International Nuclear Physics Conference  
June 3 – 8, 2007  
Tokyo International Forum
International Nuclear Physics Conference
June 3 – 8, 2007
Tokyo International Forum

For the further advancement of nuclear physics, large-scale research facilities have been constructed in recent years.
Flash Report

on the first outcome from RIKEN RI beam factory commissioned on March 27, 2007

Y. Yano

RIKEN Nishina Center

June 6, 2007
Flash Report
on the first outcome from RIKEN RI beam factory
commissioned on March 27, 2007

Discovery of a very neutron-rich
new isotope Pd 125 (N=79, Z=46)

The first test experiment of RIBF, Last week

Y. Yano
RIKEN Nishina Center
June 6, 2007
World’s First and Strongest
K2600MeV (8,300tons)
Superconducting Ring Cyclotron

345 MeV/u Uranium ($^{238}$U$^{86+}$) beam

$10^8$ particles/s (5 orders of magnitude smaller than the goal intensity)

World’s Largest Acceptance
9 Tm (77 m)
Superconducting RI beam Separator

Fission fragments produced in 7 mm thick Be target
Total dose: $1.08 \times 10^{13}$
Total time: 25.4 hour
Yield Distribution for Z=46

\begin{align*}
119\text{Pd}^{45+} & \ 2.6444(2.6495) & 118\text{ counts} \\
122\text{Pd} & \ 2.6521(2.6577) & 850 \text{ counts} \\
120\text{Pd}^{45+} & \ 2.6666(2.6722) & 157 \text{ counts} \\
123\text{Pd} & \ 2.6739(2.6800) & 580 \text{ counts} \\
121\text{Pd}^{45+} & \ 2.6888(2.6943) & 59 \text{ counts} \\
124\text{Pd} & \ 2.6956(2.7026) & 187 \text{ counts} \\
122\text{Pd}^{45+} & \ 2.7111(2.7177) & 33 \text{ counts} \\
125\text{Pd} & \ 2.7174(2.7255) & 26 \text{ counts} \\
123\text{Pd}^{45+} & \ 2.7333(2.7392) & 7 \text{ counts} \\
126\text{Pd} & \ 2.739() & \\
\end{align*}

A/Q resolution(r.m.s): 0.07%
The great launch
to explore nuclear world
so far inaccessible!
Experiment Team

Y. Mizoi (OECU/Osaka, Japan)
M. Matsushita (Rikkyo U., Japan)
H. Suzuki, T. Nakao, H. Kimura, (U. Tokyo, Japan)
T. Kuboki, T. Yamaguchi, K. Suzuki (Saitama U., Japan)
A. Ozawa, T. Moriguchi, Y. Yasuda (U. Tsukuba, Japan)
T. Nakamura, T. Nannichi, T. Shimamura, Y. Nakayama (Tokyo Tech., Japan)

H. Geissel, H. Weick (GSI, Germany)
J. Nolen (ANL, USA)
O. Tarasov, T. Nettleton, D. Bazin, B. Sherrill, D. Morrissey (NSCL/MSU, USA)
W. Mittig (GANIL, France)
Overview
RI Beam Factory (RIBF), RIKEN Nishina Center, Wako-city
RI Beam Factory (RIBF), RIKEN Nishina Center, Wako-city
RI Beam Factory (RIBF), RIKEN Nishina Center, Wako-city
RI Beam Factory (RIBF), RIKEN Nishina Center, Wako-city

Old Facility: 1975 ~ 1990
16 BJYen
RI Beam Factory (RIBF), RIKEN Nishina Center, Wako-city

Old Facility: 1975 ~ 1990
16 BJYen

RIBF: 1997 ~ (2012)
50 BJYen
Acceleration Flow in RI Beam Production

by N. Miyauchi
Acceleration Flow in RI Beam Production

by N. Miyauchi
Acceleration Flow in RI Beam Production

by N. Miyauchi
Superconducting Ring Cyclotron (SRC) (world’s first)

