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RADIATION DESIGN OF NEW 30 kW BEAM DUMP OF J-PARC MAIN RING

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Abstract

The J-PARC Main Ring (MR) has a beam dump for the beam study and beam abort. Its present capacity is 7.5 kW in one hour average which is limited by temperature rise of iron shield, and radiation condition for the environments. The number of protons in one MR cycle is 2.6×10^{14} in recent days, which corresponds to the beam power of 500 kW. As the top energy of J-PARC MR is 30 GeV, the number of available beam shots is restricted to less than twenty in one hour with such an intense beam. It imposes a big limitation on high power beam tuning and study. The number of protons is expected to become 3.3×10^{14} for MW operation. Hence, an upgrade of the beam dump from 7.5 kW to 30 kW is planned. The backscattered neutron flux should be examined in the accelerator tunnel. The new dump design on radiation matters is described in this paper.

INTRODUCTION

The J-PARC Main Ring (MR) is a slow cycling proton synchrotron with a period of 2.48 seconds or 5.20 seconds in the J-PARC complex. It has three straight sections for beam injection, slow extraction for the hadron experiment, and fast extraction for the neutrino experiment as shown in Fig. 1. There is an abort beam dump for the beam tuning and study in the fast extraction straight on the other side of the neutrino beam line. The capacity of the present beam dump is 7.5 kW [1]. Due to the increment of beam power, the dump capacity restricts the available number of shots per one hour. This limitation is thought to be a problem for high power beam tuning and study beyond the designed beam power of 750 kW. The capacity of the beam dump should be upgraded to the three times larger or higher. The 30 kW beam dump upgrade is planned.

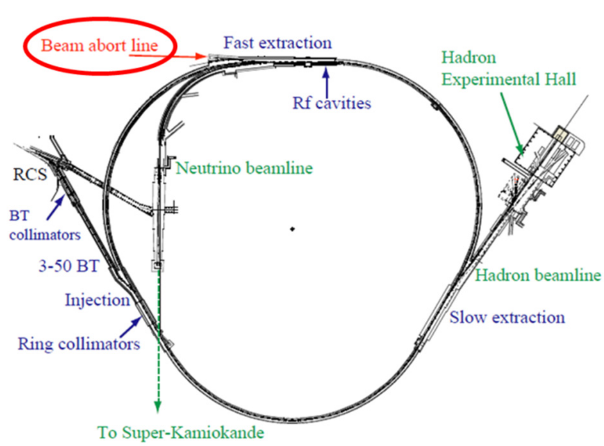

Figure 1: Layout of the J-PARC Main Ring.

BEAM DUMP

The structure of the current beam dump is simple because the number of protons to be dumped was estimated to be less than one percent of the full beam power in the first design. However, the expected beam power of MR has updated from 750 kW to 1.3 MW. The top energy has changed from 50 GeV to 30 GeV. As the result, the required number of protons in circulating beam increased. The maximum number of protons is determined to be 3.3×10^{14} as eight bunches in one MR cycle.

Present Beam Dump

The present beam dump is embedded in a two meters thick concrete wall and 20 meters far away from the MR beam line as shown in Fig. 2. The beam dump consists of a five meters long vacuum pipe made of SUS316L, iron shield blocks, and concrete structures. The inner diameter of vacuum pipe is 73.8 cm and whose thickness is 12 mm which ends with a stainless steel plate of 3.0 cm thick. The iron shield is a rectangular parallelepiped with a 3.3 m squared surface and a 6 m length. There is a square hole of 18 cm squared and 2.5 m depth at the center of it for the vacuum pipe.

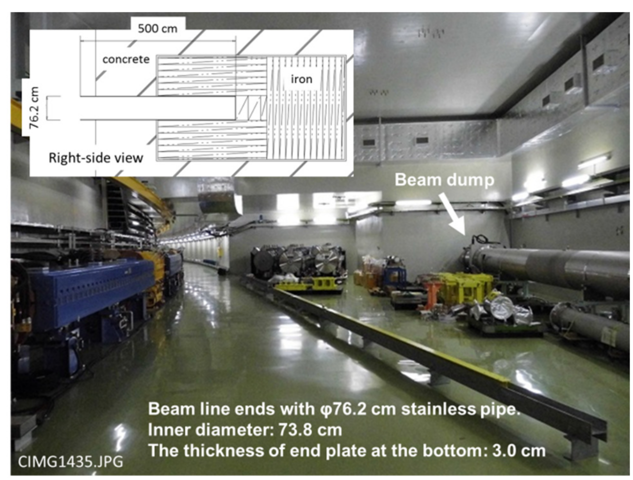

Figure 2: Present beam dump and its structure.

