Update on J-PARC Project

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Collaborators

KEK

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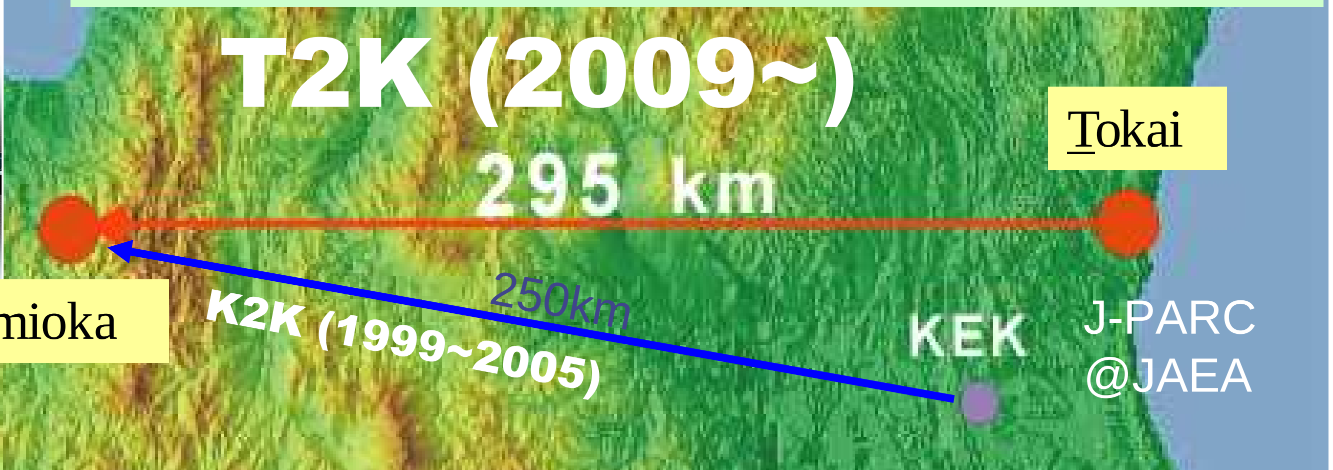
Contents

- Introduction
- System overview and Design of the Cryogenics
- Status on cryostat components
- Recent status on installation work in the tunnel
- Summary

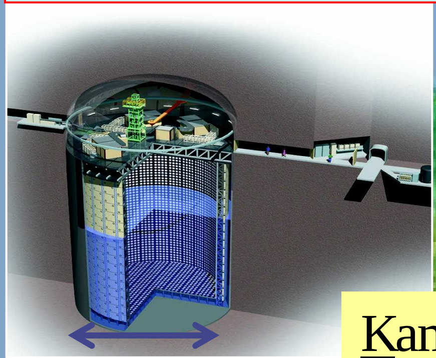
Contents

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

objective: study the nature of Neutrino in detail

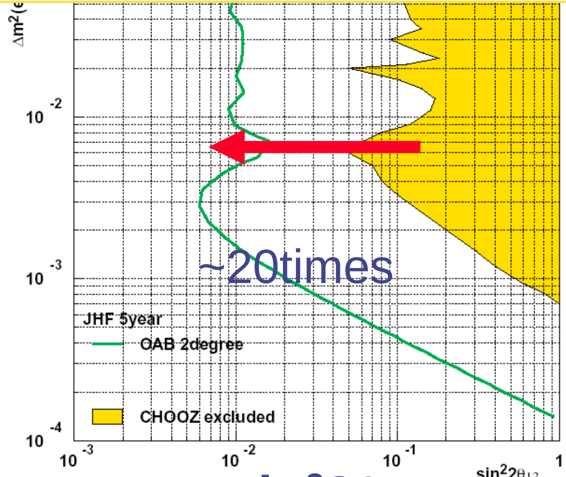


Super-Kamiokande



- 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.

