



C3Or3A-03

The first cooldown of SCL₃ cryogenic system

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1. Introduction
2. Installation
3. Operation; cooldown
4. Issues
5. Conclusions

Institute for Basic Science (2011)

Institute for Rare Isotope Science (2022~)

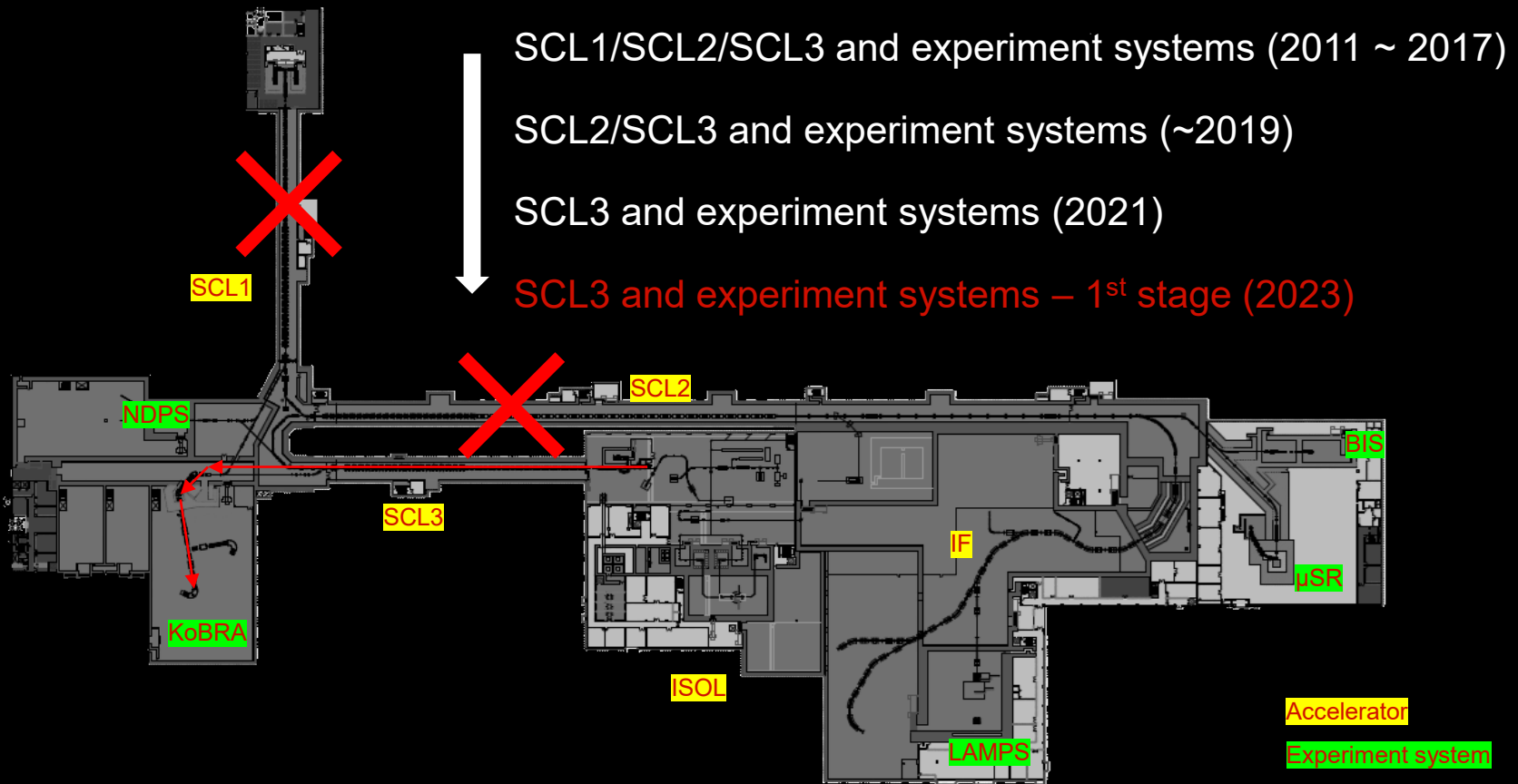
Korea Virus Research Institute (2021)

About 30 research centers

Rare Isotope Science Project (2011~2023)

“Rare Isotope Science Project” belonged to “Institute for Rare Isotope Science” in 2022 and the 1st stage of this project was finished successfully in 2023 in Daejeon, S. Korea.

