# Introduction of the 2nd KSTAR Cryoplants and Application

*Vacuum & Cryogenic Engineering Team*

*Demo Technology Division*

*Advanced Technology Research Center*

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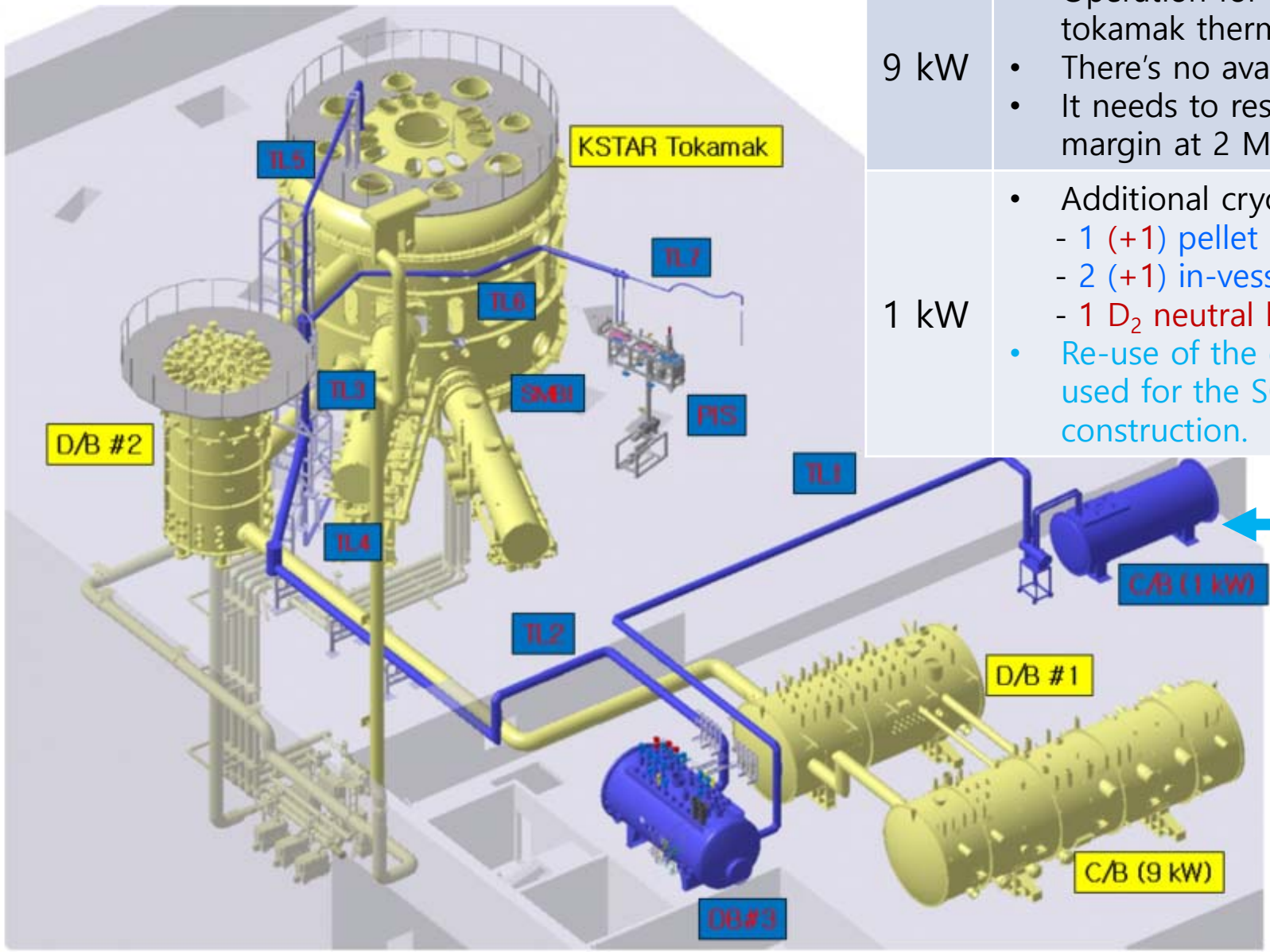
Prepared by Y. J. Lee

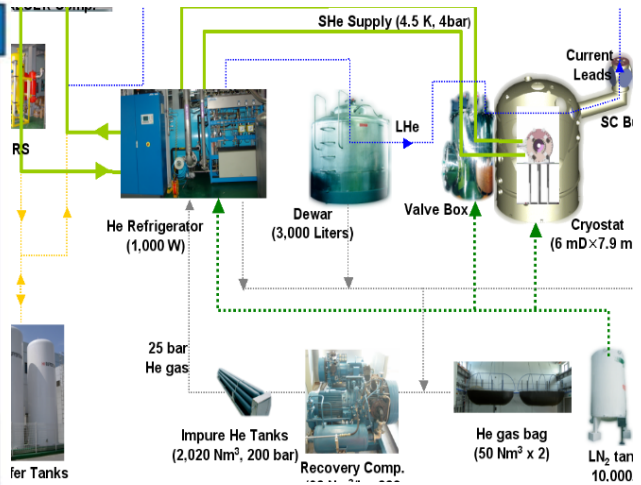
# New 1 kW Cryo-plant & Distribution System for the KSTAR Tokamak



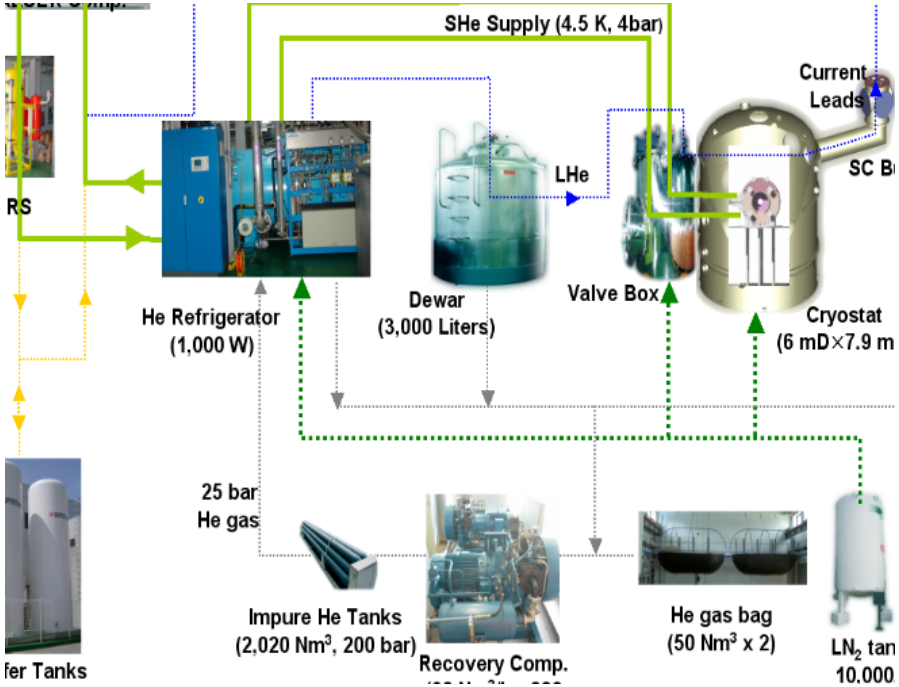
| Item | Description |
|---|---|
| 9 kW | • Operation for the SC magnets (16 TF, 14 PF), tokamak thermal shields and CFS.<br>• There's no available additional ports in DB#2.<br>• It needs to reserve SC magnet operation margin at 2 MA full plasma currents. |
| 1 kW | • Additional cryogenic components;<br>- 1 (+1) pellet injector (~ 2 g/s LHe) & 1 SMBI.<br>- 2 (+1) in-vessel cryo-pumps.<br>- 1 $D_2$ neutral beam injector (NBI#2) from 2018.<br>• Re-use of the old 1 kW plants (LINDE) that was used for the SC magnet tests during construction. |



