AFAD 2018
Summary of WG5:
Accelerator and its related technologies for hadron (neutron) science

2018. 1. 30.
Moses Chung (정 모세, 鄭 模世)
Ulsan National Institute of Science and Technology (UNIST)
**WG5: Accelerator and its related technologies for hadron (neutron) science. Room 105**

### January 29

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<th>Speaker</th>
<th>Affiliation</th>
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<td>13:30-13:50</td>
<td>Upgrade of Hokkaido University neutron source (HUNS)</td>
<td>Michihiro Furusaka</td>
<td>Hokkaido University</td>
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<td>13:50-14:10</td>
<td>Status of the RIKEN Linac upgrade</td>
<td>Narushiko Sakamoto</td>
<td>RIKEN</td>
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<td>14:10-14:30</td>
<td>Challenge and status of high intensity heavy ion accelerator facility (HIAF) in China</td>
<td>Jiancheng YANG</td>
<td>IMP (Cancel)</td>
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<td>14:30-14:50</td>
<td>Accelerator-driven compact neutron sources in Japan</td>
<td>Katsuya Hirota</td>
<td>Nagoya University</td>
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<td>14:50-15:10</td>
<td>Design of 6 MeV compact cyclotron for neutron based safety inspection</td>
<td>Jong-Seo Chai (presented by Mitra Ghergherehchi)</td>
<td>SungKyunKwan University</td>
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<td><strong>Coffee break</strong></td>
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<tr>
<td>15:40-16:00</td>
<td>Development of CW heavy ion linac at IMP</td>
<td>Xuejun YIN</td>
<td>IMP (Cancel)</td>
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<td>16:00-16:20</td>
<td>A Plan for a Pulsed Neutron Source Based on the KOMAC 100-MeV Proton Linac</td>
<td>Hyuk-Joong Kwon</td>
<td>KAERI</td>
</tr>
<tr>
<td>16:20-16:40</td>
<td>Development of BNCT at DawonSys</td>
<td>Dong-Soo Kim</td>
<td>DawonSys</td>
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<tr>
<td>16:40-17:00</td>
<td>Current Status of the 28 GHz SC-ECRIS for RISP</td>
<td>Yong-Hwan Kim</td>
<td>RISP/IBS</td>
</tr>
<tr>
<td>17:00-17:20</td>
<td>Compact neutron source Development with SKKUCY-13 Cyclotron</td>
<td>Mitra Ghergherehchi</td>
<td>SungKyunKwan University</td>
</tr>
</tbody>
</table>

### January 30

**Session 3 Chair: Jiancheng Yang (IMP) → Moses Chung (UNIST)**

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<tbody>
<tr>
<td>9:00-9:20</td>
<td>Construction and Preliminary Beam Test of RISP 81.25 MHz CW RFQ for Heavy Ions</td>
<td>Bum-Sik Park</td>
<td>RISP/IBS</td>
</tr>
<tr>
<td>9:20-9:40</td>
<td>The current status and future plans of Versatile Ion Beam Accelerator Facility</td>
<td>Byung Seob Lee</td>
<td>KBSI</td>
</tr>
<tr>
<td>9:40-10:00</td>
<td>BEST 70P Cyclotron beam commissioning at LN Legnaro</td>
<td>Vladimir Ryjkov</td>
<td>Best Cyclotron Inc.</td>
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<td></td>
<td><strong>Coffee break</strong></td>
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<tr>
<td>10:30-10:50</td>
<td>Status of an Electron Beam Ion Source for Charge Breeding for RISP</td>
<td>Young-Ho Park</td>
<td>RISP/IBS</td>
</tr>
</tbody>
</table>

15 talks originally planned → 2 talks cancelled
1. “Upgrade of Hokkaido University neutron source (HUNS)” by Michihiro Furusaka (Hokkaido Univ. → Retiring this March !)
1. "Upgrade of Hokkaido University neutron source (HUNS)" by Michihiro Furusaka (Hokkaido Univ. → Retiring this March!)

