RI beam production at BigRIPS in 2016

H. Takeda,[*1] N. Fukuda,[*1] Y. Shimizu,[*1] H. Suzuki,[*1] D. S. Ahn,[*1] T. Sumikama,[*1] D. Murai,[*1,*2] J. Amano,[*1,*2] N. Inabe,[*1] K. Kusaka,[*1] M. Ohtake,[*1] Y. Yanagisawa,[*1] T. Komatsubara,[*1] H. Sato,[*1] and K. Yoshida[*1]

The radioactive isotope (RI) beam production at the BigRIPS fragment separator[1] in 2016 is presented here. Table 1 summarizes the experimental programs that involved the use of the BigRIPS separator in this period and the RI beams produced for the programs.

The spring beam time started with a ^{238}U primary beam in April. A machine study of the SAMURAI-TPC and the measurement of the giant monopole resonance were performed with the ^{132}Sn beam produced by the in-flight fission of ^{238}U.

Subsequently, a ^{124}Xe primary beam was used to produce $^{108, 112}$Sn for symmetry-energy studies. The production yields and the production cross sections of neutron-deficient isotopes for the Br − Cd region[2] were measured during the BigRIPS tuning for the ^{124}Xe beam.

Five experiments were conducted in the second ^{238}U beam campaign started in May. The ^{132}Sn and ^{48}Ca beams were produced for the ESPRI experiment. The $^{132, 124}$Sn and Z = 1−3 beams were delivered to the SAMURAI spectrometer for symmetry-energy studies. The ImPACT program was performed using the ^{93}Zr beam with energies of 200, 100, 50, and 20 MeV/nucleon. The ^{87}Zn setting was provided for measurements of masses and beta-decay properties of r-process nuclei around N = 56. ^{60}Ti and ^{64}V were produced to study the shape coexistence along N = 40.

The spring beam time ended with an ^{18}O beam campaign, in which two experiments were performed. First, ^{3}H and $^{4, 8}$He beams were produced for the confirmation of tetra-neutron resonance. Subsequently, $^{4, 6}$He beams were delivered for the measurement of vector analyzing powers.

Table 1. List of experimental programs and RI beams produced at the BigRIPS separator in 2016.

Primary beam (Period)	Proposal No.	Spokesperson	Course	RI beams
^{238}U 345 MeV/nucleon (Apr. 6 – Apr. 22)	MS-EXP16-01	T. Isobe	SAMURAI	^{132}Sn
	NP1312-RIBF113-01	S. Ota	ZeroDegree	^{132}Sn
^{124}Xe 345 MeV/nucleon (Apr. 29 – May 6)	NP1312-SAMURAI22-01	T. Murakami	SAMURAI	$^{108, 112}$Sn
^{238}U 345 MeV/nucleon (May 14 – Jun. 13)	NP1512-RIBF79R1-01	J. Zenihiro	F12	^{132}Sn, ^{48}Ca
	NP1312-SAMURAI15-01	W. Lynch	SAMURAI	$^{132, 124}$Sn, ^{2}H/^{4}He/^{6}Li
	IMPACT16-01	H. Sakurai	ZeroDegree	^{93}Zr
	NP1306-RIBF106-01	A. Estrade	EURICA	^{87}Zn
	NP1512-RIBF140-01	F. Recchia	EURICA	^{60}Ti, ^{64}V
^{18}O 230 MeV/nucleon (Jun. 16 – Jun. 30)	NP1512-SHARAQ10-01	S. Shimoura	SHARAQ	^{3}H, $^{4, 8}$He
	NP1206-SAMURAI13-01	S. Sakaguchi	SAMURAI	$^{4, 6}$He
^{238}U 345 MeV/nucleon (Oct. 19 – Nov. 12)	IMPACT16-02	H. Sakurai	ZeroDegree	$^{126, 127}$Sn, ^{93}Zr, ^{107}Pd
	MS-EXP16-05	T. Sonoda	PALIS	^{116}Pd
	MS-EXP16-10	Y. Yamaguchi	Rare-RI Ring	^{76}Zn
	NP1412-RIBF123R1-01	M. Takechi	BigRIPS	$^{59-78}$Ni, $^{45-50}$Ca
	PE16-03	T. Sonoda	PALIS	
	PE16-01	S. Nishimura	ZeroDegree	
^{48}Ca 345 MeV/nucleon (Nov. 15 – Dec. 6)	NP1512-SAMURAI36-01	N. Orr	SAMURAI	^{20}C, ^{22}C/^{23}N
	NP1406-SAMURAI27-01	N. Kobayashi	SAMURAI	^{22}Ne, $^{30, 31}$Ne, ^{32}Ne/^{34}Na
	NP1412-RIBF132-01	R. Kanungo	ZeroDegree	$^{27, 29}$F, $^{20, 22}$C, ^{19}B
	NP1312-RIBF03R1-02	P. Fallon	ZeroDegree	^{41}Al
	PE16-02	S. Nishimura	ZeroDegree	
	NP1306-SAMURAI20-01	C. Caesar	SAMURAI	$^{26, 27}$F, ^{24}O

