

Radiation safety management at RIBF

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The results of radiation monitoring at the RIBF, performed at the border of the facility and the radiation-controlled area are reported. The residual doses along the accelerator setups are also presented. In 2021, a ^{238}U beam of about 345 MeV/nucleon was provided at an intensity of 70 particle nA in April, May, and November. Subsequently, light-ion beams such as ^{12}C beam of about 200 MeV/nucleon of 500 particle nA, ^2H beam of about 250 MeV/nucleon, and ^4He beam of about 200 MeV/nucleon were 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 2021, even the highest annual dose of $18\ \mu\text{Sv/y}$ at the IRC roof was lower than the legal limit of $5.2\ \text{mSv/y}$. The dose at the IRC roof at 2021 is sensitive to IRC and SRC operation time. In 2021, these were operated only four months. Therefore, the annual dose of IRC roof was small.

The dose rates at the site boundary, where the legal limit is $1\ \text{mSv/y}$, were monitored using neutron and γ -ray monitors. The detection limit of the neutron monitor is $2\ \mu\text{Sv/y}$. The annual dose in 2021 was $3.6\ \mu\text{Sv}$ of neutrons after the background correction. The detection limit of the γ -ray monitor is $8\ \mu\text{Sv/y}$. The annual

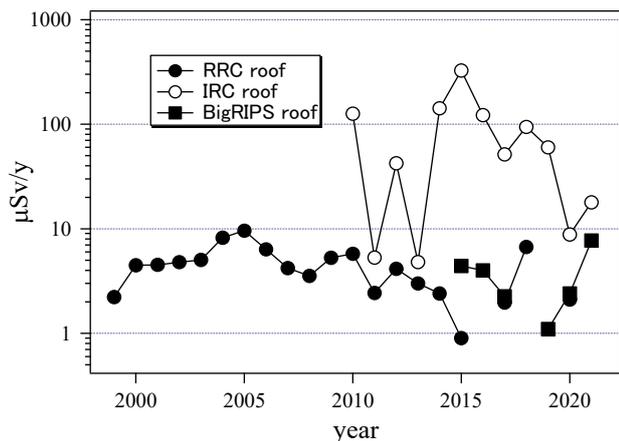


Fig. 1. Radiation dose at the boundary of the radiation-controlled area.

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dose of the γ -ray was lower than the limit. Therefore, we inferred that the annual dose at the boundary was less than $10\ \mu\text{Sv/y}$, which is 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 depends on factors such as the beam intensity, accelerator operation time, and cooling time. The data were captured at the cyclotrons maintenance works, when the deflectors were able to be accessed. Therefore, the cooling times have not been constant. The dose rates from 1986 are shown in Fig. 2. The dose rates for FRC, IRC, and SRC are shown for years after 2006, when the RIBF operation started. For the AVF, the dose rate increased in 2006 because the radioisotope production started and the beam intensity increased.

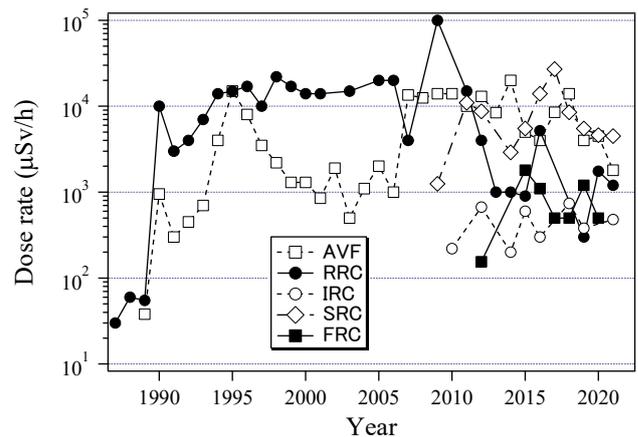


Fig. 2. Dose rates of residual radioactivity at the deflectors of five cyclotrons. Except for measurements, numbers below 10 are preferably spelled out and those above indicated numerically.

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 $13\ \text{mSv/h}$ at point 19, which is in the vicinity of the beam dump of BigRIPS.

