BRIF: from the First Proton Beam to RIB Production

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The location of CIAE

CIAE was found in 1950.
BRIF: from the First Proton Beam to RIB Production

12 Accelerators

6 Reactors

Land: 900 km²
The International Science and Technology Cooperation Forum for the 60th Anniversary of “First Reactor and First Cyclotron of China”
In 1958, the First Cyclotron was put into operation, Vice Premier Chen Yi cut the ribbon at the ceremony.
In late 1960s and earlier 1970s, it was upgraded to the varying energy, isochronous cyclotron.
In 1988, the merit cyclotron was shut down after 30 years operation.
Refer to IBA original design, CIAE redesigned and constructed a 30 MeV cyclotron CYCIAE-30 for medical isotopes production. 370 µA extracted beam was got at the end of 1994.

For the production of
- Tl-201
- Pd-103
- F-18
- Ga-67
- Co-57
- Ge-68
- I-123
- In-111


370 µA proton beam was extracted from a 30 MeV compact H⁻ cyclotron CYCIAE-30 at the end of 1994.
BRIF: from the First Proton Beam to RIB Production

10MeV, 430μA
First, Second Small Cyc
PET Cyclotron, 14 MeV, 450 μA

10th Small Cyc, under construction for BNCT
Main Parts of Small Cyclotron, 14 MeV, 100 μA to 400 μA, for Canada

EMIS- 2018, Sept. 16- 21, CERN, Switzerland
China Institute of Atomic Energy
Development of proton cyclotrons with high intensity at CIAE

- 2009, 10 MeV, 430 μA
- 2012, 14 MeV, 450 μA
- 1994, 30 MeV, 370 μA
- 2009, 10 MeV, 430 μA
- 2012, 14 MeV, 450 μA
Plan of Talk

a) BRIF - Beijing Radioactive Ion-beam Facility
   a) Introduction
   b) First Proton Beam

b) CYCIAE-100 Beam Development
   a) Increase Intensity and Improve Stability
   b) mA Acceleration Efforts
   c) Dual Beam Extraction simultaneously

c) CYCIAE-100 for ISOL and Other Applications
   a) Beam lines of CYCIAE-100
   b) ISOL system and Mass Resolution Improvement
   c) RIBs Production and Beam Time Application Opened for User
   d) Proton Irradiation and Other Applications
As one of the main projects at CIAE, the Beijing Radioactive Ion-beam Facility (BRIF) have been used in fundamental and applied research such as neutron physics, nuclear structure, material and life sciences, medical isotope ……
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General View of the 100 MeV Cyclotron

- **CW mode**, high current
- energy variable;
- Dual beam extracted simultaneously;
- Low extraction beam losses

**First stage:** 70 MeV ~ 100 MeV, 200 ~ 500 µA: 20 kW ~ 50 kW

**Second stage:** 30 MeV ~ 100 MeV, 1 mA, 100 kW.
Tolerance Control:
- Hill gap--0.05mm,
- Pole edge--0.1mm,
- others

The installation, mapping and shimming of the main magnet system are finished by July, 2013
Installation of RF, Vacuum, R-probes, extractors, central region, RF conditioning were finished by the end of 2013.
On December 18 of 2013, we got 320 μA DC beam on an internal target. The transmission efficiency from the ion source to the exit of inflector is higher than 80%.
Beam Commissioning

On December 18 of 2013, we got 320 $\mu$A DC beam on an internal target. The transmission efficiency from the ion source to the exit of inflector is higher than 80%.

July 4, 2014, we got first 100 MeV proton beam Extracted
Beam Commissioning

12 hours running test with extracted beam current > 23 $\mu$A, on July 25, 2014

- Inflector sparking
- Power supply failure

8hrs 50min
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Increase Intensity and Improve Stability

- Matching for injection line:
  - S-B-QQQ-S, 2.5m
  - 8-10 mA, 40keV

In order to Increase Intensity and Improve Stability, the:

**Beam matching from ion source to the central region,**

**Ion Source,**

**Water Cool central region etc.**
Increase Intensity and Improve Stability

- The multi-cusp ion source on the test stand:
  - 18mA, 30 keV
  - → 10mA, 40 keV
Increase Intensity and Improve Stability

