# THE INJECTION IN IPCR SEPARATED SECTOR CYCLOTRON

Takeshi Wada, Noritaka Kumagai, Hiromichi Kamitsubo, Shoshichi Motonaga,
Toru Nomura, Noriyoshi Nakanishi, Isao Kohno, Jiro Fujita, Hisao Nakajima,
Kiyoshi Ogiwara, Hideki Takebe, Fusako Yoshida

The Institue of Physical and Chemical Research
Wako-shi, Saitama Japan

## Abstract

The accelerator complex of the proposed IPCR heavy-ion facility consists of a separated-sector cyclotron (SSC), a variable frequency linac, and an AVF cyclotron. The linac and AVF cyclotron are used independently or serve as injectors for the SSC. The distance from linac to SSC is about 40 m. The beam lines of the accelerators are not in the same horizontal plane. The vertical distance between the two beam lines is about 7 m. The beam transfer system consists of a charge stripper, beam bunchers, conventional bending magnets, and quadrupoles. An apparatus which shifts the phase of beam bunch to much higher harmonic acceleration can be used for high intensity mode.

## Introduction

The characteristics of the proposed IPCR(The Institute of Physical and Chemical Research) heavy ion facility are presented in this conference.[1] This facility consists of a separated-sector cyclotron(SSC) of K=620 MeV with four 50° sector magnets, a variable-frequency linac(under construction) and an injector AVF cyclotron (K=90 MeV). The linac will be used as an injector for heavy ions($A \gtrsim 40$) and the AVF cyclotron as an injector of light ions (such as p, α, $^{12}C$,$^{20}Ne$ etc). The maximum energies of the SSC are about 120 MeV/u for light ions and about 15 MeV/u for very heavy ions (such as uranium). Fig.1 shows the layout of the accelerator combination. The horizontal distance between the linac and the SSC is about 40 m and the beam lines of the accelerators are not in the same plane. The vertical distance between them is about 7 m. On the other hand, the distance between the AVF and the SSC is about 25 m and they are in the same plane.

The beam transfer system between these accelerators has to perform the following tasks,

(1) guide efficiently the beam from the injector to the SSC,
(2) match the beam quality in the transverse and longitudinal phase space to the beam acceptance of the SSC.

For this purpose, the beam transfer system consists of a charge stripper, conventional bending magnets, quadrupole magnets, electrostatic inflector, beam buncher and a burst phase shifter.

The subject of this article is the beam transfer system between the linac and SSC.

