# J-PARC Target Helium Cooling System Upgrade & possible input for LBNF

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Tsunayuki Matsubara (KEK)
for J-PARC Neutrino Facility group

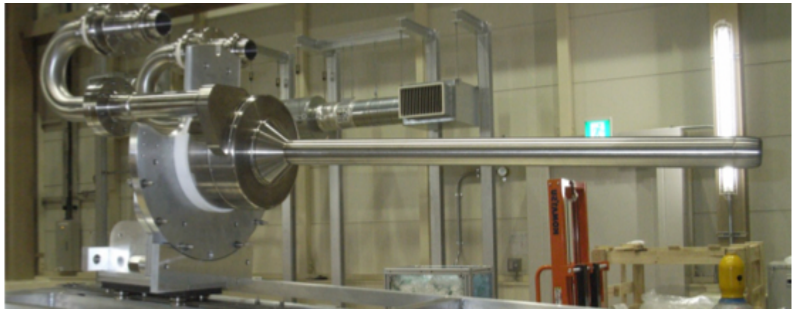
# Outline

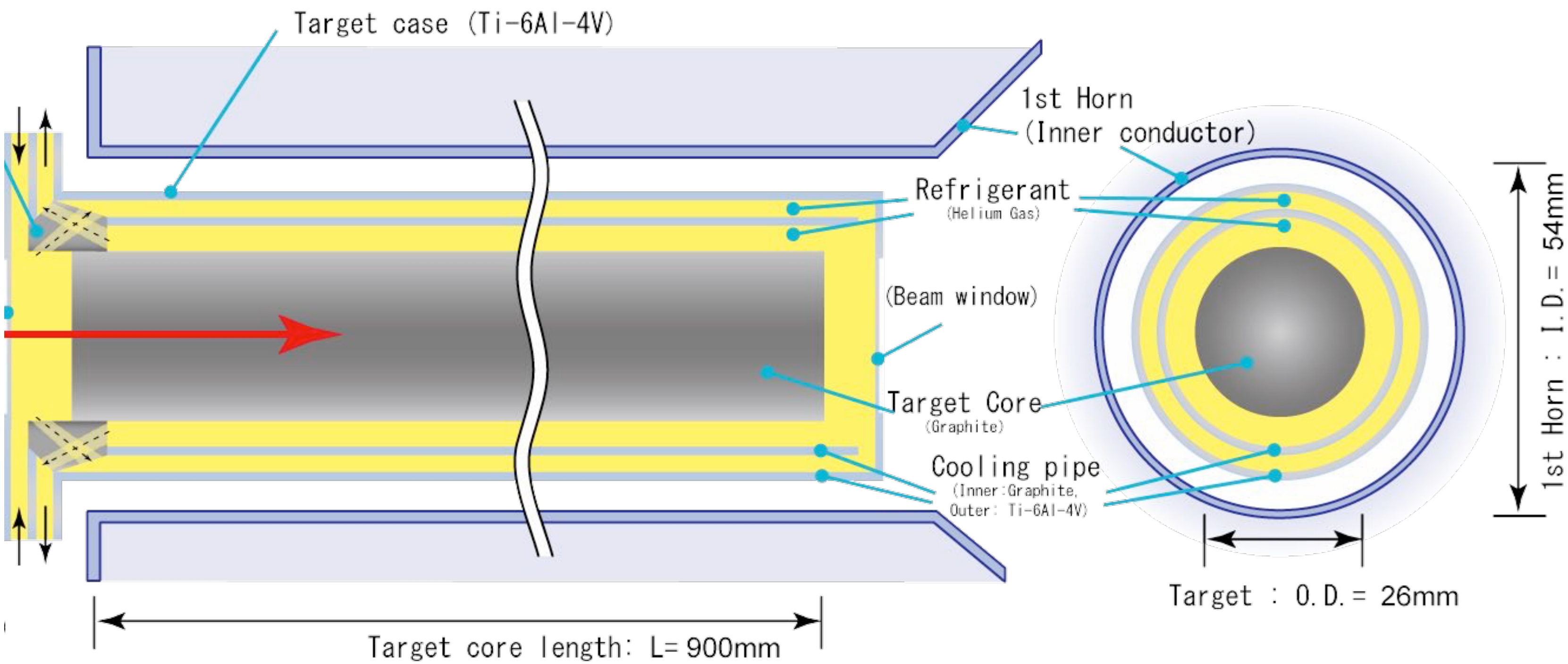
- Introduction of current system
- Upgrade for 1.3 MW beam power
- Vacuum insulated pipe replacing 1st heat exchanger
- Design of the vacuum insulated pipe
- Estimation of pressure drop at the vacuum insulated pipe
- Summary & prospects

**Q. Any useful input/feedbacks for LBNF?**

# Target

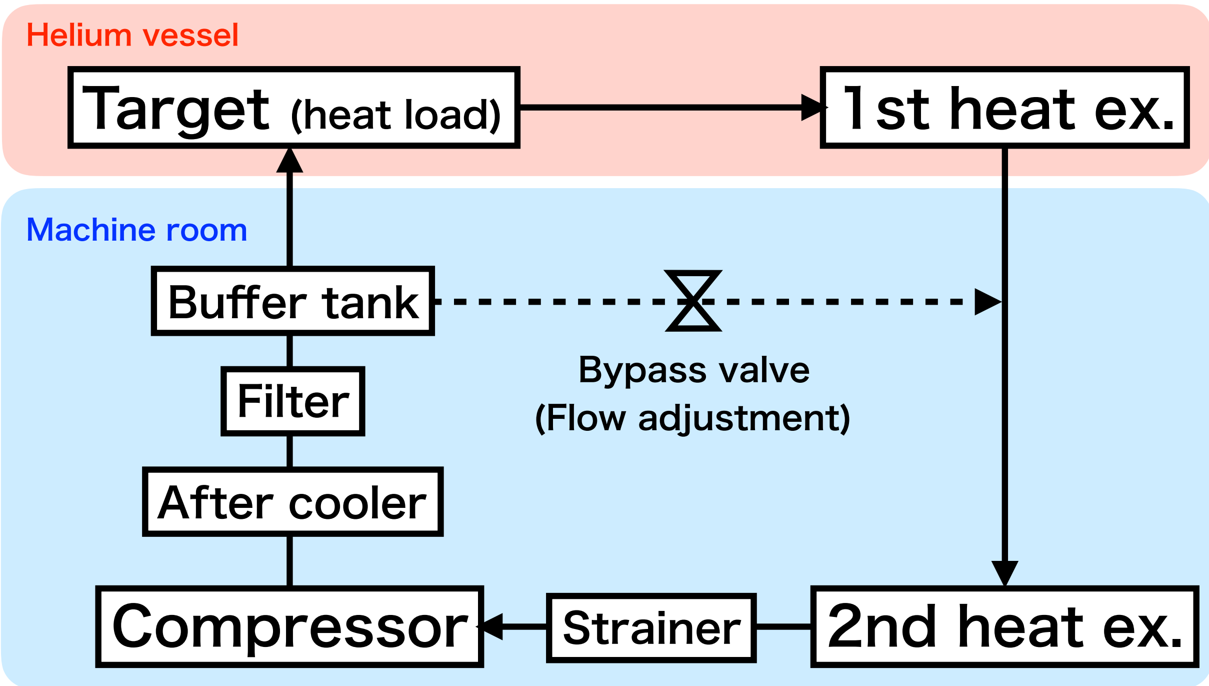
- Isotropic graphite (IG-430) with rod structure of 2.6 cmΦ & 90 cm long
- Inner graphite tube & outer tube (Ti-6Al-4V) for the Helium cooling
- Enable to detach from the 1st horn for maintenance