"Pulsed" "Cold" Neutron Source

- **Electron Linac**
  - 34 MeV, 35 μA,
  - Since 1974

- **Pulsed & Time of flight**
  - 50 PPS, 1.2 kW electron pulse
  - 3 μsec

Stopped operation in Oct. 2017

New electron accelerator

- Same ≈34 MeV (full loading)
  - 1.2 kW → 3 kW
- 50 pps → 100 pps
- Pulse duration:
  - 3 μsec → 4 μsec
On Tungsten

30 MeV electron ~ Proton (7-9 MeV)

→ Similar facilities in Korea?
1. “Upgrade of Hokkaido University neutron source (HUNS)” by Michihiro Furusaka (Hokkaido Univ. → Retiring this March!)

- Intermediate-angle neutron scattering instrument, **iANS** [irons]
- Working with 3+ major steel making companies.
- **Compact focusing SANS** [Small angle n-scattering]
- Successfully got low-Q data in Ni-alloy
- Bragg-edge transmission instrument
- Much improved resolution, 0.5%
- (Single event effects; Routine operation)
RIKEN RI-BEAM FACTORY

**Mission:** Expand the availability of heavier RIB

- Wide Mass Range: from deuteron to uranium
- High Beam Current: 1 particle µA(c.w.)
- Primary Beam Energy: < 345 MeV/u from SRC

**Injector Linac:** RILAC

- Upgrade of beam energy and its intensity

---

2. “Status of the RIKEN Linac upgrade”  
By Narushiko Sakamoto (RIKEN)
The RILAC is going to have upgrade aiming to provide intense heavy-ion beams to continue the experiment of super heavy element (SHE) synthesis challenging the 8th row of the periodic table of elements ($A \geq 119$).

The intense beams of $q/A$ larger than $1/5$ provided by newly constructed SC-ECRIS with 28 GHz rf source will be accelerated up to 6.5 MeV/u.

The superconducting linac (SRILAC) consists of three cryomodules based on QWRs made of bulk Nb.
NEW 28-GHz SC-ECRIS (basically same as the RIBF ECRIS)
1) All Superconducting Mirror System: 6 solenoids (< 4T) and 1 sextupole (< 2T).
2) Powerful microwaves: 28-GHz Gyrotron (> 5 kW) and 18-GHz Krystron (> 1 kW)
3) Large Volumes of Plasma Chamber: 10L, 575mm
4) High Temperature Oven: $^{238}\text{U}^{35+} > 100$ eμA, $^{51}\text{V}^{13+} > 100$ eμA (Higurashi et al, 2017)

Any experience exchange with RAON ECRIS?
2. “Status of the RIKEN Linac upgrade”
By Narushiko Sakamoto (RIKEN)

SRILAC

- 4 RT DTLs will be replaced by three CMs which consists of ten SC-QWRs.
- Energy upgrade:
  - 5 MeV/u (M/q=5) → 6.5 MeV/u (M/q=5)
  - 7.5 MeV/u (M/q=4)
  - 12 MeV/u (M/q=4)
- Total length of the superconducting part is about 7.5 m.
- Focusing element of RT Q-magnets are installed between CMs.
2. “Status of the RIKEN Linac upgrade”
By Narushiko Sakamoto (RIKEN)

→ How can we protect CM from bad vacuum?
3. “Accelerator-driven compact neutron sources in Japan” By Katsuya Hirota (Nagoya University)

**Neutron sources in Japan**

- **HUNS**
  - Cold-fast neutron
  - $10^4 n/sec/cm^2$ (cold)
- **AIST**
  - Under Construction
  - Cold neutron
- **RANS**
  - Thermal-fast neutron
  - $10^5 n/sec/cm^2$
- **KUANS**
  - Thermal neutron
  - $10^4 n/sec/cm^2$
- **SHIEI**
  - NRT: Thermal
- **KURRI-LINAC**
  - Under Construction
  - Epithermal neutron
- **J-PARC MLF**
  - 1MW Accelerator
  - JRR-3
  - 20MW Reactor
- **KURRI 5MW Reactor**

For Research use
3. “Accelerator-driven compact neutron sources in Japan”
By Katsuya Hirota (Nagoya University)