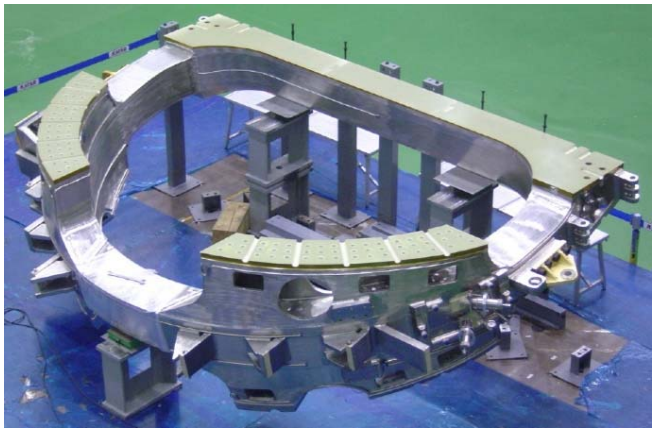

1 kW Cryo-plant

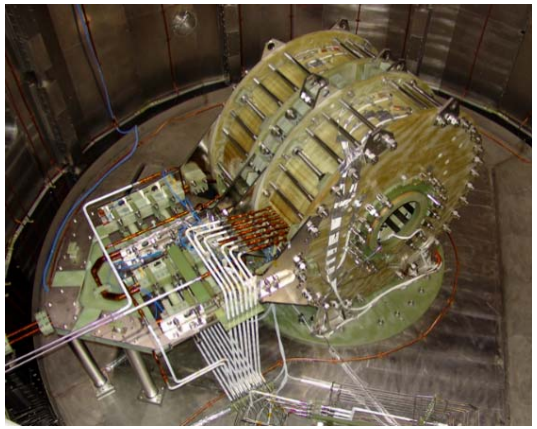


# Old 1 kW Cryo-Plant




| | | *Refrigeration 4.5K* | *Refrigeration 4.5K* | *Liquefaction 4.5K* |
|---|---|---|---|---|
| ***Cold box supply*** | | | | |
| - Helium inlet pressure | bara | 13 | 13 | 13 |
| - Helium outlet pressure | bara | 1.06 | 1.06 | 1.06 |
| - Helium temperature | K | 313 | 313 | 313 |
| - Turbo expanders | No's | 2 | 22 | |
| - LN2 precooling | - | YES | NO | YES |
| - Comp. mass flow | g/s | 131.1 | 131.1 | 131.1 |
| ***Refrigeration capacity*** | | | | |
| - Refrigeration_4.5K and supply pressure 6 bara | W | 1,000 | 650 | - |
| - Maximum supercritical helium mass flow | g/s | 75 | 75 | - |
| ***Liquefaction capacity*** | | | | |
| - Using pure gas | g/s | - | - | 9 |





Toroidal Field Coil (TF00)
- $Nb_3Sn$ CICC
- 35 kA (3.5 Tesla)
- Serial connection (16)
- STS joints ~ 1 n-Ω)
- 15 kV electrical insulation

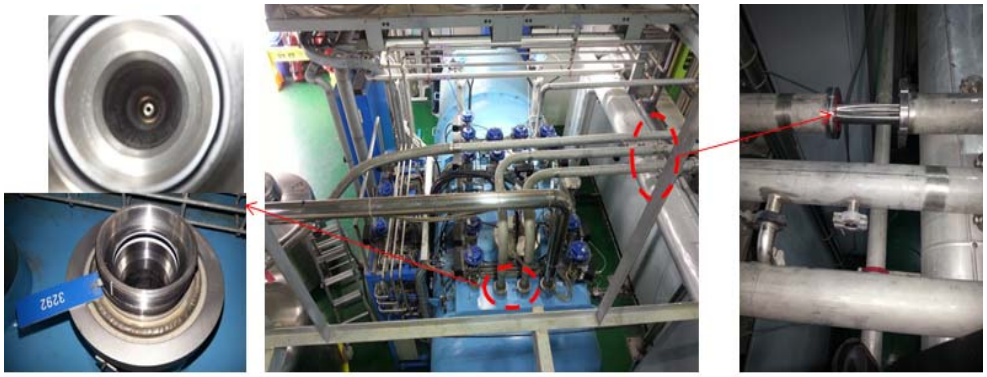
Background Coil
- NbTi CICC (Russia)
- 20 kA (8 Tesla Max)
- Lap-joint (< 2.5 n-Ω)
- Fast sweep (few s)
- Low AC loss

| *Date [year/month/day]* | *Operating day* | *Experimental content* |
|---|---|---|
| 2005/11/15 ~ 2005/12/12 | 28 | TF00 cooling |
| 2006/06/07 ~ 2005/06/22 | 16 | BKG 1st cooling |
| 2006/07/03 ~ 2006/07/24 | 22 | BKG 2nd cooling |
| 2006/08/29 ~ 2006/09/29 | 32 | BKG 3rd cooling |
| 2006/10/23 ~ 2006/11/17 | 25 | BKG 4th cooling |
| 2006/12/05 ~ 2006/12/17 | 13 | BKG 5th cooling |
| 2006/12/21 ~ 2007/01/11 | 22 | BKG 6th cooling |
| Shut down | | |

# Shifting Construction of the 1 kW Cryo-plant



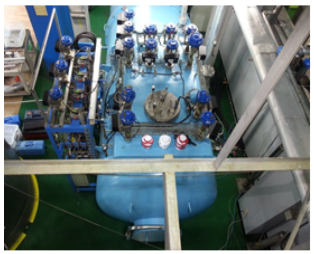
Test facility ~ 7 km far away from KSTAR building → Inside KSTAR building



Comp System

1 kW Helium Refrigeration

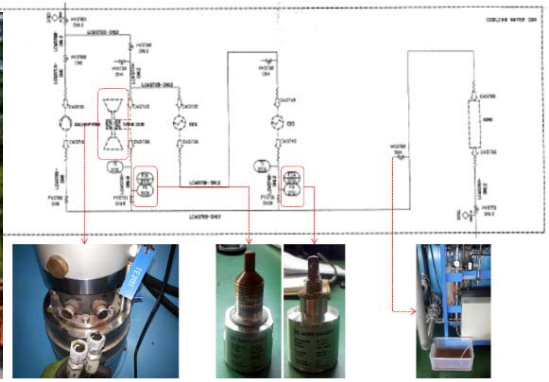
ORS



Cold Box System

LHe Dewar

Transportation



Cleaning

Assembly in the KSTAR building

# Maintenance & Testing

Electric resistance inspection

Grease injection in bearing

Insulation resistance check

Replace oil cartridge

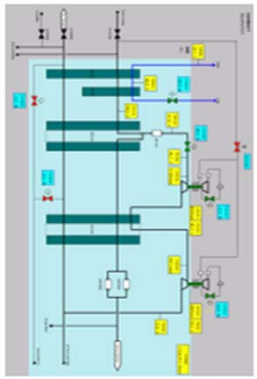
Replace oil filter

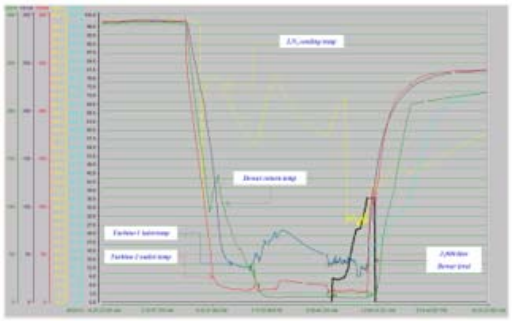
Replace Breox oil

| | Non-driving | | | | | Driving | | |
|---|---|---|---|---|---|---|---|---|
| | Resistance | | Temperature sensor | | | Vibration | | |
| Electric motor | Winding [M-ohm] | Insulation [G-ohm] | Winding [ohm] | Bearing [ohm] | Heater [G-ohm] | | DE | NDE |
| | R-S 5.552 | 46 (DC507 V) | 103.4 | 103.7 | 234.5 | H | 0.89 | 0.482 |
| | S-T 5.551 | 43 (DC1003 V) | | | | V | 1.84 | 0.672 |
| | T-R 5.560 | | | | | A | 0.73 | 1.3 |

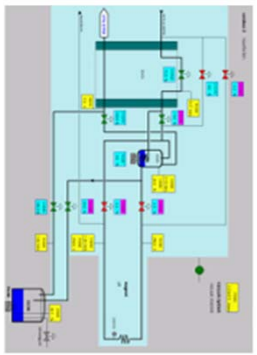
| | Vacuum pumping & helium filling | Dew-point [℃] |
|---|---|---|
| Compressor | Total 7th conduct | - |
| ORS | Total 5th conduct | -74.5 |
| Buffer tank | - | -74.8 |
| Helium process circuits | - | -78.0 |
| LHe transfer line | 6.8E-5 mbar | - |
| LHe dewar | 8.1E-6 mbar | - |

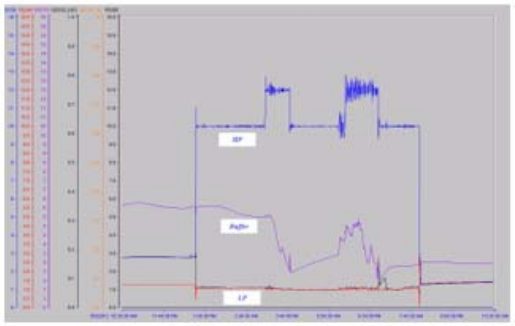
Conditioning ($LN_2$ absorber)





