RADIO-ACTIVATION CAUSED BY SECONDARY PARTICLES DUE TO NUCLEAR REACTIONS AT THE STRIPPER FOIL IN THE J-PARC RCS*

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Abstract

In the J-PARC RCS, high residual doses are obtained around the stripper foils. It is caused by not primary particles due to the beam losses but secondary particles due to nuclear reaction at the foil. This radio-activation is an intrinsically serious problem for the RCS which adopts the charge exchange multi-turn beam injection scheme with the stripper foil. In this paper, we report an experimental result of suppression of the residual dose around the foil by controlling a foil fitting rate. In addition, we introduce next plan to measure the secondary particles from the foil in detail.

INTRODUCTION

The 3-GeV Rapid Cycling Synchrotron (RCS) of the Japan Proton Accelerator Research Complex (J-PARC) accelerates protons from 400MeV to 3GeV kinetic energy at 25 Hz repetition rate. The RCS has two functions as a proton driver for neutron/muon production at the Material and Life science experimental Facility (MLF) and as a booster of the Main Ring synchrotron (MR) for the Hadron experimental facility (HD) and Neutrino experimental facility (NU) [1].

The most important issue in achieving such a MW-class high power routine beam operation is to keep machine activations within a permissible level, that is, to preserve a better hands-on maintenance environment. Therefore we adopt the ring collimator system to remove the beam halo and to localize the beam loss at the collimator area [2]. In addition, a large fraction of our effort has been concentrated on reducing and managing beam losses, in the J-PARC RCS [3].

RESIDUAL DOSE MEASUREMENT

To keep a lookout for a sharp increase of activation level in tunnel, we continue a search for high level residual doses after every stopping the beam operation. In addition, we measure the doses on upper-, lower-, inner, and outer-surfaces of vacuum chambers by using the Geiger–Muller (GM) counter. These specific dose distributions characterize the beam loss mechanisms in the RCS.

Dose Distribution Along the Ring

In April, 2016, serious trouble occurred to the ring collimator system. A collimator control system failure was occurred and then a vacuum leak was occurred at the secondary collimator no.5. In order to restart the user beam operation quickly, the Col-Abs. no5 was replaced for ducts with iron shield. Now, new collimator no. 5 is under construction, and it will be installed into the ring on the summer shutdown period in 2017.

After the collimator trouble, we started to measure the residual doses along the ring in detail to confirm a keeping the beam loss localization [4]. Figure 1 shows the schematic view of the RCS ring and recent measurement result of the residual dose distributions along the ring. The result indicates that the beam losses can be localized in the collimator successfully and then there are not high level residual doses along the ring except around the stripper foil.

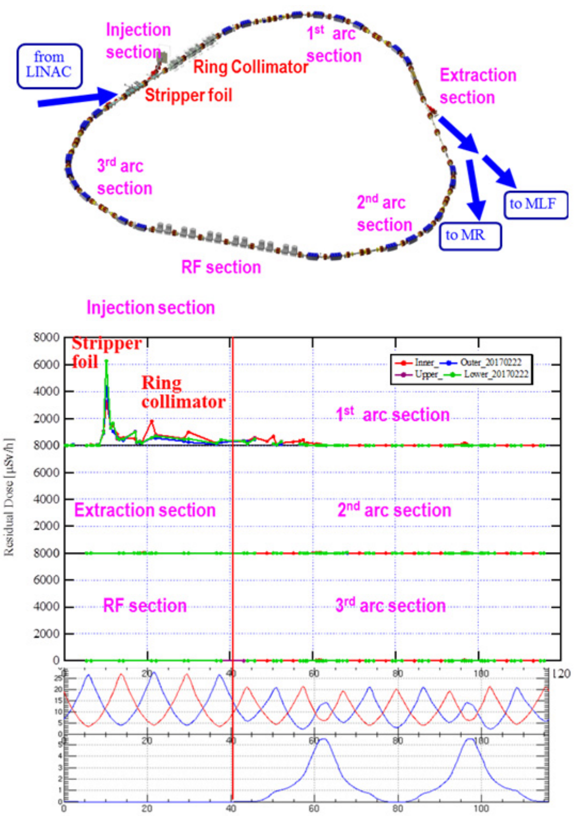

Figure 1: Schematic view of the RCS ring and measured residual dose distributions along the ring.

In the RCS, highest residual dose is observed around the stripper foil. The stripper foil is irradiated with not only the injecting H^- beam but also circulating H^+ beam during the beam injection period. As a result of our preceding studies [5, 6], it is clear that the source of high level residual dose is not the loss of the primary particle at the stripper foil but the secondary particles (proton and neutron) produced by the nuclear reaction due to the interaction between the stripper foil and the beam.

