Resent Status on Cryogenics for J-PARC Neutrino SC Magnet

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Contents

- Introduction
- System overview and Design of the Cryogenics
- Quench Relief Valve
- Elastomer Seal for the Cryostat
- Summary and Schedule

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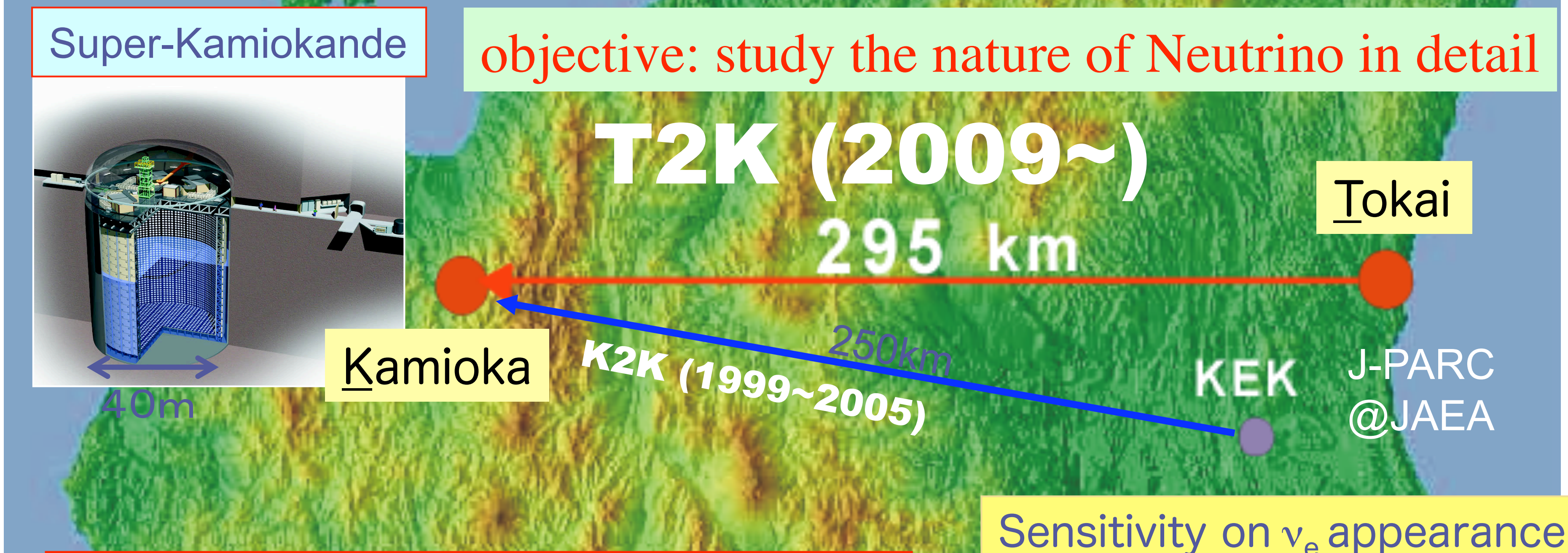
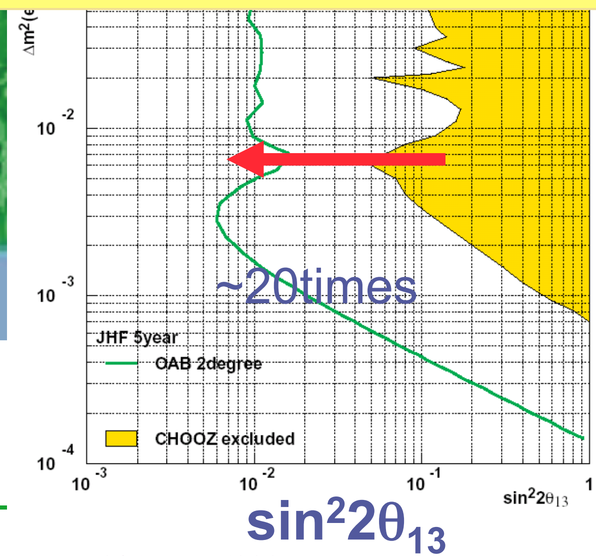
Neutrino physics at J-PARC
Tokai-to-Kamioka (T2K) Long Baseline
ν Oscillation Experiment

objective: study the nature of Neutrino in detail



Sensitivity on ν_e appearance



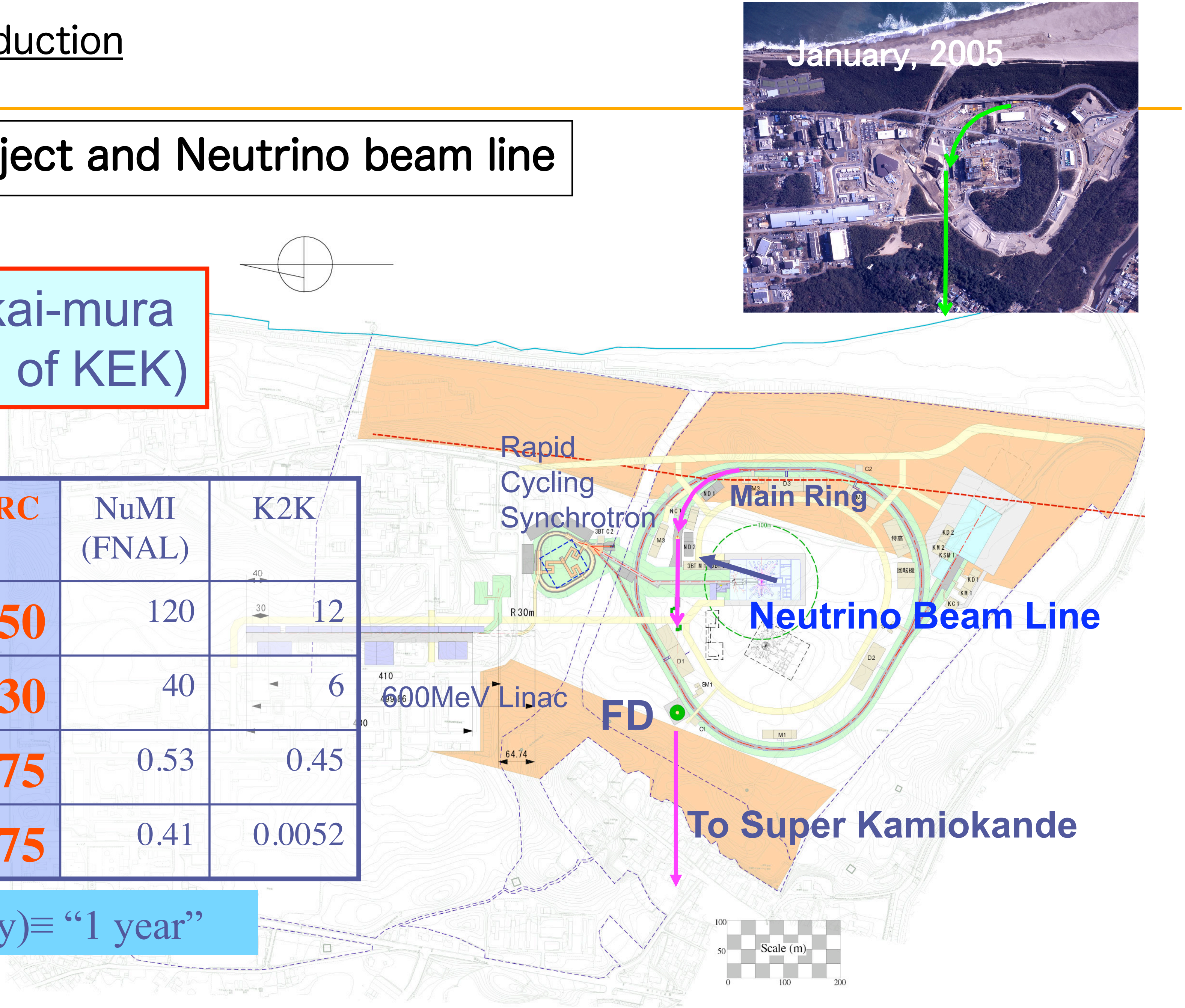
- Off-axis sub-GeV ν_μ beam from J-PARC 50GeV-PS
- ~3000 ν_μ CC int./yr (w/o osc.)
  ν_e appearance discovery
  ν_μ disapp. presice meas.
- 5 year construction
- Start experiment in 2009.

J-PARC project and Neutrino beam line

JAEA@Tokai-mura
(60km N.E. of KEK)

	JPARC	NuMI (FNAL)	K2K
E(GeV)	**50**	120	12
Int.(10^{12}ppp)	**330**	40	6
Rate(Hz)	**0.275**	0.53	0.45
Power(MW)	**0.75**	0.41	0.0052

10^{21}POT(130day)≡ “1 year”



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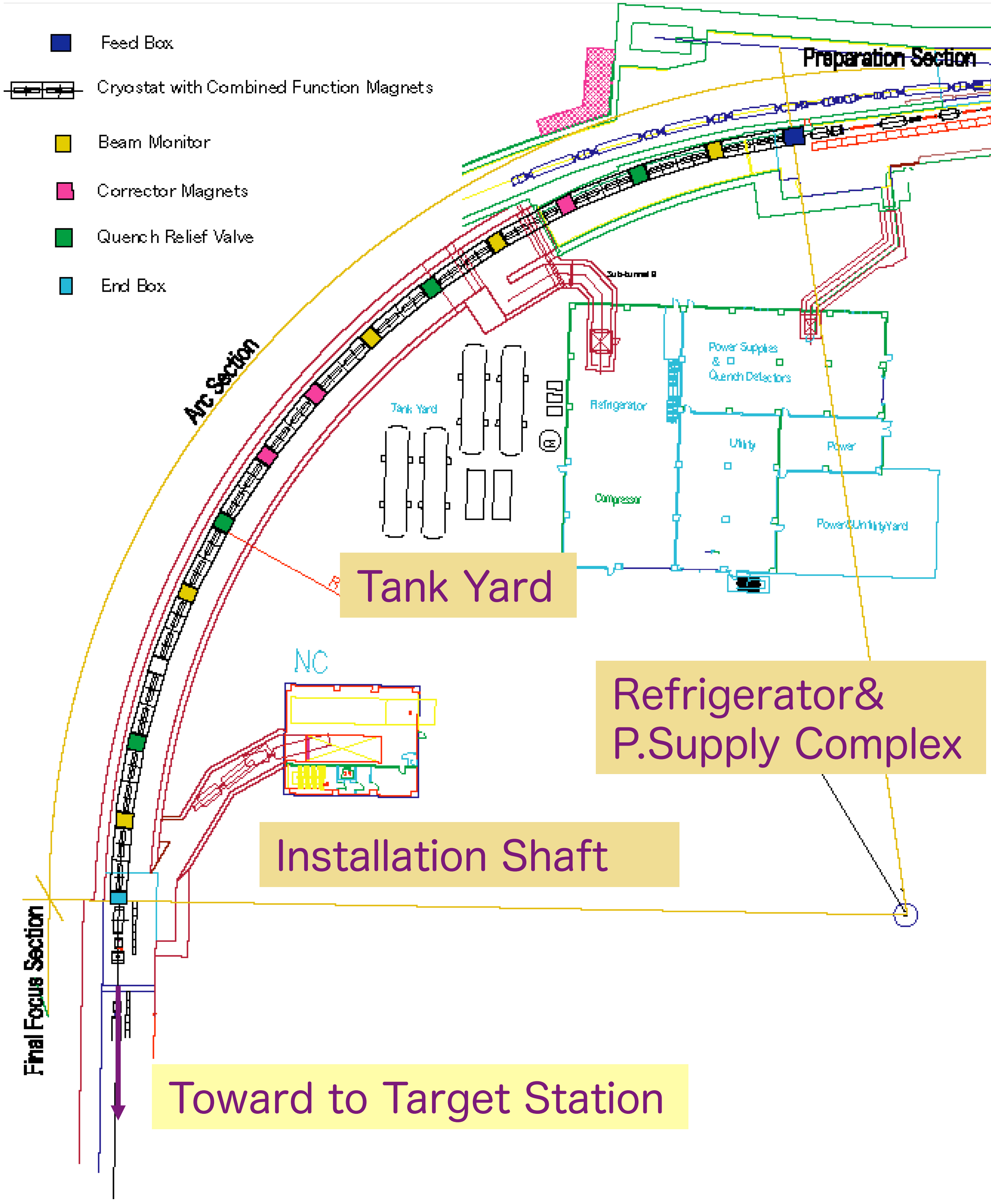
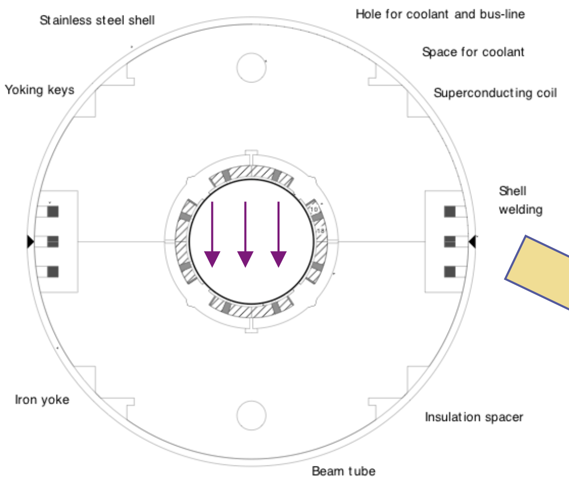


System Overview

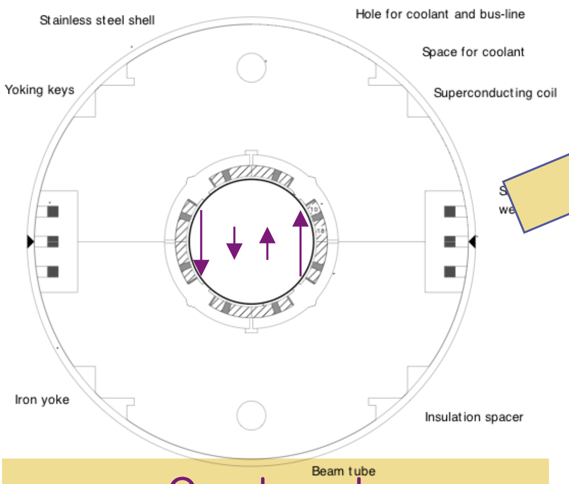
- 28 SCFM*s
  - Dipole 2.6 T
  - Quad 18.6 T/m
  - Length 3.3 m
  - 2 in 1 Cryostat
  - Total Stored Energy: 10MJ (50GeV)
- 13 interconnects
  - 5 beam monitors
  - 3 correctors
  - 4 quench valves
  - 1 none