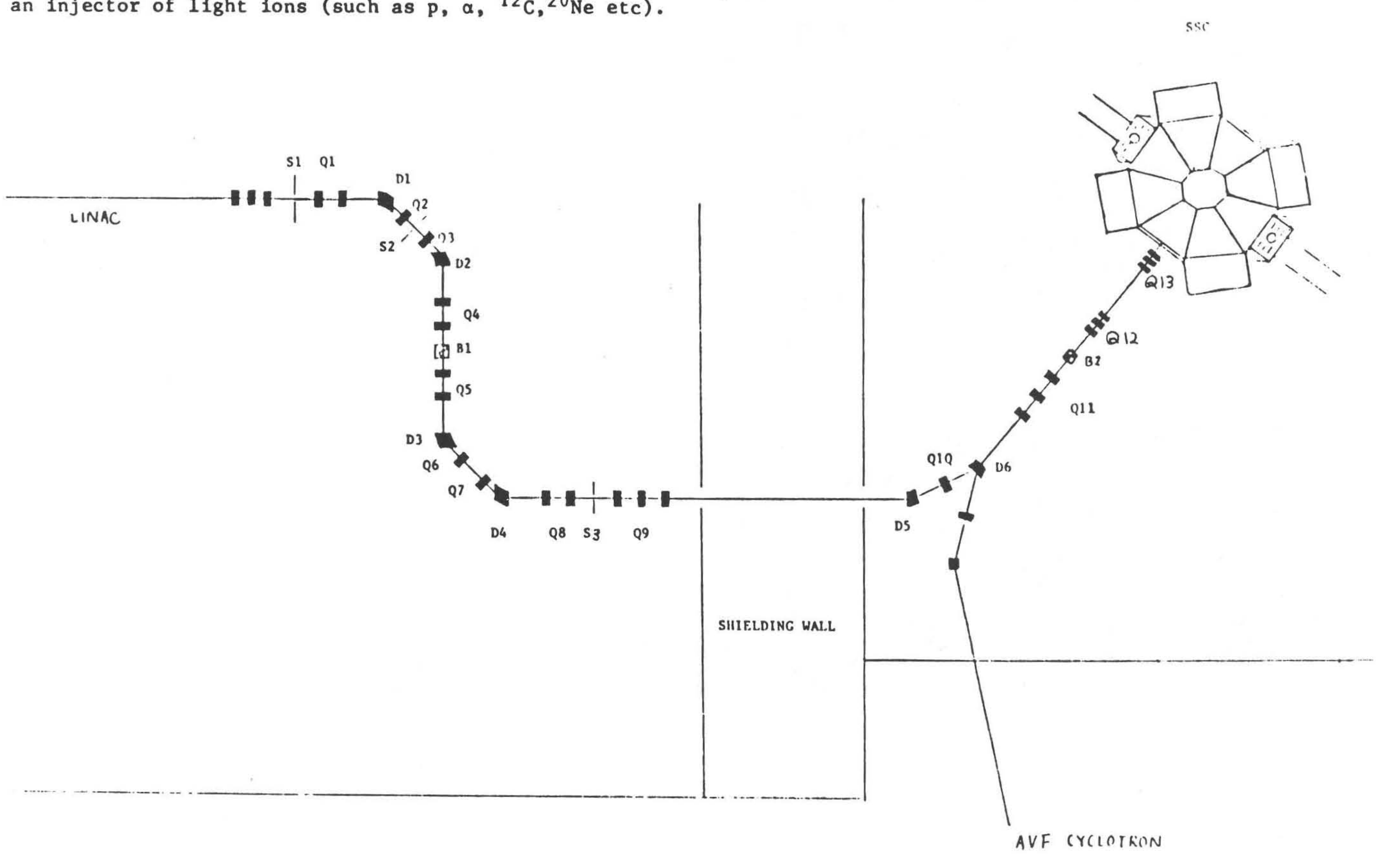


Fig. 1 Layout of the beam transfer line between linac and SSC

## Beam transfer system

For the transformation of the beam in the horizontal and vertical directions, thirteen quadrupole units(Q1 to Q13) and six dipole magnets(D1 to D6) are used. The properties of these magnetic elements are calculated by using the computer code TRANSPORT.[2] The beam envelope in the vertical and horizontal directions is shown in fig. 2. We assume the position of the slit S1 to be a starting point. A stripper can be placed in this position because of a double waist.

The section from S1 to S2 is used for charge and mass selection. For the slit S1 of 4 mm width the resolving power at the slit S2 is approximately 250. Using two achromatic systems between S1 and S3($D_1$-$Q_2$-$Q_3$-$D_2$and $D_3$-$Q_6$-$Q_7$-$D_4$), the beam is transfered vertically to the beam line of the SSC. A burst phase shifter is placed between Q9 and D5. Two quadrupole triplets, Q12 and Q13, shape the beam according to the requirement at the center of the SSC. The beam is injected via a dee-free valley into a 7° steering magnet(IMI) followed by a 79° bending magnet(IM2). The elements IM1 and IM2 bend the beam into the entrance of a 39 cm long electrostatic inflector(IS1), which finally brings the beam into the injection orbit by adding 40 % bending power to the sector field. This corresponds to a maximum field strength of 110 keV/cm for $^{6}C(6+)$ ions and 64 keV/cm for $^{238}U(40+)$ ions.

