Current Status of In-Flight Fragment Separator for RAON

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Outline

- Overview
- Beam Optics of IF separator
- Target & Beam dump system
- Magnet system
- Particle Identification system
- Summary

▪ Main features of IF separator

- RI beams are produced by projectile fragmentation, and also by in-flight fission of uranium beam for neutron rich exotic nuclei

- Projectile fragmentation using ISOL RI beam for more neutron rich exotic nuclei

- Two-stage separator scheme
  : Pre-separator for RI beam production and remove the primary beam
  : Main separator for PID of RI beams

- Large momentum and angular acceptance
  - momentum acceptance : ± 3 %
  - angular acceptance : ± 40 mrad and ± 50 mrad in horizontal and vertical, respectively
  → Large aperture superconducting (HTS, LTS) quadrupoles are adopted
  (HTS : High temperature superconducting, LTS : low temperature superconducting)

- Main specifications of IF magnet were set based on magnetic rigidity of 7.5 Tm considering a uranium beam with an energy of 200MeV/u.

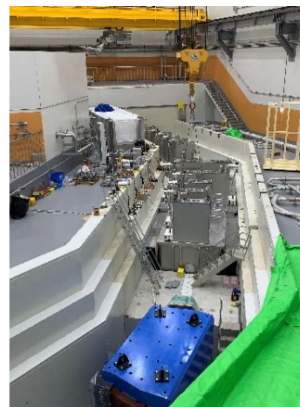
Overview

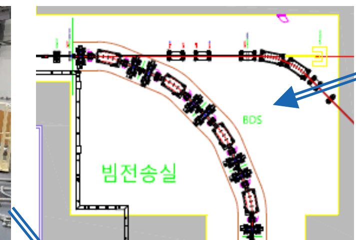
▪ Layout of IF separator

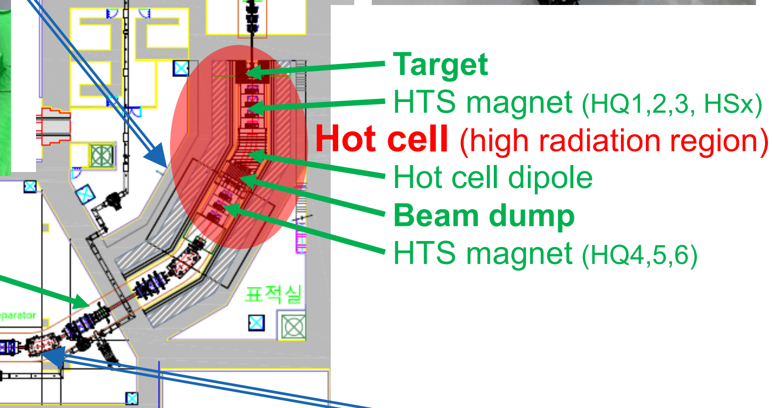
❖ List of major components

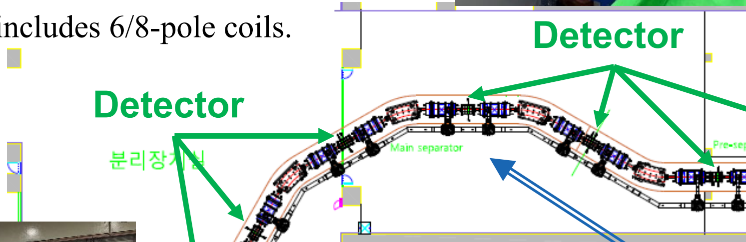
- Target & Beam dump system
- Detector system (F2~F8)
- Magnet system
  - 8 dipole magnets (NC)
  - 15 sets of quadrupole triplet (HTS & LTS*)
  - 2 sextupole magnets (HTS, NC)

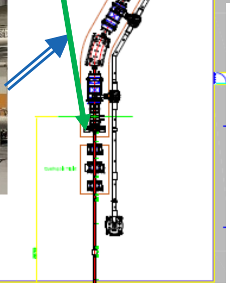
* LTS Q-Triplet includes 6/8-pole coils.