*SCFM: Superconducting Combined Function Magnet

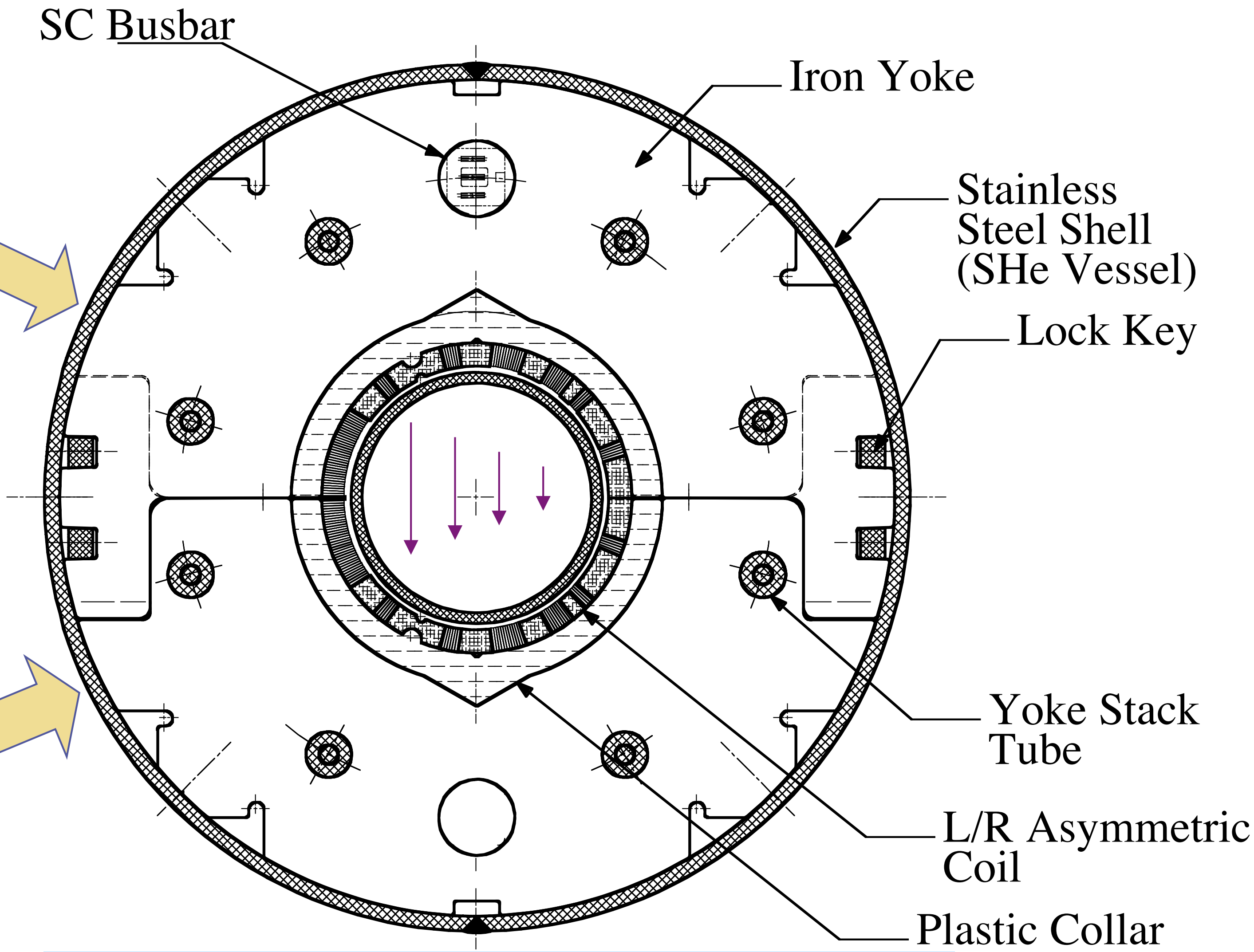
Super Conducting Combined Function Magnet



Dipole (Bending)

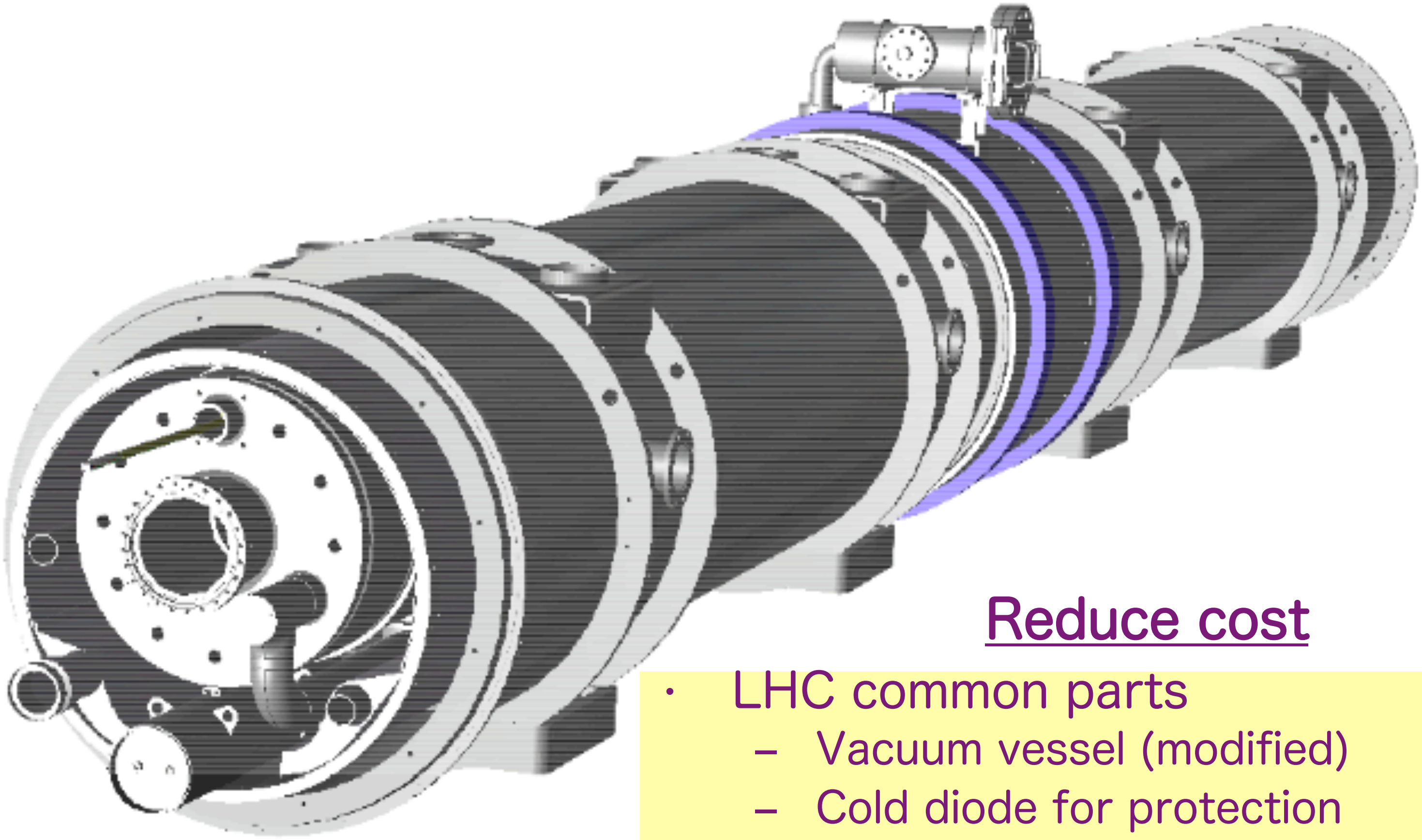


Quadrupole
(Focusing & De-focusing)



Dipole/Quadrupole Combined
Bending + Focusing (De-focusing)

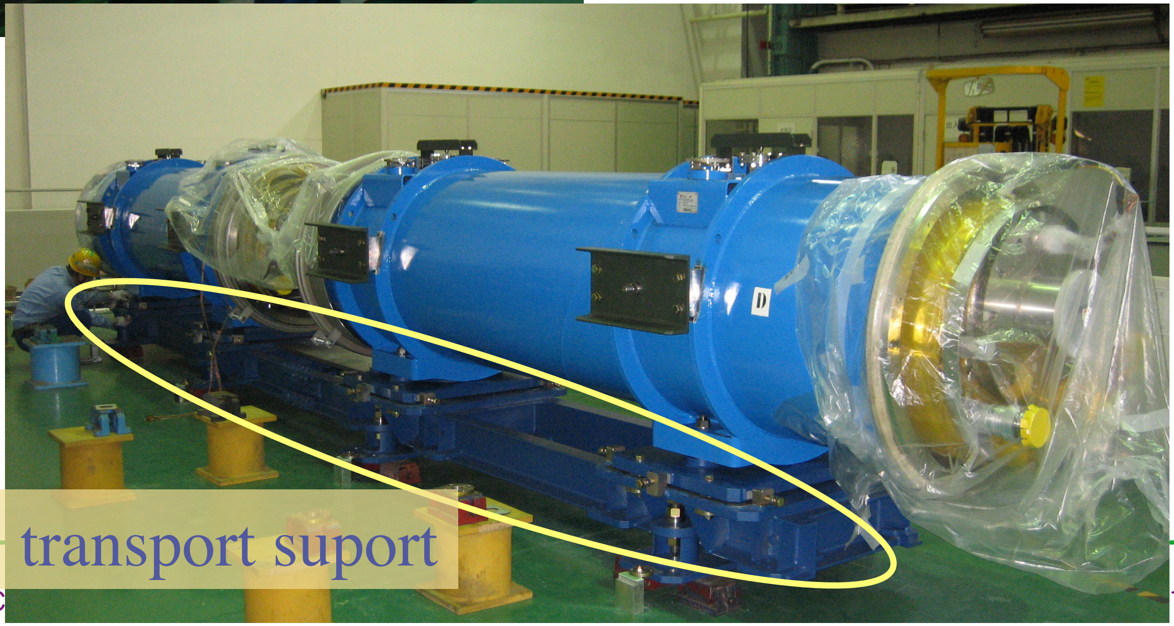
Structure of a Cryostat for SCFM



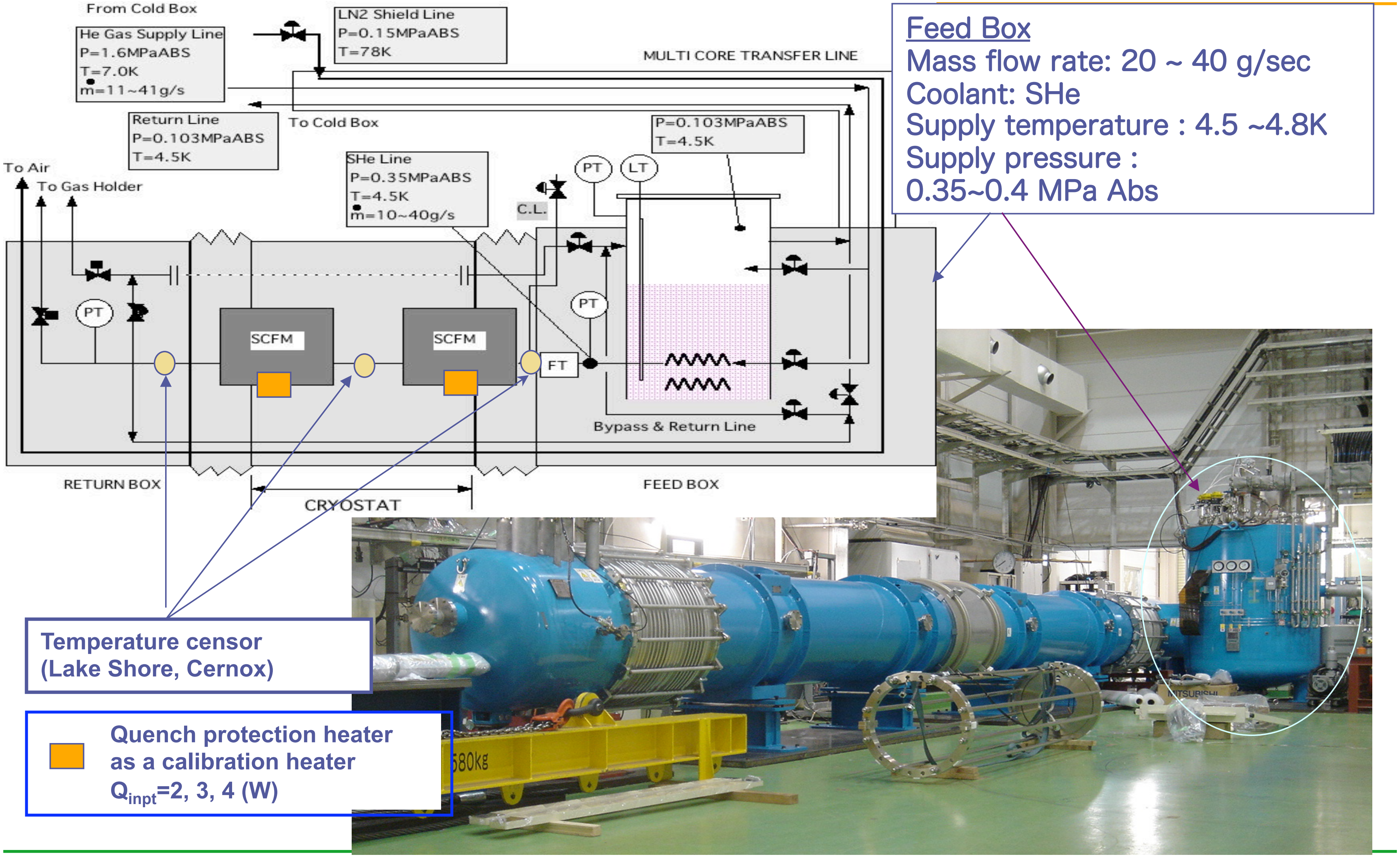
Reduce cost

- LHC common parts
  - Vacuum vessel (modified)
  - Cold diode for protection
  - Support post
  - Shield bottom tray (modified)
  - Connecting Sleeve
- 2 magnets assemble with 1 cryostat
  - F & D magnets (doublet optics)

