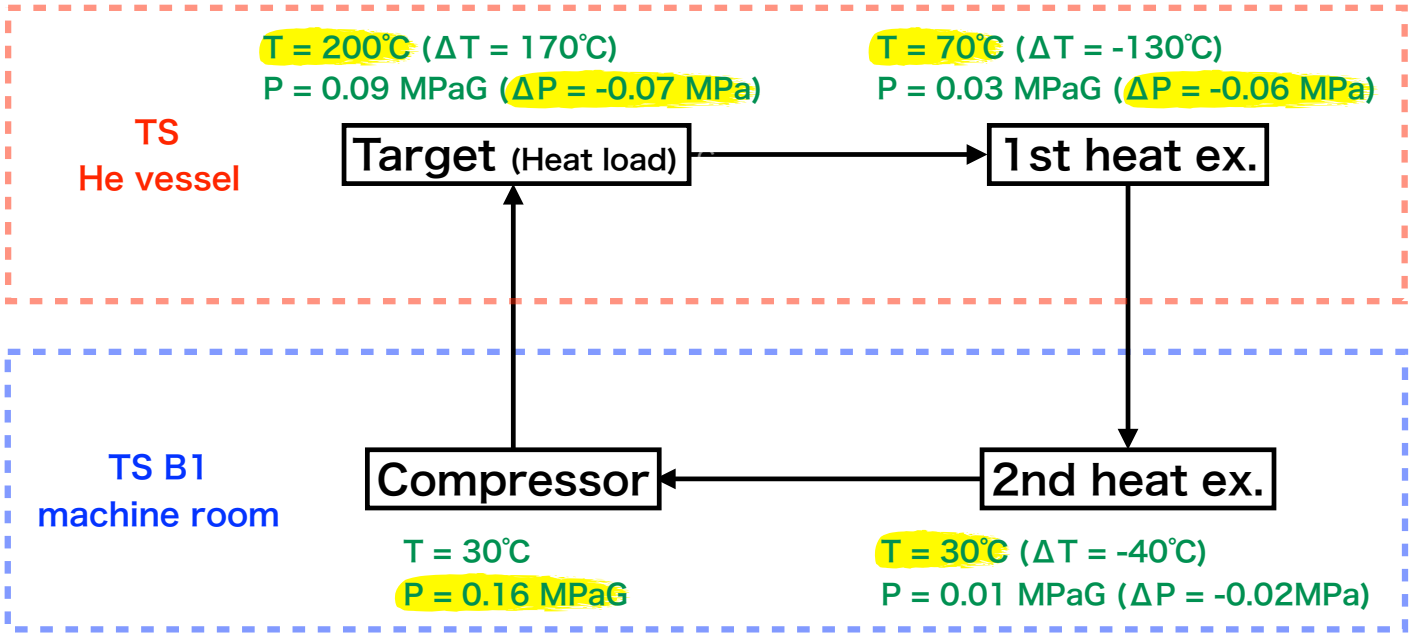
Status of vacuum insulated pipe development

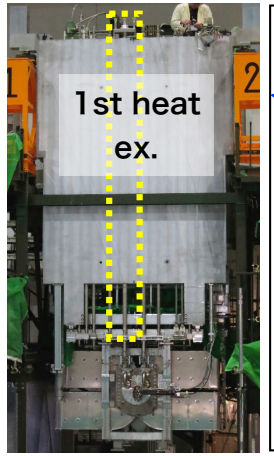
9 July 2020, FNAL/KEK meeting

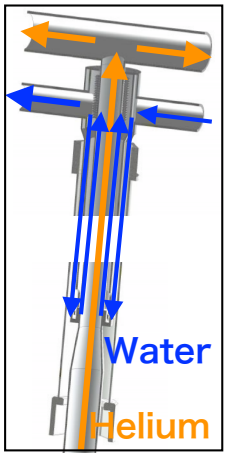
Tsunayuki Matsubara (KEK)

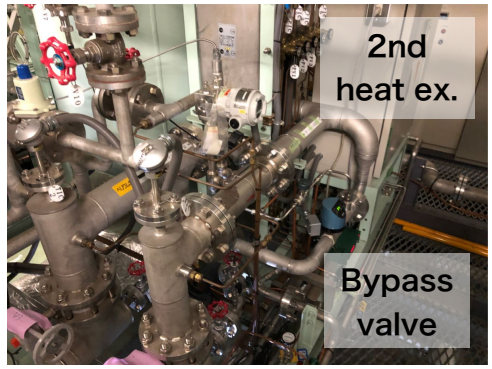
Target Helium Cooling System

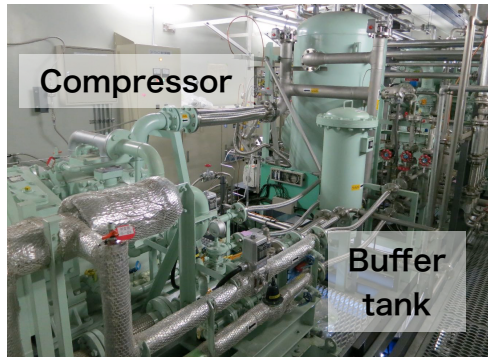
Simple diagram of the system











- Pressure applied by the compressor is 0.16 MPaG
- Helium gas from the target (~200℃) is cooled by 1st (2nd) heat exchanger to ~70℃ (30℃)
- Comparable pressure drop at target & 1st heat ex.

Upgrade toward 1.3 MW

Current target design

・Cooling capacity： 750kW + 20% margin = 900 kW → Need to upgrade

Upgraded design

・High flow rate to accept x1.7 of heat load (24 kW @ 750 kW → 41 kW @ 1.3 MW)

・High pressure tolerance ("0.16 → 0.5 MPaG" by the compressor, for reasonable flow velocity)

R&D items for the upgrade

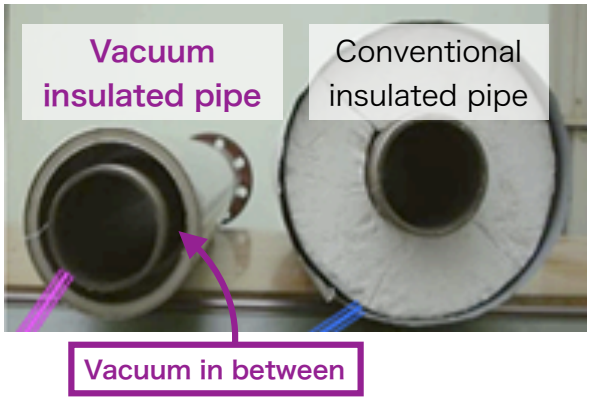
・1st heat exchanger → Vacuum insulated pipe

・Remote exchange method of the pipe

・New heat exchanger & new compressor

・Pipes from the Helium vessel to the Machine room

https://www.enoah.co.jp/



Why the new pipe?

・Re-designing for the higher pressure tolerance (bellows, especially)

・Low ΔP can relax required specification of the compressor

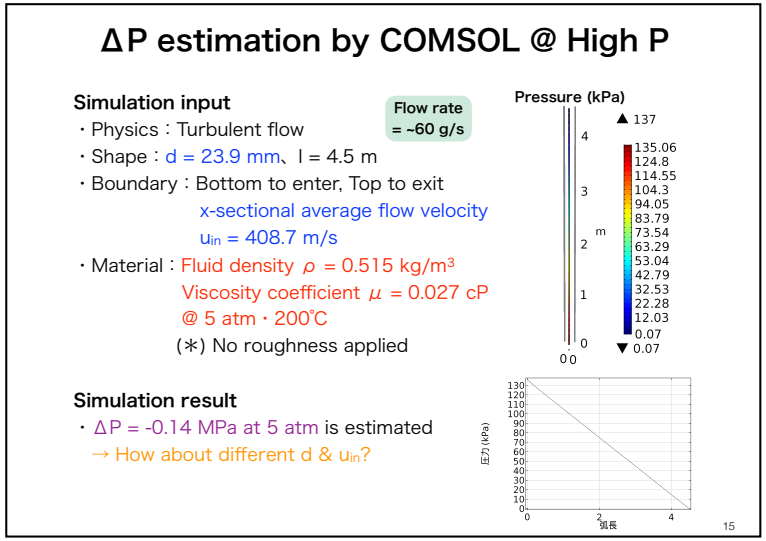
・Cooling at low radiation level to reduce radioactive water