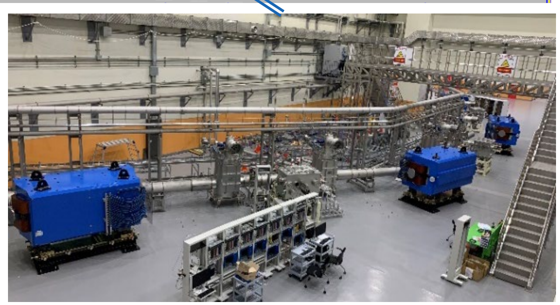




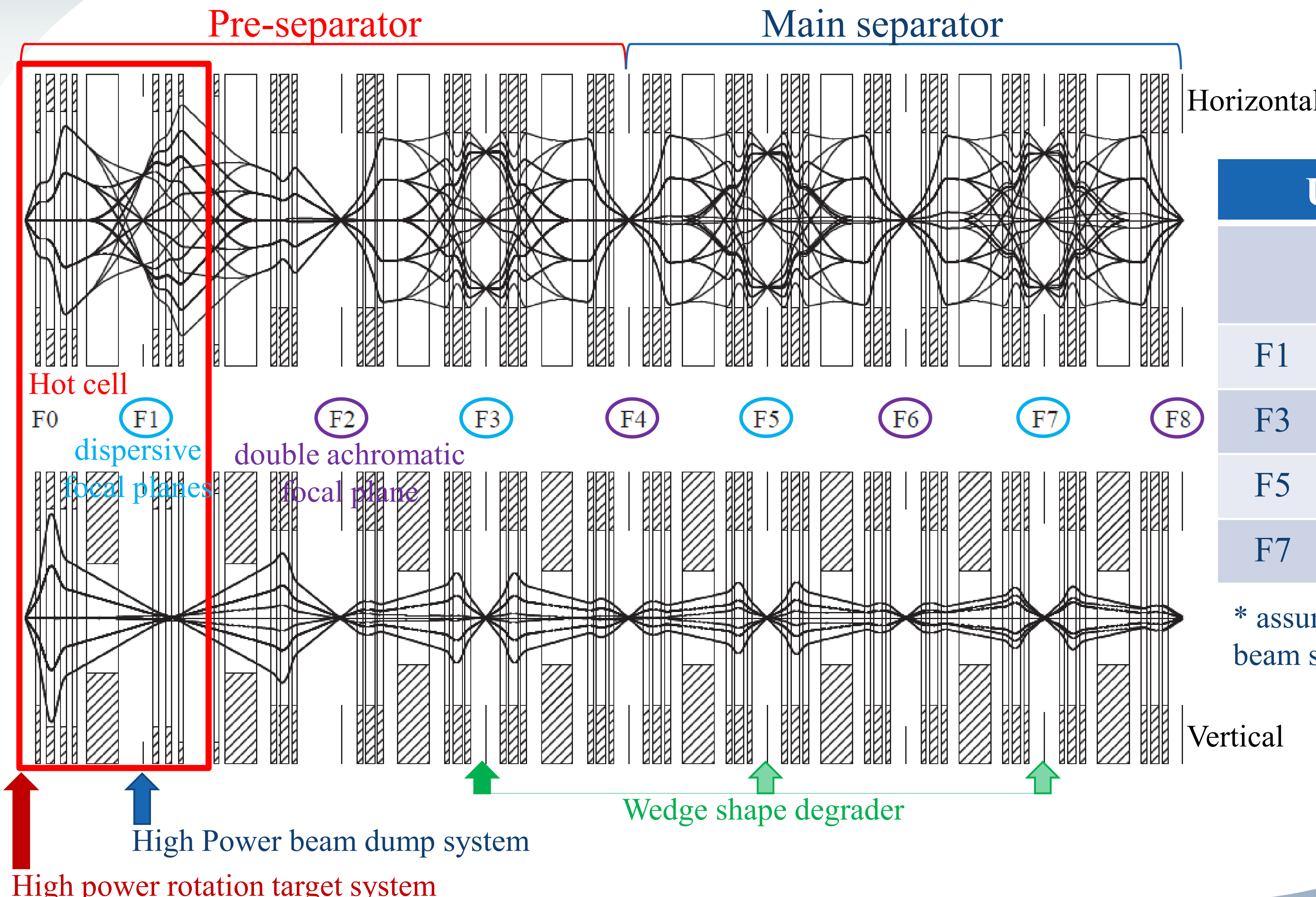








▪ Optics calculation of IF separator



UF mode	
	Resolving Power*
F1	1270
F3	3200
F5	3300
F7	3300

* assumed to be 1mm beam spot size @ target

Target & Beam dump System

Target system requirement

- Optical requirements: 1 mm diameter beam spot, Max. extension in beam direction < 50 mm
- Target lifetime of 2 weeks to meet experimental program requirements
- High power capability: Up to 80 kW in a 1.85 g/cm^3 target material for rare isotope production by in-flight fission with 200 MeV/u uranium beam with 400 kW

Beam dump system requirement

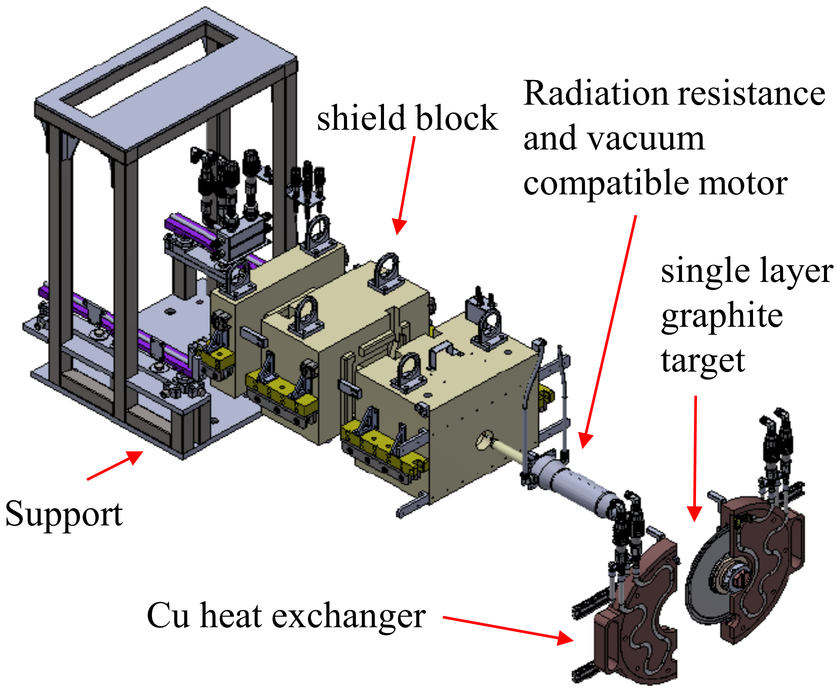
- High power capability : up to about 330 kW
- Long-lived life time : >1 year
- Horizontally move up to ± 30 cm from center
- Remote replacement and maintenance

Development strategy

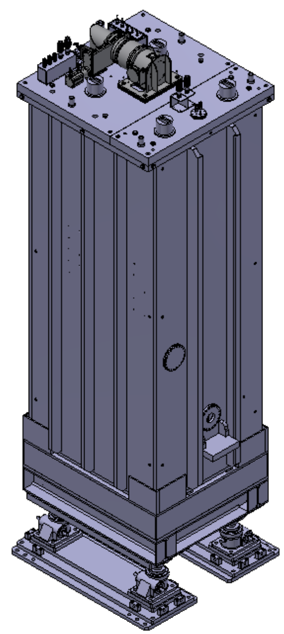
- RISP baseline design: primary beam energy of 200 MeV/u for ^{238}U, max. beam power of 400 kW
- According to a ramp-up schedule of primary beam power, the target and beam dump system are developed step by step.
- As the first step, target and beam dump system that can be used up to 80 kW primary beam has been made and tested.