Refrigeration cooling trend



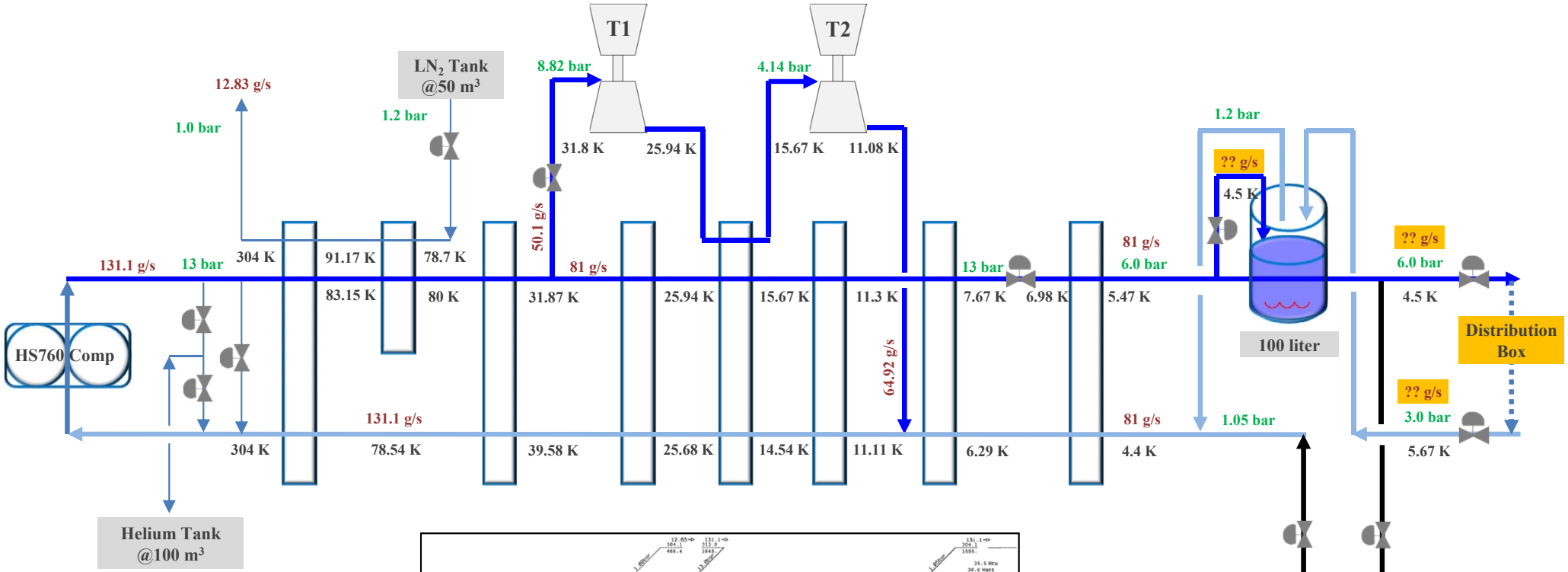


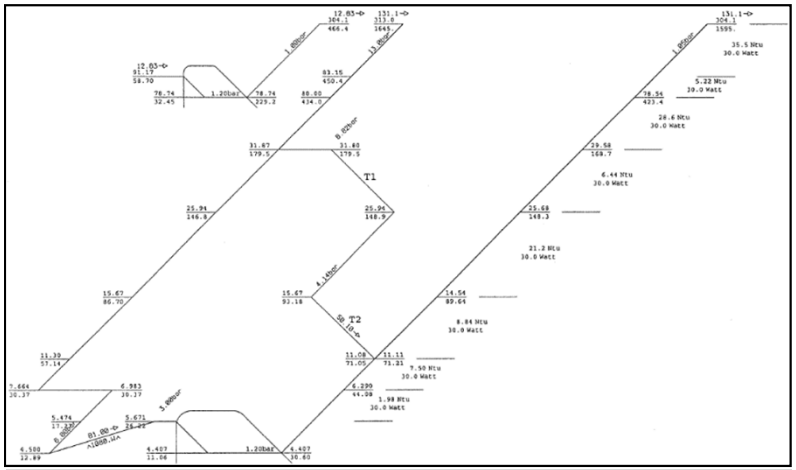
Compressor pressure trend

| Date [year/month/day] | Time | Substance | Note |
|---|---|---|---|
| 2012/05/21 | 08:35 | Vacuum system 'ON' | |
| | 10:18 | Comp 'start' | 10 bara |
| | 12:32 | CB cooling 'start' | |
| 2012/05/22 | 01:30 | CB#1 cooling 'complete' | T1 : 43.6K |
| | | | T2 : 14.8K |
| | | CB#2 cooling 'connect' | TI3270 : 83.9K |
| | 16:40 | Cool down 'HOLD' | TI3270 : 19K |
| | | Buffer pressure low limit | 1.85 bara |
| 2012/05/23 | 08:30 | Buffer pressure rising | 2.93 bara |
| | 08:40 | CB re-cooling | |
| | 09:20 | Cool down 'complete' | TI3270 : 5K |
| | 15:00 | 'Impure Mode' | 10%_100 L |
| | 20:30 | 'Impure Mode' | 33.3%_925 L |
| | 21:00 | 'Pure Mode' | 36.6%_1050 L |
| | 21:05 | Warm up | |

# Final States of the 1 kW Cryo-plant



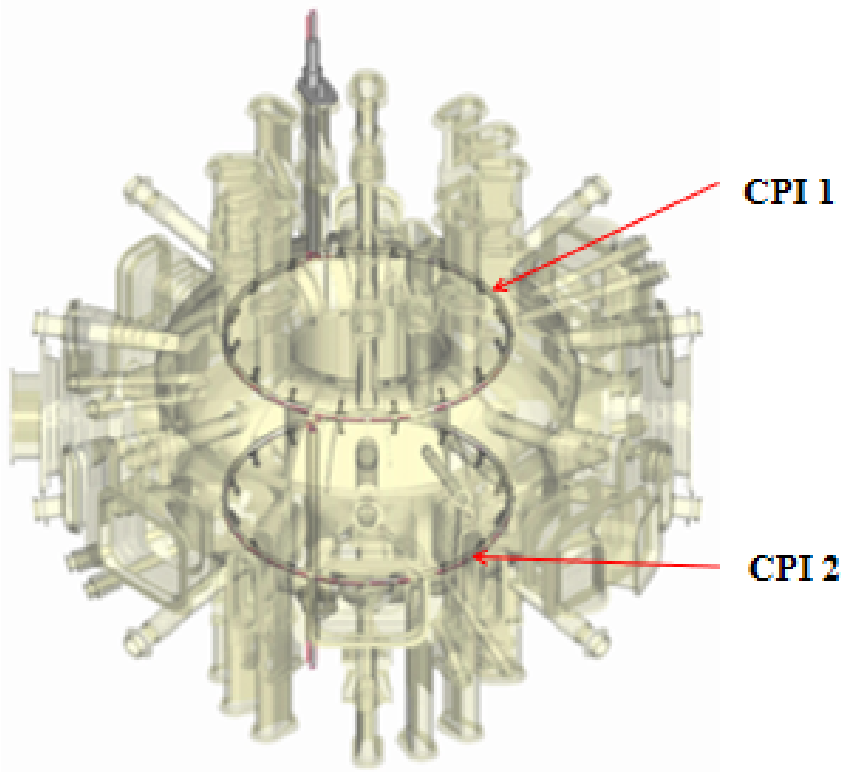


T-s diagram @ Refrigeration mode 1,000 W

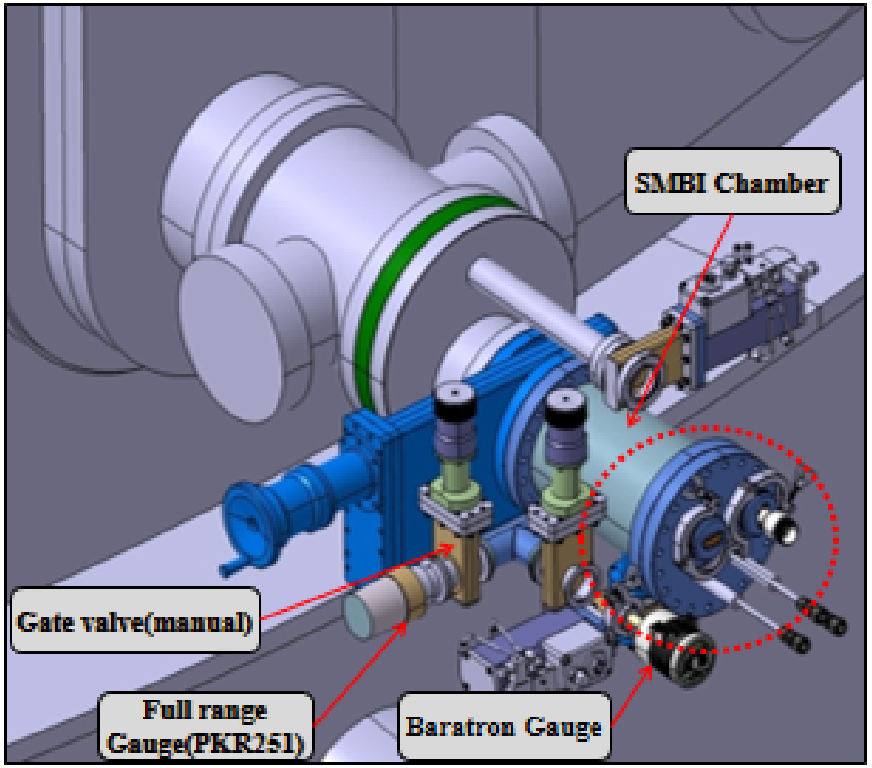
# Current Cool-down Operation Objects

## In-vessel cryo-pump (CPI)




- Two cryo-pumps in upper/lower divertor region
- $D_2$, DH, $H_2$ gas pumping during plasma operation
- LN2 thermal shields (90 K, 5 bar, 13 g/s)
- Liquide helium cryo-panel (1.3 bar, 4.5 K, 7.5 g/s)
- Regeneration up to 100 K after each plasma experiments within 15 minutes using 300 K He gas