K = 2,600 MeV
Self Magnetic Shield
Self Radiation Shield
3.8T (240 MJ)
18-38 MHz
8,300 tons
On Nov. 7 2005 full excitation of sector magnets achieved. A 140-ton cold mass cooled down to 4.5 K for 3 weeks.
Yearly trend of price of iron
Yearly trend of price of iron
BigRIPS, Tandem (two-stage) Separator to deliver tagged RI beams

To RI-beam delivery lines & experimental setups

2nd stage (4-bend FRS) Tagging of RI beams

TOF, $B_\rho, \Delta E \rightarrow Z, A/Q (A, Q), P$

Identify RI-beam species in an event-by-event mode

1st stage (2-bend FRS) Production and Separation of RI beams

Isotope separation

Wedge degrader from SRC

Target

T. Kubo, RIKEN
Large acceptance for in-flight fission fragments of $^{238}$U at 350 MeV/u:
$\Delta \phi \sim 100$ mr; $\Delta p/p : 6\%$.
$\sim 50\%$ can be collected.

345 MeV/u U-beam from SRC

Production Target

RI Beam

Second Stage

First Stage

STQ:
14.1 T/m
24 cm $\phi$ warm-bore

5000 tons concrete shielding
Commissioning
First beam extracted from Superconducting Ring Cyclotron At 16:00 on Dec. 28, 2006

27AL10+ 345MeV/nucleon
Japan speeds up nuclear physics

No particle accelerator in the world is strong enough to create a usable beam of uranium ions. But that will change next month, when Japan switches on a huge facility of connected accelerators, to produce the world's most powerful beams of heavy radioactive isotopes. Radioisotopes are forms of elements that are unstable because they contain either more or fewer neutrons than usual, and undergo radioactive decay. Nuclear physicists are studying rare short-lived isotopes to understand their properties and how they are formed. The RIKEN research institute in Saitama, Japan, already has accelerators that can create the world's strongest radioactive beams, but even these are only powerful enough to produce usable beams for the lighter elements.

But next month, RIKEN will switch on a major upgrade. The $4.4 billion ($5.5 billion) Radioactive Isotope Beam Factory will add two more ring cyclotrons and the world's first superconducting ring cyclotron to the existing linear accelerator and ring cyclotron. It will then be able to accelerate beams of any element up to uranium at 70% of the speed of light. The accelerated beams will be used to study the very rare and unstable isotopes that exist in nature. The facility will allow scientists to study nuclear isotopes that exist only in the hottest stars of the Universe, says John Schiffer, a senior scientist at the Argonne National Laboratory in Chicago, Illinois.

As well as exploring the formation of uranium, RIKEN plans to use the properties of various very short-lived nuclei, as well as looking for magic numbers of neutrons and protons that allow heavy nuclei to be surprisingly stable. These experiments will start from next year, with full operation scheduled for 2011. The facility makes Japan the world leader in the field, says Toshiki Fujita, director of the RIKEN Nishina center for accelerator-based science, adding that Japan's other big physics facilities have just been upgraded of US and European countries. "But this time it is different," he boasts. "This time, Japanese scientists are leading the way." Rivals aim to get Japan's investment in new detectors out of the way of the facility. A US plan for a superconducting linear accelerator called the Rare Isotope Accelerator or has stalled, at a proposed cost of $5 billion. But France is expected to complete construction of its new radioisotope facilities, including experiments, by around 2012 and Germany by 2014. "In five or six years, Japan may lose the number one position," says Sydney Gates, director of the French heavy-ion accelerator GANIL, in Caen.

***

BRYON MAXWILLIAMS

Bryon Max Williams is a writer in Moscow.

