PLAN OF A 70 MEV H$^-$ CYCLOTRON SYSTEM FOR THE ISOL DRIVER IN THE RARE ISOTOPE SCIENCE PROJECT

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Abstract

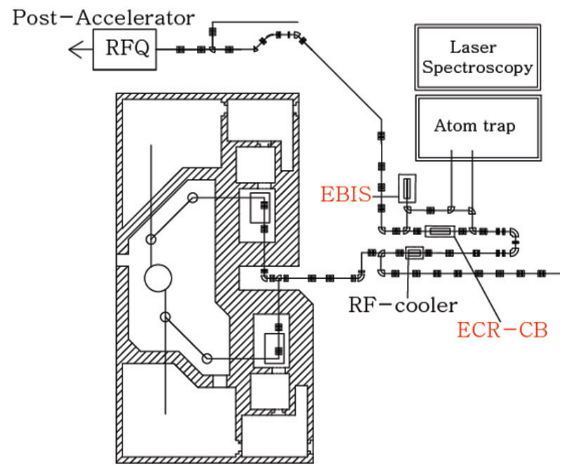
A 70 MeV H$^-$ cyclotron system has been planned for the rare isotope science project (RISP) in Korea mainly to be used as ISOL driver. The proton beam will be also used for the nuclear and neutron science programs and a maximum beam current requested is 1 mA. A commercial cyclotron with two extraction ports is planned for the facility, and the beam distribution lines have been designed considering some aspects of radiation shielding. The injection beam line has been studied to produce a pulsed beam in the range of 0.01-1 MHz for neutron users to utilize a time of flight technique. A chopper and collimator system is thought as a feasible scheme for beam pulsing. The cyclotron is scheduled to produce a first beam in 2017.

INTRODUCTION

An ISOL facility is planned in the rare isotope science project underway in Korea, in which both ISOL and in-flight fragmentation methods will be utilized [1]. The ISOL driver accelerator is 70-MeV H$^-$ cyclotron, whose energy can be varied in the range of 35-70 MeV with a beam current of up to 1 mA. A layout of the ISOL facility is given in Fig. 1, in which two target stations will be installed. A main target material is UC_x to utilize ^{238}U fission reactions. The SPES project of INFN in Italy preciously adopted a similar facility layout including two target stations [2].

An H$^-$ cyclotron commercially available will be procured, which is often used to produce radioisotopes for nuclear medicine [3, 4]. Main cyclotron parameters are listed in Table 1. The extracted beam current of 1 mA by electron stripping at 70 MeV has not been tested before. The lifetime of the foil, which is relatively well known in the range of 0.5 mA, cannot be clearly extrapolated to 1 mA. We have studied the dependence of foil lifetime upon its thickness using a high-power electron beam as described in ref. [5]. The electron beam can be used to simulate thermal stress, which is produced by secondary electrons when H$^-$ hits a carbon foil. However, it does not simulate radiation effects by proton itself. The current result indicates there is an optimal foil thickness, at which the foil temperature is minimum.

The primary use of the cyclotron will be to provide a cw beam for the ISOL target. The initial target design will be for the beam power of 10 kW and then for 35 kW. A pulsed proton beam has been also considered for the users to apply a technique of time of flight in using mono-energy neutron beams. Beam optics for the injection beam line was studied to produce pulsed beams in the range from 0.01 MHz to 1 MHz with a fast chopper system.



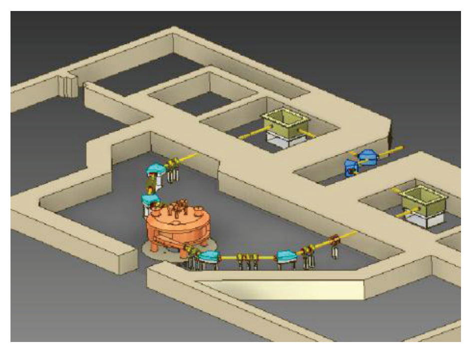


Figure 1: Upper: Layout of the ISOL facility, Lower: view of the cyclotron facility in the RISP.

