# Radiation safety management at RIBF

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Residual radioactivity at the cyclotron deflectors was measured just before maintenance works were carried out in the summer of 2014. The same measurement has been performed regularly since 1986, and the variations in the dose rates are shown in Fig. 1. Considering that the dose rate depends on the beam intensity and the cooling time, the trend has not changed considerably since 2006, when RIBF operation started.

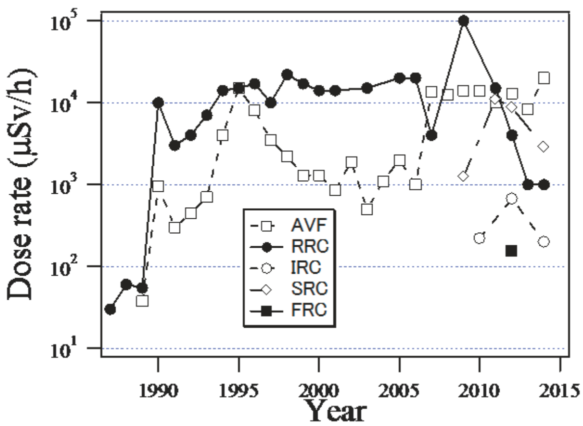


Fig. 1. Dose rates of residual radioactivity at the deflectors of five cyclotrons.

The residual radioactivity was measured along the beam lines after almost every experiment. Points 1–26, marked with solid circles in Fig. 2, are locations where high-residual dose rates were usually observed. Table 1 lists these dose rates and the measurement dates, beam conditions, and the decay periods after the end of operation. The conditions for the data are chosen to be maximum doses among the measured data at each points. The maximum dose rate was found to be 17 mSv/h at point 13, which is the neighbor of the G01 Faraday cup.

We continuously monitor the radiation in and around the RIBF facility by using neutron and gamma area monitors. In 2014, the annual dose at the site boundary were less than the detection limit of the monitors after background correction. The neutron dose had been lower than the detection limit of 2 μSv/y and the γ-ray dose had been lower than the detection limit of 8 μSv/y. Therefore, the annual total dose in 2014 was less than 10 μSv/y, which was considerably lower than the legal limit of 1 mSv/y.

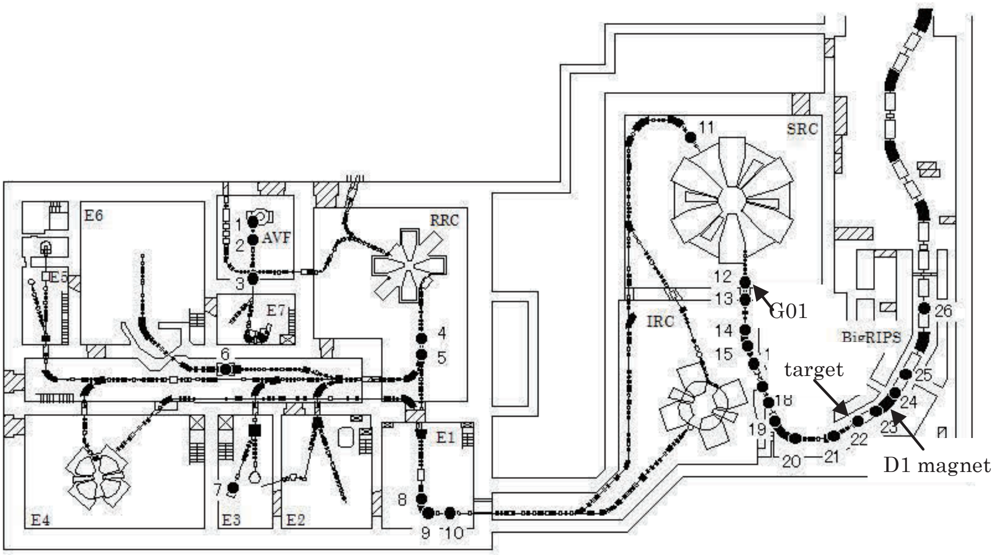


Fig. 2. Layout of beam lines at RIBF. Locations listed in Table 1 are indicated. G01, the target, and D1 magnet are also shown.