Cryostat Assembly



Horizontal Test Bench with the Cryostat

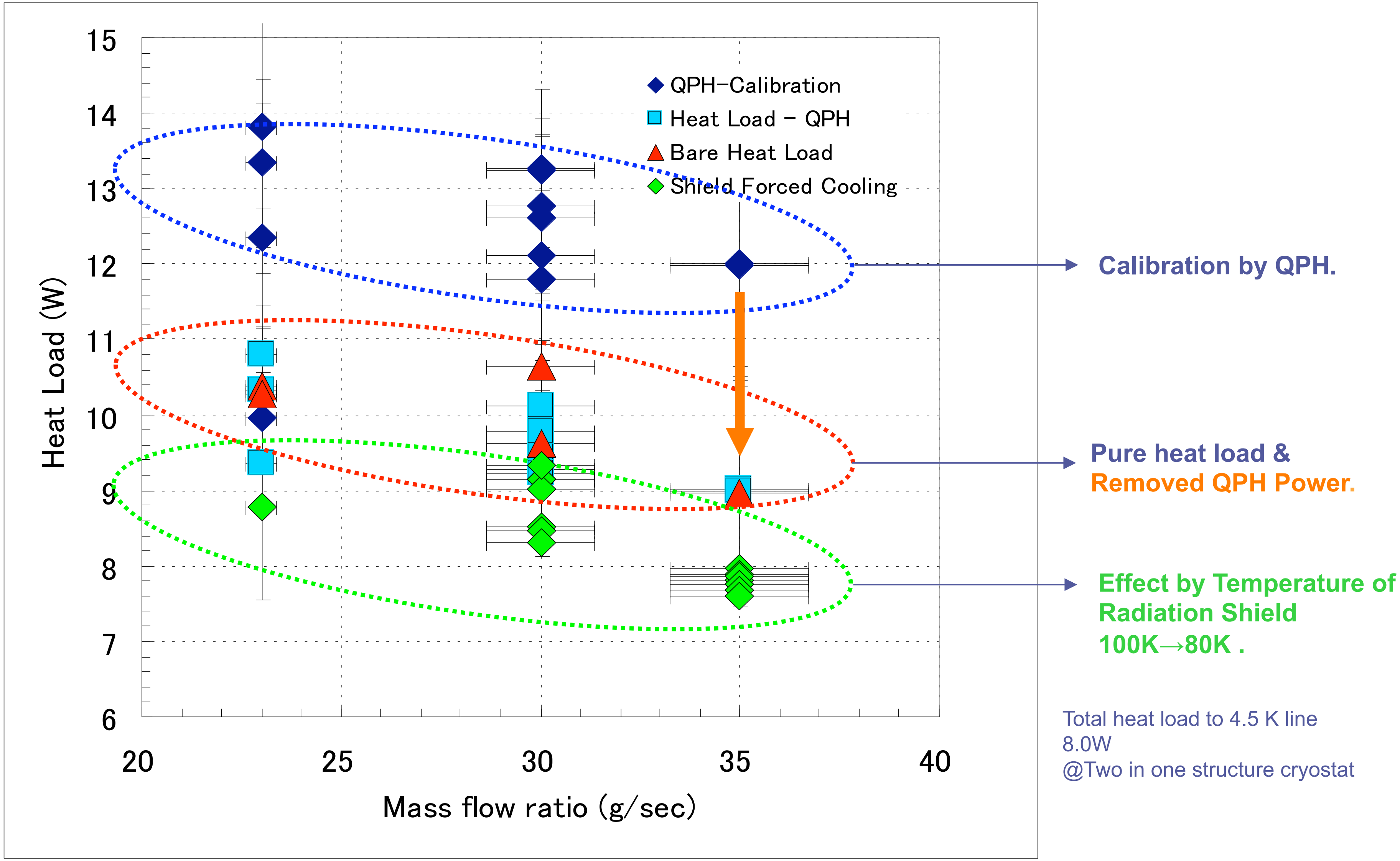


Feed Box
Mass flow rate: 20 ~ 40 g/sec
Coolant: SHe
Supply temperature : 4.5 ~4.8K
Supply pressure :
0.35~0.4 MPa Abs

Temperature censor
(Lake Shore, Cernox)

🟧 **Quench protection heater**
as a calibration heater
Q_{inpt}=2, 3, 4 (W)

Heat Load of the Cryostat



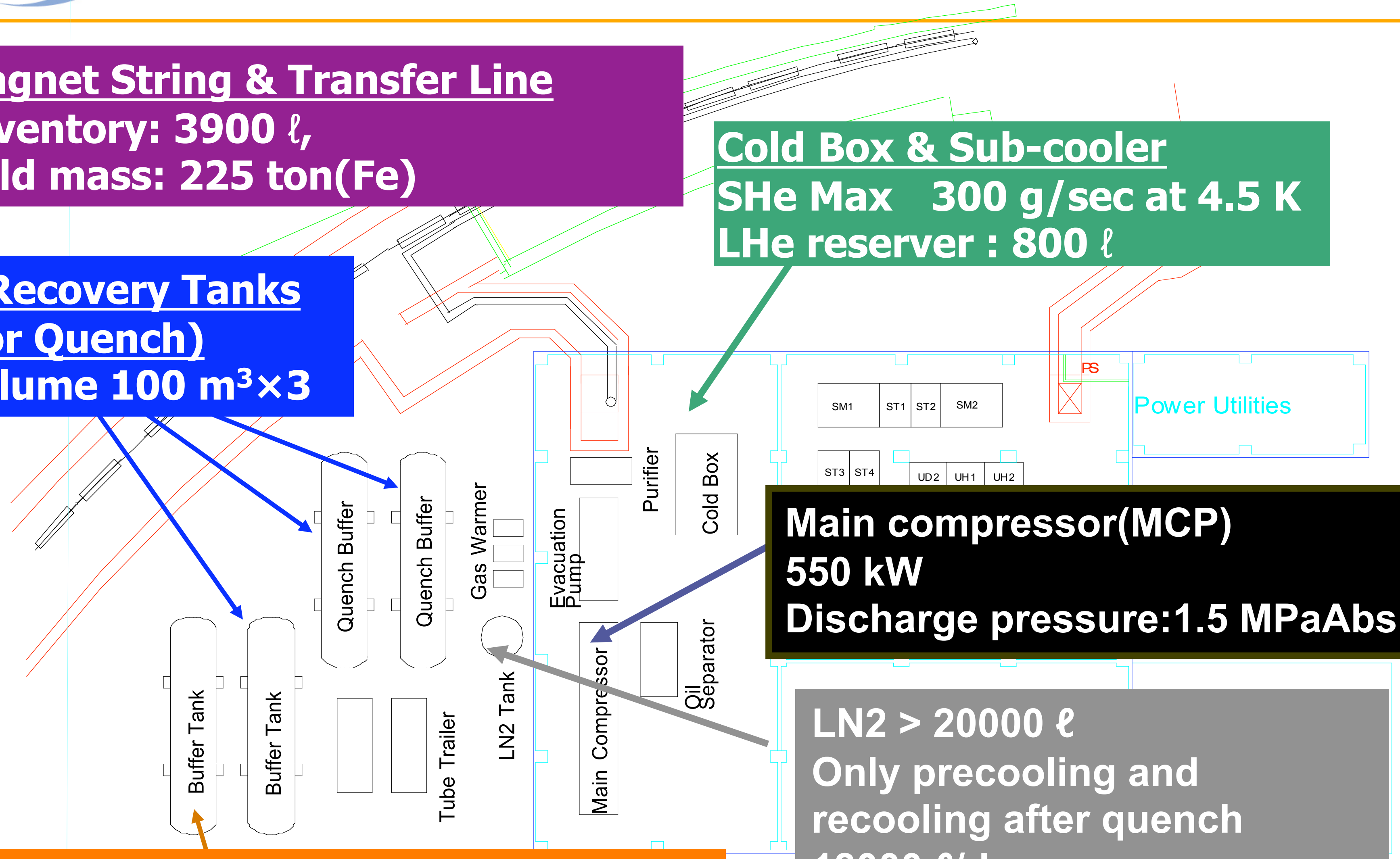
Calibration by QPH.

Pure heat load &
Removed QPH Power.

Effect by Temperature of
Radiation Shield
100K→80K .

Total heat load to 4.5 K line
8.0W
@Two in one structure cryostat

Layout of Cryogenic Components



Magnet String & Transfer Line
Inventory: 3900 ℓ,
Cold mass: 225 ton(Fe)

Cold Box & Sub-cooler
SHe Max 300 g/sec at 4.5 K
LHe reserver : 800 ℓ

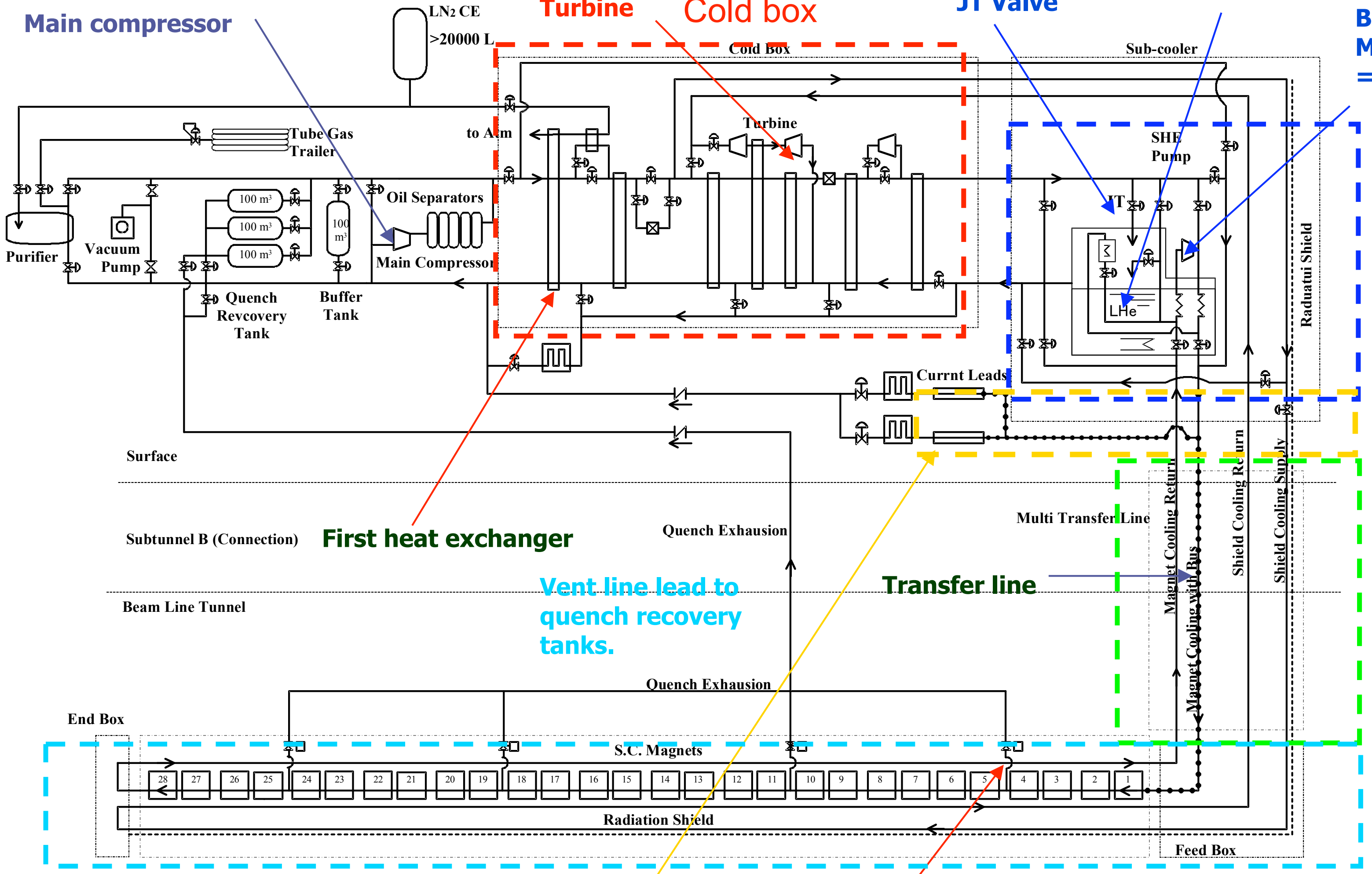
3 Recovery Tanks
(for Quench)
Volume 100 m³×3

Main compressor(MCP)
550 kW
Discharge pressure:1.5 MPaAbs

LN2 > 20000 ℓ
Only precooling and recooling after quench
18000 ℓ/day
For first heat exchanger (cold box)

Buffer Tank for Main Compressor (steady state)
Volume 100m³×1

Conceptual Flow Diagram



Main compressor

Turbine

Cold box

JT Valve

LHe reserve

SHe pump made by Burber-Nicholes
Max mass flow rate
=300 g/sec at 4.5 K

Sub-cooler

Current lead box

Transfer line

First heat exchanger

Vent line lead to quench recovery tanks.