1678

15 DECEMBER 2006 VOL 314 SCIENCE www.sciencemag.org

Published by AAAS

NATURAL PHYSICS

Japan Gets Head Start in Race to Build Exotic Isotope Accelerators

A new facility begins to explore the structure of the nucleus as Europe awaits two machines and the United States revises its plans

WAKO, JAPAN, AND ROSEMONT, ILLINOIS—Sometime this month, a warning siren will ring through the town of Wako, a city just east of Tokyo. Then, the world's most powerful cyclotron will produce a stream of uranium ions at a cost target. The resulting stream will be sent to a rare isotope accelerator that has never existed before, a superconducting magnetic field of matter that has not been created before. Scientists meeting at the American Physical Society meeting in Chicago, Illinois, one of the institutions that helped finance the machine, say that the universe contains so much more matter than antimatter. They believe that the universe contains so much more matter than antimatter. They believe that the universe contains so much more matter than antimatter. They believe that the universe contains so much more matter than antimatter. They believe that the universe contains so much more matter than antimatter. They believe that the universe contains so much more matter than antimatter.

Meanwhile, a U.S. National Research Council (NRC) report released last week makes the case for building the most powerful machine in all of U.S. researchers hope the report will jump-start a project, once known as the Rare Isotope Accelerator (RIA) that stalled last year after the U.S. Department of Energy (DOE) canceled funding to researchers out in half the project's $5.1 billion cost. "This report helps get the project back on track," says a U.S. researcher who helped finance the machine.

According to the report, more than 99.9% of an atom's mass and less than a billionth of its volume, the nucleus is a knot of protons and neutrons. Nature provides 20 stable nuclei, and researchers have glimpsed 10 times that number of unstable ones. But particles that produce even more would provide new insights into the structure of the nucleus.

For example, since the 1940s, physicists have known that nuclei with certain "magic" numbers of protons or neutrons are more stable than might otherwise be expected. However, recent findings suggest that the known magic numbers—2, 8, 20, 28, 50, 82, and 126—may not apply to nuclei with an extreme excess or deficiency of...
Milestones of Commissioning

At 16:00 on December 28 2006, the first beam extracted from the SRC: a 345 MeV/nucleon 27Al10+ beam was extracted. Its mass to charge ratio is the same as that of a 238U88+ beam. In this acceleration trial we skipped the fRC, because the vacuum leaking took place in this cyclotron. We could, however, confirm the acceleration performance of the SRC.
Milestones of Commissioning

At 16:00 on December 28 2006, the first beam extracted from the SRC: a 345 MeV/nucleon 27Al$^{10+}$ beam was extracted. Its mass to charge ratio is the same as that of a 238U$^{88+}$ beam. In this acceleration trial we skipped the fRC, because the vacuum leaking took place in this cyclotron. We could, however, confirm the acceleration performance of the SRC.

At 3:00 on March 15 2007, the first RI beams were generated and identified by the BigRIPS. A 345 MeV/nucleon 86Kr$^{31+}$ beam, mass to charge ratio of which is the same as that of a 238U$^{86+}$ beam, was projectile-fragmented. In this test run, we succeeded in operating the full cyclotron cascade including the fRC for the first time. After the first beam run, we accelerated a uranium beam with the fRC, and we observed that the most probable charge state after the stripping at 51 MeV/nucleon is 86+ in stead of 88+ originally expected.
Milestones of Commissioning

At 16:00 on December 28 2006, the first beam extracted from the SRC: a 345 MeV/nucleon 27Al10+ beam was extracted. Its mass to charge ratio is the same as that of a 238U88+ beam. In this acceleration trial we skipped the fRC, because the vacuum leaking took place in this cyclotron. We could, however, confirm the acceleration performance of the SRC.

At 3:00 on March 15 2007, the first RI beams were generated and identified by the BigRIPS. A 345 MeV/nucleon 86Kr31+ beam, mass to charge ratio of which is the same as that of a 238U86+ beam, was projectile-fragmented. In this test run, we succeeded in operating the full cyclotron cascade including the fRC for the first time. After the first beam run, we accelerated a uranium beam with the fRC, and we observed that the most probable charge state after the stripping at 51 MeV/nucleon is 86+ in stead of 88+ originally expected.