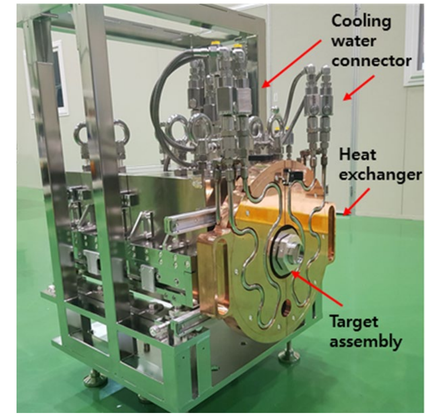
▪ Characteristics of the IF target system

- Self rotating radiation-cooled single or multi-slice target was designed based on the FRIB design.
- Material: graphite (allowable temperature : 1900 °C)
- Single slice target: 1.6 mm x1 ea below 80 kW
- Multi-slice target: 0.2 mm x8 ea with 400 kW
- A target of 2 mm thick is tapered to be 0.2 mm or 1.6 mm
- Installed inside a large vacuum chamber



Target chamber





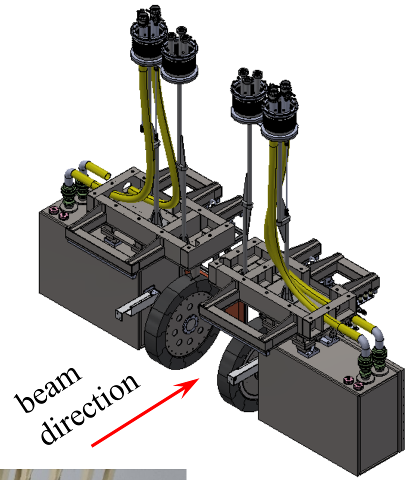
Target & Beam dump System

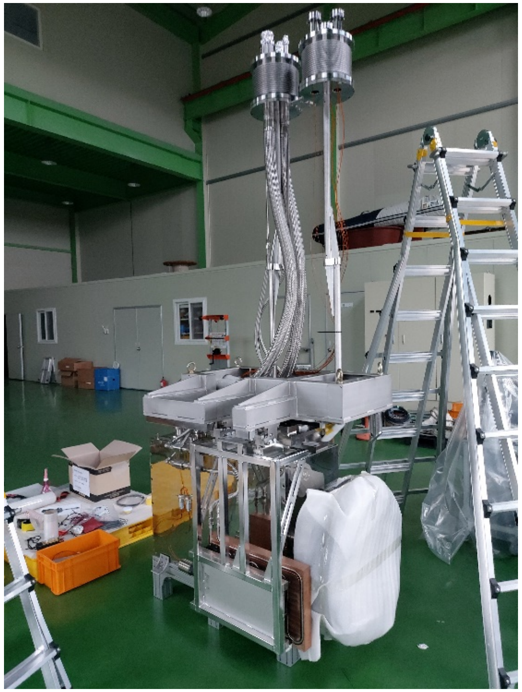
RAON

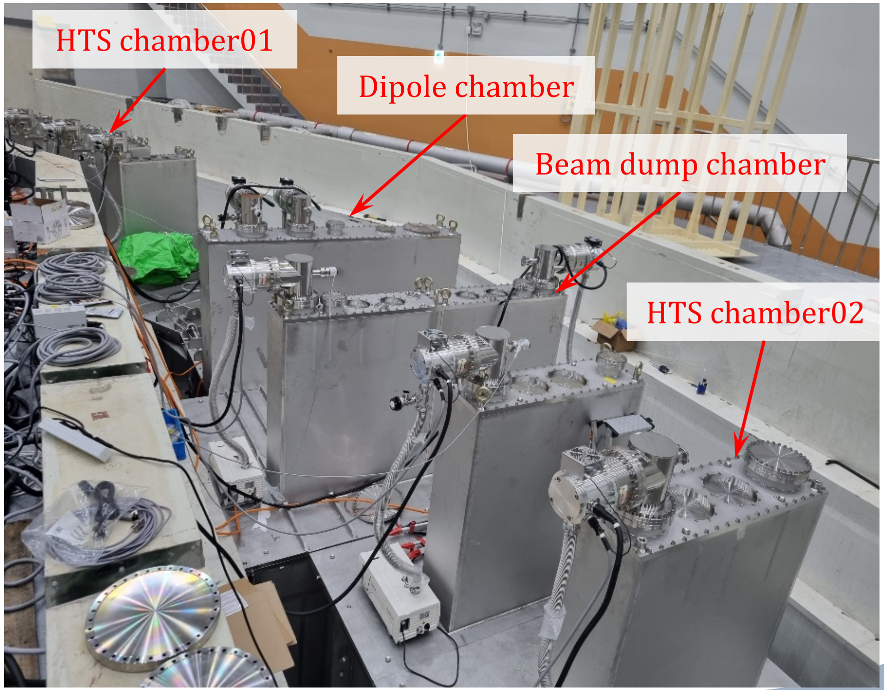
▪ Characteristics of the beam dump system

❖ **80kW beam dump system**

- Self rotating graphite cylinder type
- Material: graphite (allowable temperature : 1900 °C)
- Outside diameter of graphite cylinder : 70 cm
- The height of graphite cylinder : 12 cm
- Rotation speed : ~ 400 rpm