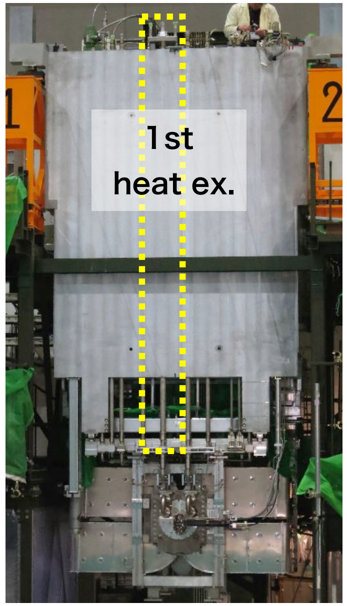


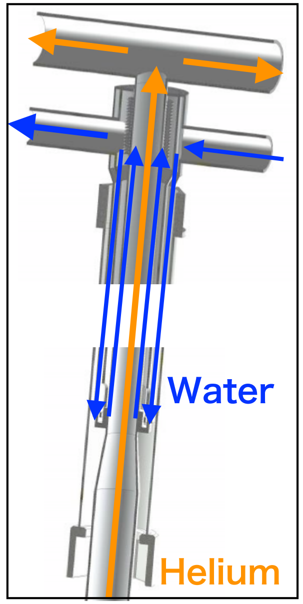


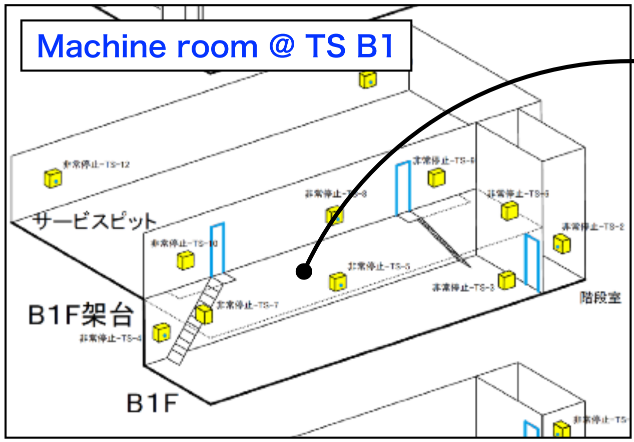
# Helium cooling system

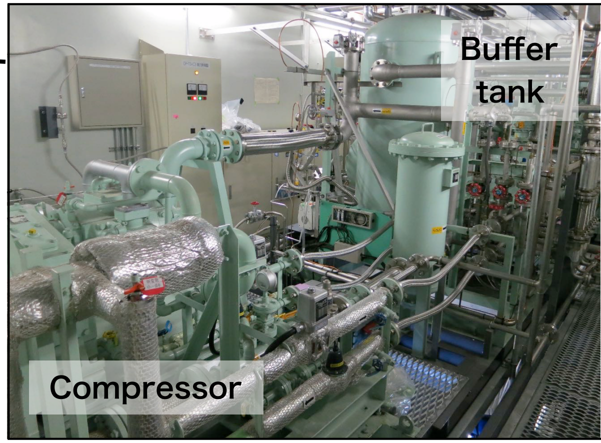
Helium gas from the target return to the compressor via 2 heat exchangers

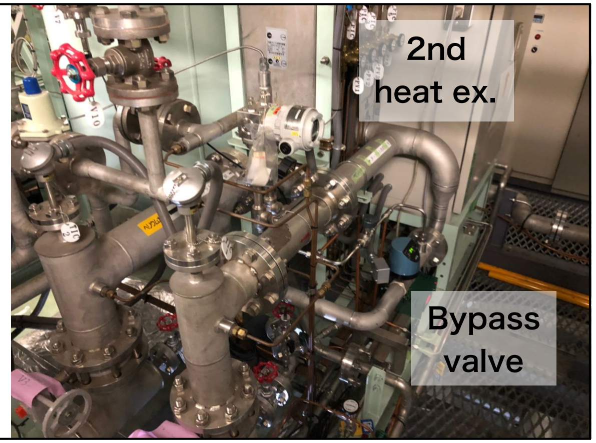


# Upgrade for 1.3 MW beam power

## Current target design

- Design intensity : 3.3 x $10^{14}$ ppp → 3.4 x $10^{14}$ ppp is no problem
- Cooling capacity :  750kW + 20% margin = 900 kW → Need upgrade

## Upgraded design

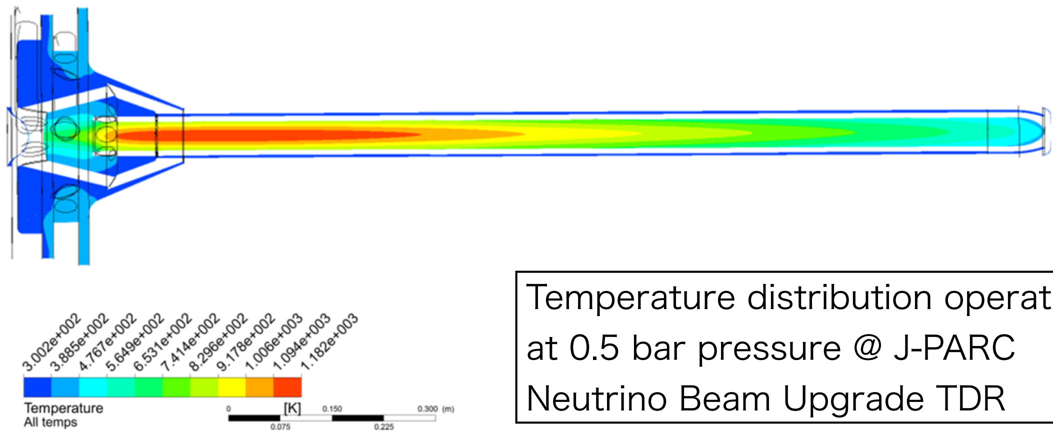
- High flow rate to accept x1.7 of heat load (24 kW @ 750 kW → 41 kW @ 1.3 MW)

## Requirement

- High pressure tolerance (“0.16 MPaG → 0.5 MPaG” is our target)