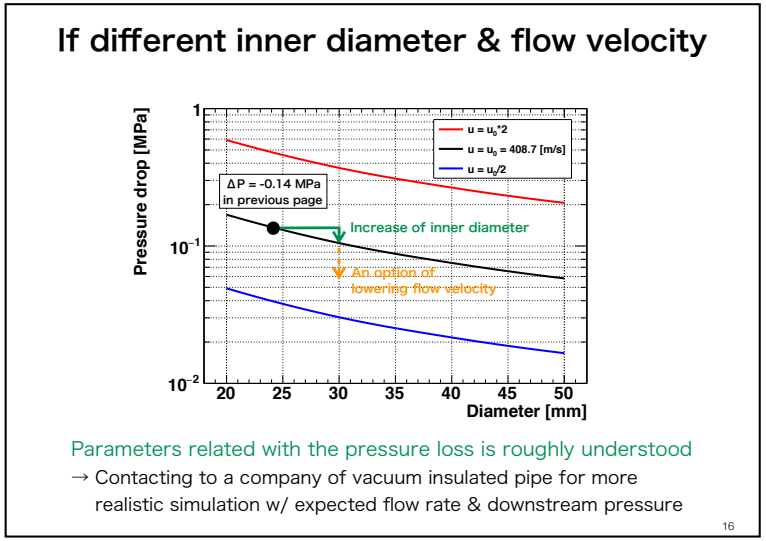
・Good maintainability of the heat exchanger

→ Possible input for LBNF?

Reminder : Last meeting (21 Oct. 2019)

・Preliminary results of pressure drop at the pipe are reported





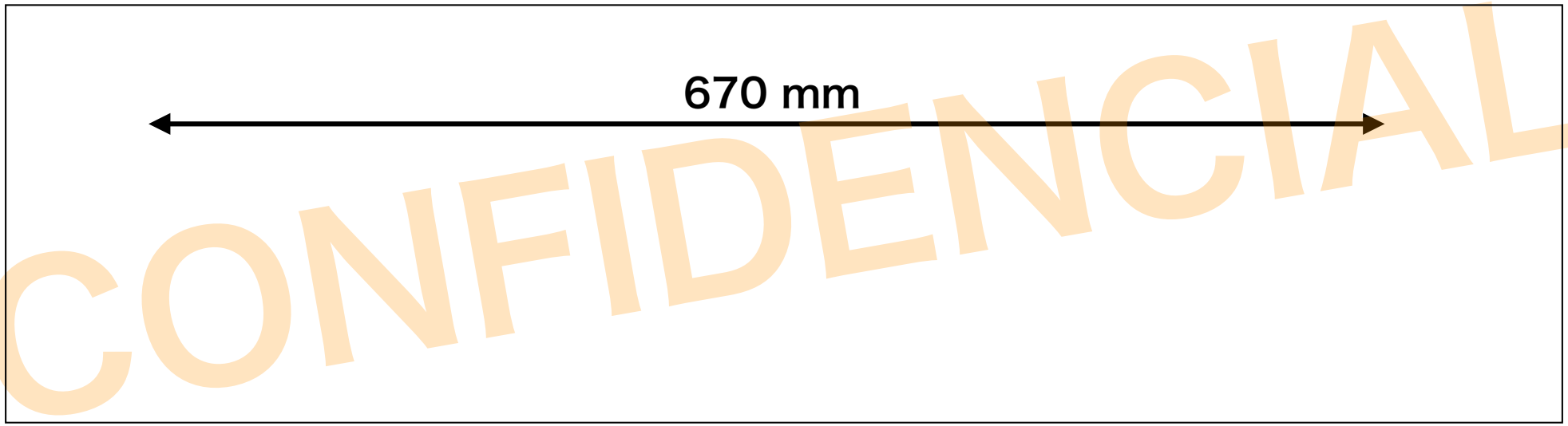
・Updated boundary conditions: Fixed mass flow rate @ inlet & velocity @ outlet

	Mass flow [g/s]	R_{pipe} [mmΦ]	ΔP [MPa] @Tsuna	Comment
Current system	30	23.9	0.044	Comparable w/ 0.06MPa.
Updated system (0.1→0.5 MPaG)	60	23.9	0.051	0.14 MPa in the past sim.
		30.7	0.015	Increased diameter.

・Negligible ΔP for the increased diameter is found

→ No problem in the pressure drop (i.e. 0.015 MPa << 0.5 MPa if 30.7 mmΦ)