At 21:00 on March 23 2007, we succeeded in accelerating a 238U86+ beam up to 345 MeV/ nucleon.
At 16:00 on December 28 2006, the first beam extracted from the SRC: a 345 MeV/nucleon $^{27}$Al$^{10+}$ beam was extracted. Its mass to charge ratio is the same as that of a $^{238}$U$^{88+}$ beam. In this acceleration trial we skipped the fRC, because the vacuum leaking took place in this cyclotron. We could, however, confirm the acceleration performance of the SRC.

At 3:00 on March 15 2007, the first RI beams were generated and identified by the BigRIPS. A 345 MeV/nucleon $^{86}$Kr$^{31+}$ beam, mass to charge ratio of which is the same as that of a $^{238}$U$^{86+}$ beam, was projectile-fragmented. In this test run, we succeeded in operating the full cyclotron cascade including the fRC for the first time. After the first beam run, we accelerated a uranium beam with the fRC, and we observed that the most probable charge state after the stripping at 51 MeV/nucleon is 86+ in stead of 88+ originally expected.

At 21:00 on March 23 2007, we succeeded in accelerating a $^{238}$U$^{86+}$ beam up to 345 MeV/ nucleon.

And eventually, at 6:40 on March 27, we successfully identified a large variety of RI beams produced via the in-flight fission of the 345 MeV/nucleon uranium beam.
First RIB Prod.
15\textsuperscript{th} Mar. 2007

$^8_6\text{Kr} + \text{Be}(2\text{mm})$ at 345 MeV/u
First Fission Fragment Prod.
27th Mar. 2007

$^{238}\text{U} + \text{Be}(7\text{mm})$
at 345 MeV/u

T. Kubo et al.
Beam Transmission efficiency in the first test run

Charge Striping: 35+ to 71+ at 11 MeV/u 15% by a 0.3 mg/cm² thick carbon foil

Charge Striping: 71+ to 86+ at 51 MeV/u 25% by a 17 mg/cm² thick carbon foil

U35+ 2,000 enA (3.400 × 108 particles/sec.)

U86+ 2 enA (1.4 × 108 particles/sec.)
Miserable efficiency: 1%

We were confronted with a variety of machine troubles in this first long run. The troubles were as follows:

A flat-top cavity of the IRC could not be excited because its high-power leakage rf electromagnetic wave damaged discharge damper resistors of electrostatic inflector and deflector placed nearby this cavity; the deflector channel for the beam extraction with a curvature of 90 m was incorrectly manufactured to have inverse curvature against the beam trajectories;

In the SRC, 1 rf cavity among 4 rf cavities and a flat-top cavity could not be excited due to burn out of the contact fingers and the oscillator trouble; even in the operational three rf cavities, enough acceleration voltages could not be generated due to the lack of enough conditioning time.

These troubles brought about miserable beam transmission efficiency and experimental duty factor. This test experiment run was carried out for machine debugging and conditioning, and operator training, as well.
Acceleration performance of RIBF

by AVF → RRC → SRC for \( m/q = 2 \) inc. \( d \)

with fRC (SRC)

\[ I = 1 \mu A \text{ (goal)} \]

Energy (MeV/nucleon)

Atomic Mass

H O Ar Kr Xe Bi U

1 40 80 120 160 200 240
Acceleration performance of RIBF

by AVF→RRC→SRC for m/q=2 inc. d

with fRC (SRC)

$^{27}\text{A}^{10+}$

$I = 1 \mu A$ (goal)

with fRC (IRC)

RRC

IRC

Atomic Mass

H O Ar Kr Xe Bi U

1 40 80 120 160 200 240

Energy (MeV/nucleon)
Acceleration performance of RIBF

by AVF→RRC→SRC for m/q=2 inc. d

with fRC (SRC)

$^{27}\text{Al}^{10+}$ $^{86}\text{Kr}^{31+}$

$I = 1 \mu\text{A} \ (\text{goal})$
Acceleration performance of RIBF

by AVF→RRC→SRC for m/q=2 inc. d

with fRC (SRC)