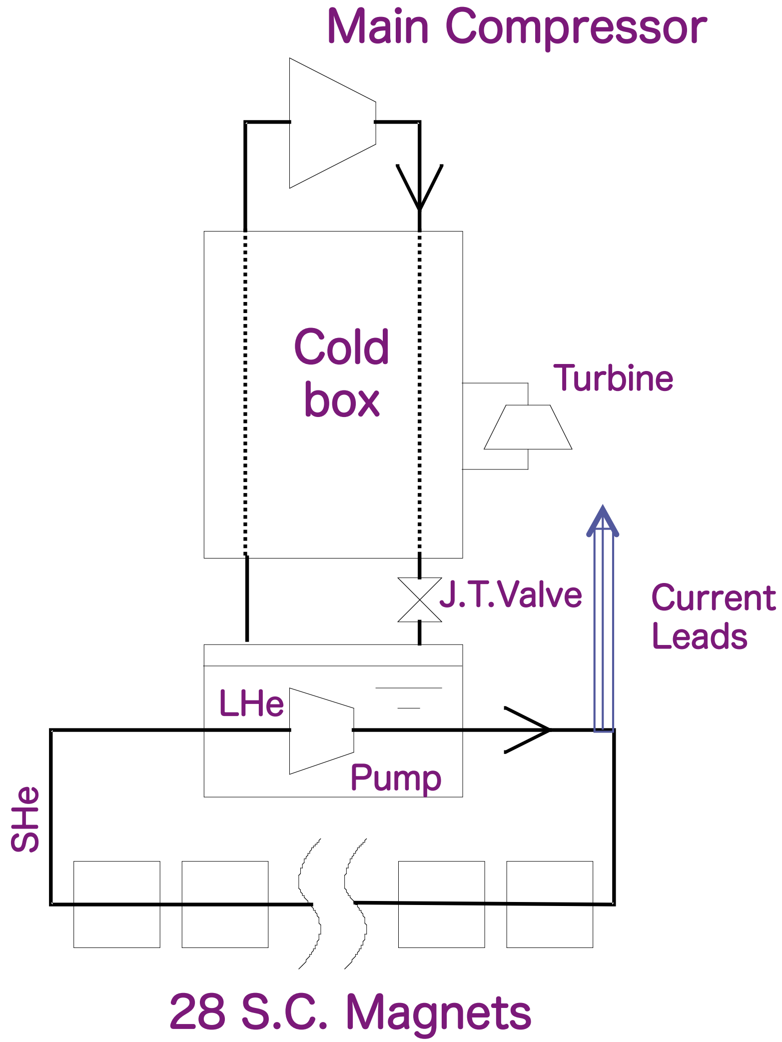
Transfer line

Current lead
Forced flow cooling

Quench relief valves
4 quench relief valves are installed

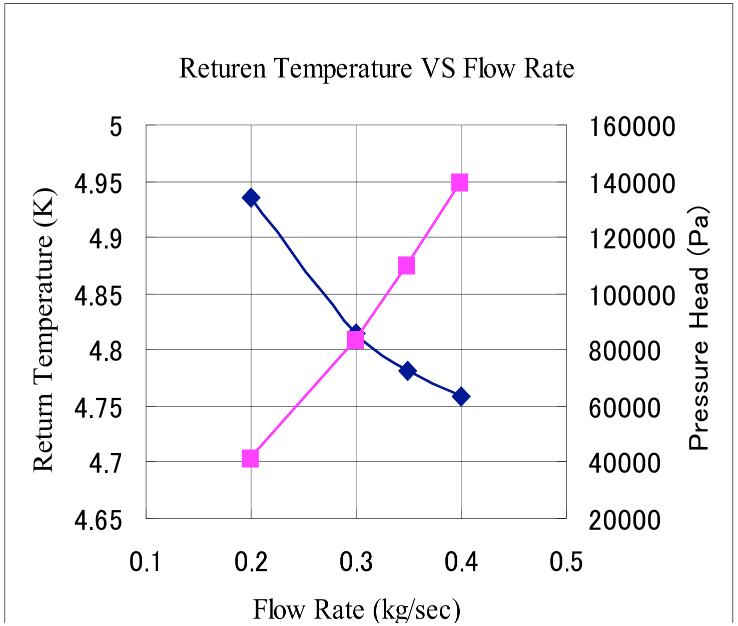
Required Cooling Capacity

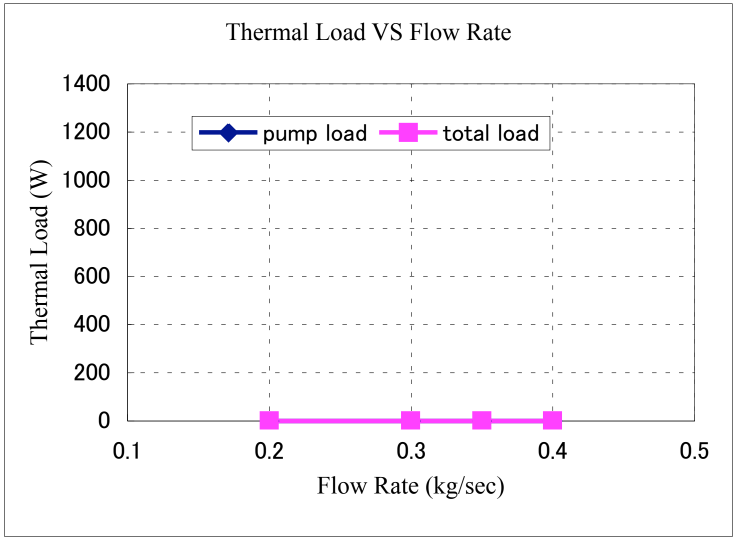
SHe Flow Rate	max 300 g/s
SHe Condition	0.4 MPa(A), 4.5 K
SHe Return	4.9 K
Thermal Load to SHe Flow	410 W
Pressure Head of SHe	85 kPa
Current Lead cooling gas	1.1 g/s (1 pair)
Shield Temperature	60～100 K
Shield Cooling	Cold Helium Gas
Thermal Load to Shield Line	1710 W
Shield Cooling Gas Condition	Not specified
LN2 usage	Only Pre-cooling and re-cooling after quench
Pre-cooling duration	< 20 days
Re-cooing duration	<6 hours (30GeV operation)



Schematic diagram of SHe circulation system

Required Cooling Capacity - Estimation





$$\Pr essureHead = f\frac{L}{D_h}\frac{\rho u^2}{2}$$

f : Friction Coefficient, L : Length,
D_h : Hydraulic Diameter, u : Flow Velocity

$$
\begin{aligned}
&TotalLoad = \\
&[Mag \,\&\, Trans.T + 20\%] \\
&+[PumpLoad] \\
&+[Sub-coolerLoad : 143W]
\end{aligned}
$$

$$PumpLoad = \frac{\Delta P \dot{M}}{\rho \eta}$$

Expected Operational Flow Rate :
300 g/s ◊ Pump Load : < 300 W
Mag. Temp. : ~ 4.8 K

Mass-flow rate is controlled to be 300 g/s at the maximum.

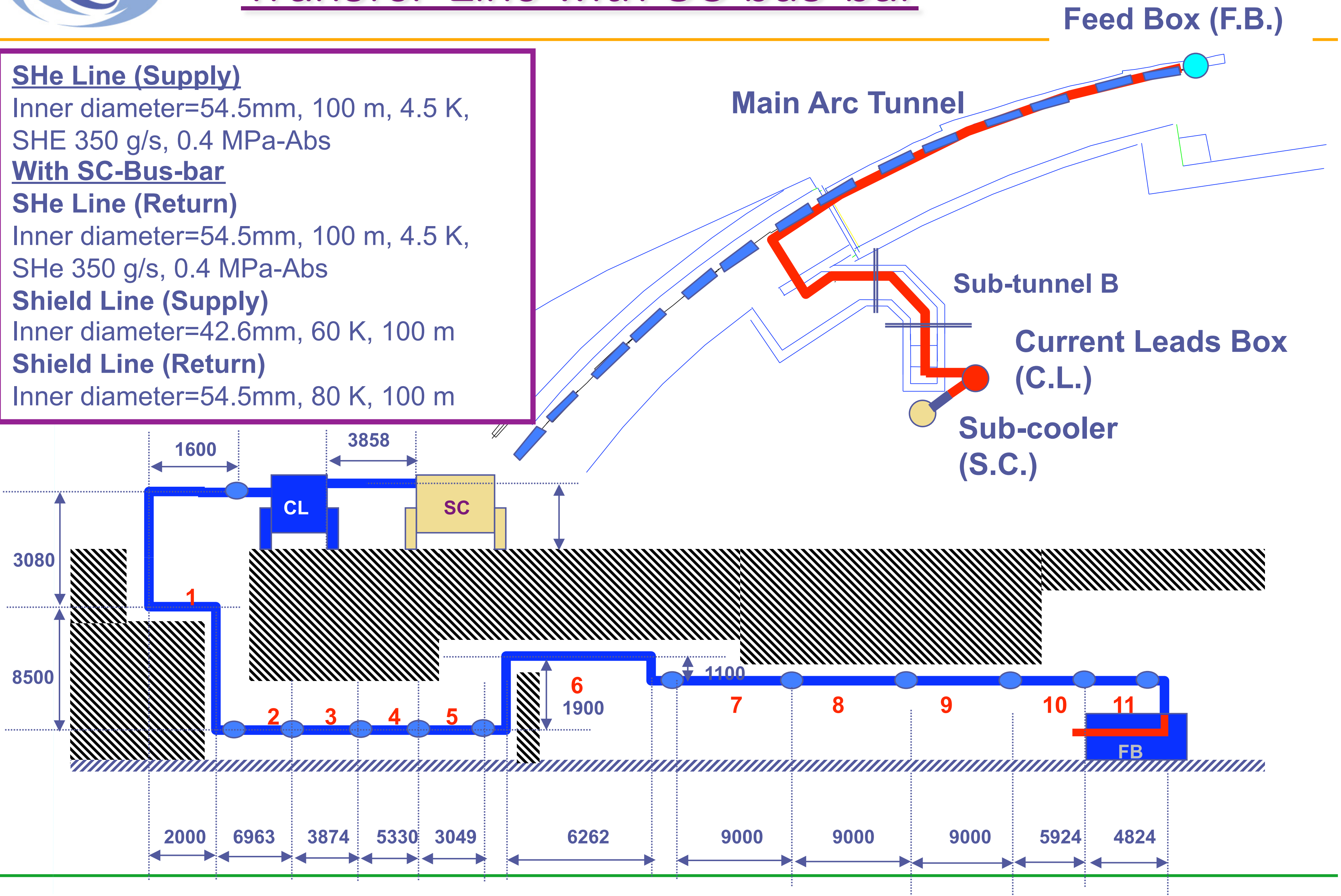
Required Refrigeration Capacity – Design by Contractor

		Thermal Load @4.5 K Level	Thermal Load @shield Level
KEK Requirement	Magnet & Transfer Line	410 W + 1.1 g/s	1710 W
	SHe Flow conditions	Max 300 g/s, 4.5 K, 0.4 MPa Pressure Head 85 kPa	
Contractor Design	SHe Pump Load	330 W	
	Sub-cooler, Transfer Line b/w CB	150 W	250 W
	Required Refrigeration	890 W + 1.1 g/s → 1.0 kW	1960 W → 2 kW
	+ 20 % Margin	1.2 kW	2.4 kW

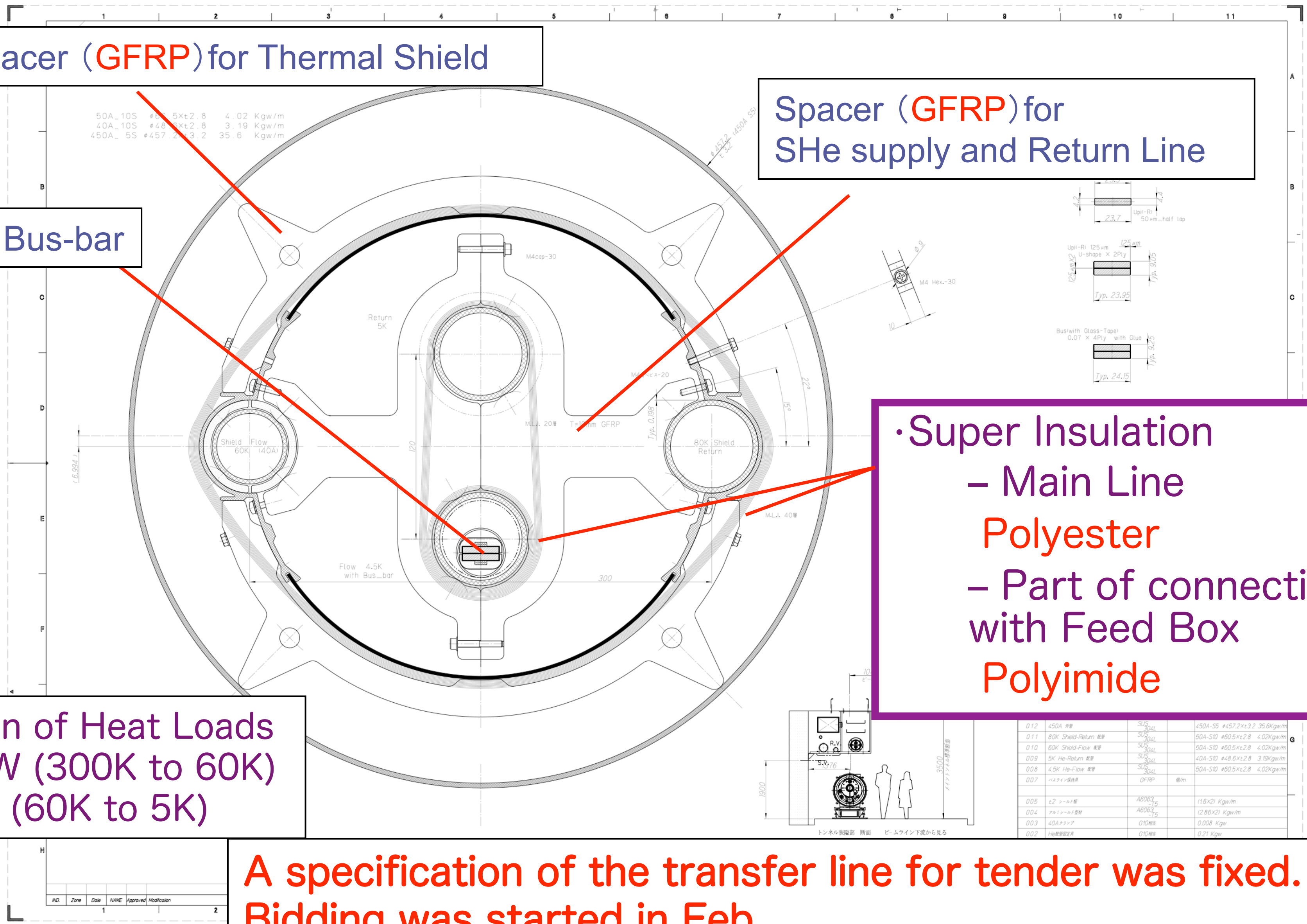
Taiyo-Nissan Co. in the business collaboration with LINDE won the bid.

Transfer Line with SC bus-bar

SHe Line (Supply)
Inner diameter=54.5mm, 100 m, 4.5 K,
SHE 350 g/s, 0.4 MPa-Abs
With SC-Bus-bar
SHe Line (Return)
Inner diameter=54.5mm, 100 m, 4.5 K,
SHe 350 g/s, 0.4 MPa-Abs
Shield Line (Supply)
Inner diameter=42.6mm, 60 K, 100 m
Shield Line (Return)
Inner diameter=54.5mm, 80 K, 100 m



Cross section of the Transfer Line



Spacer（GFRP）for Thermal Shield

Spacer（GFRP）for
SHe supply and Return Line

SC Bus-bar

·Super Insulation
- Main Line
  Polyester
- Part of connection with Feed Box
  Polyimide

Design of Heat Loads
440 W (300K to 60K)
55 W (60K to 5K)

A specification of the transfer line for tender was fixed.
Bidding was started in Feb.
Contractor will be decided in this April.

