BEAM DUMP DESIGN FOR THE IN-FLIGHT FRAGMENT SEPARATOR USING HIGH-POWER BEAM*

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Abstract

The beam dump is a critical component for the in-flight fragment separator using high-power primary beams at the rare isotope science project (RISP) in Korea. The maximum beam power is planned to be 400 kW, and a third of the primary beam power deposits at the isotope production target and the rest are dissipated at the beam dump. The beam dump is designed to be a rotating water drum, which is movable in the perpendicular direction to the beam to select the isotope beam of interest. The main primary ion beam is U, and its range at the energy of 200 MeV/u is only a couple of mm after passing through the shell structure of the drum. This short range requires its internal structure to confine water flow on the wall and to keep high-pressure. Some detailed thermo-mechanical and thermo-fluid analysis has been done using ANSYS and other codes.

INTRODUCTION

Rare isotope science project (RISP), which is to produce rare isotope beams by using both the in-flight fragment (IF) separation and isotope separation on-line (ISOL) methods is undergoing in Korea [1]. The main accelerator, which can provide a wide range of heavy ion beams, accelerating ^{238}U beam to 200MeV/u and proton to 600 MeV, is a superconducting linear accelerator for the IF separator. The IF separator uses a thin target to produce rare isotope beams and a beam dump is located after the first dipole magnet so as to remove unwanted primary beam.

The design of beam dump for in-flight separator using high power primary beam has been performed considering high power density deposited in beam dump. Approximately 30% of the primary beam power, which is used to produce RI beam, will be dissipated in a production target with typical thickness of d/R = 0.3, whereas the rest of primary beam that does not react with production target, will pass through magnetic system and be absorbed in beam dump. The maximum beam power deposited in the beam dump is up to about 300 kW for 200 MeV/u ^{238}U beams and the beam size on beam dump is expected to be around 10 mm in diameter.

Removal of high power primary beam in an IF separator is complicated due to different charge states in primary beam, short range in material and high power density at beam dump. Furthermore, if assuming the primary beam directly impacted on beam dump in the case of target malfunction, the beam dump should be capable of absorbing up to 400 kW during a short time. The cooling system, which can handle high power, is required to avoid structural breakdown and thermal runaway.

If wanted fragment beam is close to the primary beam in rigidity, the task of separation becomes more difficult. Trajectories of off-rigidity fragments and non-reacted beam can overlap with that of the isotope beam of interest at the beam dump. Beam dump system is required to intercept unwanted fragments and non-reacted primary beam minimizing the loss of wanted beam. For the purpose of intercepting the primary beam and off-rigidity fragments with different trajectories, it is necessary that the beam dump has two units and is movable.

A conceptual design of beam dump, and thermal analysis using ANSYS [2] and PHITS [3] are described.

DESIGN OF BEAM DUMP

Figure 1 shows a schematic layout of the separator, which has been designed to consists of two-stages. The purpose of the first stage, pre-separator is to produce RI beams and then to separate the primary and unwanted RI beams, while the second stage, main separator serves to identify the RI beam of interest. The momentum and angular acceptance of the separator have been designed to be ±5 % and ±50 mrad, respectively.

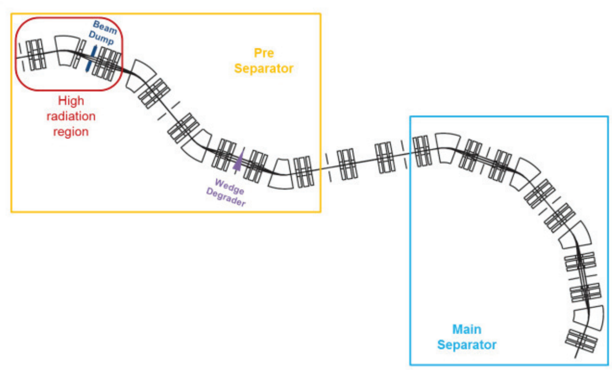

Figure 1: Schematic layout of the fragment separator.

As shown in Fig. 1, a dispersive focal plane is located after the first dipole magnet, and the beam dump is placed near the focal plane. The isotope beam of interest is separately by magnetic rigidity, but unwanted beam with the same Bρ is overlapped.

To remove the heat efficiently, we considered the beam dump consisting of two rotating water-filled cylinder as was adopted for FRIB [4]. A conceptual drawing of the beam dump system is shown in Fig. 2. The beam dump system will be located in a common vacuum space together with the dipole magnet and the production target. The beam dump rotates to prevent localized heating, and cooling water directly absorbs the beam power acting as a liquid beam dump. Titanium is chosen for the material of

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the beam dump. The thickness of titanium shell is set to be 1 mm and the outside diameter is 60 cm. The depth of water chamber is 10 cm. The water flows into beam dump through the tube in the side plate, and flows along the helical blades, remove the heat deposited close to the drum surface and water itself.

