DESIGN STUDY OF IN-FLIGHT FRAGMENT SEPARATOR FOR RARE ISOTOPE SCIENCE PROJECT IN KOREA

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Abstract

A heavy-ion accelerator complex has been designed for rare isotope beam production utilizing both in-flight fragmentation and ISOL methods in Korea. The project had been planned with conceptual design efforts, and was officially launched in January this year. The driver accelerator is a superconducting linac with a beam power of 400 kW. The uranium beam for projectile fragmentation is to be accelerated to 200 MeV/u. The in-flight fragment separator can be divided into pre and main separators. The target system and beam dump to handle the full beam power are located in the front part of the pre-separator. Radiation transport and shielding have been studied using PHITS and MCNPX. Beam optics design performed in the previous conceptual study is being further optimized. The separator will be composed of superconducting quadrupole magnets and conventional dipole magnets. Prototyping of the superconducting magnets is planned.

INTRODUCTION

The rare isotope science project (RISP) was initiated in Korea this year to establish a radioisotope beam facility. The facility will use both in-flight fragmentation (IF) and ISOL methods to produce rare isotope beams. A superconducting linear accelerator with the maximum beam power of 400 kW will drive the IF system, and an H^- cyclotron of 70 kW will be used for ISOL. The uranium beam of 200 MeV/u is a main beam for IF.

A schematic configuration of the facility is shown in Fig. 1 [1]. The separator is divided into pre and main stages. The shape of pre-separator is close to S as the two dipole magnets bend the beam in the opposite direction while the shape of main separator is C using four dipole magnets. Beam optics of different configurations of pre-separator has been studied in the aspect of removing unwanted beams. The basic beam optics design of main separator is currently thought to be kept the same as the one previously designed [1], and we are trying to refine the pre-separator design.

The pre-separator includes a target and beam dump system to separate the isotope beam of interest so that the primary and unwanted isotope beams are dumped into water-cooled shielding structure in a localized area, where remote handling devices are employed. The pre-separator should be well isolated from downstream components. The radiation shielding, damage and heat deposit have been calculated using PHITS [2] and MCNPX [3]. The entire separator is located at the same vertical level in the current design.

The separator consists of large-aperture superconducting quadrupole magnets for large angular and momentum acceptance, which operate at 4 K, and conventional dipole magnets with the maximum magnetic rigidity of 8 T·m. In the front end of pre-separator, superconducting magnets utilizing high-Tc superconductor are considered to avoid large cryogenic loads at 4 K. We will prototype both low-temperature and high-Tc superconducting magnets, and will be tested in a cryostat with cryo-coolers installed.

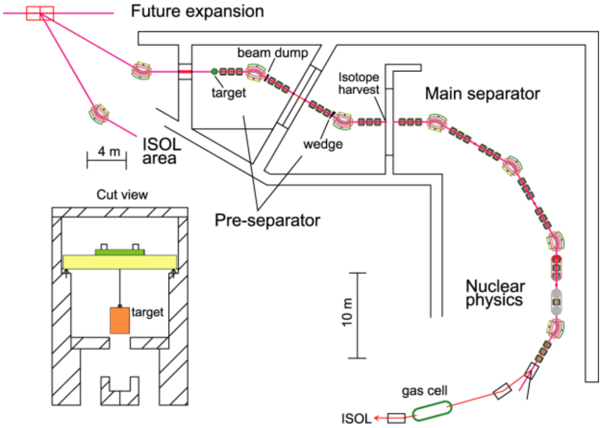

Figure 1: Conceptual layout of the in-flight fragment separator facility.

BEAM OPTICS DESIGN OF PRE-SEPARATOR

An array of magnetic elements of the pre-separator, which employs four dipoles in C-shape, is shown in Fig. 2 together with beam trajectories in the transverse planes. The calculations were performed using COSY Infinity [4]. The locations of beam dump, radiation shielding wall and a wedge are indicated. Momentum dispersion at the beam dump is enlarged compared to the S-shape pre-separator case using two dipole magnets. However, beam is vertically not focused at the wedge, which can cause additional momentum spread.