The layout of the injection system is presented in fig. 3. Outside the vacuum chamber of the SSC the maximum beam envelope is about 8 cm. Therefore, a beam duct of at least 10 cm diameter must be used.

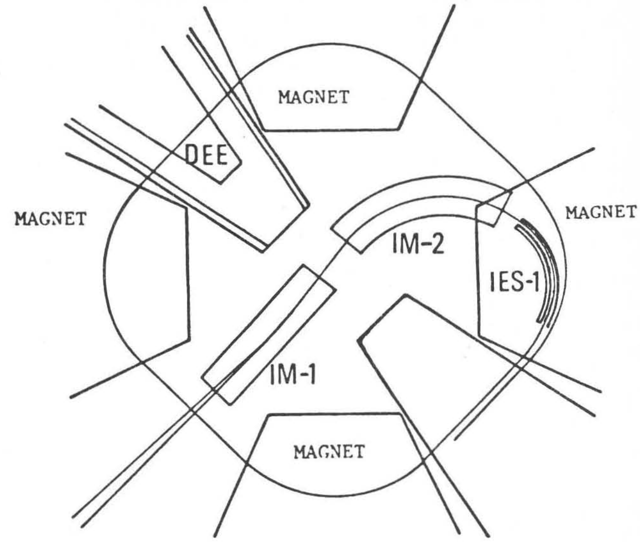


Fig. 3 Layout of injection system at central region of SSC.

## Beam Buncher

Because the distances between two injectors and SSC are long, we must use beam bunchers in order to match beam in the longitudinal phase space. A sinusoidal buncher can be approximated as a thin lens if the phase width of the beam bunch at the buncher is not large compared with the linear part of a sinusoidal wave. So the magnification is given by the ratio of image distance to object distance.