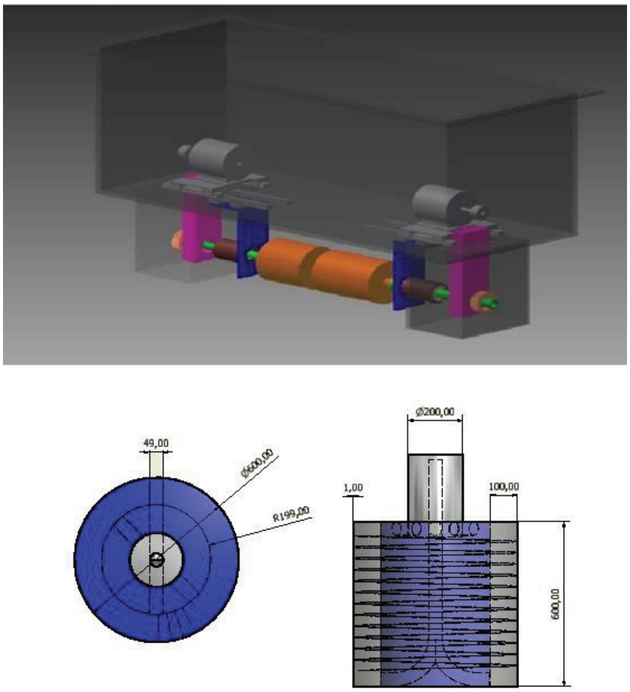

Figure 2: Schematic layout of the beam dump.

ENERGY LOSS AT THE BEAM DUMP

The non-reacted primary beam impacting the beam dump has a diameter of about 10 mm and a power of about 300 kW, which depend on chosen nuclear reaction and the thickness of the production target. Simulation using the codes LISE++ [5] and TRIM [6] was performed to study the energy loss at the beam dump assuming the target thickness corresponding to approximately 30% of the primary beam range.

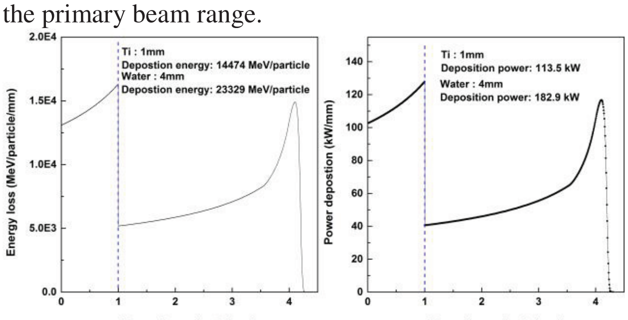

Figure 3: The energy loss (a) and the power deposition (b) of non-reacted ^{238}U beam at beam dump.

In the case of ^{238}U beam with 200 MeV/u, 400 kW, the energy and power of the non-reacted primary beam passing through the target are about 160 MeV/u, 300 kW. The energy loss and power deposition of ^{238}U beam at the beam dump are shown in Fig.3. When the ^{238}U beam hits the beam dump, about 40% of the ^{238}U beam power is lost in the 1-mm thick shell of beam dump and the rest is deposited in water. The energy loss and the range of charged particles depend on the incident particle and, its energy and on the material. The energy loss of different primary beams in the Table 1 assuming a full power beam hits the bam dump, which is an accident scenario.

Table 1: The energy loss and the power deposition assuming a 400 kW beam hitting the beam dump

Primary beam	Energy (MeV/u)	Intensity (pps)	Energy loss (MeV)		Power deposition (kW)	
			Ti	Water	Ti	Water
$^{238}U^{79+}$	200	5.17E+13	12453	35871	103.1	297
$^{124}Xe^{54+}$	235	8.58E+13	4053	25065	55.6	344.1
$^{112}Sn^{50+}$	242	9.22E+13	3412	23670	50.3	349.3
$^{40}Ar^{18+}$	268	2.33E+14	403	10307	15	384.6
$^{18}O^{8+}$	266	5.22E+14	79	4709	6.6	393.4

THE HEATING AND FLUX DISTRIBUTION IN THE BEAM DUMP

The radiation heating was estimated by using PHITS which simulate radiation transport. The beam dump was assumed to be a simple cylinder with 30 cm diameter and 60 cm high. The flux of unwanted fragments produced via in-flight fission of ^{238}U beam at 200 MeV/u, 400 kW, and the flux secondary particles which were produced by the reaction of ^{238}U beam and components of a beam dump is shown in Fig. 4. The flux is expressed in units of 1/cm^2/second, and the major flux of secondary particles is forward directed. The scattered in wide distribution in the outside of the beam dump, radiation is dominated by neutrons. Figure 4 (b) is the distribution of energy deposition due to absorb the primary beam and secondary particles in the beam dump.

