Status of RAON accelerator system

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RAON site

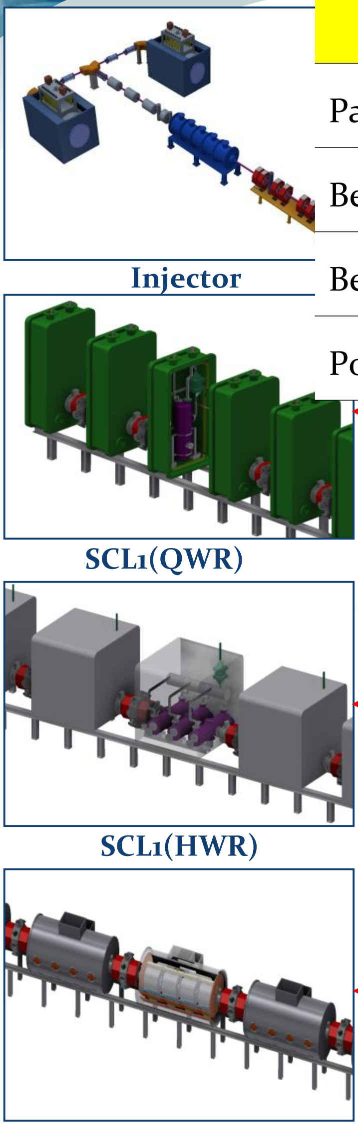
Project period: 2011.12-2021.12 (10 years 1 month)

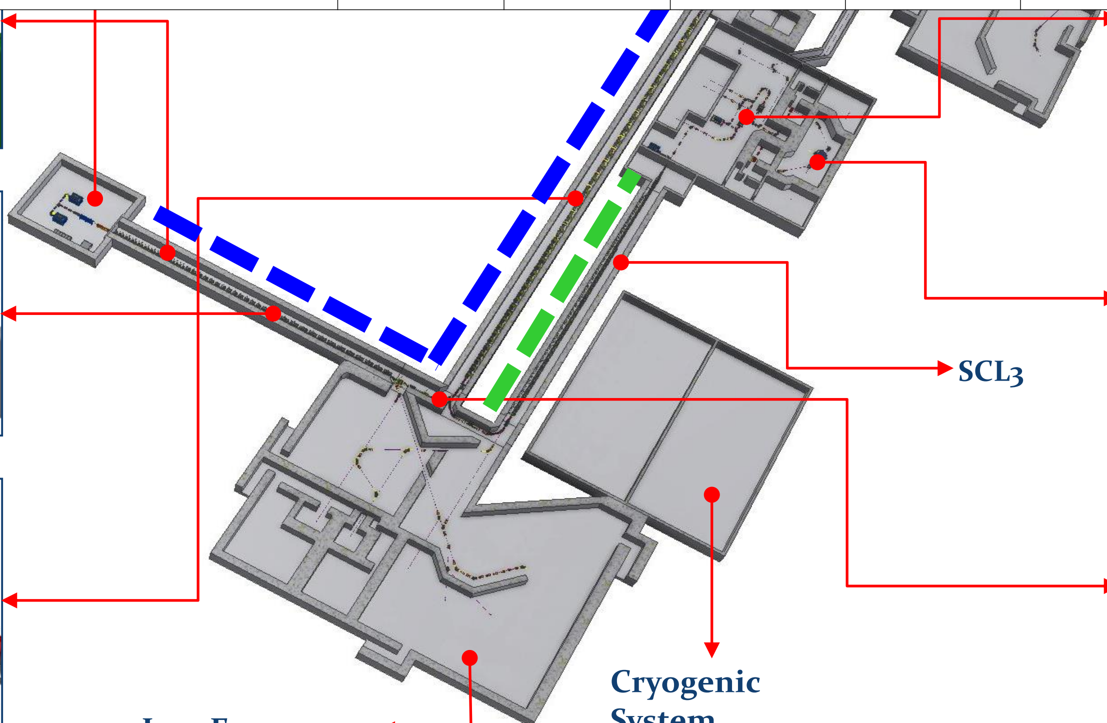
Site area: 952,066㎡

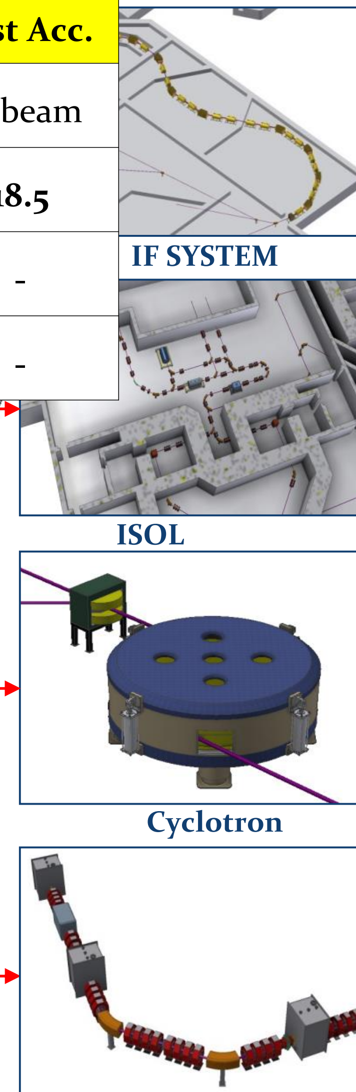
Budget: 382M$(Acc.), 299M$(Land), 519M$(Bld.)

RAON Layout and Beam Parameters

	Driver Linac				Post Acc.
Particle	H^{+}	O^{+8}	Xe^{+54}	U^{+79}	RI beam
Beam energy (MeV/u)	**600**	**320**	**251**	**200**	**18.5**
Beam current (pμA)	660	78	11	8.3	-
Power on target (kW)	> **400**	**400**	**400**	**400**	-

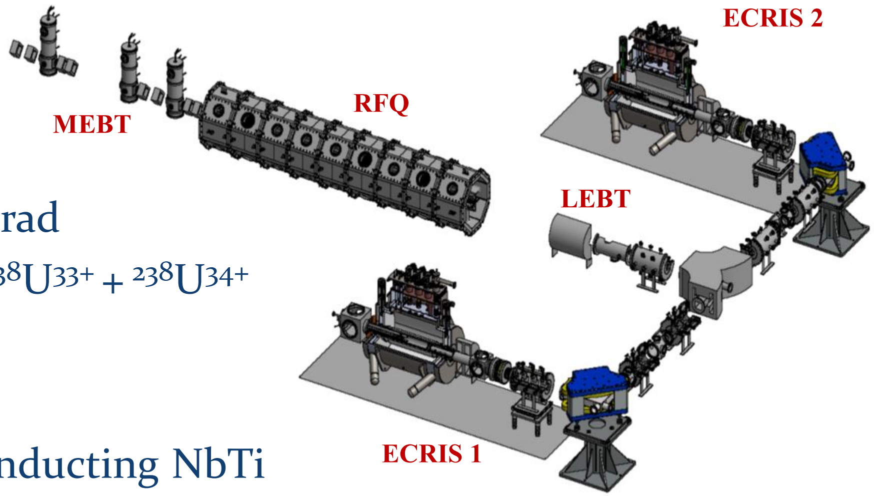






Progress of Accelerator Systems

Injector specification

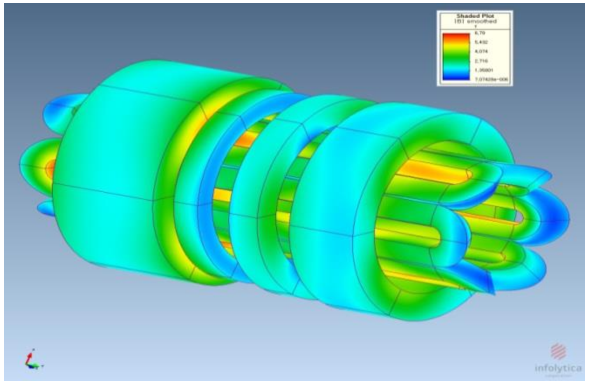


- ECR-IS
  - Output norm(rms) emittance 0.12 π mm-mrad
  - Beam current 400euA for $^{238}U^{33+}$ + $^{238}U^{34+}$
  - Output beam energy 10 keV/u
  - RF frequency 28+18 GHz
  - Magnets Fully superconducting NbTi
- LEBT
  - Pre-bunchers Multi-harmonic buncher, Velocity equalizer
  - Two Bends 90 deg.
- RFQ
  - RF frequency 81.25 MHz
  - Output beam energy 500keV/u
  - 4 Vane types
- MEBT
  - 3 Re-bunchers RF freq. 81.25 MHz

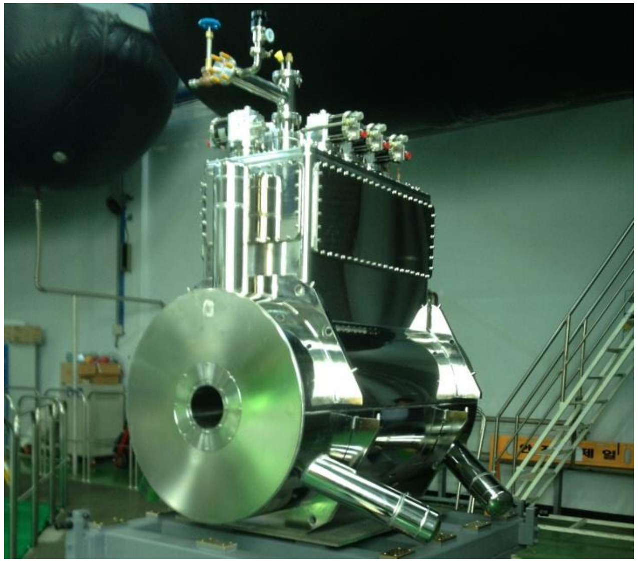
28 GHz ECR Ion Source

RAON

- Superconducting sextupole and solenoid prototypes were tested in 2013.
- Superconducting magnet assembly (6 sextupoles + 4 solenoids) was completed in 2014.
- Cryostat fabrication and assembly was done in 2014
- Beam test is in progress.