Although the radioactivity in the closed cooling system at BigRIPS have been reported annually, it is omitted because the radioactivity was not measured in 2021.

The E-learning module, which can be accessed any-

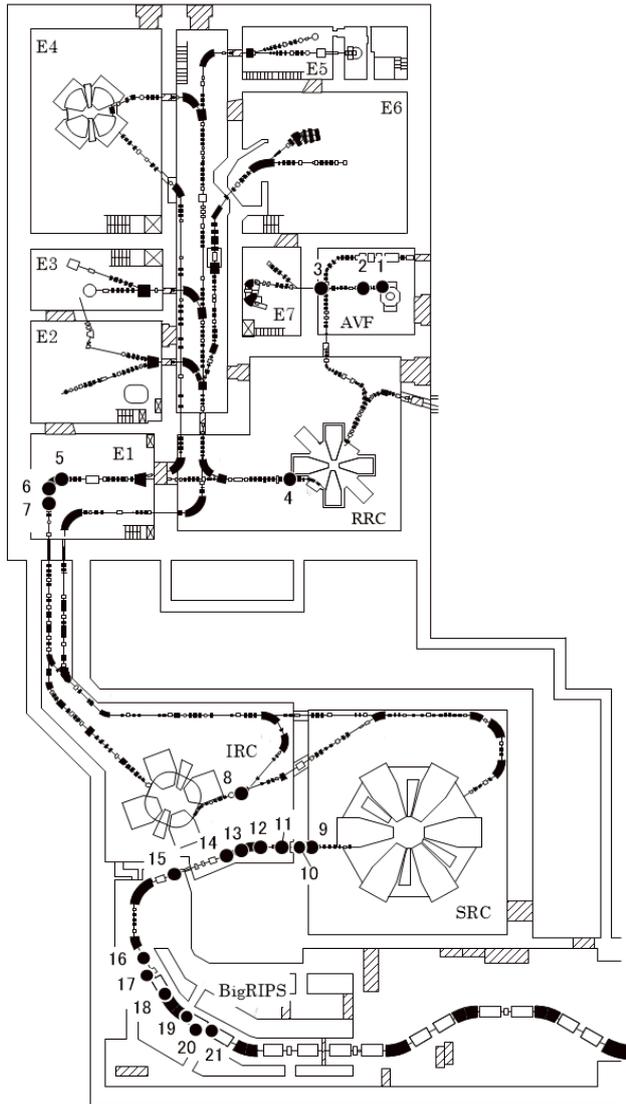


Table 1. Dose rates measured at beam lines in 2021. Points 1–21 indicate the locations where measurements were performed as shown in Fig. 3.

Point	Dose rate ($\mu\text{Sv/h}$)	Date (M/D)	Particle	Energy (MeV/u)	Intensity (pnA)	Decay period (h)
1	130	7/30	Li-7	6	1000	313
2	150	7/30	Li-7	6	1000	313
3	650	7/30	Li-7	6	1000	313
4	400	7/30	N-14	100	200	476
5	2400	7/20	α	74	1200	694
6	2200	7/20	α	74	1200	694
7	450	7/20	α	74	1200	694
8	100	7/20	α	200	1000	708
9	5100	7/20	α	200	1000	708
10	8000	7/20	α	200	1000	708
11	350	7/20	α	200	1000	708
12	130	7/20	α	200	1000	708
13	350	7/20	α	200	1000	708
14	380	7/20	α	200	1000	708
15	250	7/20	α	200	1000	708
16	240	12/14	U-238	345	72	269
17	1570	12/14	U-238	345	72	269
18	2300	12/14	U-238	345	72	269
19	13000	12/14	U-238	345	72	269
20	200	12/14	U-238	345	72	269
21	180	12/14	U-238	345	72	269

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

time and from anywhere (even from outside RIKEN), has been used for the re-training of radiation workers at the RIBF. A total of 595 radiation workers completed the training in 2021. It is lower than that in recent years because of COVID-19 restriction on immigration, *etc.*

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