Radiation safety management at RIBF

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The results of radiation monitoring at RIBF, performed between the border of the facility and the radiation-controlled area, are reported. The residual doses along the accelerator setups are also presented. In 2019, a ^{238}U beam of about 345 MeV/nucleon was provided at an intensity of 70 particle nA in November and December. A ^{78}Kr beam of about 345 MeV/nucleon of 300 particle nA was used in March and April. Subsequently, ^{128}Xe beam of about 345 MeV/nucleon of 80 particle nA was used in May and June.

The dose rates at the boundary of the radiation-controlled area were monitored. Neutron and γ-ray monitors were used at three locations roofs of the RRC, IRC, and BigRIPS. Figure 1 shows the annual neutron dose at these positions. In 2019, even the highest annual dose of 60 μSv/y at the IRC roof was lower than the legal limit of 5.2 mSv/y.

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 2019 was found to be lower 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 maintenance work.

The residual dose depends on factors such as the beam intensity, accelerator operation time, and cooling time. The dose rates from 1986 are shown in Fig. 2. The dose rates for FRC, IRC, and SRC are shown for the years scince 2006, when the RIBF operation started. For AVF, the dose rate increased in 2006 because the radioisotope production was started and the beam intensity increased.

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 the measurement points. The maximum dose was 46 mSv/h at point 23, which is in the vicinity of the beam dump of BigRIPS.

The radioactivity in the closed cooling system at BigRIPS was measured. The water for the F0 target, the exit beam dump, and the side-wall dump were sampled

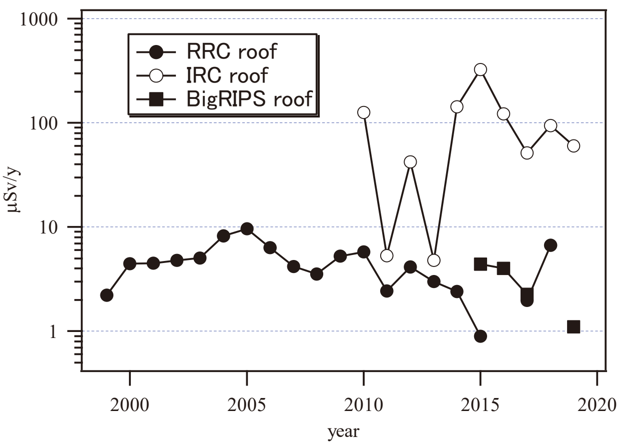

Fig. 1. Radiation dose at the boundary of the radiation-controlled area.

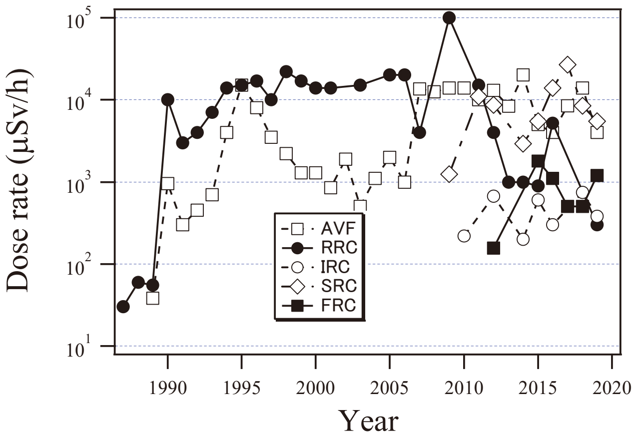

Fig. 2. Dose rates of residual radioactivity at the deflectors of 5 cyclotrons.

in June. The water in the closed cooling systems for the F0 target was not replaced in 2019. 1300 L of water for the exit beam dump was replaced in April 2018, following which 200 L and 130 L of water was supplied in March and October 2019, respectively. For the side-wall beam dump, all of the water was replaced in July 2018. The results are listed in Table 2. A liquid scintillation counter (LSC-7400, Hitachi Co. Ltd.) was used for low-energy γ ray of 18 keV from H-3 nuclide. A Ge detector (GC2019, Canbbera Co. Ltd.) 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

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than the legal limit for drain water, as summarized in Table 2, the water from the closed cooling system will be dumped into the drain tank before the next operation to prevent contamination in the room in the case of a water leakage.

The E-learning module, which can be accessed anytime and from anywhere (even from outside RIKEN), has been used for re-training the radiation workers at RIBF. About 670 radiation workers have completed the training in 2019.