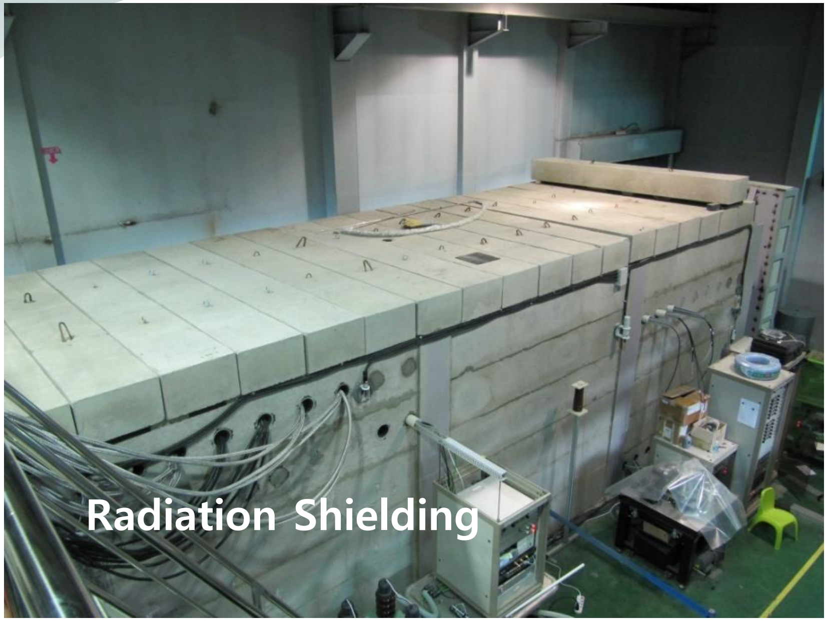
B_{inj}= 3.5 T, B_{ext}= 2.2 T,
B_r= 2 B_{ecr} , B_{min}= 0.7 T



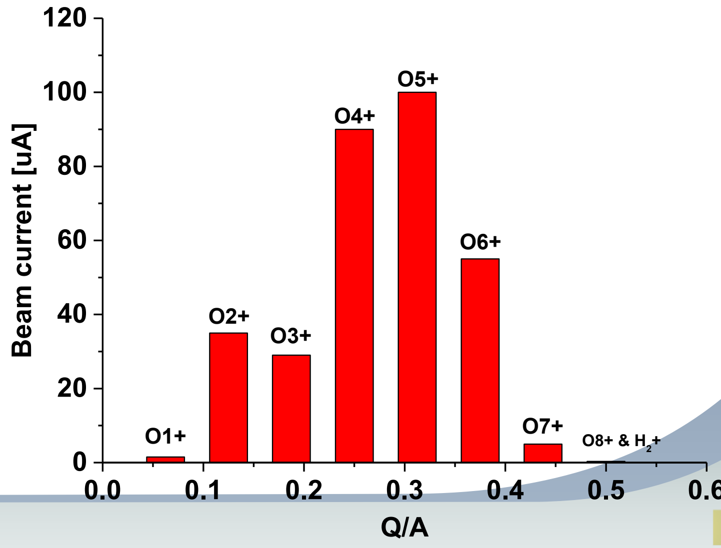
Six 4K cryocoolers,
One single stage cryocooler

28GHz Gyrotron

ECR Ion Source commissioning

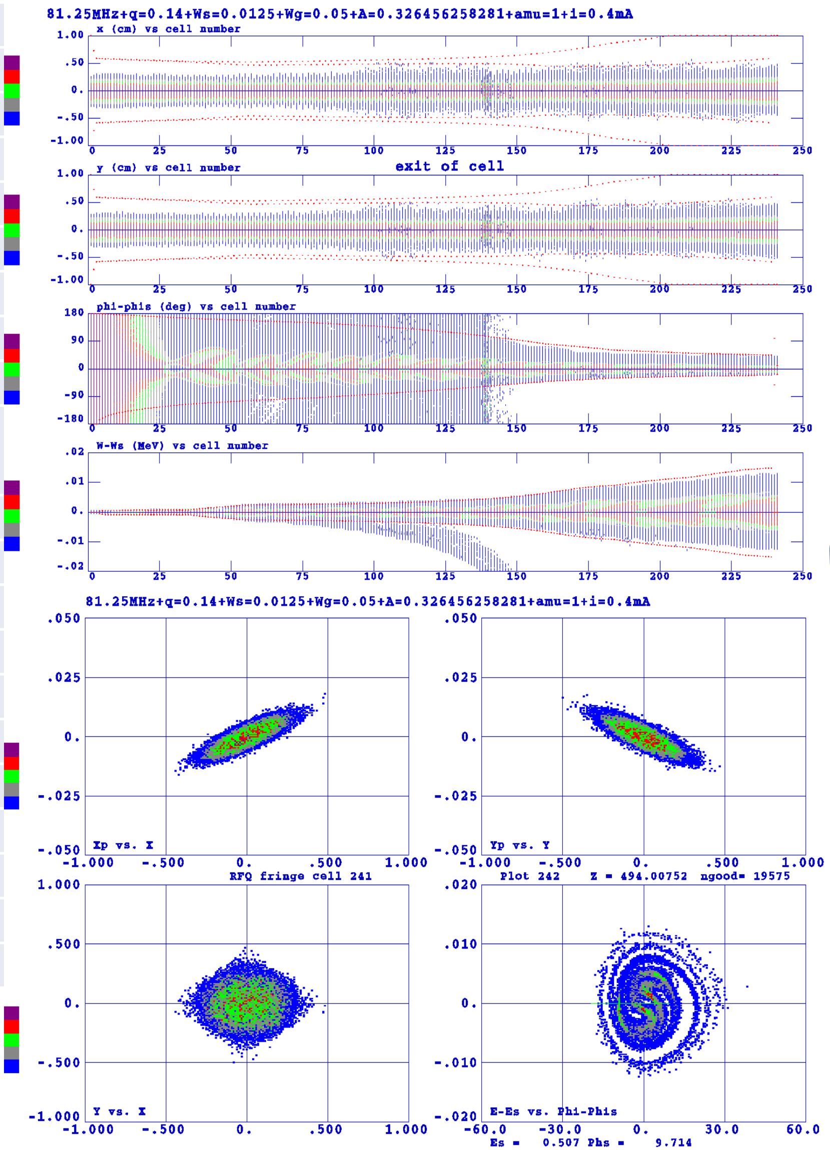


Parameters	value
Magnetic field	70% of the designed value
Operating pressure	8.4e-8 @ injection chamber (not in plasma chamber)
Microwave power	28GHz, 1 kW
Bias disk voltage	-50 V
Electrode structure	Triode structure
Extraction voltage Extraction current	20 kV, -0.5kV, 0V 2.1 mA
Electrode distance	24 mm – 15 mm



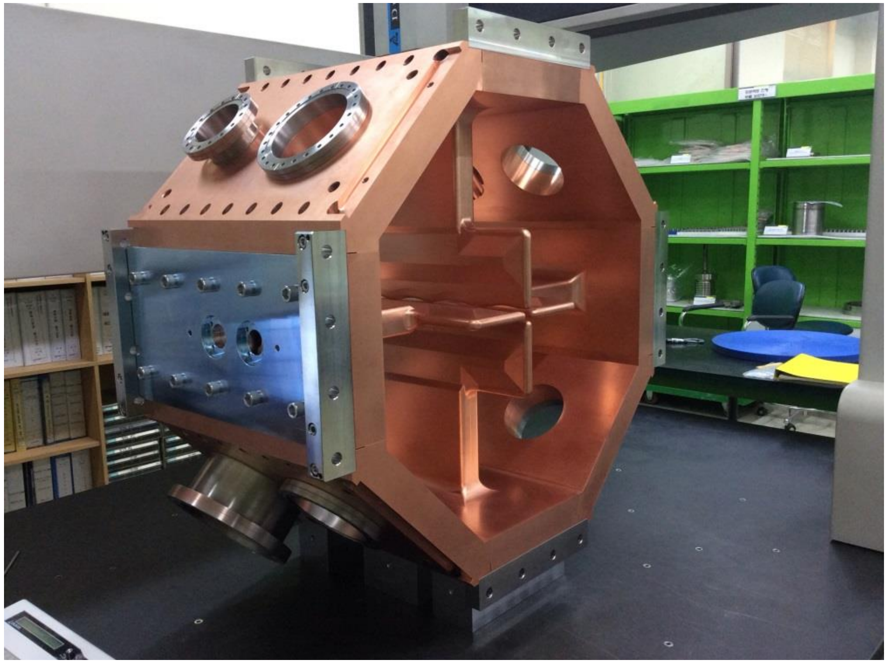
RFQ design parameters

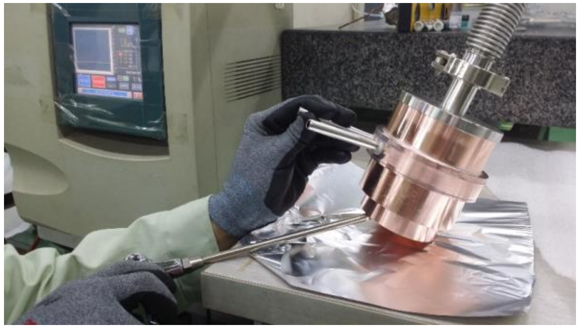
PARAMETER	VALUE
Beam Properties:	
Frequency	81.250 MHz
Particle	H^{+1} to U_{238}^{+33}
Input Energy	10 keV/u
Input Current	0.4 mA
Input Emittance: transverse (rms, norm)	0.012 .cm. mrad
Output Energy	0.507 MeV/u
Output Current for 0.4mA in.	~0.39 mA
Output Emittance: transverse (rms, norm)	0.0125 .cm. mrad
longitudinal (rms)	~26 keV/u-Degree
Transmission	~98 %
Structures and RF:	
Peak surface Field	1.70 Kilpatrick
Structure Power (for U_{238}^{+33})	92.4 kW
Beam Power (for 0.2mA each $U_{238}^{+33\&+34}$)	1.44 kW
Total Power	94 kW
Duty Factor	100%
RF Feed	1 Drive loops
Mechanical:	
Length	4.94 meter
Operating Temperature	TBD Degree C



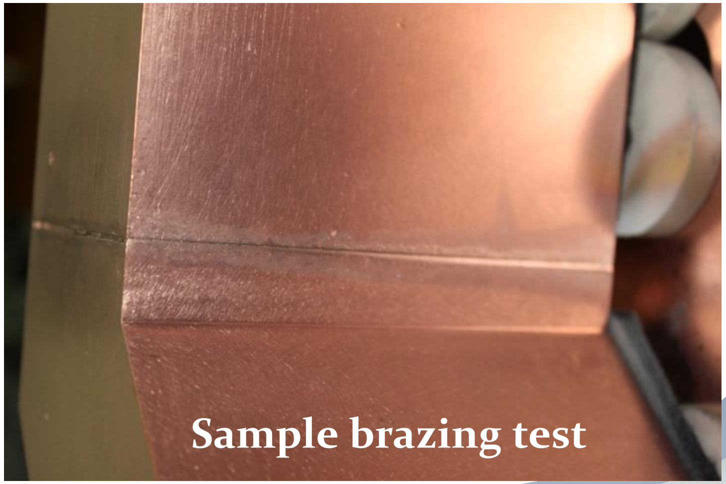
RFQ Prototype

- RFQ Design (2013.08)
- Design review (2013.11)
- RFQ Prototype
  - vane machining and 3D measurement
  - The 1st brazing failed (2014.04)
  - Assessed the related issues
  - Brazing procedure modified (2014.05)
  - Confirmed brazing procedure (2014.06)
  - RFQ prototype fab. completed (2014.09)
- RFQ Prototype test
  - 15kW SSA, coupler, RCCS are installed