## Equipments to be upgraded

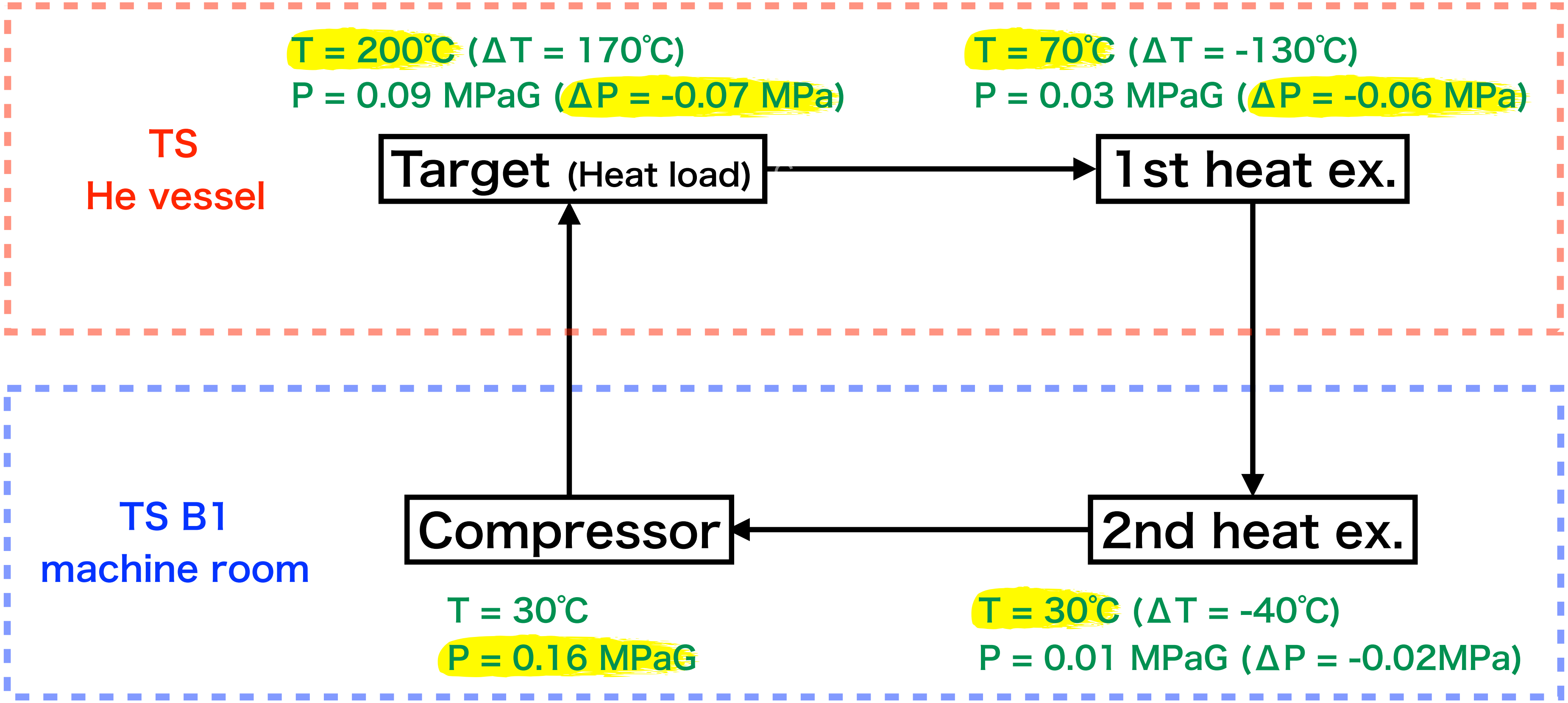
- 1st heat exchanger
- Compressor (< 0.9 MPaG)
- Pipes at service pit




Temperature distribution operating at 0.5 bar pressure @ J-PARC Neutrino Beam Upgrade TDR

# Current system

・Cooled by 1st (2nd) heat ex. to 70℃ (30℃) from 200℃ at the target

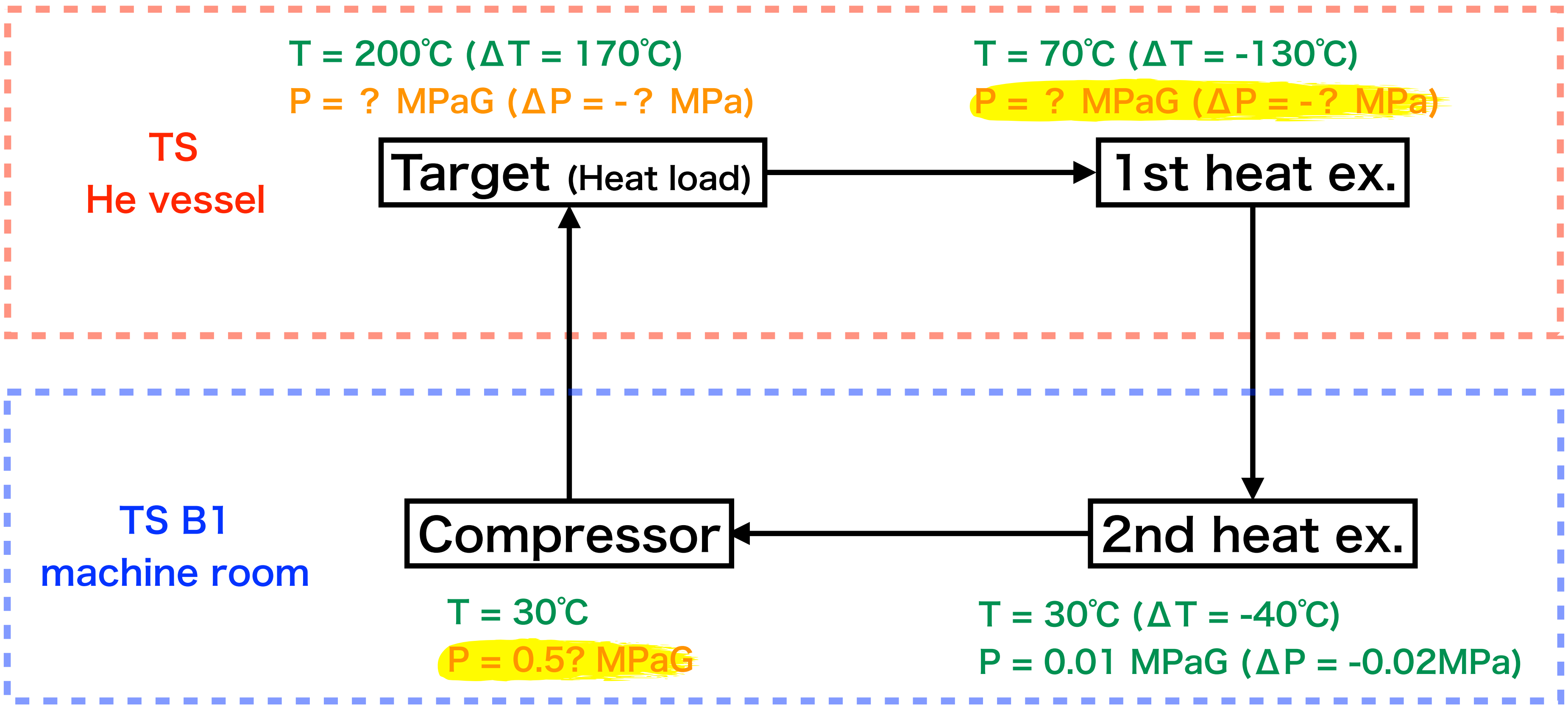



・Control pressure for the current compressor is 0.16 MPaG

・Comparable with sum of pressure loss in the target & 1st heat ex.