Base Design

For an upgrade of the beam dump capacity, a kind of beam absorber with some cooling system has to be installed. It is difficult to reconstruct the present beam dump, for example, drilling a hole in the concrete wall. The end of the vacuum pipe in the beam abort line is called as “abort-end.” There is just a vacuum space, currently. To accept the 30 kW beam power, the dump core method with cooling fins is planned to be adopted refer-

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ring the CERN PS-Booster [2]. Although the air cooling is assumed here, there is also the possibility of adopting water cooling depending on the result of the cooling design.

The expected beam sizes at the abort-end are examined with the present and planned beam tunes for the neutrino experiment as shown in Table 1. The maximum widths are estimated to be 27 cm in horizontal plane and 20 cm in vertical plane, respectively. In addition, the orbit fluctuation of dumped beam is examined from the orbit records in 2017. The beam abort line has two beam position monitors. The beam orbits are extrapolated to the abort-end as shown in Fig. 3. The orbit fluctuation is about ±4 cm in horizontal plane, and ±2 cm for vertical plane. The required diameter of dump core becomes close to 40 cm adding the estimated beam width and observed orbit fluctuation. The diameter of dump core has been determined to be 50 cm adding a margin of 5 cm for the radial direction.

Table 1: Expected Full Beam Width at the Abort-End

Tune (nx, ny)	**Horizontal width [cm]**	**Vertical width [cm]**
(21.35, 21.44)	22.71	19.22
(22.35, 22.45)	26.95	18.78

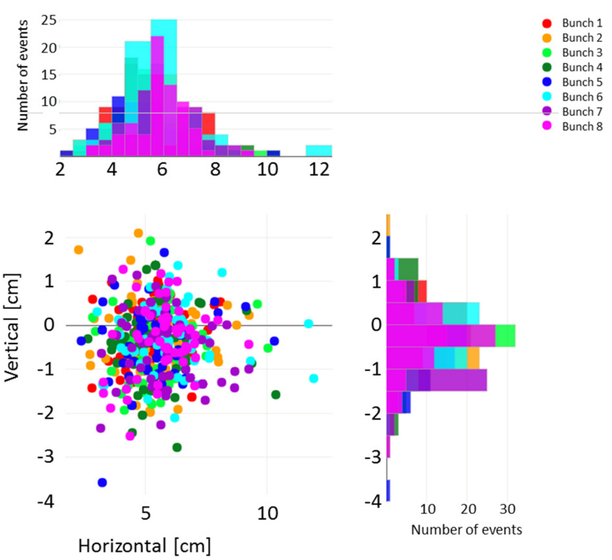

Figure 3: Orbit fluctuation at the abort end.

The schematic design of the upgraded beam dump is shown in Fig. 4. A dump core and an inner vacuum pipe are introduced. The inside of existing dump pipe becomes atmosphere. The area in the inner pipe is kept in vacuum. The inner pipe separates the vacuum and the atmosphere. The dump core is put in atmosphere. The beam power is mainly absorbed in the dump core made of copper alloy, and the beam energy is removed by a cooling system. It is not necessary for all energy to be absorbed by the core, because the downstream iron shield can accept about 7 kW. As the one meter long core length in Fig. 4 is temporary, and it may be shorter in fact. The radiation dose rate should be less than the 0.25 μSv/h on the ground. Fortunately, because the current radiation shield design has an enough margin, the additional shielding is not necessary.

