates in the projectile-fragmentation reaction. Upper panel (a) shows the case of present AVF-RRC acceleration. The panel (b) shows intensities estimated assuming I=1pμA and E=115 AMeV projectiles of all stable elements.

This plan is fully capitalized if a time-sharing beam delivery between BigRIPS and RIPS is realized. At the present, 9:1 beam delivery has been proposed. Many experiments proposed to use RIPS in this configuration require beam intensities $I \sim 10^{3\text{-}4}$ pps, which can be easily obtained in the light-to-medium mass region even in the time-sharing operation. Also one important subject proposed to RIPS is material science. Usually probe nuclei for those studies are placed near the β-decay stability line, required intensities can be provided. Also studies on proton-rich nuclei can be carried out with RIPS, since an RF-deflector system [YA01,02,03] for beam purification has already been equipped.

III. RESEARCH SUBJECTS

In this project, radioactive-isotopve beams (RIBs) are provided at the intermediate energy using the existing fragment-separator RIPS at RARF. Thus, this IRC-RIPS configuration should partly be dedicated to the stopped-RI type decay experiments and low–to-medium energy RI beam experiments. One of the exclusive features of this facility is that spin-polarized RIBs could be obtained. The facility also allows precision decay-particle detection because the RI's are stopped in a relatively thin stopper. Thus, in addition to the basic β-γ spectroscopy and β-decay experiments for nuclear structure study, the project provides opportunities to carry out material science and spin-related researches such as the β-NMR, γ-PAD, γ-PAC, and in-beam Mössbauer experiments.

(A) WORKSHOPS

Research subjects have been surveyed so far by organizing the following workshops [WS02, 04]: *"RIKEN Symposium on Condensed Matter Studies with Radioactive Ion Beams"*, Feb. 2002, Wako, Japan, *"RIKEN Symposium on Research Projects Dedicated to RIPS in the RIBF Configuration"*, Oct. 2004, Wako, Japan, and *"RIKEN-UEC Mini-Workshop on Nuclear Spectroscopy using Stopped and Low-Energy Unstable Nuclei."* Sep. 2005, Wako, Japan. Many groups from different institutions proposed to use RIPS in the RIBF configuration. The workshops include many topics such as nuclear physics, material science, and fundamental physics. They could be listed up in the following categories: i) polarized/aligned RIBs, ii) highly-polarized slow RIBs, iii) stopped RIBs, and iv) in-flight intermediate/low energy RIBs.

Spin-oriented RIBs (fragment-induced polarization)				
• N	RIKEN	*μ & Q*	β-NMR	up to Kr
• N	Osaka	*μ& Q*	β-NMR	T_z=-3/2,-5/2
• N, M	RIKEN	Magnetism	γ-PAD	heavy elements
• M	Osaka	Hyperfine Int.	β-NMR	~ Ni
• M	KEK	Semiconductor	β-NMR (?)	
Highly spin-polarized RIBs (RIABR)				
• N	RIKEN	*μ& Q*	RIABR	up to Xe
• N	Osaka	Nuclear structure	β-n-γ	*sd-pf*
• M	RIKEN	Surface	β-NMR, PAC	*4f,* rare earth
• F	Rikkyo	Symmetry	β-ν corr	*sd-pf*
Stopped RI (implantation)				
• N	Niigata	*μ& Q*	NMR-ON	Sc, Fe
• C	RIKEN	Exotic states	Mössbauer	^{57}Mn, ^{119}Sb
• C	TUS	Exotic species	Mössbauer	^{57}Mn
• M	Shizuoka	Impurity	Mössbauer	^{57}Mn
• C	ICU	Noble-gas comp.	Mössbauer	^{83m}Kr, Xe
• A, N	RIKEN	Super-liq. He	Laser	Mg, Al, Ca
• A, N	RIKEN	Spectroscopy	SLOWRI	*p*-shell
• C, M	Osaka	Magnetism	TDPAC	^{19}O
Low-to-medium energy RIBs (in-flight)				
• N	RIKEN	*μ*	Trans. Field.	up to Xe
• N	Osaka	Cross section	nuclear reaction	*sd-pf*

Note: N (Nuclear Physics), M (Material science), F (Fundamental interaction and symmetry), C (Chemistry), A (Atomic physics)

In category i), measurements of nuclear electro-magnetic moments, PAD experiments for studies of magnetism, β-NMR experiments for material studies are included. In category ii), measurements of nuclear electro-magnetic moments of heavy elements, studies of surface, nuclear structure through β-n-γ spectroscopy, and fundamental symmetry through β-ν correlation. In category iii), in-beam Mössbauer experiments, NMR on low-temperature oriented nuclei, ion trap with RF-ion guide method etc. are included. Category iv) includes studies of reaction cross section, and transient field experiments with RI beams.

