PRE-SEPARATOR DESIGN OF THE IN-FLIGHT FRAGMENT SEPARATOR USING HIGH-POWER BEAM*

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Abstract

In-flight fragment separator of the rare isotope science project (RISP) is a main device to produce isotope beams for nuclear science research and applications. The separator is divided into pre and main stages. The pre-separator contains a thin target to produce the isotope beam and beam dump to remove unreacted primary beam. The maximum primary beam power is 400 kW. As a result, radiation level is very high in the target area and some of the magnets will utilize high-Tc superconductor coils operating at 20-50 K to efficiently remove the radiation heat deposited on the coil. A major function of the pre-separator is to remove the primary beam, which is complicated by different charge states produced when the primary beam passes through the target and wedge-shaped energy degrader. Some detailed calculations in beam optics and on the layout of the major separator components have been performed using GICOSY and LISE++ considering contaminant isotope beams due to nuclear reactions.

INTRODUCTION

In-flight fragment separator using the high power primary beam with large acceptance will allow researches for rare isotopes near the boundary of the nuclear chart. The next-generation in-flight separator is characterised by two major features: large acceptances of wanted isotope beam and two-stage scheme [1]. In-flight fragmentation and in-flight fission by using U beam are two major reactions to produce RI beam with an in-flight fragmentation method. It is expected new understanding on the nuclear physics can be obtained with this new device.

Currently, rare isotope science project (RISP) to construct a next-generation radio-active isotope (RI) beam facility is underway in Korea. Both Isotope separation on-line (ISOL) and the in-flight fragment separation methods will be utilized [2]. A super-conducting linear accelerator is the main driver that can accelerate a uranium beam to 200 MeV/u at a maximum beam power of 400 kW. The optical design of the in-flight separator has been performed by using GICOSY [3].

Figure 1 shows a schematic layout of the two-stage separator, in which superconducting magnets with large aperture are used to achieve large acceptance. The first stage serves to produce an RI beam of interest and to remove the unreacted primary and unwanted RI beams. The second stage aims to purify and to identify the isotope beam of interest. Major technical challenges are associated to the design and construction of the pre-separator, where the target and beam dump are located. The area including the target and beam dump is under the influence of high radiation.

In this paper, in-flight fragment separator of RISP is briefly introduced. Then optical properties and performance of the pre-separator are mainly discussed.

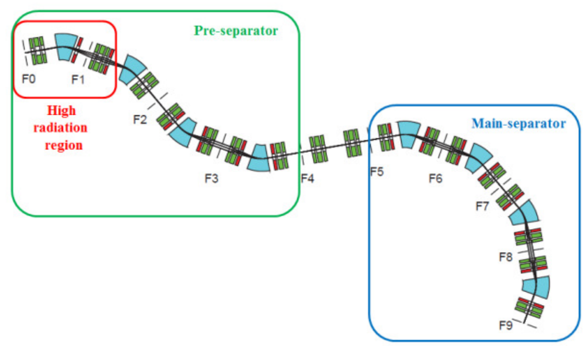

Figure 1: Schematic layout of the fragment separator.

DESIGN OF AN IN-FLIGHT SEPARATOR

The separator consists of pre and main separator, and a matching section in between is placed. The pre-separator from the production target to the F4 focus is composed of a four-bend achromatic spectrometer, consisting of four super-conducting dipole magnets with bending angle of 30 degree and seven superconducting quadrupole triplets.

As mentioned above, radiation level is very high in the target and beam dump area, so that radiation heating in superconducting coils is concerned. To remove the heat efficiently, one dipole and two quadrupole magnet triplets in the front end of the pre-separator will use high-Tc superconducting (HTS) coils. The rest of magnets in the pre-separator will use low-Tc superconducting (LTS) coils.

The main separator from the F5 focus to the F9 focus consists of eight superconducting quadrupole triplets and four dipole magnets. The F1, F3, F6 and F8 are momentum-dispersive focal planes, and the rest are achromatic planes. A wedge-shaped degrader can be used at each momentum dispersive focus to separate isotopes with the same q/A ratio by Z-dependent energy loss.

The goals of momentum acceptance and angular acceptance of the IF separator are ±5 % and ±50 mrad, respectively.

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OPTICS OF THE PRE-SEPARATOR

The pre-separator contains four dipoles and seven quadrupole triplets, and its maximum magnetic rigidity is chosen to be 10 Tm considering the accelerator energy upgrade to 400 MeV/u for uranium beam in the future. The first-order optics of pre-separator is shown in Fig. 2. The production of RI beam using high power primary beam demands substantial radiation shielding compared to the facilities utilizing the maximum beam power of a few tens of kW. Radiation damage and shielding structure are main consideration in the design of pre-separator.