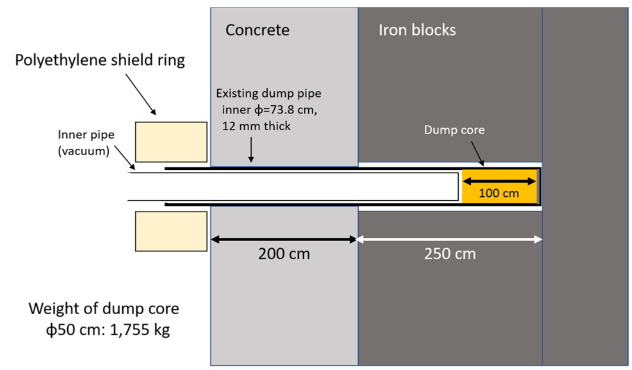

Figure 4: A schematic design of the 30 kW beam dump.

Beam Induced Heat Estimation

The radiative reactions are simulated by PHITS code [3] developed in Japan Atomic Energy Agency (JAEA). Firstly, the heat deposition in the end-plate of inner pipe is estimated. The dumped beam is assumed as a round beam whose diameter is 16 cm for the safe-side estimation. The energy is 30 GeV, and the intensity is 3.3×10^{14} protons. The end-plate of inner pipe becomes a beam window. Since the thickness of the window is 30 mm, the deposited heat in it is the first matter. In order to mitigate the heat shock on the end plate, the graphite moderator is introduced as shown in Fig. 5. The graphite thickness was varied from 10 to 50 cm. In order to confirm the effect of blurring the beam spot, the cases of 10 or 20 cm long graphite placed 50 cm upstream from the end-plate were also considered.

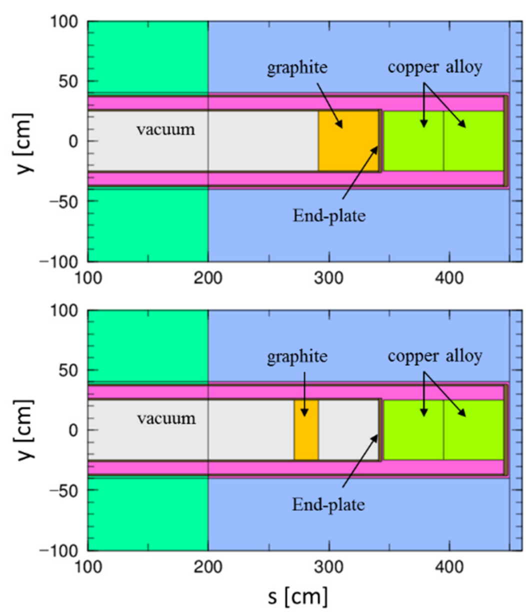

Figure 5: Set-up of graphite moderator.

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The deposited heat distributions by using [T-Heat] tally are shown in Fig. 6. There are several areas that generate heat locally. The deposited heat values of 5.9×10^5 Gy in stainless steel and 3.8×10^5 Gy in copper correspond to the temperature rise of Δt = 1000 degrees. According to the thickness of graphite, peak temperature decreases, though the effect is limited. Placing the graphite away from the endplate was counterproductive as shown in below two cases. The graphite moderator lowers the maximum temperature of the end-plate, but the amount of heat deposited to it increases in total. On the other hand, the amount of that deposited to the downstream core decreases as shown in Fig. 7. It depends only on the graphite thickness, regardless of its position. Since the position where the beam collides largely affects an amount of the neutrons backscattered to the accelerator tunnel, it is better to move the loss point as downstream as possible. By adding graphite moderator, the core made of copper alloy can be shortened. For example, when the core length is optimized with a 30 cm graphite design, about 50 cm long core length can be enough.

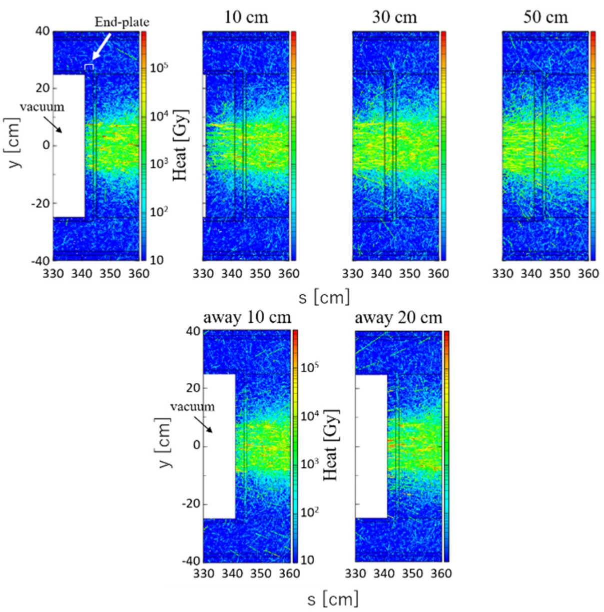

Figure 6: Deposited heat distribution.