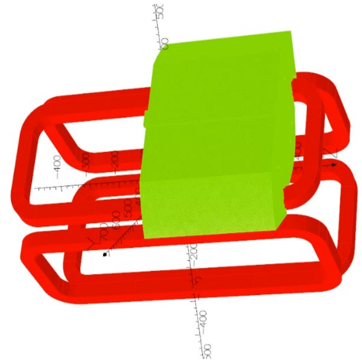
Magnet System

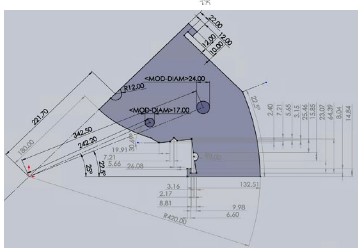
▪ LTS Q-magnet Triplet (Design, numerical analysis)

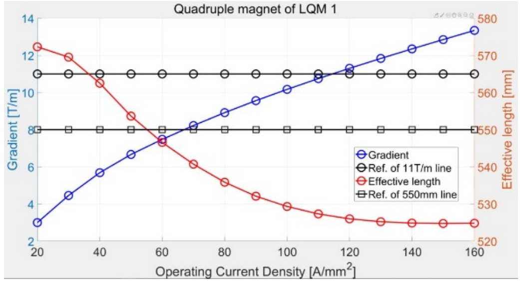
- LTS triplet requirement

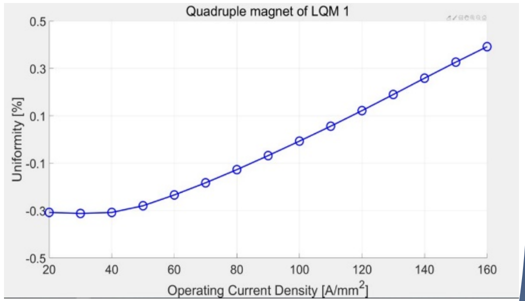
Item		requirement
Field gradient	LQ1	≥ 11.0 T/m
	LQ2	≥ 11.0 T/m
	LQ3	≥ 11.0 T/m
	LSx	≥ 10 T/m^2
	LOc	≥70 T/m^3
Effective length	LQ1, LQ3, LSx, LOc	550 mm ± 1mm
	LQ2	900 mm ± 1mm
Field uniformity	LQ1, LQ2, LQ3	≤± 0.5%
Heat load	Helium vessel(4.5K)	≤5 W
	Thermal shield(40K)	≤120 W

- Electromagnetic analysis

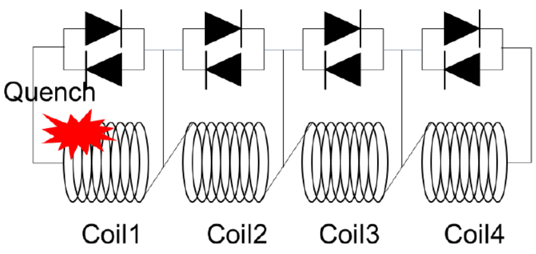




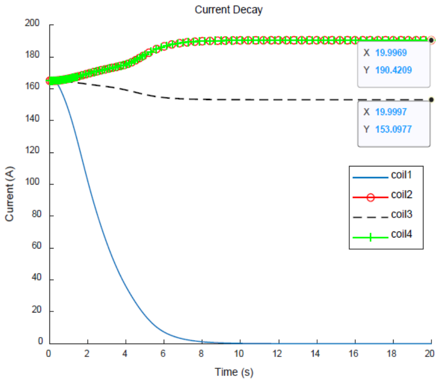


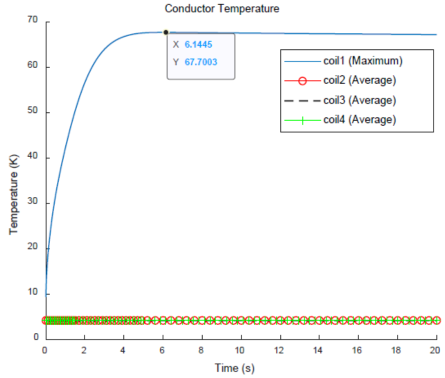


- Quench analysis



Four-loop circuit for a quadrupole





- $T_{coil,max}$ = 68 K

(design requirement : < 150K)

- V_{max} = 286 V

(design requirement : < 2 kV)

Magnet System

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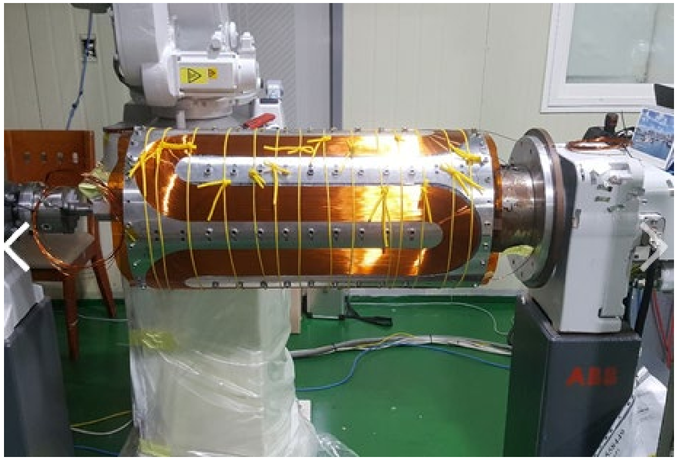
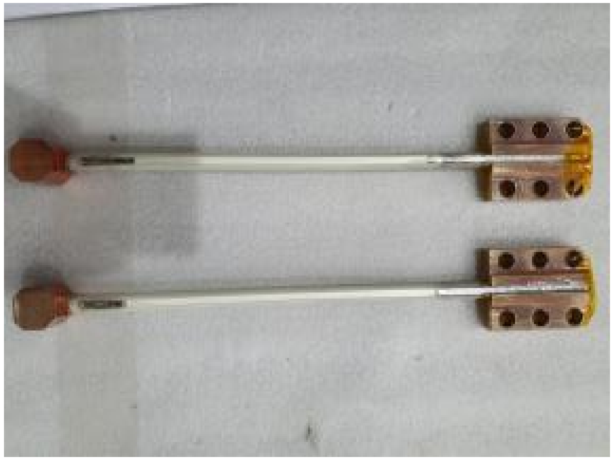
- **LTS Q-magnet Triplet** (Manufacturing)

