RESIDUAL RADIATION MONITORING BY BEAM LOSS MONITORS AT THE J-PARC MAIN RING*

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Abstract

At J-PARC (the Japan Proton Accelerator Research Complex), high intensity proton accelerator, controlling and localizing beam losses and residual radiations are key issue, because the residual radiation limits maintenance work in efficiency and working hours, and then limits machine availability. We are accumulating continuous measurement data of residual radiation after the beam stopped using beam loss monitors in the Main Ring (MR). The wire cylinder gaseous radiation detectors are used in a proportional counting region. The heads are DC-connected and have a gain as large as 30000 with a bias of -2 kV. We switch the DAQ trigger, change the ADC sampling rate, and raise the gain when the accelerator operation ends. The offsets are measured with zero bias voltage. Identification of radionuclides has been performed with time decay analysis, with assistance of energy spectrum measurements with the Gamma Ray Spectrometer.

INTRODUCTION

In the high intensity proton accelerators the residual radiation limits the available time and procedure of maintenance works. Monitoring the residual radiation level without entering the accelerator tunnel after the beam stopped has been tried at the KEK-PS [1]. Recently at the J-PARC MR using a proportional counter type BLM (pBLM), residual radiation was measured at the hot spots [2]. Such a continuous measurement is to be extended to all pBLMs along the MR. The system configuration, initial results and radionuclide identification are reported.

pBLM SYSTEM

The detector used for residual radiation measurement comprises an inner wire and double coaxial conductors. The inner wire is connected to the inner conductor of a coaxial cable, inner cylinder to the high potential of a HV power supply as a bias and outer cylinder to the ground of the coaxial cable (Figure 1). The pBLMs are set on the quadrupole magnets (Figure 2). Iron cylinder of 3 mm thick covers the detector to shield magnetic fields from the neighboring electromagnets.

At a low radioactive level such as exposed only by cosmic ray, the linearity is good [3]. On the other hand at highly radioactive circumstances, the output is saturated. The condition of saturation was estimated in [3]. When to use the pBLM as a beam loss monitor, -1.3 kV is set at the hot spots such as the MR collimator section and slow extraction section, and -1.6 kV at the other locations. For residual radiation measurements, bias HVs for the detectors are changed to -1.8 kV for hot spots and -2.0 kV for the others.

The block diagram of the system is shown in Fig. 3. The signal is sent to the local control room (LCR) via coaxial cables DC-connected to the pBLM detectors in the tunnel. In the processing circuits at the LCR the signal is divided into two ways, one way for machine protection system and another way for beam loss record and display. The signals are integrated within the gate time and digitized in the PLC modules. The sampling interval is input from the control terminal, 16 ms in this case. For the beam loss record and display, the gate is triggered with the "beam trigger" (TYPE B or C) [4]. For residual radiation measurements the gate trigger is changed to "no beam trigger" (TYPE A) [4].

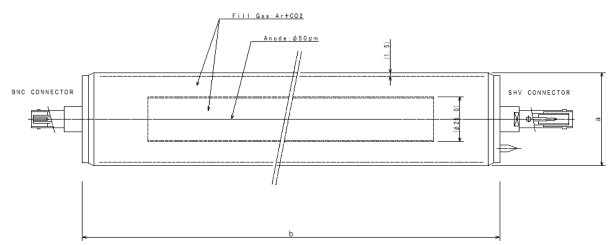

Figure 1: "Proportional counter" type beam loss monitor.

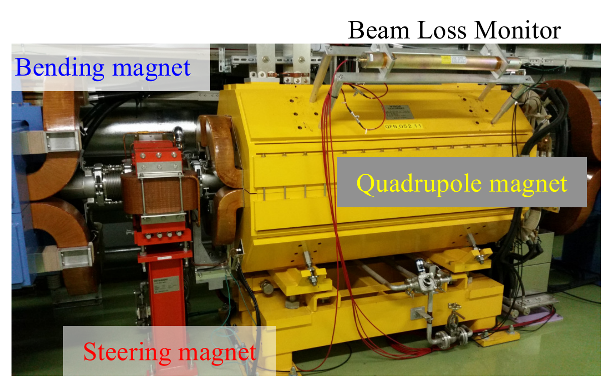

Figure 2: BLM setting on the quadrupole magnets.

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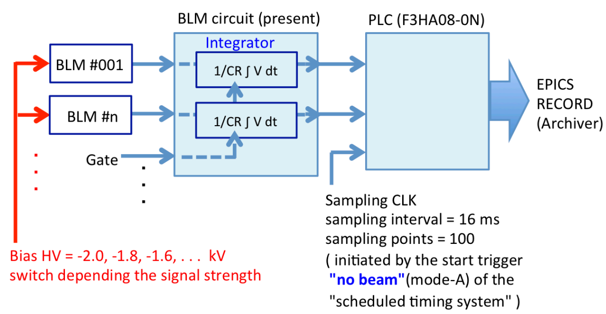

Figure 3: Block diagram of the MR pBLM system.

