Radiation safety management at RIBF

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The results of radiation monitoring at RIBF, carried out at the border of the facility and radiation-controlled area, are reported. The residual doses along the accelerator setups are also presented. In 2016, on average, a 345 MeV/u ^{238}U beam was provided at an intensity of 30 particle nA in April, May, October, and November. A ^{124}Xe beam of 100 particle nA was used in May, an ^{18}O beam of 1000 particle nA was used in June, and a ^{48}Ca beam of 300 particle nA was used in November and December.

The dose rates at the boundary of the radiation-controlled area were monitored. Neutron and γ-ray monitors were used on the roofs at three locations: RRC, IRC, and BigRIPS. Figure 1 shows the annual neutron dose at these positions. In 2016, even the highest annual dose of 120 μSv/y at the IRC roof was lower than the legal limit of 5.2 mSv/y. The γ-ray dose of these positions were background level.

The dose rates at the site boundary, where the legal limit is 1 mSv/y, were monitored. Neutron and γ-ray monitors were used, and the annual dose in 2016 was found to be smaller than the detection limit after background correction. The detection limit of the neutron monitor is 2 μSv/y and that of the γ-ray monitor is 8 μSv/y. Therefore, it was inferred that the annual dose at the boundary was less than 10 μSv/y, which is considerably lower than the legal limit.

The residual radioactivity at the deflectors of the cyclotrons was measured just before the maintenance work. The residual dose depends on factors such as the beam intensity, accelerator operation time, and cooling time.

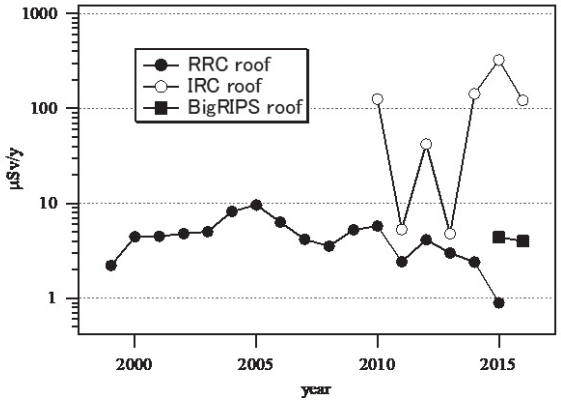

Fig. 1. Radiation dose at the boundary of the radiation-controlle area.

The dose rates from 1986 are shown in Fig. 2. The dose rates for FRC, IRC, and SRC are shown after the year 2006, when the RIBF operation started. For the AVF, the dose rate increased in 2006 because radioisotope production was started and the beam intensity increased. In 2008, the residual dose measurements were highest because high intensity N_2 beam of 500 particle nA was accelerated for RI production just before the measurement.

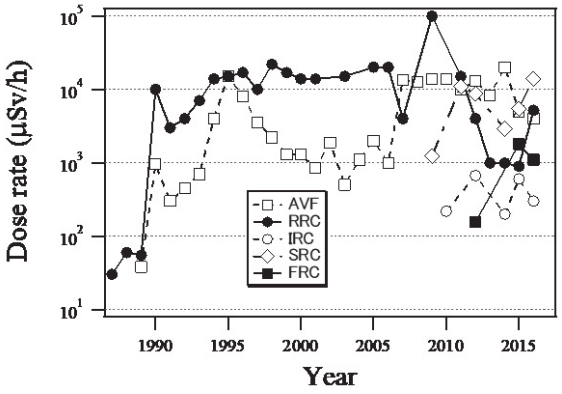

Fig. 2. Dose rates of the residual radioactivity at the deflectors of five cyclotrons.

The residual radioactivity along the beam lines was measured after almost every experiment. Figure 3 shows the locations of measurement points where high residual doses were observed. Table 1 lists the dose rates, beam conditions, and cooling time at these measurement points. The beam conditions are beam nuclides, energies, and maximum intensity in the experiments just before the measurements. The maximum dose was 50 mSv/h at point 12, which is in the vicinity of the G01 Faraday cup.

The radioactivity in the closed cooling system at BigRIPS was measured. The water for the F0 target, exit beam dump, and sidewall dump were sampled in September. The water in the closed cooling systems was replaced in February 2015; therefore, the detected radioisotopes were generated during one and a half years operation in RIBF. The results are shown in Table 2. A liquid scintillation counter was used for the low energy β ray of 18 keV from H-3 nuclide. A Ge detector was also used for γ rays emitted from other radionuclides. The radionuclides, except for H-3, were already filtered by an ion exchange resin in the closed cooling systems. Although the overall value of contamination was less than the legal limit for drain water, as shown in Table 2, the water from the closed cooling system will be dumped into a drain tank before the next

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operation to prevent contamination in the room in case of a water leakage.