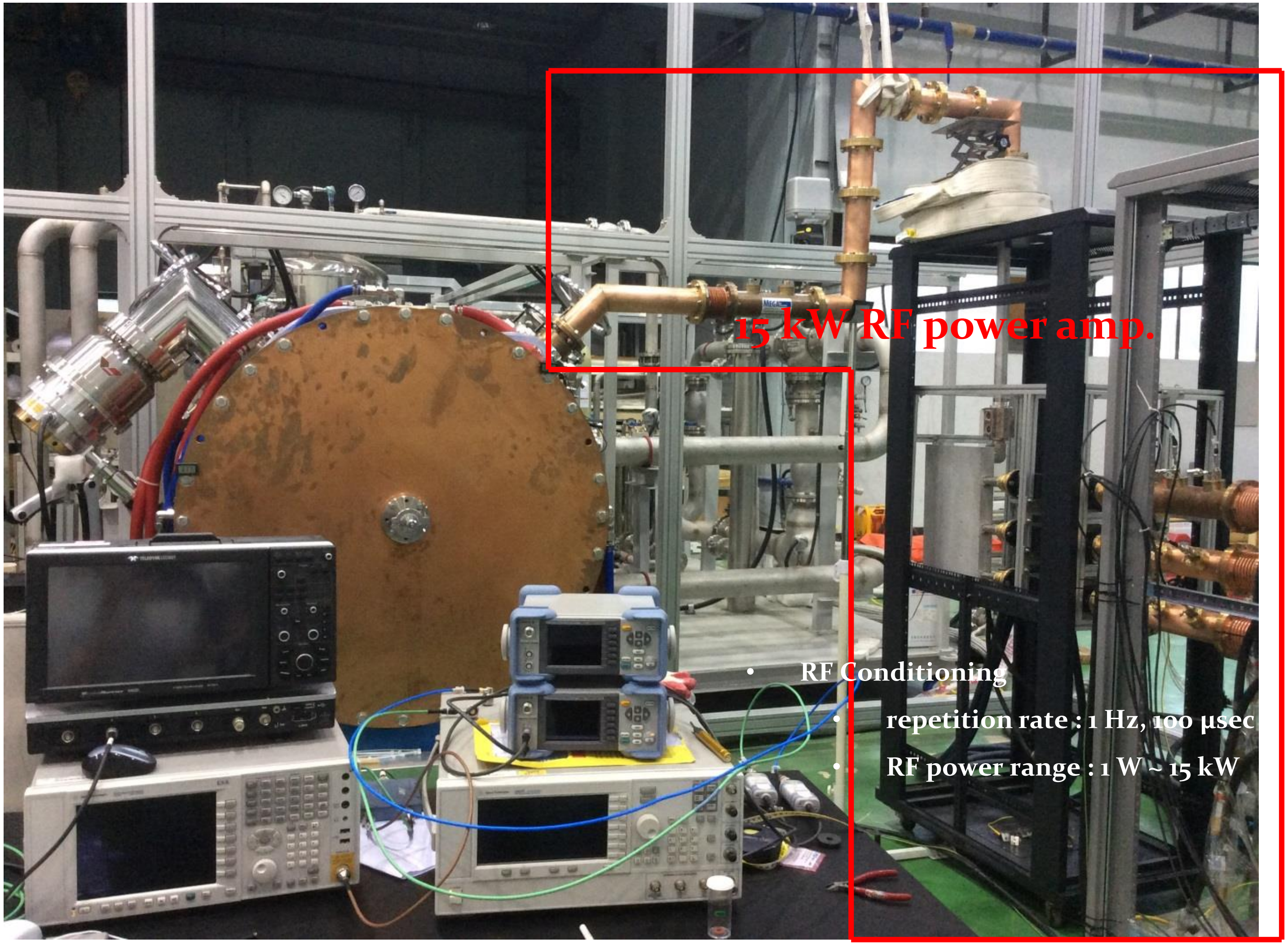


RFQ coupler
Leak test



Sample brazing test

Prototype RFQ – RF conditioning

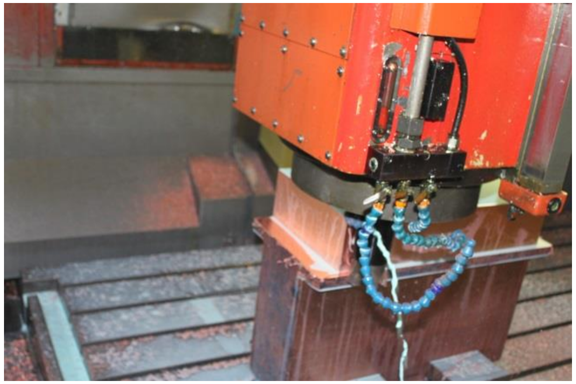


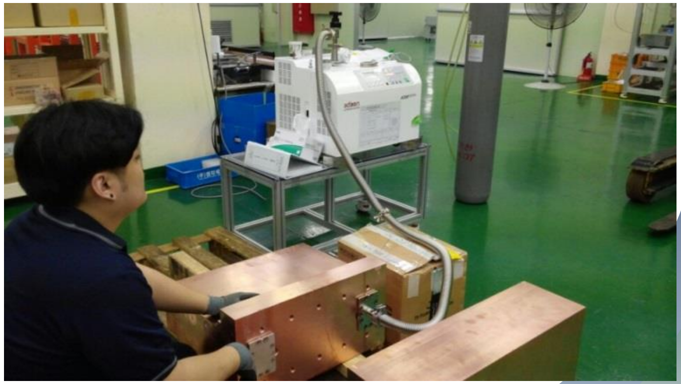
- RF Conditioning
  - repetition rate : 1 Hz, 100 μsec
  - RF power range : 1 W ~ 15 kW

RFQ Fabrication

RFQ Fabrication: delivered in 2016.08

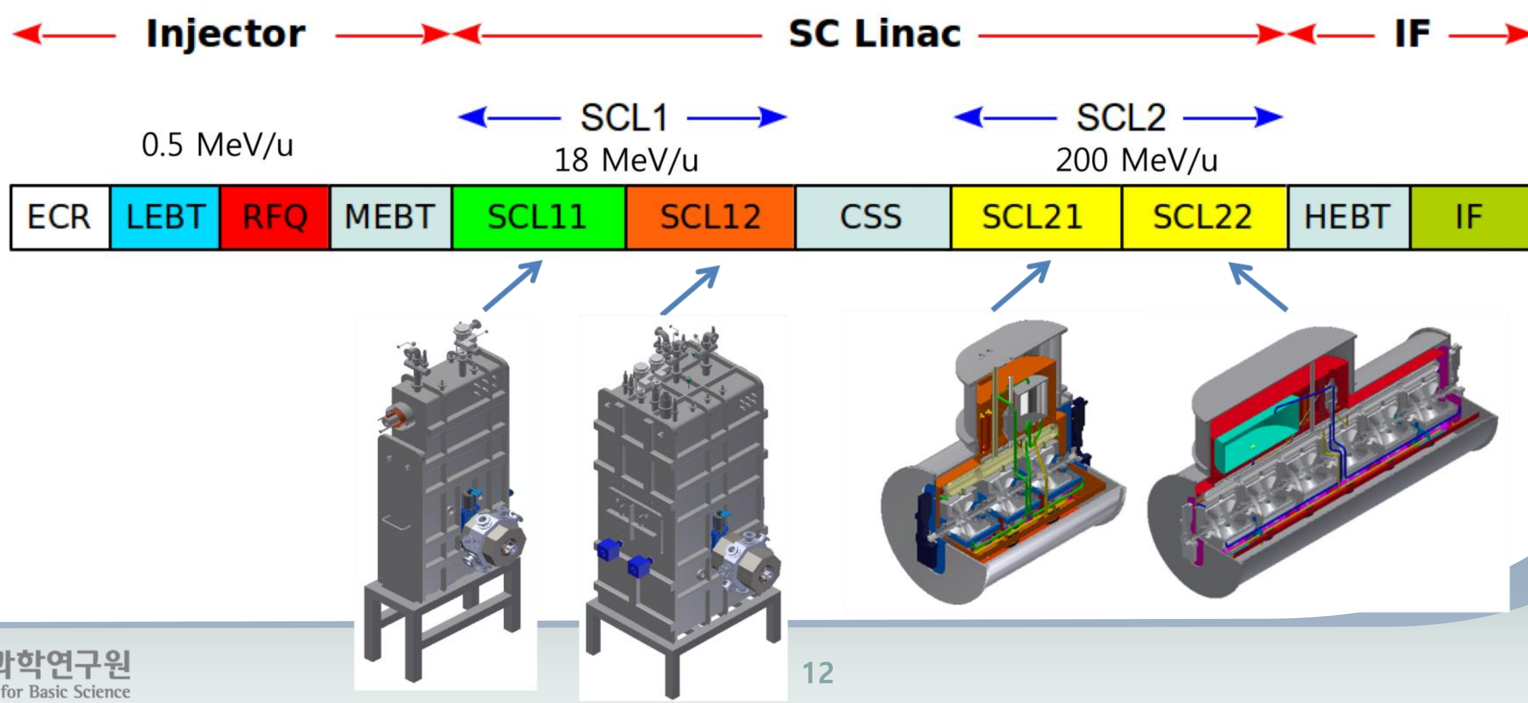




RAON Superconducting Linac

- RAON SCL is designed to accelerate high intensity beams.
- Focusing by NC quad doublets rather than SC solenoids.
- Optimized geometric beta of SC cavities (0.047, 0.12, 0.30, 0.51).
- Employs larger aperture to reduce beam loss (40 mm and 50 mm aperture).
- Prototyping of SC cavities and cryomodules is done.



Layout of Driver Linac

RAON

ECR	LEBT	RFQ	MEBT	SCL11	SCL12	STRIP	SCL21	SCL22
				QWR (81.25MHz)	HWR (162.5MHz)		SSR1 (325MHz)	SSR2 (325MHz)

CAV QF QD — 22 cryomodules → Output 2.7 MeV/u

22 β=0.047 QWRs, 44 quadrupoles

CAV CAV QF QD — 13 cryomodules → Output 6.0 MeV/u

CAV CAV CAV CAV QF QD — 19 cryomodules → Output 18.5 MeV/u

98 β=0.12 HWRs, 64 quadrupoles

Stripper: charge state 33, 34 → 77,78,79,80,81 for Uranium

C C C QF QD — 23 cryomodules → Output 56.5 MeV/u

69 β=0.30 SSR1, 46 quadrupoles

C C C C C C QF QD — 23 cryomodules → Output 200 MeV/u

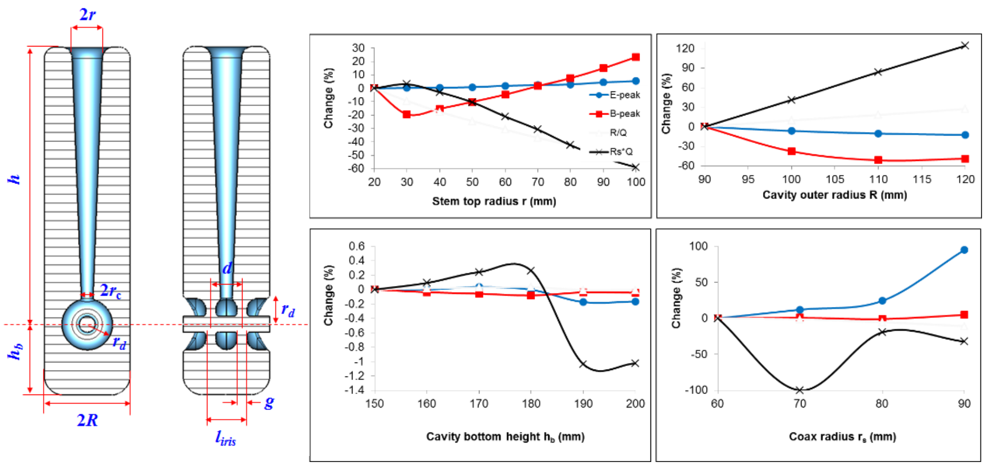
138 β=0.51 SSR2, 46 quadrupoles

Total 331 cavities, 100 cryomodules, 196 quadrupoles, 122m (LEL,CSS), 181m (HEL)

