Commissioning of a 70 MeV proton cyclotron system of IBS, Korea

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Layout of Rare Isotope Science Project (RISP)

Budget: ~1.3 billion USD (~0.9 billion for building and land)
Total area: ~0.95 km$^2$
RI beam production by **ISOL method for RISP**

1. ISOL system
   - SCL3
   - SCL2
2. In-flight fragment separator
   - 70 MeV proton Cyclotron

**Layout of ISOL**

**Charge breeding by EBIS**

<table>
<thead>
<tr>
<th>Ion</th>
<th>TIS</th>
<th>EBIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{132}\text{Sn}^{1+}$</td>
<td>$^{132}\text{Sn}^{3+}$</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>60 keV</td>
<td>10 keV/u</td>
</tr>
</tbody>
</table>
Chronology of cyclotron system installation and beam tests

2019  June: **Contract with IBA of Belgium**

2020  Jan.: **Finalizing the beam line design**
        Oct.: Field mapping and shimming completed

2021  July−Aug.: **Factory Acceptance Tests** and shipping
        Nov.: Cyclotron rigging and start installation

2022  June: **Internal beam test**
        Sep.: Start of **Site Acceptance Tests**
        Oct.: Max. beam power test (70 MeV, 50 kW) for ~6 hrs

**Specifications of the cyclotron (C70p)**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Energy</td>
<td>30-70 MeV</td>
</tr>
<tr>
<td>Maximum proton intensity</td>
<td>750 μA</td>
</tr>
<tr>
<td>Simultaneous extracted beams</td>
<td>2</td>
</tr>
<tr>
<td>Number of sectors</td>
<td>4</td>
</tr>
<tr>
<td>Hill field</td>
<td>1.6 Tesla</td>
</tr>
<tr>
<td>Harmonic mode</td>
<td>4</td>
</tr>
<tr>
<td>Frequency (fixed)</td>
<td>62 MHz</td>
</tr>
<tr>
<td>Injected H-current</td>
<td>10 mA (H−)</td>
</tr>
<tr>
<td>Total weight</td>
<td>140 tons</td>
</tr>
<tr>
<td>Cyclotron dia.</td>
<td>3.8 m</td>
</tr>
</tbody>
</table>
Beam line design finalized in Jan. 2020

An issue: a long distance (>8m) from the last quadrupole doublet to the ISOL target if a quadrupole doublet is located in cyclotron room

Building was designed based on the previous contract with Best Cyclotron Inc. (2017)
Beam line configuration chosen with beam optics study

Configure 1: Quadrupole doublet in ISOL tunnel (chosen)

Configure 2: No quadrupole magnets in ISOL tunnel
Factory Acceptance Tests remotely (June 2021)

C70 cyclotron at IBA

Magnet current ramping

RF power test

Isochronization of magnetic field

Removable pole edge

Phase excursion

\[ \phi(E_f) = \int_0^{E_f} \frac{2\pi h}{f} \frac{\Delta f(E)}{\Delta E_n \cos \phi(E)} \, dE, \]
Cyclotron System Rigging (Nov. 2021)

Crane (1200 tons)
Installation of all components and utilities (April 2022)

Cyclotron cooling room

Power Supply room

Final focusing & wobbler module in ISOL bunker
RF system test (May 2022)

LLRF $\rightarrow$ Solid State Amp. (5 kW) $\rightarrow$ Final Power Amp. (100 kW)
Optimization of magnet field using Smith-Garren method (June, 2022)

Before Smith-Garren

C70 - H. smith and garren from 120 to 1620nm at 61,062MHz - Configuration 0

Main coil current (A)

After a few iterations

Beam current scanning at differing radii
Turn separations in the cyclotron center region

Radius: 120 mm  220 mm

$V_{\text{dee}}$: 50 kV

$V_{\text{dee}}$: 35 kV

Radial (differential) probe

Radius: 120 mm
Preparation for Site Acceptance Test (Aug. 2022)

- **Cave A** (beamline setup for SAT)
- **Cave B** (radiation shielding for 50 kW)

**ISOL module**
First beam operation in Cave A

Beam dump at ISOL target location

Beam Profile Monitor (IBA)

Measuring beam off-center
ΔX: ~1 mm
ΔY: <0.5 mm

Beam Position Monitor (IBS)

I: ~10 µA

Cave A

Oct. 7 2022
BPM to monitor beam off-center and beam current

1. Calibration of position by moving wire

2. Calibration of beam current using current readings at beam dump

Pohang Light Source (July 2022)
Beam wobbling tests for ISOL operation

Two collimators (15 kW) with apertures of ø2~5cm (target diameter)

- Tune the beam envelope to be at a waist at target location (Beam Profile Measure)
- Adjust ø of beam shape and wobble the beam (60 Hz) to produce beam shapes required

\[ \sigma: 1.5 - 6 \text{ mm} \]
First beam tuning to 700 µA (Oct. 27, 2022)

SAT: 70 MeV, 50 kW for 6 hrs (Oct. 28, 2022)
Preparation for ISOL target operation (Dec, 2022)

ISOL target module

ISOL target (10 kW max, thin slice, UC$_{x}$..) $\rightarrow$ 2000 °C

Not hermetically sealed

Proton diagnostic module (FC, wire scanner, BPM)

Molecular backflow expected

Sectional view of TIS module

No foil to separate vacuum

A beam pipe model for Molflow(CERN)

Cold trap with cryopump

Radioactive gas flow in normal operation is always toward the cyclotron. ~9 m
Fast closing valve and Cryopanel system for safety of ISOL operation

Neutron shutter is replaced by Cryopanel system (20~30 K)

Fast closing valve (< 20 ms, VAT)
Utilizations of C70 (ISOL, neutron, medical isotopes)

- Need to add a new beamline
- Neutron Science?
- Medical isotope?

- ISOL
- Neutrons
- Cave A
- Cave B
- 30 m
- ISOL Cave A
- Medical isotopes
- Space for general utilization
- Ta target for 70 MeV proton (Julich)

Beam line extension needed for target, modulator, reflector
Conclusions

- The cyclotron was successfully tested at 70 MeV, 50 kW for ~6 hrs.

- The beam line in Cave A is being prepared for ISOL operation to provide a test beam this year.

- The cyclotron facility has spare areas in Cave B and a bunker for neutron science and medical isotope production, respectively.