

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 the radiation-controlled area are reported. The residual doses along the accelerator setups are also presented. In 2020, a ^{238}U beam of approximately 345 MeV/nucleon was provided at an intensity of 70 particle nA in October and November. Subsequently, a ^{70}Zn beam of approximately 345 MeV/nucleon of 800 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 at three locations: the roofs of the RRC, IRC, and BigRIPS. Figure 1 shows the annual neutron dose at these positions. In 2020, even the highest annual dose of $9\ \mu\text{Sv}/\text{y}$ at the IRC roof was lower than the legal limit of $5.2\ \text{mSv}/\text{y}$. The dose at the IRC roof sensitive to IRC and SRC operation time. In 2020, these operated for only three months. Therefore, the annual dose of the IRC roof was small.

The dose rates at the site boundary, where the legal limit is $1\ \text{mSv}/\text{y}$, were monitored by neutron and γ -ray monitors. The detection limits of the neutron monitor were $2\ \mu\text{Sv}/\text{y}$ and $0.01\ \mu\text{Sv}/\text{h}$. The annual dose in 2020 was $3.6\ \mu\text{Sv}$ of neutron but less than the hourly detection limits any time after the background correction. The detection limit of the γ -ray monitor was $8\ \mu\text{Sv}/\text{y}$. The annual dose of the γ -ray was lower than the limit, which is considerably lower than the legal limit.

The residual radioactivity at the deflectors of the cy-

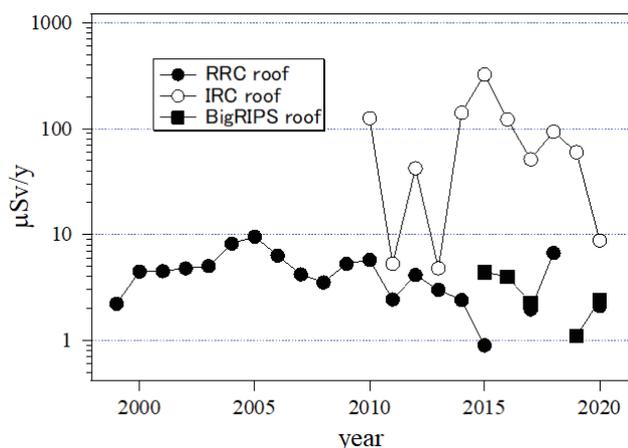


Fig. 1. Radiation dose at the boundary of the radiation-controlled area.

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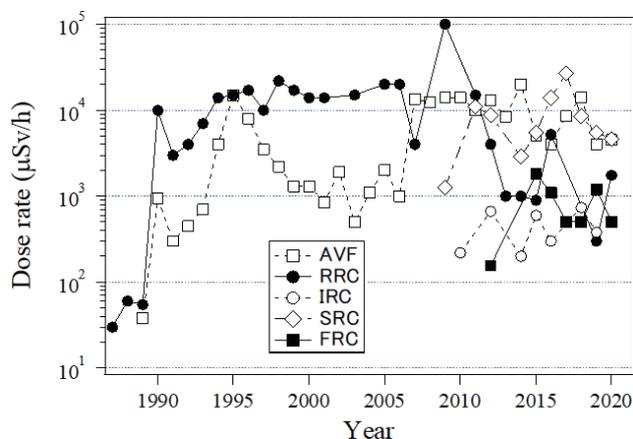


Fig. 2. Dose rates of residual radioactivity at the deflectors of 5 cyclotrons.

clotrons was measured just before maintenance work.

The residual dose depends on factors such as the beam intensity, accelerator operation time, and cooling time. The data were obtained from the cyclotrons maintenance works, when the deflectors were accessible. 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 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.

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 were observed. Table 1 lists the dose rates, beam conditions, and cooling time at the measurement points. The maximum dose was $46\ \text{mSv}/\text{h}$ at point 23, which is in the vicinity of the beam dump of BigRIPS.

Although the radioactivity in the closed cooling system at BigRIPS is reported annually, it is omitted because the radioactivity was not measured in 2020.