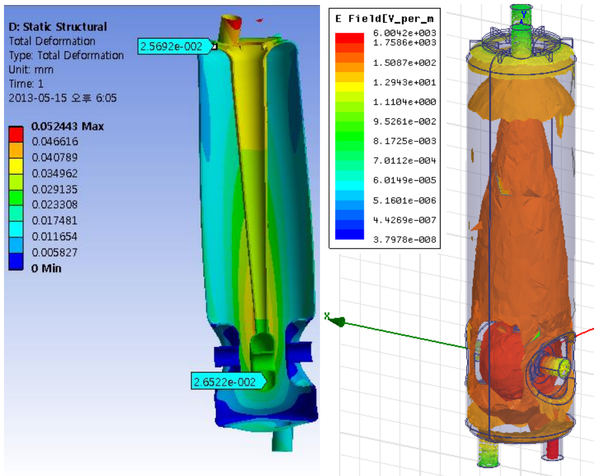
Design of SC Cavity

RAON

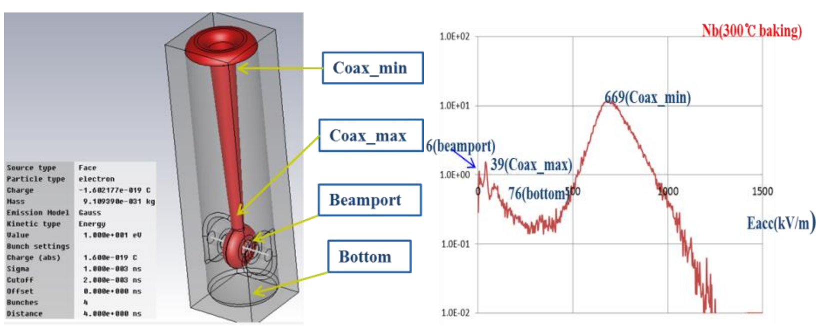
Optimization of Cavity Parameters



Mechanical analysis



Multipacting analysis



Frequency shift

Frequency shift	QWR
Resonant Frequency	81.25MHz
Cavity length(upper)	-67.1kHz/mm
Cavity length(lower)	+1.3kHz/mm
Welding (0.58mm shrink)	+38.2kHz
EP/BCP (125um)	+267kHz
External pressure(Vacuum, L-He)	-4.6Hz/mbar
Cool down(293K→2K)	+203kHz
Lorentz Detuning	-1.7Hz/(MV/m)^2

Superconducting cavity

Parameters	Unit	QWR	HWR	SSR1	SSR2
β_g	-	0.047	0.12	0.30	0.51
F	MHz	81.25	162.5	325	325
Aperture	mm	40	40	50	50
QR_s	Ohm	21	42	98	112
R/Q	Ohm	468	310	246	296
V_{acc}	MV	0.9	1.3	1.9	3.6
E_{peak}/E_{acc}		5.6	5.0	4.4	3.9
B_{peak}/E_{acc}		9.3	8.2	6.3	7.2
$Q_{calc}/10^9$	-	1.7	4.1	9.2	10.5
Temp.	K	4.5	2	2	2

EM design optimization: Parameters sweeping

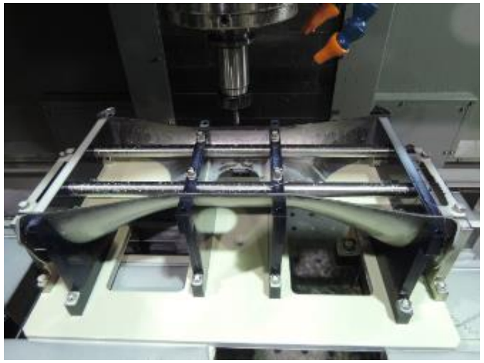
SC Cavity Prototyping

RAON

➢CAVITY Manufacturing Process

MATERIAL INSPECTION

DEEP DRAWING



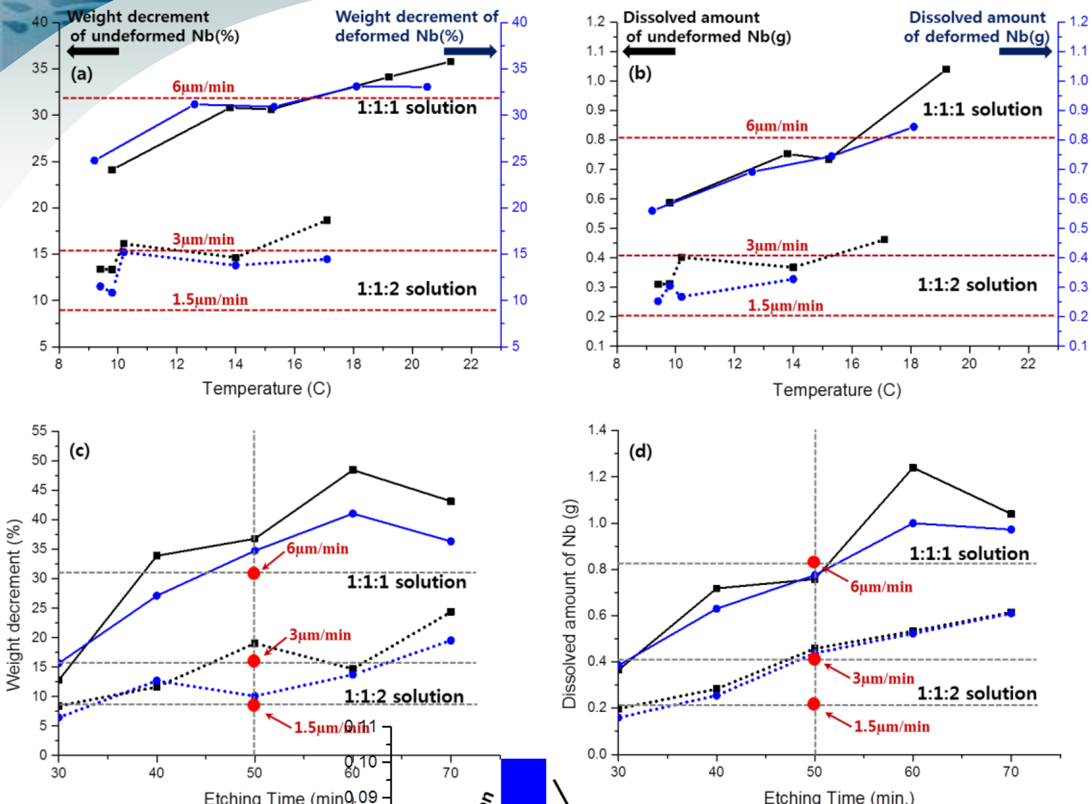
MACHINING

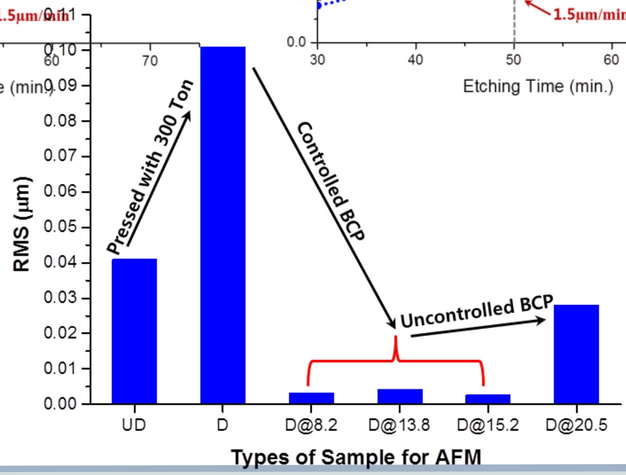
3D SCAN (CMM)

BCP

EBW

Buffered Chemical Polishing





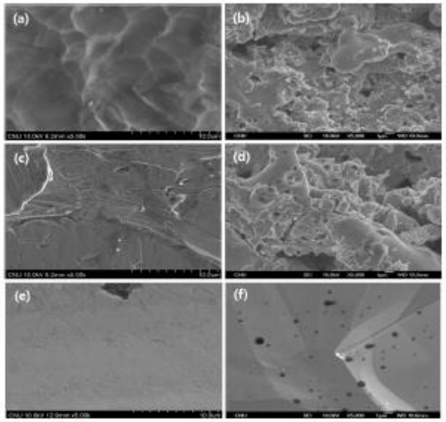
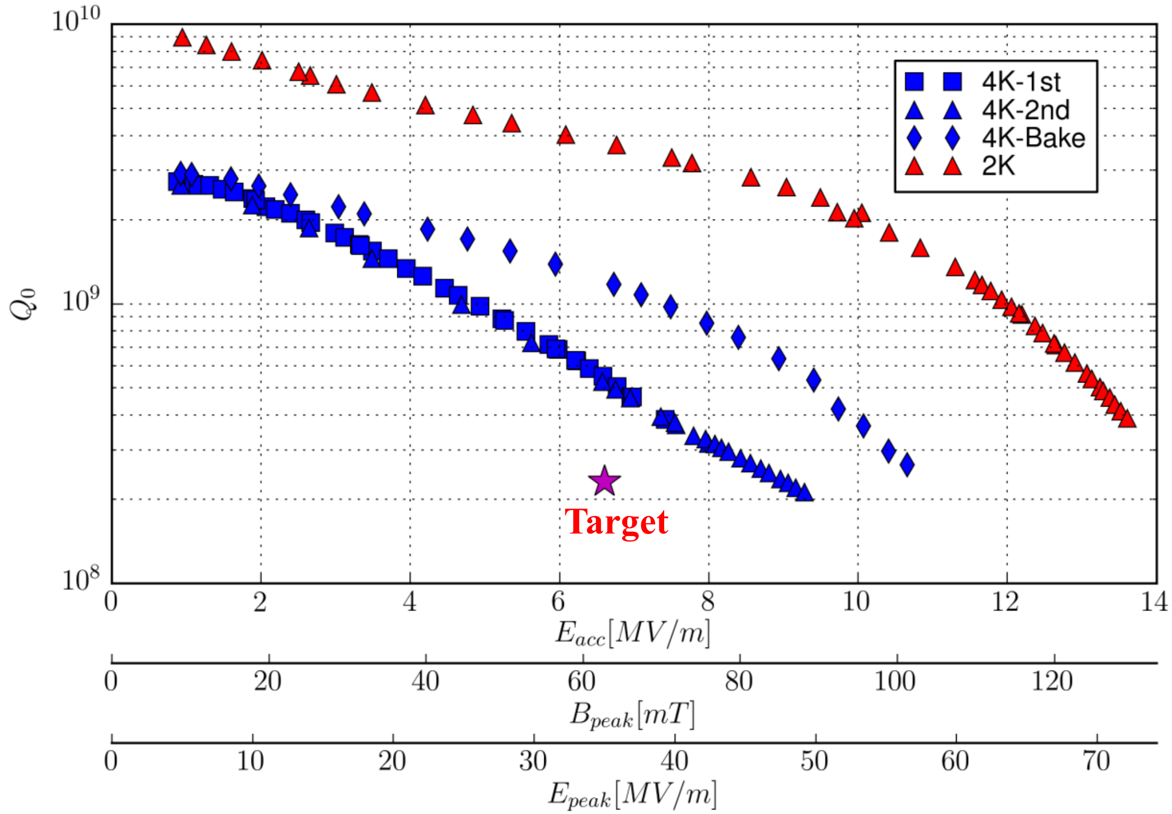