The goal of Rare Isotope Science Project (Heavy ion SC linear accelerator, RAON)



Installation

Buildings ready (2020)



RAON site in Daejeon, S. Korea (Area: 952,066 m²)

Installation

Cryogenic system I (2018-2023)



Design reviews (2018 -2019)



Manufacture (2019 -2020)



Transportation (2020 -2021)



Installation (2020 -2021)



Inspection (2020 -2022)



1st cooldown (2022 -2023)

RAON cryogenic system

Cryogenic plants (CP)

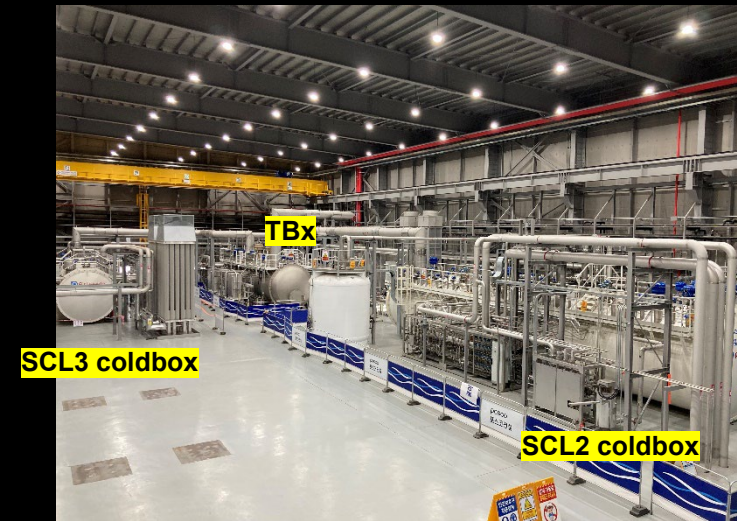
- 1 CP for SCL3 (4.2 kW cooling power at 4.5 Keq),
- 1 CP for SCL2 (13.5 kW cooling power at 4.5 Keq),
- 2 K circuit, 4.5 K circuit, and 35-55 K circuit

Helium management system (HMS, recovery system)

- 1 purifier with 3 recovery compressors at 30 barA,
- 1 gas bag with 2 types of recovery heaters,
- 1 LN₂ system to supply GN₂ and LN₂,
- 8 helium storages (8 x 250 m³)

Cryogenic distribution system (CDS)/cryomodules (CM)/cryostats

- 1 distribution box (TBx), - C3Or4C-05
- 107(44) valve boxes (VBx) and 2(1) end boxes (EBx)
- 104(55) CM and 14 magnet cryostats
- 1 cooling system for high temperature SC magnets (40 K)



2022

2023

• Sep. 7th – Oct. 26th
Cooldown under 4.5 K

• Sep. 21th – Oct. 7th
Beam commissioning (6 QWR)

• Nov. 24th – Jan. 11th
1st cooldown under 2 K

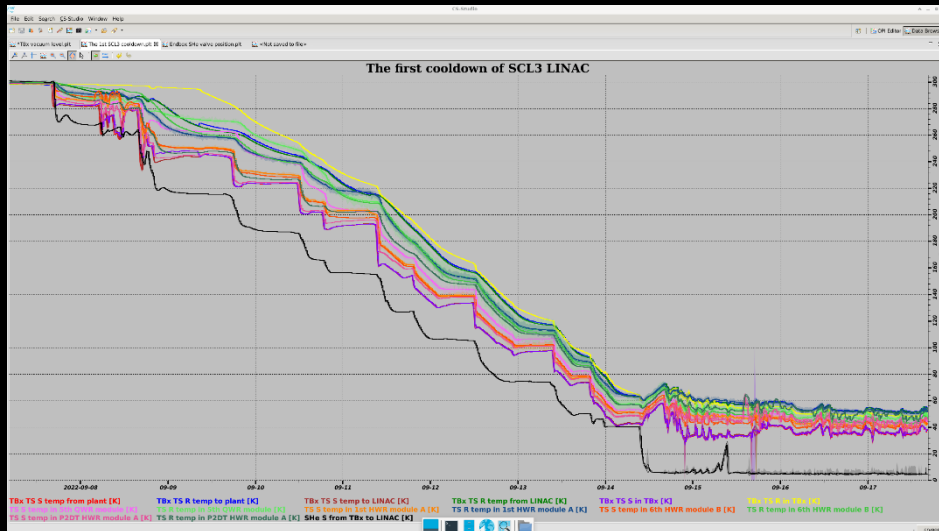
• Nov. 4th – Dec. 16th
Beam commissioning (22 QWR)