$^{27}_{A}^10^+$

$^{86}_{Kr}^{31}$

$^{238}_{U}^{86}$

$\ L = 1\ \mu A\ (goal)$

Energy (MeV/nucleon)

 SRC

 with fRC (IRC)

 RRC

 IRC

 Atomic Mass

 H O Ar Kr Xe Bi U

 1 40 80 120 160 200 240
Future Upgrades

- Repair, Conditioning
- New Injector to RRC, with 28 GHz SC-ECRIS
- Liquid Li Charge Stripper
- Construction of Major Experimental Installations
New injector to RRC will be operational late in 2008

These components will be constructed by modifying the existing ones
Conceptual design of new SC-ECRIS (28 GHz)
Operation test will be started in summer 2008

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(B_{\text{axial}})_{\text{max}}$</td>
<td>4T</td>
</tr>
<tr>
<td>$(B_{\text{rad}})_{\text{max}}$</td>
<td>2T</td>
</tr>
<tr>
<td>$B_{\text{min}}$</td>
<td>0~1T</td>
</tr>
<tr>
<td>Chamber length</td>
<td>51 cm</td>
</tr>
<tr>
<td>Mirror-mirror space</td>
<td>51 cm</td>
</tr>
<tr>
<td>Chamber diameter</td>
<td>15 cm</td>
</tr>
</tbody>
</table>

Final goal
$U^{35+} > 15 \mu A$
## Comparison of other operational ECR sources

<table>
<thead>
<tr>
<th></th>
<th>AECR-U</th>
<th>RIKEN</th>
<th>VENUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq. (GHz)</td>
<td>14GHz</td>
<td>18GHz</td>
<td>28GHz</td>
</tr>
<tr>
<td>$B_{inj}/B_{min}$</td>
<td>4</td>
<td>2.8</td>
<td>4</td>
</tr>
<tr>
<td>$B_{rad}/B_{min}$</td>
<td>2.1</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Plasma volume (cm$^3$)</td>
<td>$\sim$125</td>
<td>$\sim$100</td>
<td>$\sim$500</td>
</tr>
<tr>
<td>DB/DR (kG/cm)</td>
<td>$\sim$2.7</td>
<td>2.7</td>
<td>$\sim$2.6</td>
</tr>
<tr>
<td>RF power (kW/L)</td>
<td>$\sim$1.0</td>
<td>0.3</td>
<td>$\sim$0.5</td>
</tr>
<tr>
<td>Method</td>
<td>UO$_2$+Oven</td>
<td>UF$_8$</td>
<td>Bi+Oven</td>
</tr>
<tr>
<td>$^{35}$U</td>
<td>16µA</td>
<td>2µA</td>
<td>180µA</td>
</tr>
<tr>
<td></td>
<td>(0.45pµA)</td>
<td>(0.06pµA)</td>
<td>(5. pµA)</td>
</tr>
</tbody>
</table>

$$I_q = \frac{n_q q V}{\tau_c}$$

- $n_q$ : ion density
- $q$ : charge state
- $V$ : plasma volume
- $\tau_c$ : ion confinement time
### Comparison of other operational ECR sources

<table>
<thead>
<tr>
<th></th>
<th>ABCR-U</th>
<th>RIKEN</th>
<th>VENUS</th>
<th>SC-ECRIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq. (GHz)</td>
<td>14GHz</td>
<td>18GHz</td>
<td>28GHz</td>
<td>28</td>
</tr>
<tr>
<td>$B_{\text{inj}}/B_{\text{min}}$</td>
<td>4</td>
<td>2.8</td>
<td>4</td>
<td>&gt;4</td>
</tr>
<tr>
<td>$B_{\text{rad}}/B_{\text{min}}$</td>
<td>2.1</td>
<td>2.2</td>
<td>2.2</td>
<td>&gt;2.2</td>
</tr>
<tr>
<td>plasma volume (cm$^3$)</td>
<td>~125</td>
<td>~100</td>
<td>~500</td>
<td>~1100</td>
</tr>
<tr>
<td>DB/DR (kG/cm)</td>
<td>~2.7</td>
<td>2.7</td>
<td>~2.6</td>
<td>2.7</td>
</tr>
<tr>
<td>RF power (kW/L)</td>
<td>~1.0</td>
<td>0.3</td>
<td>~0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Method</td>
<td>UO$_2$+Oven</td>
<td>UF$_6$</td>
<td>Bi+Oven</td>
<td>UO$_2$+IH oven</td>
</tr>
<tr>
<td>$^{35}$U</td>
<td>16µA</td>
<td>2µA</td>
<td>180µA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.45µA)</td>
<td>(0.06µA)</td>
<td>(5.0µA)</td>
<td></td>
</tr>
</tbody>
</table>