(B) EXPERIMENTAL CASES

・Systematic measurement of the ground-state magnetic moments μ for nuclei over a wide range of the proton and neutron numbers Z and N will be carried out. For instance, the g-factor determinations for a series of even-Z, odd-N nuclei reveal what j, l orbit is occupied by the valence neutron in the ground state of a neutron-rich nucleus, and should clarify how the energy ordering of the single-particle orbitals vary as the N/Z ratio increases and how the magic numbers consequently appear/disappear. For another example, seven new g-factors for Sc (odd-Z) isotopes would be measured for mass numbers A = 48 to 54. The magnetic moment in even N cases are primarily described by a valence proton in the $f_{7/2}$ orbital, and an additional contribution to this is expected from the 2^+ excitation of the core. When passing through the neutron numbers N = 30 and 32 where some expectation for the presence of a shell gap is suggested in neutron-rich nuclei, possible changes in the size of the 2^+ core contribution would be examined. The determination of magnetic moments for mirror pairs ($T_z = \pm 1/2, \pm 3/2$, …) will provide a unique and stringent test of nuclear structure theories.

・Magnetic moment of the first 2^+ excited state is a very useful observable in studying the evolution of shell gaps. This has been demonstrated in the recent discovery of the disappearance of Z = 64 sub-shell gap in the N ~ 90 region, where the measurement of the 2^+ state magnetic moments has provided much clearer evidence than the excitation energy data have. They have extracted from the magnetic moment data, the effective valence proton and neutron numbers, and have shown a rapid disappearance of the proton sub-shell gap as manifested by an increase in the effective proton number. The data, however, are scarce for the region of unstable nuclei. We are developing the transient field and TDPAD methods for systematic measurements of μ for the first 2^+ excited states in unstable nuclei. RI beams provided by the IRC-RIPS configuration are quite suited to this purpose. This is because (i) large transient field is expected at these energies for the ions in the heavier mass nuclei, and (ii) stopper materials hardly become the back-ground source in the gamma-ray detection because of the lower beam energies.

・The β-γ-n spectroscopy on spin-polarized nuclei enables unambiguous spin-parity assignments of excited states in the daughter nuclei that are fed through the Gamow-Teller (GT) β decays. The angular distribution of β particle from the GT transition of a polarized nucleus shows an asymmetry of a size $A_\beta P$ with respect to the polarization axis, where A_β and P denote the asymmetry parameter of the GT transition and the degree of polarization of the parent nucleus, respectively. Since P is common for all transitions, the spin-parities of the final states can be determined through the observed $A_\beta P$ values. The spin-parity assignment for excited states should play an essential role in studying the evolution of nuclear structure with increasing neutron excesses. In a neutron-rich nucleus, the valence neutrons tend to occupy a different major shell from the valence protons. Consequently, GT transitions occur mostly toward non-normal parity states in the daughter. Disappearance of the shell gap would manifest itself as a lowering of the non-normal parity states. The experiments with neutron-rich isotopes with $Z = Z_{magic}+1$ would be interesting.

・Polarized radioactive atoms at thermal energies soft-landing on a surface will be sensitive spin probes even at rates as low as 10^3 atoms/s, thanks to the radiation counting nature of the β-NMR technique. In the conventional solid-state NMR technique, surfaces are impossible to study because the number of atoms on a surface is on the order of $N^{2/3} \sim 10^{15}$ which is at least 3 orders lower than those needed for the most sophisticated setup for the conventional NMR experiment. Surface atoms are subjected to large structural and magnetic instabilities (and sometimes these two types of instability are interrelated) and produce rich physics. By the soft-landing β-emitting nuclear probes, the magnetic hyperfine field, electric field gradient which reflects structures surrounding the probe atom, and spin relaxation which senses dynamical aspects of the system can be studied. To realize this type of experiment, however, we must anticipate a challenging problem of maintaining an extremely high vacuum while allowing for the entrance of a probe beam in the sample chamber.