• Feb. 21st – 24th
2nd Cooldown under 2 K

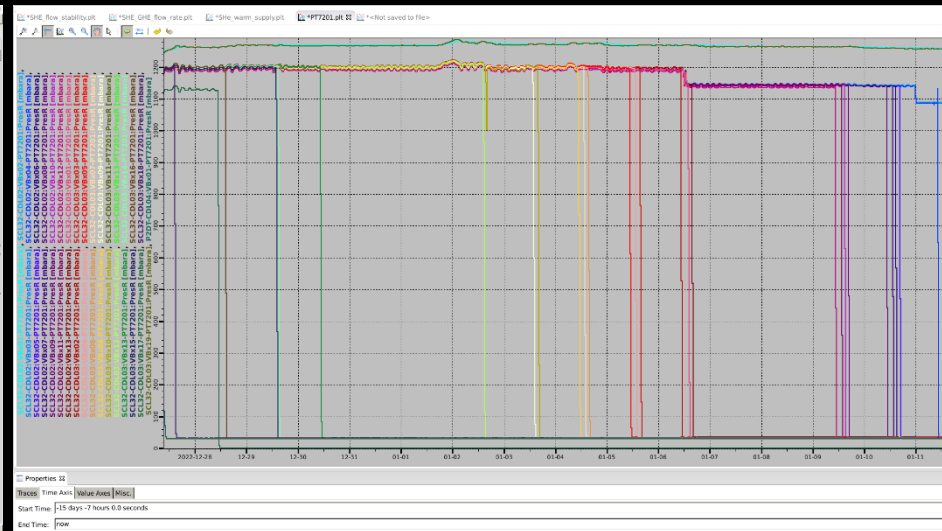
• Feb. 27th – Jun. 7th
Beam commissioning (SCL3)

• Apr. 21st
3rd Cooldown under 2 K

• Jun. 8th – 31st
Warmup



Cooldown from 300 K to 4.5 K



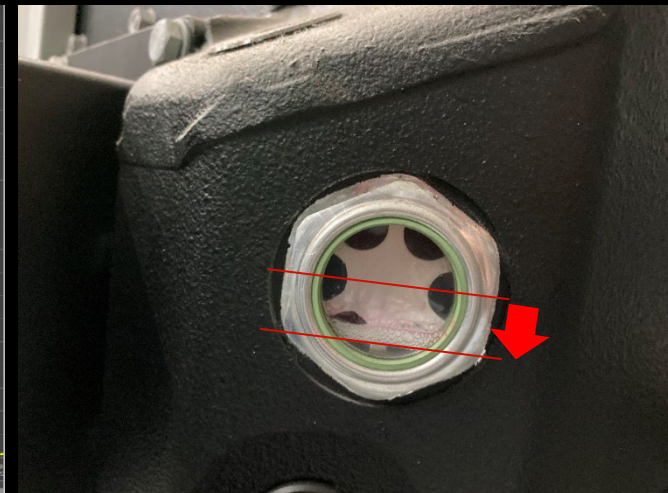
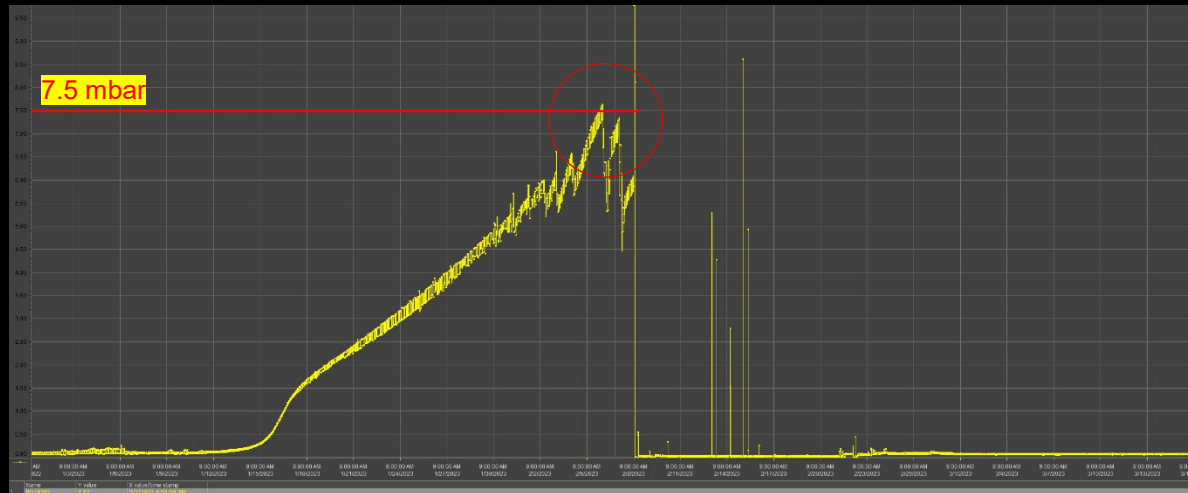
Cooldown from 4.5 K to 2.05 K

Total 2.05 K operation times, 3,133 hours

4 K operation time due to failures, 401 hours

- Issue on inlet filter of cold compressors (air inleak) : 385 hours
- Issue on oil loss of process vacuum pumps : 16 hours

Availability ~ 87.2%



Differential pressure [mbar] of inlet filter of cold compressors string

SCL3 heat loads

	Expected	Design*	Real**	Remark
Total thermal shield	6,781 W	10,172 W	7,454 W	CBx+TBx+CDS+CM
QWR CM*** 4 K	17.1 W	25.7 W	11.7 W	Except for #5, #6, #14, #21
HWR CM A*** 4 K	3 W	4.5 W	5.1 W	Except for #1, #12
HWR CM A 2 K	9.4 W	14.1 W	9.3 W	Except for #1
HWR CM B**** 4 K	5.0 W	7.5 W	8.7 W	Except for #11
HWR CM B 2 K	17.3 W	26.0 W	9.79 W	Except for #11