Sensitivity on ν_e appearance

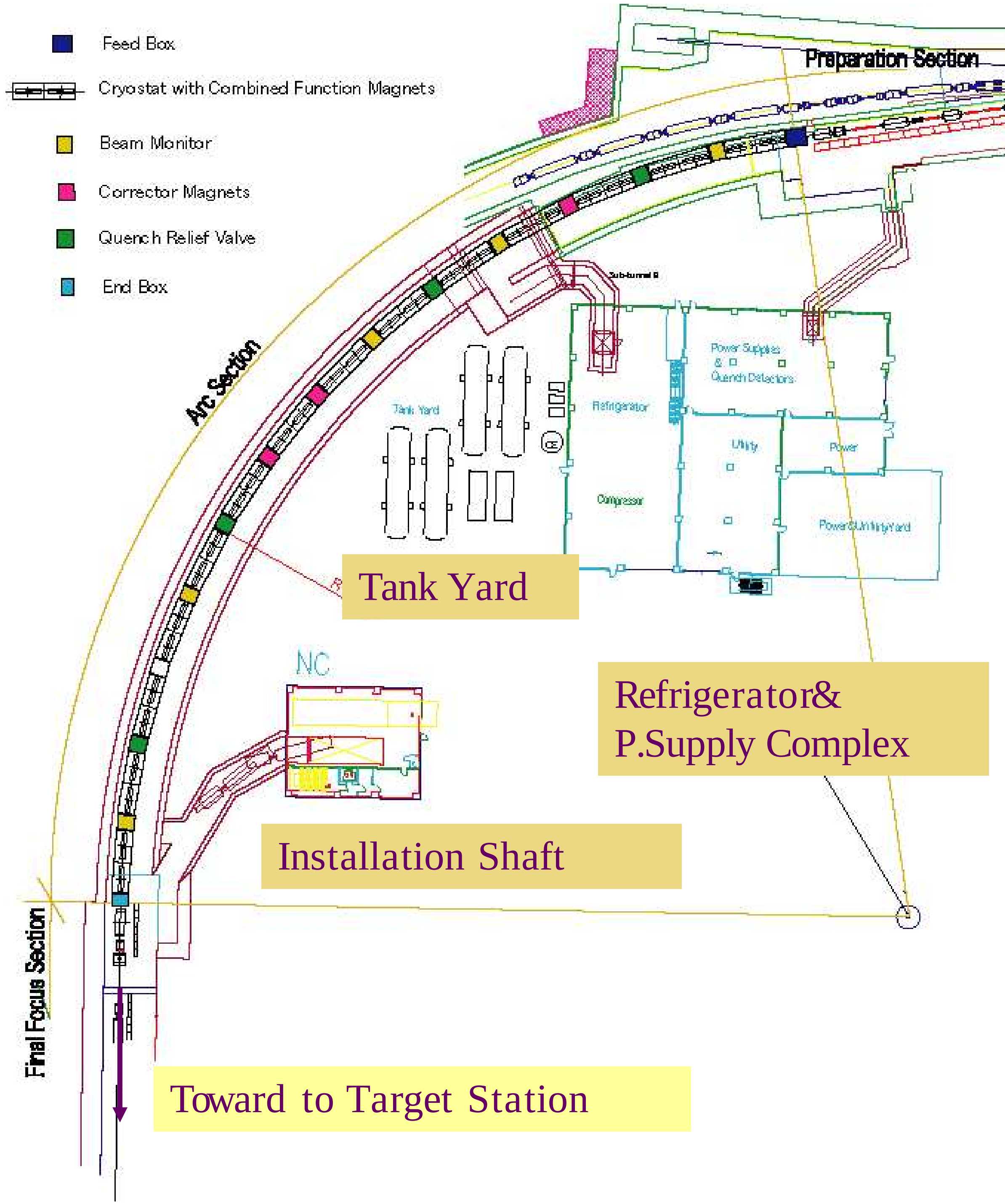


$\sin^2 2\theta_{13}$

Overview of Project History

- 2001FY
  - Design of Neutrino beam line project (T2K) was started with
    10 FODO = 40 Superconducting(SC) Magnets
- 2002FY
  - Superconducting Combined Function Magnets system,
    which consists of 14 doublet: 28 SCFM, was proposed as bending magnet system.
- 2003FY
  - SCFM was approved by internal review in KEK
  - The first production of prototype magnet was started in-house at the KEK
- 2004FY
  - Civil construction work of Neutrino beam line was started at Tokai
  - A prototype magnet was completed and tested in KEK
  - Design of cryostat and cooling system were started
  - Production of the magnets and cryostats were started at Mitsubishi Electric
- 2006FY
  - Continuing magnet production and cryostats
- 2007FY
  - Continuing magnet production and cryostats and started installation work in the tunnel
  - Production of the Transfer line was started
- 2008FY
  - Installation work should be completed and started commissioning on end of 2008.