・Development of a large variety of PAC probes, such as ^{19}O, ^{43}Ar, ^{73}Se, and ^{77}Br, is to be realized by using this facility, which enables us to explore extensive fields of condensed matter studies by means of on-line measurements. Fluorine-19 as the disintegrated daughter nuclide of a short-lived ^{19}O is a candidate for a PAC probe, for instance. Because ^{19}F has a spin of $I = 5/2$ at the 197-keV intermediate state of the PAC cascade, the relevant on-line PAC method has the advantage of providing insight into quadrupole interactions with the extranuclear charge distribution, which is not the case for the only stable fluorine isotope ^{19}F at the ground state ($I = 1/2$). Because the initially implanted nuclide is ^{19}O, application of the proposed method to the hyperfine interaction studies of many types of oxides is also expected: superconducting oxides, magnetic oxides, manganites of colossal magnetoresistance and so forth.

・In-beam Mössbauer spectroscopy (IBMS) is performed to study the diffusion of impurities and intrinsic defects in semiconductors at high temperatures over 600 K exploiting the magnified intensities (2-3 orders higher compared to the present RARF-RIPS, for a ^{57}Mn case for example) of RI beams expected at the RI Spin Laboratory. Mechanisms for the fast jumping and recombination of interstitial impurity atoms can be identified from the line broadening and the intensity decrease of the IBMS spectra.
Recent theoretical studies suggest the existence of inert-gas compounds such as HXeCCH, and HKrCN, but there has been no experimental evidence yet. Ion implantation and succeeding IBMS study will be useful for the identification and characterization of such exotic chemical species. By implanting ^{83m}Kr into gas matrices (O_2, C_2H_2, CH_4, C_6H_6, H_2O, *etc.*) at low temperatures and acquiring the ^{83}Kr Mössbauer spectra, the isomer shift and the quadrupole splitting are obtained which must provide us useful information in understanding the nature of chemical bonding.

IV. DEVICES

(A) BEAM TRANSPORT SYSTEM FROM IRC TO RIPS

A layout of the IRC-RIPS beam transport line is shown in Fig. 2. Since this beam energy is lower than that provided to BigRIPS after the SRC acceleration. (E = 350 A MeV), the production rate of the RI beams is also lower, which is roughly ~ 1/10 for the RI produced in the case of the projectile-fragmentation reaction. In spite of this, the situation that both of the fragment separators are available in RIBF makes the project more productive.

The maximum magnetic rigidity of the beam-transport line from IRC to RIPS is designed to be $B\rho$ = 4.2 Tm [FU02]. This value is sufficiently large to accept the beam extracted from IRC except for the very heavy ions near uranium. Thus large variety and high intensity beams are introduced to existing RIPS at the intermediate energy E = 115 A MeV.

It should be noted that we could have spin-polarized RI beams in this energy region. The energy region around 100 A MeV is preferred in experiments utilizing the fragment-induced spin polarization because of its mechanism (Sect. IV-(B)). Also, to obtain much higher polarization compared with the fragment-induced polarization, development of the RI-atomic beam system is in progress now (Sect. IV-(C)).

In addition to the DC-mode beam operation, a time-sharing beam delivery to

BigRIPS and RIPS has been proposed (Sect. V), which fully capitalizes the unique and valuable experimental opportunities as well as the detector development for BigRIPS experiments.

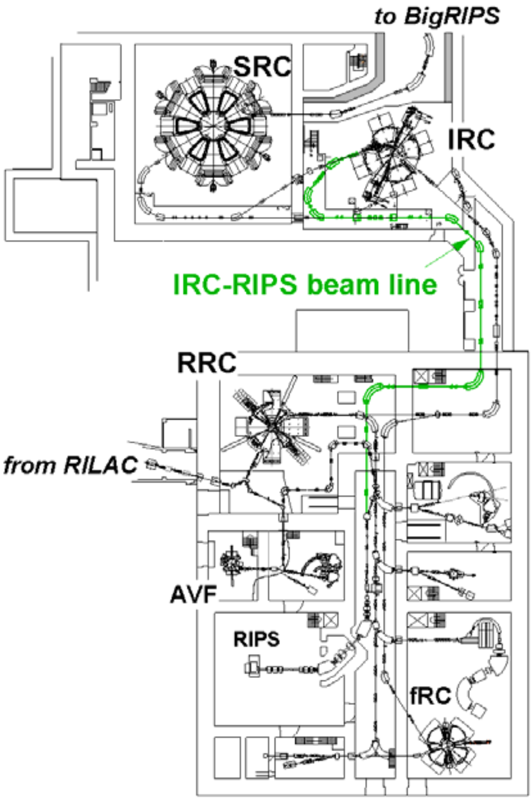

FIG. 2. Layout of the beam transport line from IRC to RIPS.