Neutron sources in Japan for BNCT use

Southern Tohoku BNCT research center
Cyclotron 30MeV 1mA
Clinical trial study

Conditioning
IQBRC- iBNCT
Linac 8MeV 10mA

Conditioning
National Cancer Center Hospital
Linac 2.5MeV

KURRI C-BENS
Cyclotron 30MeV 1mA
Clinical trial study

KURRI 5MW Reactor
3. “Accelerator-driven compact neutron sources in Japan”
By Katsuya Hirota (Nagoya University)

**NUANS  Nagoya University**

Two beamlines are designing at NUANS

1st beamline  (42kW)
- Device and system development for BNCT (Li-Target, moderator, etc…)

2nd beamline  (4kW)
- Neutron Imaging
- Neutron Detector Development
- Neutron optics Development (mirror, lens, etc…)
- Education

1st BL : 7Li target
  - high neutron intensity
  - Chemically unstable

2nd BL : 9Be target
  - Chemically stable
  - Succeeded to use at RANS, KUANS

Dynamitron Accelerator (DC beam) by IBA Indust.
- Proton Energy: 1.9MeV-2.8MeV
- Proton beam current: Maximum **15mA**, 1.5mA(2nd BL)
- Size : 7.5m x 2.8m 6.5ton
By Jong-Seo CHAI (SKKU)

Prof. Mitra delivered the talk on behalf of Prof. Chai
4. “Development of Cyclotron for Neutron Radiography in KOREA” By Jong-Seo CHAI (SKKU)

## Neutron Source Characteristics

<table>
<thead>
<tr>
<th>Source</th>
<th>Flux capabilities $n.\text{cm}^{-2}\cdot\text{s}^{-1}$</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor</td>
<td>$10^{10}-10^{15}$</td>
<td>High flux</td>
<td>High cost, complex</td>
</tr>
<tr>
<td>Accelerator</td>
<td>$10^{7}-10^{10}$</td>
<td>Good flux, Portability</td>
<td>Target life - poor moderately complex to operation</td>
</tr>
<tr>
<td>Isotopic</td>
<td>$10^{5}-10^{9}$</td>
<td>Small size, Easy operation, portability</td>
<td>Low flux level, decay of intensity, continuous output</td>
</tr>
</tbody>
</table>

[Electron linac](#)

[Proton linac](#) (RF vs DC)

[Proton cyclotron](#)
Light elements has more contrast for neutron than x-ray and gamma ray. Neutron has relatively higher transmission ability for massive elements.

Neutron radiography can be used complementally for non-destructive test with x-ray and gamma radiography.
4. “Development of Cyclotron for Neutron Radiography in KOREA” By Jong-Seo CHAI (SKKU)

- **Magnet design**
  - Pancake type
  - 4 Sector-magnet with deep valleys
  - 4 holes for vacuum pump & RF cavity
  - 1 central hole for axial injection

- **RF system**

- **Vacuum system**
  - Bottom view of the magnet

- **Injection system**

- **Extraction System of SKKUCY-4**

- **Spiral Inflector simulation results**

- **Schematic of RF ion source**
By Jong-Seo CHAI (SKKU)

- Target material: Li
- Target thickness: 100 μm
- Target base: Cu
- Angle of inclination: 30 degree
- Energy absorption length: 200 μm
- Energy to Target: 1.7986 MeV
  - Incident energy: 2.5 MeV
  - Final energy: 0.7014 MeV

- Beam type: Proton
- Target size: 30 x 64 mm (ellipse)
- Irradiation area: 14.13 cm²
- Cooling flow: 40 L/min (water)

<table>
<thead>
<tr>
<th>Incident Energy</th>
<th>Absorption length</th>
<th>2.8MeV</th>
<th>2.5MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 μm</td>
<td>1.4734</td>
<td>1.7986</td>
<td></td>
</tr>
<tr>
<td>300 μm</td>
<td>stopped</td>
<td>stopped</td>
<td></td>
</tr>
</tbody>
</table>

Diagram showing the layout of the cyclotron with labels for lithium, copper, aluminum, and cooling water.
5. “A Plan for a Pulsed Neutron Source Based on the KOMAC 100-MeV Proton Linac”
By Hyuk-Joong Kwon (KAERI)
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By Hyuk-Joong Kwon (KAERI)
Cylindrical CM
6. “Development of BNCT at DawonSys”
By Dong-Soo Kim (DawonSys)