The E-learning module, which can be accessed anytime and from anywhere (even from outside RIKEN), has been used for the re-training of the radiation workers at RIBF. Approximately 580 radiation workers have completed the training in 2020. This is lower than the number in recent years because of the COVID-19 restriction of immigration and etc.

As described above, radiation management to comply with laws and to keep radiation levels as low as possible has been carried out successfully.

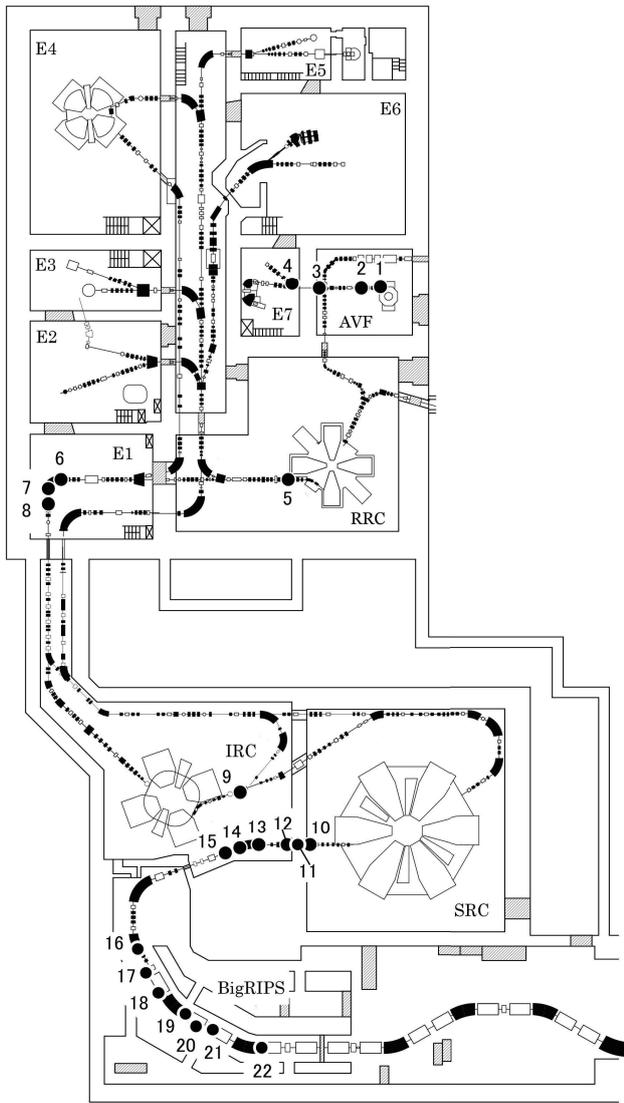


Table 1. Dose rates measured at beam lines in 2020. Points 1–24 indicate the locations where measurements were taken as shown in Fig. 3.

Point	Dose rate ($\mu\text{Sv/h}$)	Date (M/D)	Particle	Energy (A MeV)	Intensity (pnA)	Cooling time (h)
1	100	8/12	α	7.3	10000	554
2	139	8/12	α	7.3	10000	554
3	250	8/12	α	7.3	10000	554
4	100	12/28	α	6.5	10	281
5	188	8/12	C-12	135	2	882
6	4000	12/24	Zn-70	50	990	270
7	2500	12/24	Zn-70	50	990	270
8	110	8/12	Ar-40	66	24	979
9	200	12/24	Zn-70	114	800	270
10	7000	12/24	Zn-70	345	760	271
11	14000	12/24	Zn-70	345	760	271
12	120	12/24	Zn-70	345	760	270
13	150	12/24	Zn-70	345	760	270
14	581	12/24	Zn-70	345	760	270
15	110	12/24	Zn-70	345	760	270
16	130	12/24	Zn-70	345	760	271
17	3300	12/24	Zn-70	345	760	271
18	6000	12/24	Zn-70	345	760	271
19	30000	12/24	Zn-70	345	760	271
20	530	12/24	Zn-70	345	760	271
21	280	12/24	Zn-70	345	760	271
22	230	12/24	Zn-70	345	760	271

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