# Upgrades of cooling capacity for 1.3 MW

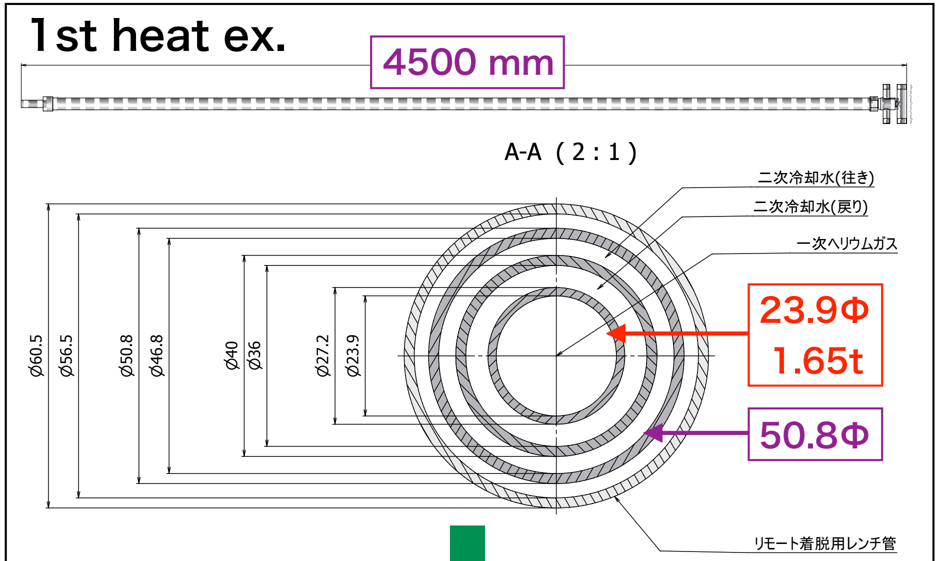
- Cooled w/ high flow rate by high pressure keeping helium temperature




Issues are in current 1st heat exchanger

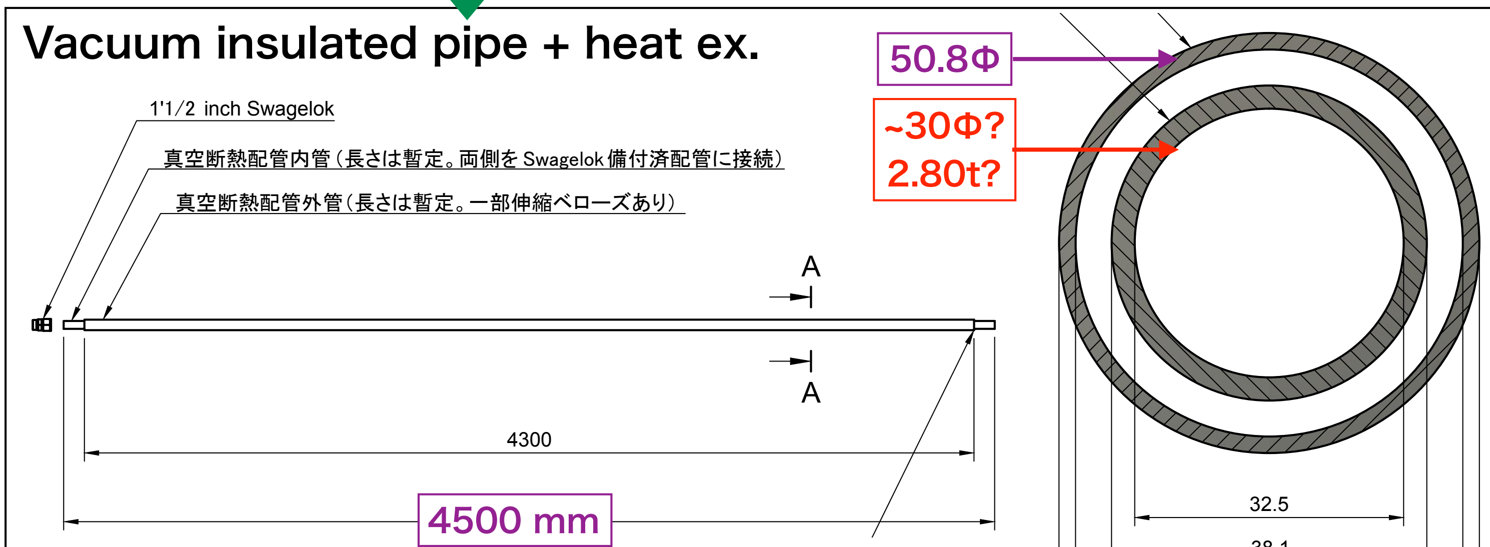
- Pressure tolerance is not enough after the upgrade
- High pressure drop requires higher discharge pressure by compressor

# An idea : Vacuum insulated pipe




- Thicker pipe thickness (5S to 10S)
  → Pressure resistance
- Triple to double co-axial pipe with heat insulated in the pipe
  → Low ΔP by bigger inner diam.
- Outer diameter is kept
- Same as 2nd heat ex. on the top

Nakadaira-san's idea




(*) Wrench tube for remote tightening is not drawn here

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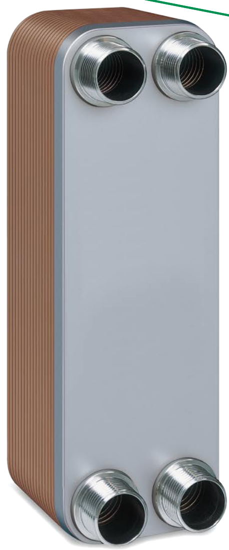


# Rough timeline

Need to upgrade by 2023 to accept > 1 MW

- Upgrade to vacuum insulated pipe during the horn exchange in 2021 JFY
- Upgrade of compressor/pipes in the machine room in 2023 JFY

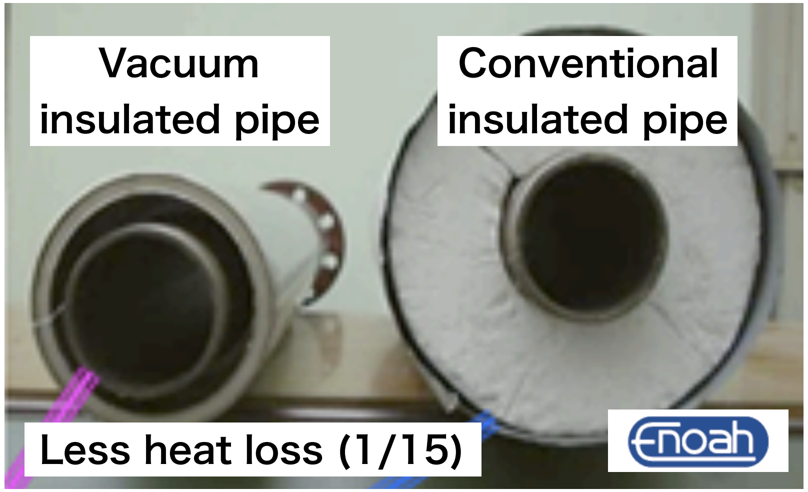
| JFY | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|
| Vacuum insulated pipe | Design & ΔP estimation | Prototyping & test<br>R&D of remote exchange method & new heat exchanger<br>Production | Installation | | |
| Compressor | | | Choice of new compressor baed on ΔP & production | | Installation |
| Pipes at the service pit | | | Design of new angle valve at the strainer & production | | Installation |

# Design of vacuum insulated pipe

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

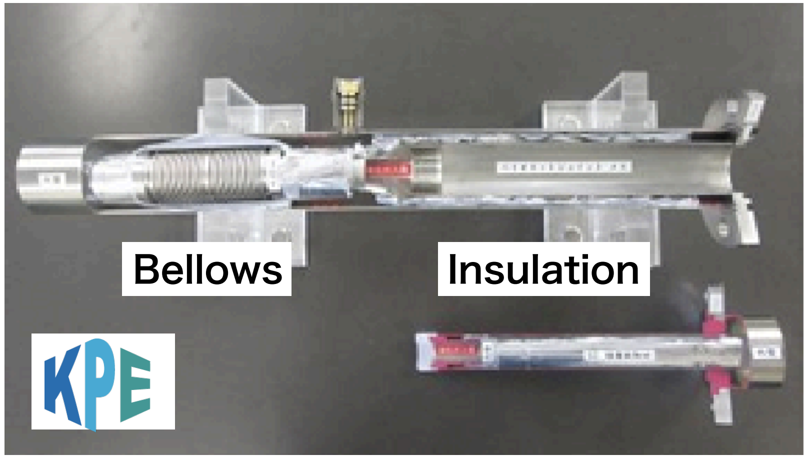
## Contacting to two companies

- Enoah Co., Ltd.
- KEIYO PLANT ENGINEERING Co., Ltd.