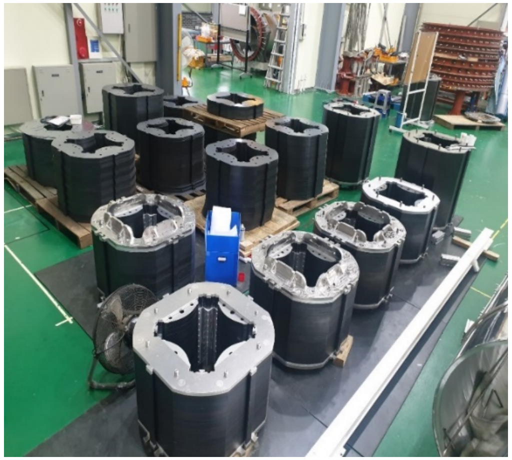
Quadrupole coil winding
(automatic winding method)



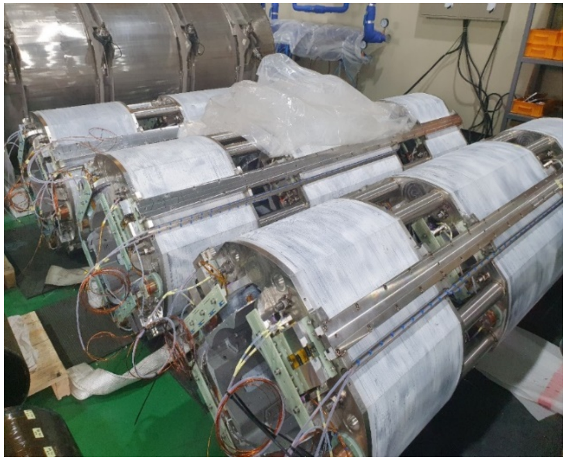
Sextupole & Octupole coil winding
(jointless winding method)



HTS current lead
(performance test at 77K)



Laminated iron yoke



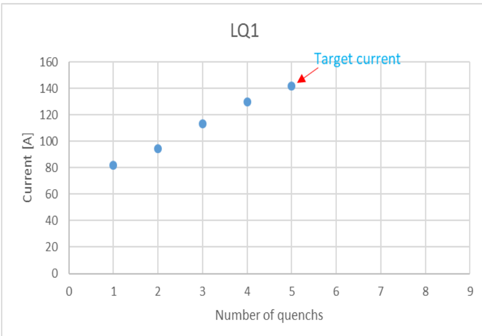
Quadrupole triplet assembly

Quadrupole triplet cryostat assembly

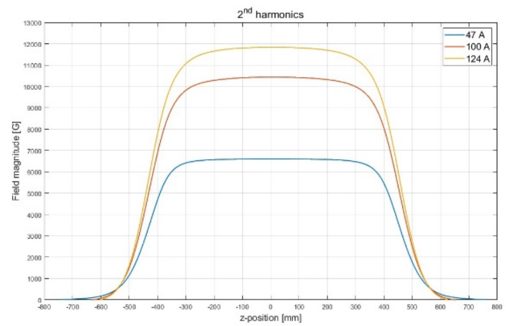
Magnet System

▪ LTS Q-magnet Triplet (Test results)

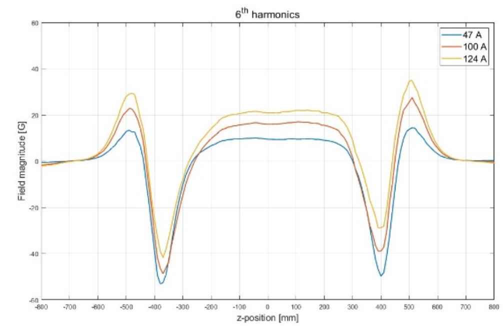
- Quench training and field measurement of LTS magnet



Quench training (LQ1)



Quadrupole component (B2)

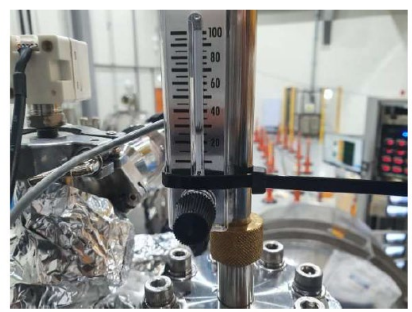


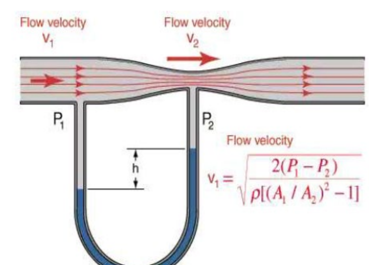
Dodecapole component (B6)

- Average 5~6 times quench occurs in quadrupole magnet. Quench not occurs in sextupole and octupole magnets.

- Vacuum and leak rate measurement

- Heat load measurement





Measurement using a flow meter

Helium vessel : ~ 4.3 W, Thermal shield : ~ 92 W

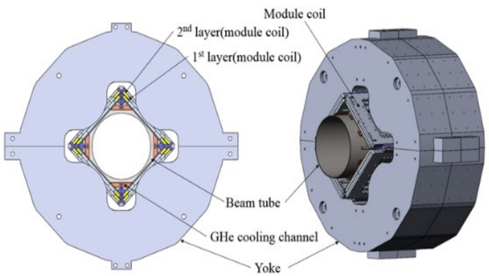
- 9 out of 13 LTS quadrupole triplets have completed the performance test, and all of them have satisfied the magnetic field and cryogenic requirement so far.