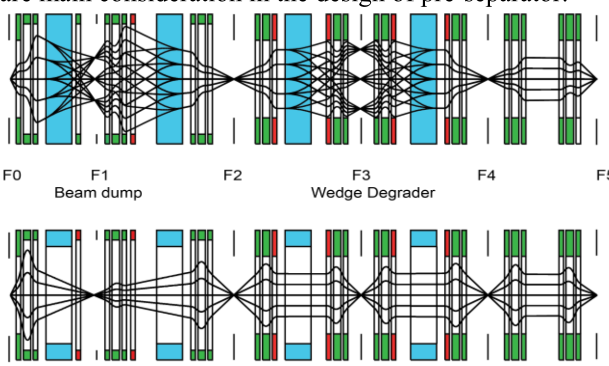

Figure 2: The first-order optics of pre-separator under consideration: The upper envelopes are in the horizontal plane, while the lower ones in the vertical plane.

To reduce radiation damage on magnetic components behind production target, the optics of pre-separator has a dispersive focus directly after the first dipole, where the dump is located. A merit of this solution is to limit an area of high level activation thereby minimizing the number of radiation resistant magnets.

For the space of the shielding walls, we leave long drift spaces of 2.6 m after second quadrupole triplets and 5.2 m between third and fourth triplets. A drift space of 1.95 m after the first dipole is to be occupied by the beam dump. Some parameters of the pre-separator are listed in table 1.

Table 1: Some Parameters of the Pre-Separator

Configuration	Four bends
Maximum magnetic rigidity	10 T/m
Momentum acceptance	±4.3%
Angular acceptance	±40 mrad (h)
	±50 mrad (v)
Momentum dispersion	+2.3 cm/% at F1
	-3.05 cm/% at F3

The large acceptance is needed to collect RI beam produced via ^{238}U fission. The angular and momentum spreads of RI beam produced by in-flight fission of uranium beam at 200 MeV/u can be over 100 mrad and 10%, respectively, when symmetric fission is assumed. The superconducting quadrupole triplets need to have large apertures and the dipole a large gap. The total length of pre-separator is currently about 57 m.

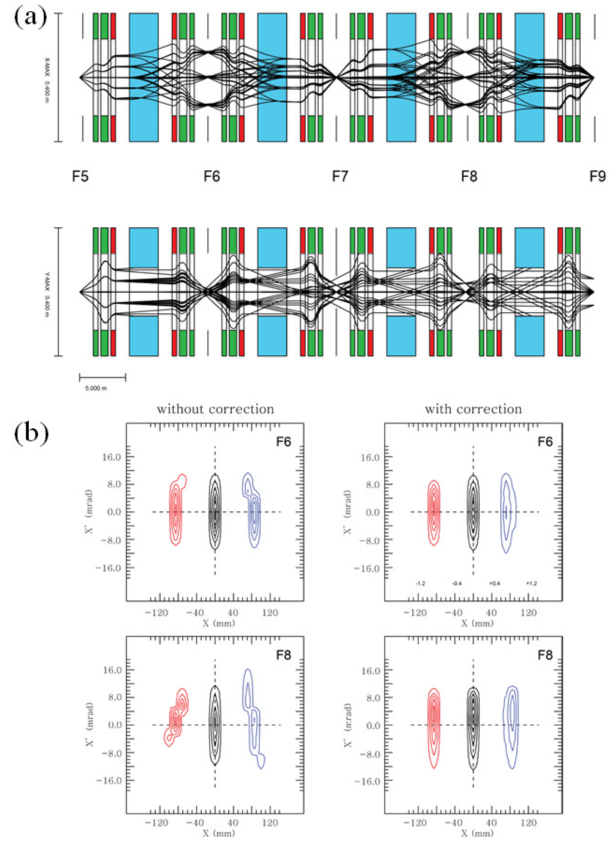

Figure 3: Correction of phase space distortion in the second order optics of pre-separator at F1 and F3.

Figure 3 is the result of 2nd order correction with hexapole magnet (red color). The beam phase spaces at F1 and F3 are compared before and after 2nd correction in Fig. 3 (b), which shows significant improvement.

PRE-SEPARATOR PERFORMANCE

Parameters of the pre-separator and the purity of ^{132}Sn at the exit of pre-separator were evaluated by simulations with the LISE++ code [4]. ^{132}Sn ion, which is double magic nucleus, is a main isotope beam of interest used for the separator design. A 200 MeV/u $^{238}U^{79+}$ primary beam was used with a graphite target of 303 mg/cm^2 thick to produce ^{132}Sn in the simulation. The momentum acceptance of ±3% was assumed using a wedge shaped degrader in F3 focus. The material of degrader is aluminium with central (on-rigidity) thickness of 1.57 mm corresponding to approximately 30% of ^{132}Sn beam range.

As can be seen in Fig. 4, the transmission of ^{132}Sn in 1st order simulation was calculated to be about 25.3%, when the selection slits in the pre-separator were completely open. Large losses of ^{132}Sn occur at the F1 focus, where the beam dump is located. Fission fragments are produced from the target with large spreads in both angle and

ISBN 978-3-95450-138-0

momentum. Magnetic rigidities that are larger by 3% than the selected value are removed at the beam dumps, as shown in Fig. 5.