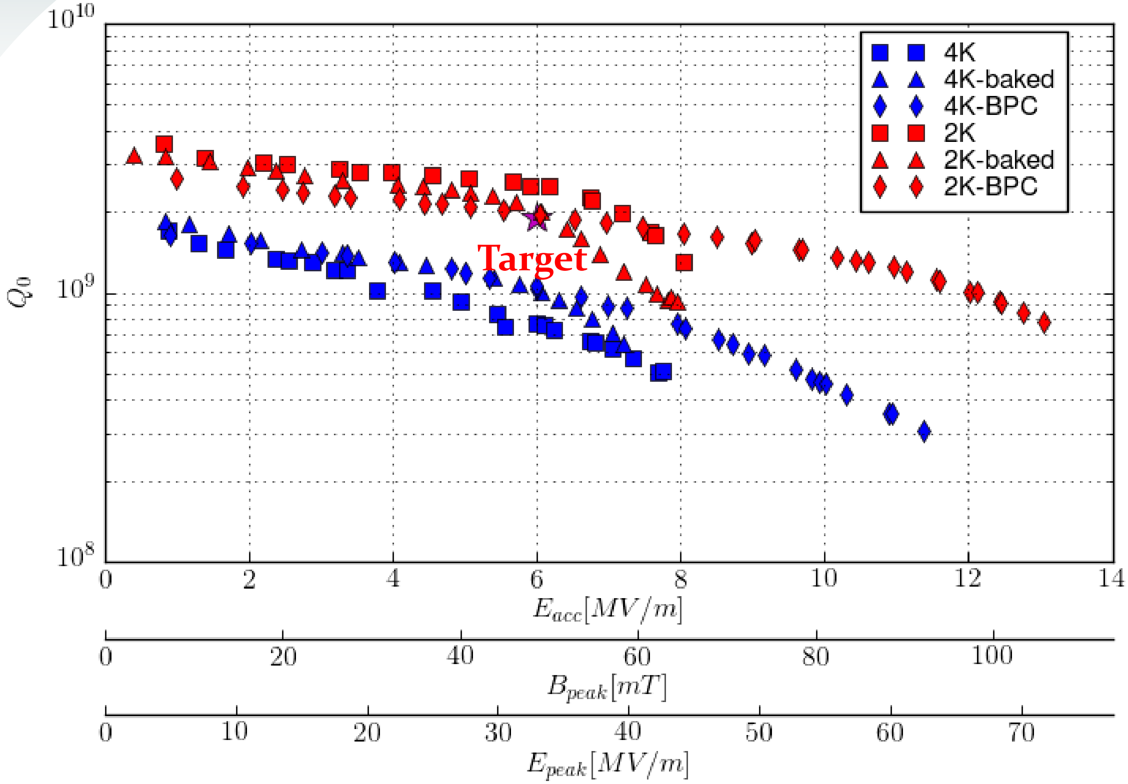
Figure 3: SEM Images of Nb samples (×5000), (a) surface of undeformed Nb, (b) cross-section of undeformed Nb, (c) surface of deformed Nb, (d) cross-section of deformed Nb, (e) surface of undeformed Nb with 1:1:1 BCP treated for 50 min, and (f) cross-section of undeformed Nb with 1:1:1 BCP treated for 50 min.

(Courtesy of TRIUMF)

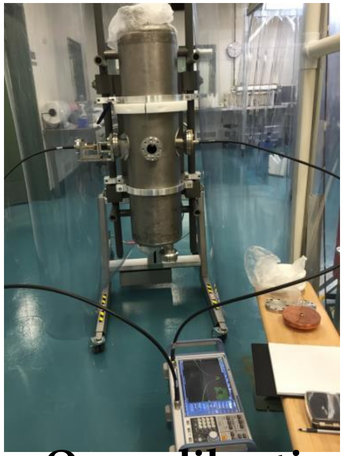
Vertical test of QWR cavity



Vertical test of HWR cavity

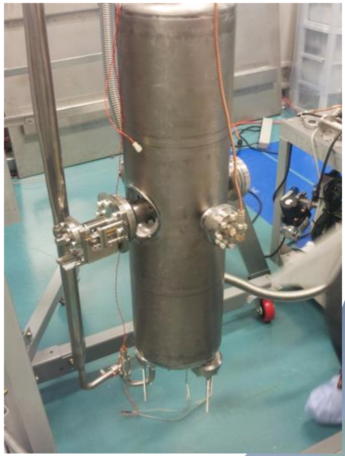


HWR in HPR



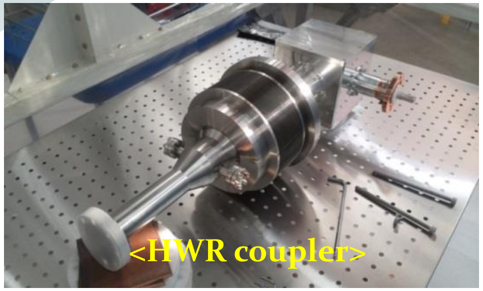
Qext calibration

RF system



Leak check

RF coupler prototyping


<HWR coupler>


<Power meter, vacuum gauge>

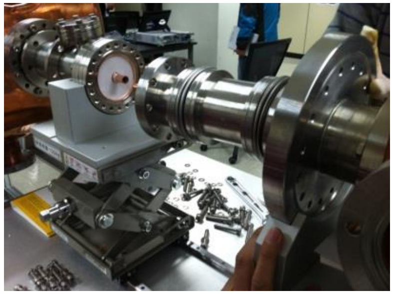

<High power test>

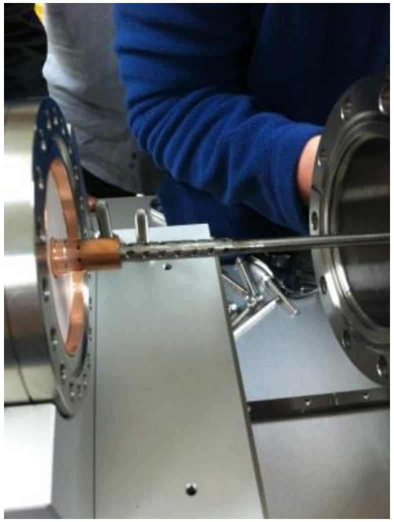
High power test: TW 16kW, SW 5kW

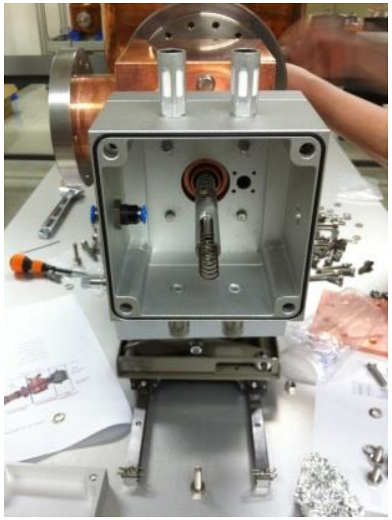
Frequency: 162.5 MHz

Nominal RF power: 5kW

Q_{ext}=~2 x 10^6







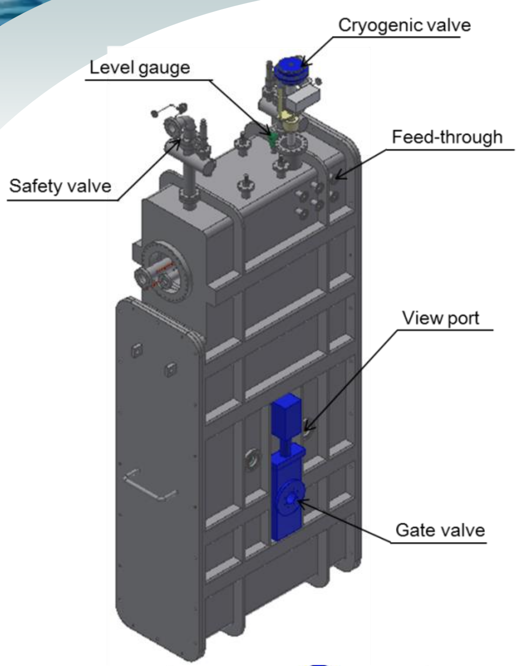
Frequency: 325 MHz

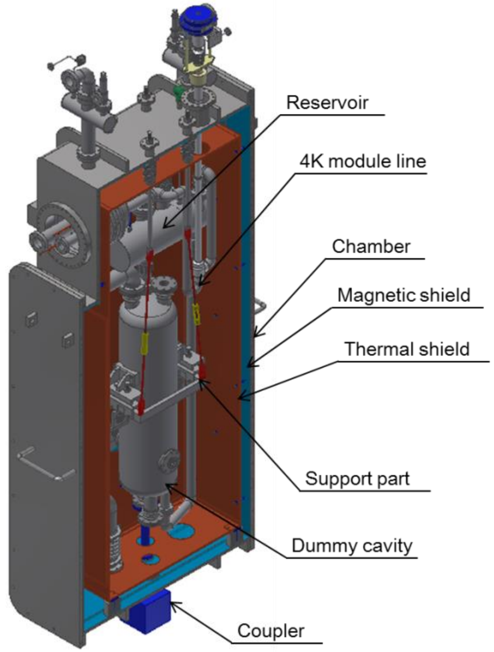
Nominal RF power: 20 kW

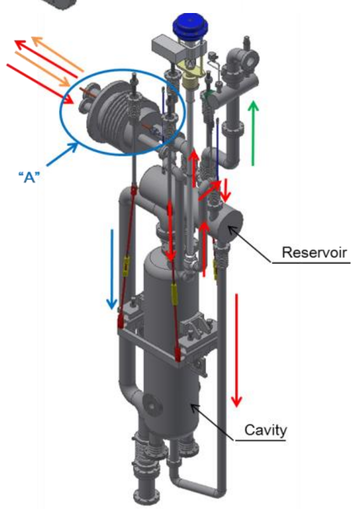
Q_{ext}=6 x 10^6~7 x 10^6


High power test in progress

Cryomodule design (QWR)







4K He line

Material : STS316L
Pipe inlet Size : 32A Sch5S
Pipe outlet Size : 50A Sch5S
Gasket : Helicoflex