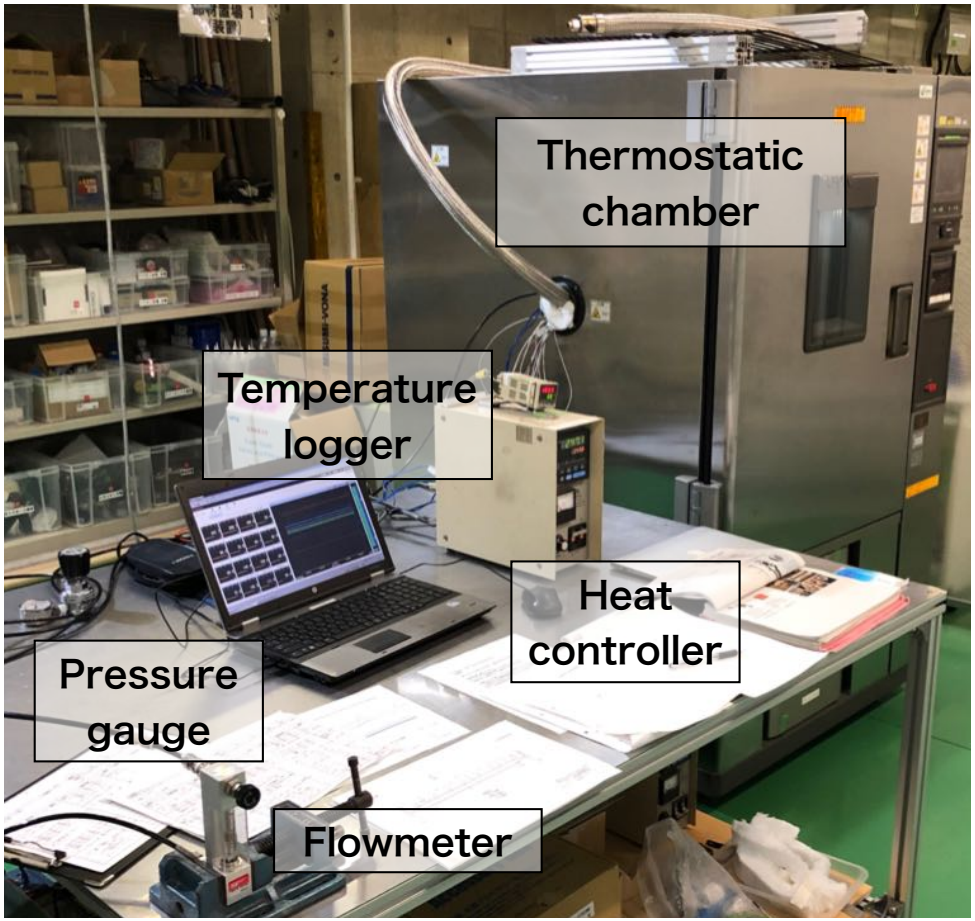
Prototype

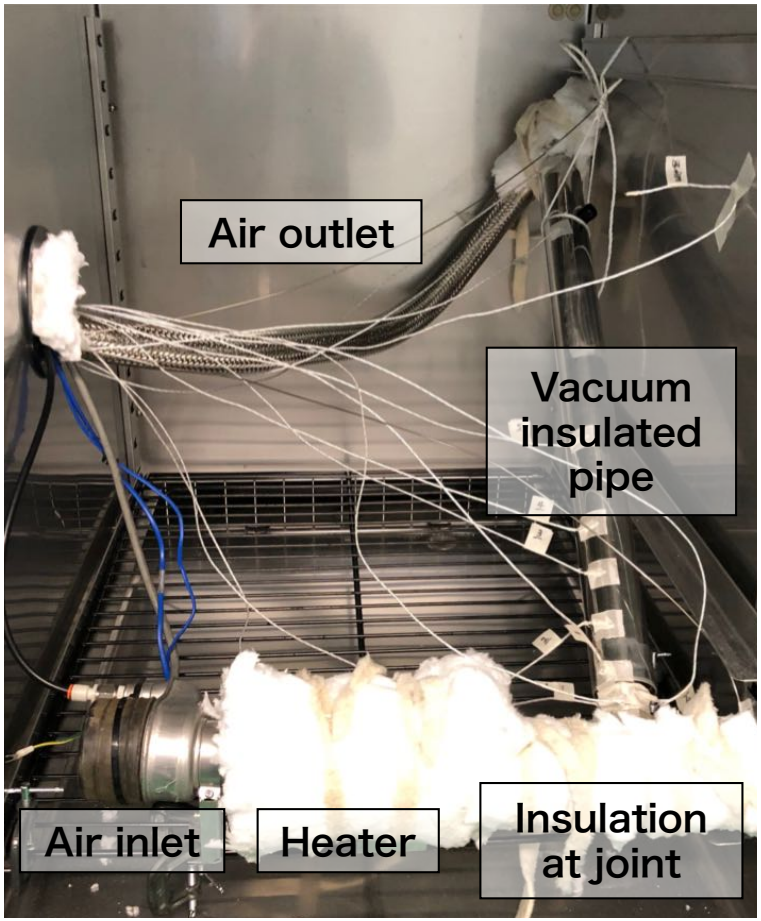


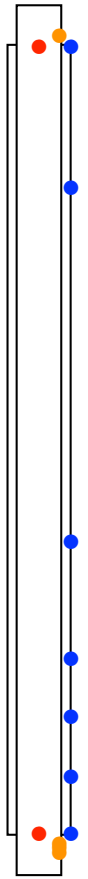
Point of the design

- Inner diameter : 30.7 mmΦ → Acceptable pressure drop
- Thickness of inner pipe : Sche. 5S (t = 1.65 mm) → 0.5 MPaG tolerance
- Outer diameter : 50 mmΦ → Same as current 1st heat exchanger
- Radiation tolerance : SUS304 (pipe), Al (insulation), No solvent → OK
- Temperature tolerance : < 800℃, Baking process to reduce out gas → OK
- Long stability : Record of 7 years operation at least → OK
- Length : ~0.7 m → Long enough to do heat insulation test

Test of the heat insulation (16 Mar. 2020)



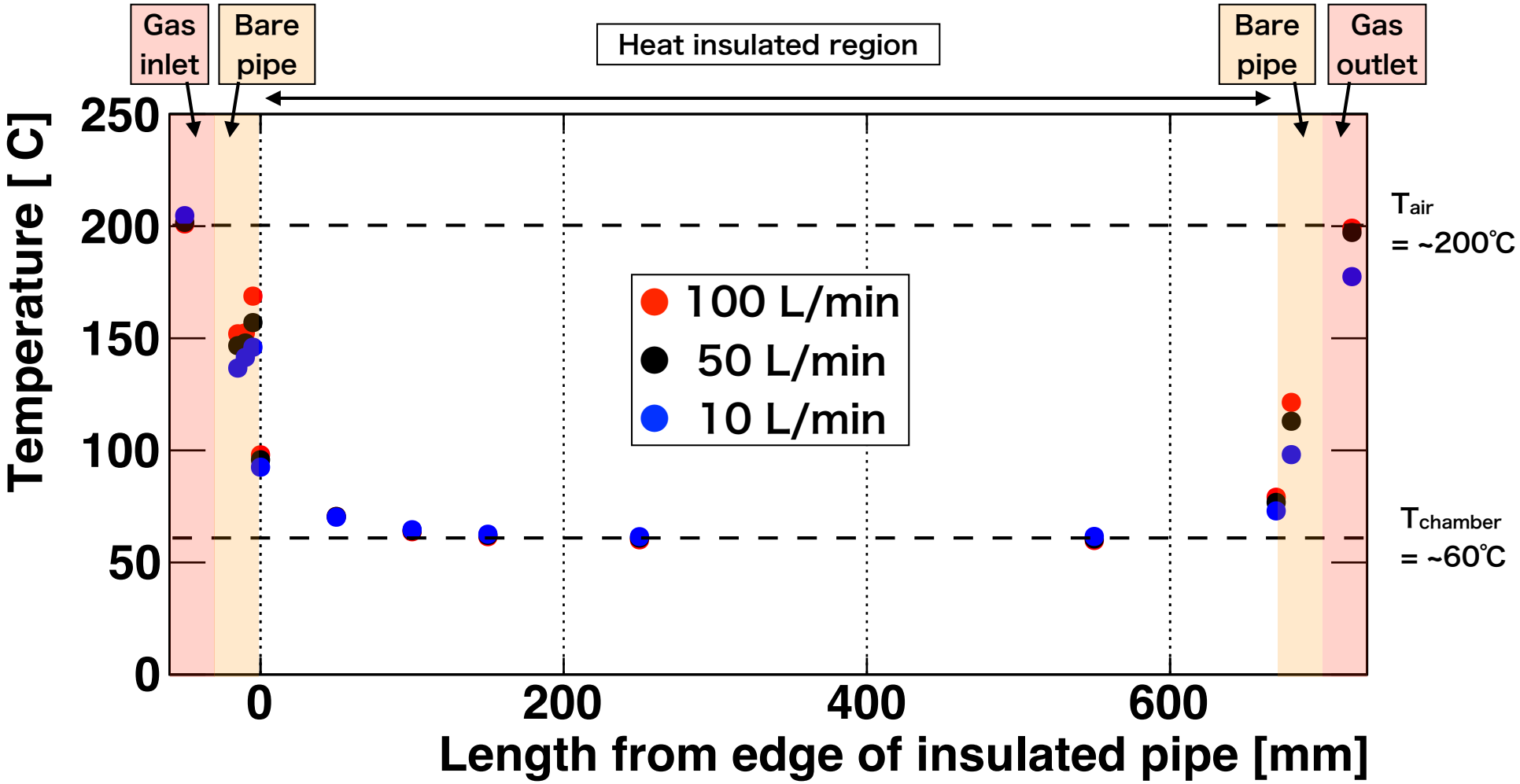




- Heat insulation test in a thermostatic chamber (Stable ~60℃)
- Air flow (~200℃) within a range of flow rate of 10~100 L/min
- Temperature measurement
  - 2 points at gas inlet/outlet, 4 points at surface of bare pipe, 7 points at surface of insulated pipe & one in the chamber

Test results

・Equilibrium temperature was measured for 3 different flow rate

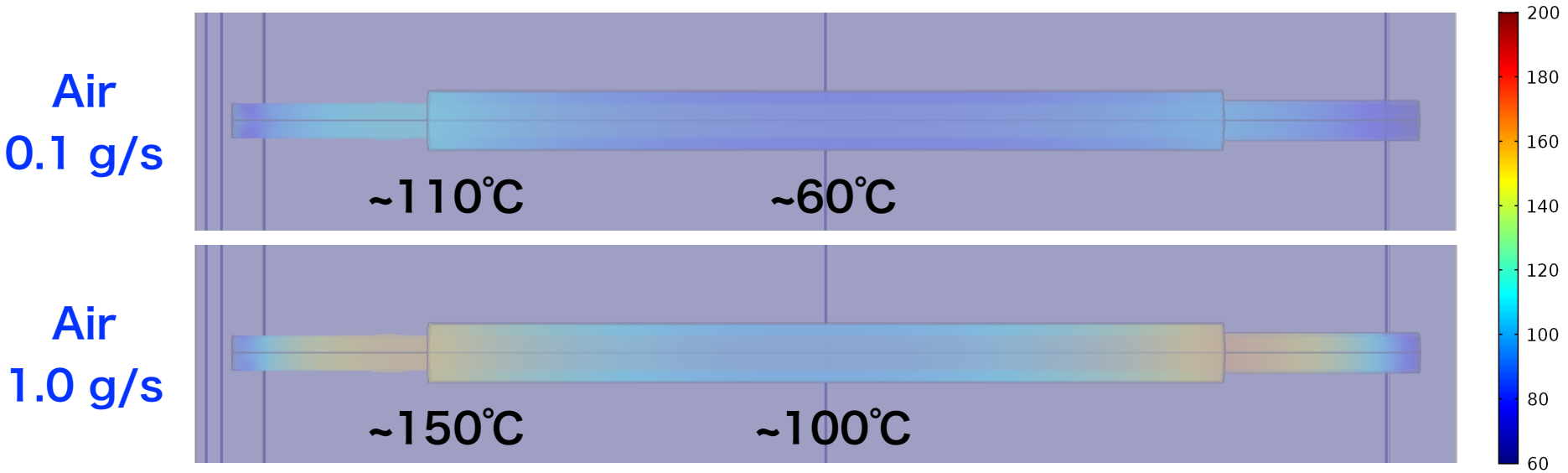


・Good capability of heat insulation at the region is confirmed

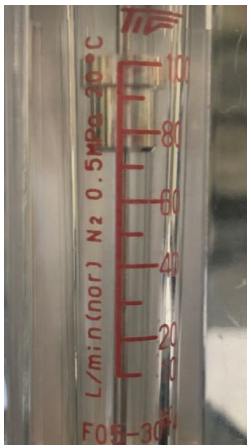
・No significant difference in this range of flow rate