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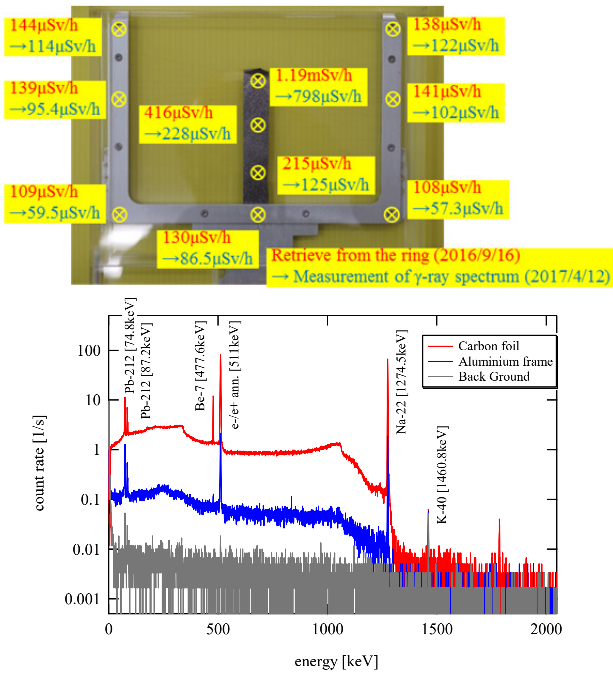

Figure 2: Residual doses and gamma ray spectra of the stripper foil retrieved from the ring.

Radio-Activation of the Stripper Foil

In the RCS, the stripper foil, which had been irradiated with the beam, can be retrieved from the ring and stored in a closed acrylic case in safety [5]. It has advantages capable of readily handling and individual analysing. Figure 2 shows the residual doses of the stripper foil and the aluminium (Al) frame observed by the GM counter and the gamma ray spectra detected by the portable germanium (Ge) detector with lead collimator. The highest dose is observed at the beam irradiation spot of the stripper foil. On the other hand, relatively high doses are also measured at another area of the stripper foil and Al frame. In order to investigate process of the nuclear reaction in the stripper foil and the frame, produced nuclei are identified from analysis of the gamma ray spectra obtained by using the Ge detector. Because lead shielding blocks are set in front of the foil and the Ge detector head is covered with lead collimators, it aims to shrink and localize the measured area. Nuclides in the stripper foils are mainly Be-7 and Na-22. Maybe Na-22 is contamination from the Al frame because it was an insufficiency piling the lead blocks up for shielding the gamma ray from the Al frame. On the other hand, Al frame is also activated and the nuclide is only Na-22. And then, it is assumed that this activation is caused by the secondary particles produced by the nuclear reactions in the foil.

EFFORT TO REDUCE RESIDUAL DOSE

Charge exchange multi-turn beam injection scheme with stripper foil is key technique to achieve high power beam with low beam loss during the beam injection. However, our preceding studies indicate clearly that the secondary particles generated by the nuclear reactions due to the interaction between the beam and stripper foil have to cause the high machine activation around the foil. Namely this machine activation around the stripper foil is an intrinsic problem of the charge exchange multi-turn injection with the stripper foil.

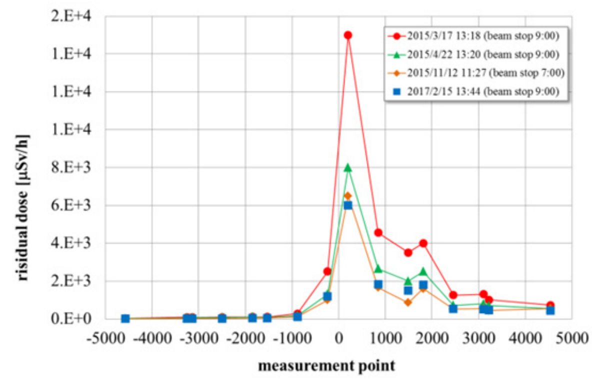

Figure 3: Transition of the specific residual dose distribution around the stripper foil.

Table 1: Injection Painting Parameters and Foil Parameters.

●	**2015/03/17**	**(foil hitting rate ~ 41)**
	MLF	400kW (100π/100π-Cor.)
	MR/NU	316kW (50π/50π-Cor.)
	foil width	30mm
	foil edge position	+13mm
▲	**2015/04/22**	**(foil hitting rate ~ 18)**
	MLF	500kW (150π/100 π -Cor.)
	MR/HD	24kW (100 π/100 π -Cor.)
	foil width	30mm
	foil edge position	+9mm
◆	**2015/11/14**	**(foil hitting rate ~ 13)**
	MLF	500kW (150 π/150 π-Anti.)
	MR/HD	39kW (50 π/50 π-Cor.)
	foil width	20mm
	foil edge position	+9mm
■	**2017/03/17**	**(foil hitting rate ~ 7)**
	MLF	151kW (200 π/200 π-Anti.)
	MR/NU	470kW (50 π/50 π-Cor.)
	foil width	20mm
	foil edge position	+9mm

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Effect of Transverse Painting Injection

It is impossible to erase the injecting H^- particle hit to the stripper foil. But numbers of the circulating H^+ particles hit to the foil can be decreased. Transverse injection painting is one of the important issues to mitigate the space charge effect [7]. When the transverse painting area is expanded, circulating beam orbit is separated from the injecting beam orbit quickly. As a result, total foil hitting number can be decreased drastically, and then the machine activation can be also reduced. Now, we introduce "foil hitting rate" as a key parameter. It is defined a ratio of the total number of the foil hitting particles to the number of the injecting particles. To reduce the machine activation, we made effort to decrease the foil hitting rate by expanding the injection painting area and adjusting the stripper foil setting parameters as shown in Table 1. Figure 3 shows a transition of the specific residual dose distribution around the stripper foil. The machine activation can be reduced certainly.