A result of beam optics calculation using TURTLE [5] is shown in Fig. 3 for the case of four dipole magnets in C-shape. Beam emittance is 4 π•mm·mrad assuming a Gaussian beam distribution, and momentum dispersion of the beam is ±5%. The beam distributions at the locations of beam dump and wedge show the beam spreads by momentum dispersion.

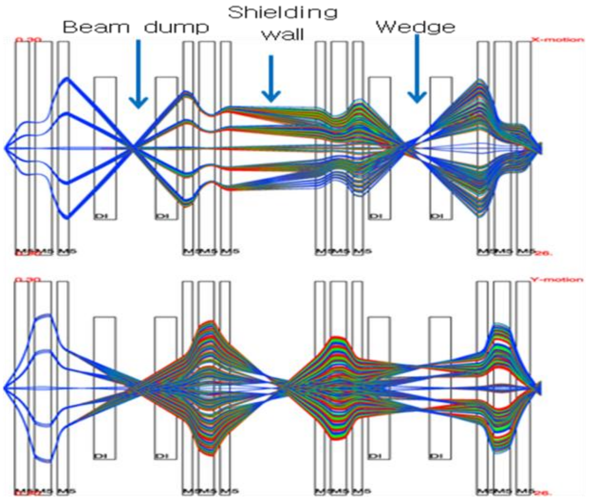

Figure 2: (Upper) Horizontal and (Lower) vertical beam trajectories for the pre-separator in C-shape. The locations of the major components are indicated.

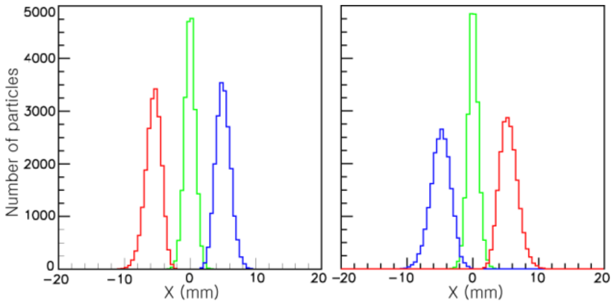

Figure 3: (Left) Beam distribution at the location of beam dump, (Right) at the location of the wedge.

To accomplish an enhanced separation of primary and unwanted beams, we have considered the feasibility of using more magnetic elements as shown in Fig. 4. A better separation of primary beam can be achieved at the cost of larger number of magnetic elements, which is applicable to both C and S shapes.

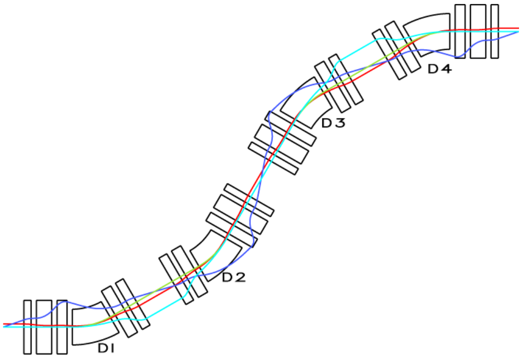

Figure 4: S-shape pre-separator with four dipole magnets and a larger number of quadrupole magnets.

RADIATION SHIELDING AND TRANSPORT CALCULATION

The pre-separator is designed to remove unwanted beams including the primary beam. The shielding for the beam dump area is a critical consideration in the design. The radiation shielding and transport have been calculated using MCNPX and PHITS. Heat deposits in the elements of the front end of pre-separator have been calculated using the geometry as shown in Fig. 5 [6].

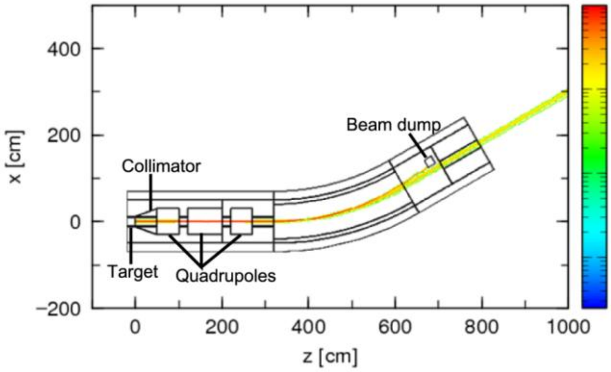

Figure 5: Geometry of the front end of the pre-separator used for calculations on radiation heat deposit.