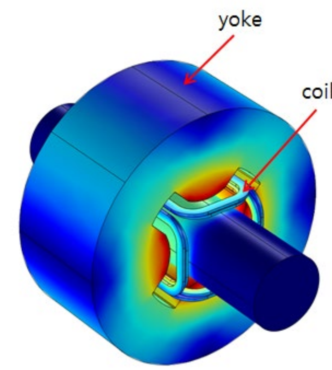
Magnet System

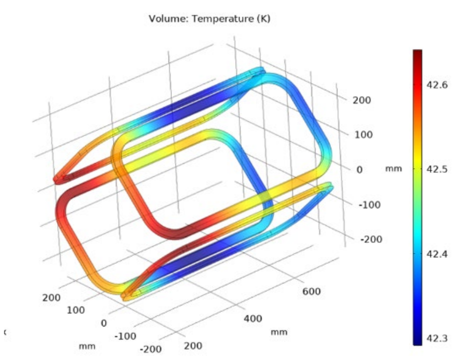
RAON

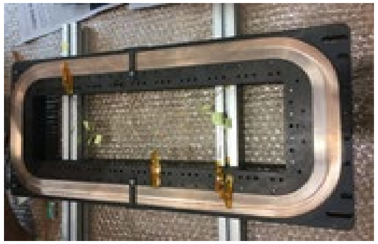
- **HTS Magnet** (Design, fabrication)

Magnet	HQ1	HQ2	HQ3	HQ4	HQ5	HQ6	HSx
Effective length [mm]	550	800	550	550	550	550	450
Aperture radius[mm]	120	150	150	150	150	170	150
Field gradient [T/m, T/m^2]	10.5	9.2	7.9	3.3	2.9	4.0	1.4
Field uniformity	≤±0.5%						
Heat load	≤150	≤180	≤180	≤160	≤160	≤200	≤170

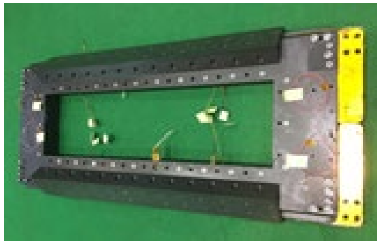




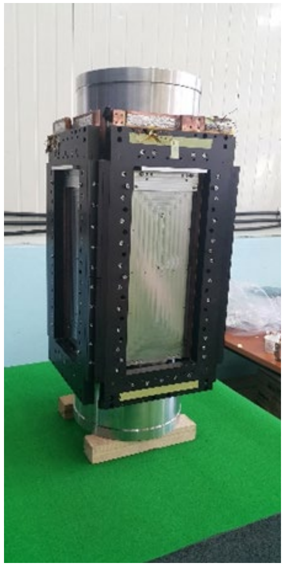




Single coil winding



Single coil assembly



Coil assembly

Cryostat assembly

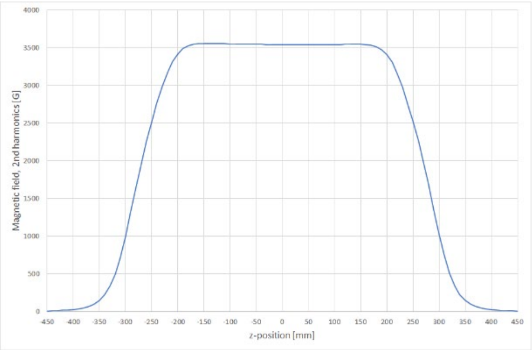
Performance test

<Design>

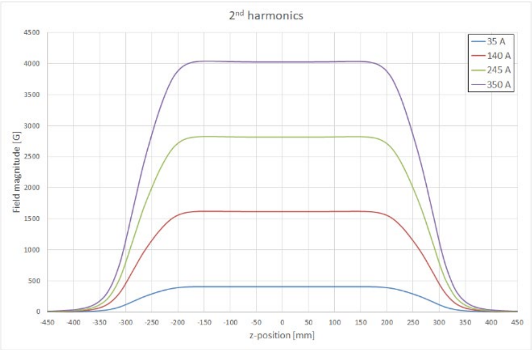
Magnet System

▪ HTS Magnet (Test results)

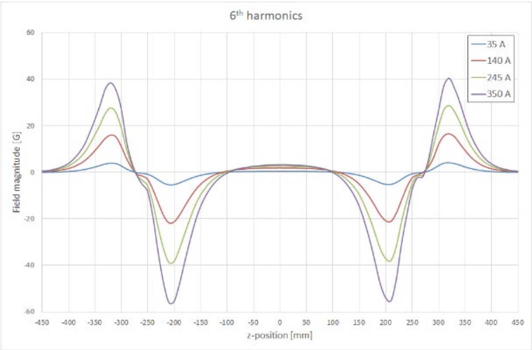
- Magnetic field measurement of HTS magnet (HQ4)



Radial component (Br, Θ=45º, 350A)

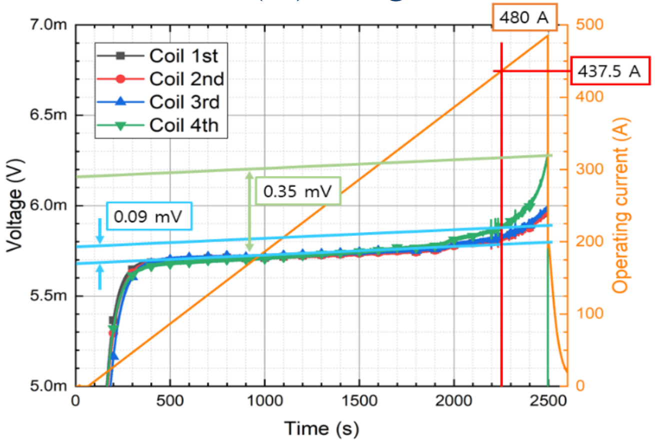


Quadrupole component (B2)