40K He line

Material : Cu
Pipe inlet Size : 3/8" Tube
Gasket : VCR fitting

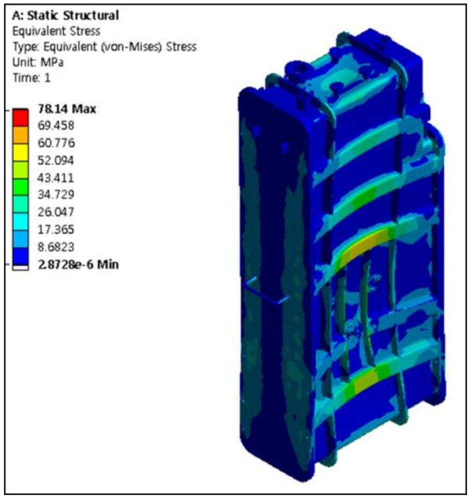
Vacuum line

Material : STS316L
Pipe inlet Size : 65A Sch5S
Gasket : Helicoflex

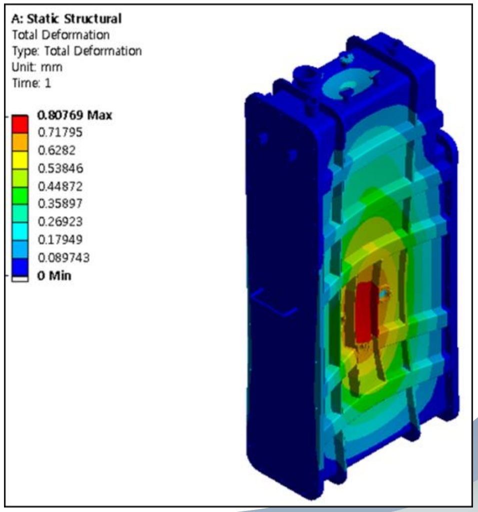
Safety line

Material : STS316L
Pipe inlet Size : 65A Sch5S
Gasket : Helicoflex

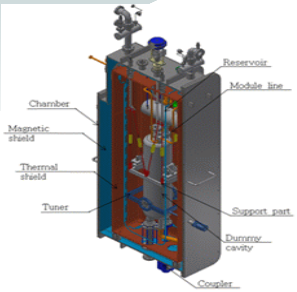
Stress (Condition : Vacuum)

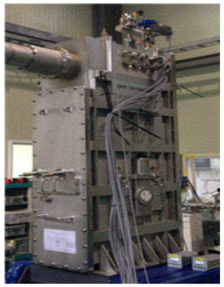


Displacement (Condition : Vacuum)

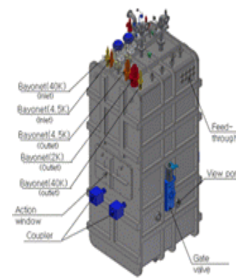


Cryomodule development

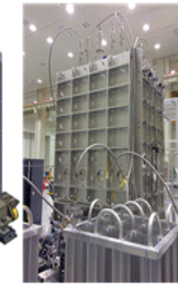




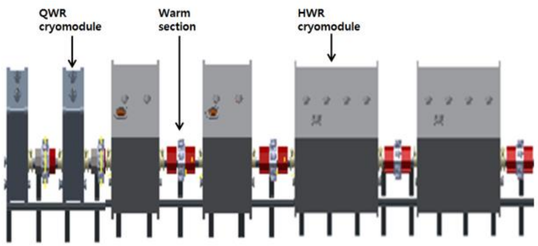
QWR Cryomodule
(LHe/LN test)

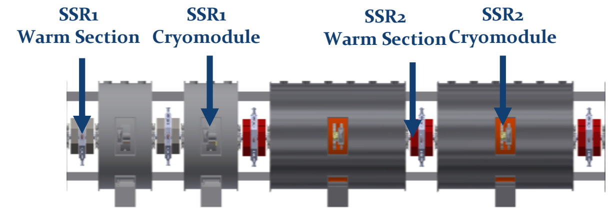


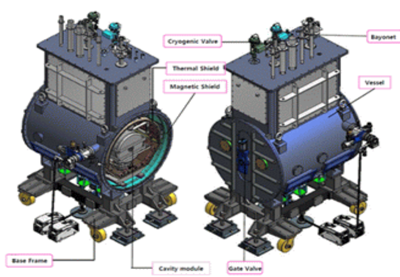




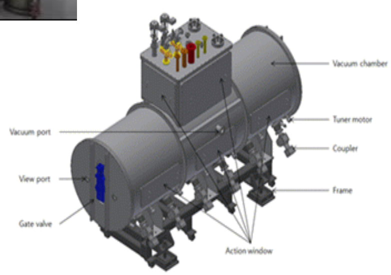
HWR Cryomodule
(LHe/LN test)







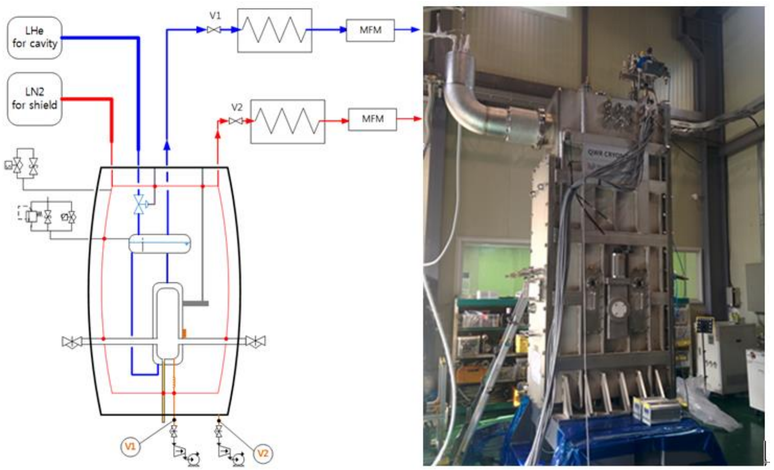
SSR1 Cryomodule
(LN test)

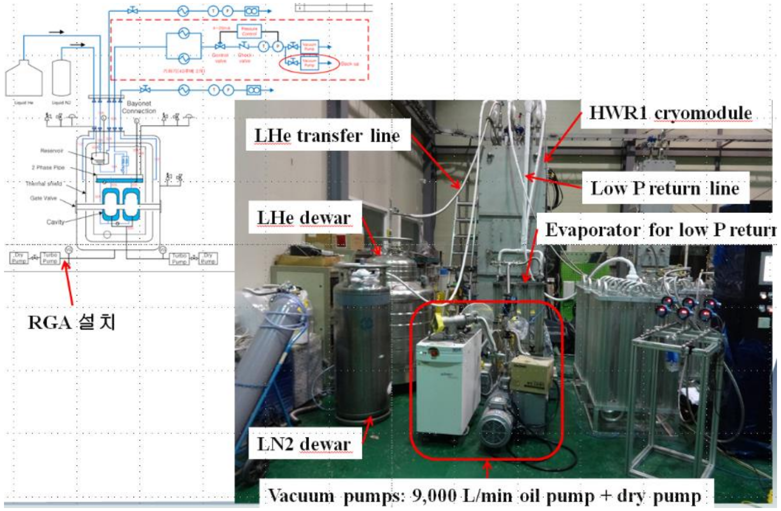


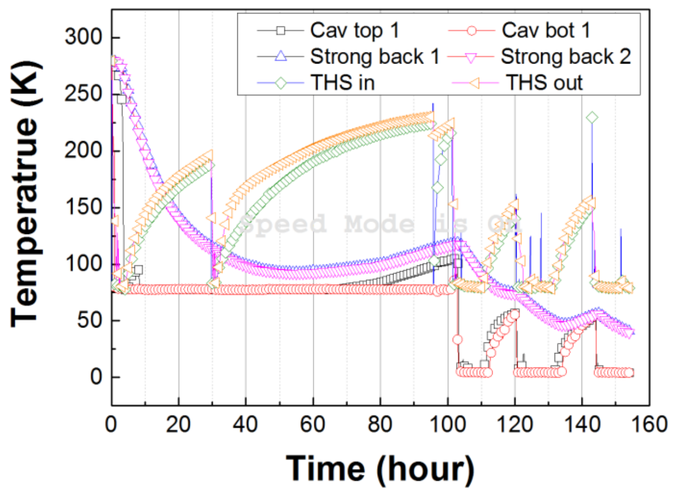
SSR2 Cryomodule
(LN test)

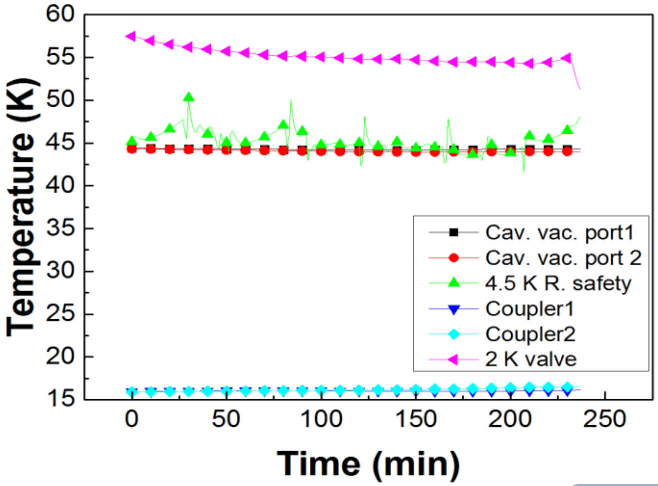
Static load of cryomodule

- QWR static load: 3.9 W (expectation: 3.2 W)
- HWR static load: 13.5 W (expectation: 14.7 W)