The maximal heat influx is calculated to be about 0.3 W/cm^3 for a U beam at 400 kW in the front-end quadrupole magnet. This high heat deposit makes the use of low-temperature superconductor difficult. Feasibility of using high-Tc superconducting magnet has been explored for the FRIB project [7].

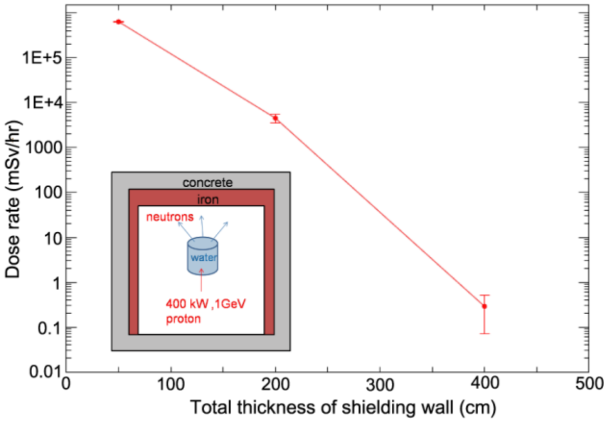

Figure 6: Estimation of shielding wall thickness in the beam direction at the beam dump assuming a proton beam of 1 GeV irradiates a water target. Also shown is the geometry for the MCNPX calculation.

A result of radiation shielding in the beam dump area calculated using MCNPX is shown in Fig. 6. The dose rate in the beam direction becomes below 1 mSv/h when the total shielding wall is roughly thicker than 4 m. The thickness of concrete is assumed to the same as that of iron wall in the beam direction as shown in Fig.6. A proton beam of 1 GeV at 400 kW is used as neutron generation in the forward direction is highest when compared to the bombardment of other kinds of primary beams.

A thin target is used to induce fragmentation of the projectile beam. Thickness of the target has been first optimized using LISE++ [8]. Heat generation by neutron and gamma radiations, and radiation dose deposit were calculated using PHITS. Radioactivity on the target was then calculated using DCHAIN-SP [9].

The heat deposit up to 30 % of the primary beam power on fragmentation target makes a usual single-slice target unsustainable. Use of multi-slice target has been proposed and will be tested.

SC-MAGNET PROTOTYPING

We plan to prototype both the superferric and high-Tc superconductor magnets, which are the major components of the separator. For the superferric quadrupole magnet, multipole coils will be wound on the bore tube. The beam optics tells that efficient correction of multiple field components can be performed by placing them at the locations of quadrupole magnets. The test cryostat will house two or three quadupole magnets to test interference among adjacent quadrupole magnets and with multipole coils. Also, measurement results will be compared with 3D calculations. The heat leak to 4 K in the cryostat is estimated to be roughly 3 W.

RF DEFLECTOR

In-flight fragmentation method has advantage in producing neutron-rich rare isotopes as the wedge at the location of dispersive focusing is effective in separating them. The IF separator also produces proton-rich radio-isotopes, but the long-tails of neighbouring unwanted beams make the separation of isotope beam of interest difficult by magnetic dispersion and energy loss mechanism.

Contamination can be severe for highly proton rich isotope beams. A method to increase the beam purity is to utilize velocity difference in the isotope beams after the IF separator. The beam contaminant can be largely deflected away by the rf reflector located downstream of the separator, which requires well defined longitudinal emittance of the primary beam at the target.

CONCLUSION

The design of a fragment separator is underway for the rare isotope science project in Korea. Feasible design schemes have been studied in beam optics to optimize the configuration of the separator especially for the pre-separator. The other main design considerations include radiation transport, shielding, heat deposit and radioactivity calculations. Different codes have been used to evaluate differing design aspects.

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