(B) INTERMEDIATE-ENERGY SPIN-POLARIZED RI BEAMS

It has been revealed that spin-polarized RIBs can be obtained in the PF reaction at the energy E ~ 100 A MeV [AS91, OK94]. By utilizing the fragment-induced spin-polarization with the β-NMR method, measurements of the nuclear moments far from the stability has been carried out mainly in the *p*-shell region.

The mechanism of PF-induced spin-polarization is based on the fact that a portion of the projectile to be removed through the fragmentation process has non-vanishing angular momentum due to the internal motion of nucleons. In order to have the spin-polarized RI beam, we need simply select the emission angle and the outgoing momentum of the fragments. Because of this general feature of the PF reaction, essentially any fragments would be polarized irrespective of their chemical properties.

Recently the observation has been extended to the *sd*-shell region. The ground-state magnetic moments of $^{30,\,32}$Al have been measured from the fragmentation of ^{40}Ar projectile at an energy E = 95 A MeV[UE05], where polarization P ~ 1 % was observed. The obtained polarizations provide a promising prospect that substantial magnitude of spin polarization would be obtained in the PF reaction from other projectiles, thus making the nuclear-moment measurements feasible in the heavier-mass region. However, β-NMR measurements might be difficult in some cases, since the preservation of polarization in the stopper crystal becomes difficult for RIBs having long β-decay lifetime. For such nuclei, the new method described in the next section IV-(C) could be applied.

(C) LOW-ENERGY HIGHLY-POLARIZED RI BEAMS

The basic principle for the production of highly-polarized low-energy RIBs is based on the atomic beam resonance method (RIABR). A layout of the setup is shown in Fig. 3. In order to employ the atomic beam resonance method, atomic beams should have low energy and low temperature. The RIBs produced in the PF reaction, however, have high energy and large momentum width to apply the ABR method. Thus incoming RIBs are decelerated with an energy degrader and introduced to a gas cell filled with a noble gas for the beam stopping. The stopped isotopes tend to have q = +1 charge in the noble gas, so that they could be drifted to an extraction area following an electrode potential produced using electrode plates. The drifted RI ions are guided into evacuated area through a nozzle with thermal velocity. After the extracted RI ions are neutralized there, they are transported to sextupole magnetic field arrangement. At the focus point of the RI ions due to this magnetic field, P ~ 100 % atomic polarization could be expected in principle. Here, the atomic polarization is converted to the nuclear polarization by using an RF transition system. The conversion efficiency is defined by the combination of atomic spin J and nuclear spin I. The converted component is physically collected with a quadrupole magnet located downstream of the RF transition part. Thus, highly spin-polarized and slow (v ~ 500 m/s) RIBs are obtained, when their nuclear moments are known. Reversely, unknown nuclear moments can be measured by detecting the beam focusing as a function of the RF frequency. Since the beam particle is directly detected as the signal, the method can be applied to RIBs even if they have a long β-decay lifetime.

Such polarized RIBs with a low kinetic energy are useful as a probe to study surface magnetism and adatom dynamics. Also, fundamental physics experiments, in which the β-ν correlation in the in-flight β-decay will be measured using the spin-polarized slow RIBs, are proposed