## Common design

- Two pipes keeping vacuum in between
- Insulation to reduce radiant heat
- Choice of pipe thickness & length
- Bellows inside
- Proven long-term operation
  (More than 7 years at least)




## Main differences

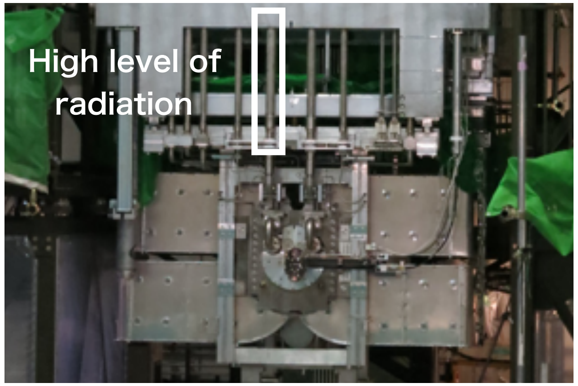
- Different materials in insulation
- Experience of high temperature

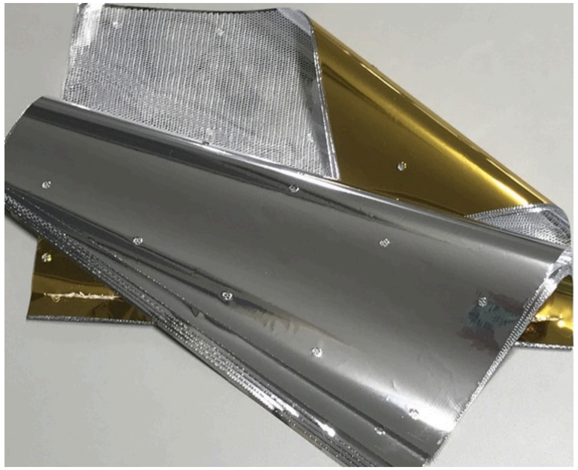
# Design choice

Those are related with heat insulation performance

**Materials for the heat insulation**

- Super insulation by Kaneka Co. Ltd. [KPE]
  - Al-evaporated polyimide film
    → Heat tolerance (~200 degree)
    → Radiation tolerance grade
    (but we need a valve for evacuation
    of out gas due to radiation damage)
- Al only insulation [Enoah]
  - No solvent is used. Adsorbent is placed



https://makesat.com/ja/products/multi-layer-insulation-mli-super-insulation-si

**Experience of high temperature**

- Degree of vacuum may degrade due to out gas
  → Can be mitigated by a baking process
- Experience to provide pipes with high temperature operation [Enoah]

# Current status of the design

**No critical issue is found for the upgrade**

- Asking for realistic design & quotation
- Planning to develop short prototype without bellows to test heat insulation performance
  → Any possible tests for LBNF?

**Estimation of pressure drop is ongoing in parallel**

- Important to know required specifications of the upgraded compressor
- FEA simulation is performed to see the impact of bigger diameter for the inner pipe
  → Any possible input/feedbacks for LBNF?

# ΔP by hand calculation @ Present

Darcy–Weisbach equation relates ΔP for steady flow in a circular pipe as:

$$\Delta P = \lambda \times \frac{l}{d} \times \frac{\rho \times u^2}{2} = -0.036 \text{ MPa}$$

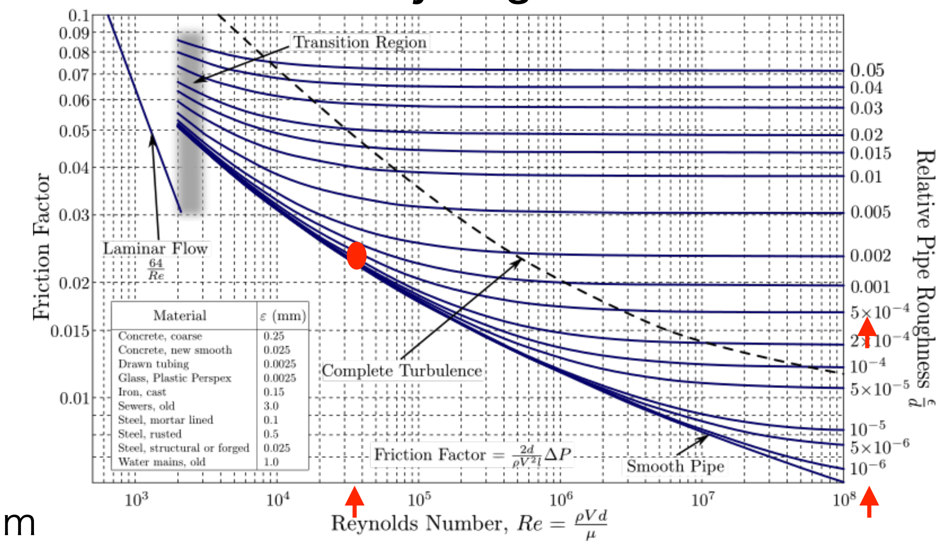
**Flow rate = ~32 g/s**

| | | | |
|---|---|---|---|
| $\lambda$ | Friction loss factor | 0.022 | From Moody diagram with Reynolds number & ε /d (See below) |
| l | Length | 4.5 m | From drawing |
| d | Diameter | 23.9 mm | From drawing |
| $\rho$ | Density of the fluid | 0.103 kg/m3 | @1 atm, 200˚C、From $\rho$ (K, P) = 0.1785 x 273.2/K x P/101.3 |
| u | Average flow velocity | 408.7 m/s | From u = Q/($\pi$*(d/2)$^2$) & Flow rate Q = 660 Nm$^3$/h |
| $\mu$ | Viscosity | 0.027 cP (=mPa・s) | @1 atm, 200˚C、From $\mu$ (K) = 0.0186 x (K/273.2)$^{2/3}$ |

**Details of friction loss factor**

- Calculated Reynolds number to know Laminar or turbulent flow
  $Re = \rho \times u \times d/\mu = 37263$
  where, $\mu$ = 0.027 cP (= mPa・s) at 1atm・200˚C is used
- If Re > 2000 in steady flow, it becomes turbulent flow.
  Colebrook equation gives Darcy's friction loss factor.
  <u>Conventionally, Moody diagram from the equation is used.</u>
  <u>The $\lambda$ can be estimated with Re & roughness</u>
- Here, $\lambda$ is obtained assuming no roughness.
  Relative pipe roughness (ε /d) is $\epsilon/d = 0.001252$
  assuming seamless SS pipe without any degradation.
  Then $\lambda$ = ~0.025 (+20%) is obtained from the right diagram