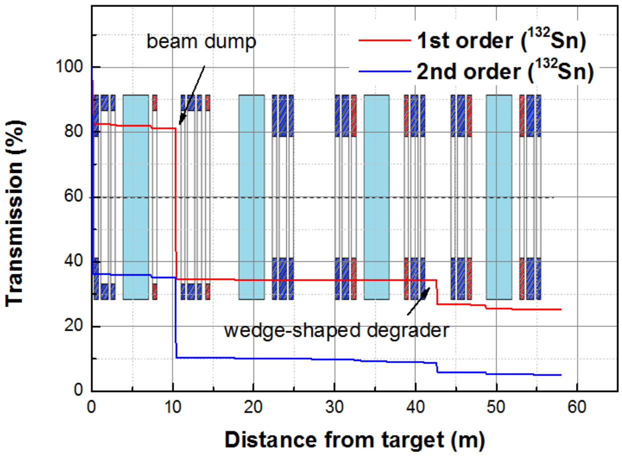

Figure 4: Comparison of transmission efficiency of ^{132}Sn produced via in-flight fission simulated in 1st and 2nd order optics on the pre-separator.

A less significant loss occurs due to multi charge states of ^{132}Sn ions generated by the electronic interactions in the wedge. The loss in transmission for ^{132}Sn derived from 2nd order aberrations is due to the increase in the size of the beam envelope compared to the first order beam envelope. The transmission of ^{132}Sn in 2nd order simulation is about 5.1%. Further optimization on high order aberration correction scheme is necessary to improve the 2nd order or higher order transmission efficiency.

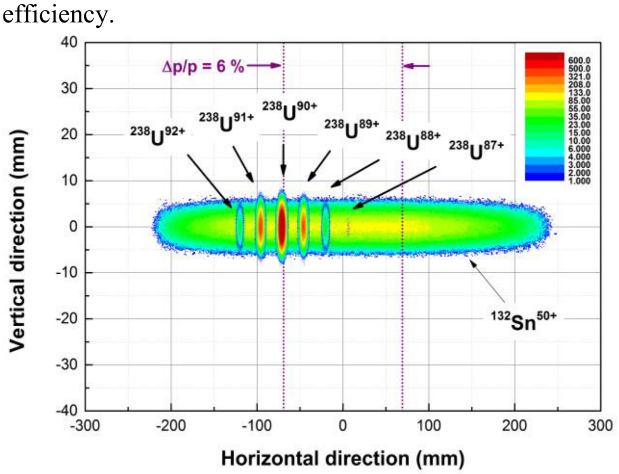

Figure 5: The primary beam and ^{132}Sn beam profiles at the F1 focus, where the beam dump are located.

Figure 6 is a part of the chart of nuclides indicating the yield rate of ^{132}Sn and un-wanted fragments at the end of the pre-separator. The production rate of ^{132}Sn is about 1.34×10^{7} pps with the purity of about 0.03%. The most intense contaminants are nuclei which are located closer to the valley of stability. The purity of ^{132}Sn can be improved by isotopic selection of the main separator.

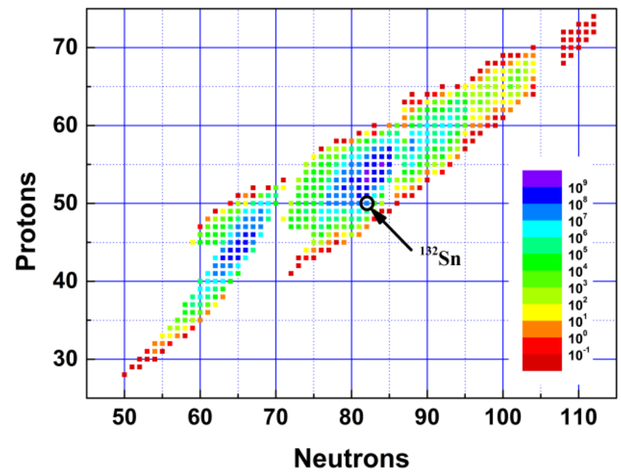

Figure 6: The rate of ^{132}Sn and un-wanted fragments transmitted to the end of pre-separator.

CONCLUSIONS

The design of in-flight separator using high-power primary beam has been carried out for the RISP in Korea. Main considerations on optical design of pre-separator are associated with shielding high-level radiation and removing the primary beam almost completely. The optimization process has been underway to deal with main considerations, and to improve the purity and the transmission of fragments. To evaluate the performance of current pre-separator, transmission efficiency and rate of ^{132}Sn were calculated by using LISE++ to be achieved 25.3 %, 1.34×10^{7} pps, respectively.

ACKNOWLEDGMENT

This research was supported by the Rare Isotope Science Project of the Ministry of Science, ICT and Future Planning (MSIP) and by the National Research Foundation (NRF) of Korea.

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