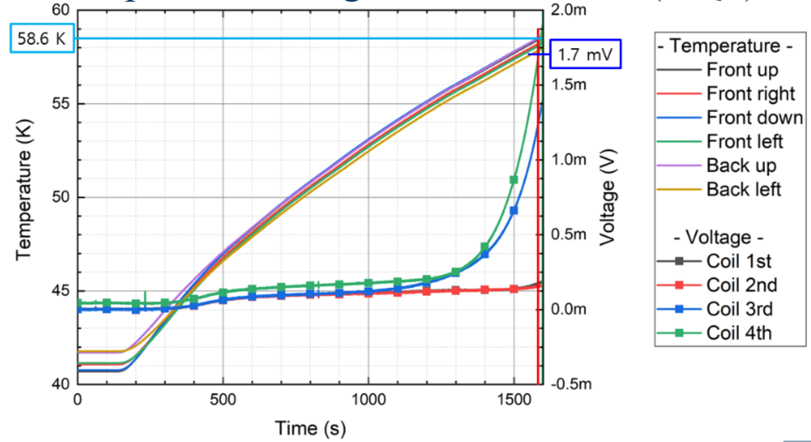
Dodecapole component (B6)

- Critical current (Ic) margin measurement (HQ4)



Hold GHe temperature 40K & Ramping up Current
→ 0.35 mV(0.02 μV/cm < criterion of 0.1 μV/cm) at 437.5A
Critical current margin is more than 30%

- Temperature margin measurement (HQ4)



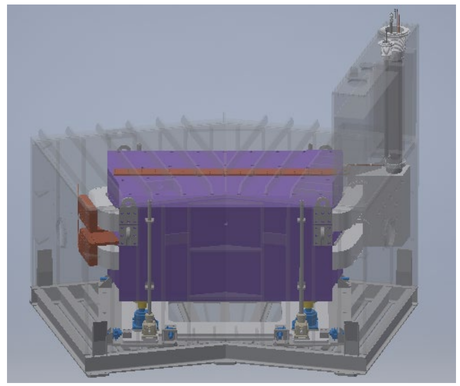
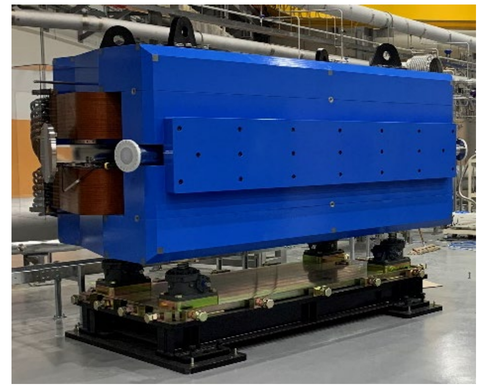
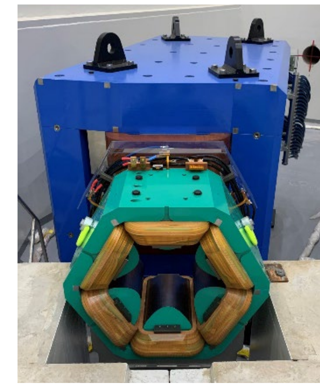
Hold target current of 350A & increase GHe temperature
→ Quench occurs at 58.6K
Temperature margin is 13.6K

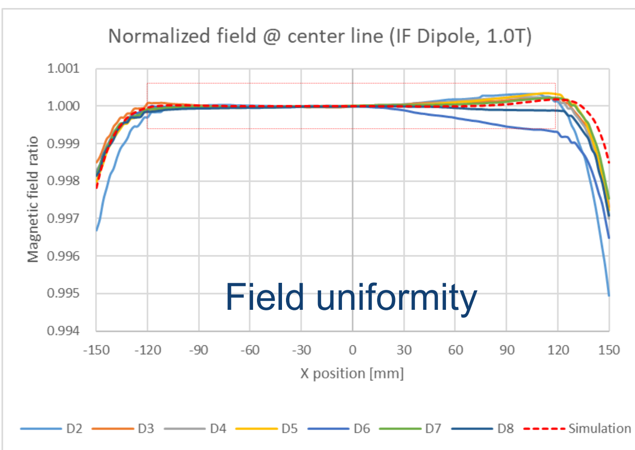
Magnet System

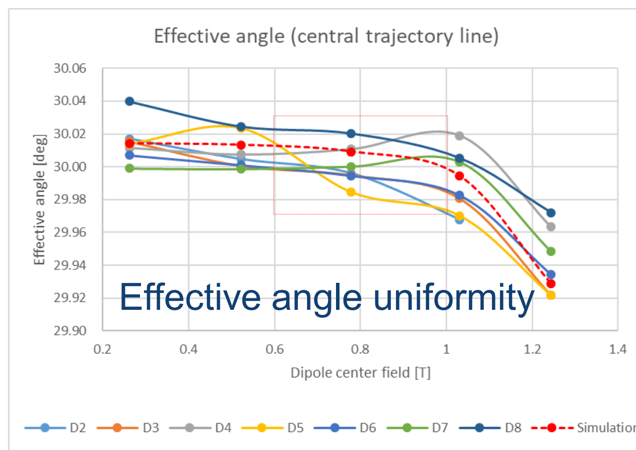
▪ NC (Resistive) Magnet

- Hot cell dipole (D1) : Coil molding using radiation-resistant epoxy (cyanate ester), in production
- NC dipole (D2~D8) & sextupole : On-site installation after completion of manufacturing

Dipole parameter	Value
Bending angle	30º
Bending radius	6.0 m
Magnetic field	1.25 T
Aperture height	150/110 mm
Good field region	120 mm





Main operation range
: 0.6 ~ 1.0 T

- NC dipoles satisfy the field requirements (field uniformity: ±0.05%, effective angle uniformity: ±0.1%).

