QUANTITATIVE EVALUATION OF BEAM LOSS BASED ON RADIATION DETECTION IN HIGH-DUTY BEAM COMMISSIONING OF LIPAC RFQ

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1. INTRODUCTION

For examination of beam loss characteristics in a high current deuteron accelerator, several kinds of radiation measurements have been performed during the beam commissioning in the Linear IFMIF Prototype Accelerator (LIPAc) at Rokkasho in Japan. Intense deuteron beam accelerators the beam current of which is in the order of more than 100 mA are required for material irradiation tests for a fusion DEMO reactor. The LIPAc beam campaign what we call 'Phase B+' [1] has been conducted at the nominal beam current of 125 mA to validate the high-duty beam acceleration by the radiofrequency quadrupole (RFQ) to 5 MeV. While controlling the beam loss within the acceptable level is a common issue for high-current ion beam accelerators to avoid severe damages as well as activation of the beam ducts and the components, beam losses at unexpected points were observed qualitatively by beam loss monitors in the LIPAc beam campaign [2]. Not only controlling beam loss of the beam core, reducing beam loss of the beam halo is also significantly important in high-current ion beam accelerators. The goal of the present study is to evaluate the beam loss quantitatively to clarify the mechanism of the beam losses.

2. METHODS

The beam loss monitors installed along the LIPAc beam line only provide the magnitude relationships of the beam loss among the monitors. The present study aims to evaluate absolute quantities of the beam loss by measuring activation of the beam line using a NaI(Tl) survey meter, a portable HPGe detector, and by using activation foils such as Al and Ni. The shutdown dose rate measurements were performed on a daily basis along the Medium/High Energy Beam Transport lines (MEBT/MEL/HEBT) to specify the locations of beam losses. In-situ portable HPGe measurements were performed by setting it nearby the beam duct surface to identify radionuclides which contribute to the shutdown dose rate. The lost deuterons can also produce secondary neutrons by generating nuclear reactions with the beam duct. The activation due to the secondary neutrons was quantified with the activation foil method. The relationship between the deuteron loss and the secondary neutron production has been precisely evaluated using the latest prototype JENDL-5 deuteron sublibrary for the Fe(d,xn) nuclear reactions. These activation foils were recovered after the daily beam commissioning.

3. RESULTS

Fig. 1 shows the results on the shutdown dose rate measurement using the survey meter. Increase in the dose rate has been observed on the beam ducts at several points around the quadruple magnets (i.e. LMAxx, HMAxx) and the MEL – HEBT interface. The result suggests that high-energy deuterons are lost at the points because the stainless-steel beam ducts can be activated by deuterons whose energy is higher than approx. 1 MeV. As shown in Fig. 1, the shutdown dose rate at the MEL – HEBT interface is about 0.5 μSv/h. This is equivalent to the beam loss of around 10 μA assuming the deuteron energy of 5 MeV. The bottom part in Fig. 1 shows the results of a beam dynamics simulation. In comparison with the measurements, the shutdown dose rate is increased at several points where the beam is expanded, the beam duct is narrow at the MEL – HEBT interface, or halo particles are generated at HMA06 exit. The results on the in-situ HPGe measurement shows that the radionuclides seem to be produced by the nuclear reactions between deuterons and stainless steels, e.g. Tc-96 (the half-life: $\tau_{1/2}$=4.28 days), Co-55 ($\tau_{1/2}$=17.5 h) and Cu-61 ($\tau_{1/2}$=3.34 hours), and they mainly contribute to the shutdown dose rate. Because the cross sections of the nuclear reactions depend on the deuteron energy, the energy of the lost deuterons can be estimated by the production ratio of these radionuclides. In comparison between the measurements and the activation calculations, the energy of lost deuterons is estimated to be close to 5 MeV at the MEL – HEBT interface. The nuclear reaction rates obtained from the activation foil measurements are compared with the calculation results using the MCNP code to evaluate the quantity of the beam loss. When the deuteron energy is assumed to be 5 MeV, the amount of the loss has been estimated to be in the order of 10 μA at the MEL – HEBT interface.

4. CONCLUSION

With the LIPAc deuteron accelerator, characteristics of the beam loss have been quantitatively evaluated successfully by radiation measurements. The results of the analysis show that the amount and the deuteron energy of the beam loss evaluated from the three different ways of radiation measurements are compatible each other. These results suggest some high-energy deuterons close to 5 MeV exist in the lost deuterons while zero beam loss was expected in the original design of beam optics. Since the activation at a certain point is not simply correlated with the beam and duct sizes, further studies are necessary to clarify the detailed mechanisms of the beam loss such as beam halo generation. The knowledge of the beam loss mechanism will be beneficial to achieve the higher-duty cycle and the higher-energy up to 9 MeV in future beam operations where more severe control of the beam loss will be required.

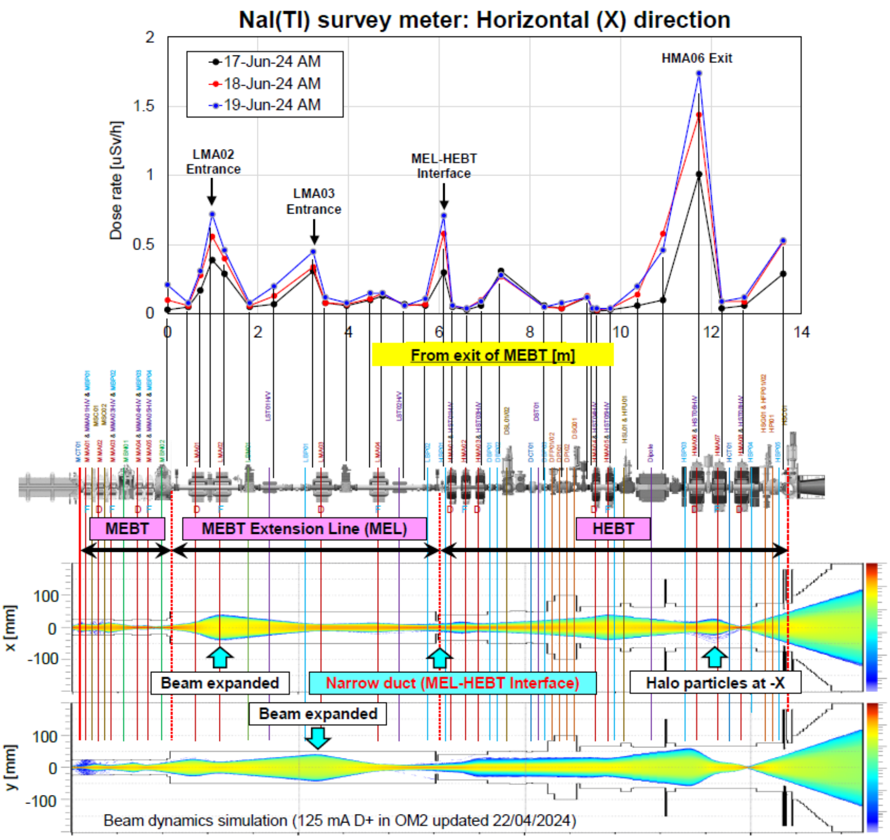

Fig. 1 Experimental results on the daily shutdown dose measurement on the horizontal side beam tube surface along the LIPAc beam line by a NaI(Tl) survey meter. The contour plot at the bottom shows the calculation results on the beam dynamics simulation in the horizontal (X) and vertical (Y) directions.

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