Current Status of Experimental Facilities at RAON

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Rare Isotope Science

Nuclear Physics

- Structure of exotic nuclei
- Properties of exotic nuclei: masses, radii, life-time etc.
- Search for super heavy elements
- Nuclear theory: nuclear force, nuclear model

Nuclear Astrophysics

- Stellar evolution
- Nucleosynthetic processes under stellar environments
- EoS of asymmetric nuclear matter such as neutron stars

Applications

- Bio-medicine & Breeding
- Material sciences
- Nuclear data for next generation nuclear power plant
- National security

• **RISP = Rare Isotope Science Project (2011. December - 2021. December)**
  - Plan & build Rare Isotope accelerator and experimental facilities in Korea

• **RAON = Rare isotope Accelerator complex for ON-line experiments**
  - Provide that one could access to unexplored regions of the nuclear chart
  → More exotic, More intense, and More various Rare Isotope Beams (RIBs)
RAON Accelerator & RI Production

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>Driver Linac</th>
<th>Post Acc.</th>
<th>Cyclotron</th>
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<tbody>
<tr>
<td>Particle</td>
<td>proton</td>
<td>U^{+79}</td>
<td>RI beam</td>
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<tr>
<td>Beam energy</td>
<td>600 MeV</td>
<td>200 MeV/u</td>
<td>18.5 MeV/u</td>
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<tr>
<td>Beam current</td>
<td>660 µA</td>
<td>8.3 pµA</td>
<td>-</td>
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<tr>
<td>Power on target</td>
<td>400 kW</td>
<td>400 kW</td>
<td>-</td>
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- See Poster by Bum-Sik Park for RAON RFQ on Mon.
- See Poster by Taeksu Shin for the status of RISP on Mon.
- See Talk Byoung Hwi Kang for RAON ISOL on Fri.
RAON Experimental Facilities

- **Budget**
  - Total: 418.4M US$
  - RI production system: 57.9M US$
  - Experimental system: 22.4M US$
Plan for Development of Experimental Systems

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<tbody>
<tr>
<td>Stage 1: ISOL, IF, KOBRA, LAMPS, HPMMS (MR-TOF)</td>
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<td>Stage 2: CLS, µSR, Bio-medical, Nuclear Data</td>
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<td>Stage 3: upgrade, new facilities</td>
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Staged Approach

- KOBRA Collaboration
- LAMPS Collaboration
- MR-ToF-MS, Gamma Array (KEK)
- Detectors & DAQ (GET Collaboration, TRIUMF, etc.)
- UCx target (KNF, ISOLDE)
- ISOL RH (TRIUMF & J-PARC)
- ISOL TIS (TRIUMF, ISOLDE)
- EBIS (BNL)
- IF target test (BINP)
- IF magnet (KERI)
- and more

- Established
- RAON User Liaison Center
- RAON Users Association

➡ They cooperate with RISP to develop experimental system, training students, looking for international collaborations
KOBRA (KOrea Broad acceptance Recoil spectrometer and Apparatus)

<table>
<thead>
<tr>
<th>Conceptual design</th>
<th>Prototype &amp; Test</th>
<th>Manufacturing</th>
<th>Installation &amp; Commissioning</th>
<th>Operation</th>
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</thead>
</table>

• Multi-purpose experimental instrument using stable or rare isotope (RI) beams for nuclear structure and nuclear astrophysics Studies
  - RI beam productions using stable or rare isotope (RI) beams
  - Recoil mass separator
  - High-resolution spectrometer, and so on

PPAC
- We have two 10 x 10 cm², two 20 x 20 cm², one 40 x 20 cm² active area PPACs
- Position resolution: < about 0.7 mm in FWHM, (C₄H₁₀ gas, ²⁴¹Am)
- Four 10 x 10 cm² and one 40 x 20 cm² PPACs will be produced

SSD
- We have two 5 x 5 cm² active area, 50 µm-thick, 16 channel SSD
- Energy resolution ~ 0.7%, S/N ~ 272 for 5.486 MeV α in vacuum

Plastic scintillator detectors
- We have one 10 x 10 cm² active area, 100 µm thick both side readout plastic detector
- Time resolution < 42 ps for 5.486 MeV α in vacuum
- One 10 x 10 cm² active area, 100 µm thick one side readout plastic will be produced

HPGe gamma ray detectors
- 32 segmented HPGe detectors (6set)
- Compton suppressor BGO crystals (6set)
- Complete set of TIGRESS electronics