- **Development of BNCT systems**

- **BNCT Facility**
  - Nuclear Reactor (Thermal Neutron)
    - Treatment depth (1-3cm)
    - Treatment time (1-2 hr)
    - Irradiation with harmful radiation
    - Non-hospital based faculty
    - Hard nuclear licensing
  - Modified Reactor (Epithermal Neutron)
    - Treatment depth (5-6cm)
    - Treatment time (1-3 hr)
    - Irradiation with harmful radiation
    - Non-hospital based faculty
    - Hard nuclear licensing

- **Accelerator (Epithermal Neutron)**
  - Treatment depth (7-8cm)
  - Treatment time (less 1 hr)
  - Reduction of harmful radiations
  - Hospital based facility
  - Easy a radiation licensing

- **LINAC**
  - High flux epithermal neutron
  - Reduction of harmful radiations
  - A good hospital based facility

- **Cyclotron**
  - Medium flux epithermal neutron
  - Production of harmful radiations
  - A good hospital based facility

- **Electrostatic**
  - Medium flux epithermal neutron
  - Production of harmful radiations (Tritium, Induced Radiation)
  - Compact size for a medical facility
6. "Development of BNCT at DawonSys"
By Dong-Soo Kim (DawonSys)

- **Project Name**: Development of the accelerator based Boron Neutron Capture Therapy system for the cancer treatment within “1 hour” therapeutic time
- **Project Period**: 2016.5 ~ 2020.12
- **Leading Organization**: Dawonsys Inc.
- **Participating Organizations**: Gil Hospital, Gachon Univ., PAL, KAERI and KBSI
- **Developed Items**: Proton Linac, Be Target / Moderator Assembly, Dosimetry (Neutron & Gammas), Radiation Safety & Licensing, Boron Compounds, TPS(Treatment Planning System), Clinical Trials, Government Approvals of Boron Compounds & BNCT Treatment

![Diagram of Facility and Medical Treatment]

- **Facility**
  - Accelerator (Dawonsys)
  - Target Assembly (PAL)
  - Building & Utility (BRC / Gil Hos.)
  - Radiation Safety Permission (KAERI / Medax)
  - FRM (Facility Review Meeting)

- **Medical Treatment**
  - Boron Drug (Gachon U.)
  - Clinical Trial (Gil Hospital)
  - Diagnostics (PET/MRI) (Gachon U. / Gil Hos.)
  - Drug & Treatment Permission (Medax)
  - MRM (Medical Review Meeting)
6. “Development of BNCT at DawonSys”
By Dong-Soo Kim (DawonSys)

- **Proton Injector** (Under Beam Test)
- **RFQ** (under Fabrication)
- **DTL** (Under Fabrication)

**Features & Achievements**
1. Proton injector under beam test has achieved separated machine parameters: 50keV, 60mA, 80% of proton ratio, 1.7ms pulse length etc.
2. RFQ under fabrication targets a high beam current of 50mA and high duty of 20%.
3. DTL under fabrication targets also a high averaged beam current of 8 mA to achieve 80kW beam power.
6. “Development of BNCT at DawonSys”
By Dong-Soo Kim (DawonSys)

- 3 beamlines (two for treatment, one for research)
- How to do real-time neutron monitoring?
7. "Current Status of the 28 GHz SC-ECRIS for RISP" 
By Yong-Hwan Kim (RISP/IBS)
7. “Current Status of the 28 GHz SC-ECRIS for RISP”
By Yong-Hwan Kim (RISP/IBS)

• Screw structure is modified

• Change the heat transfer cable between cryo-cooler and SC coil current lead into thicker and wider one
7. “Current Status of the 28 GHz SC-ECRIS for RISP” by Yong-Hwan Kim (RISP/IBS)

- Conditioning procedure

Issues of electronics damage by surge potential from a spark

- When a spark occurs, some electronic devices have some shock induced by the surge potential
  - We installed a protection circuit to protect the electronics and
  - We established the conditioning routine to suppress the spark occurrence
  - Especially we found that vacuum level showed a fluctuation, and we increased HV after the vacuum level was recovered

![Graphs and plots related to conditioning procedure and vacuum level fluctuations.](image-url)
7. “Current Status of the 28 GHz SC-ECRIS for RISP”
By Yong-Hwan Kim (RISP/IBS)

Issues of the plasma stability

- When we applied just more than 400W of RF power for higher beam current test, plasma goes to an unstable region.