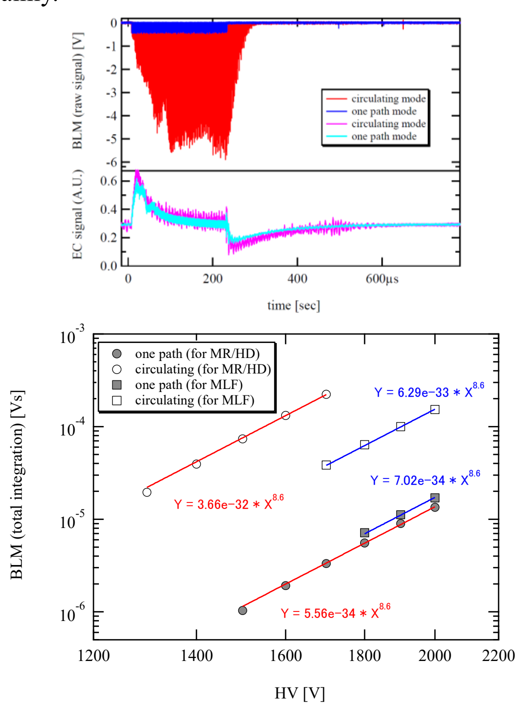

Figure 4: Estimation of the total foil hitting rate by comparing beam loss signals between the single pass extraction mode and the circulating mode in the RCS.

Estimation of Foil Fitting Rate

The RCS can choose between the circulating mode and the single pass extraction mode by switching between fast kicker magnets and dc kicker magnets. In the single pass mode, only the injecting H^- particles hit to the foil. In addition, circulating H^+ particles hit repeatedly during the beam injection period in the circulating mode. By detecting the radiation from the foil directly and comparing between two modes, foil hitting rate can be estimated experimentally. To detect the radiation from the foil, a new beam loss monitor (BLM), in which a scintillator and a PMT are connected by optical fiber, is developed [4]. Upper plot in the Fig. 4 shows typical new-BLM raw signal waveforms compared between two modes. This time, estimation of the foil fitting rate in following two operation conditions was carried out: for MLF (225μs, 200 π/200π-Anti.) and for MR/HD (300μs, 50 π/50 π-Cor.). Measurement results included HV dependencies are summarized in lower plot in the Fig. 4. And we can estimate the foil hitting rate for MLF at 8.95 and one for MR/HD at 65.8. This method is utilised a tool to take an advantage of finer tuning of the injection painting.

CONCLUSION AND NEXT PLAN

In the J-PARC RCS, high residual doses are obtained around the stripper foils. It is caused by not primary particles due to the beam losses but secondary particles due to nuclear reaction at the foil. By controlling the foil hitting rate, we can suppress the high residual dose successfully.

Now, we are planning to measure the secondary particles from the foil in detail. New secondary particle measuring chamber has been assembled as shown in Fig. 5. In this summer, it will be installed at L3BT-100deg line and beam experimental will be started.

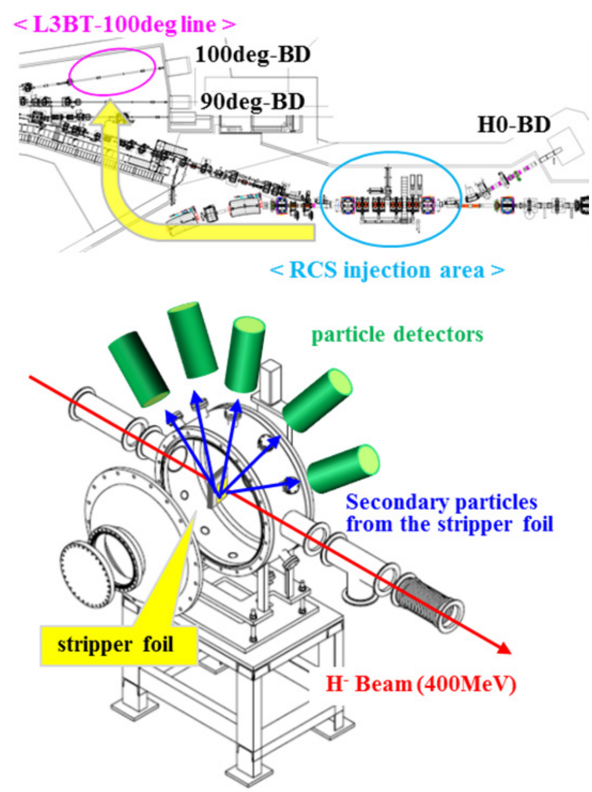

Figure 5: Layout of the next plan to measure the secondary particles from the stripper foil.

ACKNOWLEDGMENT

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