Status of High Intensity Proton Beam Facility at Laboratori Nazionali di Legnaro (INFN)

MARIO MAGGIORE ON BEHALF OF LNL CYCLOTRON TEAM
Final Configuration of Cyclotron and Beamlines

• Up to 9 irradiation target points
• 2 ISOL target stations (A6, A4)
• 3 Shielded bunkers (RI #1, #2, #3) for High Intensity irradiation
• 4 medium and low intensity target areas (A8, A9, A15)

Production and research on radioisotopes for medical application (LARAMED project)

Neutron sources and other applications (NEPIR)

Research with radioactive beams
Beam Sharing (example)

<table>
<thead>
<tr>
<th>ROOM</th>
<th>BTL name</th>
<th>MAIN USE</th>
<th>MAX ENERGY AND CURRENT BEAM (protons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A6</td>
<td>L1</td>
<td>SPES ISOL TARGET 1</td>
<td>40 MeV, 250uA</td>
</tr>
<tr>
<td>A8</td>
<td>L1B</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>A9</td>
<td>L2</td>
<td>NEUTRONS (NEPIR)</td>
<td>35-70 MeV, 50uA</td>
</tr>
<tr>
<td>A9</td>
<td>L3</td>
<td>NEUTRONS (NEPIR)</td>
<td>TBD (low power)</td>
</tr>
<tr>
<td>RI3</td>
<td>L3b</td>
<td>LARAMED-INFN</td>
<td>35-70 MeV, 200uA</td>
</tr>
<tr>
<td>A15</td>
<td>L3c</td>
<td>LARAMED-INFN</td>
<td>35-70 MeV, low power</td>
</tr>
<tr>
<td>RI1</td>
<td>L4</td>
<td>RADIOISOTOPE PRODUCTION</td>
<td>35-70 MeV, 500-700uA</td>
</tr>
<tr>
<td>RI2</td>
<td>L4b</td>
<td>RADIOISOTOPE PRODUCTION</td>
<td>35-70 MeV, 500-700uA</td>
</tr>
<tr>
<td>A4</td>
<td>L6</td>
<td>SPES ISOL TARGET 2</td>
<td>40 MeV, 250uA</td>
</tr>
</tbody>
</table>

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The New Building for SPES project

- 4 years to complete the work
- No additional costs respect to the initial budget
- It was a success of public tender management... in Italy
• 3 levels:
  • -1 floor: heavy shielded section to hold cyclotron and high activation areas (bunkers, ISOL target and RIBs transport)
  • 1st floor: services, conventional and special plants, ancillary laboratories and control room
  • 2nd floor: offices and labs
Cyclotron Areas Arrangement

- CYCLOTRON AND BEAMLINES ROOM (A1)
- SERVICE ROOM (A17)
- BEAM DUMPER ROOM (A6)
- POWER SUPPLY ROOM (A11)
The Cyclotron

Main Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerator type</td>
<td>Cyclotron AVF with 4 sectors, Resistive Magnet</td>
</tr>
<tr>
<td>Particle</td>
<td>Protons (H⁻ accelerated)</td>
</tr>
<tr>
<td>Energy range</td>
<td>35-70 MeV</td>
</tr>
<tr>
<td>Max Current Intensity</td>
<td>700 µA (variable within the range 1µA-700µA)</td>
</tr>
<tr>
<td>Extraction</td>
<td>Dual stripping extraction</td>
</tr>
<tr>
<td>Max Magnetic Field</td>
<td>1.6 T (Bo = 1 T)</td>
</tr>
<tr>
<td>RF System</td>
<td>nr. 2 delta cavities; harmonic mode=4; f_h =56 MHz; 70 kV peak voltage; 50 kW RF power (2 RF amplifiers)</td>
</tr>
<tr>
<td>Ion Source</td>
<td>Multi-cusp volume H⁻ source; ( I_{ext} =8\text{mA} ); ( V_{ext}=40 \text{kV} ); axial injection</td>
</tr>
<tr>
<td>Dimensions</td>
<td>( \Phi=4.5 \text{ m}, \ h=2 \text{ m}, \ W=190 \text{ tons} )</td>
</tr>
</tbody>
</table>

Vacuum system → 4 cryopumps → 5 x 10⁻⁸ torr (beam OFF)
Brief Summary of Cyclotron Roadmap till 2014

- **Cyclotron and one beamline** supplied by BEST Cyclotron System Inc (CAN) who won the public tender in 2010
- Study and Design started in 2011
- Magnet ready in factory (Ottawa) in 2013 (magnetic field mapping)
- RF cavity system installed on mid 2013
- Ion source and injection line installed in 2014
- First beam injected (1 MeV) in factory in Sept. 2014
- Factory Acceptance Test concluded in Nov. 2014
Cyclotron installation at LNL (2015)

- Ottawa, Jan 2015, Cyclotron leaving Factory
- Legnaro, May 2015, Cyclotron at LNL
- LNL, May 2015, first day of operation
- Upper pole installation during 2nd day

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BEST and INFN staff partnership

INFN staff supervises the work, providing technical support and supplies some component:

- Low power faraday cups (1kW)
- High power beam dumper (50 kW)
- Last section of beamline (high radiation environment)
- Beam loss monitors (prototypes)
- Safety and Radiological Survey System
Completion of installation (cyclotron and infrastructure) in 2015- mid2016

Power Supply room

Services room

Water plant

Beamlines Installation

Sliding shielded doors

Labyrinth between A1/A2 rooms

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Cyclotron and beamlines today
50 kW Beam Dump

- Two copper plates tilted by 10 deg
- Aluminum frame
- Indium sealing between Cu and Al material
- Water cooled (6 bar)
- Lead shielding (gamma radiation) and additional external layers of HDPE for neutron flux reduction
- Up to 12 probes for monitoring of temperature of different sections
- All safety devices are redundant
- In June 2016 the installation in the bunker was accomplished out
- Alignment done by laser tracker system
- Vacuum level (beam OFF) $1.5 \times 10^{-5}$ mbar
Control system Beam Dump
Beam Diagnostics

Wobbler system

Faraday cups (500 W)
Beam Halo Monitor 4 sectors (BHM)
Beam Current Monitor (BCM)
Beam Halo Monitor

Wire scanner
Beam dump

Extraction baffles

Beam profile monitor
Wobbling effect

Beam Halo cutter
Radial and Vertical Misalignment Beam check
Beam Halo Monitor
Misalignment Beam check
Beam Commissioning (high power tests)

- On Feb 2016 BEST started the beam commissioning and FAT:
  - Low power test (injection): 900 µA at 1 MeV and 8.5 mA ion source current (Feb 2016)
  - Low power beam accelerated and extracted (May 2016)
  - High power beam extracted and delivered to beam dumper (July 2016-September 2016)

- Up to 500 µA current and 70 MeV energy proton beam (35 kW) delivered to the BD

- Very good Cyclotron vacuum performance (8x10^{-8} mbar with beam ON)
Beam dump vacuum leak

• That vacuum leak maybe is due to some beam hot spot on the BD structure or to the beam trips leading very fast thermal transient on the structure of BD

• Leak is recovered with the beam ON

• Maybe thermal effects lead mechanical movement of plates

• Indium sealing between two different materials (Cu and Al) seems to have failed.
• Beam tests at different power have been done in order to verify the mechanical integrity of the BD structure and its vacuum seal (no visual inspection is available!!).

• The BD appeared not fully compromised and an acceptable vacuum level is achieved ($10^{-4}$ mbar) with beam OFF.

• Nevertheless we decided for safety reason to limit the maximum beam power delivered at 10 kW in order to proceed with the FAT and accomplished out the commissioning.

• Moreover, in January 2017 an additional pumping station has been installed by INFN staff in order to increase the pumping speed of last leg of beamline.
Endurance test

• Final FAT
• 5 days operation 24h
• 200 µA and 40 MeV (SPES target beam parameter)
• Limited number of interventions by the operator
• Automatic procedure to restore the beam after any trip due to accidental sparks (inflector, ion source, RF)

Test passed successfully in June and FAT concluded
Neutron radiation in A1 during beam run (200µA, 40 MeV)

Very low beam losses along beamline: less than 1% after tuning optimization
Gamma radiation survey of A1 after endurance test
Summary

• The high intensity facility whose core is the cyclotron is developing: two main projects for applications of high intensity beam are respectively in advanced phase (LARAMED) and design evaluation (NEPIR).

• The commissioning of cyclotron supplied by BEST is concluded and the training of INFN staff is almost completed.

• The machine achieved 500 µA (35kW) and shows very good performance in terms of vacuum level, acceleration efficiency and transmission as well.

• The endurance test has shown no particular critical issues related to the reliability of the machine and the main system as well.

• From October 2017 the supply should be finally delivered to the INFN cyclotron group whose mission is to provide safe and efficient delivery of high quality and high power proton beam for nuclear physics program (SPES) and applications.
Thanks to people involved in this project:

**Cyclotron**: A. Lombardi, P. Antonini, A. Calore, D. Campo, M. Contran, L. Pranovi

**Infrastructure and Service**: M. Calderolla, N. Ciatara, P. Favaron

**Target and Safety**: J. Esposito, D. Benini, L. De Ruvo, E. Boratto

**Radioprotection**: D. Zafiropulos, L. Sarchiapone

**Controls and Diagnostics**: M. Bellato, F. Gelain, M. Poggi, E. Fioretto, M. Gulmini

**Cyclotron Consultants**: L. Calabretta, C. De Martinis

**Team of Best Cyclotrons System Inc.**
fine
Beam Dump Vacuum trend during endurance test
Beam loss monitoring by the Radiation Survey System

70 MeV 100 µA thru BL1 to BD

limit: 1 Bq/g
Dose rate A1 with 70MeV 100uA
Dose rate Ag with 70MeV 100uA
Accelerators at Legnaro Labs...

- TANDEM – 15 MV
- PIAVE – SC RFQ
- ALPI – SC LINAC
- CYCLOTRON
- CN- 7 MV
- AN- 2 MV

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