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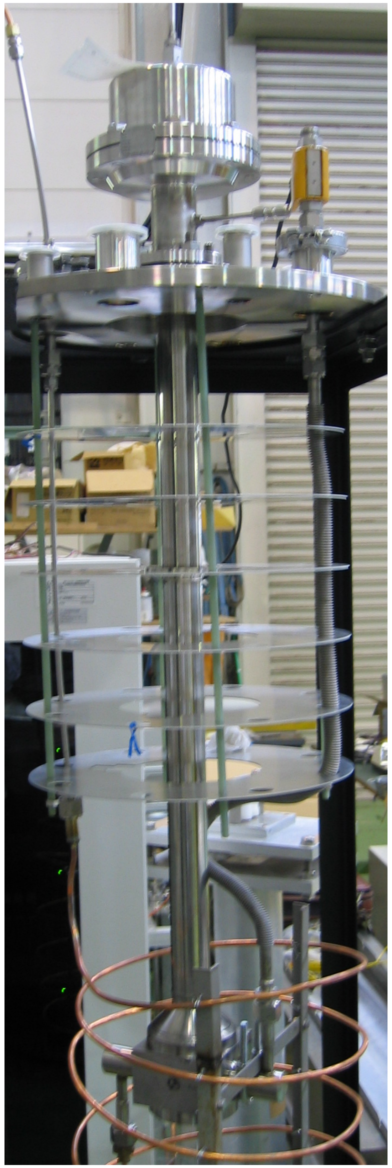
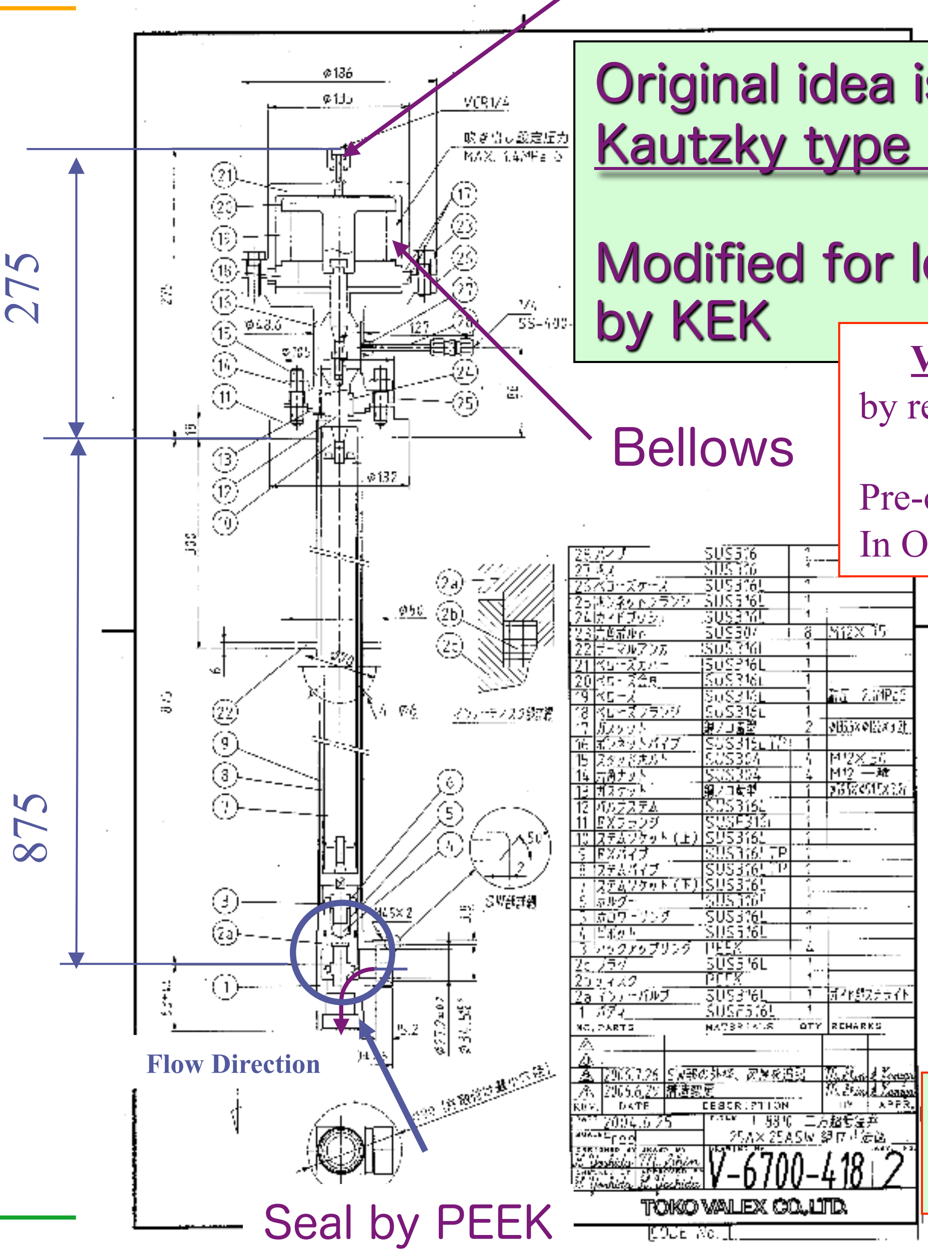
- Quench Relief Valve
- Elastomer Seal System
- Summary and Schedule

Quench Relief Valve





Reference pressure input

Original idea is
Kautzky type Valve @FNL

Modified for low temperature use by KEK

Variable Relief Pressure
by reference pressure

Pre-cooling: 1.2 MPa
In Operation: 0.45 MPa

Bellows

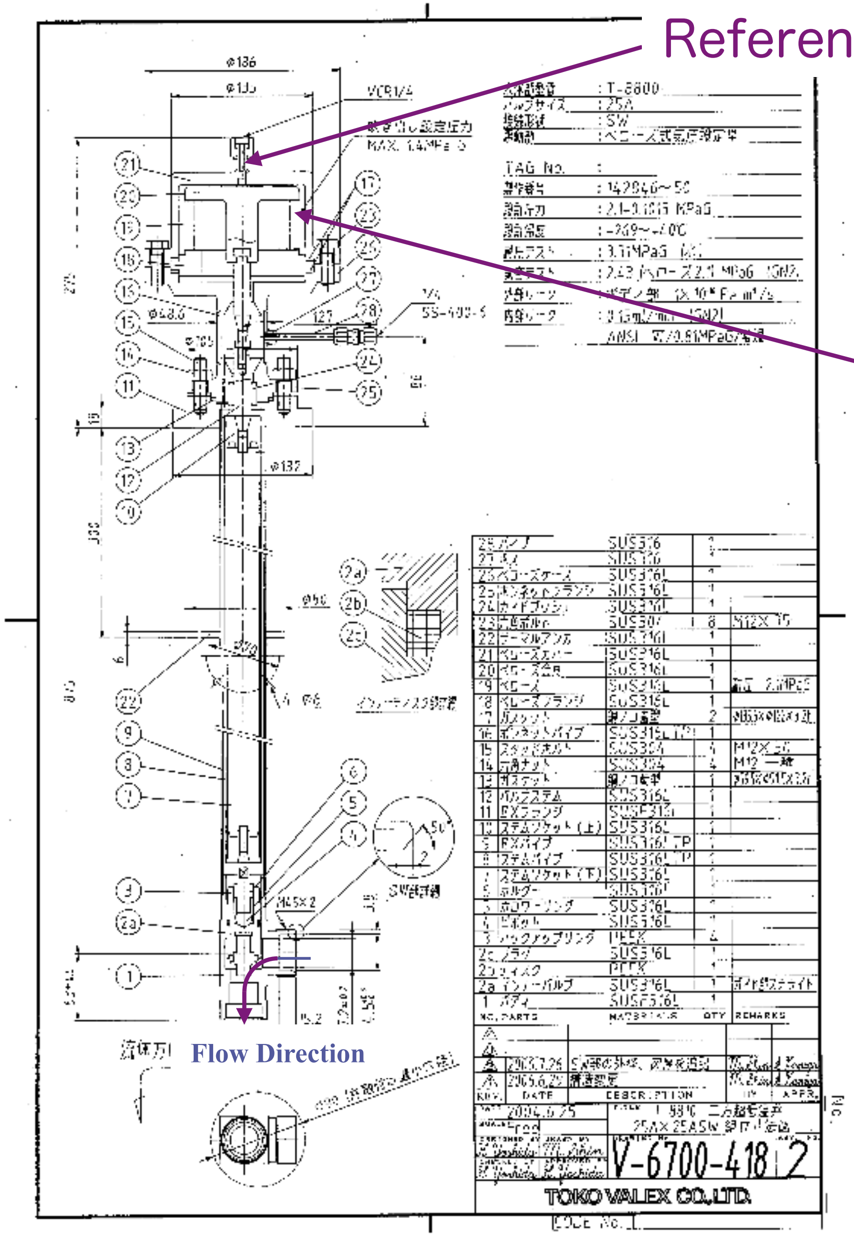
Flow Direction

Seal by PEEK

Assembling of Inter-connect Cryostat
For Quench Valve

Quench Relief Valve

Conceptual Idea



Reference pressure input

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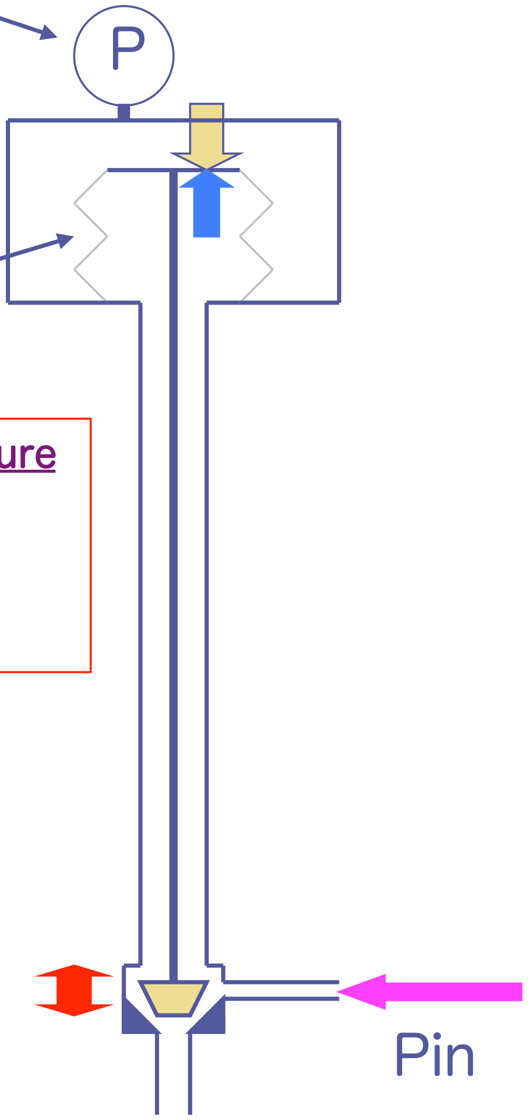


Variable Relief Pressure
by reference pressure

Pre-cooling: 1.2 MPa
In Operation: 0.45 MPa

P >Pin= Close
P <Pin= Open

Quench Release Analysis

OKAMURA Takahiro
takahiro.okamura@kek.jp

Contents

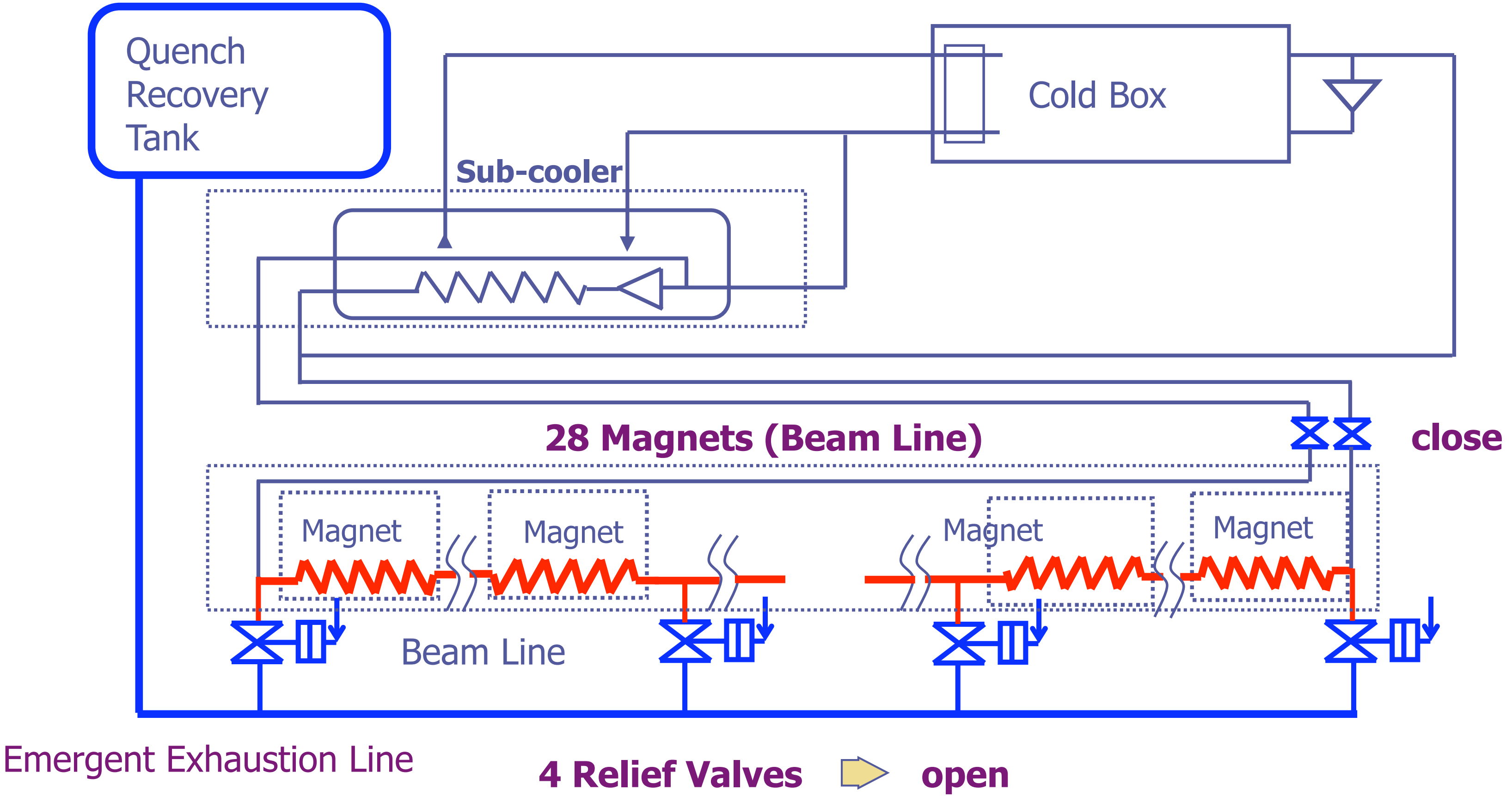
Conceptual diagram of quench release

Allowable pressure of SC magnet system: 2.0 MPa

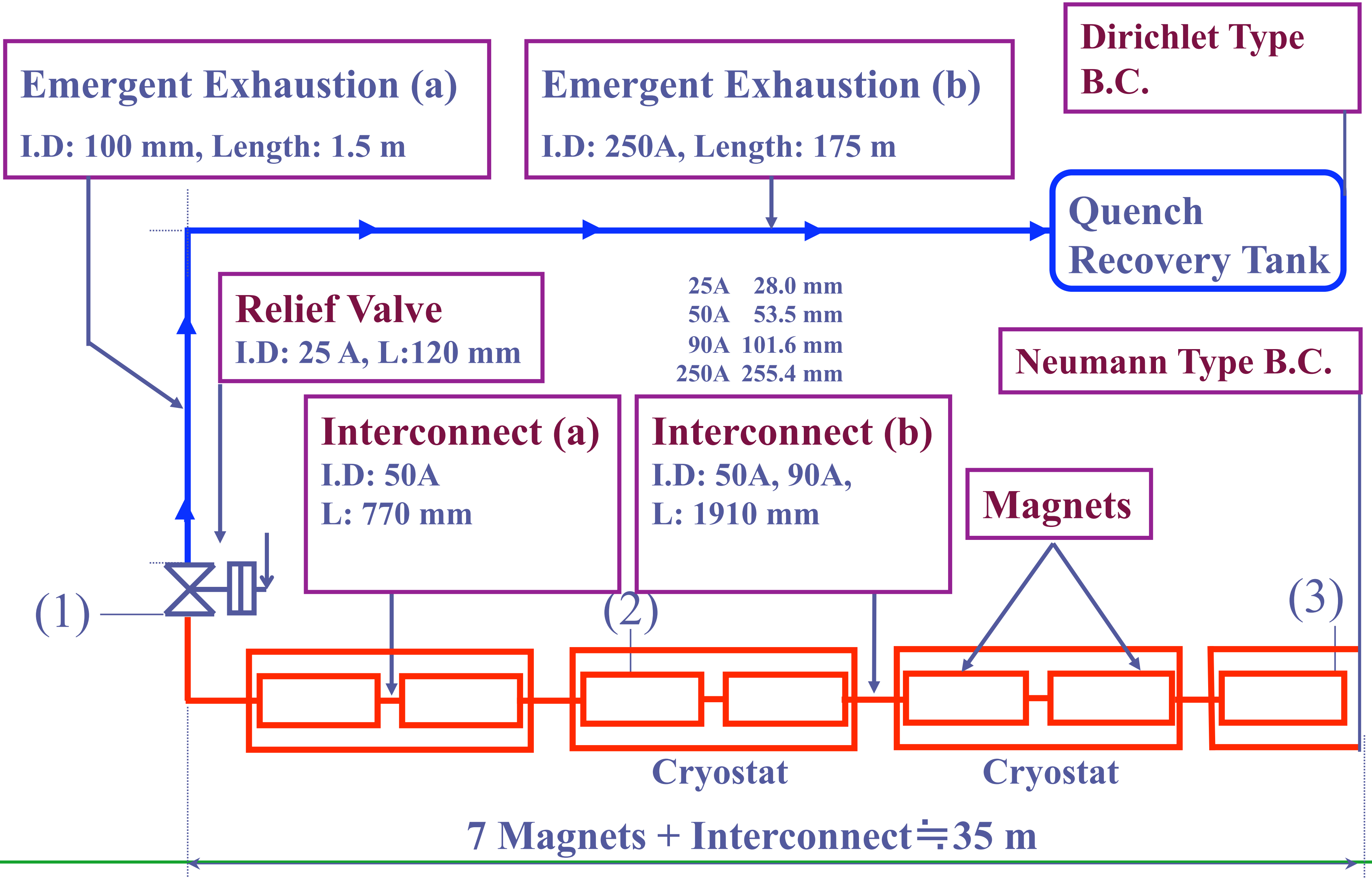
Essential qualification of He gas
Max Pressure of He gas < 2.0 MPa

⇔

Determination
of Geometric Parameter
I.D. of Relief Valve



Simulation Model



Emergent Exhaustion (a)
I.D: 100 mm, Length: 1.5 m

Emergent Exhaustion (b)
I.D: 250A, Length: 175 m

Dirichlet Type B.C.