An E-learning module that can be accessed anytime and anywhere, even from outside RIKEN, has been used for retraining the radiation workers at RIBF. About 600 radiation workers completed the training in 2016.

Table 1. Residual dose rates measured at beam lines in 2016. Points 1−26 indicate the locations where measurements were taken as shown in Fig. 3. At points 24-27, secondary radioactive-isotope beams (RI) were provided whose intensities were limited to 10^7 particles per second.

Point	Dose rate (μSv/h)	Date (M/D)	Particle	Energy (MeV/u)	Intensity (pnA)	Cooling time (h)
1	400	7/28	p	20	2000	77
2	1500	7/28	p	20	2000	77
3	210	7/22	U-238	11	42	74
4	1500	7/6	O-18	80	1320	133
5	1400	7/6	O-18	80	1320	133
6	180	7/6	O-18	80	1320	133
7	110	7/6	O-18	230	837	134
8	320	12/15	Ca-48	345	700	222
9	350	12/15	Ca-48	345	700	222
10	700	7/6	O-18	230	837	134
11	10000	7/6	O-18	230	837	134
12	50000	7/6	O-18	230	837	134
13	300	7/6	O-18	230	837	137
14	350	7/6	O-18	230	837	137
15	1200	12/15	Ca-48	345	700	222
16	450	7/6	O-18	230	837	137
17	450	7/6	O-18	230	837	137
18	1500	7/6	O-18	230	837	136
19	150	7/6	O-18	230	837	136
20	350	7/6	O-18	230	837	136
21	4100	12/15	Ca-48	345	700	222
22	5700	12/15	Ca-48	345	700	222
23	31000	12/15	Ca-48	345	700	222
24	760	12/15	Ca-48	345	700	222
25	260	12/15	Ca-48	345	700	222
26	240	12/15	Ca-48	345	700	222

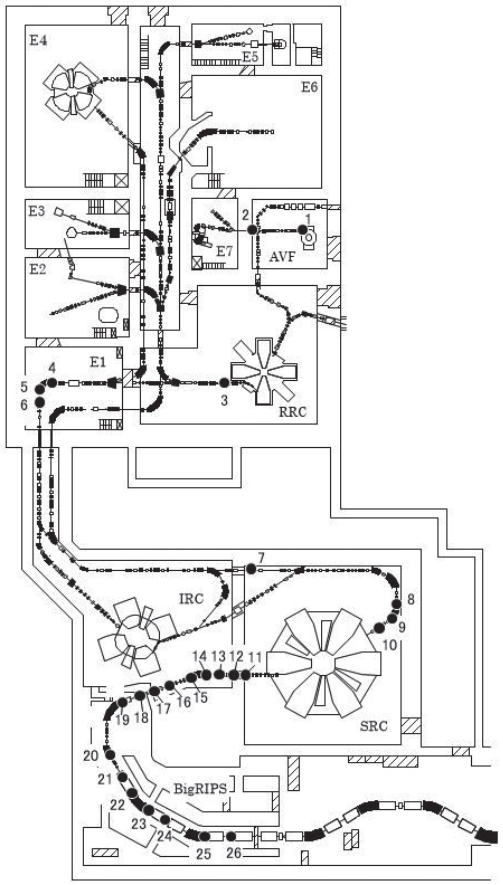

Fig. 3. Layout of the beam lines at RIBF. The measurement locations listed in Table 1 are indicated.

Table 2. Concentrations of radionuclide in the cooling water at BigRIPS, the allowable legal limits for drain water, and the ratios of concentration to the allowable limit.

Cooling water	Nuclide	Concentration[a] (Bq/cm^3)	Limit[b] (Bq/cm^3)	Ratio to limit [a/b]
BigRIPS F0 target	H-3	25	60	0.42
	Co-57	8.7e-4[1)]	4	2.2e-4
	Co-58	7.7e-4	1	7.7e-4
	Mn-54	7.5e-4	1	7.5e-4
			summation	0.42
BigRIPS exit beam dump	H-3	17	60	0.29
	Co-57	1.5e-3	4	3.8e-4
	Co-58	8.9e-4	1	8.9e-4
	Mn-54	2.0e-3	1	2.0e-3
			summation	0.29
BigRIPS side-wall beam dump	H-3	25	60	0.42
	Co-57	1.3e-3	4	3.2e-4
	Co-58	1.4e-3	1	1.4e-3
	Co-60	6.1e-4	0.2	3.1e-3
	Mn-54	8.5e-4	1	8.5e-4
			summation	0.43

1) read as 8.7×10^{-4}