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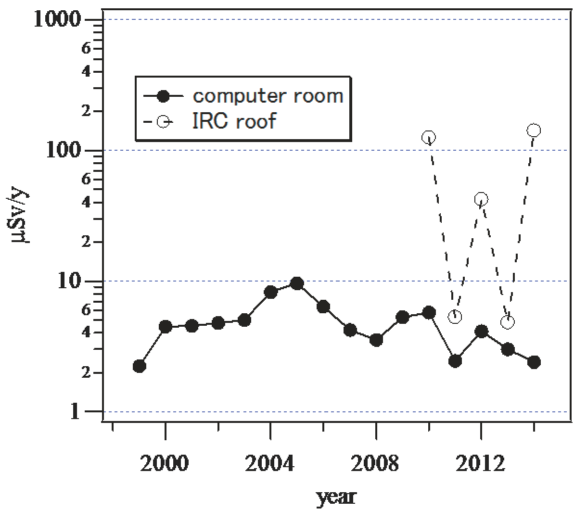


Fig. 3. Accumulated leakage radiation at the boundary of the radiation-controlled area.

The dose rates at the radiation-controlled area in 2014 have been monitored. Three monitors are placed at the boundary of the radiation-controlled area. One is in the computer room of the Nishina building, and the other two are on the roofs of the IRC and BigRIPS. The highest observed value was 142 μSv/y at the IRC roof as a result of beam loss at the transport line between SRC and BigRIPS. Figure 3 shows the annual neutron dose at these locations since 1999. These were considerably lower than the legal limit of 1.3 mSv/3 month. The dose on the BigRIPS roof was below the detection limit of 3 μSv/y for neutrons.

The water in closed cooling systems at BigRIPS was sampled after the 2014 operation of RIBF. A 345-MeV/u 20 particle nA, on average, $^{238}$U beam was provided during April and May, and during October and November. A $^{70}$Zn 75 particle nA was provided in May and June. A 400 particle nA $^{48}$Ca beam was in November and December. Radionuclide concentrations were measured by using a liquid-scintillation counter and a Ge detector to compare them with the legal limit. The results are shown in Table 2. After operation with the intense $^{48}$Ca beam, the summation of the ratios of the concentrations to the legal limits for the drain water of all the radionuclides at the BigRIPS became approximately 1/4, and the water was transferred into the drain tank before the next operation. This is to prevent contamination of the room in case of a water leakage. The water in the drain tank, which contains drain water from other places, is released after the concentration of radionuclides is confirmed to be lower than the legal limit. This water circulates in the closed system with ion exchange resins. Thus, the nuclides in waters listed in Table 2, with the exception of tritium, are already filtered values. However, tritium accumulates in the water because the nuclide has a long half life of 12.3 year and is difficult to remove with filters. At the measurement before beam irradiation in 2014, the concentration of tritium in water in all systems was approximately 3 Bq/cm$^3$.

In 2014, the primary beam mode was newly mounted on the safety management system of RIBF by considering the high radiation dose risk due to the intense beam. The target intensity of the primary beam in RIBF is $6 \times 10^{12}$ particle/second on the production target of BigRIPS. Then, a secondary beam of low intensity is generated via a nuclear reaction and separation through BigRIPS. However, in the experimental rooms located downward from BigRIPS, the permitted beam intensity is $10^7$ particle/second both for primary and secondary beams. In RIBF operation, faint primary beams are sometimes derived to the experimental rooms directly. If intense primary beams more than the permission derived to the experimental rooms owing to accelerator trouble etc., the interlock system work in a moment and stop the beam automatically. However, a delay of few seconds is necessary before a beam is stopped by the interlock system operation. There may be a serious risk of radiation exposure to workers even in the neighbor rooms that are outside the irradiated area. Therefore, the safety

Table 1. Dose rates measured at beam lines in 2014. Points 1−26 indicate the measured locations shown in Fig. 2.