## Supersonic molecular beam injector

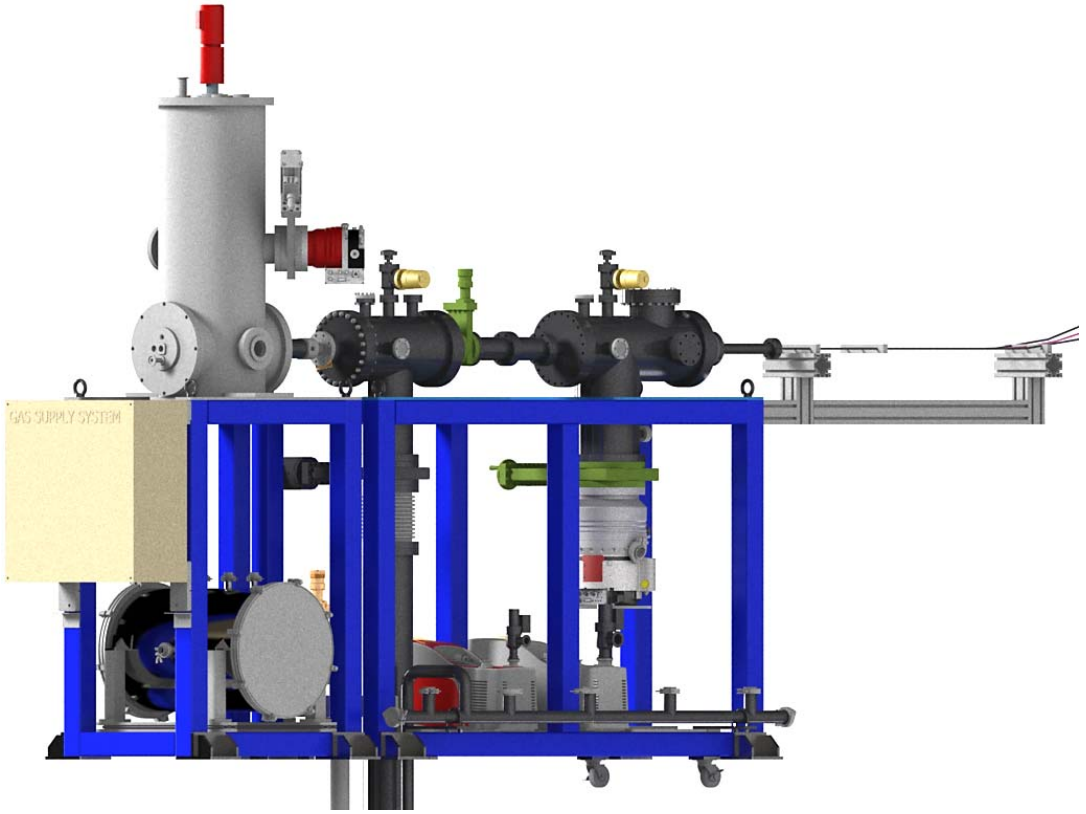



- $D_2$ gas injection to the vacuum vessel inside during plasma experiments
- LN2 cool-down (5 bar, 90 K, 6.6 g/s)
- ‡" pipe cool-down line in the SMBI chamber

# Current Cool-down Operation Objects



| Parameters | Baseline |
|---|---|
| Injection type | Repetitive Pneumatic Injection |
| Pellet material | $D_2$ |
| Extrusion type | Screw extrusion |
| Pellet shape | Cylinder |
| **Pellet size** | **D: 2 ㎜ (fixed size)<br>L: 1.5 ㎜ ($2.78*10^{20}$D), 1.8 ㎜ ($3.34*10^{20}$D), 2.0 ㎜ ($3.71*10^{20}$D)** |
| **Pellet velocity** | **Min. 200 ㎧** |
| **Injection frequency** | **~ 20 ㎐** |
| Operation time | > 1,000 s |
| Reliability | > 95 % |
| **Cooling method** | **LHe supply** |
| **Amount of gas per fired pellet** | **< 15 mbar*L** |
| **LHe consumption** | **15 ~ 20 L/h** |

