# RI beam production at BigRIPS in 2022

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Here, the radioactive-isotope (RI) beams produced at the BigRIPS fragment separator[1] in 2022 are presented. The experimental programs involving the use of BigRIPS during this year and the RI beams produced for each experiment are summarized in Table 1.

In the spring beamtime, a $^{238}$U-beam campaign was conducted, followed by another with a $^{78}$Kr beam. The $^{238}$U-beam campaign was divided into two parts: a series of director's Discretionary Allocation (DA) programs with low-intensity (∼10 particle nA) primary beams, and experimental programs with full-intensity (∼70 particle nA) beams.

The first part of the $^{238}$U-beam campaign began in March. The performance of a newly developed ionization chamber (IC) specialized in heavy-mass beams with a Xe-based gas was examined with the primary beam, energy-degraded $^{238}$U beams, a $^{210}$Rn$^{84+}$-centered cocktail beam, and an $A/Q = 2.5$ setting beam with wide range of atomic number $Z = 30$–$90$.[2] Then, a production test of a $^{237}$Np beam was performed for the DA to investigate the energy dependence of its production cross section. The energy of the $^{238}$U beams for this DA was degraded via the use of degraders located at T11 in the primary beamline, not at F1 or F5. For the next DA in the search for unusual nuclear pathways in nuclear synthesis, 300- and 70-MeV/nucleon $^{238}$U beams were supplied. Subsequently, $^{225}$Ac-centerd cocktail beams were produced for their production cross-section measurement. These beams were also supplied for the following DA of PALIS. Thereafter, the IC test with P10 and $CH_4$ gases were performed[2] with the same beams as in the previous IC test. Energy measurement of the $^{238}$U primary beam was conducted using the primary and energy-degraded $^{238}$U beams. This DA was performed for an application of SRC as the world's highest-beam-energy cyclotron as per the Guinness Book of Records. For the final DA, $^{99}$Tc was produced for the measurement of its transmutation cross section.

The second part of the $^{238}$U-beam campaign began in April, 1.5 days after the accelerator tunning. First, a $^{79}$Ni-centered cocktail beam was supplied for multi-reflection time-of-flight mass spectrometer (MRTOF-MS) experiment at F11. Subsequently, a Machine Study (MS) and an experiment for the nucleosynthesis in $r$-process were conducted using OEDO with $^{124}$Sn, $^{130}$Te, and $^{130}$Sn beams whose energies were adjusted to be 180 MeV/nucleon in BigRIPS. A $^{202}$Re-centered cocktail beam was produced for the second MRTOF-MS experiment to measure the mass in vicinity of the neutron magic number $N = 126$ region. A tertiary spin-aligned $^{99}$Zr beam at F7 was produced from the secondary $^{100}$Zr beam impinging on a wedge-shaped Al target at F5 for an experiment to measure the quadrupole moment of an isomeric state of $^{99}$Zr. Finally, a MS for production cross-section measurements was conducted with $^{132}$Sn-, $^{138}$Te-, $^{144}$Xe-, $^{150}$Ba-, and $^{154}$Ce-centered cocktail beams.[3] In addition, an auto-PID system was tested with the $^{132}$Sn setting in this MS.[4]

The $^{78}$Kr-beam campaign began in May. An OEDO experiment to study $vp$-process nucleosynthesis was conducted with $^{56}$Ni and $^{58}$Ni beams. During changes of the magnet configurations and detector setups in OEDO, two MSs were performed. The first MS was for a development of automatic ion-optics tuning in the primary beam line with low-intensity primary beam. The second one was for production cross-section measurements with $^{64}$As-, $^{39}$Ca-, $^{37}$Ca-, and $^{35}$Ca-centered cocktail beams.[5] Subsequently, mass measurements around the proton-drip line using SHARAQ were performed with $^{50}$Fe-, $^{46}$Fe-, and $^{23}$Si-centered cocktail beams.