\[ I_q = \frac{n_q q V}{\tau_c} \]

- $n_q$ : ion density
- $q$ : charge state
- $V$ : plasma volume
- $\tau_c$ : ion confinement time
### Comparison of other operational ECR sources

<table>
<thead>
<tr>
<th></th>
<th>ABCR-U</th>
<th>RIKEN</th>
<th>VENUS</th>
<th>SC-ECRIS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Freq. (GHz)</strong></td>
<td>14 GHz</td>
<td>18 GHz</td>
<td>28 GHz</td>
<td>28</td>
</tr>
<tr>
<td>$B_{inj}/B_{min}$</td>
<td>4</td>
<td>2.8</td>
<td>4</td>
<td>&gt;4</td>
</tr>
<tr>
<td>$B_{rad}/B_{min}$</td>
<td>2.1</td>
<td>2.2</td>
<td>2.2</td>
<td>&gt;2.2</td>
</tr>
<tr>
<td>plasma volume (cm³)</td>
<td>~125</td>
<td>~100</td>
<td>~500</td>
<td>~1100</td>
</tr>
<tr>
<td>DB/DR (kG/cm)</td>
<td>~2.7</td>
<td>2.7</td>
<td>~2.6</td>
<td>2.7</td>
</tr>
<tr>
<td>RF power (kW/L)</td>
<td>~1.0</td>
<td>0.3</td>
<td>~0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Method</td>
<td>UO₂+Oven</td>
<td>UF₆</td>
<td>Bi+Oven</td>
<td>UO₂+IH oven</td>
</tr>
<tr>
<td>$^{35}\text{U}$</td>
<td>16μA (0.45μA)</td>
<td>2μA (0.06μA)</td>
<td>180μA (5.μA)</td>
<td>&gt;530μA (16μA)</td>
</tr>
</tbody>
</table>

\[
I_q = \frac{n_q q V}{\tau_c}
\]

- $n_q$: ion density
- $q$: charge state
- $V$: plasma volume
- $\tau_c$: ion confinement time
Conceptual design of Liquid Li Stripper
Operation test will be started in autumn of 2007

SH200 silicone oil of 50 cst kinematic viscosity is used. An about 0.1-mg/cm²-thick film (of silicone oil withstanded approximately 8 W/cm² heat deposit at maximum. (10 kW/cm² for 1 pμA 350 MeV U beam)
Conceptual design of Liquid Li Stripper
Operation test will be started in autumn of 2007

SH200 silicone oil of 50 cst kinematic viscosity is used. An about 0.1-mg/cm²-thick film (of silicone oil withstood approximately 8 W/cm² heat deposit at maximum. (10 kW/cm² for 1pµA 350 MeV U beam)
Conceptual design of Liquid Li Stripper
Operation test will be started in autumn of 2007

SH200 silicone oil of 50 cst kinematic viscosity is used. An about 0.1-mg/cm²-thick film (of silicone oil withstood approximately 8 W/cm² heat deposit at maximum. (10 kW/cm² for 1pμA 350 MeV U beam)

11 MeV/u
25 pμA
U beam

Liquid Li
Major Experimental installations planned

- Electron Scattering (ISOL+SCRIT+e-Storage Ring)
- Zero-degree Spectrometer
- Polarized RI beam (IRC return beam line+RIPS + Gas Catcher+Steen Gerlach)
- SLOWRI (Gas Catcher+rf Ion Guide)
- SHARAO
- SAMURAI
- Rare RI ring
- New Injector
Major Experimental installations planned