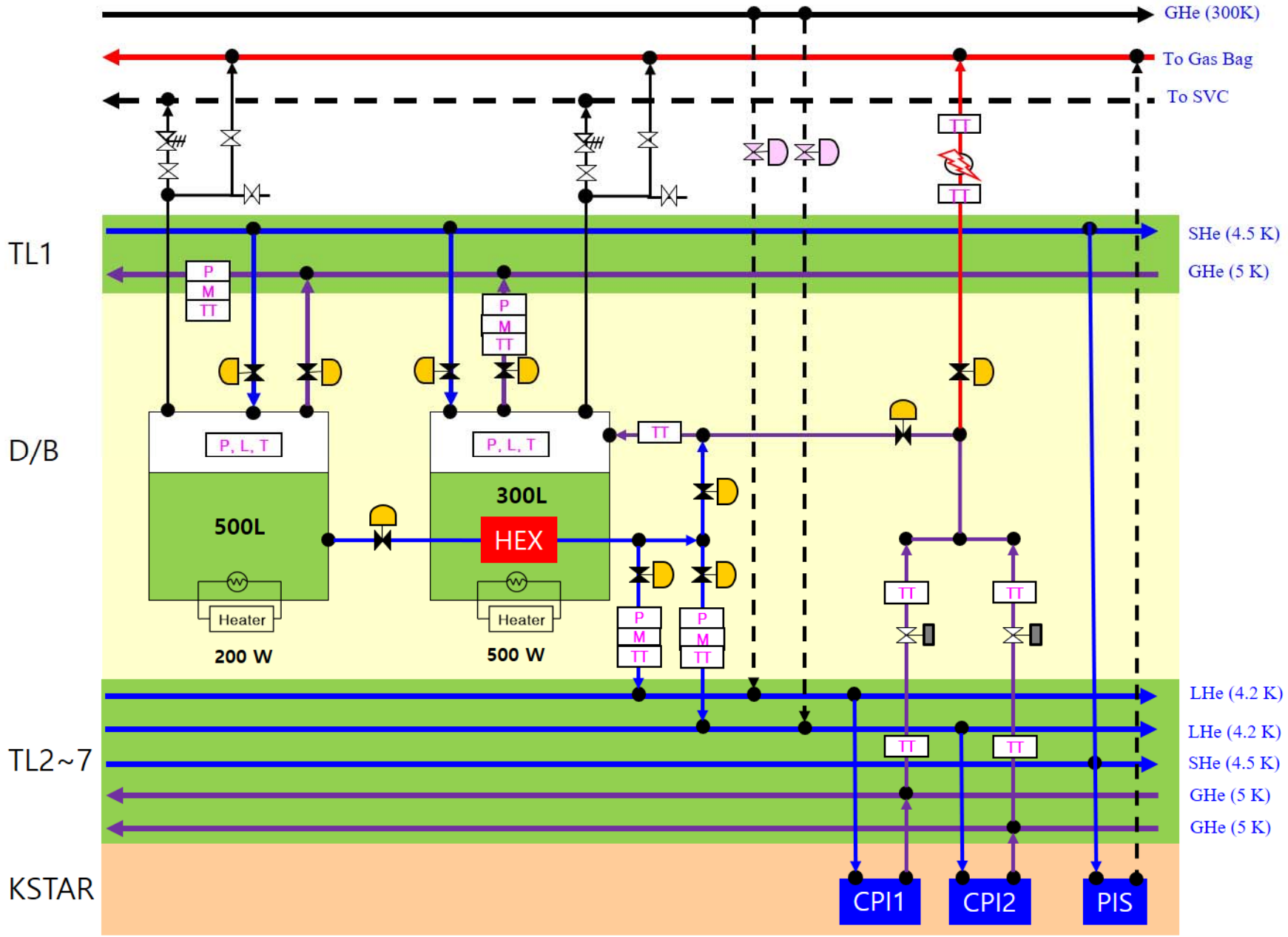


# Cryogenic Loads



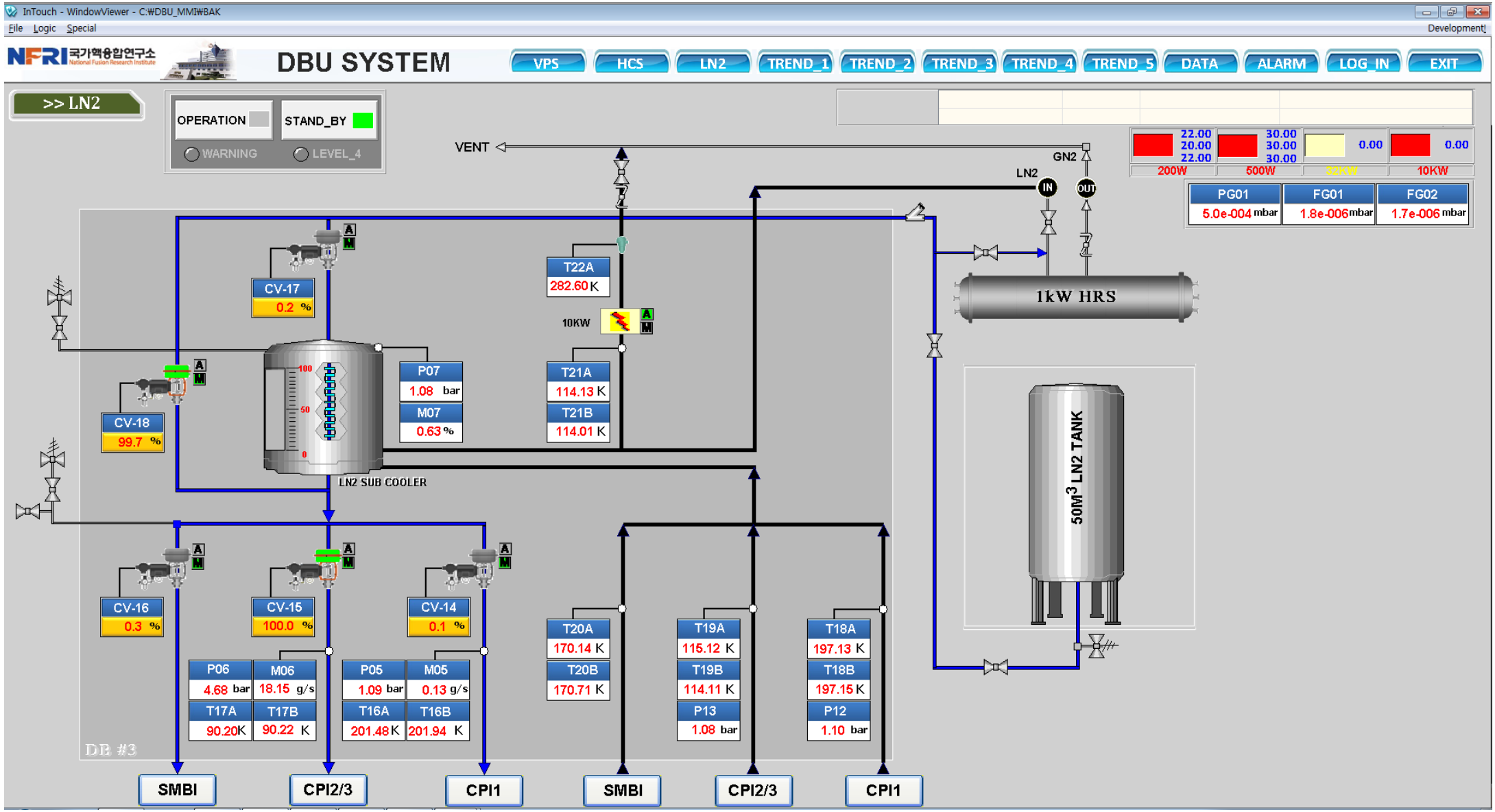
| Item | $P_{in}$ (bar) | $T_{in}$ (K) | Q (W) | dm/dt (g/s) | ΔP (mbar) |
|---|---|---|---|---|---|
| **Helium circuits** | | | | | |
| CPI1 | 1.3 | 4.5 | 32 | 7.5 | <50 |
| CPI2/3 | 1.3 | 4.5 | 53 | 12.5 | <50 |
| Cold compressor | 0.5 | 3.5 | 255 | 25 | <750 |
| PIS | 1.3 | 4.5 | 200 | 2 | <50 |
| Warm gas | 10 | 300 | - | 3 | <100 |
| CPI (100→4.5 K) | 1.3 | 4.5 | 410 | 4 | <50 |
| **Liquid nitrogen circuits** | | | | | |
| CPI1 | 5 | 80 | 1300 | 7 | <50 |
| CPI2/3 | 5 | 80 | 2000 | 14 | <50 |
| SMBI | 5 | 80 | 1200 | 7.5 | <50 |