As described above, radiation management to comply with lows and to keep the radiation level as low as possible has been conducted successfully.

Table 1. Dose rates measured at beam lines in 2019. Points 1–24 indicate the locations where measurements were taken as shown in Fig. 3.

Point	Dose rate (μSv/h)	Date (M/D)	Particle	Energy (MeV/u)	Intensity (pnA)	Cooling time (h)
1	300	12/27	O-18	6.0	1000	50
2	240	12/27	O-18	6.0	1000	50
3	100	12/27	O-18	6.0	1000	50
4	800	12/27	O-18	6.0	1000	50
5	90	7/29	α	7.25	5000	1014
6	400	7/29	V-51	6.0	1000	276
7	120	7/29	V-51	6.0	1000	276
8	120	12/27	U-238	10.75	2629	497
9	95	7/29	V-51	6.0	1000	291
10	110	7/29	N-14	135	142	355
11	2600	6/26	Xe-124	50	370	163
12	2800	12/18	U-238	50	508	286
13	150	12/18	U-238	50	508	286
14	315	12/18	U-238	345	94	284
15	33500	6/26	Xe-124	345	148	161
16	280	12/18	U-238	345	94	284
17	150	6/26	Xe-124	345	148	161
18	1100	6/26	Xe-124	345	148	161
19	250	6/26	Xe-124	345	148	161
20	790	6/26	Xe-124	345	148	161
21	1860	6/26	Xe-124	345	148	161
22	2800	6/26	Xe-124	345	148	161
23	46000	6/26	Xe-124	345	148	161
24	415	12/18	U-238	345	94	284

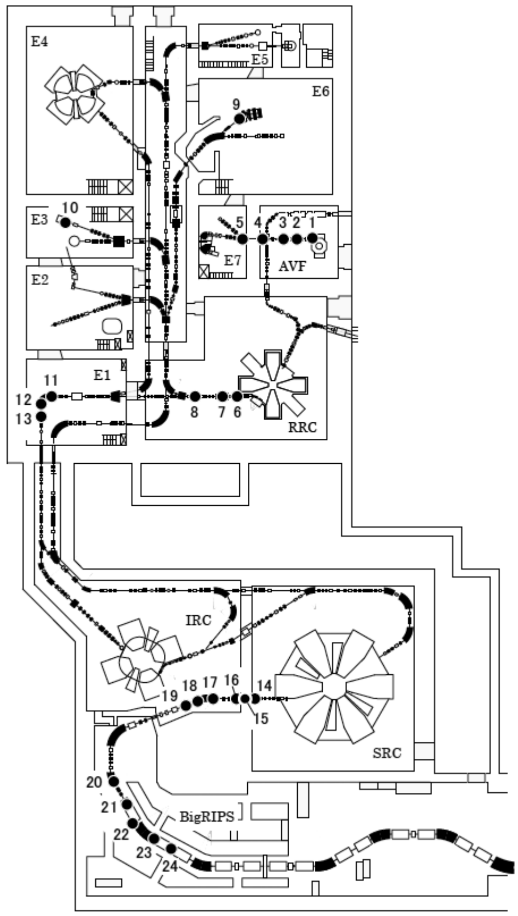

Fig. 3. Layout of the beam lines at RIBF. The measurement locations listed in Table 1 are indicated.

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	3.2	60	5.3e-2
	Mn-54	3.9e-4[1)]	1.0	3.9e-4
			summation	5.3e-2
BigRIPS exit beam dump	H-3	7.6	60	1.3e-1
	Be-7	1.4e-2	30	4.5e-4
	Mn-54	5.1e-3	1	5.1e-3
	Co-56	2.1e-3	0.3	6.9e-3
	Co-57	5.1e-3	4	1.3e-3
	Co-58	1.3e-2	1	1.3e-2
	Co-60	2.2e-3	0.2	1.1e-2
			summation	1.7e-1
BigRIPS side-wall beam dump	H-3	8.4	60	1.4e-1
	Be-7	8.5e-3	30	2.8e-4
	Mn-54	1.5e-3	1	1.5e-3
	Co-57	2.3e-3	4	5.6e-4
	Co-58	1.3e-3	1	1.3e-3
	Co-60	1.7e-3	0.2	8.6e-3
			summation	0.15

1) read as 3.9×10^{-4}