- The multi-cusp ion source on the test stand:
  - 18mA, 30 keV
  - → 10mA, 40 keV

New XY steering magnet

Improvement of the extractor

New ground electrode
Increase Intensity and Improve Stability

High Power Beam Dump

- For 100 MeV extracted beam
- 200 µA

Water cool Central region
Research Activities Related to Low Energy Accelerators in CIAE
China Institute of Atomic Energy
EMIS-2018, Sept. 16-21, CERN, Switzerland

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Vacuum Dissociation, H- Beam Losses

Double layer pumping system for main vacuum improvement
Increase Intensity and Improve Stability

BD, for 200μA

DCCT, for 5-500μA cw beam, accuracy: 0.5%

FC, for 10pA-50μA
Beam Intensity can be fine adjustable from 10pA, nA to a few μA, with about 1% stability for one week continuous operation.

Proton Irradiation

Proton Radiography

Principle Experiment
mA Beam Acceleration Efforts

- Matching for injection line:
  - S-B-QQQ-S, 2.5m
  - 8-10 mA, 40keV

In order to get mA level acceleration beam, several aspects are improved. Besides the ion source, beam matching from ion source to the central region, also the buncher system, beam loading of the RF system, space charge effects limit, etc.
mA Beam Acceleration Efforts

- Non-intercepting 2-gap buncher
- Between the first solenoid and the triplet, ~1.1m away from the inflector.
- Gap=5 mm and D=0.5\(\beta\gamma\) instead of 1.5\(\beta\gamma\) at TRIUMF

LC matching circuit

Buncher driven by 600W amplifier

CTS model
### mA Beam Acceleration Efforts

**Buncher**

- **In June, 2016, we got accelerated beam > mA**
  - 1073μA

<table>
<thead>
<tr>
<th>Ion source (mA)</th>
<th>Without Buncher (μA)</th>
<th>With Buncher (μA)</th>
<th>Bunching efficiency</th>
<th>Acceleration efficiency (%)</th>
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</thead>
<tbody>
<tr>
<td>1.33</td>
<td>100</td>
<td>201</td>
<td>2.01</td>
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<td>9.52</td>
<td>636</td>
<td><strong>1073</strong></td>
<td>1.68</td>
<td>11.2</td>
</tr>
</tbody>
</table>
mA Beam Acceleration Efforts

- The mA level beam is a heavy load for the RF system and may cause an open-loop condition for the Dee voltage regulation.
- To achieve an accurate amplitude control, the LLRF adopts a self-adaptation strategy to ensure the control loop is always closed, unless the power requirement exceeds 120% of nominal value.

![Diagram of mA Beam Acceleration Efforts](image)
The tuner of the cavity consists of a fine capacitor and a coarse capacitor driven by two DC motors.

Based on the thermal situation after some operation of the cavities, the fine tuner was changed to a smaller one to achieve more precise tuning of the RF cavity. The residual tuning errors are reduced to less than 3 degrees for both cavities.
In June, 2016, we got accelerated beam $> \text{mA}$

$1073 \mu\text{A}$
In June, 2016, we got accelerated beam > mA

1 mA

RF sparking

Inflector sparking

1135 μA
**Dual Beam Extraction simultaneously**

- Fine adjustments of the two stripping foils
  1. The positions = Energy,
  2. Orientations = Beam Optics
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| S1: 1-5μA, S2: 50-200μA, S3: 10pA -10nA | N1: 300nA – 200μA, N2: 5-10μA (potential intensity of 200μA, ISOL) |

South Extracted Beam | North Extracted Beam
Dual Beam Extraction simultaneously

The proton beams have been extracted in dual opposite directions by charge exchange stripping devices at the same time, from CYCIAE-100. The extracted proton beam energy can be adjusted continuously between 70 MeV and 100 MeV.
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Proton Radiography