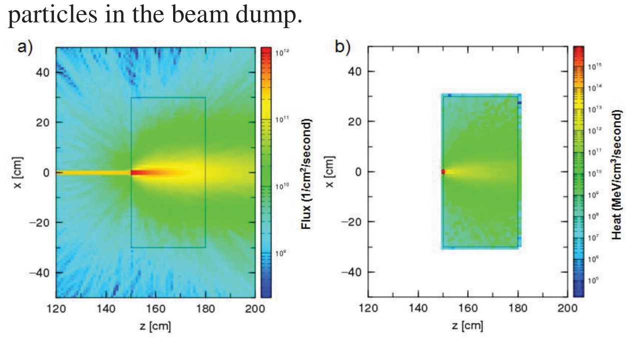

Figure 4: The distribution of the radiation flux (a) and the heat (b) on the beam dump.

Figure 5 shows, the flow velocity in the beam dump, which was calculated by using ANSYS in the same geometry as used PHITS calculation. We assumed that the deposited power is about 110 kW on titanium and about 290 kW on the water. The inlet temperature of cooling water was assumed 295 K. To cool beam dump considering margin of safety, the velocity of cooling

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water needs to be much higher than 5 m/s considering the melting point of Ti is about 1940 K. The energy deposition is highly concentrated on the titanium and the adjacent of the water.

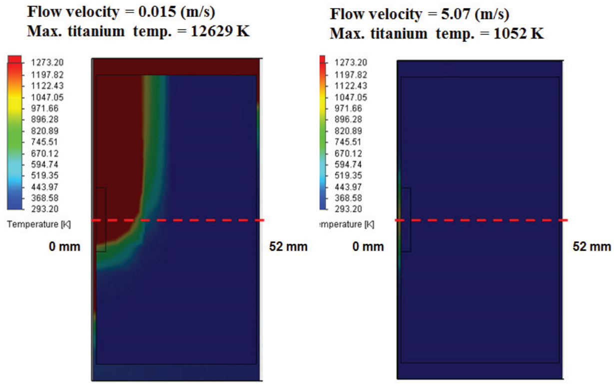

Figure 5: The temperature distribution in the beam dump due to absorption of 400 kW primary beams

The water is activated by nuclear reaction with the primary beam in the beam dump. The activity in water as function of cooling time is presented in Fig. 6. The activity calculation by using the PHIS was performed assuming 5600 h of irradiation with ^{238}U beam (200 MeV/u, 400 kW), which is an expected operation time of separator. With waiting time increasing, the activity of the tritium is dominant because the life time of tritium becomes relatively longer than others. Therefore, for the purpose of decreasing the activation level of the water used to cool the beam dump, there are essentially needed a filtering system to remove long-lived isotopes from water

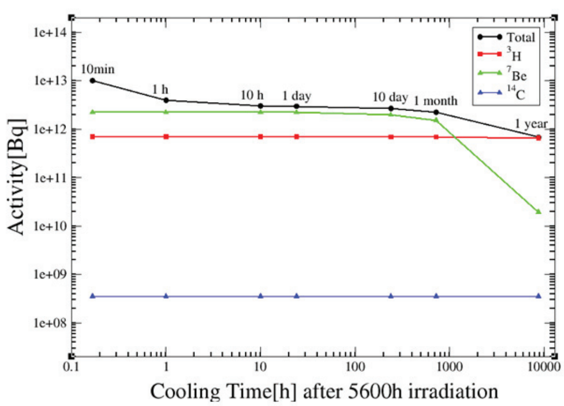

Figure 6: Activity of the beam dump as function of waiting time.

CONCLUSIONS

The designs of beam dump and water cooling loop in the IF separator for the RISP have been studied. As a first step, we calculate the power density deposited in beam dump, heat deposit distribution and cooling water flow. Considering the energy loss of a few different primary beams, it was decided that the path length inside the beam dump needs at least 150 mm to stop the primary beam. Based on this result, some mechanical design and thermo-fluid analysis on the beam dump system was performed. Since the activation of cooling water is significant, we will plans to filter some isotopes from activated water, which is included in the design of the water loop system.

ACKNOWLEDGMENT

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