• The first part of stage 1 (stage 1 part 1) has been contracted with foreign and domestic companies in April 2018, and production is ongoing
• The present design of the second part of stage 1 (stage 1 part 2) was finally decided among the various design options in June 2018 by consultation with domestic potential users, and now bidding is ongoing
• Stage 1 will be installed in Low Energy Experimental room (E1) until the end of June 2020
• The commissioning of Stage 1 will be started from beginning of 2021 with stable ion beam
LAMPS (Large Acceptance Multi-Purpose Spectrometer)

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- Nuclear matter and nuclear reaction studies with intermediate energy stable and rare isotope beams, especially nuclear symmetry energy at supra-saturation density via heavy-ion collision (e.g. measure $n/p$ ratio & collective flow at the same time in the combination of $^{106,112,124,130,132}$Sn + $^{112,118,124}$Sn)

- **Beam Energy**: up to 250 MeV/u for $^{132}$Sn ($\leq 10^8$ pps)

- **Solenoid Spectrometer**
  - Max. 1T solenoid magnet
  - TPC ($\sim 3\pi$ sr acceptance, charged particle tracking)
  - Scintillation counter (trigger & ToF)

- **Neutron Wall (neutron tracking)**
  - All of LAMPS system will be ready by 2020
  - Start installation from 2021 then standalone commissioning during 2021

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- **Almost completed design of cylindrical superconducting magnet**
  - 3200 mm (D) x 3320 (L)
  - Coil-turn starts from 850 mm in radius
  - Max. B-filed ~ 1 T, Operation B-filed = 0.5 T
  - $\Delta B/B \sim 1.87\%$, current 131.2 A
  - Procurement will be started next year

- **Test with prototype of TPC completed**
  - Fulfill the requirement of TPC

- **Based on test results, change TPC design**
  - Both side readout $\rightarrow$ one side readout
  - P-10 gas $\rightarrow$ P-20 gas

- **Construction and tested from 2019 to 2020**

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- **Solenoid Magnet**
- **Time Projection Chamber**
- **Forward Neutron Detector Array**

- **Completed all R&D processes**
- **Detector production in progress**
  - 2 veto detectors (total: 20)
  - 148 neutron detectors (total: 160)
- **Array frames are in house**
- **Finish integration & test by the middle of 2019**
High Precision Mass Measurement System (MR-ToF)

• Multiple Reflection ToF Mass spectrograph, chosen for mass measurement of unstable nuclei with short life time of < 100 ms and with sufficient precision of better than 10⁻⁶

- MR-ToF-MS construction under the collaboration
  - R&D work, led by WNSC MR-ToF group (Leader : Prof. Wada)
  - Additional beam line to the MR-ToF-MS, already constructed (2017)
  - Differential pumping system, gas cell (or catcher), Trap system, and MR-ToF analyzer have been assembled, waiting for offline ion source test
  - Test of the differential pumping system with the gas cell filled with 1 mbar helium gas, performed : 3.4x10⁻⁴ Pa upstream side
  - Optimizing the beam transmission through the φ 2-mm gas cell hole, performed : 72% efficiency, but will be improved by additional beam steerer
CLS (Collinear Laser Spectroscopy)

• Measurement of the electron energy levels of rare isotopes produced in RAON
  - Tool to acquire information on nuclear charge distribution, nuclear spins, nuclear shape, etc.
  - Study the nuclear structure or verify the accuracy of nuclear models

- Optical sources and spectroscopy system
- CLS beam line: Deflector, Neutralizer, Fluorescence detector

• Main Specifications
  - Resolution: ~ 10MHz @ E=40keV and ΔE=1 eV
  - Wavelength range: UV, VIS, IR
  - CLS beam line including 10°-deflector, neutralizer, and reionizer etc.

• Laser system is already procured
• Conceptual design of the CLS beam line is finished
• Resume development works from 2019
**NDPS (Nuclear Data Production System)**

- Fast neutron nuclear data production system for developing next-generation nuclear power plant
  - fast neutron production system
  - fast neutron ToF and Fission cross-section detection system

**Main Specification**
- n-ToF system: 5 m and 20 m (Extendable ~ 70 m)
- Neutron beam: ≤ 53 MeV pulsed beam (white)
- Repetition rate: 300 kHz ~ 1 MHz
- Beam intensity: $2 \times 10^{12}$ neutron/sr/µC
- Beam width: 1 ~ 2 ns (need single bunch selector)
- Beam line for deuteron & neutron
- Collimator and dump
- Fission cross-section uncertainty: < 10%

**Target System for White Neutron Production**

- Carbon target
- Deuteron
- Fast Neutron
- Neutron Beam

**Single Bunch Selector**

- Length: 35 cm, OD: 47 cm, ID: 26 cm

**Radiation Safety**

- Emittance: $0.3 \pi \text{ mm mrad}$
- $d$ energy: 1 MeV
- Radius: 2 mm, angle: $0.027\degree$
- Total length for SBS: 2.1 m
- RF field: 1550V, magnetic field: 45 gauss