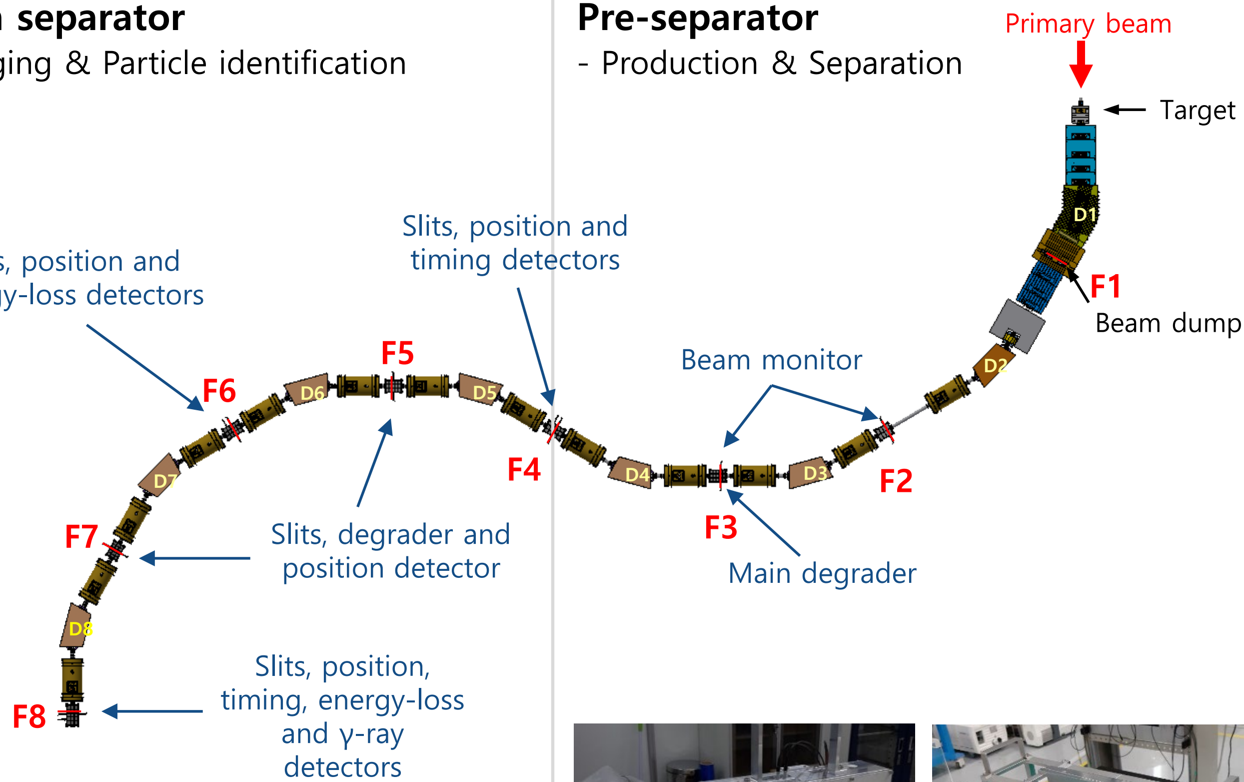
▪ Particle identification (PID) of RI beams

Main separator

- Tagging & Particle identification

Pre-separator

- Production & Separation



Bρ-TOF-ΔE method

$$B\rho = \frac{A}{Q}\frac{m_u c}{e}\beta\gamma$$

$$TOF = \frac{L}{\beta c}$$

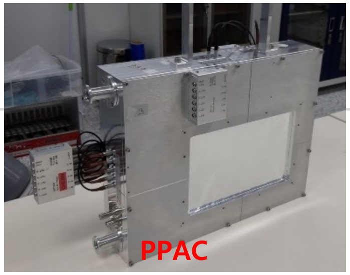
$$\Delta E \sim Z^2/\beta^2$$

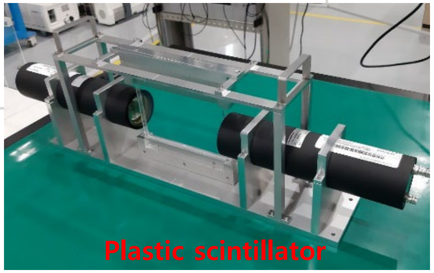
measurement

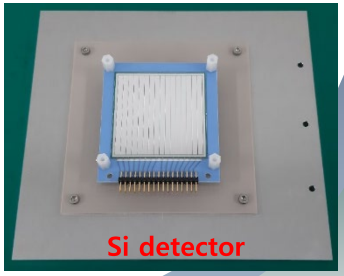
PID plot

- Detectors for PID

- Position (Bρ) : PPAC
- Timing (TOF) : plastic scintillator
- Energy-loss (ΔE): Si-detector/IC







※ Refer to "Development Status of the Detector System for IF Separator at RAON (PS-8-6)" at the poster session.

Summary

▪ Current status

- Most of the components of the IF Separator have been fabricated and are being installed on site.
  : 80kW class target and beam dump, HTS magnets (6 quadrupole, 1 sextupole), NC magnets (7 dipole, 1 sextupole), and detector system are all manufactured and performance test completed
  : Of the 13 LTS Q-triplets, 9 have been performance tested and the remaining 4 are in testing.
  : Hot cell dipole magnet and power supplies for magnets are in production.
  : The large vacuum chamber (for hot cell) is undergoing vacuum testing after field installation.

▪ Future plans

- By the end of this year, the production and performance tests of all components will be completed, and field installation will be completed.

- Next year, we plan to conduct a single-acting test of each component and establish a control system for the IF separator.

Thank you for your attention