Contents

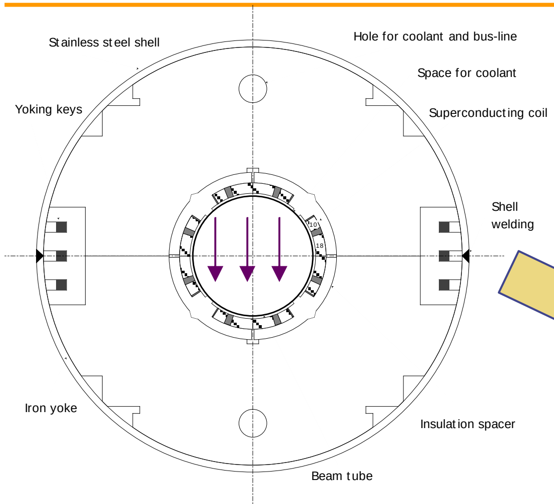


System Overview

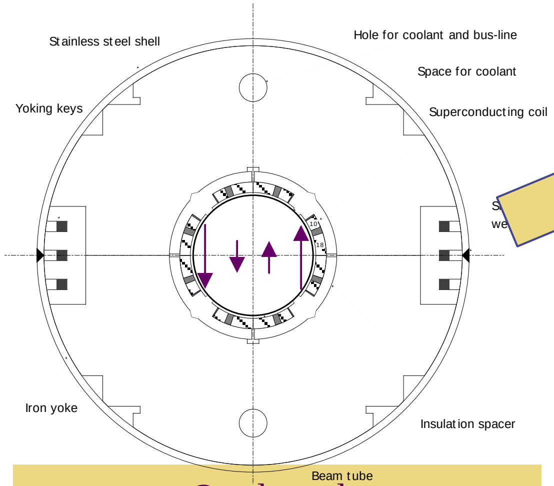
- 28 SCFM*s
  - Dipole 2.6 T
  - Quad 18.6 T/m
  - Length 3.3 m
  - 2 in 1 Cryostat
  - Total Stored Energy: 10MJ (50GeV)
- 13 interconnect cryostats
  - 5 beam monitors
  - 3 correctors
  - 4 quench valves
  - 1 none

*SCFM: Superconducting Combined Function Magnet

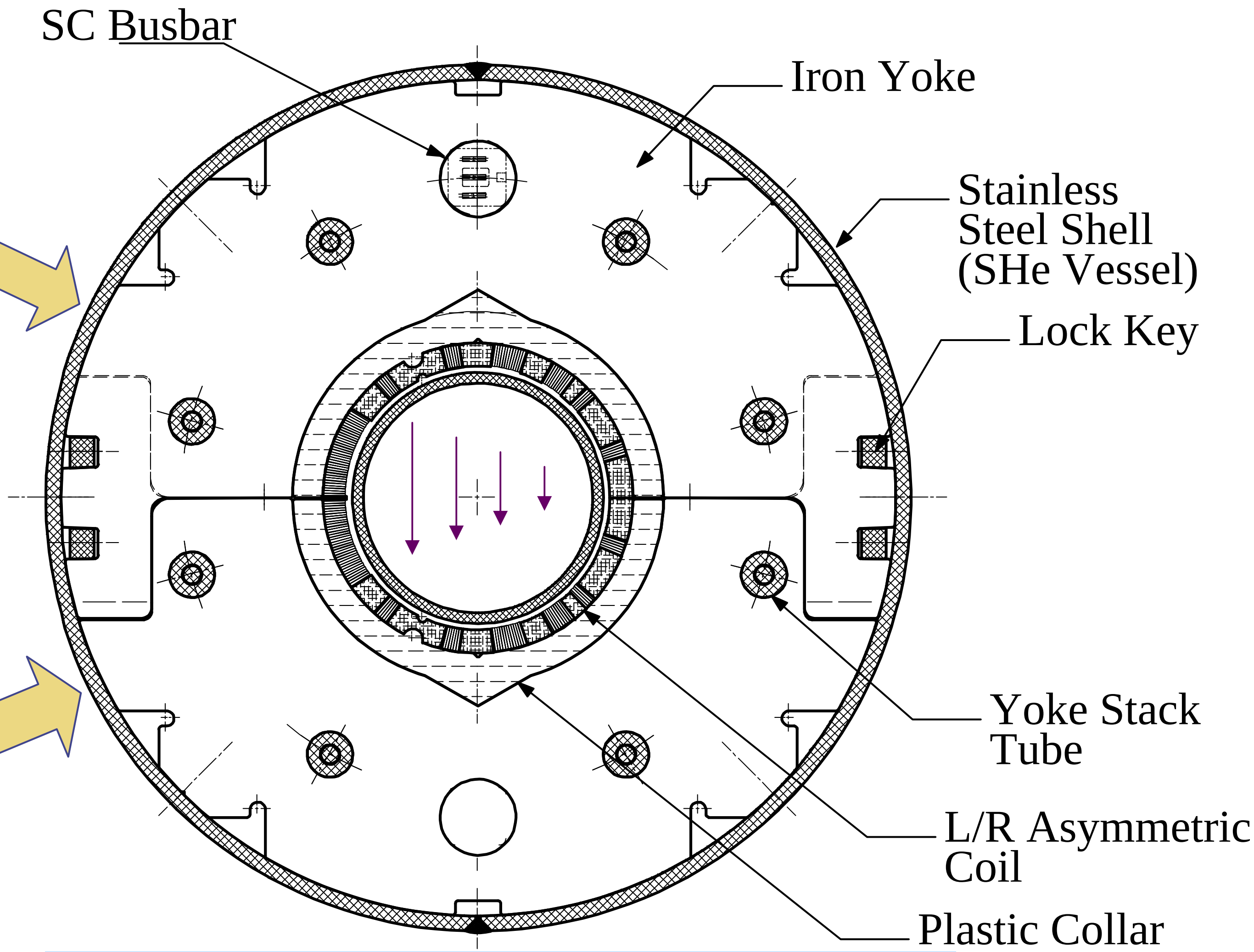
Superconducting Combined Function Magnet