Quench Recovery Tank

Relief Valve
I.D: 25 A, L:120 mm

25A	28.0 mm
50A	53.5 mm
90A	101.6 mm
250A	255.4 mm

Neumann Type B.C.

Interconnect (a)
I.D: 50A
L: 770 mm

Interconnect (b)
I.D: 50A, 90A,
L: 1910 mm

Magnets

7 Magnets + Interconnect≒35 m

Governing Equations & Method

Continuity Equation:

$$\frac{\partial}{\partial t}(\rho A) + \frac{\partial}{\partial x}(\rho u A) = 0$$

Momentum Equation:

$$\frac{\partial}{\partial t}(\rho u A) + \frac{\partial}{\partial x}(\rho u u A) = -\frac{\partial}{\partial x}(p A) + G(u)$$

Energy Equation:

$$\frac{\partial}{\partial t}(\rho e A) + \frac{\partial}{\partial x}(\rho e u A) = -pA\frac{\partial u}{\partial x} - \frac{\partial}{\partial x}(q A) + \underbrace{\dot{Q}}$$

Thermal Equation of State:

$$de = \left(\frac{\partial e}{\partial p}\right)_{\rho} dp + \left(\frac{\partial e}{\partial \rho}\right)_{p} d\rho$$

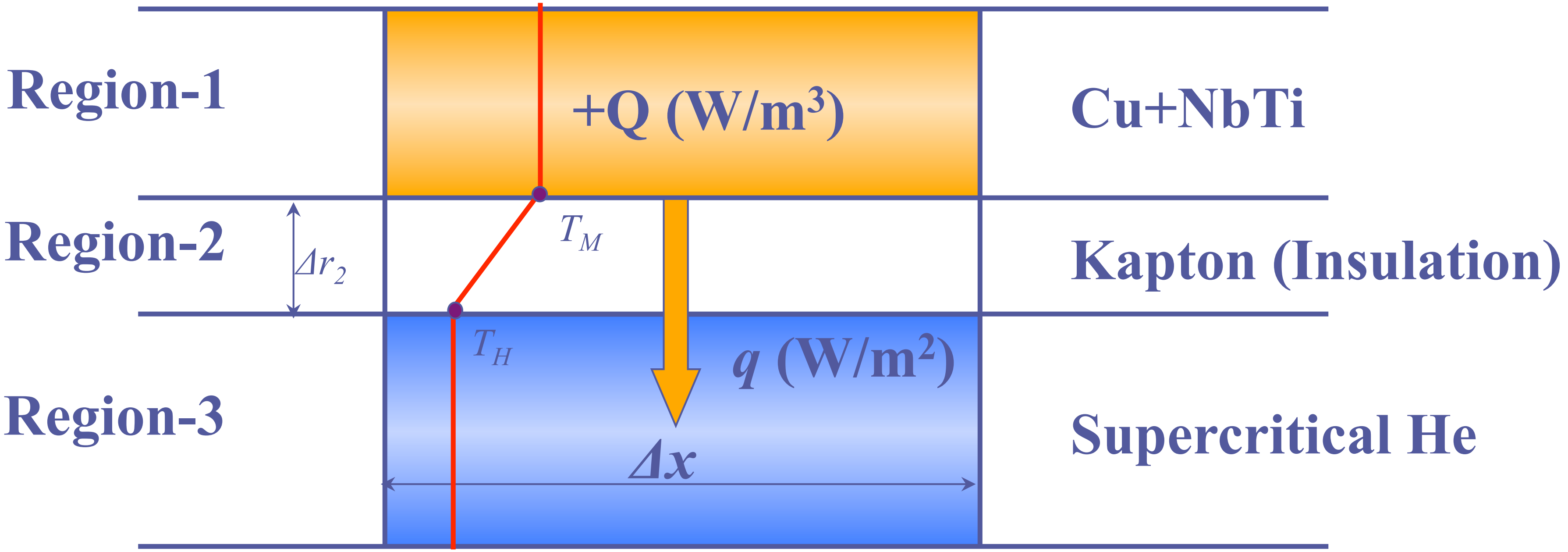
Mass, Momentum, Energy are directly coupled.
(Semi-Implicit Pressure Based Scheme)

Solving Pressure Poisson equation
Finite Difference Method (FDM)+FCT Algorithm

Heat generation term from Magnet.
Most Important Term !!?

1-Dimensional Heat Transfer Model

Heat Transfer Model



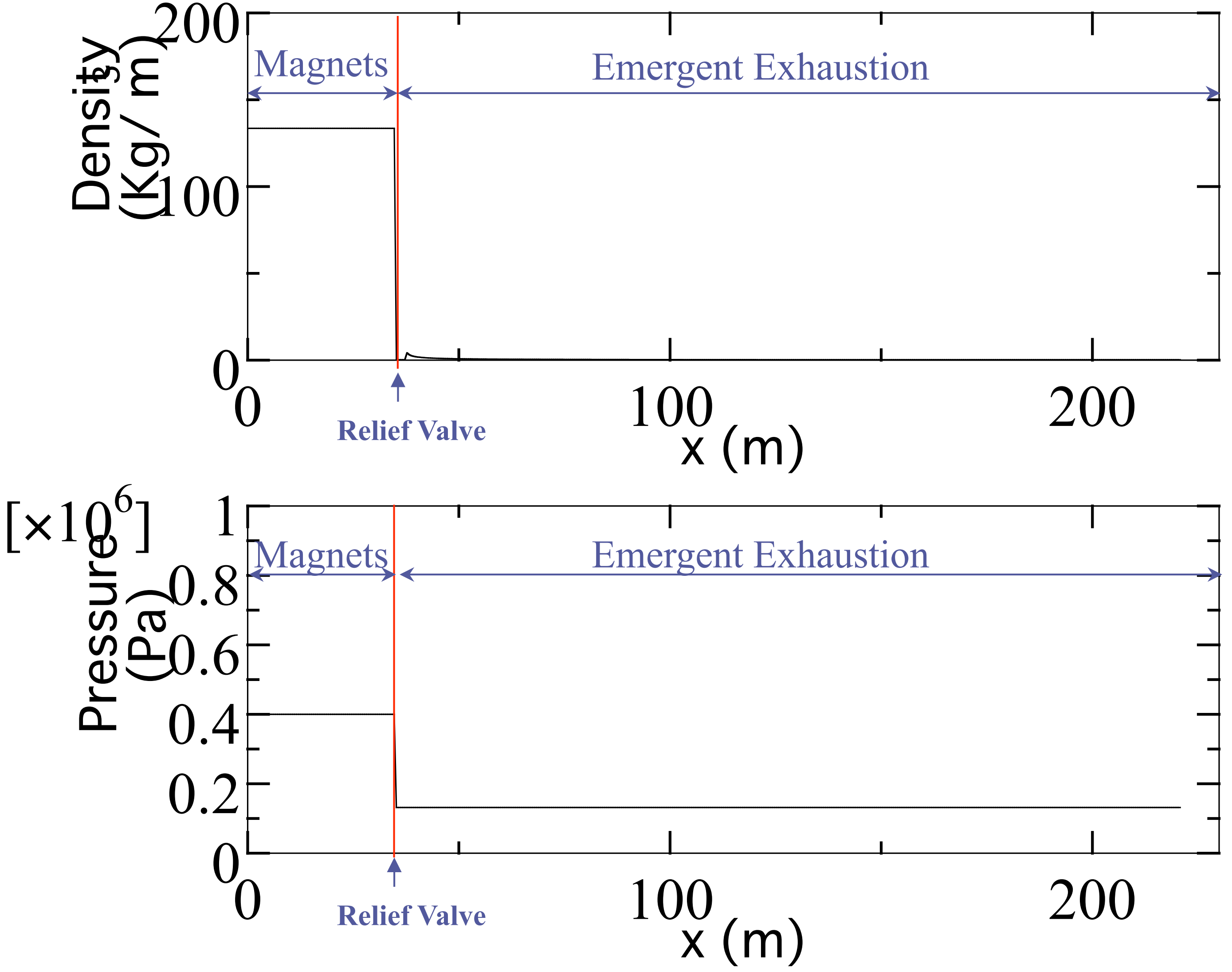
Region-1: Energy Balance Equation

$$\rho c_p \frac{\partial T_M}{\partial t} \Delta V = Q \Delta V - q \Delta S \ , \qquad q = \lambda_K \frac{T_M - T_H}{\Delta r_2}$$

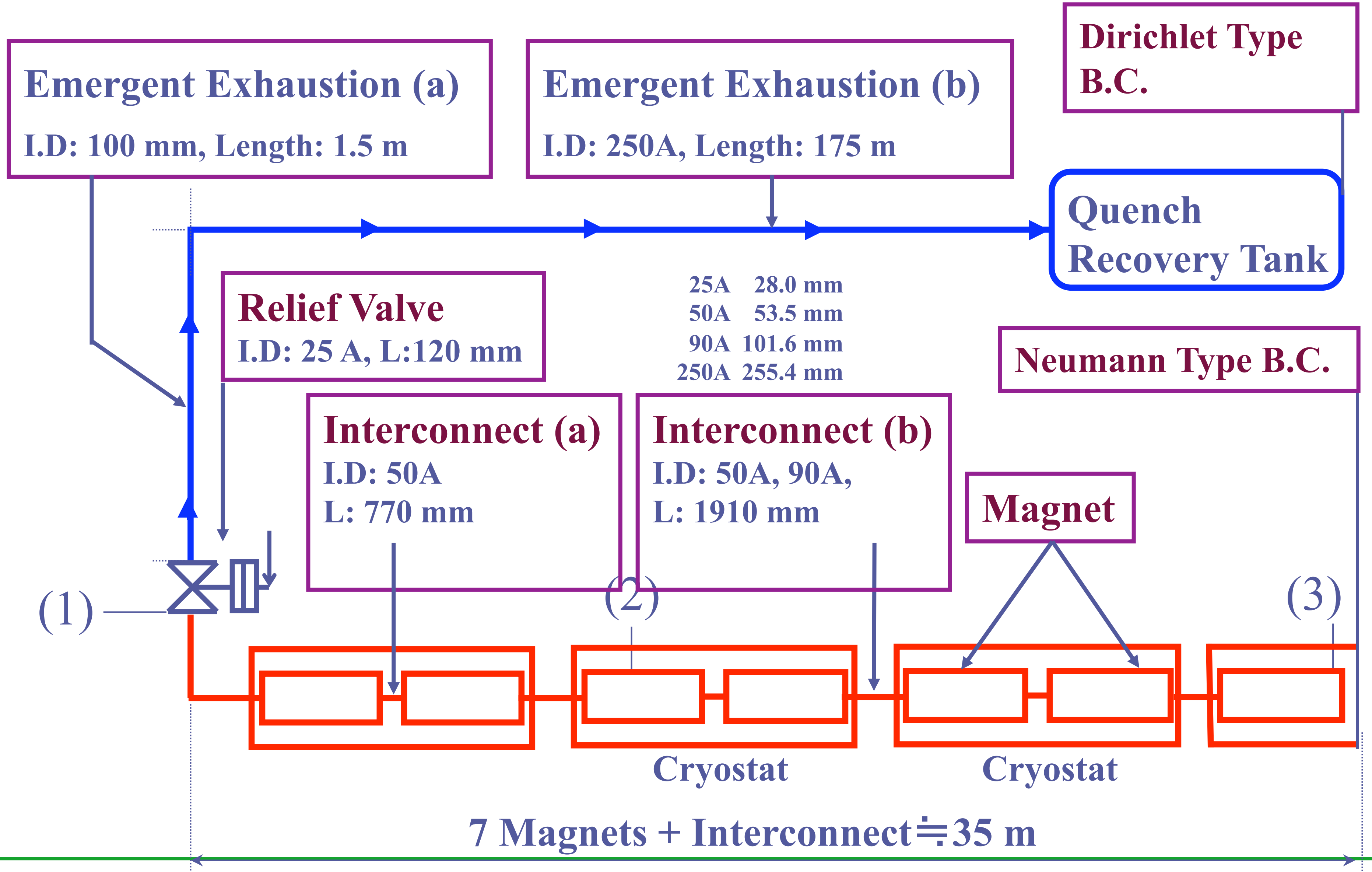
Heat Generation term from Magnet to SHE

$$\dot{Q} = \frac{q \Delta S}{\Delta x}$$

Initial Conditions



Simulation Model



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Neumann Type B.C.