# Distribution Box (DB#3); Helium Line



# Distribution Box (DB#3); LN2 Line

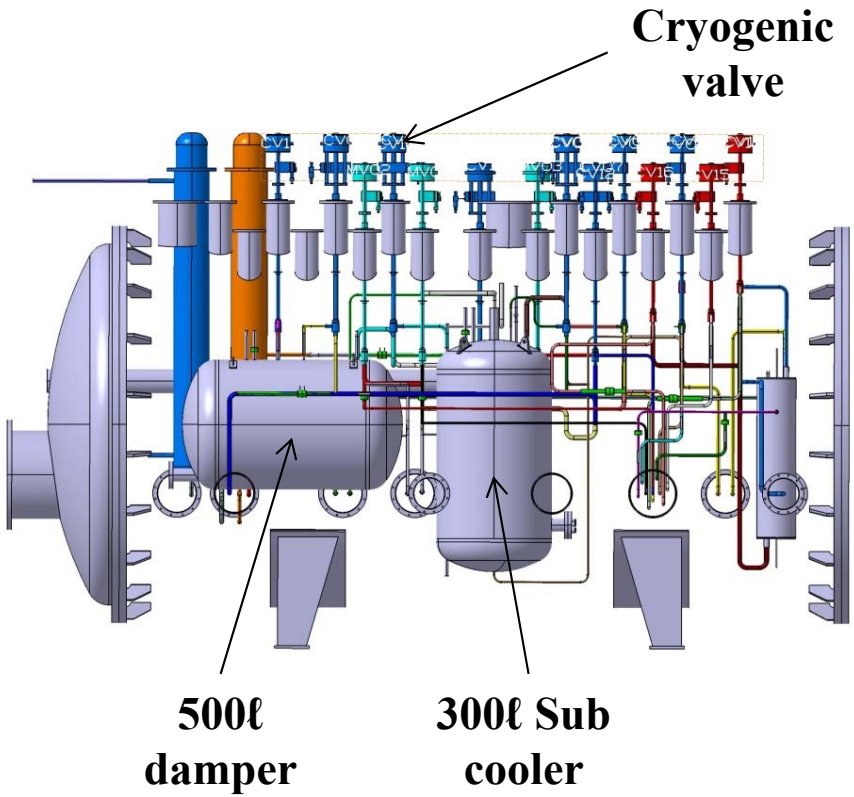


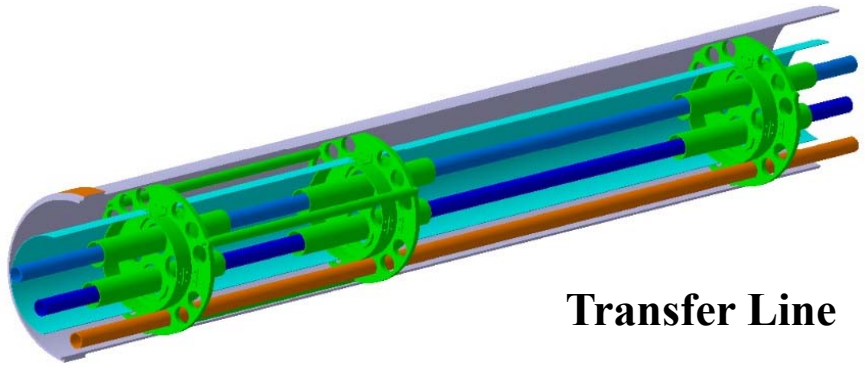


# Design of the DB#3

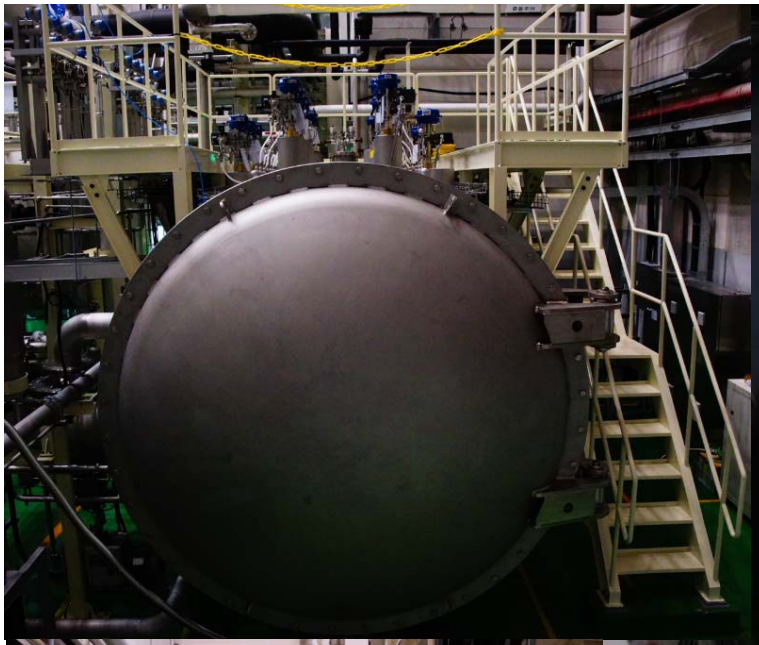


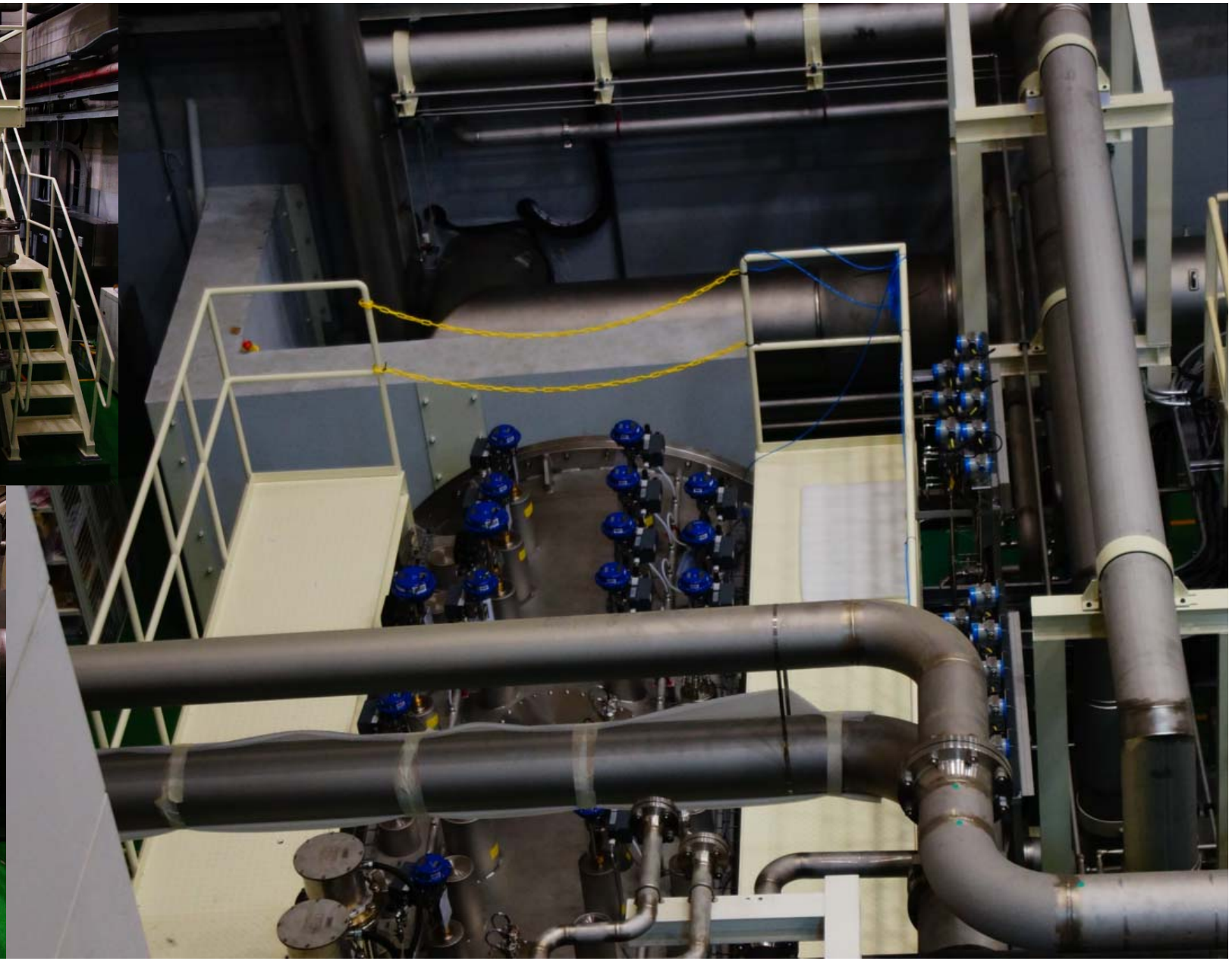
| Item | Sub-item | Dimensions [D×L×T] | Unit | Material | Qt'y |
|---|---|---|---|---|---|
| Cryostat | Chamber | 2,500×5,000×12 | mm | STS304L | 1 |
| | Sub-cooler | 650×1,500×8 | mm | STS304L | 1 |
| | Damper | 600×1,000×8 | mm | STS304L | 1 |
| | Cold compressor | 300×500 | mm | STS316L | 1 |
| Transfer line | TL1 | 267×20,000×5.0 | mm | STS304L | 1 |
| | TL2 | 318×50,000×6.5 | mm | STS304L | 1 |
| | TL3 | 165×10,000×4.0 | mm | STS304L | 1 |
| | TL4 | 165×20,000×4.0 | mm | STS304L | 1 |
| | TL5 | 165×20,000×4.0 | mm | STS304L | 1 |
| | TL6~7 | 165×20,000×4.0 | mm | STS304L | 2 |
| Vacuum system | HVC | Diffusion pump | | | 1 |
| | RP | Mechanical B&R pump | | | 1 |
| | FP | Mechanical rotary pump | | | 1 |
| | P&F | Dry pump | | | 1 |
| Valve | Cryogenic | Eq.% Fail open & close | | | 17 |
| | Warm | Eq.%, Fail close | | | 2 |
| Local I&C | Temperature | Lakeshore CX-1050-SD-HT | | | 28 |
| | Pressure | 0~10 bar | | | 12 |
| | Mass flow | Orifice 0~20 g/s | | | 6 |
| | PLC | Siemens S7 - 400 | | | 1 |
| | Local PC | Workstation z230 | | | 2 |