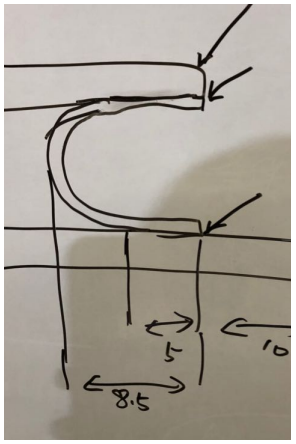
Comparison with simulation (COMSOL)

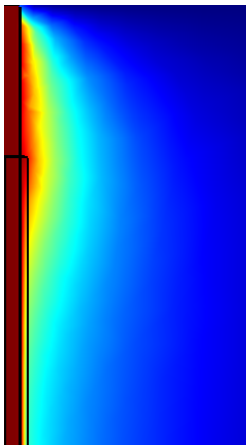
- Flow rate of 10~100 L/min → Mass flow rate of 0.12~1.2 g/s
  if calculating with density of air (1 atm・200℃) is 0.72 g/l
- Simulation was performed with conditions below



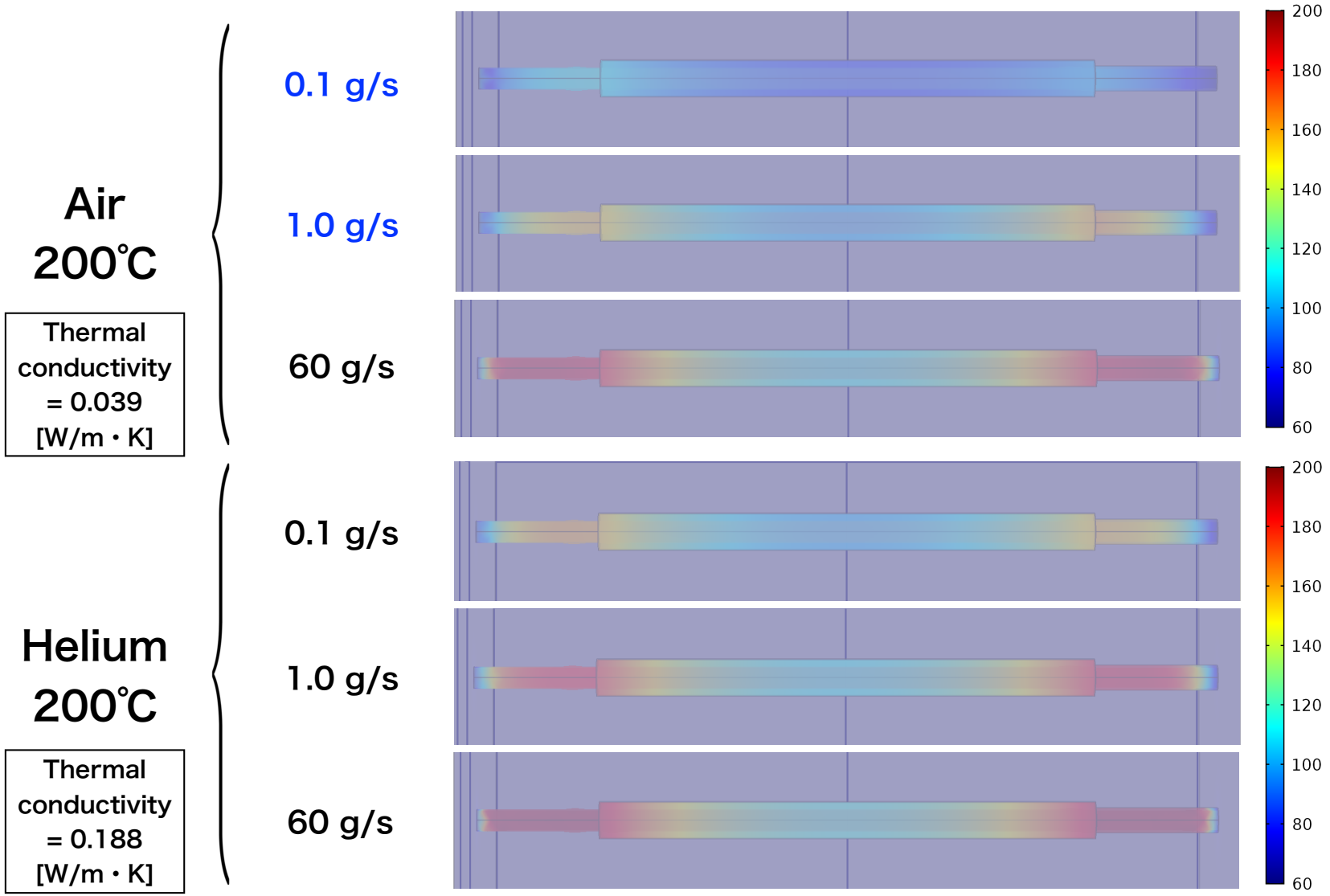
- Comparable results in case of 0.1 g/s
  but higher than observation in 1.0 g/s
- Investigating the difference with observation
  - Flow rate correction?
  - Design of the edge of insulated region?
  - Boundary condition in a chamber?







Extrapolation to higher flow rate & He gas

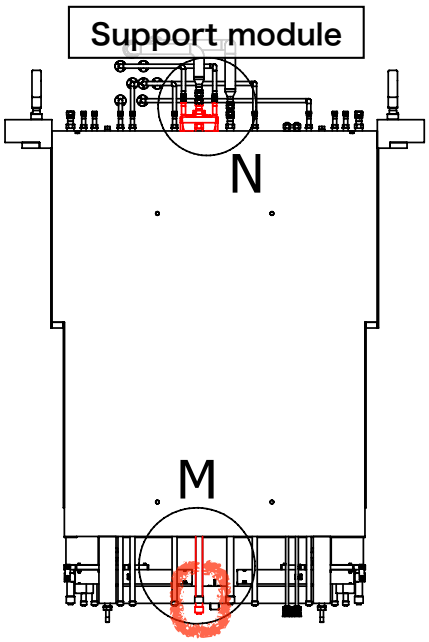


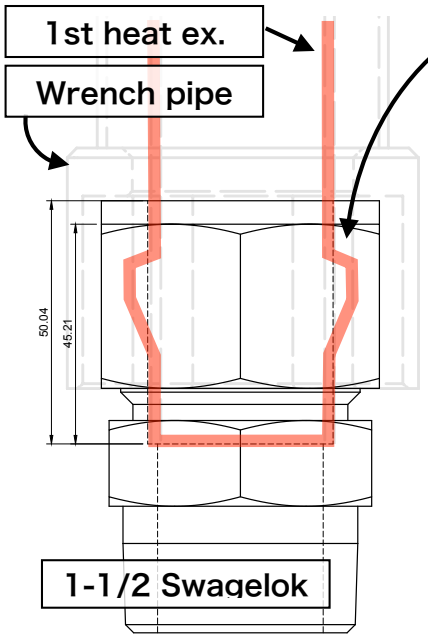
- More flow rate makes heat transfer around edge to middle of the pipe
- Helium gas has x5 higher thermal conductivity than air

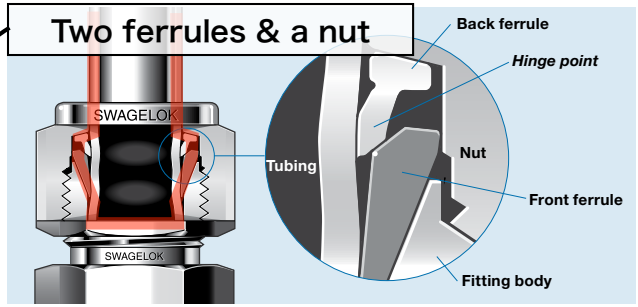
Remote exchange - Difficulty

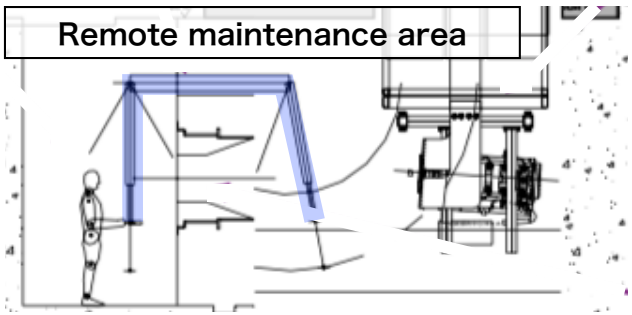
- Current 1st heat exchanger is not designed for replacement
  - Max. diameter of the wrench pipe is too large to pull up through the support module
  - The nut of 1-1/2 Swagelok prevents to pull up through the wrench pipe