Plasma instability!

- Revise the connection of hexapole polarity
- Change the waveguide into a shorter one
- Remove the sharp edge inside of the chamber
- Now we are ready to start a beam extraction experiments again
8. “Compact neutron source Development with SKKUCY-13 Cyclotron”
By Mitra Ghergherehchi (SKKU)

13 MeV Cyclotron (TR-13)

<table>
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<th>General Specifications</th>
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<tr>
<td>Accelerating Particle</td>
</tr>
<tr>
<td>Beam Energy</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Beam Current</td>
</tr>
<tr>
<td>RF Frequency</td>
</tr>
<tr>
<td>RF Power</td>
</tr>
<tr>
<td>Ion Source</td>
</tr>
</tbody>
</table>

* TR13 ion source beam check (BaF6 with colliding H-)
* Possible Deuteron beam
  - Multicusp beam current: 3 mA,
PROPPOSED TARGET STRUCTURE FOR LOW ENERGY BE(p,n) REACTION

Hydrogen (proton) stay in certain depth due to Bragg peak effect

Hydrogen embrittlement -> Blistering, Cracking -> Destruction of target
Neutron yield of Be(p,n) has threshold of 2MeV -> protons can penetrate Be without losing neutron yield
8. “Compact neutron source Development with SKKUCY-13 Cyclotron” By Mitra Ghergherehchi (SKKU)

Monte Carlo Simulation for Target Design

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>Cross-section (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.15</td>
<td>50.42</td>
</tr>
<tr>
<td>9.17</td>
<td>45.38</td>
</tr>
<tr>
<td>10.06</td>
<td>43.25</td>
</tr>
<tr>
<td>11.06</td>
<td>40.02</td>
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<tr>
<td>12.04</td>
<td>38.16</td>
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<tr>
<td>13</td>
<td>35.2</td>
</tr>
<tr>
<td>13.5</td>
<td>35.37</td>
</tr>
<tr>
<td>14</td>
<td>32.74</td>
</tr>
<tr>
<td>14.99</td>
<td>29.18</td>
</tr>
<tr>
<td>15.68</td>
<td>27.17</td>
</tr>
</tbody>
</table>

Thermal Neutron Yield = 10^5 n/cm^2.s

Neutron Yield: 0.78 x 10^{12}
NANOSTRUCTURED BORON NITRIDE WITH LASER ABLATION

More effective in delivering Boron
→ Need animal clinical trials
9. “Construction and Preliminary Beam Test of RISP 81.25 MHz CW RFQ for Heavy Ions” By Bum-Sik Park (RISP/IBS)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>HLI GSI(^1)</th>
<th>SPIRAL II GANIL(^1)</th>
<th>ISAC TRIUMF(^1)</th>
<th>ATLAS ANL(^1)</th>
<th>FRIB MSU(^1)</th>
<th>RISP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle</td>
<td>A/q&lt;8</td>
<td>A/q=2.3</td>
<td>A/q&lt;30</td>
<td>A/q&lt;7</td>
<td>3&lt;A/q&lt;7</td>
<td>1&lt;A/q&lt;7</td>
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<tr>
<td>Frequency</td>
<td>MHz</td>
<td>108.5</td>
<td>88</td>
<td>35.3</td>
<td>61</td>
<td>80.5</td>
<td>81.25</td>
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<tr>
<td>Type</td>
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<td>4-vane</td>
<td>4-rod</td>
<td>Window</td>
<td>4-vane</td>
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<tr>
<td>Injection Energy</td>
<td>keV/u</td>
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<td>20</td>
<td>2</td>
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<td>Final Energy</td>
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<td>Length</td>
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<td>5.077</td>
<td>8</td>
<td>3.75</td>
<td>5.04</td>
<td>4.94</td>
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<tr>
<td>Inter-vane Voltage</td>
<td>kV</td>
<td>80</td>
<td>100-113 Voltage Ramp</td>
<td>75</td>
<td>70</td>
<td>60-112 Voltage Ramp</td>
<td>50-140 Voltage Ramp</td>
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<tr>
<td>RF Power</td>
<td>kW</td>
<td>75-100</td>
<td>60</td>
<td>15-100</td>
<td>94</td>
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<td>Beam Power</td>
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<tr>
<td>Kilpatrick factor</td>
<td>%</td>
<td>1.65</td>
<td>1.6</td>
<td>1.70</td>
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<td></td>
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<tr>
<td>Duty</td>
<td>%</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<td>100</td>
</tr>
<tr>
<td>Transmission efficiency</td>
<td>%</td>
<td>97</td>
<td>80</td>
<td>98</td>
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</tr>
<tr>
<td>Status</td>
<td>Operated</td>
<td>Test</td>
<td>Operated</td>
<td>Operated</td>
<td>Test</td>
<td>Test</td>
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</tr>
</tbody>
</table>
RFQ Fabrication Procedure