Dipole (Bending)

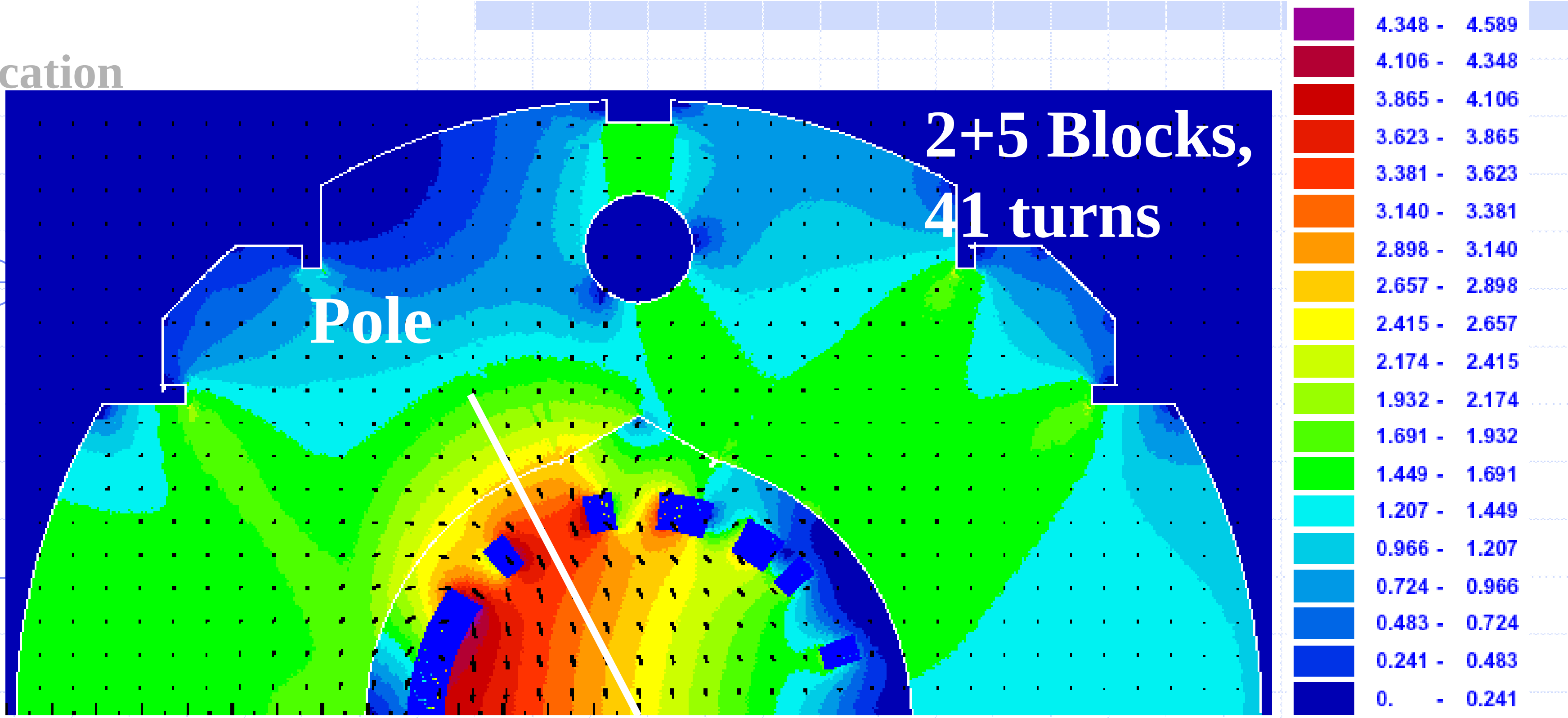


Quadrupole
(Focusing & De-focusing)



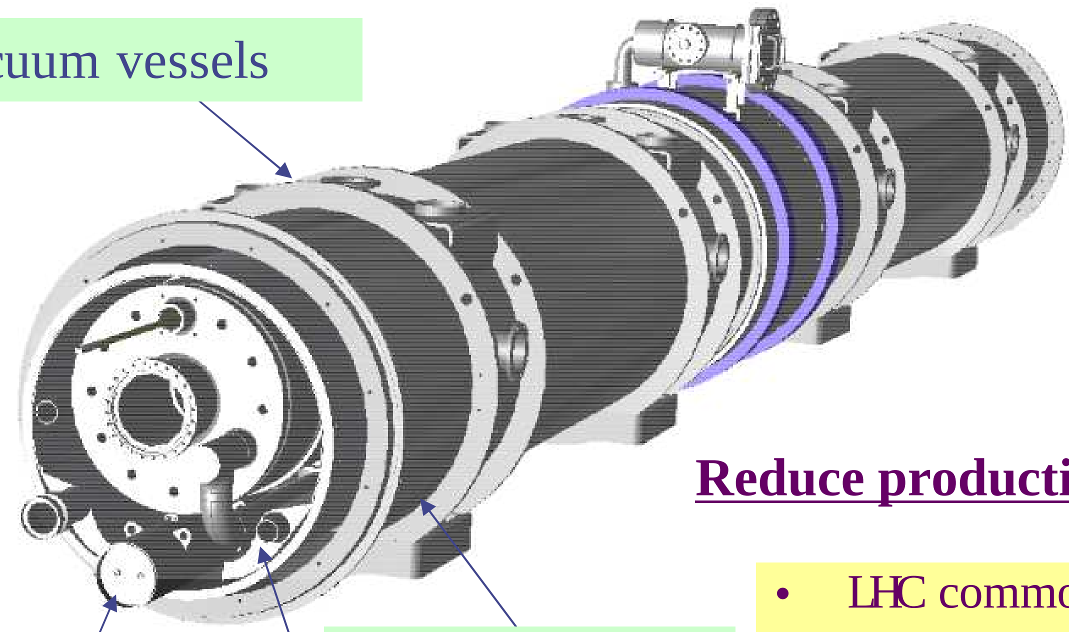
Dipole/Quadrupole Combined Bending +
Focusing (De-focusing)

Specification



Coil ID.:	173.4mm	Op. Current:	7345 A
Mag. Length:	3300 mm	Op. Margin:	72%
Mech. Length:	3630 mm @RT	Inductance:	14.3 mH
Tmax:	< 5.0K	Stored Energy:	386 kJ
	(Supercritical Helium)	# of Magnet:	28
Dipole Field:	2.59 T	SC Cable:	NbTi/Cu for LHC
Quad. Field:	18.6 T/m		Dipole Outer - L
Field Error:	< 10^-3		