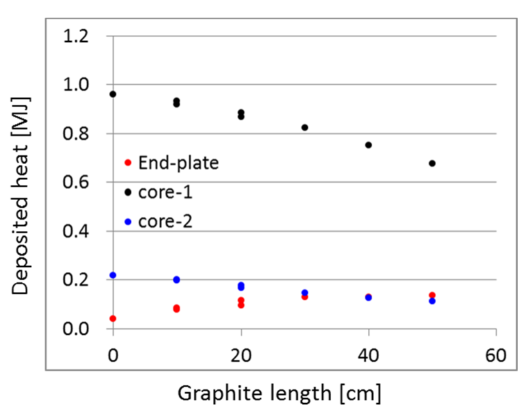

Figure 7: Deposited total heat in dump elements.

Backscattered Neutrons

When the beam hits the graphite moderator or dump core, many secondary neutrons are produced. Backscattered neutrons come out to the accelerator tunnel, and activate the equipment. In order to suppress the backscattered neutron, additional shield around the beam duct is investigated. Because the target particle is a neutron, a light material such as hydrogen is effective for shielding. Polyethylene shield has advantages that it is light and easy to build up. The residual radiation is very low. The distributions of backscattered neutron fluxes in accelerator tunnel are compared with and without polyethylene shield. Spreading of neutron flux can be suppressed by arranging 48 cm thick, 1 m long torus type polyethylene so as to wrap the dump pipe as shown in Fig. 8.

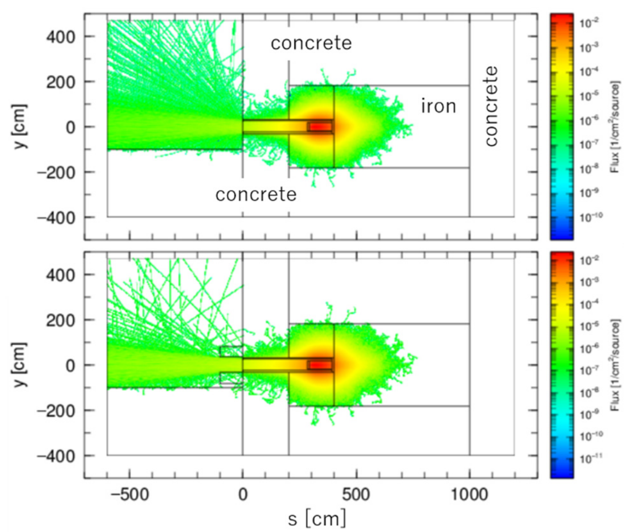

Figure 8: Backscattered neutron flux distributions into the accelerator tunnel.

SUMMARY

The radiation design of beam dump can be summarized as followings:

- To accept the 30 kW beam power, the dump core method with cooling fins is planned to be adopted.
- The peak temperature rise of the end-plate of inner pipe can be mitigated by the graphite moderator.
- The dump core length of copper alloy will be optimised to be around 50 cm.
- The light material shield surrounding the dump pipe is important to avoid the radio-activation of equipment placed in MR tunnel.

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REFERENCES

[1] Accelerator Group of JAERI/KEK JPT, ACCELERATOR TECHNICAL DESIGN REPORT, March 2003. https://www-intra.j-parc.jp/MR/hadron/tda/tdr2003/

[2] M. Calviani., "High capacity beam dump for accelerator", in *Slide at the International Workshop on Future Potential of High Intensity Accelerators for Particle and Nuclear Physics (HINT2016)*, Tokai, Japan, Dec. 2016. https://kds.kek.jp/indico/event/22193/session/3/contribution/30

[3] T. Sato *et al.*, Features of Particle and Heavy Ion Transport code System (PHITS) version 3.02, J. Nucl. Sci. Technol. 55, 684-690 (2018). https://phits.jaea.go.jp/indexj.html