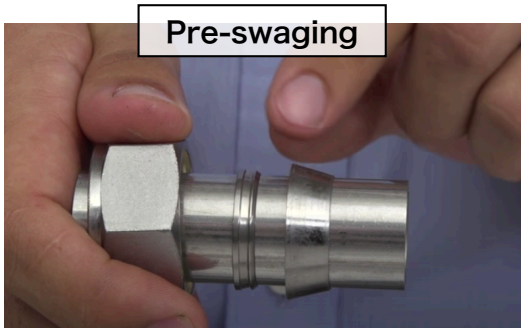
- Pre-swaging before mounting is necessary for the new pipe
  - If we do in the same way as performed in the 1st heat exchanger installation, this have to be done remotely as it is close to the irradiated materials now.

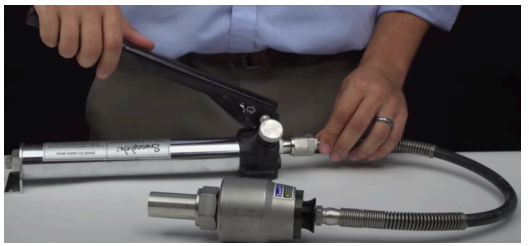












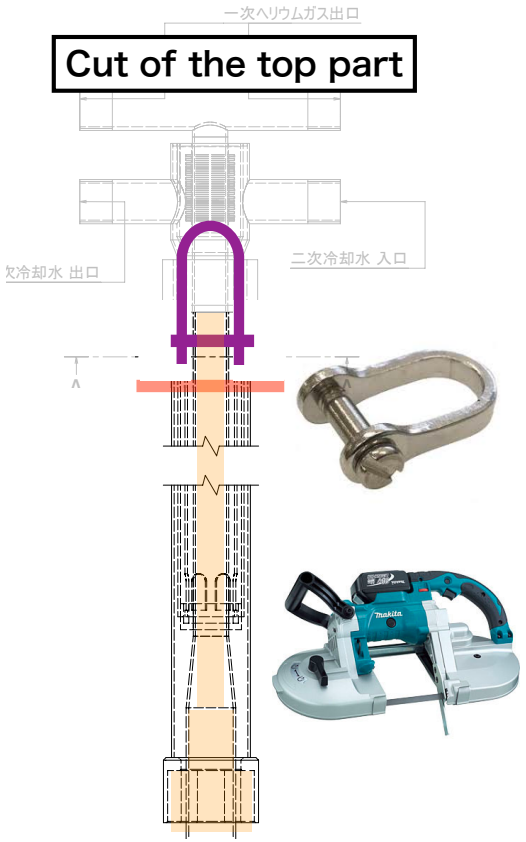
Using a Swagelok® Multihead Hydraulic Swaging Unit (MHSU)
https://www.youtube.com/watch?v=T33O_NtUTM8

Remote exchange - Solution

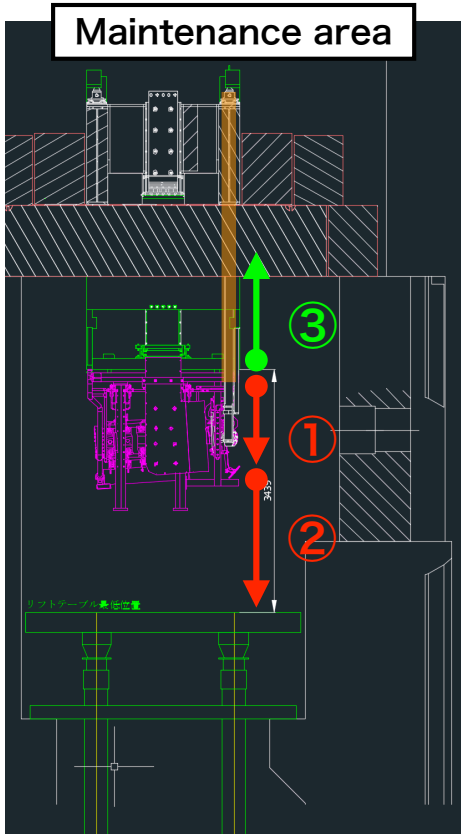
Cut top & pull down

- Cutting both 1st heat ex. & wrench pipe on the support module
- Remote operation become very simple

Cut of the top part



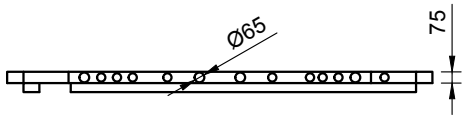
Maintenance area



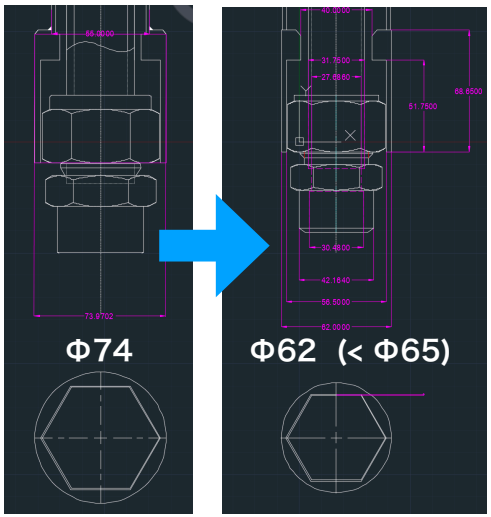
New joint & wrench pipe

- Smaller joint (1-1/2” → 1-1/4”) allows us to insert it from the module top
- No remote work. Easy to replace again

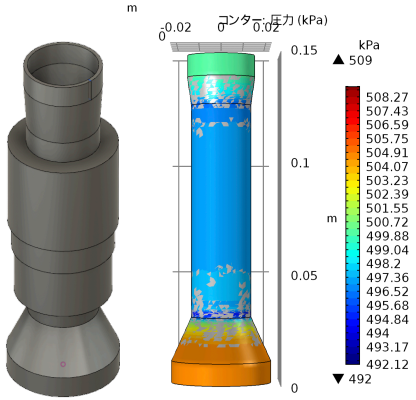
Support module - Top view



Joint/wrench design (Current → New)