**Nuclear Data Measurement (FIC for fission CX)**

- Chamber dimension: 10 cm x 10 cm x gap
- Gap: variable
- Gas composition: Ar (90%) + CF₆ (10%)
- Gas pressure: variable
- Sample: U235
- Sample dimension: 1 cm x 1 cm x thick.
- Sample thickness: variable
- Source: variable
µSR (Muon Spin Rotation/Relaxation/Resonance)

- Facility for studying characteristics of new materials (e.g. high temperature SC, semiconductor, etc.)
  - production of polarized moun beams
  - high sensitive X & γ ray detections

  • **Main Specification**
    - $\mu^+$ (surface muon, >$10^5$ pps, CW)
    - 600 MeV proton with an intensity up to 400 µA

- Conceptual design of µSR is finished
- Some of R&D for target, spectrometer, muon transport line completed
- Resume development works from 2019
BIS (Beam Irradiation System)

Conceptual design
2011 ~ 2012

R&D Pause
~ 2018.12

R&D, Manufacturing
~ 2020.12

Installation
~ 2021.12

Commissioning
2021.12 ~

Operation
After Commissioning

• Bio-medical beam irradiation system for biomedical R&D
  - Passive scanning system including magnet and magnet power supply can be enabled in active scanning system
  - Uniform irradiation system with large area
    ➔ Studies of the response of cancer cell and normal cell to various heavy ions including RIBs
    ➔ Studies of useful genetic resources using high LET heavy ion beams and developments of new variety

• Main Specification
  - $E_{beam} = 310$ Mev/u with $> 50$ ppA for $^{12}$C
  - Irradiation rate: $> 2$ Gy/min
  - Irradiation area: $>\text{the diameter of 20 cm}$
  - Non-uniformity: $< 5\%$
  - SOBP: $< 4$ cm because of the limited acceleration energy
  - Available LET: $\sim 10$ keV/mm

• Uniform beam irradiation system
  - Wobbling magnet, W scatter, ripple and ridge filter, MLC
  - Use of both passive ($\varphi < 200$ mm) and active beam ($\varphi < 80$ mm)

• Conceptual design of the BIS beam line is finished
• Resume development works from 2019

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<tbody>
<tr>
<td>$^{12}$C</td>
<td>310</td>
<td>50</td>
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<tr>
<td>$^{14}$N</td>
<td>300</td>
<td>64</td>
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<tr>
<td>$^{16}$O</td>
<td>305</td>
<td>100</td>
</tr>
<tr>
<td>$^{40}$Ar</td>
<td>270</td>
<td>58</td>
</tr>
<tr>
<td>$^{40}$Ar</td>
<td>270</td>
<td>58</td>
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• Biological dose: 5.022 Gy/min @ 0.1 nA C beam
• LET (keV/mm): 12@entrance to 130@peak, 2.5% for 4 cm SOBP
• Neutron dose distribution : $4\sim5\times10^{-4}$/beam paths of C and N
## RAON Schedule

<table>
<thead>
<tr>
<th>Accelerator system</th>
<th>~2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
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<td>Injector</td>
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<td>Post Accel. (SCL3)</td>
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<tr>
<td>Main Driver (SCL2)</td>
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<td>SRF Test Facility (KAIST, Munji)</td>
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<td>SRF Test Facility (Shindong)</td>
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<td>Cryoplant (for SCL3)</td>
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<tr>
<td>Cryoplant (for SCL2)</td>
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<tr>
<td>Cyclotron</td>
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<td>ISOL System</td>
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<td>IF System</td>
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<th>Experimental System</th>
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<tr>
<td>KoBRA</td>
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<td>LAMPS</td>
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<td>MMS/CLS</td>
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<td>Applied Science Facility</td>
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Summary

• RAON is Rare Isotope Beam Accelerator and Experimental Facilities in Korea
• Staged approach for development of experimental facilities
  - HPMMS, KOBRA, and LAMPS are being developed with priority
  - R&D and production of other experimental facilities will be resumed from next year
  - Installation start from 2019 year, experiment start on 2021

• Status
  - KOBRA: Manufacturing of Stage 1 is ongoing, Stage 2 will be developed by user community
    Installation will be started from the middle of 2019
  - LAMPS: Manufacturing of solenoid R&D magnet and TPC from 2019
    Complete integration & test of forward neutron array by the middle of 2019
  - MR-ToF-MS: Under development with KEK-KISS group as HPMMS
  - CLS, NDPS, μSR, BIS: Detailed design is under discussion with RAON User Liaison Center and user community

Thanks for your attention!