* SCL3 cryogenic plant process design for RAON (2019)

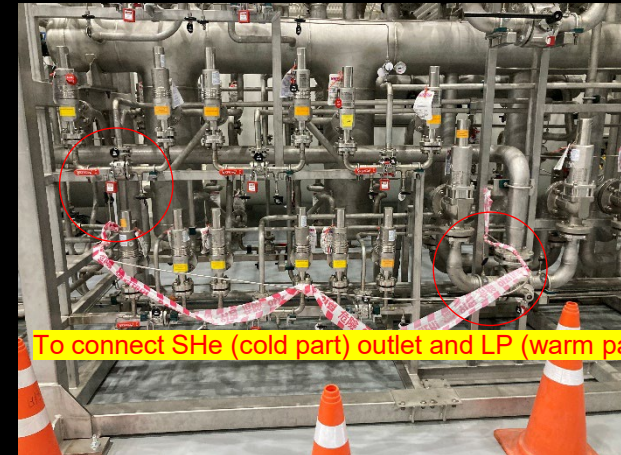
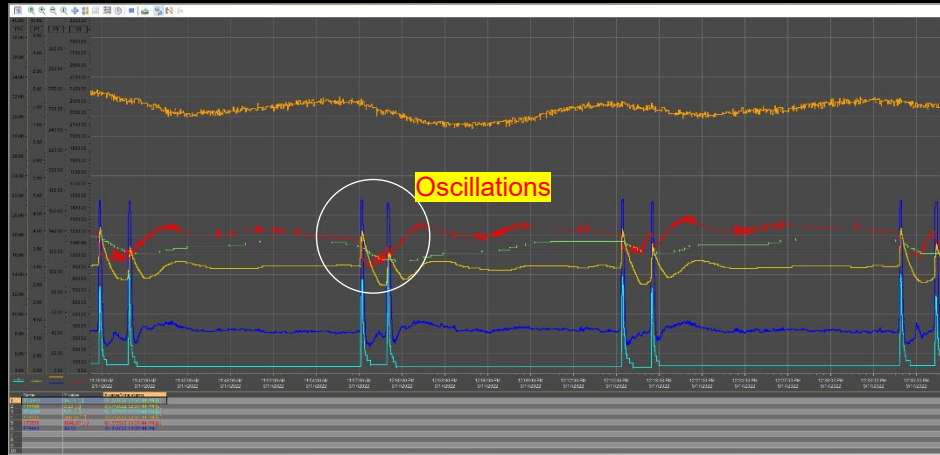
** Average values, leak of JT valve not considered