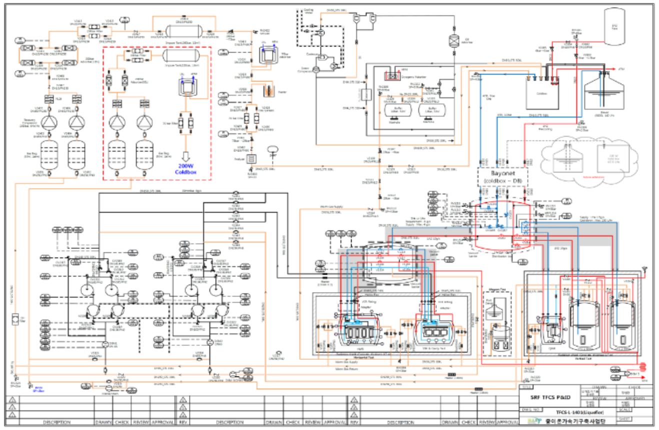


SRF Test Facility

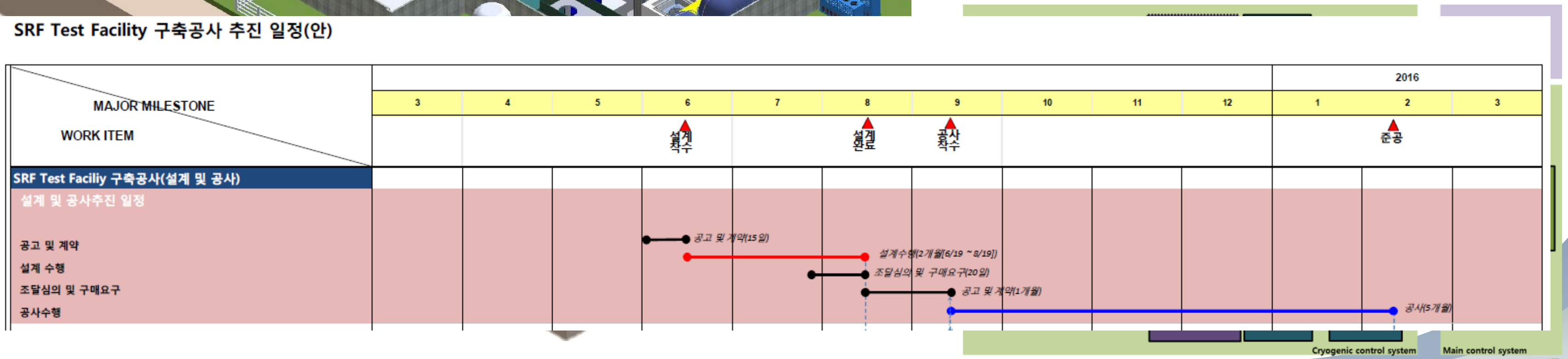
- Install Helium Liquefier (New & Old)
- Install Warm Pump for 2K-module and 2K-module testing
- Remodeling of the facility is under way

[SRFTF Layout]

[P&ID]



[Control System Logic]

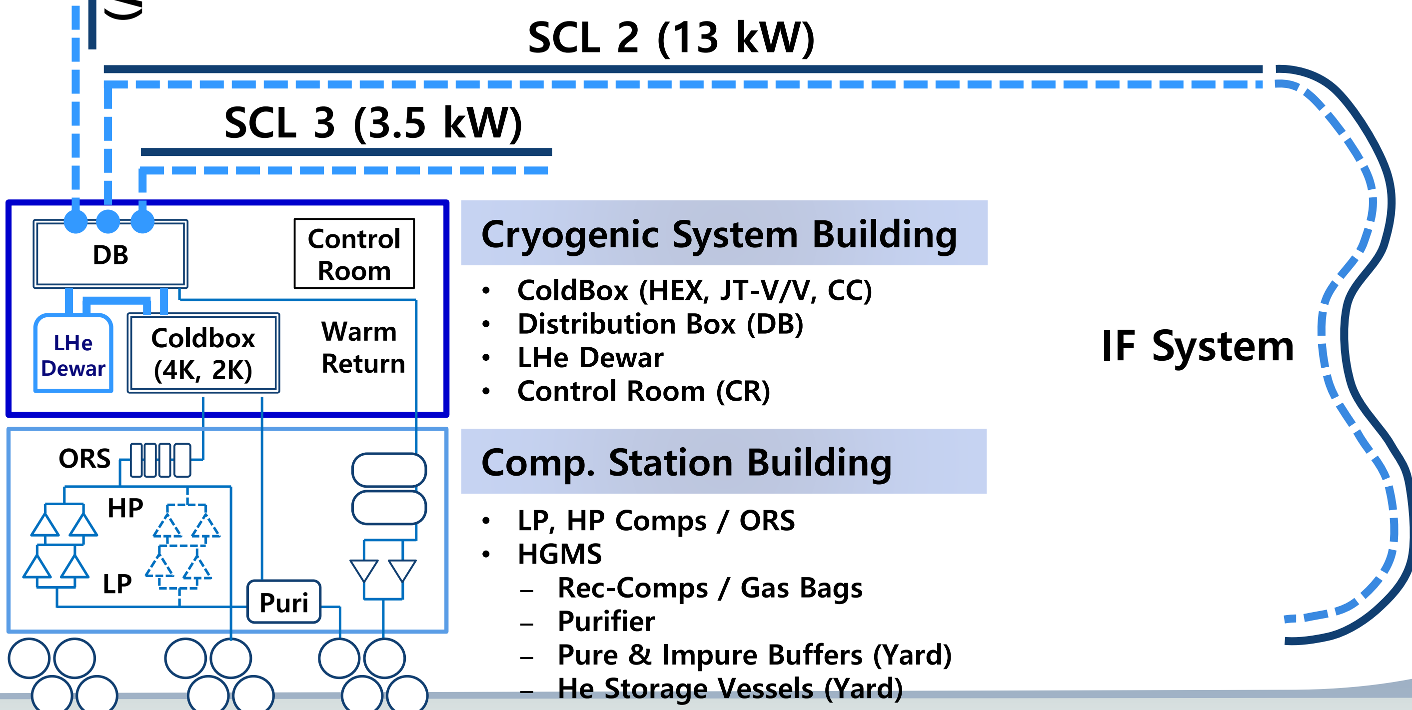


Main Cryoplant Schematics

- Report on Strategy of Constructing the Cryoplant of RAON were submitted.
- HRS Capacity options, HRS/HDS Construction Budgets were included.

- **Cryoplant Capacity**
  - Option 1: 3.5 | 13 | 3.5
  - Option 2: 13 | 7
  - Option 3: 20

Load (kW)	SCL 1	SCL 2	SCL 3
Static	1.5	3.9	1.5
Dynamic	1.95	9.0	1.95
Total	19.8 kW @ 4.5 K		



Cryogenic System Building

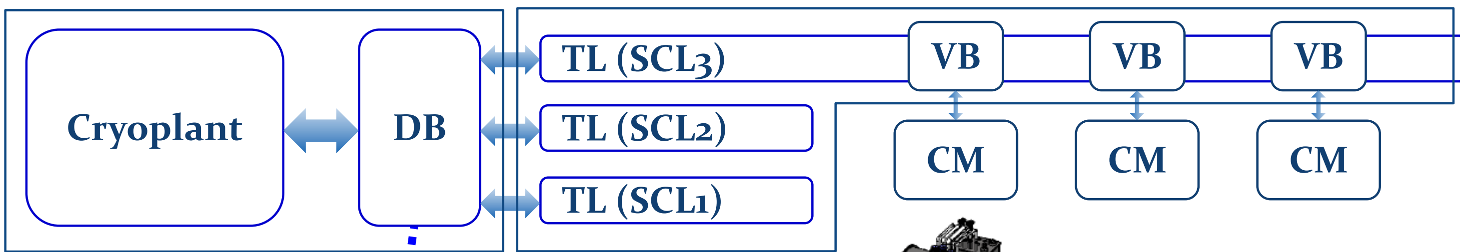
- ColdBox (HEX, JT-V/V, CC)
- Distribution Box (DB)
- LHe Dewar
- Control Room (CR)

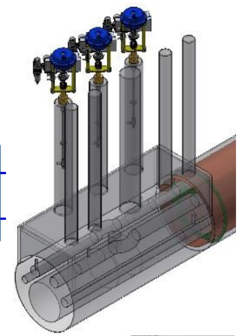
Comp. Station Building

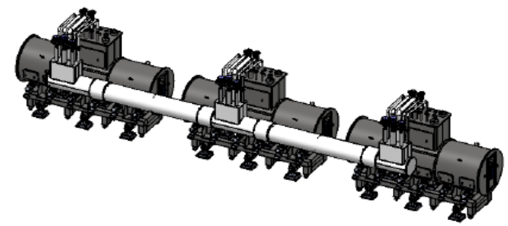
- LP, HP Comps / ORS
- HGMS
  - Rec-Comps / Gas Bags
  - Purifier
  - Pure & Impure Buffers (Yard)
  - He Storage Vessels (Yard)
- LN2 Tanks (Yard)

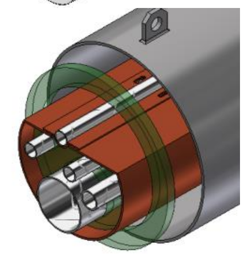
Helium Distribution System

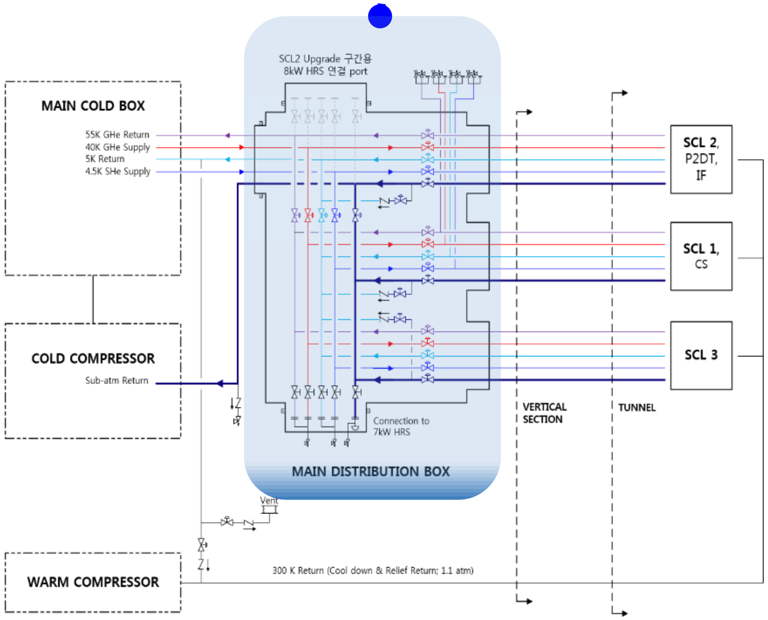
- **Helium Distribution Flow : Cryoplant → DB (Distribution Box) → TL (Transfer Line) → VB (Valve Box) → CM (Cryomodule)**



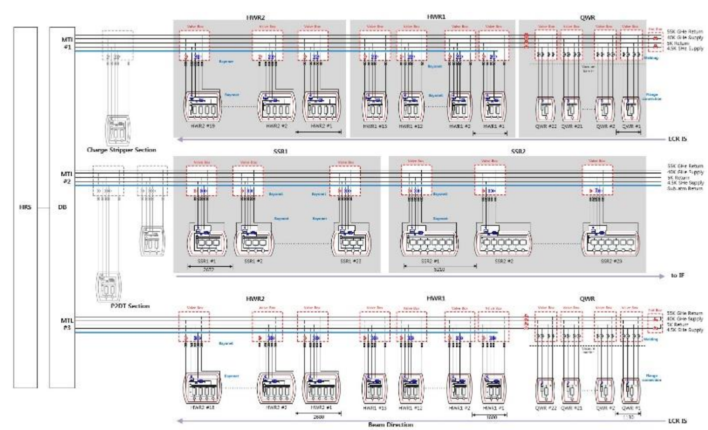








[DB P&ID]