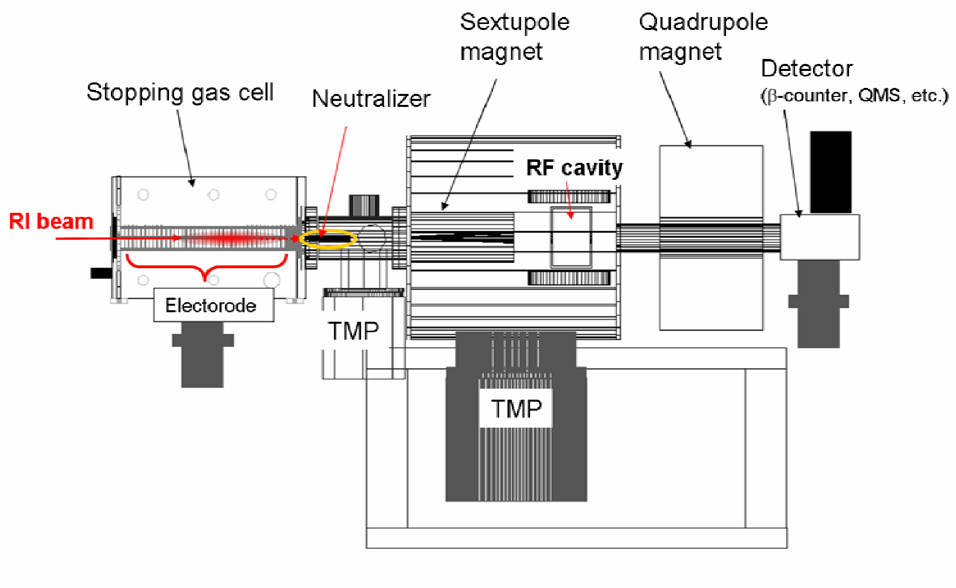

FIG. 3. Layout of an RIABR system

The RIABR device consists of three sections: i) stopping gas cell section including an electrode and an extraction nozzle, ii) neutralization section, and iii) spin selection section. For the issue i), the following results have been obtained so far [MIYO05, NA05]; the drift of the stopped ions was measured with an injecting RI beam of ^{30}Al in the RIPS beam line. With the electric field of 3.1 V/cm in the drift area, 72 % of the stopped Al ion in the Ne gas was efficiently drifted to the extraction area. The drift time is estimated to be 500 ms. For the extraction of drifted ions, the measurement was conducted with the nitrogen ions produced by arc discharge. Drifted nitrogen ions in 150 torr gas cell are extracted into evacuated area with 10^{-2} torr through a Laval-type nozzle with carrier gas flow. The measured extraction efficiency up to now is 3.3 %. Although the present efficiency 3.3% is not enough, experiments to measure the nuclear moments is possible for some elements near the stable isotope region. For the issue ii), the on-line test experiment with a neutralization tube consisting of Yttrium is being performed. For the issue iii), the magnets and RF cavity system would be developed with the off-line setup.

V. ADVANCED CONFIGURATION: TIME-SHARING BEAM DELIVERY

Many experiments proposed to use RIPS in the IRC-RIPS configuration are concerned with nuclear structure studies in the light-to-medium mass range, and with material science using probe nuclei near the β-stability line. In the workshops on the RI beam science with IRC-RIPS, most of the proposed experiments require RIBs with 10^3-10^4 pps production rates. On the other hand, some works such as development of detector system aiming at BigRIPS experiments may not require intense projectile particles.

In the above IRC-RIPS beam transport system, only DC beams are available at the moment. However, for the above purpose, high intensity beams are not always required. A time-sharing use of the beam between BigRIPS and RIPS, which is optional at present, makes the facility more productive, offering enhanced opportunities to perform the above stated experiments and developments. The beam delivery with 9:1 intensity ratio between BigRIPS and RIPS is proposed.

(A) STEP 1: PULSING-MAGNET MODE

In the first step, a time-sharing beam delivery using a pulsing magnet system, whose maget arrangement is shown in Fig. 4, is proposed. The magnet has already been installed for introducing beams to the IRC-RIPS beam transport line. This magnet is able to be operated not only in a DC mode but also in a pulse mode. The designed switching time of the pulsing magnet is 10 ms. Within this period, the magnet current is stabilized to better than 1×10^{-4} [KO01, KU02]. One example of the operation pattern of the beam-delivery sequence is 10 ms (switching) - 100ms (flat top) - 10ms (switching) - 900ms (flat base). On the flat top, the pulsing magnet is excited and the beam is transported to the IRC-RIPS beam line. On the flat base, the magnet is set to 0 T, thus the beam is transported to SRC just through the magnet.

In this mode, beam-loading effects should be carefully investigated, since a high-intensity heavy-ion beam stays in SRC for a duration ~100 ms, which is much longer than the SRC time constant ~ 100 μs. The estimated loading effects on the RF cavity of SRC are as follows. In the case of an $^{238}U^{88+}$ beam (I = 1pμA), which causes a maximum loading effect, a waiting time of 2 ms is required for the Dee voltage stabilization (permissible range is $\delta V_{\mathrm{Dee}}/V_{\mathrm{Dee}}$ = 1/10,000) just after the beam on/off. In the cases of $^{136}Xe^{52+}$ and $^{86}Kr^{33+}$ beams with I = 100 pnA currents (here we consider the first beam situation), the stabilization times are 1ms and 0.8ms, respectively. This result indicates that the beam loss could be kept below 1 % in the scheme of beam splitting with 900 ms and 100ms.