Interconnect (a)
I.D: 50A
L: 770 mm

Interconnect (b)
I.D: 50A, 90A,
L: 1910 mm

Magnet

(1)

(2)

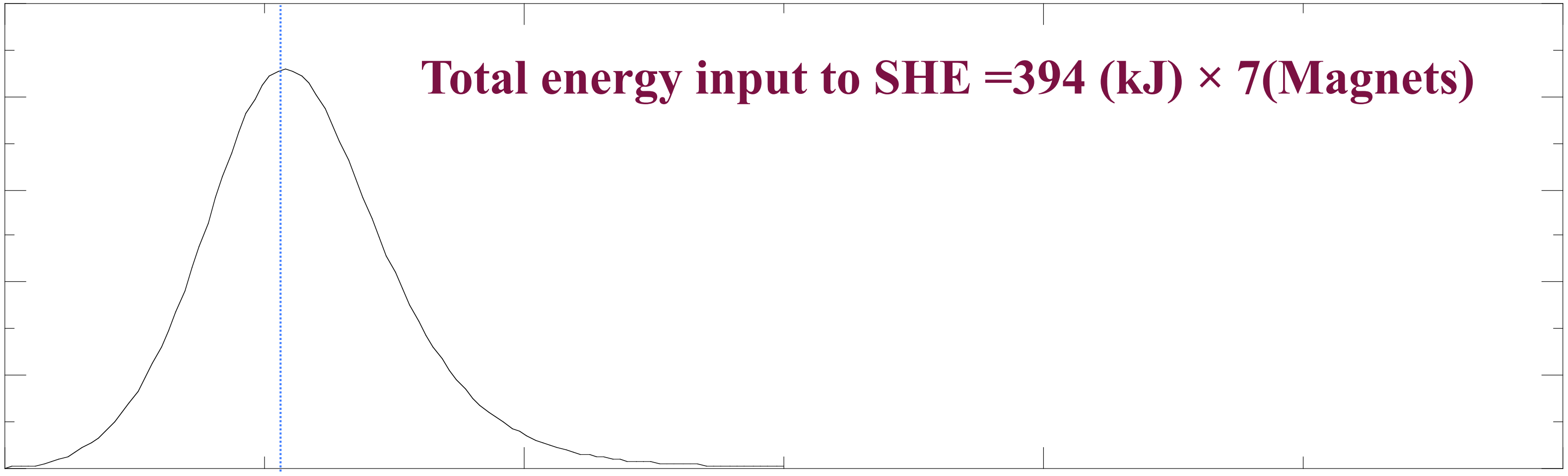
(3)

Cryostat

Cryostat

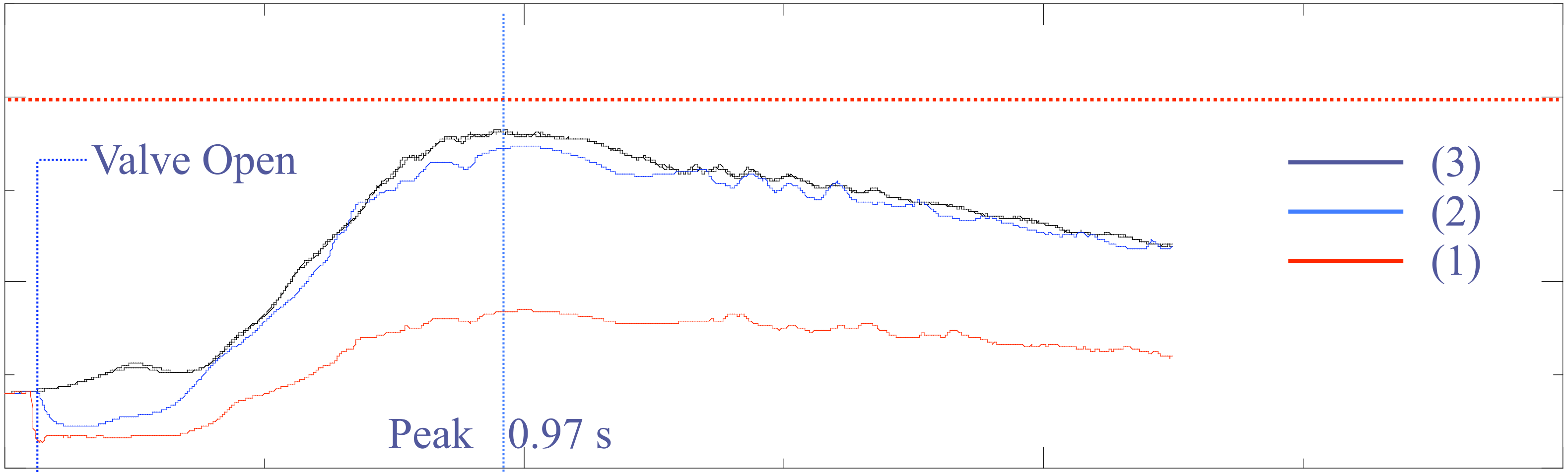
7 Magnets + Interconnect≒35 m

Highlight Result

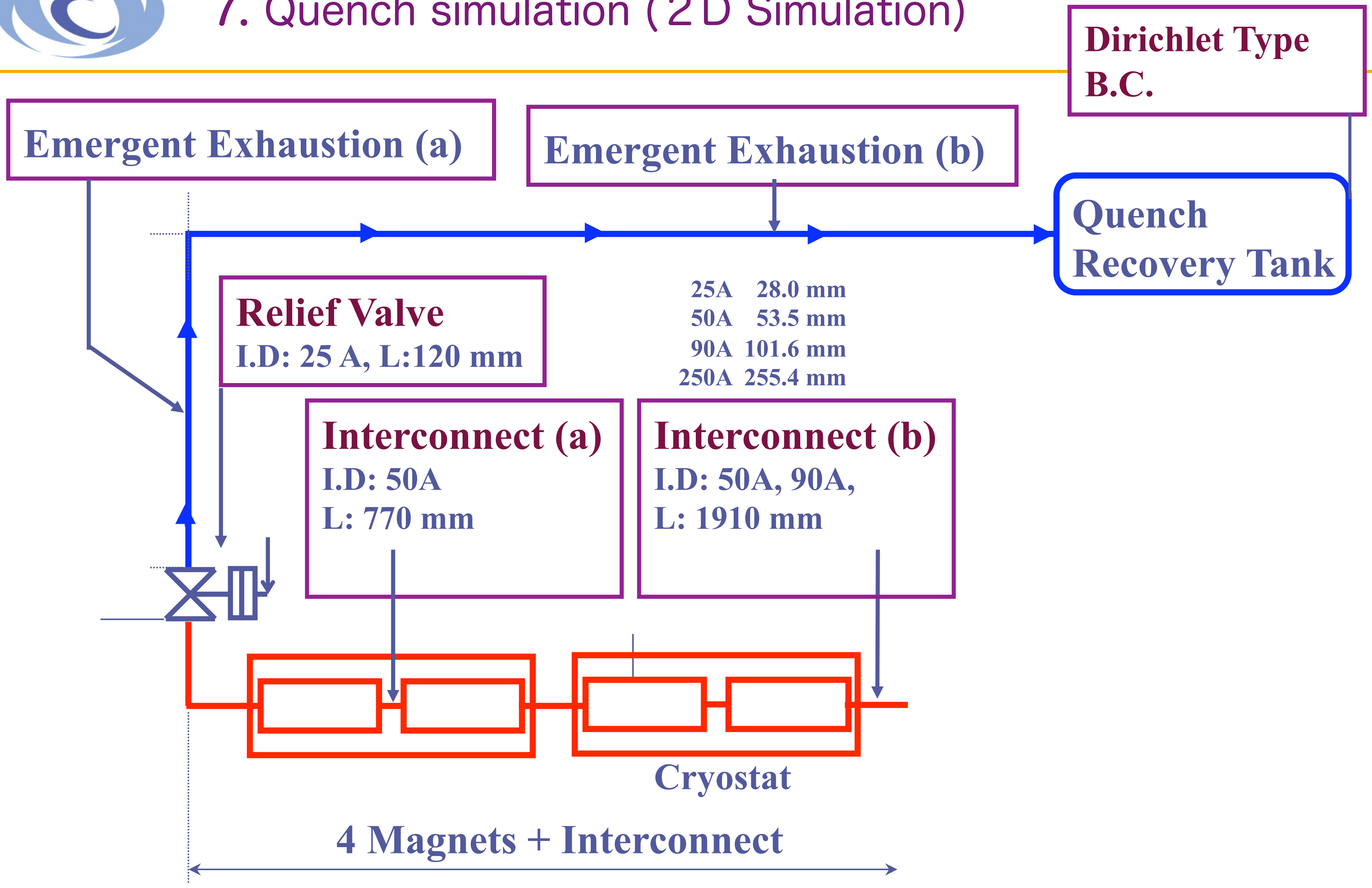


Total energy input to SHE =394 (kJ) × 7(Magnets)

Peak
0.55 s



7. Quench simulation (２D Simulation)



Dirichlet Type B.C.

Emergent Exhaustion (a)

Emergent Exhaustion (b)

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Interconnect (a)
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Interconnect (b)
I.D: 50A, 90A,
L: 1910 mm

Cryostat

4 Magnets + Interconnect

This model is based on an assumption that flow is Two-dimensional
Numerical simulation is carried out involving four magnets, one relief valve, venting line and buffer tank.

Simulation Method

- E.Q.: NSE+Equation of State

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}) = 0$$

$$\frac{\partial}{\partial t}(\rho \boldsymbol{v}) + \nabla \cdot (\rho \boldsymbol{v}\boldsymbol{v}) = -\nabla p + \nabla \cdot \boldsymbol{\tau} + \rho \boldsymbol{g}$$

$$\frac{\partial}{\partial t}(\rho e) + \nabla \cdot (\rho e \boldsymbol{v}) = -\nabla \cdot \boldsymbol{q} - p(\nabla \cdot \boldsymbol{v}) + \boldsymbol{\tau} : \nabla \boldsymbol{v}$$

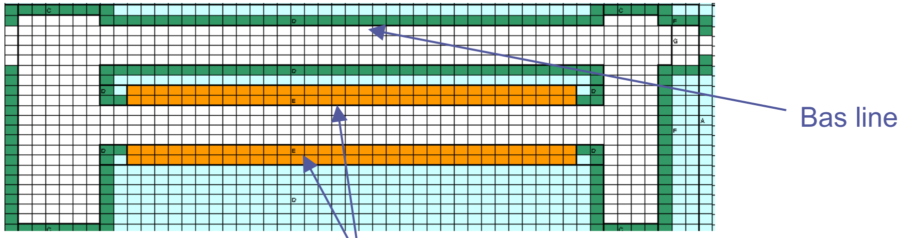
$$de = \left(\frac{1}{\varphi \rho}\right) dp - \left(\frac{c^2}{\varphi \rho} - \frac{p}{\rho^2}\right) d\rho$$

where

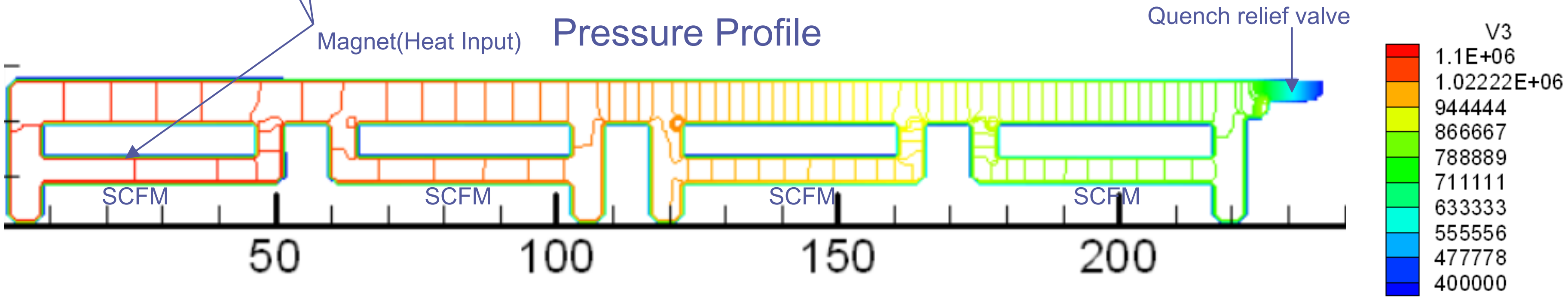
$$\begin{cases} \boldsymbol{\tau} = \mu\left\{\nabla \boldsymbol{v} + (\nabla \boldsymbol{v})^T\right\} - \frac{2}{3}\mu(\nabla \cdot \boldsymbol{v})\boldsymbol{I} \\ \boldsymbol{q} = -\lambda \nabla T \end{cases}$$

- Method: FVM+Pressure Based Scheme
- Coordinate: BFC

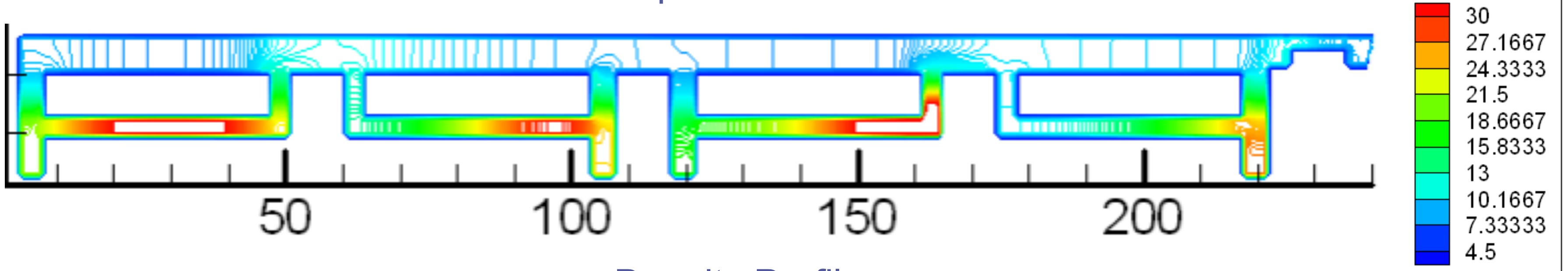
7. Simulation Results at 4/4 Magnets Quench



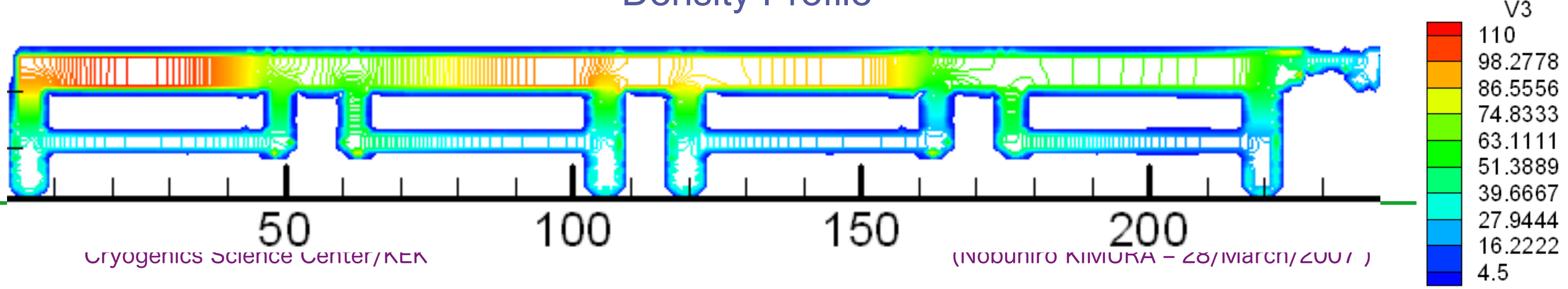
Pressure Profile



Temperature Profile



Density Profile



Summary

- A new Implicit Continuous-fluid Eulerian code for SHe venting simulation has been developed
  by means of 1 & 2 Dimensional Heat transfer model.