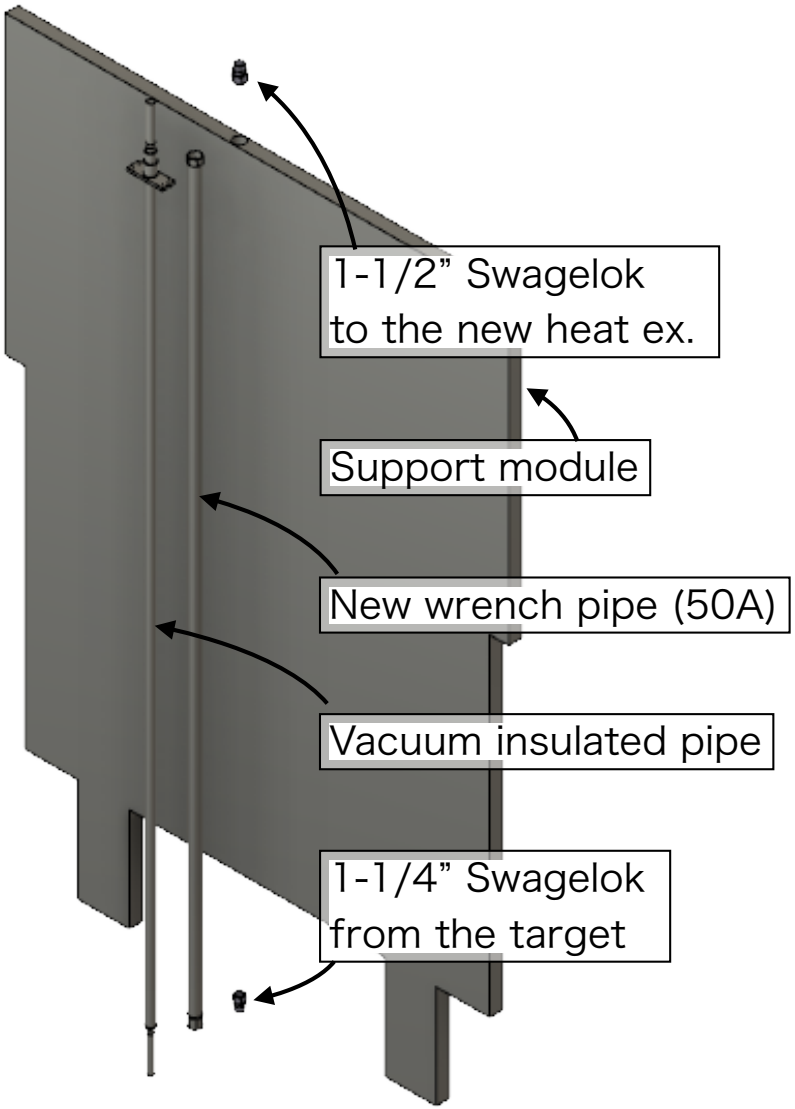


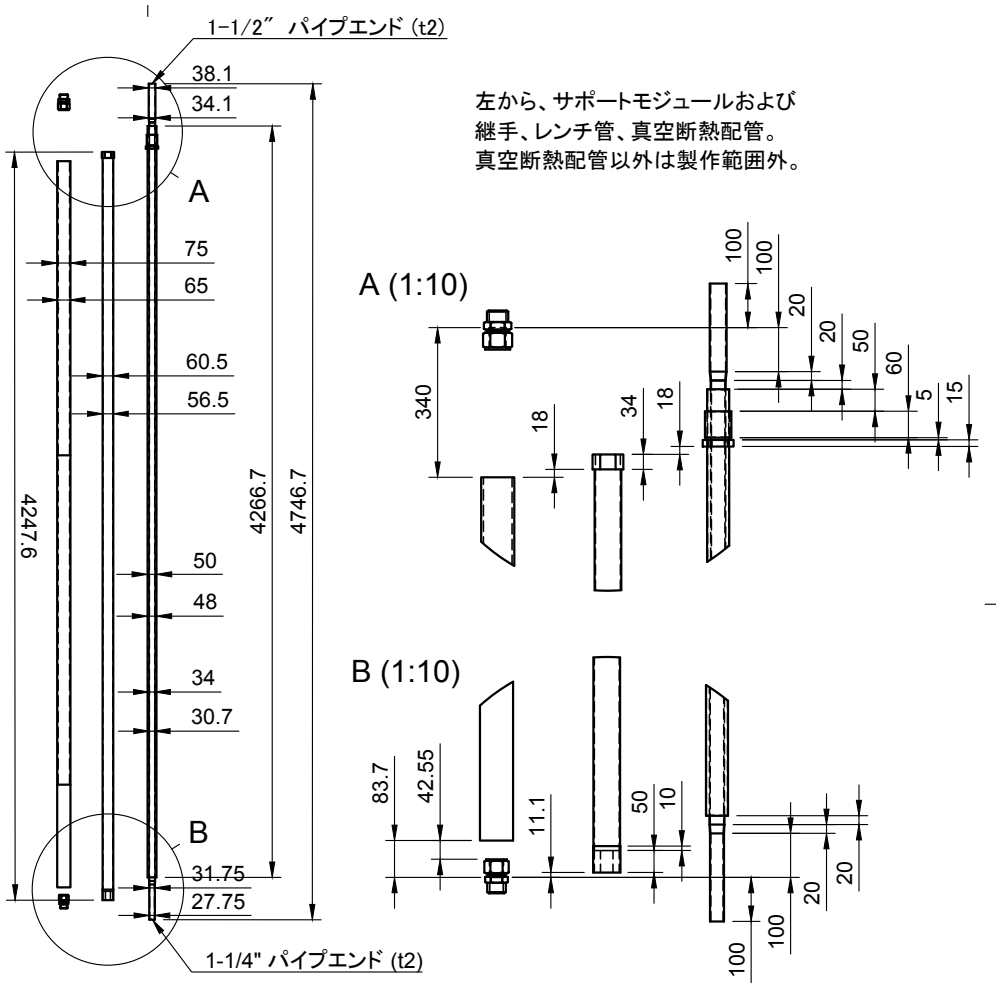
ΔP estimation for the smaller joint



Final design of the pipe (not yet finalized)

・Designed to fit current equipments (e.g. Limited space on the module)

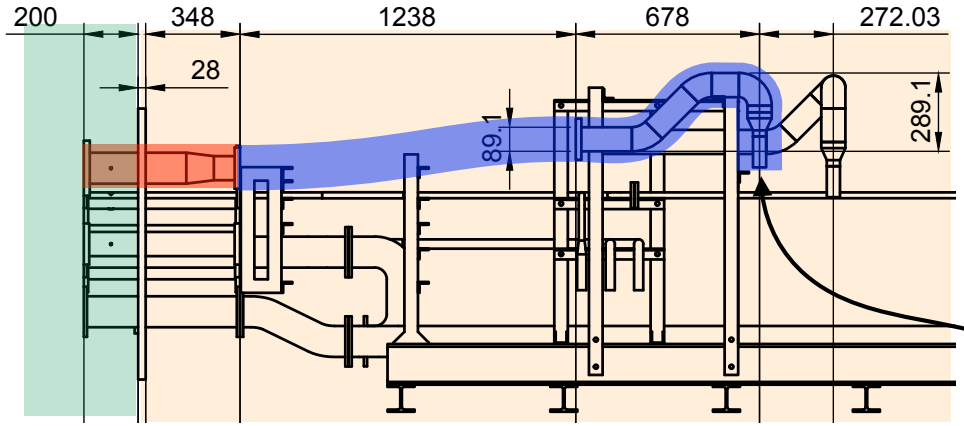




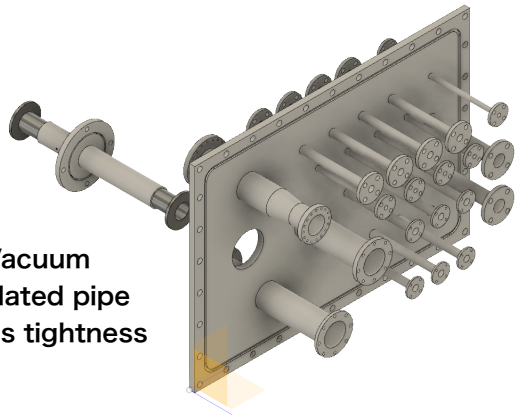
・Plan : Production in this JFY & Test before installation in next JFY

Other works toward the upgrade

- Extension of the vacuum insulated pipe to outside of the Helium vessel
  - For easier access to the new heat exchanger
  - Need new flexible pipe & new feed through with vacuum insulation