*** 22 QWR cryomodules

**** 14 HWR cryomodules A

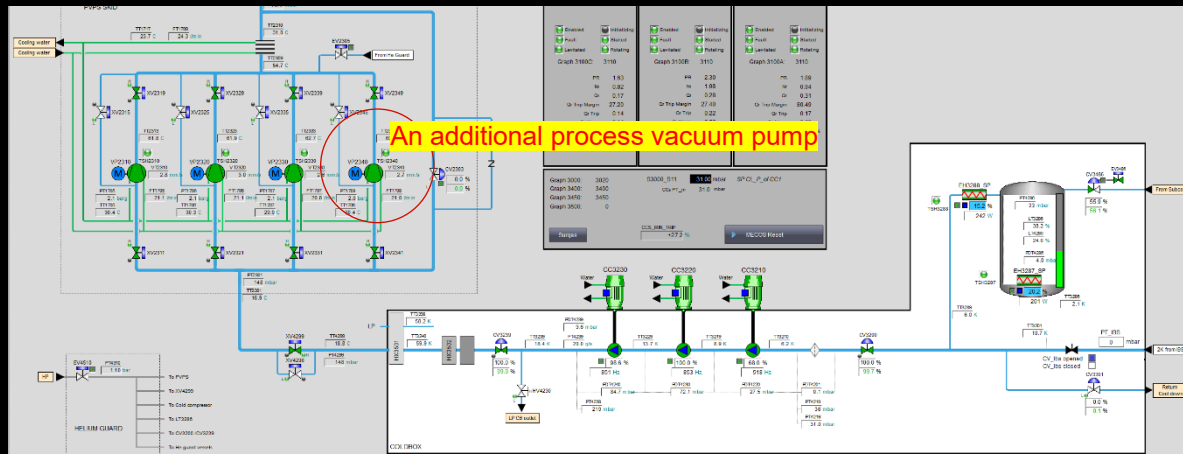
***** 19 HWR cryomodules B

Subcooled SHe instability by trapped gas



To connect SHe (cold part) outlet and LP (warm part) outlet

Heat inleak (or warm gas inleak) on VLP return line



Issues

Cryogenic refrigeration system parts II

Icing on 2nd and 3rd turbines



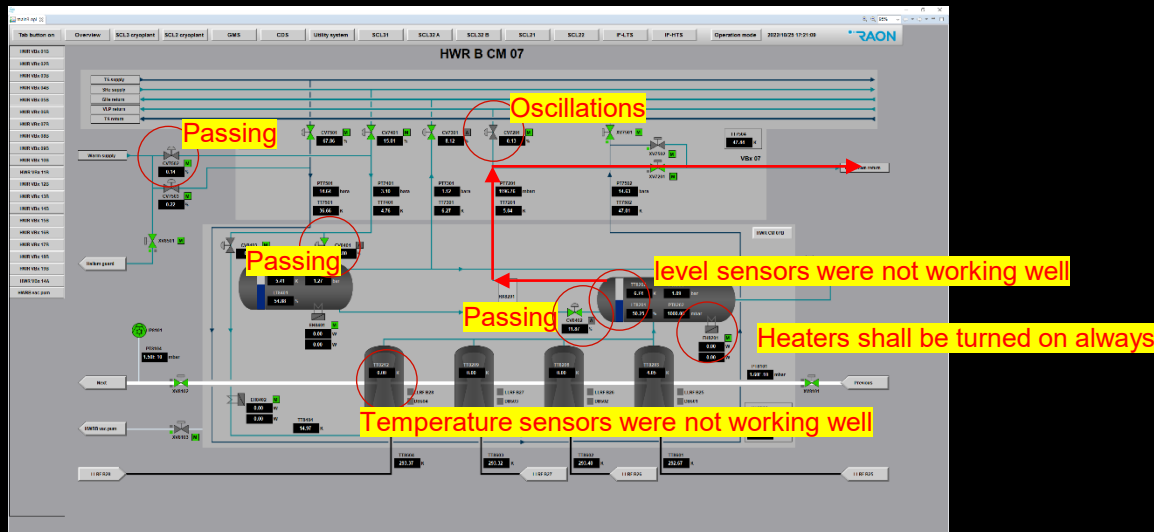
Oil check at 3rd coalescer



Issues

Cryogenic distribution system parts

Thermo acoustic oscillation at 4.5 K



Cold leak (process line to vacuum chamber) – 1 cryomodule

Sensor problems – Temperature sensor, level sensor

Leakage from valve seats

SCL3 was cooled down under 2.05 K successfully, January, 2023.

Ar⁹⁺ stable ion beams were accelerated and delivered to KoBRA.

KoBRA found some rare isotope ion beams, such as ¹⁴Be and ¹¹Li.

SCL3 cryogenic system was warmed up to 297 K in June, 2023.

Availability of the cryogenic system is about 87%.

We have some issues but we believe that we will solve them with suppliers.