**Moody diagram**

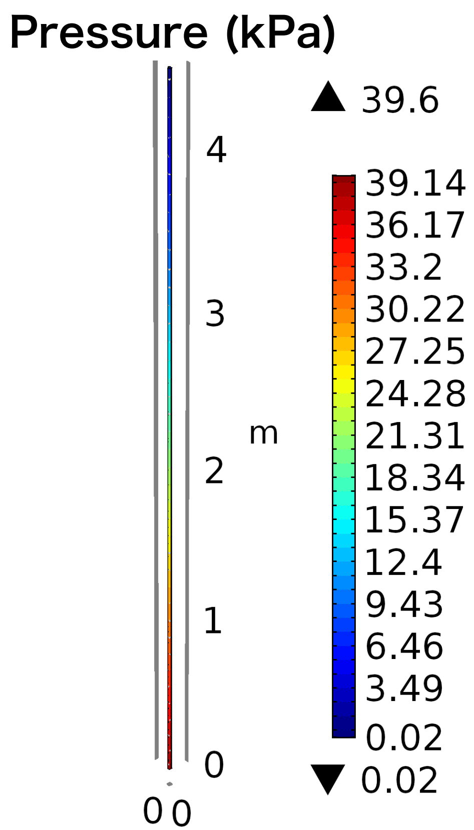


# ΔP estimation by COMSOL @ Present

**Simulation input**

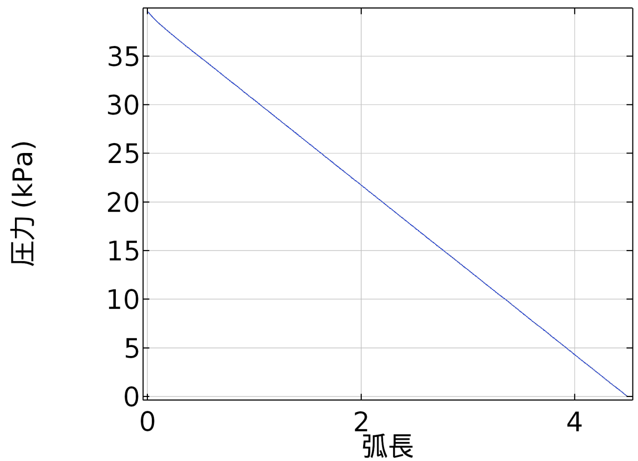
Flow rate
= ~32 g/s

- Physics：Turbulent flow
- Shape：d = 23.9 mm、l = 4.5 m
- Boundary：Bottom to enter, Top to exit
  x-sectional average flow velocity
  $u_{in}$ = 408.7 m/s
- Material：Fluid density $\rho$ = 0.103 kg/m$^3$
  Viscosity coefficient $\mu$ = 0.027 cP
  @ 1 atm・200℃
  (∗) No roughness applied




**Simulation result**

- ΔP = -0.04 MPa at 1 atm is estimated
  → Comparable with the hand calculation
  → How about ΔP in high pressure?

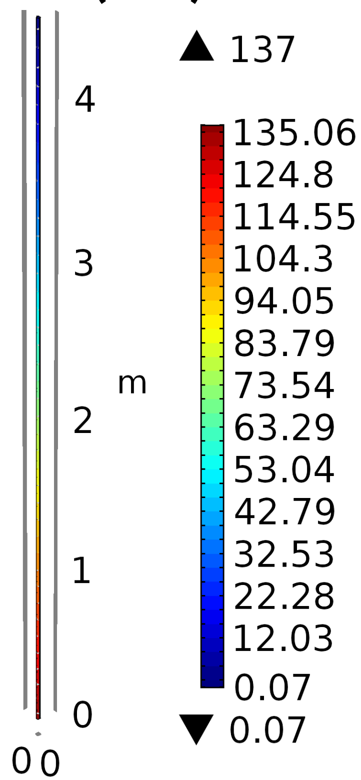


# ΔP estimation by COMSOL @ High P

**Simulation input**

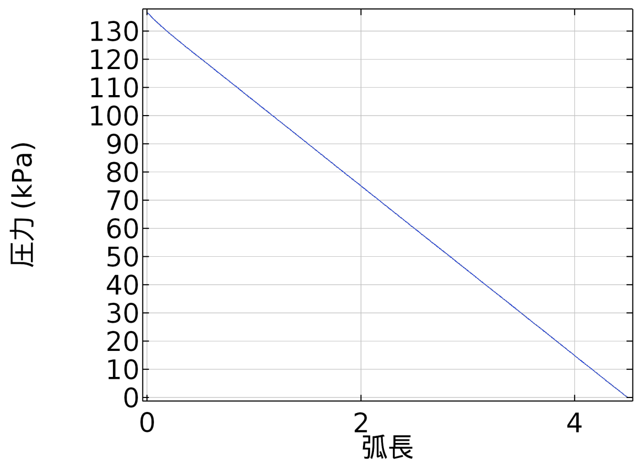
Flow rate = ~60 g/s

- Physics：Turbulent flow
- Shape：d = 23.9 mm、l = 4.5 m
- Boundary：Bottom to enter, Top to exit
  x-sectional average flow velocity
  $u_{in}$ = 408.7 m/s
- Material：Fluid density $\rho$ = 0.515 kg/m$^3$
  Viscosity coefficient $\mu$ = 0.027 cP
  @ 5 atm・200℃
  (∗) No roughness applied

