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  - Accelerator Development
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- Commissioning Plan

- Summary
Introduction

- Project: Proton Engineering Frontier Project (PEFP)
  - 21C Frontier R&D Program, MEST, Republic of Korea

- Objectives
  - To develop a High Power Proton Linac (100MeV, 20mA)
  - To develop Beam Utilization & Accelerator Application Technologies
  - To Industrialize Developed Technologies

- Period: July 2002 – December 2012

- Budget: 307.4 B KRW (~275.0 M US$)
  - Gov.: 176.3B(57.3%), Local Gov.: 118.2B(38.5%), Industry: 12.9B(4.2%)T
  - 66B KRW to Accel. & Beamline (including R&D & personnel expenses)
Project Site: Gyeongju

- Historic city (Capital of Silla Dynasty)
- Conference host city (LINAC2002, APAC2004)
- Easy access (KTX & Express way)
- Near to the light source (PLS) (30min by car)
- Near to Busan (IPAC2016)
Site Plan

1. Accelerator Tunnel
2. Experimental Hall
3. Ion Beam Facility
4. Utility Building
5. Substation
6. Cooling Tower
7. Water Storages
8. Main Office Building
9. Regional Cooperation Center
10. Dormitory
11. Information Center
12. Sewage Plant
PEFP 100-MeV Linac

Features of the PEFP 100MeV linac

- 50 keV Injector (Ion source + LEBT)
- 3 MeV RFQ (4-vane type)
- 20 & 100 MeV DTL
- RF Frequency : 350 MHz
- Beam Extractions at 20 or 100 MeV
- 5 Beamlines for 20 MeV & 100 MeV

<table>
<thead>
<tr>
<th>Output Energy (MeV)</th>
<th>20</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Peak Beam Current (mA)</td>
<td>1 ~ 20</td>
<td>1 ~ 20</td>
</tr>
<tr>
<td>Max. Beam Duty (%)</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>Avg. Beam Current (mA)</td>
<td>0.1 ~ 4.8</td>
<td>0.1 ~ 1.6</td>
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<tr>
<td>Pulse Length (ms)</td>
<td>0.1 ~ 2</td>
<td>0.1 ~ 1.33</td>
</tr>
<tr>
<td>Max. Repetition Rate (Hz)</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>Max. Avg. Beam Power (kW)</td>
<td>96</td>
<td>160</td>
</tr>
</tbody>
</table>
**PEFP Beam Lines**

- Designed by reflecting user’s requirements (through User Program)
- Developed components: QM, ACM, DM & beam instruments, Beam window

### 20 MeV Beamlines

<table>
<thead>
<tr>
<th>Beam Line</th>
<th>Application Field</th>
<th>Rep. Rate</th>
<th>Avg. Current</th>
<th>Irradiation Condition</th>
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</thead>
<tbody>
<tr>
<td>TR21</td>
<td>Semiconductor</td>
<td>60Hz</td>
<td>0.6mA</td>
<td>Hor. Ext. 300mmØ</td>
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<tr>
<td>TR22</td>
<td>Bio-Medical Application</td>
<td>15Hz</td>
<td>60µA</td>
<td>Hor. Ext. 300mmØ</td>
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<tr>
<td>TR23</td>
<td>Materials, Energy &amp; Environment</td>
<td>30Hz</td>
<td>0.6mA</td>
<td>Hor. Ext. 300mmØ</td>
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<tr>
<td>TR24</td>
<td>Basic Science</td>
<td>15Hz</td>
<td>60µA</td>
<td>Hor. Ext. 100mmØ</td>
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<tr>
<td>TR25</td>
<td>Radio Isotopes</td>
<td>60Hz</td>
<td>1.2mA</td>
<td>Hor. Vac. 100mmØ</td>
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</tbody>
</table>

### 100 MeV Beamlines

<table>
<thead>
<tr>
<th>Beam Line</th>
<th>Application Field</th>
<th>Rep. Rate</th>
<th>Avg. Current</th>
<th>Irradiation Condition</th>
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</thead>
<tbody>
<tr>
<td>TR101</td>
<td>Radio Isotopes</td>
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<td>0.6mA</td>
<td>Hor. Ext. 100mmØ</td>
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<tr>
<td>TR102</td>
<td>Medical Research (Proton therapy)</td>
<td>7.5Hz</td>
<td>10µA</td>
<td>Hor. Ext. 300mmØ</td>
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<tr>
<td>TR103</td>
<td>Materials, Energy &amp; Environment</td>
<td>15Hz</td>
<td>0.3mA</td>
<td>Hor. Ext. 300mmØ</td>
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<tr>
<td>TR104</td>
<td>Basic Science Aero-Space tech.</td>
<td>7.5Hz</td>
<td>10µA</td>
<td>Hor. Ext. 100mmØ</td>
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<tr>
<td>TR105</td>
<td>Neutron Source Irradiation Test</td>
<td>60Hz</td>
<td>1.6mA</td>
<td>Hor. Vac. 100mmØ</td>
</tr>
</tbody>
</table>

**Note:** 33, 45, 57, 69, 80, 91, 100 MeV beam
20 MeV Linac

- Operation at KAERI in Daejeon: Linac test and Beam supply to users
  - RFQ, DTL: designed (PEFP), fabricated (domestic company)
  - Integrated (May 2005)
  - First beam extraction (July 2005)
  - Operation license (June 2007): Avg. Current 1 μA, 4-hour/week
  - User beam service (from July 2007)
  - Operation finish (Nov. 2011)
  - Installation at project site in Gyeongju (Feb. 2012)
Microwave Ion Source

- Goal: 100 hrsoperation without maintenance
- Proton beam with 50keV, 20mA
- DC or Pulse beam operation
- It was installed and successfully working at 20-MeV linac for 240 hrs without maintenance.