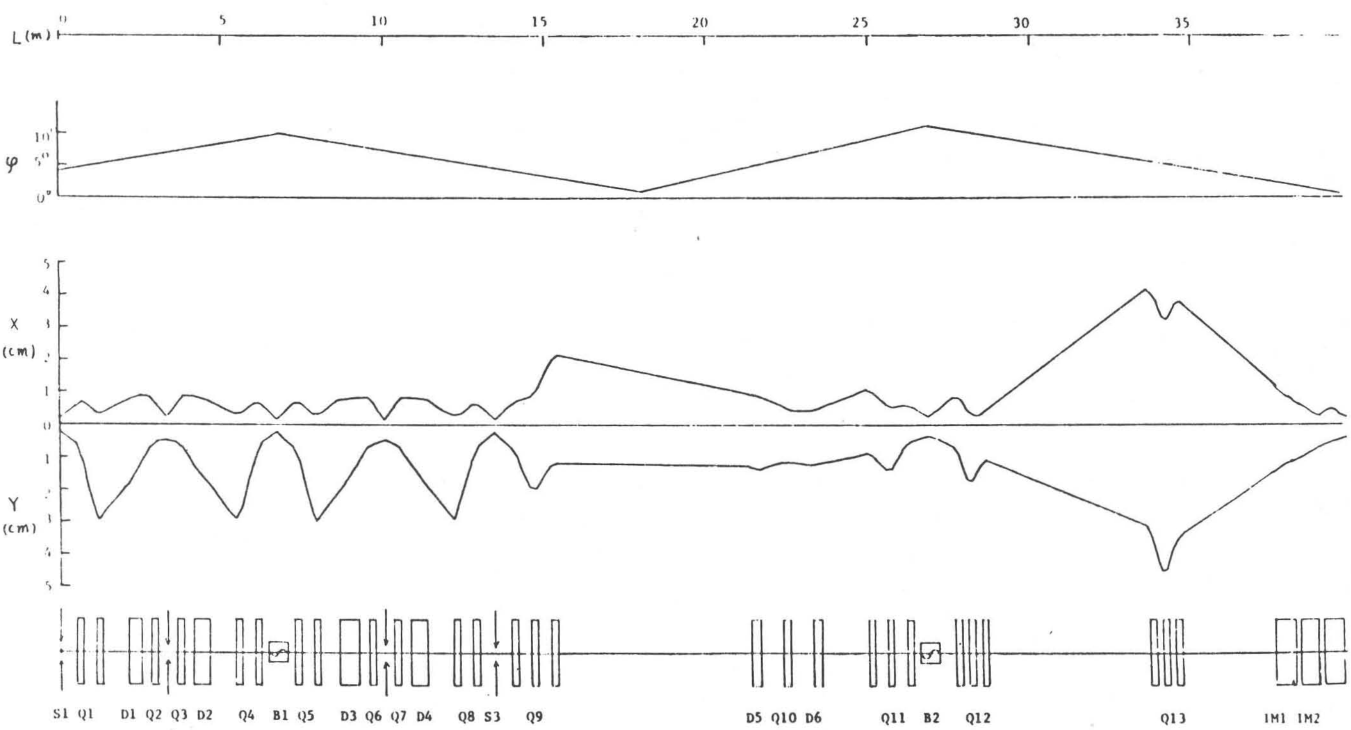


Fig. 2 Beam envelopes for the matching system between the linac and SSC in the longitudianl, vertical and horizontal direction. The beam moves from left to right.

The phase width of the beam bunch from the linac is estimated to be about 6° and the RF acceptance of the SSC is considered to be similar, while the effective phase width of the beam bunch from the AVF is estimated to be about 2-3 times as large as that from the linac because the RF frequency of the AVF is half of SSC.

The buncher B1 is placed at a double waist point of an achromatic system and focuses the pulse length at the middle point of a burst phase shifter (BPS) and an energy compensator(EC). The next buncher(B2) is used to match the final phase to the SSC. The beam pulse from the AVF is focused by the buncher B2. The distance between B2 and SSC must be selected to be shorter than that between B2 and AVF. Fig. 2(c) shows the beam envelope in the longitudinal phase space.

### Burst Phase Shifter

If the lowest frequency of the RF system of the SSC is limited to 20 MHz, the ions with orbit frequency lower than 3 MHz have to be accelerated with harmonic number 12. In this case, every other beam bunch from the linac cannot be accelerated as shown in fig. 4(a) and the intensity becomes 1/2. However, if the relative phase of the bunch 2 to the bunch 1 is shifted by $2\pi/3$ of the RF of the linac ($\pi$ of the RF of SSC), the bunch 2 can also be accelerated.

This can be achieved by a burst phase shifter which accelerates/decelerates alternate bunches as shown in fig. 4(b). The frequency is half of that of the linac.

The variation of the relative phase of the two bunches after a drift length L is

$$\frac{G}{\pi}\cdot\frac{\varphi}{L} = \frac{1}{2}\frac{2qV_p}{E}$$

where G is the distance between the final two acceleration gaps of the linac, q is the charge number, $V_p$ is the RF voltage of the phase shifter and E is the total energy of ion. After the desired shift is obtained, one more acceleration gap is used to reduce the energy difference of the adjacent two bunches and to stop the phase from changing.

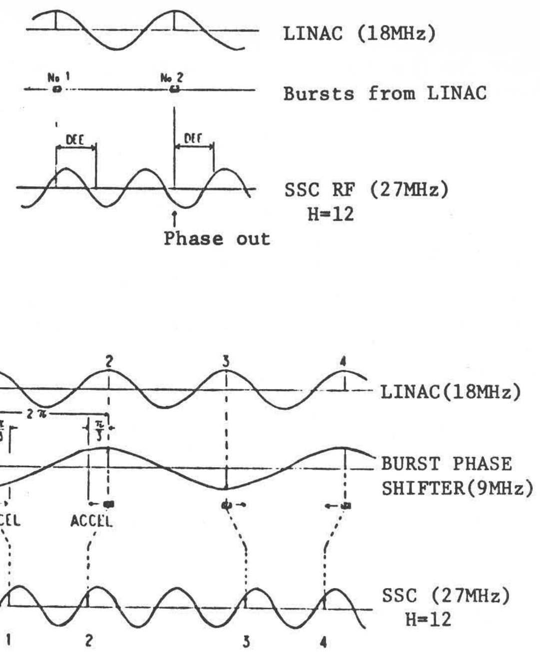


Fig. 4 Operationa scheme of the proposed burst phase shifter.

