Radiation safety management at RIBF

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The results of radiation monitoring at RIBF, conducted at the border of the facility and the radiation-controlled area are reported. The residual doses along the accelerator setups are also presented. In 2022, ^{238}U beam of approximately 345 MeV/nucleon was provided at an intensity of 70 particle nA in April. Then ^{75}Kr beam of about 345 MeV/nucleon of 600 particle nA were used in May and June. Further, ^{70}Zn beam of approximately 345 MeV/nucleon of 400 particle nA were used in December.

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. As the thickness of the radiation shield at IRC roof was relatively small, the dose rate was high. In 2017, additional local-concrete shield of 1 meter thick was set on a beamline in IRC room. The dose was successfully reduced. In 2022, even the highest annual dose of 4.1 μSv/y at the IRC roof was lower than the legal limit of 5.2 mSv/y. The dose at IRC roof at 2022 is sensitive to IRC and SRC operation time. In 2022, these were operated for only four months. Therefore, the annual dose of IRC roof was small.

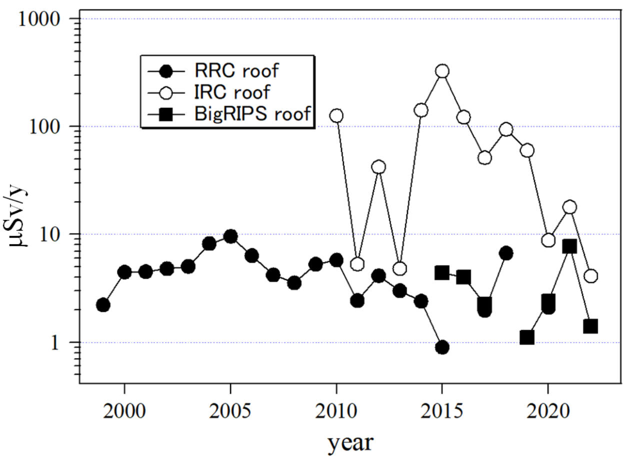

Fig. 1. Radiation dose at the boundary of the radiation-controlled area.

The dose rates at the site boundary with Wako city, where the legal limit is 1 mSv/y, were monitored by neutron and γ-ray monitors. The annual dose in 2022 was 9.0 μSv neutrons after the background correction. The annual dose of the γ-ray was under the background level. Therefore, the radiation dose rate was considerably lower than the legal limit.

The residual radioactivity at the deflectors of the cyclotrons was measured immediately before the maintenance work. The residual dose is dependent on factors such as the beam intensity, accelerator operation time, and cooling time. The data have been obtained at the cyclotrons maintenance works, when the deflectors were able to accessible. Therefore, the cooling times were not constant. The dose rates from 1986 are shown in Fig. 2. The dose rates for FRC, IRC, and SRC are shown for the years after 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.

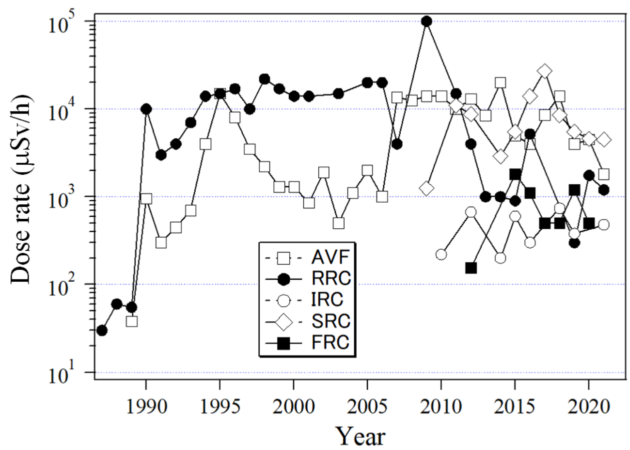

Fig. 2. Dose rates of residual radioactivity at the deflectors of 5 cyclotrons.

The residual radioactivity along the beam lines was measured after almost every experiment. Figure 3 shows the locations of the measurement points where high residual-doses rates greater than 100 μSv/h were observed. Table 1 lists the dose rates, beam conditions, and cooling time at the measurement points. The maximum dose was 28 mSv/h at point 15, which is near the beam dump of BigRIPS.