- Electron Scattering (ISOL+SCRIT+e-Storage Ring)
- Zero-degree Spectrometer
- Polarized RI beam (IRC return beam line+RIPS + Gas Catcher+Stern Gerlach)
- SLOWRI (Gas Catcher+rf Ion Guide)
- SHARAQ
- SAMURAI
- Rare RI ring
- New Injector
Major Experimental installations planned

- Polarized RI beam (IRC return beam line + RIPS + Gas Catcher + Stern Gerlach)
- Electron Scattering (ISOL + SCRIT + e-Storage Ring)
- Zero-degree Spectrometer
- SLOWRI (Gas Catcher + rf Ion Guide)
- SHARQ
- SAMURAI
- Rare RI ring

October 2007

October 2008
Major Experimental installations planned

Observed elastically scattered electrons off self-confined Cs ions on Apr. 28 2007

Electron Scattering (ISOL+SCRIT+e-Storage Ring)

Zero-degree Spectrometer

Polarized RI beam (IRC return beam line+RIPS + Gas Catcher+Stern Gerlach)

SLOWRI (Gas Catcher+ rf Ion Guide)

SAMURAI

SHARAQ

Rare RI ring

New Injector

October 2007

October 2008
Great expansion of nuclear world by RIBF
Intensity > 1 particle/day

(EPAX@GSI)

New Element $^{278}_{113}$
04 July 23 18:55
57 fb

protons

$^{125}$Pd

(Sn) 50

(Ni) 28

(Ca) 20

(O) 8

(He) 2

neutrons

126 (magic number)
Great expansion of nuclear world by RIBF
Intensity > 1 particle/day

(EPAX@GSI)

\[ ^{125}\text{Pd} \]

\[ ^{278}\text{113} \]
04 July 23 18:55
57 fb

New Element

(neutrons)
Great expansion of nuclear world by RIBF
Intensity > 1 particle/day
(EPAX@GSI)

\[
\text{protons} \quad \uparrow \quad \text{neutrons} \quad \rightarrow
\]

- \( ^{125}\text{Pd} \)
- \( \text{(Sn) 50} \)
- \( \text{(Ni) 28} \)
- \( \text{(Ca) 20} \)
- \( \text{(O) 8} \)
- \( \text{(He) 2} \)
- \( \text{(U) 82} \)
- \( \text{(Pb) 82} \)
- \( \text{(magic number) 126} \)
- \( \text{New Element} \ 278^{113} \)
  04 July 23 18:55
  57 fb

- Projectile Fragmentation
- In-flight U fission & P.F.
Great expansion of nuclear world by RIBF
Intensity > 1 particle/day
(EPAX@GSI)

278
113
04 July 23 18:55
57 fb

New Element

125Pd

(Sn) 50

(Pb) 82

(U)

(Ni) 28

(Ca) 20

(O) 8

(He) 2

(neutrons →

protons

magic number

Projectile Fragmentation

In-flight U fission & P.F.
Great expansion of nuclear world by RIBF
Intensity > 1 particle/day
(EPAX@GSI)
Great expansion of nuclear world by RIBF
Intensity > 1 particle/day

(EPA@GSI)

125Pd

10 particles/sec. (goal) by 1pμA

Projectile Fragmentation
In-flight U fission & P.F.
Back Up
Cool-down of the SRC

Cold Mass
Stainless Steel: 101 ton
Aluminum: 41 ton

T (ColdMass, Ret.)
T(Sup)
Calculation

23 Days
Example of field mapping of SRC
Along the center line of the sector magnet

Field strength

\[ B(T) \]

\[ R (\text{m}) \]

Radius from machine center

**Main 5000A, trim 1-4 3000A**
Example of field mapping of SRC
Along the center line of the sector magnet

Field strength vs. Radius from machine center

- \text{main 5000A, trim 1-4 3000A}

- \text{B_{meas}}

- \text{B_{calc(hnish)}}
Example of field mapping of SRC
Along the center line of the sector magnet