During the autumn beam time, the $^{70}$Zn campaign was conducted from December following the repair of the large helium refrigerator in BigRIPS. During the BigRIPS tuning, the performance of a new DAQ system with Mesytec MDPP-16 module for germanium-detectors array for isomer tagging was examined with a $^{52}$Ca-centered cocktail beam.[6] Then, a $^{50}$Ca beam was produced for an OEDO experiment, wherein the single-particle structure of $^{51}$Ca was studied. During this experiment, a severe problem occurred on the SRC cyclotron caused the beam time to stop. Consequently, the other scheduled experiment was postponed.

RI beam production at BigRIPS from the start of the operation in March 2007 is summarized in our database[7] available at `https://ribeam.riken.jp/`.

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References
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2) M. Yoshimoto *et al.*, in this report.
3) Y. Shimizu *et al.*, in this report.
4) Y. Shimizu *et al.*, in this report.
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Table 1. List of experimental programs with RI beams produced at the BigRIPS separator in 2022.

| Primary beam (Period) | Proposal No. | Spokesperson | Course | RI beams |
|---|---|---|---|---|
| $^{238}$U 345 MeV/nucleon (Mar. 21 – May 31) | MS-EXP21-10 | M. Yoshimoto | BigRIPS | primary, energy-degraded $^{238}$U, $A/Q$=2.5, $^{210}$Rn$^{84+}$ |
| | DA21-03-01 | H. Otsu | F12 | $^{237}$Np |
| | DA21-05-01 | D. Suzuki | F12 | 300, 70-MeV/nucleon $^{238}$U |
| | DA21-08-01 | T. Sumikama | BigRIPS | $^{225}$Ac |
| | DA21-07-01 | T. Sonoda | PALIS | $^{225}$Ac |
| | MS-EXP21-11 | M. Yoshimoto | BigRIPS | primary, energy-degraded $^{238}$U, $A/Q$=2.5, $^{210}$Rn$^{84+}$ |
| | DA21-09-01 | H. Okuno | BigRIPS | primary, energy-degraded $^{238}$U |
| | DA21-04-02 | H. Otsu | ZeroDegree | $^{99}$Tc |
| $^{238}$U 345 MeV/nucleon (Apr. 2 – Apr. 20) | NP2012-RIBF202-03 | M. Rosenbusch | ZeroDegree | $^{79}$Ni |
| | NP1912-SHARAQ18-01 | N. Imai | SHARAQ | $^{124}$Sn, $^{130}$Te, $^{130}$Sn |
| | MS-EXP22-01 | N. Imai | SHARAQ | $^{124}$Sn, $^{130}$Te, $^{130}$Sn |
| | NP2012-RIBF199-03 | M. Wada | ZeroDegree | $^{202}$Re |
| | NP1912-RIBF175-01 | Y. Ichikawa | ZeroDegree | $^{100}$Zr→$^{99}$Zr |
| | MS-EXP22-04 | Y. Shimizu | BigRIPS | $^{132}$Sn, $^{138}$Te, $^{144}$Xe, $^{150}$Ba, $^{154}$Ce |
| $^{78}$Kr 345 MeV/nucleon (May 16 – Jun. 3) | NP1912-SHARAQ19-01 | D. Suzuki | SHARAQ | $^{56}$Ni, $^{58}$Ni |
| | MS-EXP22-03 | T. Nishi | BigRIPS | primary |
| | MS-EXP22-02 | H. Suzuki | BigRIPS | $^{64}$As, $^{39}$Ca, $^{37}$Ca, $^{35}$Ca |
| | NP1812-SHARAQ13-01 | S. Michimasa | SHARAQ | $^{50}$Fe, $^{46}$Fe, $^{23}$Si |
| $^{70}$Zn 345 MeV/nucleon (Dec. 5 – Dec. 11) | NP1812-SHARAQ12R1-01 | K. Wimmer | SHARAQ | $^{50}$Ca |