(1) SSC vault (2) Injector Cyclotron
(3) Experimental room for Injector Cyclotron
(4) Atomic and solid state physics
(5) Nuclear physics (6) Nuclear spectroscopy
(7) Radiation biology and Radiation chemistry
(8) Radiation therapy
(9) Solid state physics and Material science
(10) ISOL
(11) Nuclear chemistry and RI production
(12) Counting room, data processor
(13) Control room (14) Power supply

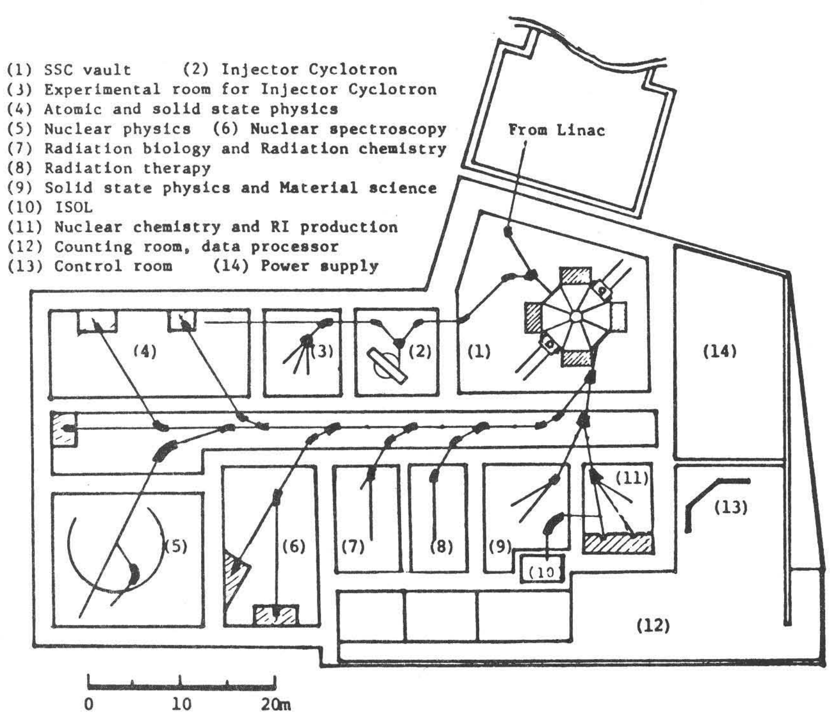


Fig. 5 The proposed layout of beam lines in the experimental area.


0018-9499/79/0400-2002$00.75 © 1979 IEEE

## Beam Transport System

Fig. 5 shows the proposed layout of beam lines in the experimental area. The calculation of beam optics is in progress using the TRANSPORT code.

## Conclusion

We have designed the beam transfer system between the linac and SSC. The characteristic feature of our transfer system is that the beam lines of the injector linac and the SSC are not on the same horizontal line. We have utilized this feature in designing an effective transfer system. A new apparatus (burst phase shifter) is proposed in order to accelerate all beam bunches from the linac in a higher harmonic mode.

## Acknowledgements

The authors wish to express their thanks to Dr.M.Odera and the members of the linac laboratory for many valuable discussions.

## References

[1] H. Kamitsubo et al., these proceedings

[2] K.L. Brown et al. SLAC-Report No. 91

0018-9499/79/0400-2003$00.75 ©1979 IEEE