Present status of RIBF accelerators at RIKEN

1) Introduction to RIBF (2007)
2) Improvements & Present status (2008 - 2010)
3) Recent results from RIBF (2008 - 2010)
4) Further developments & Plans (2009 - 2010)
   a: SC-ECR
   b: New Injector (RILAC2)
   c: Charge Strippers

O. Kamigaito
Accelerator Group, RIKEN Nishina Center
RIKEN RI Beam Factory (RIBF)

Old facility: 1975 ~ 1990

RIBF: 1997 ~ (2012)
K = 2,600 MeV
Self Magnetic Shield
Self Radiation Shield
3.8T (240 MJ)
18-38 MHz
8,300 tons

SRC (Superconducting Ring Cyclotron) => World’s first!

Cooled by liquid He bath
Indirectly cooled by two phase forced He flow
K = 2,600 MeV
Self Magnetic Shield
Self Radiation Shield
3.8T (240 MJ)
18-38 MHz
8,300 tons

First beam of 345 MeV/u $^{27}$Al$^{10+}$ extracted from SRC on Dec. 28, 2006 at 16:00
(A. Goto, Cyclotrons2007)
2 Injectors: RILAC & AVF

4 Booster Cyclotrons: RRC, fRC, IRC, SRC

from Hydrogen to Uranium => 345 MeV/u

CW-mode acceleration

RILAC-RRC-fRC-IRC-SRC (fixed freq.): 345 MeV/u
AVF-RRC-SRC (var. freq.): Max 440 MeV/u
RILAC-RRC-IRC-SRC (var. freq.): Max 400 MeV/u

RIBF Accelerators
Improvement plan was started, but not fully executed due to lack of operation time in FY2007…

0.05 pnA ($2.8 \times 10^8$ pps) @345MeV/u ($\beta = 0.68$)
2) Improvements (08 - 10)

- Beam phase stability
- RF stability
- Noise in phase probes
- Beam interlock system
- Phase probe noise
- Radial probe noise
- FT phase

- Accurate Faraday cups
- TOF monitors
- Actual value of RF voltage
- Charge strippers
- SC-ECR
- EIC High Voltage
- Oil contamination in refrigerators
- AND SO ON.....

N. Fukunishi et al., PAC09
K. Yamada et al., HIAT09
Radial probe problems

SRC 2007/6 $^{238}$U

Inj.  Ext.

Zero

Effect of secondary electrons + FT Noise
New differential electrode
Tungsten 0.3mm × 3mm

Radial probe improvements

Differential probe modified
SRC (,fRC)

Probe-shaft grounded on both sides
IRC, SRC
Radial probe problems

Effect of secondary electrons + FT Noise

SRC 2007/6 U

Zero

SRC 2008/12 Ca

Zero

Solved!
**Turn pattern in IRC**

FT-phase: 0deg

**Other Improvements**

- RF system => N. Sakamoto, WEM2CCO02
- Beam monitor => T. Watanabe, WEM2CCO05
- RF stability => K. Suda, MOPCP068
- Beam phase => R. Koyama, MOPCP094

**Single turn extraction** => High quality beams
Transmission efficiencies for U beam (stripping efficiency excluded)

N. Fukunishi et al., PAC09
Transmission efficiencies for Ca beam (stripping efficiency excluded)

N. Fukunishi et al., LINAC10

Transmission efficiencies for O beam in Jul. 2010 (stripping efficiency excluded)
Achieved beam intensities

- pol-d(250 MeV/u): 120 pnA: May2009
- $^4$He(320 MeV/u): 1000 pnA: Oct2009
- $^{14}$N(250 MeV/u): 80 pnA: May2009
- $^{18}$O(345 MeV/u): 1000 pnA: Jul2010 => 6.2 kW
- $^{48}$Ca(345 MeV/u): 230 pnA: Jun2010 => 3.8 kW
- $^{86}$Kr(345 MeV/u): 30 pnA(<1min): Nov2007
- $^{238}$U(345 MeV/u): 0.8 pnA: Dec2009
Operational statistics of RIBF