The radioactivity in the closed cooling system at BigRIPS was measured. The water for the F0 target, exit beam dump, and side-wall dump were sampled in March 2022. The water in the closed cooling systems were partly replaced on October 2021. The results are shown in Table 2. A liquid scintillation counter (LSC-7400, Hitachi Co. Ltd.) was used for the low energy β ray of 18 keV from H-3 nuclide. A Ge detector (GC2019, Canbbera Co. Ltd.) was used for γ rays emitted from other radionuclides. The radionuclides,

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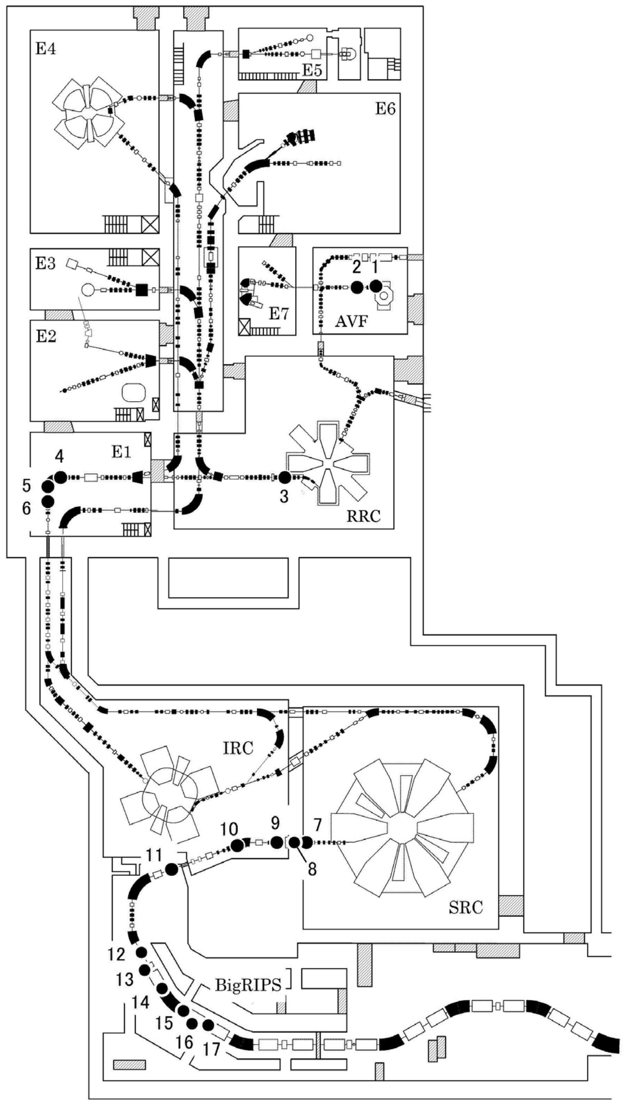

Fig. 3. Layout of the beam lines at RIBF. The measurement locations listed in Table 1 are indicated.

except for H-3, were already filtered by an ion exchange resin set 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 the drain tank prior to the subsequent operation to prevent contamination in the room in case of a water leakage.

The E-learning module, which can be accessed anytime and from anywhere (even from the outside RIKEN), has been used for the re-training to the radiation workers at RIBF. Approximately 612 radiation workers have completed the training in 2022.

As described above, radiation management to comply with lows and to maintain a radiation level as low as usual has been conducted successfully.

Table 1. Dose rates measured at beam lines in 2021. Points 1–17 indicate the locations where measurements were taken as shown in Fig. 3.

Poi nt	Dose rate (μSv/h	Date (M/ D)	Particle	Energy (MeV/ u)	Intensity (pnA)	Decay period (h)
1	130	7/27	α	7.3	2500	362
2	260	7/27	α	7.3	2500	362
3	300	7/27	U-238	10.8	300	343
4	2200	6/14	Kr-78	50	940	269
5	1700	6/14	Kr-78	50	940	269
6	130	6/14	Kr-78	50	940	269
7	4400	6/14	Kr-78	345	631	269
8	6900	6/14	Kr-78	345	631	269
9	140	6/14	Kr-78	345	631	269
10	200	6/14	Kr-78	345	631	269
11	100	6/14	Kr-78	345	631	269
12	730	6/14	Kr-78	345	631	269
13	2380	6/14	Kr-78	345	631	269
14	3650	6/14	Kr-78	345	631	269
15	27500	6/14	Kr-78	345	631	269
16	910	6/14	Kr-78	345	631	269
17	470	6/14	Kr-78	345	631	269

Table 2. Concentrations of radionuclide in the cooling water at BigRIPS, allowable legal limits for drain water, and 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	2.0	60	3.3e-2
			summation	3.3e-2
BigRIPS exit beam dump	H-3	9.3	60	1.6e-1
	Be-7	4.3e-3[1)]	30	1.4e-4
	Mn-54	5.0e-3	1	5.0e-3
	Co-56	8.2e-4	0.3	2.8e-3
	Co-57	7.4e-3	4	1.8e-3
	Co-58	3.9e-3	1	3.9e-2
	Co-60	6.7e-3	0.2	3.4e-2
			summation	0.20
BigRIPS side-wall beam dump	H-3	15.8	60	4.3e-1
	Be-7	3.7e-3	30	1.2e-4
	Co-57	4.4e-4	4	1.1e-4
	Co-60	6.0e-4	0.2	3.0e-3
			summation	0.43

1) read as 4.3×10^{-3}