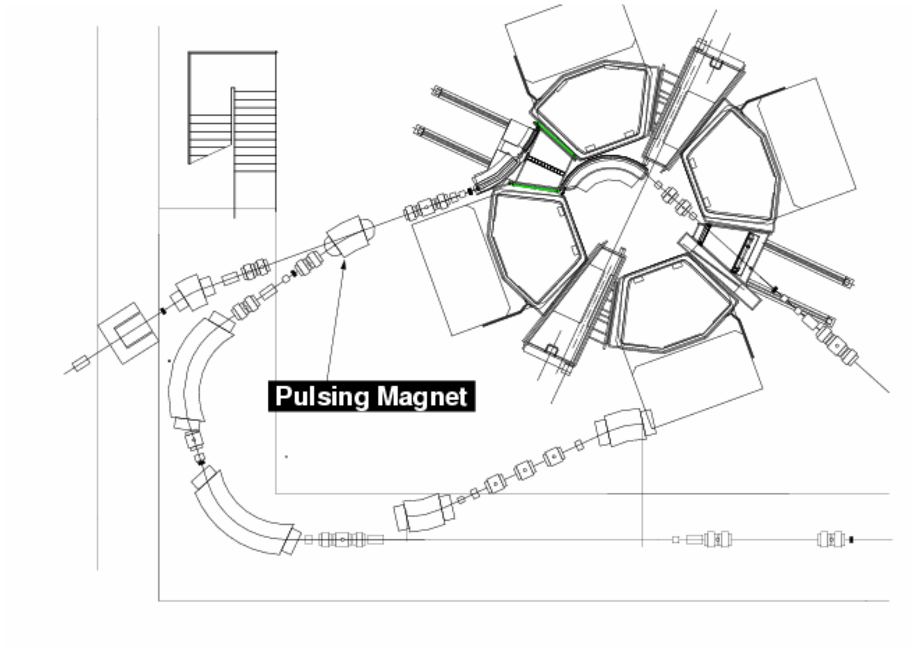

FIG. 4. Arrangement of magnets around IRC for a time-sharing beam delivery in a pulsing-manget mode

Also, it is desirable that beam intensities of BigRIPS and RIPS are controlled independently without affecting each other. In principle, it is possible, but a special intensity control system should be inserted upstream of the pulsing magnet. However, as the starting point of the time-sharing beam delivery, simple system and operation would be preferable. They should avoid serious problem on the beam delivery to BigRIPS. Alternatively the following beam control scheme is proposed. The "*main site*" BigRIPS takes priority of the intensity control: standard intensity control system placed upstream of the pulsing magnet is used by BigRIPS users. On the other hand, "*satellite site*" RIPS users do the intensity control by installing slits in the middle of the IRC-RIPS beam transport line. In this time-sharing mode, the intensity control of the RIPS beam might not be very convenient: the beam introduced to RIPS is put on and off every few seconds. Its intensity varies when the intensity setting for BigRIPS is changed by BigRIPS users. Also, depending on β-decay lifetime, some experiments would be affected by the beam on/off timing. Nevertheless, the time-sharing beam delivery will be realized in this scheme without a large investment. As the starting point, this scheme seems realistic.

(B) STEP 2: RF BEAM-SPLITTER MODE

For the next step, the time-sharing operation using an RF beam-splitter system is proposed. In this mode, the beam is switched every 1 μs so that the beam is delivered to both BigRIPS and RIPS almost in a DC mode.

A conceptual drawing of the beam splitting and its magnet arrangement in this mode are shown in Figs. 5. and 6. The extracted beam from IRC is introduced into an RF beam splitter system. The basic structure of the system is similar to that of the existing RF beam deflector system [YA01, 02, 03]. A high voltage is applied to vertically arranged parallel electrodes at a frequency of ~ 9 MHz, which is one fourth of the frequency (~36 MHz) adopted at fixed RF-frequency Ring Cyclotron (fRC). The system deflects each extracted particle bunch up and down at angles of $\pm\theta_{\mathrm{def}}$ alternately. Here, a static magnetic field is applied to the beam on the horizontal plane perpendicular to the incoming beam, which changes the beam angles of $-\theta_{\mathrm{def}}$ and $+\theta_{\mathrm{def}}$ into $-2\theta_{\mathrm{def}}$ and 0, respectively. The required magnetic field strength is ~ 0.04 T. Then the beam is introduced into a Lambertson-type septum magnet [OL73], which is located downstream of the RF beam splitter.