- Maximum Pressure is about 1.8 MPa
  and lower than allowable pressure of the magnet
  under the present relief valve
  and emergent exhaustion line design conditions.

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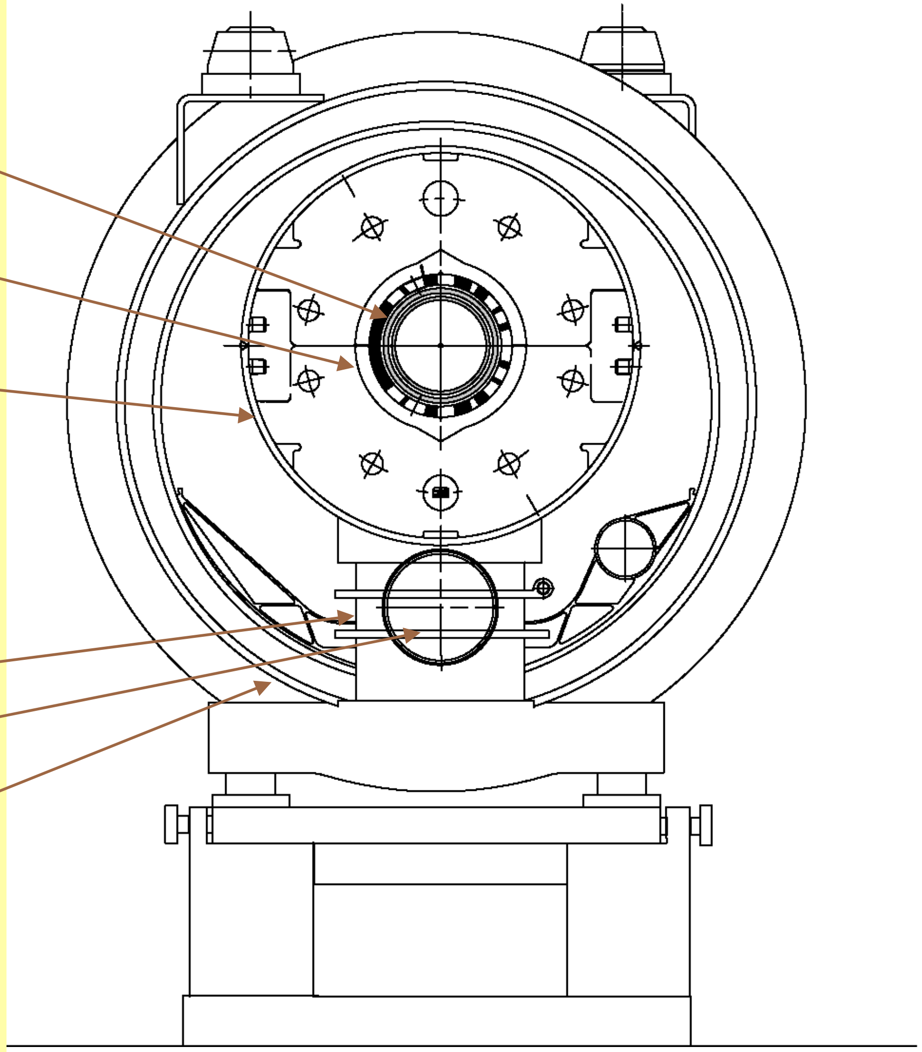
Summary of Organic Materials in Magnet and Radiation Resistance



1 w/m, 4000 hr/year

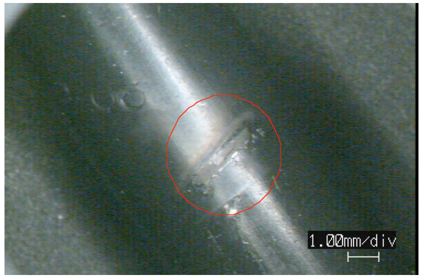
- Coil (~30kGy/y)
  - GFRP (10^7Gy)
  - Polyimide (10^7Gy)
- Plastic Collar (~10kGy/y)
  - Glass Filled Phenol (10^7Gy)
- Super Insulator
  - Body (~200Gy/y)
    - Polyester (10^6Gy)
  - End (~30kGy/y)
    - Polyimide ($6{\cdot}10^7$Gy)
- Support Post (~200Gy/y)
  - GFRP (10^7Gy)
- Cold Diode (~200Gy/y, $1.2 \bullet 10^{13}$ n/cm^2)
- Elastomer Seals (~30kGy/y)

New Elastomer Seal for the Cryostat

New EPDM type Elastomer seal were developed with collaboration of KEK, JAEA and Hayakawa Rubber Co..
New Elastomer seal have been tested up to Dose=9.1 MGy with γ ray source.

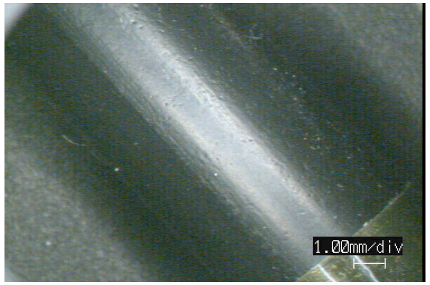
区分①

Dose=9.1 MGy



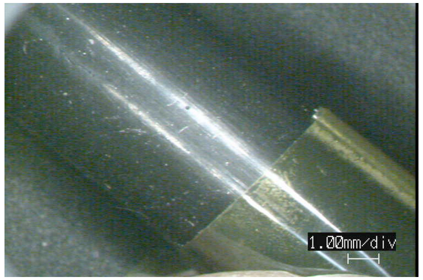
区分②

Dose=2.6MGy



区分③

Dose=1.2MGy

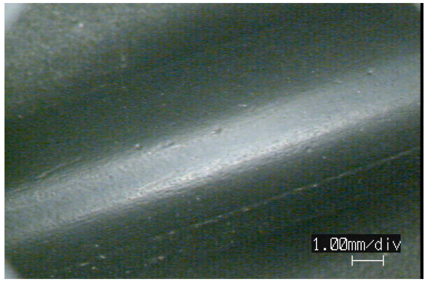


区分④

Dose=0.34 MGy

区分⑤

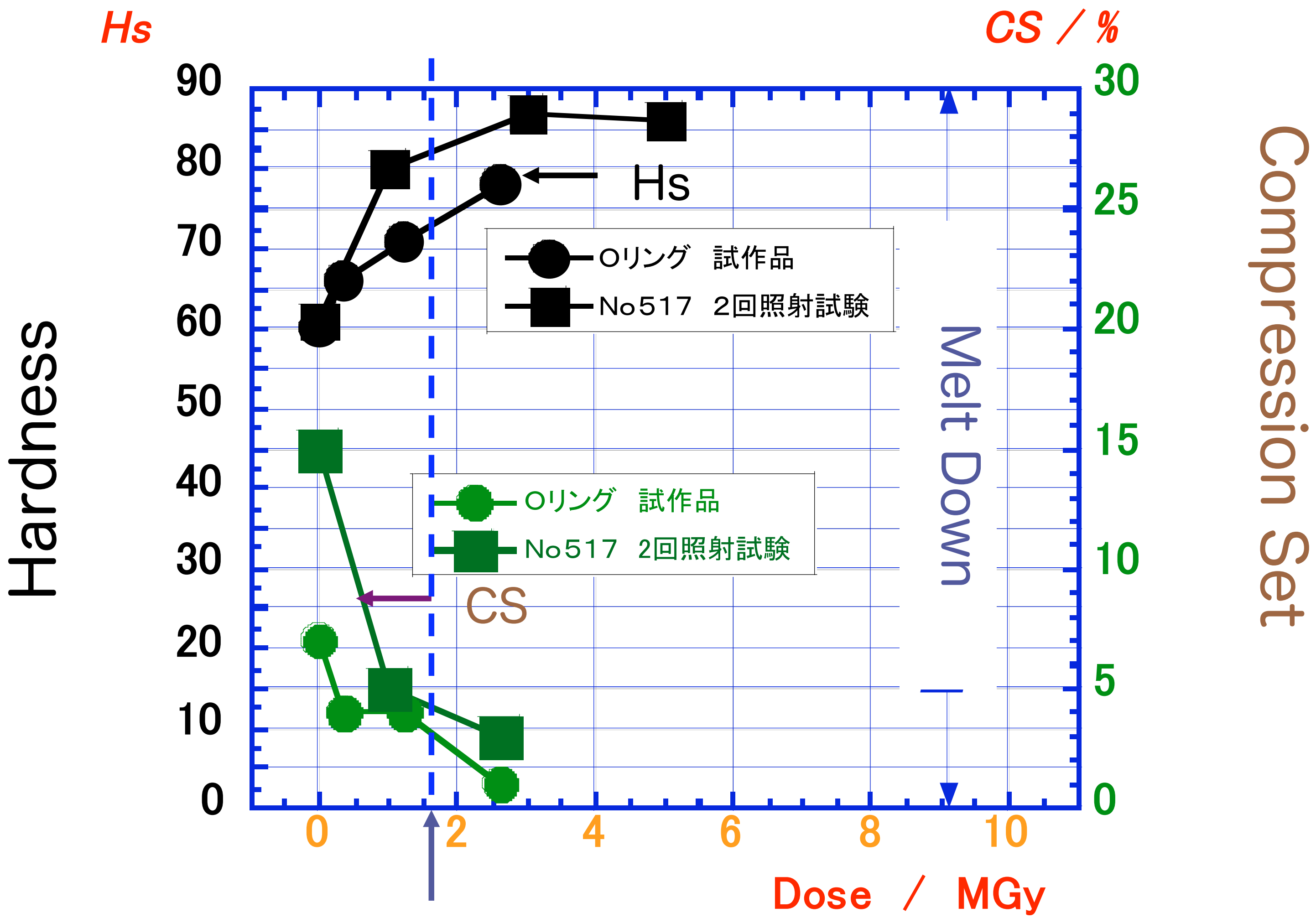
Dose=0 MGy



Blank

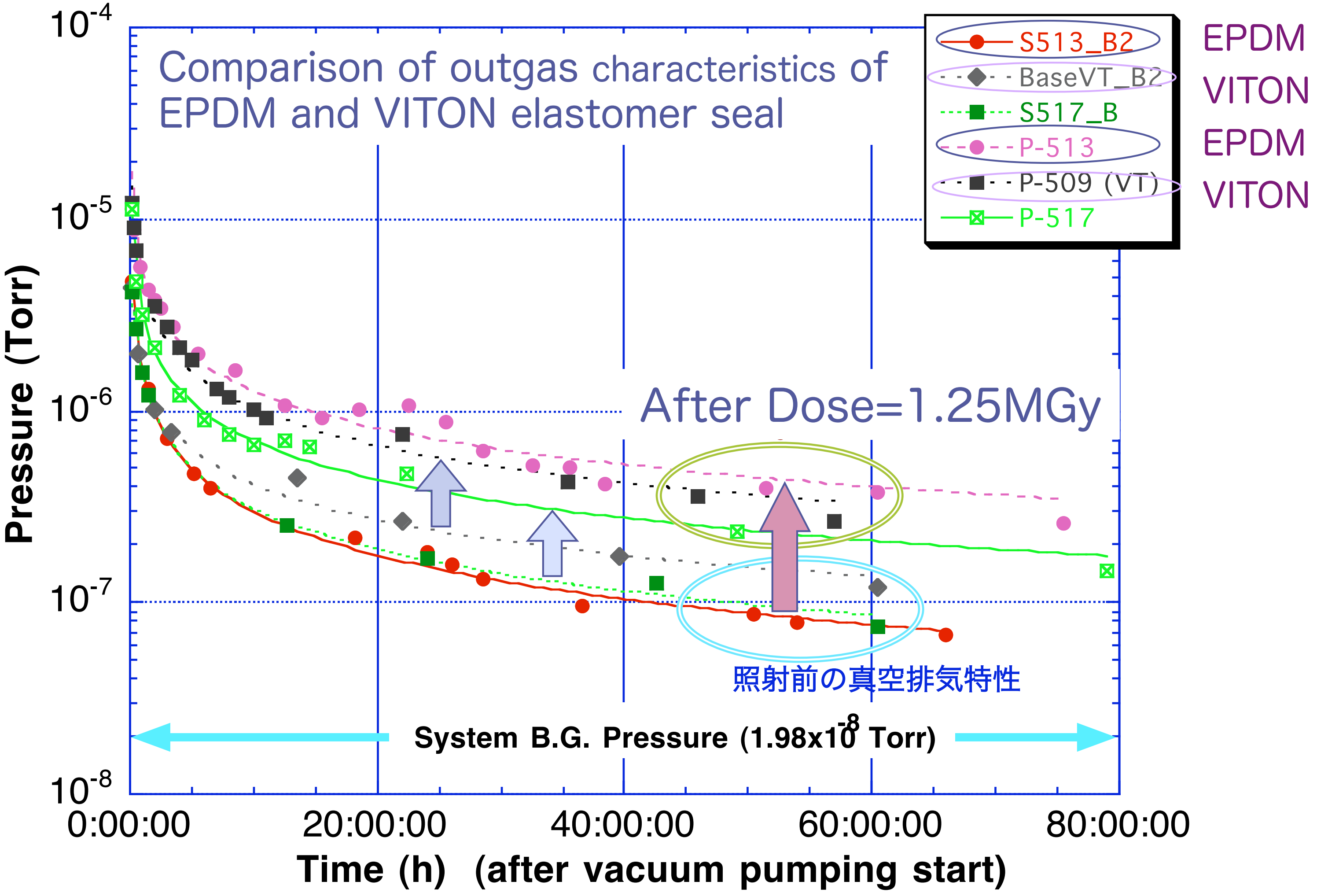
Dose=0 MGy

Hardness and Compression set



Neutrino Beam Line

Outgas Characteristics of EPDM Elastomer Seal



It is confirmed that new EPDM type elastomer seal can be used up to Dose=1.2 MGy.

Contents

Summary

・It is confirmed that the heat load of two in one structure cryostat has lower than 8 W.
Six cryostat are completed, and first one is still testing in KEK.
Left five cryostat were transferred to J-PARC.

・The performance of cooling system was fixed and
is being manufactured by LINDE. Tank foundation design,
machine room design is in progress.

・Maximum Pressure in the magnet after quench is
about 1.8 MPa and lower than allowable pressure
of the magnet under the present relief valve and emergent
exhaustion line design conditions.

・New EPDM type Elastomer seal are developed with

・Collaboration of KEK, JAEA and Hayakawa Rubber Co..
It is confirmed that new EPDM type elastomer seal can be
used up to Dose=1.3 MGy.

Schedule

	2005	2006	2007	2008
Cryostat w/ 2-SCFMs	1 (proto)	6 (12 Mag.)	6 (12 Mag.)	2 & Install
Transfer Line			🟧	Install
Refrig.		🟧	🟧	Install
PS			🟧	Install
Corrector Magnet		🟧	🟧	Install
Quench Detector		🟧	🟧	Install