- Physical & mechanical design
- Rough machine for vanes and quadrants
- 1\textsuperscript{st} and 2\textsuperscript{nd} Braze for cooling channels and vacuum flanges
- Flow and leak test
- Fine machining including the vane modulations
- Dimension inspection with CMM (Coordinate Measurement Machine)
- 1\textsuperscript{st} assembly
- Inspect the alignment
- Installation of the dowel pins for re-assembly
- Disassemble and clean
- 2\textsuperscript{nd} assembly
- Inspect the alignment
- Final braze
- Frequency and vacuum leak test
- Final machine

+ Alignment inspection
9. “Construction and Preliminary Beam Test of RISP 81.25 MHz CW RFQ for Heavy Ions” By Bum-Sik Park (RISP/IBS)

~3 μA O7+ at FC
VIBA = Versatile Ion Beam Accelerator

- The first plasma of 28GHz ECR ion source had been ignited in 2014.
- In 2015, we had opened for feasibility study and service to several users.
- We had started overhaul for maintenance of Cryocooler, upgrade control system, changed focusing magnet and so on.
Several important upgrades

- Upgrade of Launcher Disk
- Insert Yoke in SC coil
- Upgrade of electrode
- Upgrade of beam diagnostics
- Maintenance of Cryocooler
- Change focusing magnet
- Install a chamber for ion implantation
- Upgrade of control system with EPICs
III. Future Plan of VIBA

1st Stage: Ion Implantation

2nd Stage: Neutron Imaging

3rd Stage: Neutron Irradiation

4th Stage: In-situ Surface Analysis System

ECRIS
Analyzing Magnet

Linac
RFQ
Ion Irradiation Chamber

XPS
300KV TEM
SIMS
By Byung Seob Lee (KBSI)

VIBA building construction project (2015~2018.08)

<table>
<thead>
<tr>
<th>Fund: ~14 M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floors</td>
</tr>
<tr>
<td>Site Area</td>
</tr>
<tr>
<td>Building Area</td>
</tr>
<tr>
<td>Space</td>
</tr>
</tbody>
</table>

1~3월 ➔ Preparation of construction
4~6월 ➔ Public works and Piling
7~8월 ➔ Substructure and placing concrete of basement
9~12월 ➔ Finished framework
11. “BEST 70P Cyclotron beam commissioning at LN Legnaro”
By Vladimir Ryjkov (Best Cyclotron Inc.)

Commercial cyclotrons in nuclear science

- 70MeV H- cyclotrons are also great option for online rare isotope production by fission in Uranium targets.
- Cost effective and power efficient.

Best 70P in LN Legnaro

- Best 70P cyclotron selected for Italian Istituto Nazionale di Fisica Nucleare (INFN) Laboratori Nazionali di Legnaro (LN Legnaro).
- Best 70P was also selected for RISP project underway here in Daejeon, South Korea.
11. “BEST 70P Cyclotron beam commissioning at LN Legnaro”
By Vladimir Ryjkov (Best Cyclotron Inc.)