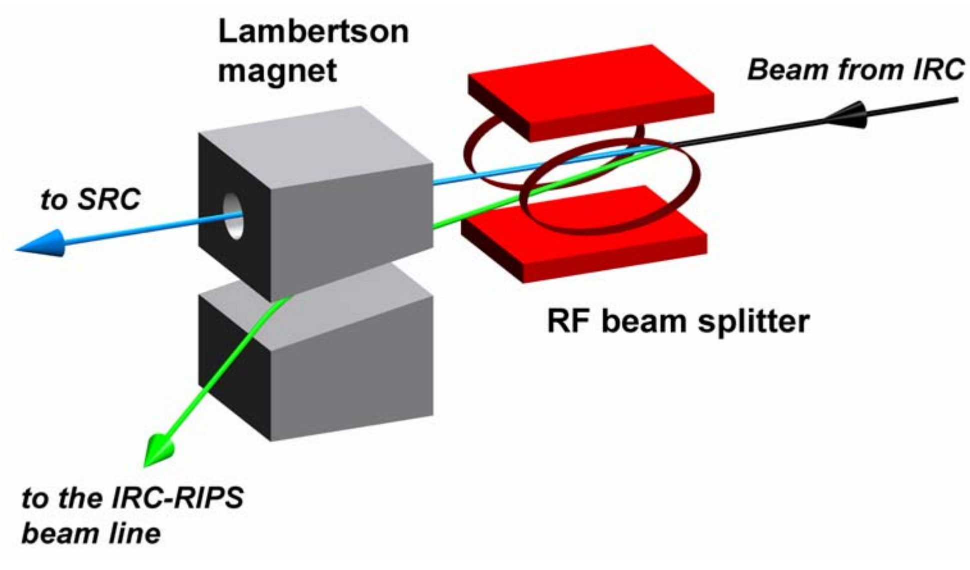

FIG. 5. Schematic drawing of an RF beam-splitter system.

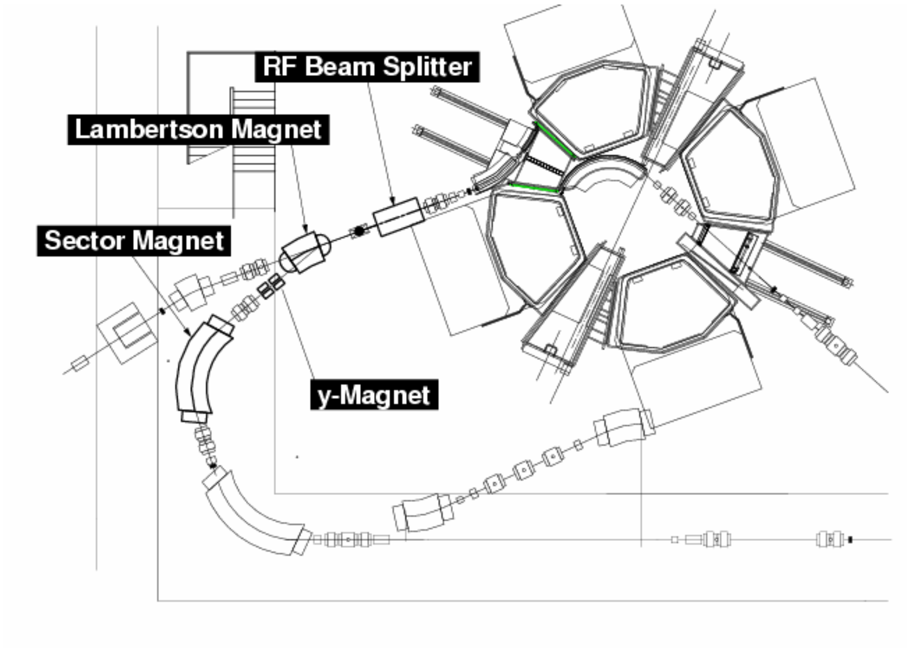

FIG. 6. Magnet arrangement around IRC for a time-sharing beam delivery in an RF beam-splitter mode.

The Lambertson magnet is a special dipole magnet that includes two paths for a beam. One area has a magnetic field and bends the beam. The other area is shielded from the field and the beam simply passes through it. The $\theta = 0°$ beam goes to SRC through a tunnel built in the pole of the magnet. The single-user operation with the beam dedicated to BigRIPS experiment is provided simply by turning off the RF beam splitter system: the beam simply goes to SRC through the tunnel of the Lambertson magnet. In this beam-sharing scheme, the beam is delivered to SRC at a period of ~ 200 ns. This beam evolution period is very short so that the beam loading effects are considered negligible. On the other hand, the $\theta = -2\theta_{\mathrm{def}}$ beam goes through the pole gap of the Lambertson magnet. The pole gap is slanted off the horizontal plane. The Lambertson magnet deflects the beam by 20 degrees. By using a couple of y-magnets, the height of the beam is adjusted to the 140-degree bending section, which is basically consists of sector magnets whose bending angles are 67.5 and 72.5 degrees. Here, the bending angle of the first magnet is changed from 72.5 to 67.5 degree (In the pulsing-magnet mode, these two sector magnets are identical).

Then the beam is introduced into the beam-transport line connected to RIPS.