Special thanks to

Cryogenic system operators,

ESS, ITER, DESY, CEA, CERN, JLab, Fermilab, SNS, FRIB, TRIUMF, KEK, SHINE, IHEP, PAL, KFE,

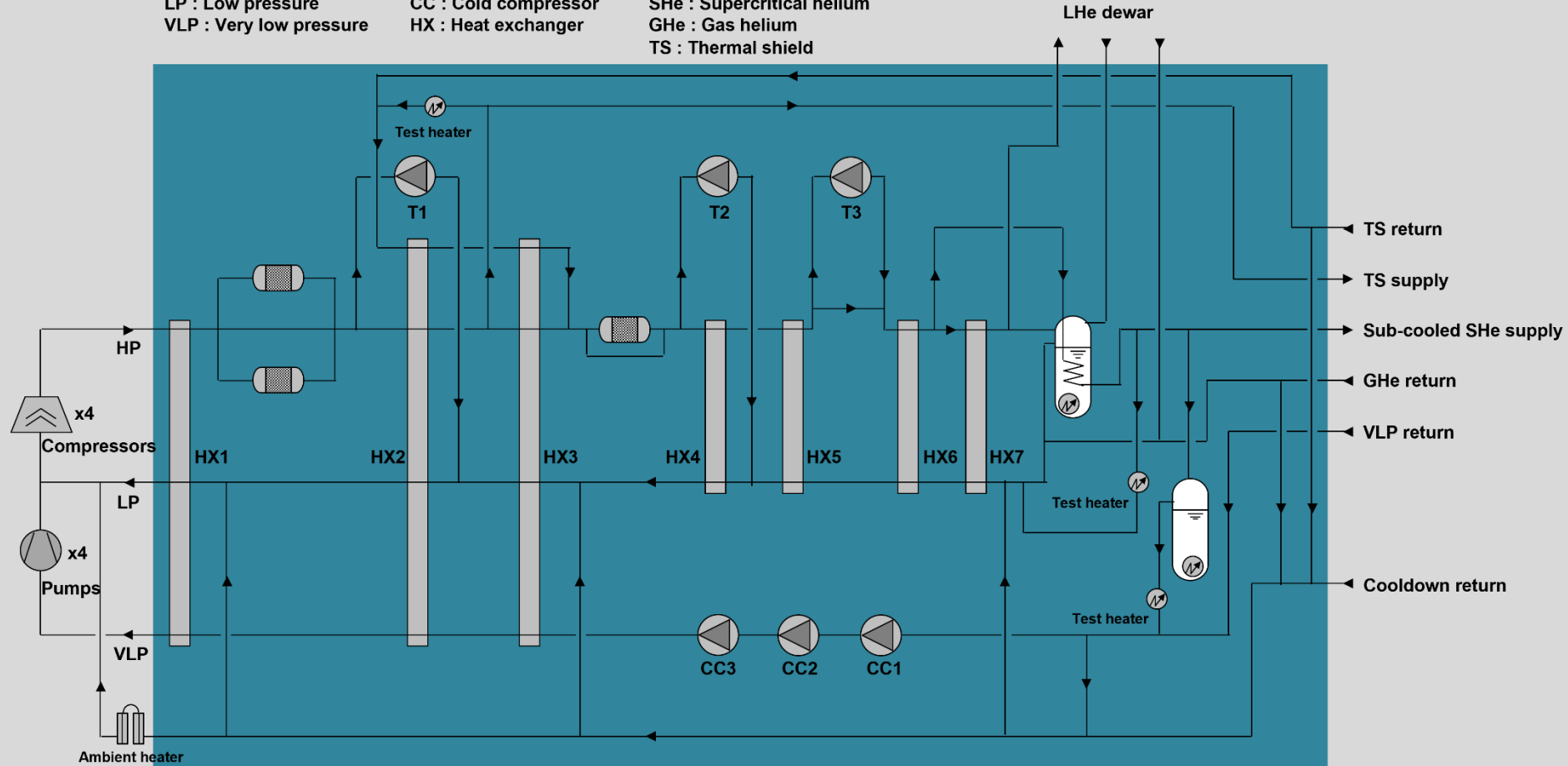
HYE, POSCO E&C, and ALAT

Mahalo Nui Loa

Appendix

SCL3 cryogenic plant PFD

HP : High pressure
 LP : Low pressure
 VLP : Very low pressure
 T : Turbine
 CC : Cold compressor
 HX : Heat exchanger
 LHe : Liquid helium
 SHe : Supercritical helium
 GHe : Gas helium
 TS : Thermal shield



Appendix

SCL3 cold end conditions

		Unit	Mode	2.05 K	4.5 K	35 – 55 K	Remark
From cold box	Pressure	bar	Nominal	-	3.0	Max. 15	
			Beam commissioning	-	3.0	Max. 15	
			Turndown	-	3.0	Max. 15	
			4.5 K standby	-	3.0	Max. 15	
			TS standby	-	-	Max. 15	
	Temperature	K	Nominal	-	4.5	< 35	
			Beam commissioning	-	4.5	< 35	
			Turndown	-	4.5	< 35	
			4.5 K standby	-	4.5	< 35	
			TS standby	-	-	< 35	
	Mass flow rate	g/s	Nominal	-	82.4	> 95.3	
			Beam commissioning	-	51.5	> 95.3	
			Turndown	-	36.4	> 95.3	
			4.5 K standby	-	37.8	> 95.3	
			TS standby	-	-	> 95.3	
To cold box	Pressure	bar	Nominal	< 0.032	1.25	$\Delta P > 0.5$	
			Beam commissioning	< 0.032	1.25	$\Delta P > 0.5$	
			Turndown	< 0.032	1.25	$\Delta P > 0.5$	
			4.5 K standby	-	1.25	$\Delta P > 0.5$	
			TS standby	-	-	$\Delta P > 0.5$	
	Temperature	K	Nominal	> 4.5	> 4.8	$\Delta T > 20$	
			Beam commissioning	> 5.3	> 4.9	$\Delta T > 20$	
			Turndown	> 7.1	> 5.0	$\Delta T > 20$	
			4.5 K standby	-	> 5.5	$\Delta T > 20$	
			TS standby	-	-	$\Delta T > 20$	
	Mass flow rate	g/s	Nominal	33.7	48.7	> 95.3	
			Beam commissioning	18.3	33.2	> 95.3	
			Turndown	9.3	27.1	> 95.3	
			4.5 K standby	-	37.8	> 95.3	
			TS standby	-	-	> 95.3	
Power	W	Nominal	894	1,038	10,172		
		Beam commissioning	566	750	10,172		
		Turndown	375	637	10,172		
		4.5 K standby	-	1,012	10,172		
		TS standby	-	-	10,172		

@ SCL3 cryogenic plant process design for RAON (2019)

Total helium for SCL3 operation is about 1,020 kg.