Table 1: Main Cyclotron Parameters

Item	Value
Beam energy range	35 – 70 MeV
Max. beam current	1 mA
Pulsed beam (option)	0.01 – 1 MHz
Extraction port number	2
Beam size at target	ϕ45 mm
Beam emittance	5 π mm mrad

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DESIGN OF INJECTION BEAM LINE

Design of the injection beam line for a pulsed beam has been studied using optics codes such as TRACE-3D [6] and SIMION [7]. SIMION was used to include a chopper system and space effects more realistically.

A chopper and slit system as shown in Fig. 2 is to be used to produce a pulsed beam. Then the average beam current of a pulsed beam is reduced by the radio of cyclotron rf frequency to pulsing frequency. The maximum chopper voltage is around 3 kV, and pulsed voltage waves with fast rising and fall time is required. The final design will depend on the cyclotron model to be selected.

A few initial beam parameters assumed in optics simulation are given in Table 2. A multi-cusp ion source is to be used. Maximum extraction voltage is up to 40 kV, while 30 kV is used in current simulation. The beam from the ion source is first chopped using by an rf deflector, and deflected beam is removed at the slit downstream. The final focusing element is a solenoid coil, and other types of focusing lens will be also considered for proper matching with cyclotron acceptance.

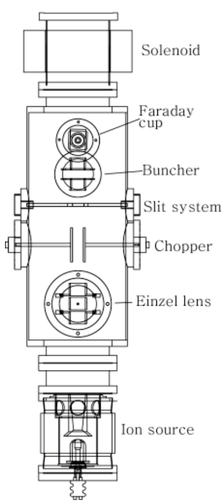

Figure 2: A preliminary layout of the injection beam line for pulsed beam.

A result of beam optics calculation by SIMION is shown in Fig. 3. This result is very preliminary, but the scheme seems to work. The placement of a chopper system after rf buncher will be also considered.

Because the main use of the cyclotron is to irradiate the ISOL target, the injection line for a cw beam will be included in the procured cyclotron. The pulsed-beam injection line is optional, and can only be installed if it does not interfere with cw injection line.

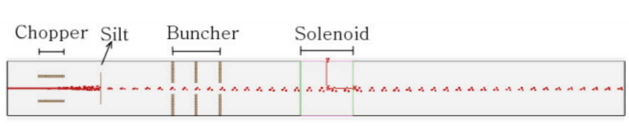

Figure 3: Beam traces in the injection line simulated with SIMION.

Table 2: Beam Parameters for Injection Optics Simulation

Parameter	Value
E (keV)	30
I (mA)	15
Emitance (πmm mrad)	100

BEAM DELIVERY LINE

The proton beam extracted from the cyclotron will be mainly delivered to the two ISOL targets. The required beam uniformity is roughly 10 % in the beam diameter of 45 mm. The target diameter was obtained by design optimization considering isotope production and diffusion rates. Two methods of uniform beam formation using multipole and wobbling magnets were considered. A wobbling method was chosen, and optics simulation was done first using TRANSPORT to arrange the beam line elements, and formation of a uniform beam at the target was simulated using TURTLE [8].

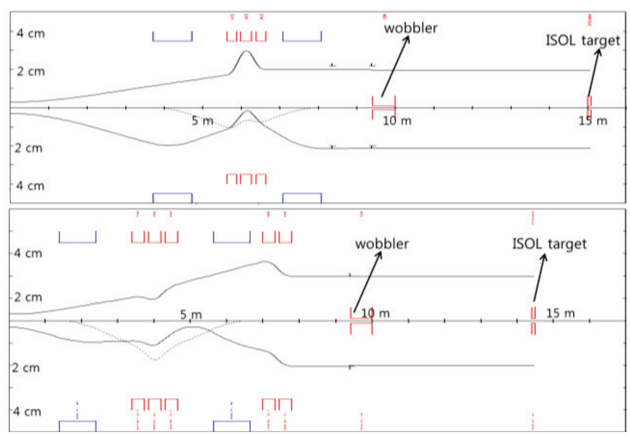

Figure 4: Two different configurations of the beam delivery line.

A uniform distribution of beam intensity on the target is required to minimize the maximum temperature and thermal stress associated. The UC_x is a main target material to produce various isotopes, and other materials will be also used [9, 10].