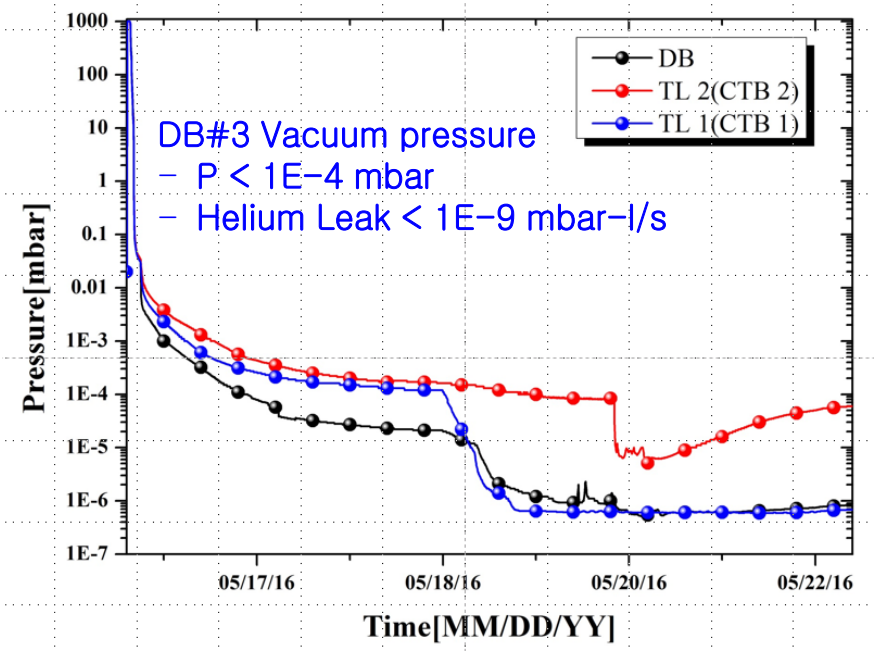
# Construction

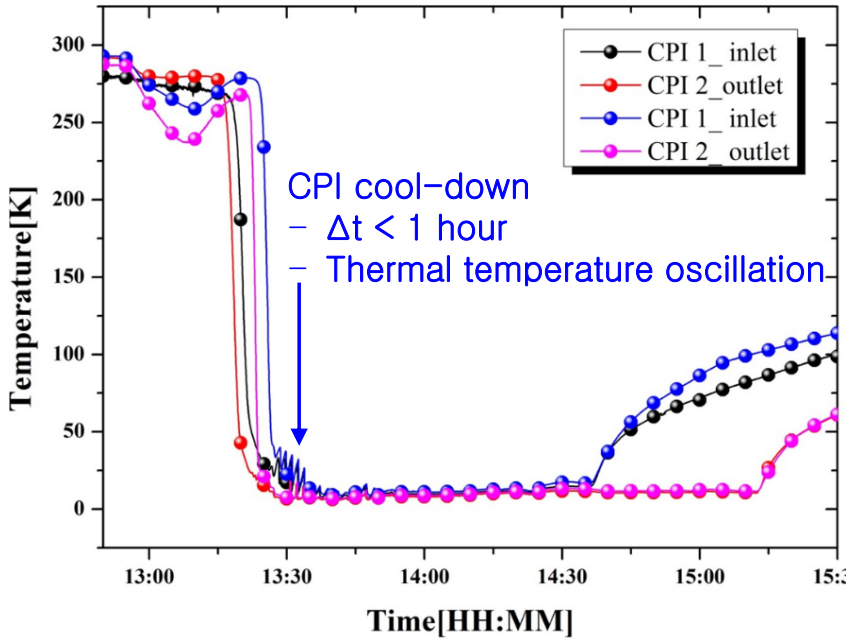


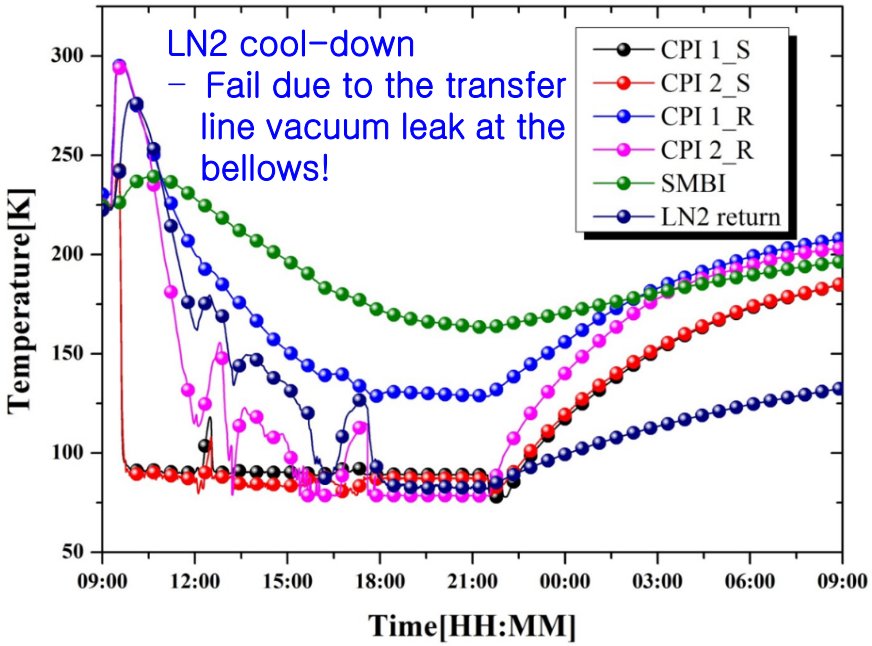


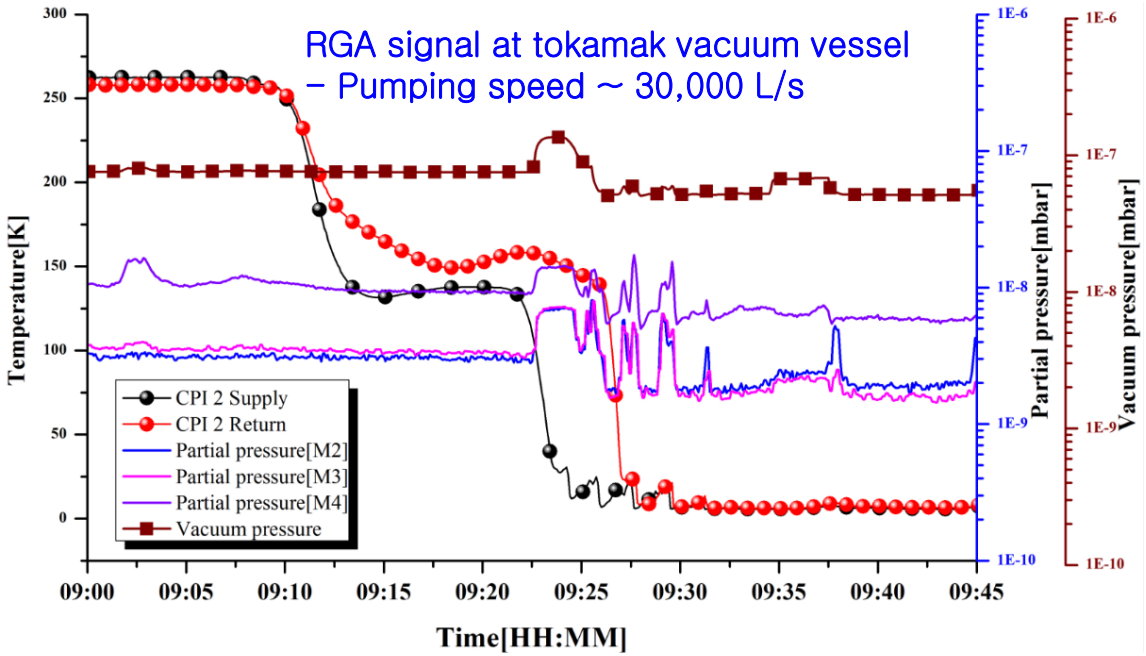
# Test Results (2016)