K2500MeV Achieved!!
Merits of the present iron-covered structure. (Y. Yano, 2000)

(Self magnetic-flux and radiation leakage-shield structure)

(1) We do not need any extra non-magnetic (!) local radiation shielding of the concrete blocks as big as 3 m cubes.
(2) The stray field in the valley (whose flux direction is opposite to that of the sector field) is reduced from 0.5 T to 0.04 T (at maximum).
(2-1) The maximum sector field needed is reduced. (3.8 T realized!)
(2-2) The maximum magnetomotive force required is also reduced. (4MAT realized! Without coil quenching)
(2-3) The maximum stored energy and the electromagnetic forces exerted onto the main coil are significantly reduced. (Confirmed!)
(2-4) We need not use the superconducting magnetic channels .
(2-5) The shift of the injection and extraction trajectory depending on the negative stray field strength is greatly reduced (almost no shift.) .
(2-6) We use the rf cavities and valley chambers having the structures with small modifications to those of the IRC because of the low stray field.

(3) The stray field outside the SRC is reduced to a few gauss. We need neither the active magnetic shielding difficult to fabricate nor the thick iron plates enclosing the huge SRC vault.
(3-1) We place the rf oscillators near the SRC like the RRC and the IRC. (<40gauss)
(3-2) The SRC vault is now very safe for working people even inside the SRC.

(4) Reducing the cold mass by placing the pole at the room temperature significantly shortens the cooling time. (~24 days)
## Basic parameters of BigRIPS

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Two-stage separator</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Two bends</td>
</tr>
<tr>
<td>First stage</td>
<td>Four bends</td>
</tr>
<tr>
<td>Second stage</td>
<td>Achromatic wedge</td>
</tr>
<tr>
<td>Energy degrader</td>
<td>Superconducting</td>
</tr>
<tr>
<td>Quadrupoles</td>
<td></td>
</tr>
<tr>
<td><strong>Angular acceptance</strong></td>
<td></td>
</tr>
<tr>
<td>Horizontal</td>
<td>80 mr</td>
</tr>
<tr>
<td>Vertical</td>
<td>100 mr</td>
</tr>
<tr>
<td>Momentum acceptance</td>
<td>6 %</td>
</tr>
<tr>
<td>Max. magnetic rigidity</td>
<td>9 Tm</td>
</tr>
<tr>
<td>Total length</td>
<td>77 m</td>
</tr>
<tr>
<td>Momentum dispersion*</td>
<td></td>
</tr>
<tr>
<td>First stage</td>
<td>-2.31 m</td>
</tr>
<tr>
<td>Second stage</td>
<td>3.3 m</td>
</tr>
<tr>
<td>Momentum resolution** (1st order)</td>
<td></td>
</tr>
<tr>
<td>First stage</td>
<td>1290</td>
</tr>
<tr>
<td>Second stage**</td>
<td>3300</td>
</tr>
</tbody>
</table>

* At the mid-focus of the stage.

** Those in the case when a 1 mm beam spot is assumed.

In-flight fission of $^{238}\text{U}$ at 350 MeV/u
\~ 100 mr
\~ 10 %

T. Kubo et al.
Setup for May-2007 Commissioning

Double Achromatic
PL 0.2mmt
PPAC(x,y) x2
Silicon 0.33 mmt x2 for $\Delta E$
NaI for E
Clover for isomeric states

Setup to search for new isotopes

Double Achromatic
PL 0.2mmt
PPAC(x,y) x2

Mom. Slit
Dp/p=2% (Max 6%)
W/o Wedge

Momentum Dispersive
PPAC(x,y) x2

Prod. Target Be 7mmt
Beam-intensity monitor
PL 1mmt x 3
Why 350 MeV/u?

Relative Yields for a Variety of Rare Isotopes

70% of light speed

Heavy-ion energy (MeV/u)