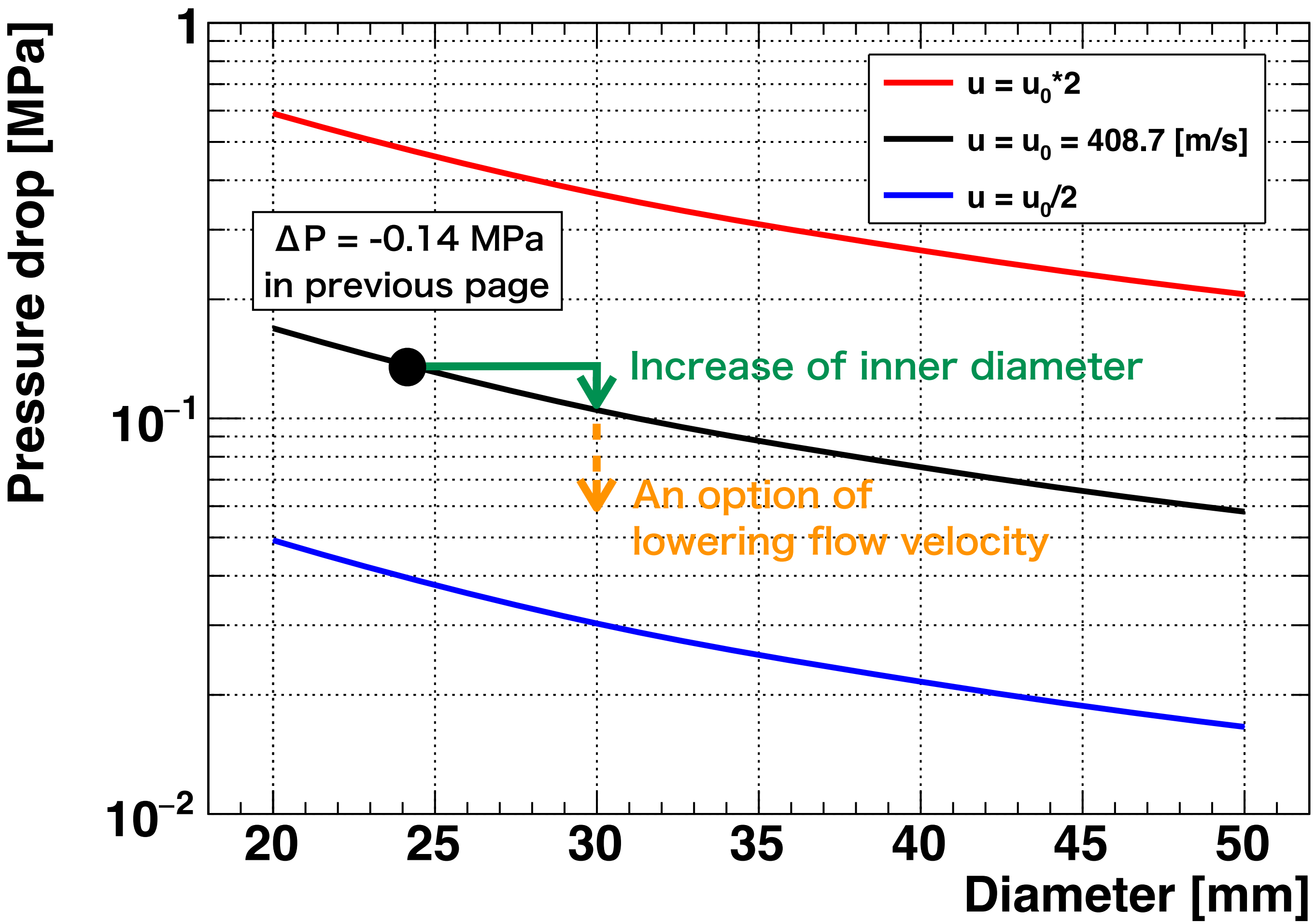



**Simulation result**

- ΔP = -0.14 MPa at 5 atm is estimated
  → How about different d & $u_{in}$?



# If different inner diameter & flow velocity




Parameters related with the pressure loss is roughly understood

→ Contacting to a company of vacuum insulated pipe for more realistic simulation w/ expected flow rate & downstream pressure

# Summary & prospects

**Target Helium cooling system will be upgraded for 1.3 MW**

- Idea is to provide high flow rate by increasing pressure
- Vacuum insulated pipe is newly used, replacing 1st heat ex.

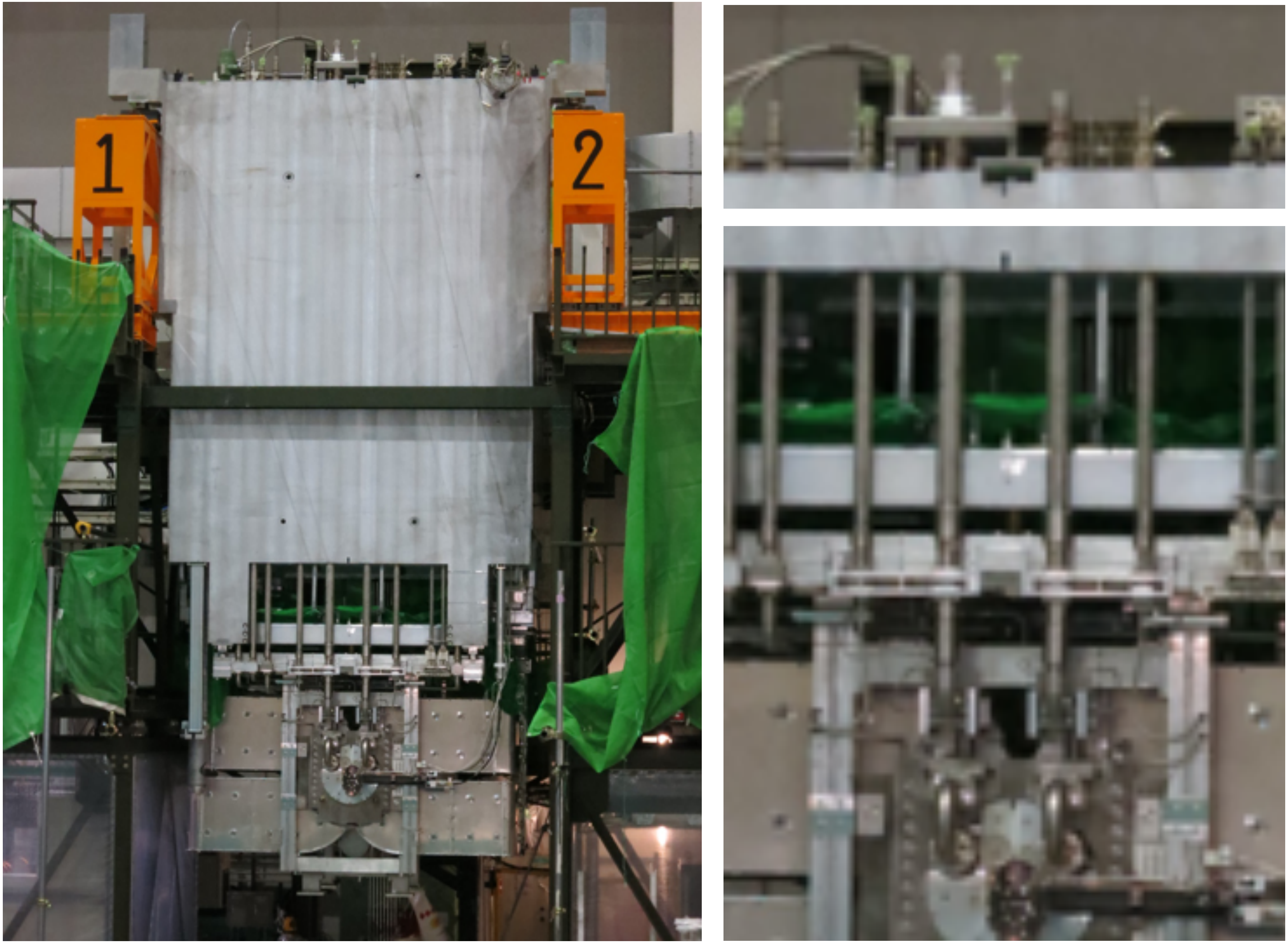
**Status**

- Designing the vacuum insulated pipe with two companies
- Initial estimation of pressure drop was performed

**Prospects**

- Prototyping & heat insulation tests ASAP
- R&D of exchange method & new heat exchanger
  toward upgrade of the vacuum insulated pipe in 2021
- Upgrade of compressor & angle valve is foreseen in 2023