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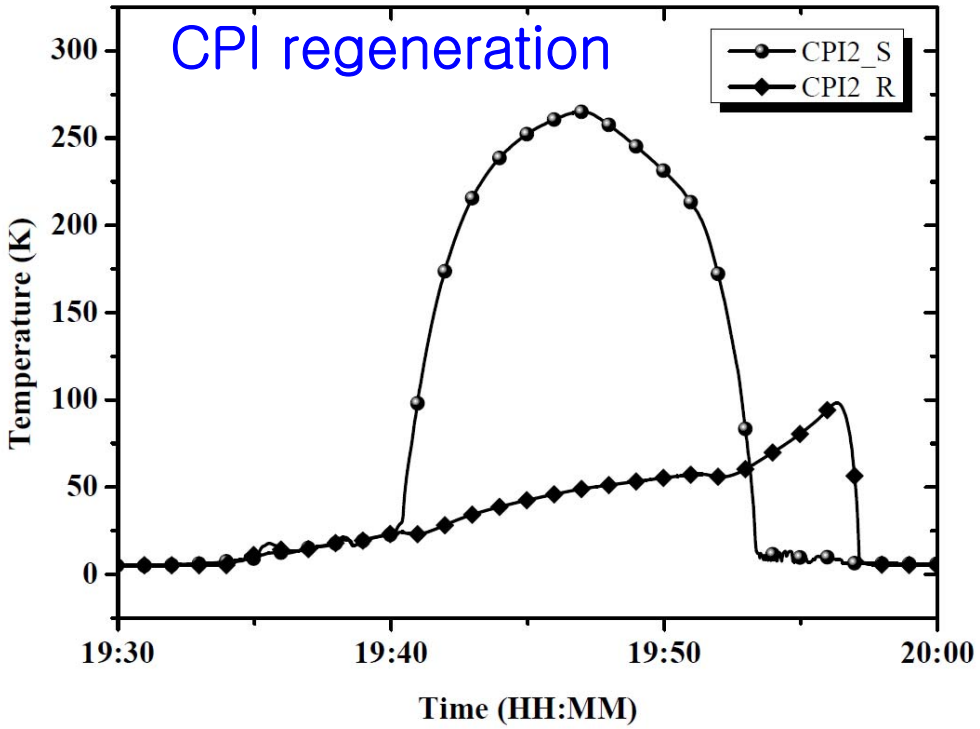
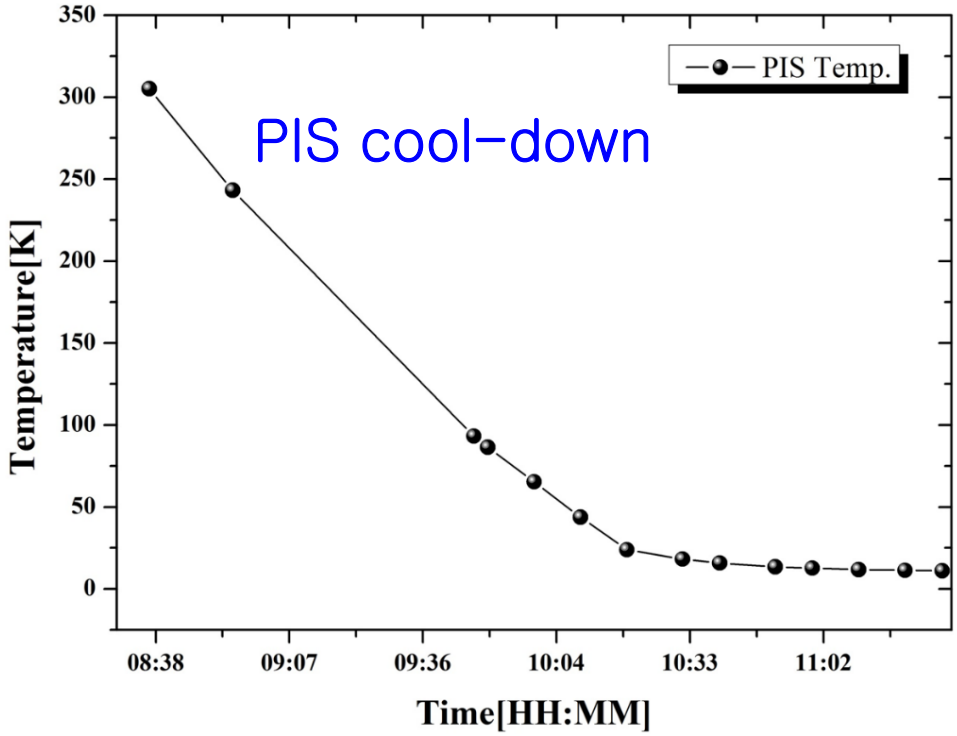
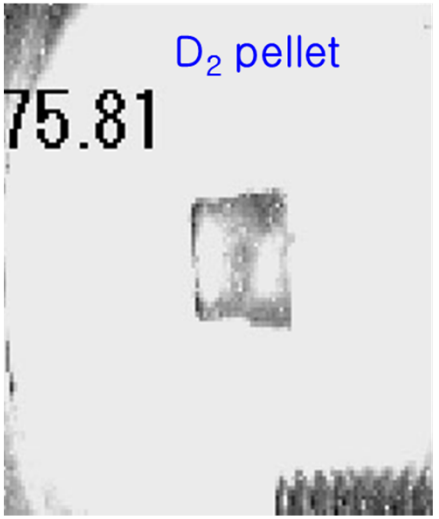
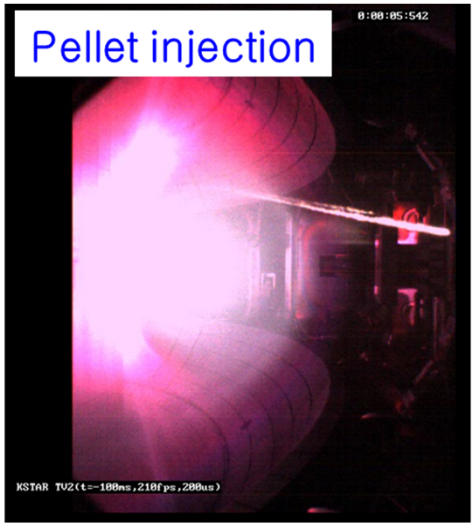



- It was regarded fast in-vessel cryo-pump regenerations between each plasma experiments.
- Process within 30 min.
  - Warm-up to 100 K within 10 min.
  - Waiting until the return T ~ 100 K.
  - Cool-down within 10 min.



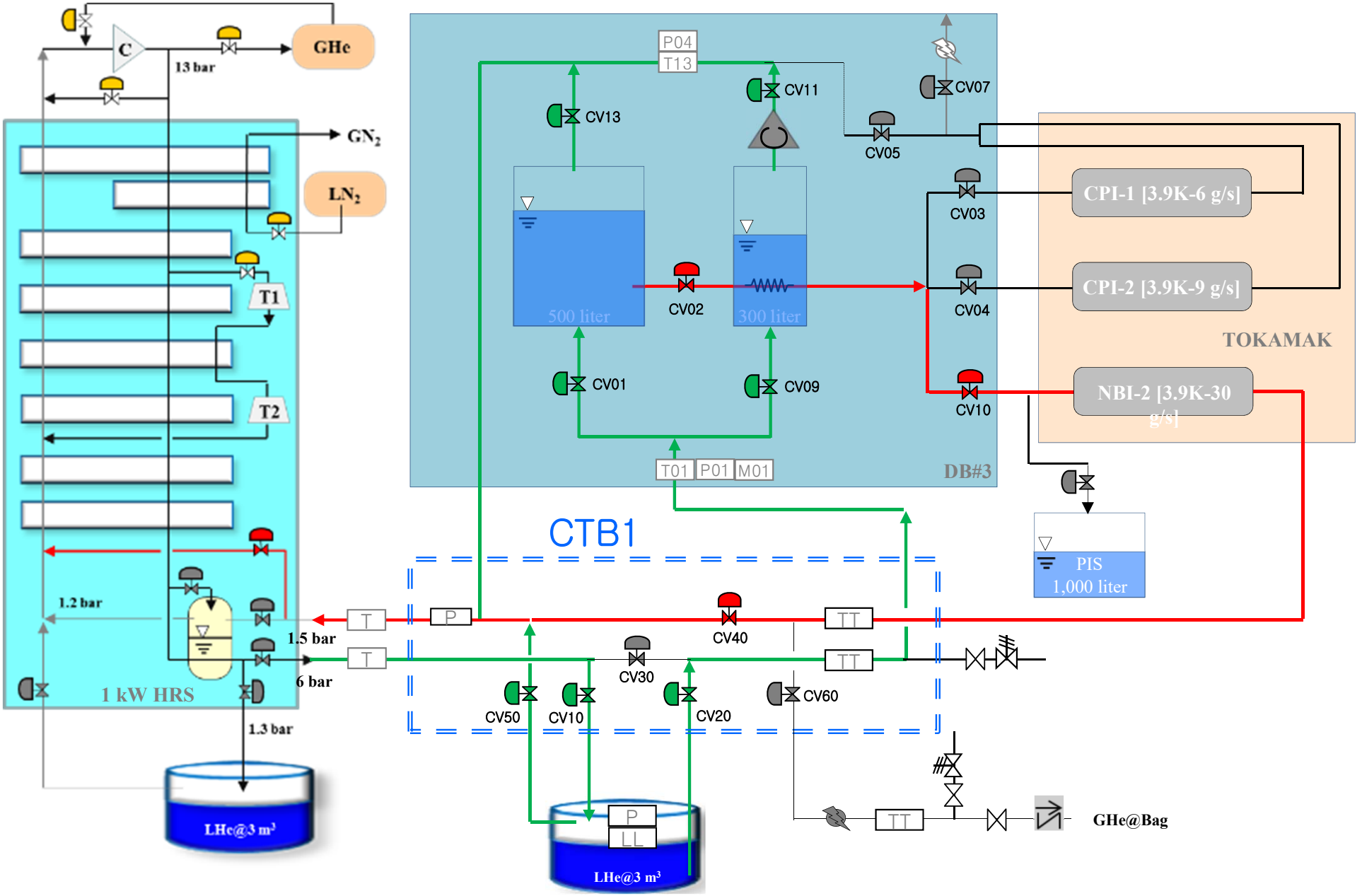
# Issue & Accidents



| Object | Issue & Accidents | Solution |
|---|---|---|
| LN2 TL | • Long (~150 m) TL from LN2 tank to DB#3<br>• and vacuum leakage in above TL bellows<br>• Low supply pressure (~3.5 bar) due to parallel connection with NBI#1 thermal shields cooling line | • Repaired the outer tube bellows<br>• Assembled new cold compressor |
| SMBI | • Narrow LN2 inlet/outlet (1/4", 1.5 m) and parallel connection with the CPI thermal shields → long cool-down time | • Newly mounted bypass line (1/2") |
| PIS | • J-T valve at DB#3 (~50 m distant from 1000L LHe tank nearby the PIS) | • Direct supply to the LHe tank |
| Cryo-pump | • Additional pump at lower divertor region<br>• Cartridge heater fail for the regeneration to 100 K | • Serial connection with lower pump, CPI#2<br>• Feed-back of both T & Flow |
| NBI#2 | • TS & cryo-panel operation using 1 kW plant<br>• 3.9 K cryo-panel | • Prepared & operation starts from July, 2018<br>• Assembly of cold compressor (2019) |

# P&ID including NBI#2






Thanks
a lot !