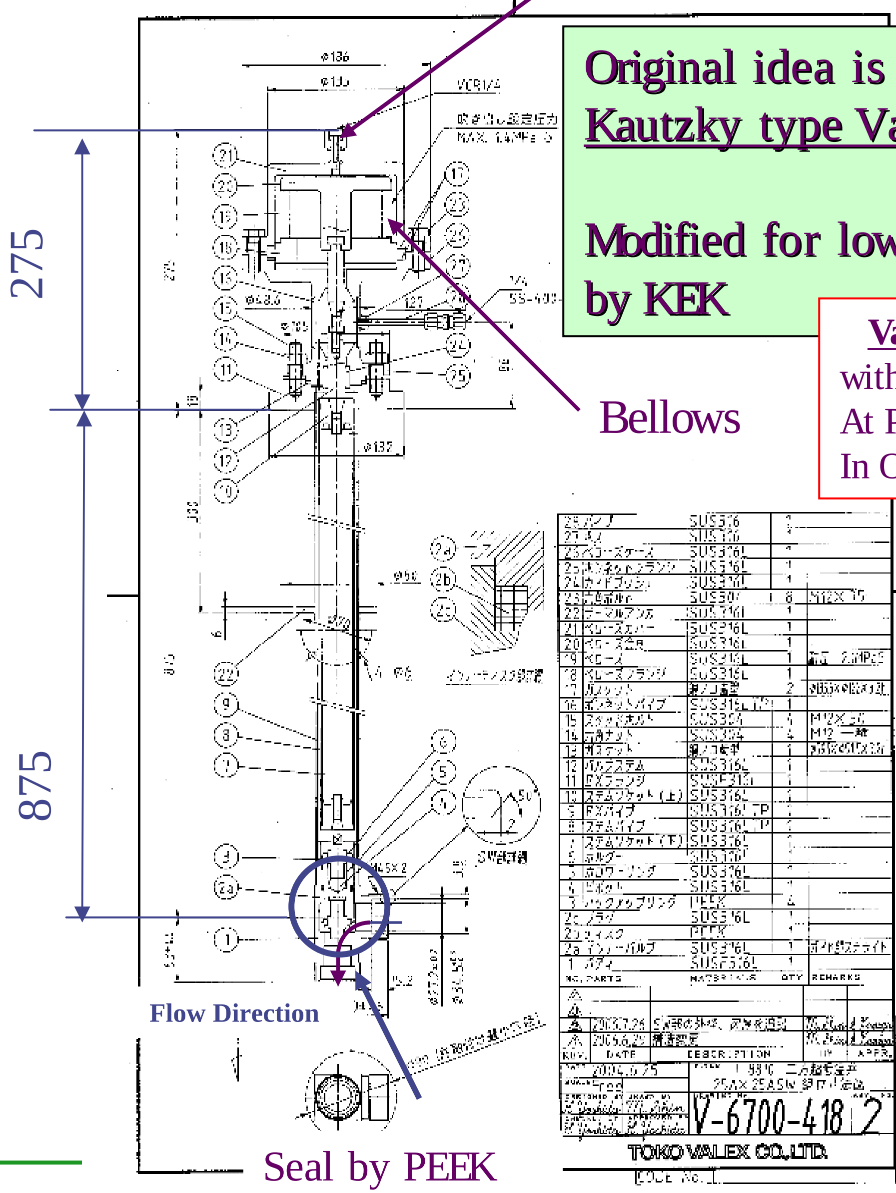
Structure design of the Cryostat for SCFM