The existing RF deflector is a type of quarter-wavelength coaxial resonator with an upright fixed-length cavity [YA01,02,03].The frequency is adjusted with the capacity tuner attached on the side. We have designed a similar type of resonator, but the cathode cavity is tuned with a sliding RF short plate. In this configuration, the width of the system becomes narrower, thus the system is only 1 m wide, whereas the RF deflector is 2.4 m wide. Since the lateral space for the installation of the RF beam splitter is limited at the exit of IRC, the present configuration is suitable.

In our design, the maximum high voltage of 150 kV is applied to the electrode with a length of 1000 mm and a gap of 30 mm. Based on a model calculation, where the transmission-line model of the distributed constant circuit is taken into account in the one-dimensional approximation, the power loss of the cavity is expected to be less than 50 kW[MIYA03]. This power loss does not cause serious problems to the cooling of the cavity.

At the exit of the RF-beam splitter, the beams of $^{86}Kr^{35+}$ and $^{136}Xe^{52+}$ with an energy of 115 A MeV are deflected by $|2\theta_{def}|$ = 1.4 and 1.3 degrees, which result in physical displacements 42 mm and 39 mm from the central trajectory, respectively, at the entrance of the Lambertson magnet placed 2 m downstream of the RF beam splitter. These displacements are sufficiently large to design the Lambertson magnet.

In this mode, independent control of the beam intensity of BigRIPS and RIPS will be realized by installing the second ion source on the RIBF-LINAC. The beam spill from the first ion source are adjusted to the phase where the RF beam splitter system delivers the beam to SRC (BigRIPS), and those from the second ion source are adjusted to the RIPS phase. Then, beam intensities can be controlled individually each other between BigRIPS and RIPS. The second ion source can be also used to produce higher intensity beams to BigRIPS. The conceptual design is shown in Fig. 7.

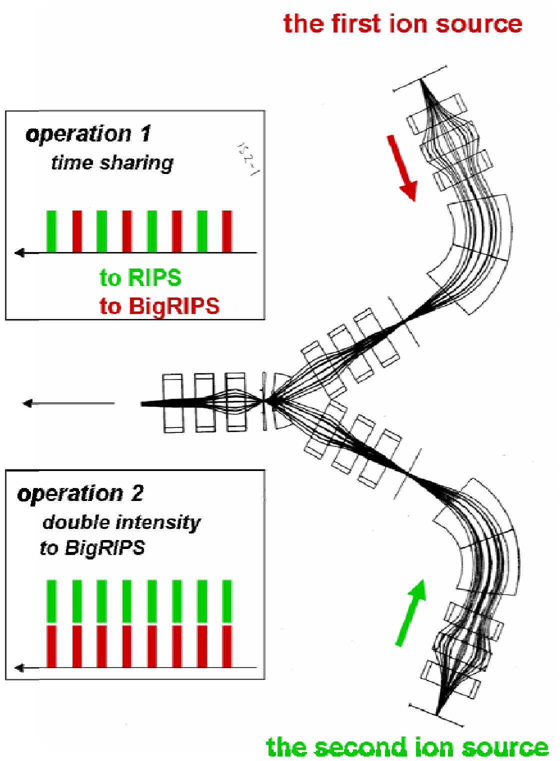

FIG. 6. Conceptual design of a double ion-source system.

VI . COSTS

For the DC beam delivery to RIPS

Basic Devices

● The IRC-RIPS beam transport line (Q-magnets, vacuum system, beam-profile monitor ….)	140 M Yen
● Power supply and water cooling system for fRC*1	100 M Yen
● RIPS beam dump for the high power beam	20 M Yen

Development of the RIABR system is performed with a research budget.

For the time-sharing by the pulsing-magnet mode (step1) *2

no special device needed

For the time-sharing by the RF beam-splitter mode (step2)*2

● RF beam splitter	100 M Yen
● Lambertson magnet	15 M Yen
● Other D- & Q-magnets	25 M Yen
● Ion source for the RIBF-LINAC	100 M Yen
TOTAL	500 M Yen

Notes: *1 At the moment, the water cooling system and power supply of RIPS are shared by fRC, thus which could be used alternatively. In order to use beams in the RIBF-RIPS configuration, another set is needed, when fRC is used in the cyclotron-cascade acceleration

*2 optional for the present

.

VI. MANPOWER

The following manpower is additionally needed.

1. Two persons for the construction and installation of the RF beam splitter, Lambertson magnet, and second ion source, and also for maintenance of RIPS and the beam tuning for RIB production.

2. One person for development of experimental setups such as the RIABR system.

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