*1 RIKEN Nishina Center
*2 Department of Physics, Rikkyo University

In the autumn beam time, ^{238}U and ^{48}Ca primary beams were used. The ^{238}U beam campaign started in October with the ImPACT program and the PALIS machine study. The Sn, Zr, and Pd isotope beams were provided. A machine study of the Rare-RI Ring was conducted with the ^{76}Zn beam. A large variety of Ni and Ca isotope beams were produced for the determination of neutron skin thickness.

After switching to the ^{48}Ca primary beam, the production cross sections of Ne isotopes were measured[3] during the BigRIPS tuning of the ^{48}Ca beam. C – Na isotope beams were produced for two SAMURAI experiments. Proton and matter radii were measured with $^{27, 29}$F, $^{20, 22}$C, and ^{19}B beams to study the evolution of halo structure of the Borromean nuclei. The ^{41}Al beam was produced for the study of ^{40}Mg spectroscopy. The $^{26, 27}$F and ^{24}O beams were used to measure the lifetime of the ^{26}O ground state. At the end of the ^{48}Ca beam campaign, searches for a new isotope ^{39}Na and the neutron drip line were scheduled but postponed because of a problem in the refrigerator of superconducting magnets of the BigRIPS separator.

The number of experiments using the RI beams at the BigRIPS separator is summarized in Table 2 for various primary beams in each year. A total of 137 experiments have been performed so far. Figure 1 shows the RI beams produced at the BigRIPS separator from March 2007 to December 2016 on the chart of nuclides. The number of RI beams produced at the BigRIPS separator is approximately 440. The number of new isotopes is approximately 150. Production yields for more than 1500 RI beams have been measured.

References

1) T. Kubo, Nucl. Instr. Meth. Phys. Res. B **204**, 97 (2003).
2) H. Suzuki et al.: In this report.
3) D. S. Ahn et al.: In this report.

Table 2. Number of experiments performed using RI beams in each year.

Year	^{238}U	^{124}Xe	^{86}Kr	^{78}Kr	^{70}Zn	^{48}Ca	^{18}O	^{16}O	^{14}N	^{4}He	^{2}H	Yearly total
2007	4		1									5
2008	2					4						6
2009	3					3			3	1		10
2010						10	1		2		1	14
2011	4	2					2					8
2012	6	3			1	4	6					20
2013	4	2					3					9
2014	11				1	3		1			1	17
2015	15			6		4					1	26
2016	13	1				6	2					22
Total	62	8	1	6	2	34	14	1	5	1	3	137

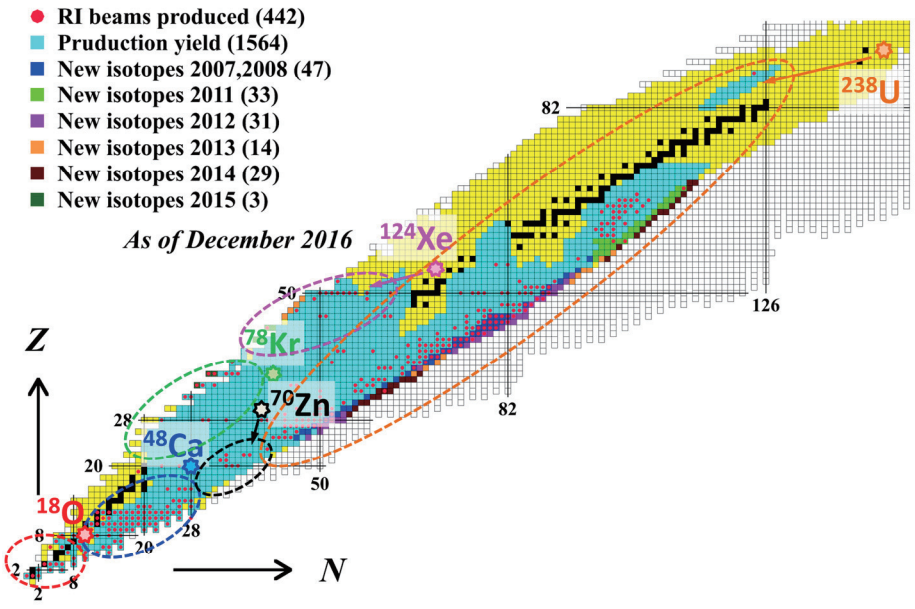

Fig. 1. RI beams produced at the BigRIPS separator from March 2007 to December 2016.