OFFSET CORRECTION

Obtained signal contains charges produced by environmental radiation (gamma rays and electrons), ones produced by the activated detector itself and leakage currents in the processing circuit. In the integration circuit a small leakage current is accumulated and yields a sizable offset at the output. Subtracting the zero bias data from the raw data yields the desired signal (Figs. 4 and 5). An object to be measured is the environmental radiation level at each detector. Although the detector itself emits gamma rays and electrons, and the above procedure doesn't subtract this contaminated detector effect, considering that the detector, magnets and peripherals have been exposed similarly to the beam losses and that their main element is iron, the above subtraction procedure may reflect the environmental radiation.

The plot in Fig. 4 is enlarged and divided into three parts in Fig. 5. The bias HVs are set -1.8 kV at address #213-#216, #1-#20, and -2.0 kV at the other BLMs. This data are taken 8 hours 30 minutes later after beam stopped in Dec. 22, 2014. The MR has a three-fold symmetry. In each super-period fifteen BLMs at the left side are located at an insertion section: from top to bottom, injection (#1-#15), slow extraction (#72-#87) and fast extraction section (#144-#159). The peak at #6 - #11 corresponds to the MR collimators. The peak around #80 corresponds to the slow extraction septa. The peak around #155 corresponds to the fast extraction septa. Even though an insufficiently collimated halo at the upstream collimators is suspected as a source, the reason of the peak at #37 is not yet clear.

For the maintenance and developing, staff enters the tunnel after the beam stopped. Unless the residual radiation is surveyed by the staff of the radiation safety office, other staff cannot enter the tunnel. Therefore direct radiation measurement in the tunnel is impossible just after the beam stopped. But the method adopted here enables us to carry out such measurement [5]. Caution should be taken for a few pBLMs. Indicated radiations by these are too small comparing to the practical radiation level measured on contact and at one-foot distance from the beam ducts, which is considered to be casued by radiation shielding effect due to magnet cores and under investigation [6].

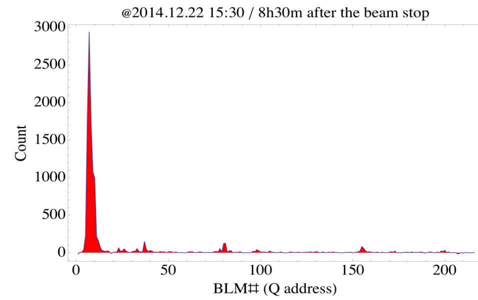

Figure 4: Residual radiation measured with the pBLM.

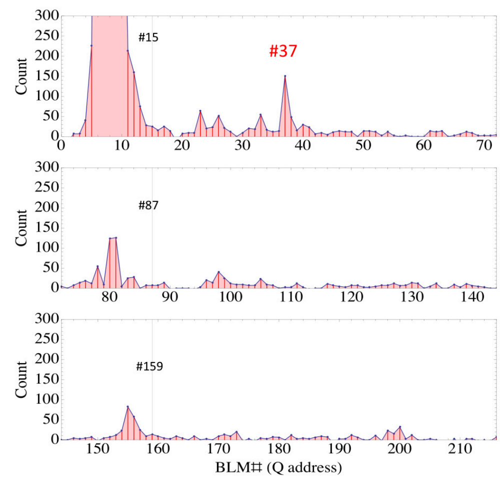

Figure 5: Residual radiation measured with the pBLM. The MR is divided into three parts. The abscissa is the pBLM number (address #), which is almost proportional to the beam path length along the ring.

FIT OF THE DECAY CURVE

Continuous decay curves of the pBLMs signals at the MR collimator section (#6, #7, #8, #9, #10) are depicted in Fig. 6. The data were taken after Dec. 22, 2014 in which the winter machine shutdown began. The abscissa is the time (hour) after the beam stopped. The ordinate is the residual radiation (μSv/h) normalized the pBLM signal counts by the dose at #6 and #7 pBLMs measured with a calibrated dosimeter [7]. Gain variation of pBLMs is not corrected here.

Approximating the residual radiation decay by three components of radioactive nuclides as

$$N(t) = c_1\,\mathrm{e}^{-t/\tau_1} + c_2\,\mathrm{e}^{-t/\tau_2} + c_3\,\mathrm{e}^{-t/\tau_3}\,, \qquad (1)$$

the data in Fig. 6 are fitted. The results are also shown with black curves in Fig. 6 and their parameters are tabulated in Table 1.

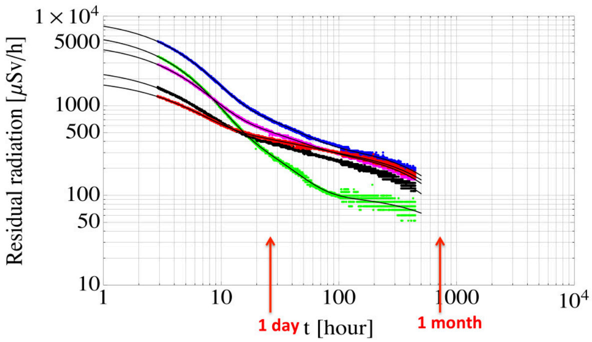

Figure 6: Residual radiation measured with the BLMs. The origin of the time axis is the beam-off timing. Data points are BLM#6: green, #7: blue, #8: magenta, #9, black, #10: red. Black curves are fitted to each data set.