| Point | Dose rate (μSv/h) | Date (M/D) | Particle | Energy (MeV/u) | Intensity (pnA) | Decay period (h) |
|---|---|---|---|---|---|---|
| 1 | 55 | 7/23 | α | 12.5 | 400 | 54 |
| 2 | 650 | 7/23 | α | 12.5 | 400 | 54 |
| 3 | 450 | 7/23 | α | 12.5 | 400 | 54 |
| 4 | 100 | 10/8 | Kr-84 | 70 | 0.07 | 19 |
| 5 | 1000 | 11/14 | U-238 | 10.75 | 1430 | 13 |
| 6 | 190 | 12/16 | Ca-48 | 63 | 200 | 2215 |
| 7 | 80 | 7/23 | N-14 | 135 | 500 | 15621 |
| 8 | 1300 | 12/16 | Ca-48 | 45.4 | 938 | 113 |
| 9 | 2000 | 7/23 | O-18 | 88 | 51 | 534 |
| 10 | 70 | 7/23 | O-18 | 88 | 51 | 534 |
| 11 | 170 | 12/16 | Ca-48 | 345 | 530 | 110 |
| 12 | 5000 | 12/16 | Ca-48 | 345 | 530 | 110 |
| 13 | 17000 | 12/16 | Ca-48 | 345 | 530 | 110 |
| 14 | 550 | 12/16 | Ca-48 | 345 | 530 | 110 |
| 15 | 700 | 12/16 | Ca-48 | 345 | 530 | 110 |
| 16 | 100 | 12/16 | Ca-48 | 345 | 530 | 110 |
| 17 | 400 | 12/16 | Ca-48 | 345 | 530 | 110 |
| 18 | 750 | 12/16 | Ca-48 | 345 | 530 | 113 |
| 19 | 100 | 12/16 | Ca-48 | 345 | 530 | 113 |
| 20 | 150 | 12/16 | Ca-48 | 345 | 530 | 113 |
| 21 | 1500 | 12/16 | Ca-48 | 345 | 530 | 113 |
| 22 | 3000 | 12/16 | Ca-48 | 345 | 530 | 113 |
| 23 | 7000 | 12/16 | Ca-48 | 345 | 530 | 113 |
| 24 | 2800 | 12/16 | Ca-48 | 345 | 530 | 113 |
| 25 | 325 | 12/16 | Ca-48 | 345 | 530 | 113 |
| 26 | 150 | 12/16 | Ca-48 | 345 | 530 | 113 |

management system was improved to inhibit the unexpected radiation exposure.

The primary beam mode in the radiation control system affects the restriction area, accelerator operation, and beam transport operation. When the primary beam mode is started, the entry-forbidden area is first expanded to the neighbor experimental rooms of the beam delivered area. Secondly, a combination of the attenuation devices of the accelerator, which control the beam intensity, is limited to regulate the beam intensity less than permitted limit. Additionally, while the primary beam mode is off, the magnetic field of the D1 magnet of BigRIPS, which determines whether the primary or secondary beam is transported to the experimental rooms, is always monitored. Moreover, if the value corresponds to a primary beam transportation, the safety management system does not permit beam irradiation until the primary beam mode is on, which means no-entry allowed to the neighbor experimental rooms. With these improvements, radiation exposure risk due to unexpected intense beams is mitigated.

Table 2. Radionuclide concentrations in cooling water of BigRIPS, the allowable legal limits for drain water, and the ratio of the 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 | 14 | 60 | 0.23 |
| | Be-7 | 1.5e-3 | 30 | 4.9e-3 1) |
| | Co-58 | 8.2e-4 | 1 | 8.2e-4 |
| | Mn-54 | 6.4e-4 | 1 | 6.4e-4 |
| | | | summation | 0.23 |
| BigRIPS exit beam dump | H-3 | 12 | 60 | 0.2 |
| | Be-7 | 1.7e-2 | 30 | 5.7e-4 |
| | Co-57 | 1.2e-3 | 4 | 2.9e-4 |
| | Co-58 | 3.7e-3 | 1 | 3.7e-3 |
| | Mn-54 | 9.7e-4 | 1 | 9.7e-4 |
| | | | summation | 0.21 |
| BigRIPS side-wall beam dump | H-3 | 11 | 60 | 0.18 |
| | Be-7 | 0.14 | 30 | 4.7e-3 |
| | Co-58 | 1.3e-3 | 1 | 1.3e-3 |
| | | | summation | 0.19 |

1) read as $4.9\times 10^{-3}$