The beam line is composed of two 45° dipole magnets and a few sets of quadrupole magnets. Figure 4 shows two different configurations of quadrupole magnets to control the beam shape. A quadrupole triplet in the middle of the two dipoles magnets is minimally needed to achieve a point to parallel focusing condition to utilize the wobbling method. The use of a quadrupole doublet after the second dipole magnet helps in beam shaping especially considering uncertainty in the property of extracted beam from the cyclotron by stripping. At the end of the two dipole magnets, achromatic condition is kept.

Figure 5 shows the formation of uniform beam distribution calculated by TURTLE for three different radii of gyration in using the wobbling method. The beam

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uniformity sensitively depends on the gyration radius. The loss of beam outside of the target along with uniformity is written in Table 3. The beam to be lost at the target will be removed by collimation system in front of the target.

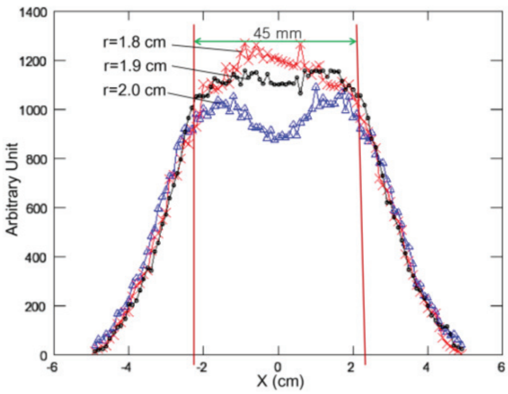

Figure 5: Beam profiles at the entrance of the ISOL target depending on the radius of gyration.

Table 3: Beam Loss Depending on Radius of Gyration

r (cm)	uniformity	beam loss (%)
1.8	±9.2	29
1.9	±4.8	34
2.0	±6.0	36

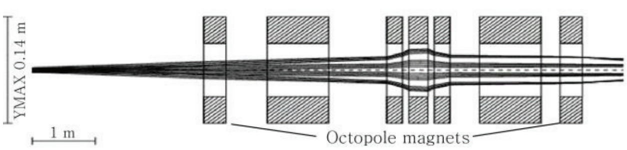

Figure 6: Configuration of a beam line employing two octopole magnets.

Instead of wobbling, multipole magnets can be used to make a uniform beam distribution [11]. This is a static method, but its beam shaping capability is rather limited. Octopole magnets as shown in Fig. 6 are placed to modify the shape of beam intensity distribution prior to wobbling. The placement of the magnet is not yet optimized. The modification of the beam shape was tested using GICOSY [12] as shown in Fig. 7, and a shaper edge can be achieved. As a result, beam loss is reduced to 21 % from 34 % for a uniform beam case given in Table 2. Further optimization in the magnet arrangement is needed.

CONCLUSIONS

A 70-MeV commercial H^- cyclotron is planned to be procured as ISOL driver for the RISP. An injection beam line to produce pulsed beams was studied to accommodate neutron beam users. A chopper and slit system is conceived and tested in beam optics. In addition, the beam delivery line after extraction from the cyclotron to the ISOL target was studied to produce uniform beam utilizing a wobbling method. The effect of multipole magnets on the modification of beam distribution was then included to reduce beam loss near the target. In addition to two ISOL target rooms, two experimental rooms are planned to accommodate various users using pulsed proton and neutron beams as well as cw beam.

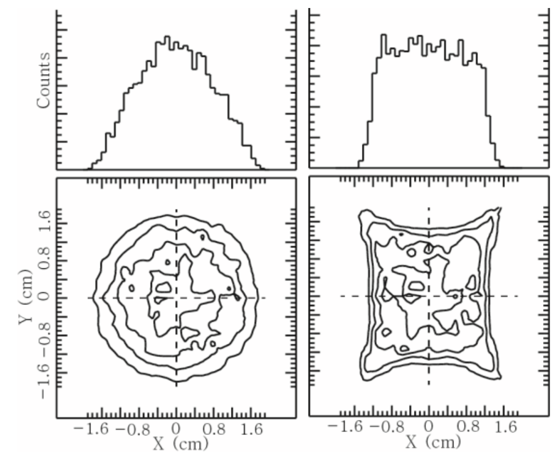

Figure 7: Left: 1D and 2D beam profiles at the target without multipole magnets employed, Right: with two octopole magnets used.

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