Table 1: Result of the Decay Fit

BLM	C_1	C_2	C_3	τ_1	τ_2	τ_3
Unit	mSv/h	mSv/h	mSv/h	hour	hour	hour
#6	6200	600	100	3.9	22	1000
#7	8300	870	380	4.0	27	610
#8	4400	490	330	3.9	28	560
#9	2200	270	270	4.0	35	530
#10	1500	220	330	4.1	33	620

Candidates of radioactive nuclides are tabulated in Table 2 according to a simulation with PHITS, assuming an activated iron collimator shield, the top six highest yielding after 30-days irradiation by the 3 GeV proton beam loss [8][9][10]. Nuclides of the lifetime between 22 and 35 hours, ^{24}Na, ^{55}Co, ^{48}Cr, ^{43}K, are not included here because yields of such nuclides in the iron bulk are very small. The fast decay component due to ^{53}Fe was observed in the previous measurement with a specified acquisition circuit [5].

Table 2: Lifetime and Gamma of Candidate Nuclides

Nuclide	Half life	Lifetime	Gammas [MeV]
^{56}Mn	2.58 h	3.72 h	0.85, 1.81, 2.11
^{51}Cr	664.8 h	959.1 h	0.005, 0.32
^{52}Mn	134.2	193.6 h	0.511, 0.744, 0.936, 1.43
^{53}Fe	2.54 m	0.06 h	0.7, 1.01, 1.33
^{54}Mn	312 d	10800 h	0.83
^{48}V	16.0 d	552 h	0.511, 0.98, 1.31

G-RAY SPECTROSCOPY

In order to identify the radionuclides, we measured energy spectra of γ-ray at some spots along the MR beam line with the γ-ray spectrometer, GR1, consisted in a semiconductor radiation detector, CdZnTe, made by Kromek [11]. The measurements were performed at addresses #8, 14, 19 and 21 in Sep. 1st, 2015, which was performed after two months after the beam stopped and at addresses #13 (only at the tunnel wall), 14, 19 and 21 in Apr. 27th, 2016, which was performed after six hours after the beam stopped. The residual radiation was too high to be measured at hottest spots as addresses #6 - #10 without excessive radiation doses to staff and detector saturation. Therefore the selection as above was decided. Figure 7 shows the preliminary results of the first and second measurements. Preliminary estimation of radionuclides is as follows: Ti pipe: Sc-46 (83.8 d), Sc-44 (58.5 d), V-48 (16 d); SUS pipe: Mn-54 (312.5 d), Co-57 (271 d), Sc-46 (83.8 d), Co-58 (70.8 d), Sc-44 (58.5 d), V-48 (16 d), Mn-52 (5.59 d); tunnel wall: Na-24 (15 h).

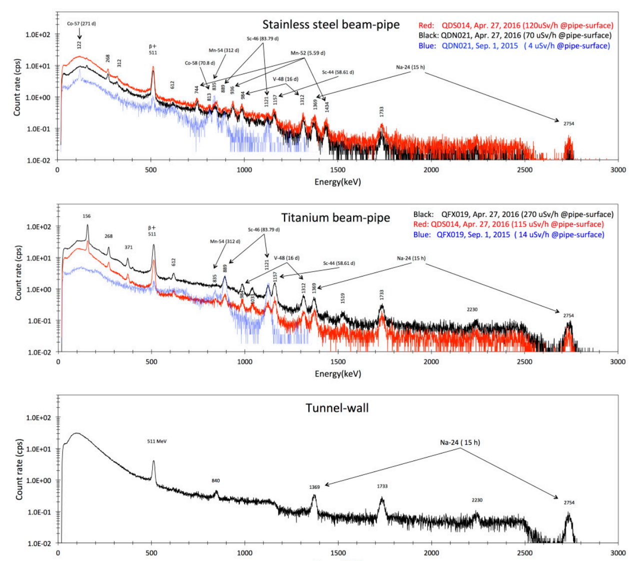

Figure 7: Residual radiation measured with the γ-ray spectrometer GR1. The top plot shows three spectra measured at the stainless steel pipe surface. The middle plot three spectra measured at the titanium (Ti) pipe surface. The bottom plot a spectrum at the tunnel wall surface at the address #13.

SUMMARY

Making use of the pBLMs attached on all the quadrupole magnets and processing circuits in the J-PARC MR, residual radiation have been measured. With assistance of the γ-ray spectrometer measurements, radionuclide identification is ongoing. Automatic measurements with new processing circuits and giving the criteria for the beam loss in terms of residual radiation is also in progress.

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