# Backup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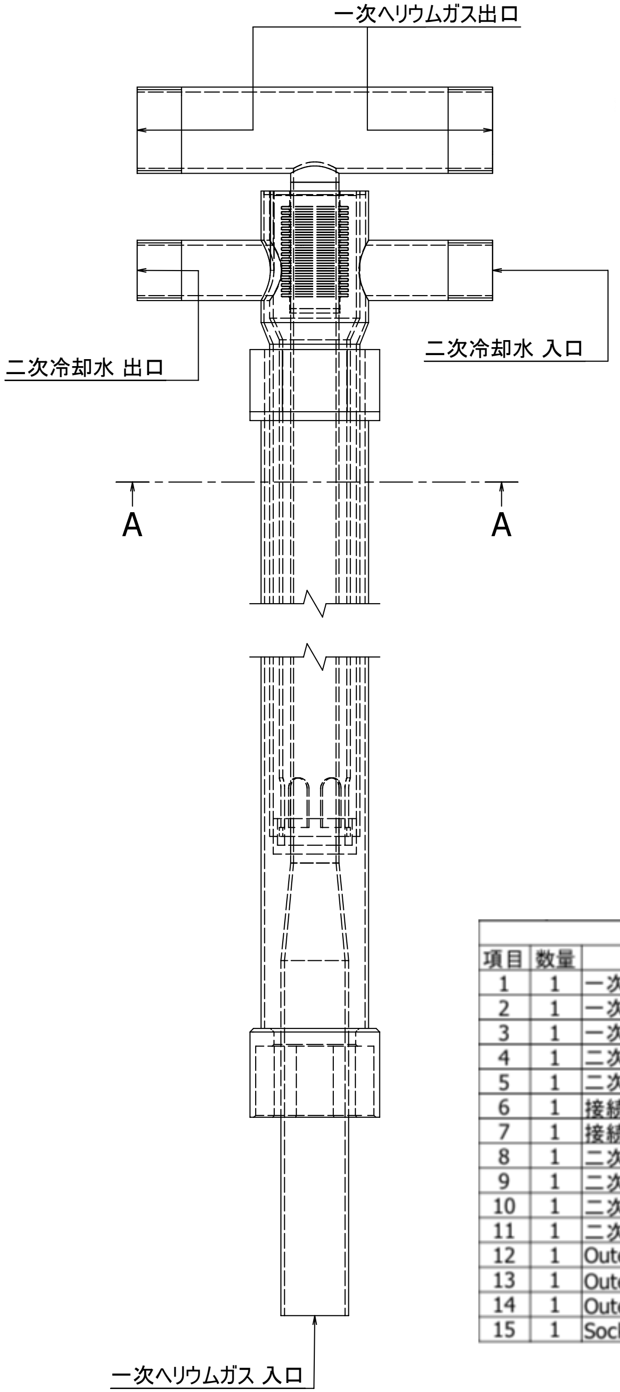
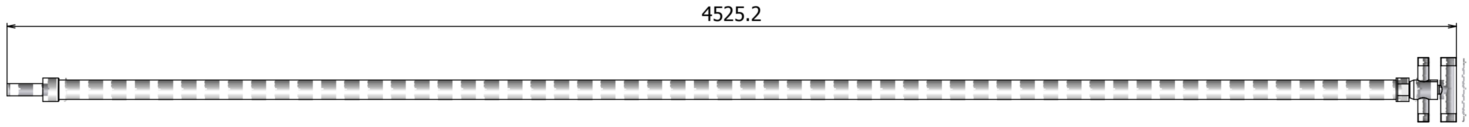
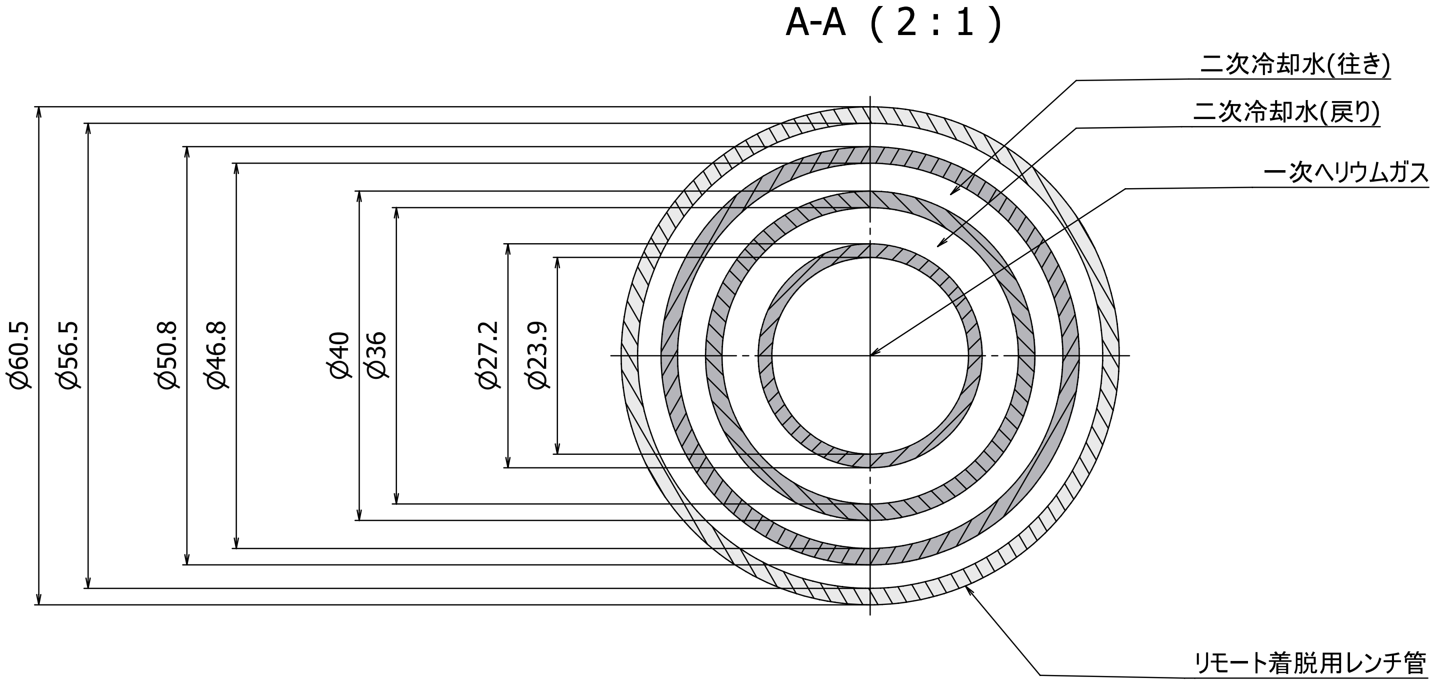
# Details of 1st heat exchanger




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

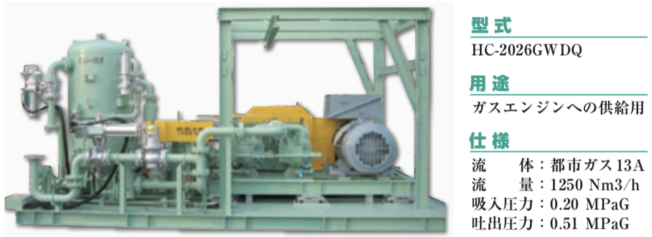
- マイテック (株) 製
- 一次ヘリウムガス系の耐圧 0.3 MPaG
- 二次冷却水系の耐圧 0.5 MPaG
- 最高使用温度 200℃

# 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

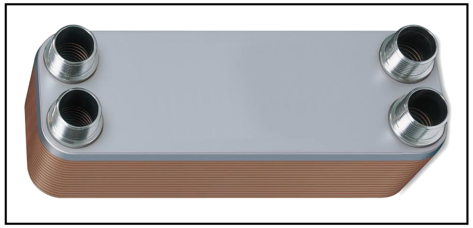



### 2nd heat exchanger

・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)