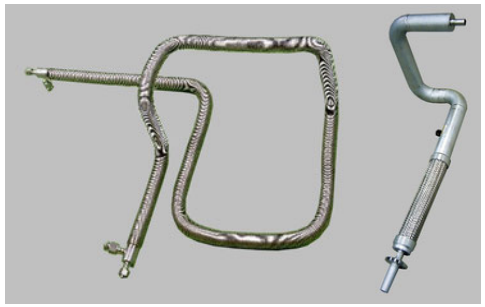


Feedthrough

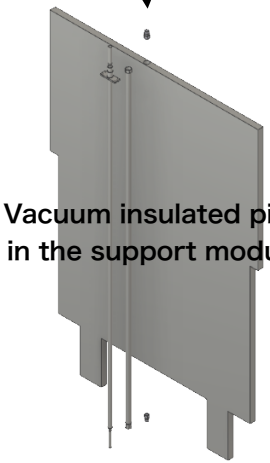


Vacuum insulated pipe w/ gas tightness

Piping in the Helium vessel



Samples of flexible vacuum insulated pipe

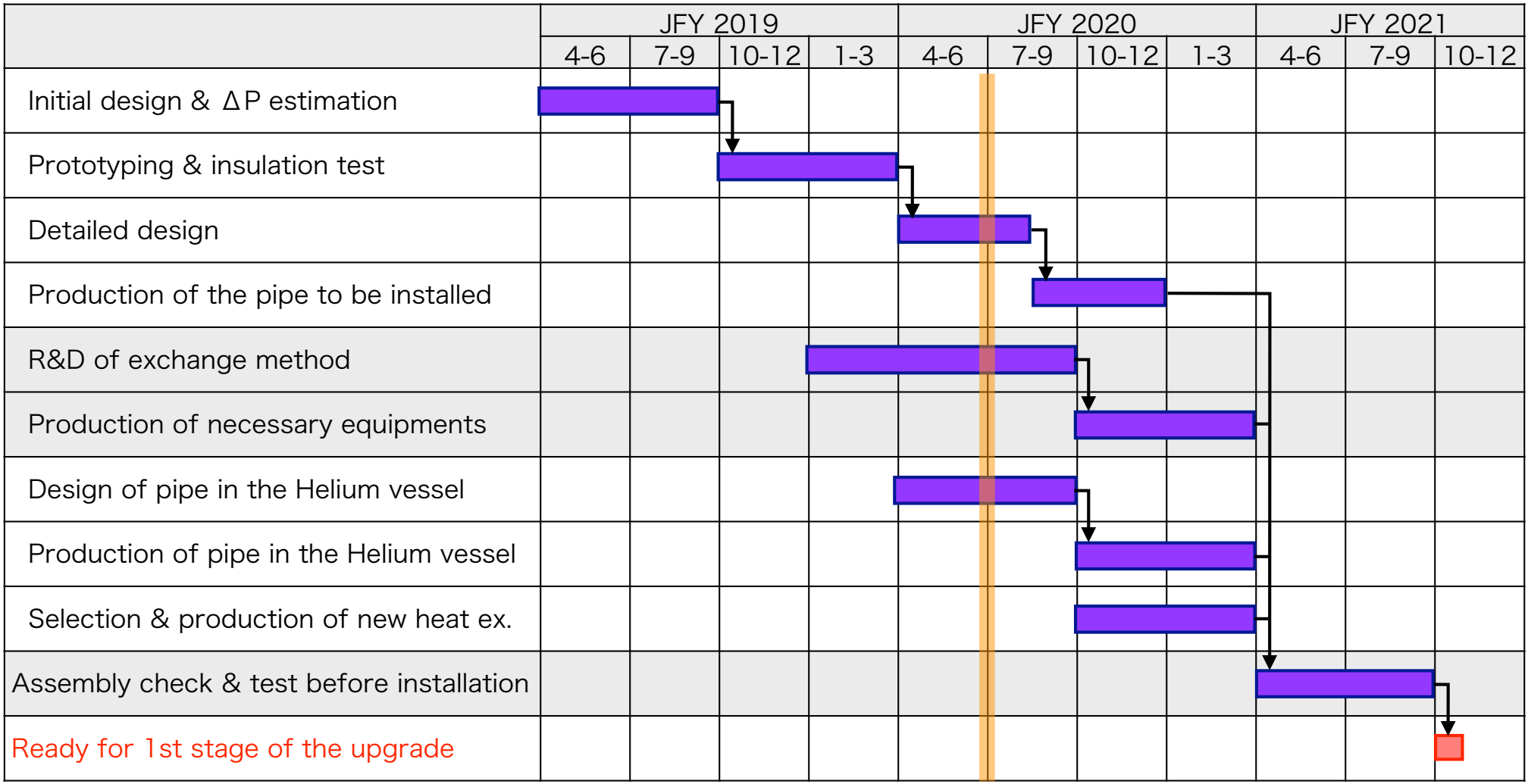


Vacuum insulated pipe in the support module

- Selection of new heat ex. (Same type as 2nd heat ex? Started investigation)
- Selection of new compressor (Less outlet pressure → Relaxing specification)

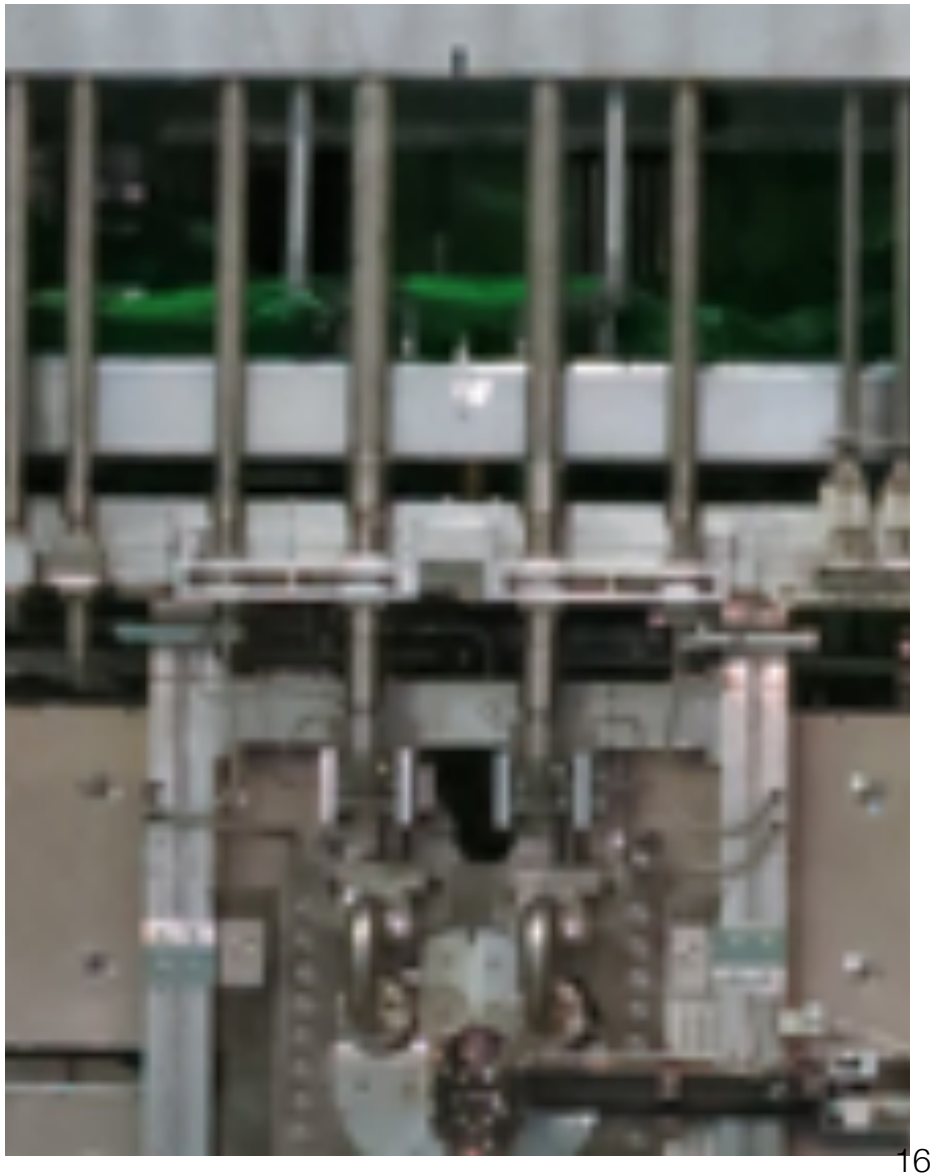
Status & prospects

- 1st stage of the upgrade : In the Helium vessel (e.g. Pipes & heat ex.)
- 2nd stage of the upgrade : In the Machine room (e.g. pipes & compressor)