Microwave ion source installed in 20-MeV linac
Digital LLRF

- Goal: 1% in amplitude, 1 degree in phase
- Control hardware: Commercially available control board
- Control software: PI implemented in FPGA and EPICS OPI by PEFP
- Digital LLRF was tested at the 20-MeV linac (2010)
Control System

- EPCIS based system
- Timing based on the event system
- Test and operation at the 20-MeV linac
Linac Integrated Test : 20-MeV

- Ion Source, HPRF, LLRF control, overall control system performance check
- 500 us pulse operation, 15Hz repetition rate operation
- Test limited by the radiation shielding at Daejeon
- Beam service : typically 20-MeV, 5mA, 1Hz

20-MeV beam target room during installation at Daejeon

Neutron dose depending on RR
20~100MeV DTL Development

- Total 7 DTL Tanks (20~100MeV)
- Development Complete (Dec, 2010)
- DT aligned (< 50 µm)
- Installed in tunnel (Feb. 2012)

Completion of the last DTL tank  (22th, Dec. 2010)

Tank inside after DT alignment
Building Construction

Accelerator building
Experimental hall

154kV power line and tower

Utility building

Cooling tower

Substation
HVAC
Cooling
Waste Water treatment
20-MeV Linac Disassembly and Movement

- Disassembly of the 20-MeV linac from Dec. 2011
- Movement from Daejeon to Gyeongju (~200km apart)
- DTL and klystron was transported by using the vibration free truck through express way.
- No notable field distortions in DTL before and after (~ 3%) (Daejeon)
- Special supporter with oil jack and caster was used in the tunnel.

DTL tanks inside vibration free truck
Special supporter inside tunnel
Accelerator Installation

- Installed inside tunnel at March, 2012
Beam Line Installation

- Magnet Installed inside experimental hall at May, 2012

TR22
TR23
TR24

45 deg. BM
25 deg. BM
AC magnet

20-MeV Beam line hall

2012/05/08
Klystron Gallery: 2nd Floor

- Installation starts at September, 2012
Modulator Installation: 3rd Floor

- Installation starts at September, 2012
Goal: 100-MeV, 1kW proton beam at TR103 target room beam dump
- Both on-line conditioning and commissioning
- High power conditioning sequence: 3rd floor -> 2nd floor -> Tunnel (1st floor)
- 20-MeV experience is helpful for 100-MeV commissioning
- Accelerator commissioning starts in this winter
- Power increase in parallel with beam service after commissioning
Beam Commissioning

- Beam commissioning plan
  - Beam energy: 100 MeV
  - Peak beam current: 20 mA
  - Average Beam power: 1 kW
  - Commissioning steps:
    - 20 MeV acceleration (experienced)
    - 100 MeV acceleration (1 kW beam dump)
    - Delivery to a 100-MeV target room
  - RF set point: Phase scan method (BPM)
  - Diagnostics:
    - BPM
    - BCM
    - Faraday cup
    - Profile monitor & Emittance scanner
    - BLM
    - Steerer
RF set point of DTL tank

We plan to use the phase scan method to determine the RF operation point.

- A RF set-point program was tested by using artificial experimental data.
- $\chi$-values were calculated for different relative amplitude $A/A_0$.

- RF set-point can be determined at the minimum points in quadratic fitting of $\chi$-values

<table>
<thead>
<tr>
<th>Amplitude</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/A_0 = 0.98</td>
<td>A/A_0 = 1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Artificial Exp.</th>
<th>Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>1.0</td>
</tr>
<tr>
<td>Phase</td>
<td>135.4</td>
</tr>
</tbody>
</table>

Artificial Experimental data includes gaussian error of $\sigma = 0.5^\circ$ in beam phase.
Future Plan

- GeV, MW-class Accelerator suggested by planning studies
  - Long-term Planning for PEFP (STEPI, 2009)
  - Efficient Management and Development Scheme for PAR (MEST, 2010)
- 1GeV, 2MW SRF Proton Linac + Spallation Sources (LP + SP)
  - Included in National Large Research Facility Road Map (2010)

Started SRF R&D from the beginning of the PEFP
SRF R&D

- Prototyping of the 700MHz, 5cell elliptical cavity with domestic company
- Design, fabrication and test experience

Design  Forming  E-beam welding  Tuning

Cleaning  Test preparation  Test  First result
Summary

PEFP Linac and beam lines
- Injector, 3 MeV RFQ, 100 MeV DTL, 10 beam lines
- Developed the linac technologies through this project.

20 MeV linac
- 5 year operation gives us experience on installation, commissioning, and operation of the proton linac.
- Test beam line: supplying proton beams to users

Linac and beam line magnet installation: completed
- 20 MeV part: disintegrated, moved and installed at project site in Gyeongju
- 20 ~ 100 MeV part, beam line magnet: fabrication, tested and installed

Commissioning
- HPRF installation started in September 2012
- Commissioning will start in this winter
- Beam service will start in spring 2013
Thank you for your attention

1GeV Linac