(c. f.RRC operation: 5238 hours)

Jul. 09 - Jul. 10

U238: Exp 287 h + Tuning 801 h
Ca48: Exp 663 h + Tuning 490 h
O18: Exp 310 h + Tuning 96 h
He4: Exp 280 h + Tuning 121 h

Machine Study:
•U238: 343 h (to RRC & fRC)
•Xe136: 154 h (to RRC & fRC)
•Zn70: 49 h (to RRC)
Operational statistics of RIBF

Machine Study:
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- Zn70: 49 h (to RRC)

Jul. 09 - Jul. 10
3) Recent results from RIBF

45 new isotopes from U-fission

T. Ohnishi et al., JPSJ79, 073201 (2010)
4) Developments - a: SC-ECRIS

- Large plasma volume: 1100 cm$^3$
- Flat B$_{\text{min}}$ configuration

Construction started in October 2007. Successfully excited to the designed field in October 2008.

T. Nakagawa, ECRIS’08
Higher extraction voltage =>
• Higher current is expected.
• Space-charge effect will be reduced.
Developments for U beam from SC-ECRIS in 2009

Apr 7: Evacuation of SCECR started
May 11: First beam
Jul 1: O6+ 150 euA
Jul 14: Xe20+ 63 euA
Sep 11: MEBT + RILAC acc. test
Oct 16: Au30+ 17 euA
Oct 29: Au30+ 30 euA
Oct 30: U test started
Nov 9: U35+ 9 euA
Nov 13 -: U35+ 10 euA

U beam intensity in Nov. 2009

(2008 /enA) 2000 870 870 240 240 80 70 35
(2009 /enA) 12600 3800 3400** 670 480* 150* 130* 72

*: FC’s have been improved.  **: Overestimated.
Developments for U beam from SC-ECRIS in 2009

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Nov 13 -: U35+ 10 euA

U beam intensity in Nov. 2009

SC-ECRIS status => T. Nakagawa, WEM1ClO02

(2008 /enA) 2000  870  870  240  240  80  70  35
(2009 /enA) 12600  3800  3400**  670  480*  150*  130*  72

*: FC’s have been improved.  **: Overestimated.
Independent operation of RIBF and SHE research

b: New injector (RILAC2)
RILAC2 Layout

SC-ECR
Upgraded to 28 GHz

M/q=7
680 keV/u

100 keV/u

3.3 keV/u

Prebuncher
18.25 MHz

DTL1-3(QWR)
36.5 MHz

RFQ(4-rod)
36.5 MHz

AVF cyclotron

To RRC
4-rod RFQ

Successfully excited at designed power in August.

H. Fujisawa, NIM A345 (1994) 23
RILAC2 in the AVF room
Commissioning will start in December. => 5 pnA of U beam in FY2011

RILAC2 status => K. Yamada, MOPCP025
4) Developments - c: Charge stripper for U beam

Lifetime of fast rotating foil (100 rpm) < several min.

Carbon Foil 300 \( \mu g/cm^2 \) => Lifetime < 12 hours
Slowly rotating stripper (Apr. 2010)

Before irradiation

After irradiation

0.05 rpm, 38 hours @ 1.4 eμA => Survived!

Fluctuation observed
• Xe beam => N$_2$-gas stripper can be used.

• U beam => The average charge state in the N$_2$-gas stripper was far below the acceptable state in the fRC.
Electron capture and stripping of U in He gas (Apr. 2010)

Low-Z gas stripper with high pressure!

=> 50 - 100 pnA of U-beam will be possible

Eq. Charge state in N₂:
56+ @ 11 MeV/u

66+ @ 11 MeV/u

73+ @ 14 MeV/u

75+ @ 15 MeV/u

Acceptable with fRC: 69+
Thank you for your attention!