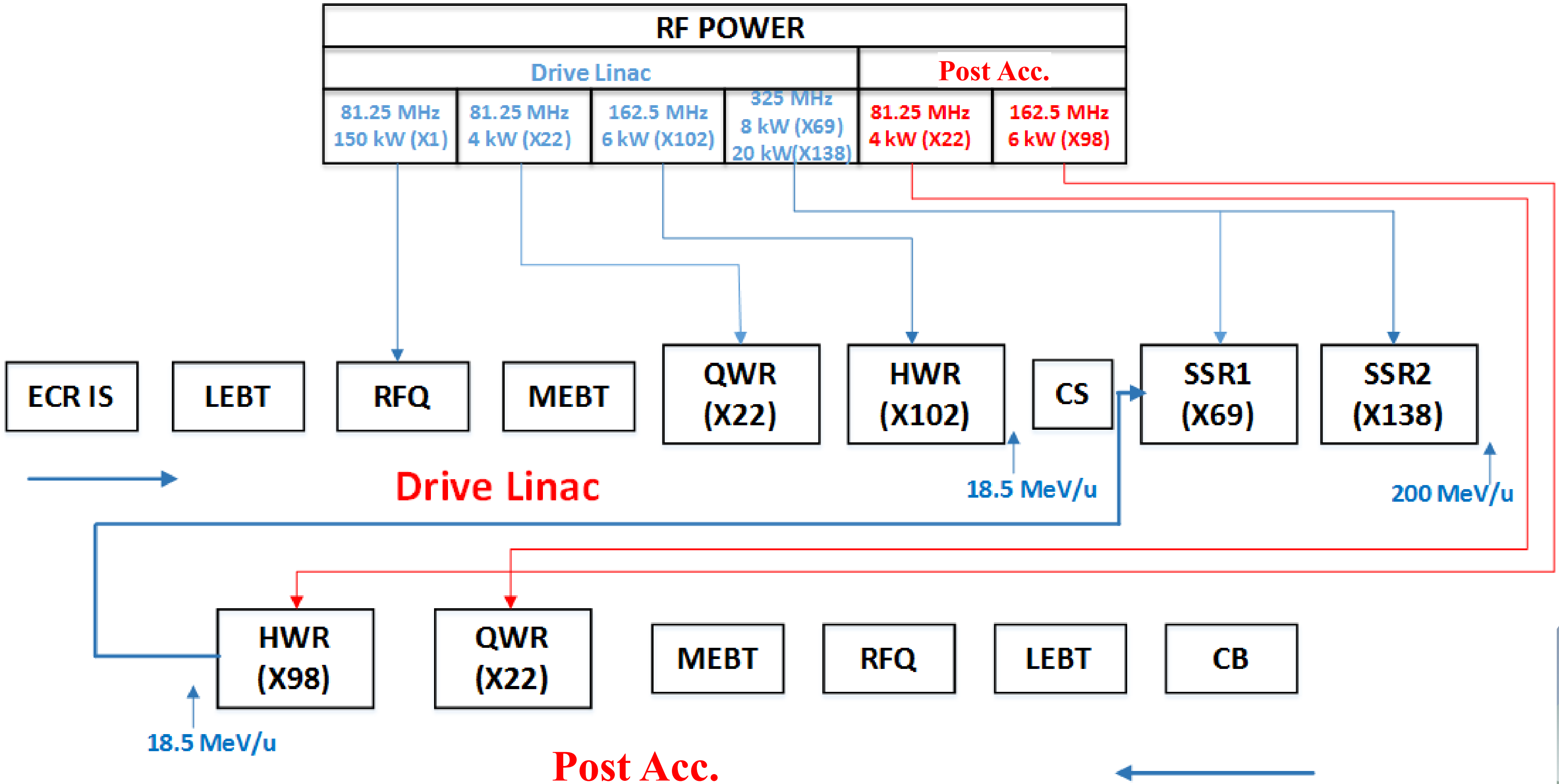
[Helium Distribution System P&ID]

RAON RF Systems

- **RF Systems : Supplying RF Power to Cavity**
  - LLRF : RF Power Control
  - HPRF : High Power Amp. , Transmission Line
  - RF Distribution

LLRF Control Stability

- **Amplitude : ± 1 %**
- **Phase : ± 1 °**

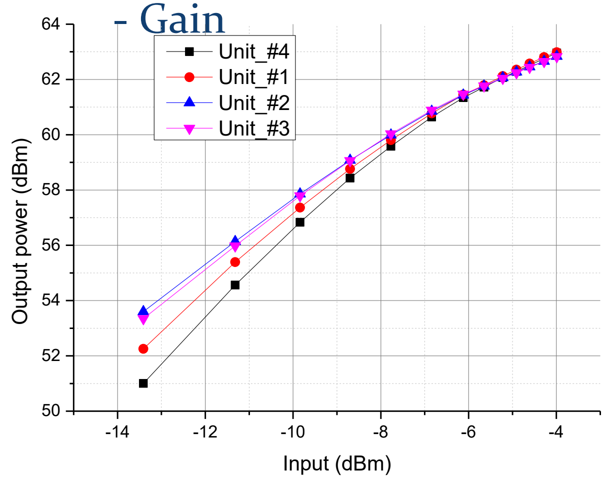


HPRF test (QWR/HWR/SSR/RFQ SSPA)

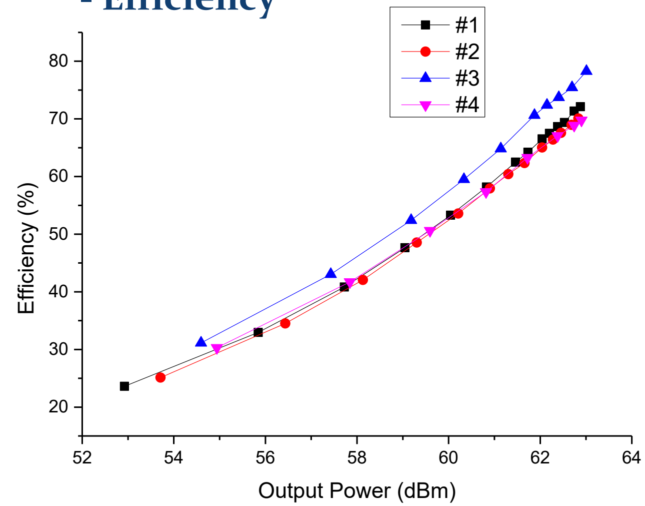
RAON

- 2 kW SSPA unit test

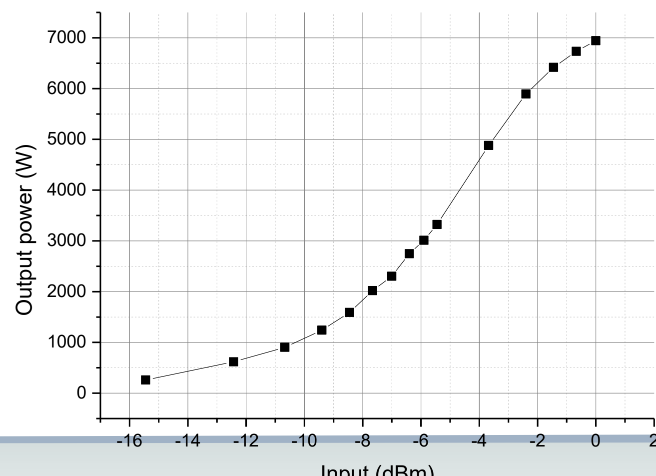
- Gain



- Efficiency

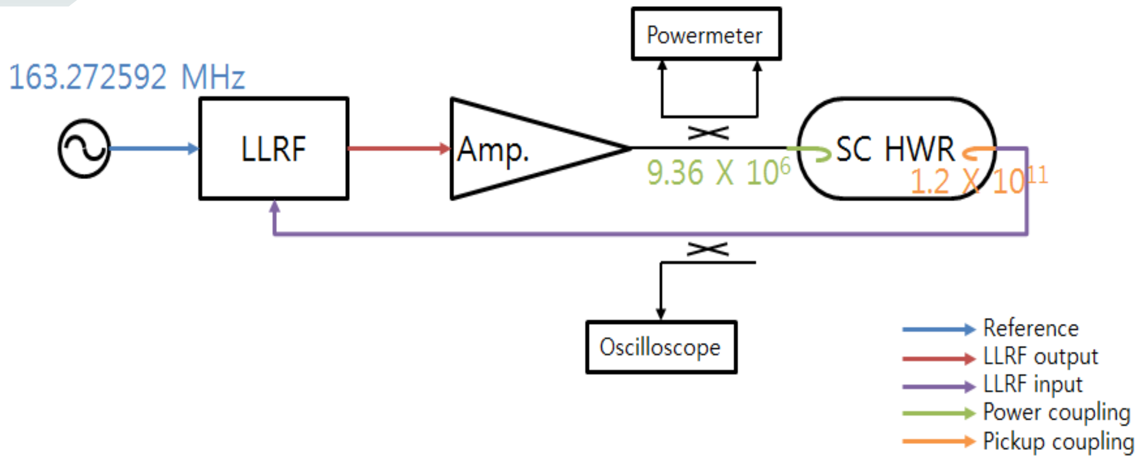


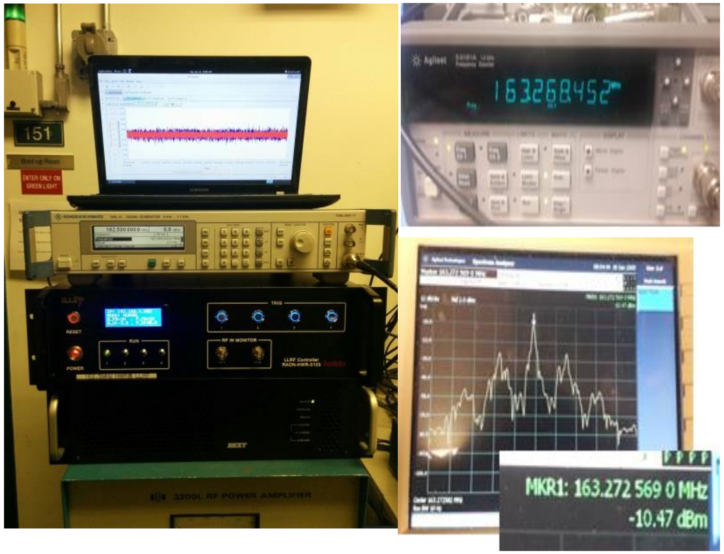
- 7 kW full power test



LLRF+HPRF+Nb cavity test

- **Setup**





- Result
  - Operation range: under 50 W, HPRF output power (T/L limitation)
  - CW operation: 1 H

LLRF		target	QWR	HWR	SSR1	SSR2
w/o PI FB (%) (ampltude shift (dB))			±2.6 (1.5)	± 58 (7)	-	-
w/ PI FB (%)	w/o P & I optimization	±1	±1.1	±7	-	-
	w/ P & I optimization	±1	±0.15	±1.05	-	-

Summary

- Prototyping of major accelerator parts has been in progress since 2013 through domestic vendors.
  - ECR ion source cryostat was fabricated (2014.09)
  - RFQ prototype fabricated successfully (2014.10)
  - SC cavity prototypes were delivered for test (since 2014.05)
  - Cryomodule prototypes were delivered for test (since 2014.12)
- Some prototypes are in testing stage.
  - ECR ion source, RFQ, MEBT buncher
  - Superconducting cavities and cryomodules (QWR, HWR)
- SRF test facility is under installation and will be ready in Feb. 2016.

Thank you !