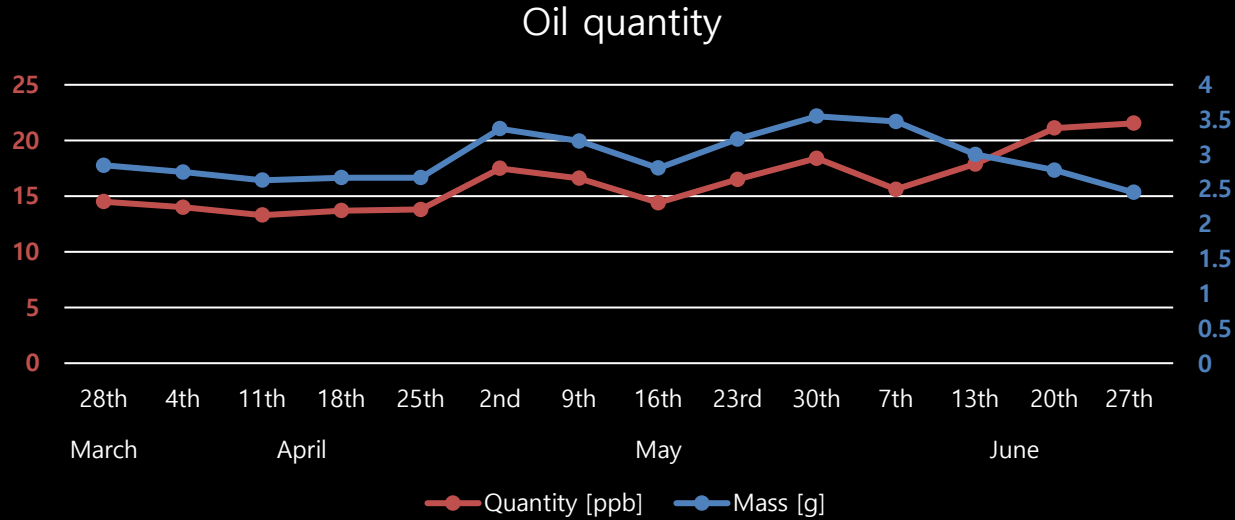
- It is not easy to measure loss of the helium gas in this moment.

We used 165 tons of LN2.

- Most of them were used for the external purifier.

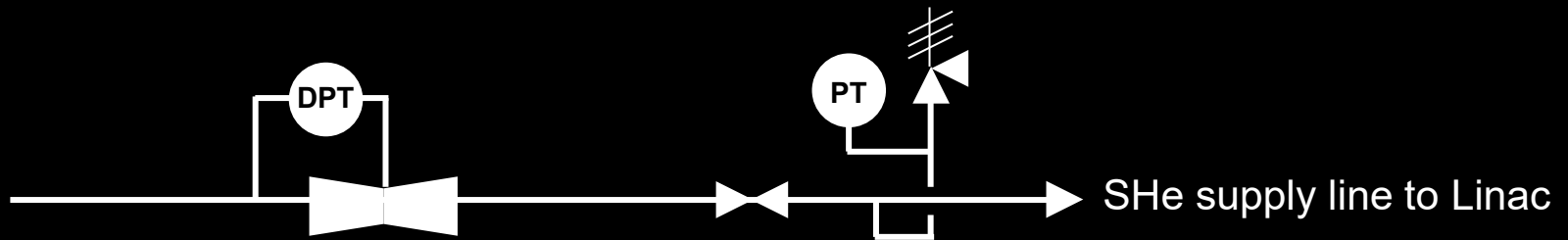
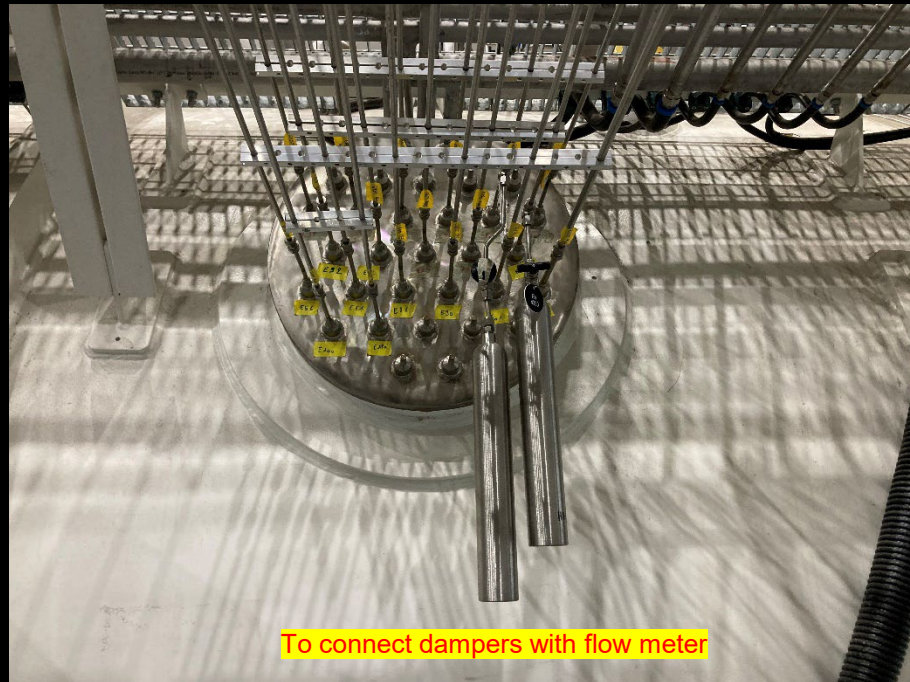
Appendix