Best Cyclotron Delivery

- Accelerate a few turns to a beam stop “pop-up probe” located <1MeV.
- Ensured we have enough to extract full power (700uA)
Endurance test: 200uA, 40MeV > 5 days

Vacuum
Operational (beam ON): ~4x10^{-8} Torr

Magnet current <0.05%
**12. “Status of an Electron Beam Ion Source for Charge Breeding for RISP”**
By Young-Ho Park (RISP/IBS)

**EBIS: Design Parameter**

![Diagram of EBIS design parameters](image)

<table>
<thead>
<tr>
<th>Design parameters @ RISP</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electron beam current</strong></td>
<td>0 ~ 3 A</td>
</tr>
<tr>
<td><strong>Electron beam current density</strong></td>
<td>500 A/cm²</td>
</tr>
<tr>
<td><strong>Extraction beam energy</strong></td>
<td>10 keV/u</td>
</tr>
<tr>
<td><strong>B-field in Trap region</strong></td>
<td>6 T</td>
</tr>
<tr>
<td><strong>A/q</strong></td>
<td>Capacity</td>
</tr>
<tr>
<td><strong>&lt; 6</strong></td>
<td>~ 10⁸ ions/bunch</td>
</tr>
<tr>
<td><strong>Breeding time</strong></td>
<td>50 ~ 100 ms</td>
</tr>
<tr>
<td><strong>Breeding efficiency</strong></td>
<td>15 % for (^{133}\text{Cs}^{27+})</td>
</tr>
<tr>
<td><strong>Repetition rate</strong></td>
<td>~ 10 Hz</td>
</tr>
<tr>
<td><strong>Pulse width</strong></td>
<td>10 ~ 20 μs</td>
</tr>
</tbody>
</table>

→ CBSIM and TRAK simulations
12. “Status of an Electron Beam Ion Source for Charge Breeding for RISP”
By Young-Ho Park (RISP/IBS)
12. “Status of an Electron Beam Ion Source for Charge Breeding for RISP”
By Young-Ho Park (RISP/IBS)
→ Electron beam extraction test was performed. The anode structure will be improved.
→ Injection/extraction beam line and ToF charge state analyzer will be manufactured soon.
→ Hope we will be able to perform the 1st charge breeding experiment at the end of this year.
By Seung-Wook Shin (SKKU)

Goal for the Research

- Toshiba E37113 Klystron
- 15 MeV
- Photo neutron reaction
- 10^5 n/cm²/s of thermal neutron

Compact Electron Linac Design

Superfish
ASTRA
CST-MWS (planned)

1st Stage  •  2nd Stage  •  3rd Stage  •  4th Stage

Gathering Information
- Limitations
  - Size
  - Thickness
  - Length
- System Requirement
  - Beam energy
  - Beam Current
  - Beam size
  - Frequency
  - RF Power

Single Cell Design
- Maximize shunt impedance
- Genetic algorithm adapted design

Beam Dynamics
- Minimize beam size
- Maximize acceleration
- Maximize capture coefficient

Full Cell Design
- Side-coupling cell design
- RF power coupler design
- Whole cell simulation

**Things About Genetic Algorithm**

*Mimicking the Nature – Biological Evolution*

- Population
- Mating Pool
- Selecting Mates
- Mating Process
- Offspring
- New Population

**Applying to Computing Algorithm**

- Selection
- Crossover
- Mutation
- Generation
Genetic Algorithm

Overall Procedures of the Genetic Algorithm

1st Generation Population
- Individual 1
- Individual 2
- Individual 3
- Individual 4
- ... (continued with N-3, N-2, N-1, N)

Fitness = Effective Shunt Impedance

Selection, Crossover, Mutation

2nd Generation Population
- Individual 1
- Individual 2
- Individual 3
- Individual 4
- ... (continued with N-3, N-2, N-1, N)

Final Generation
- Individual 1
- Individual 2
- Individual 3
- Individual 4
- ... (continued with N-3, N-2, N-1, N)

Best Value

By Seung-Wook Shin (SKKU)
Summary of “summary of WG5”

• Summary job was very demanding, however very useful to catchup and learn many exciting/new things in this field.
• Various types of accelerators (electron/proton, linac/cyclotron, DC/RF, large/compact) can be used to produce neutrons for basic science, industrial applications, and medical treatment.
• There are many common features and technologies among the projects → We need more communications, collaborations, and co-works for sharing wisdom and minimizing mistakes (Domestically, Regionally, Internationally).