Principle Experiment

Radiation effects for electronics and biology

Wide Spectra Neutron Source

Beam Dump & Isotope Production

Beam Line for ISOL System

1st 2nd separators

m/Δm=20000 ρ=2.5 m

Proton Radiography Principle Experiment

Radiation effects for electronics and biology
As one of the main projects at CIAE, the **Beijing Radioactive Ion-beam Facility (BRIF)** will be used in fundamental and applied research such as neutron physics, nuclear structure, material and **life sciences, medical isotope production**.
ISOL system, Mass Resolution Improvement & RIBs Production

1. In May of 2014, the stable $^{39}\text{K}$ beam
2. The mass resolution: $\sim10000$.
3. The transmission efficiency is higher than 70% under the high mass resolution condition.
1. On Oct 20, 2014, the stable beam, produced by ISOL system, was tested and accelerated by Tandem.

2. The mass resolution: 14385
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2. The mass resolution: 14385

3. On May 26, 2017, the mass resolution: 24460

4. The transmission efficiency is higher than 90% for the 2nd stage of separators.
ISOL system, Mass & RIBs Production

100 MeV proton beam on CaO target
Production of $^{38}\text{K}^+$: $1 \times 10^6$ pps

The first RIB by BRIF, May 2015

The gamma spectra of $^{38}\text{K}$ after separator

RIB To Tandem
In 2017, the RIB $^{20}$Na has been generated for decay data measurement. MgO is selected for the production of $^{20}$Na. The discs of MgO targets were prepared by hot-pressing sintering process at 1200°C, density of the targets is 1.2 g/cm$^3$. The significant contraction (~20%) of MgO targets was observed in the heating experiment at 1600°C for 4 hours. And the density of the target after shrinkage is about 2.4 g/cm$^3$.

Because the MgO discs shrinks obviously, to prevent the beam from passing through the target tube directly, the MgO target fragments were filled into the gap between the discs and the target tube.
ISOL system, Mass Resolution Improvement & RIBs Production

In the first On-line experiments, the $^{20}\text{Na}$ beam wobbles after passing through the main dipole magnet since the instability of proton beam. The beam fluctuation is reduced by the better stability of proton beam and high voltage platform. The experiment for the decay data measurement of $^{20}\text{Na}$ was successfully completed.

When the proton beam is 10µA, the yield of $^{20}\text{Na}$ at the experimental terminal can reach $1.35\times10^5$ PPS. The $^{20}\text{Na}$ beam has been delivering to target for more than 230 hours.
In Oct 2016, the **White light neutron source** installed, and shielded.
Proton Irradiation and Other Applications

In Nov 2016, the PIF installed, n flux tested
Proton Irradiation and Other Applications

Proton irradiation of single crystal diamond module; Radiation protection effect of typical materials for manned spacecraft

0.25μm 8×512k×8bits CMOS SRAM
Proton Irradiation and Other Applications

Proton radiography experiment

- Point-to-point imaging means $R_{12} = R_{34} = 0$, so the final position is independent of the initial angle.
- The Zumbro magnetic has a Fourier plane, where the position of a particle is determined by its initial angle only and is independent of its initial position (angle sorting).

Pinhole collimator
Proton Irradiation and Other Applications

Medical isotope production

Target Irradiation System
Cross-Section

EMIS 2018, Sept. 16-21, CERN, Switzerland
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The beam commissioning on the CYCIAE-100 is completed. We got the first 100 MeV proton beam on July 4, 2014, and the first RIB on May 4, 2015, 1mA proton beam on internal target in June, 2016. The 100 MeV cyclotron is able to provide 200 μA proton beam, dual beam extraction simultaneously. It has been put into routine operation since 2017.

It is confirmed that 10pA to a few nA proton beam is also be provided stably by the high current machine CYCIAE-100 after we deliver beam for more than 10 users for the studies of radiation damage etc.

After the first RIB production, the mass resolution of ISOL system is improved, better than 20000 with the transmission efficiency higher than 90% for the 2nd stage of separators. More RIBs was produced, e.g. $^{20}$Na last year.
By using the proton beam from 1 MeV to 100 MeV, from 10pA to mA provided by Tandem, CYCIAE-10, 30, and 100 Application is opened for users every year

Welcome to visit Cyclotron Lab at CIAE,
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