Quantity of oil at 3rd coalescer



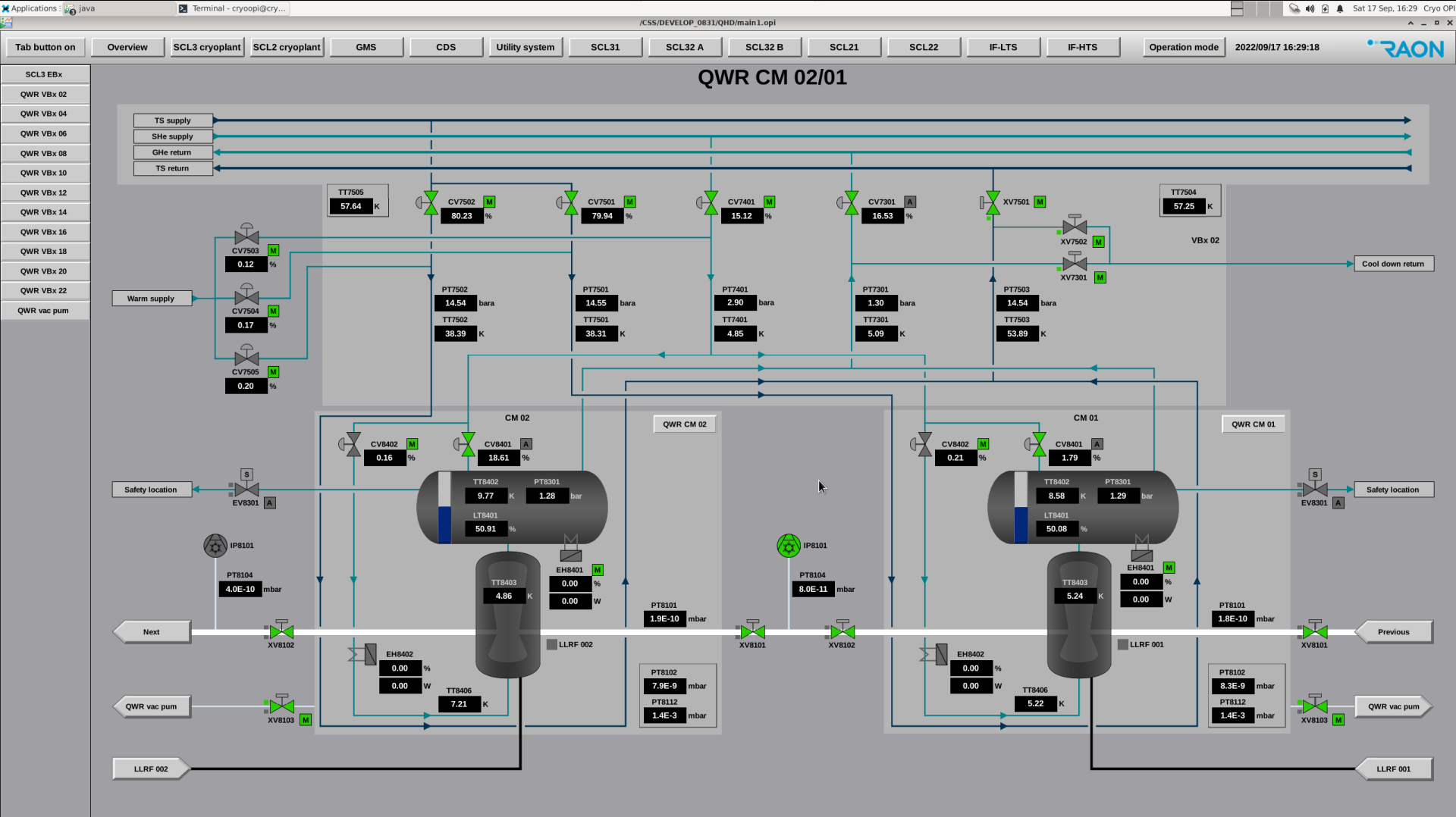
Appendix

Pressure fluctuation of SHe supply line



Appendix

GUI for cryomodules – QWR CM



Appendix

GUI for cryomodules – HWR CM B