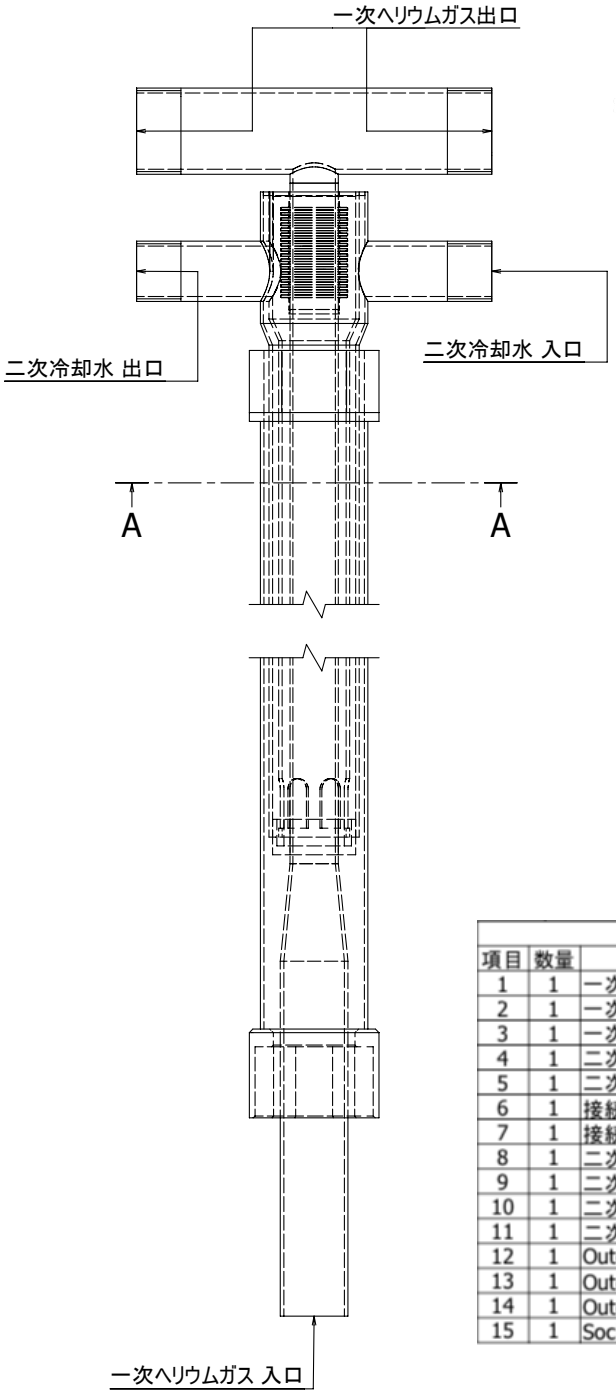


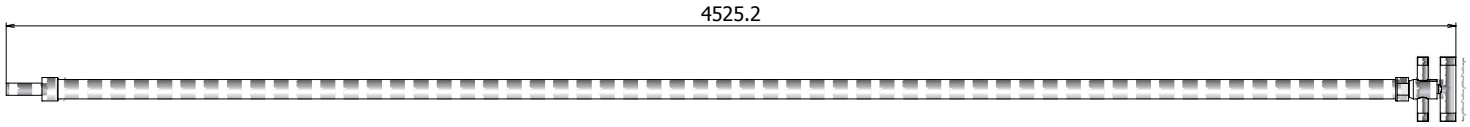
Backup

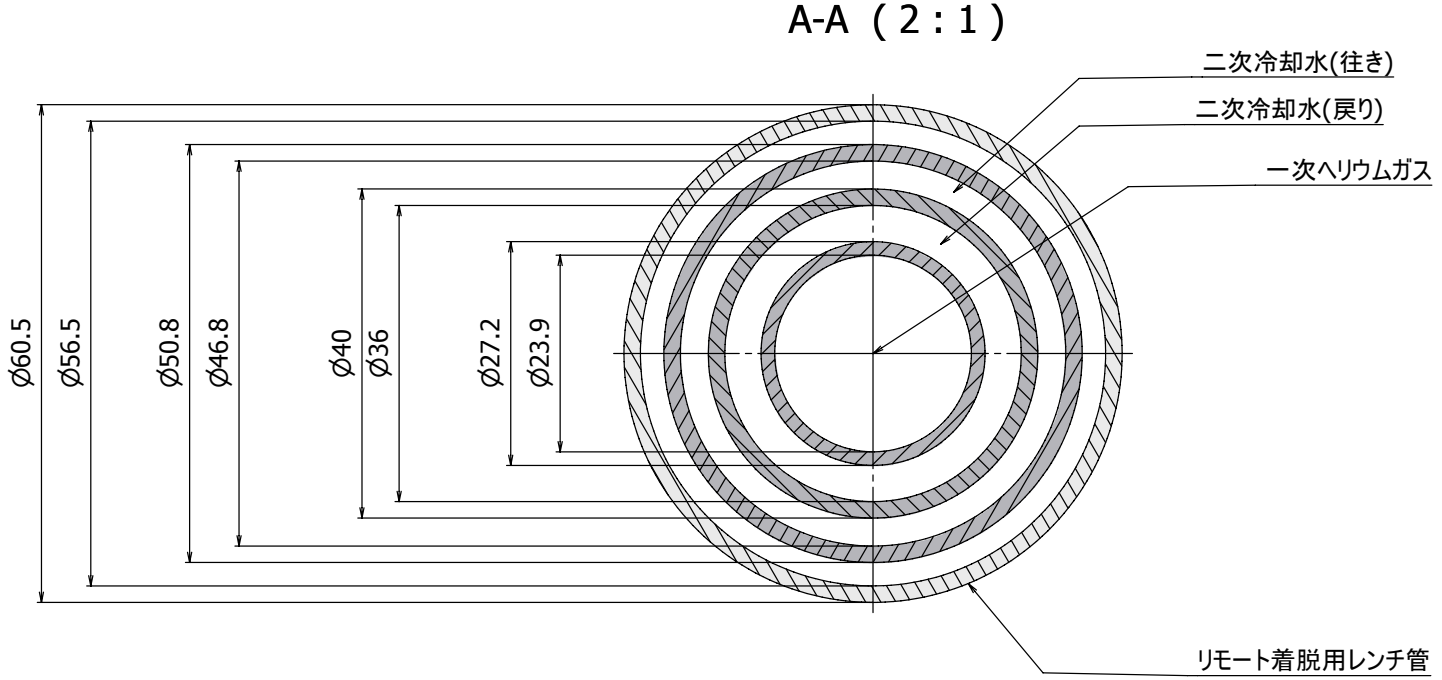

1
2



Details of 1st heat exchanger







部品表			
項目	数量	部品番号	備考
1	1	一次ヘリウムガス管	SUS304
2	1	一次ヘリウムガス入口	SUS304
3	1	一次ヘリウムガス出口	SUS304
4	1	二次冷却水内管	SUS304
5	1	二次冷却水外管	SUS304
6	1	接続ベローズ	SUS304
7	1	接続ベローズ固定具	SUS304
8	1	二次冷却水折り返し部蓋	SUS304
9	1	二次冷却水内管上端部蓋	SUS304
10	1	二次冷却水外管上部蓋1	SUS304
11	1	二次冷却水外管上部蓋2	SUS304
12	1	OuterTube50A - 4175.5mm	(製作範囲外)
13	1	OuterTubeFrange50A	(製作範囲外)
14	1	OuterTubeNut50A	(製作範囲外)
15	1	Socket - 73mm	(製作範囲外)

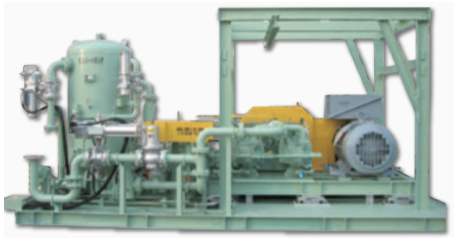
第一熱交換器

- マイテック (株) 製
- 一次ヘリウムガス系の耐圧 0.3 MPaG
- 二次冷却水系の耐圧 0.5 MPaG
- 最高使用温度 200℃

Details of other system

Compressor

・オイルフリーコンプレッサ
・堀技研工業(株)製 2640TD



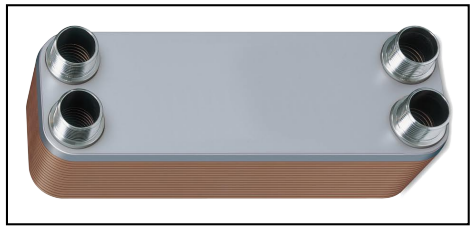
型式
HC-2026GWDQ

用途
ガスエンジンへの供給用

仕様
流　　体：都市ガス13A
流　　量：1250 Nm3/h
吸入圧力：0.20 MPaG
吐出圧力：0.51 MPaG

2nd heat exchanger

・ブレージングプレート式熱交換器
・日阪製作所(株) 製 BXC-724-PU-30
・伝熱面積：5.6 m^2



Other circulation system

・アイハラ (株) 製

(*) 圧縮熱はアフタークーラーによって除熱
(*) バッファタンク (1.24 m^3、耐圧0.97MPa) でガス貯蔵
(*) バッファタンクには0.3 MPaGの安全弁が備え付け
(*) 流量はおよび圧力は、循環系へのガスの
充填量とバッファタンクからコンプレッサに戻る
バイパス流量を調整することにより制御
(*) コンプレッサ吸入口には圧縮部への異物混入を防ぐ
ストレーナ (~数百μm以上) 、コンプレッサ吐出口には
標的部への異物混入を防ぐHEPAフィルタ (1μm以上)