Reduce production cost of the cryostat

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

Quench Relief Valve



Original idea is came from
Kautzky type Valve @FNL

Modified for low temperature use by KEK

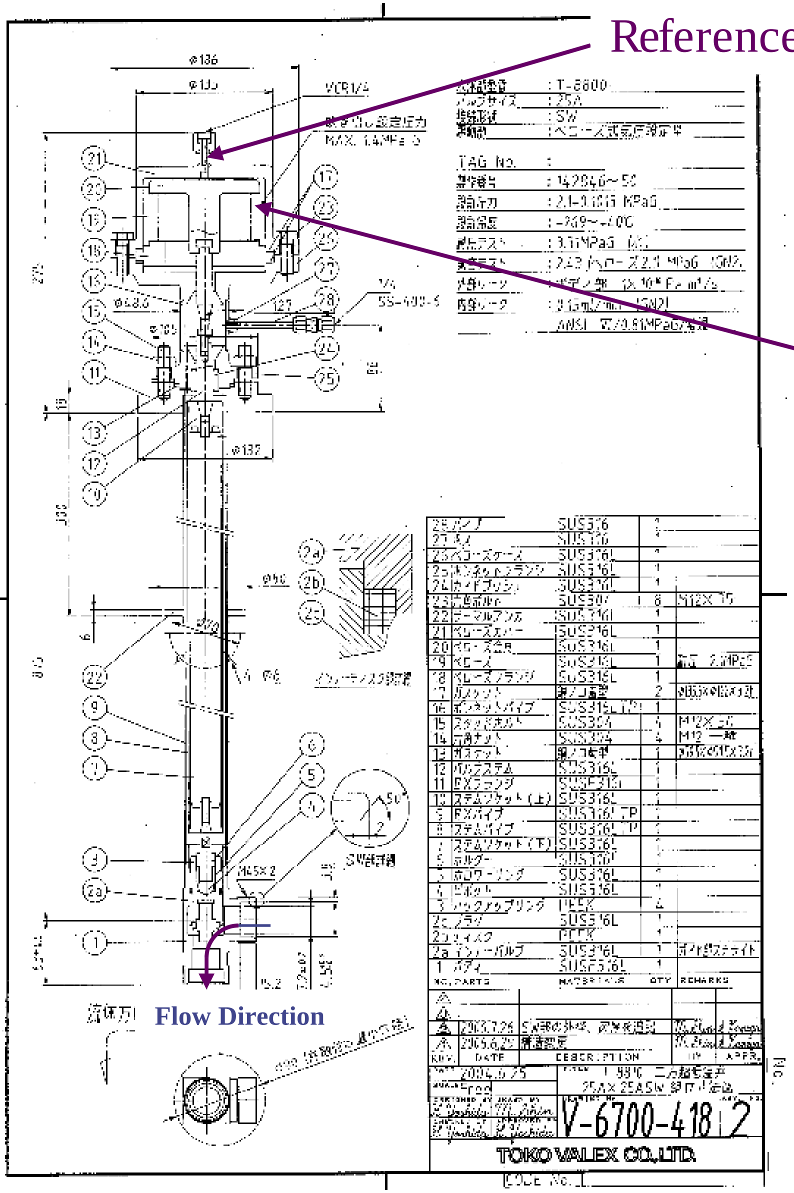
Variable Relief Pressure
with reference pressure
At Pre-cooling: 1.2 MPa
In Operation: 0.45 MPa

Assembling of Inter-connect Cryostat
For Quench Valve

Quench Relief Valve

Conceptual Idea

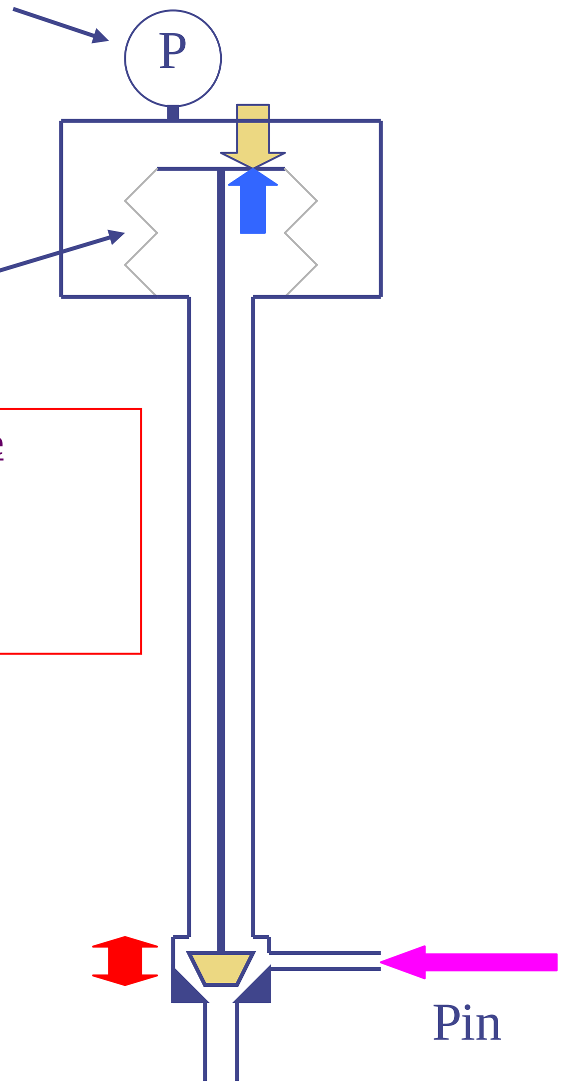
Reference pressure input



Bellows

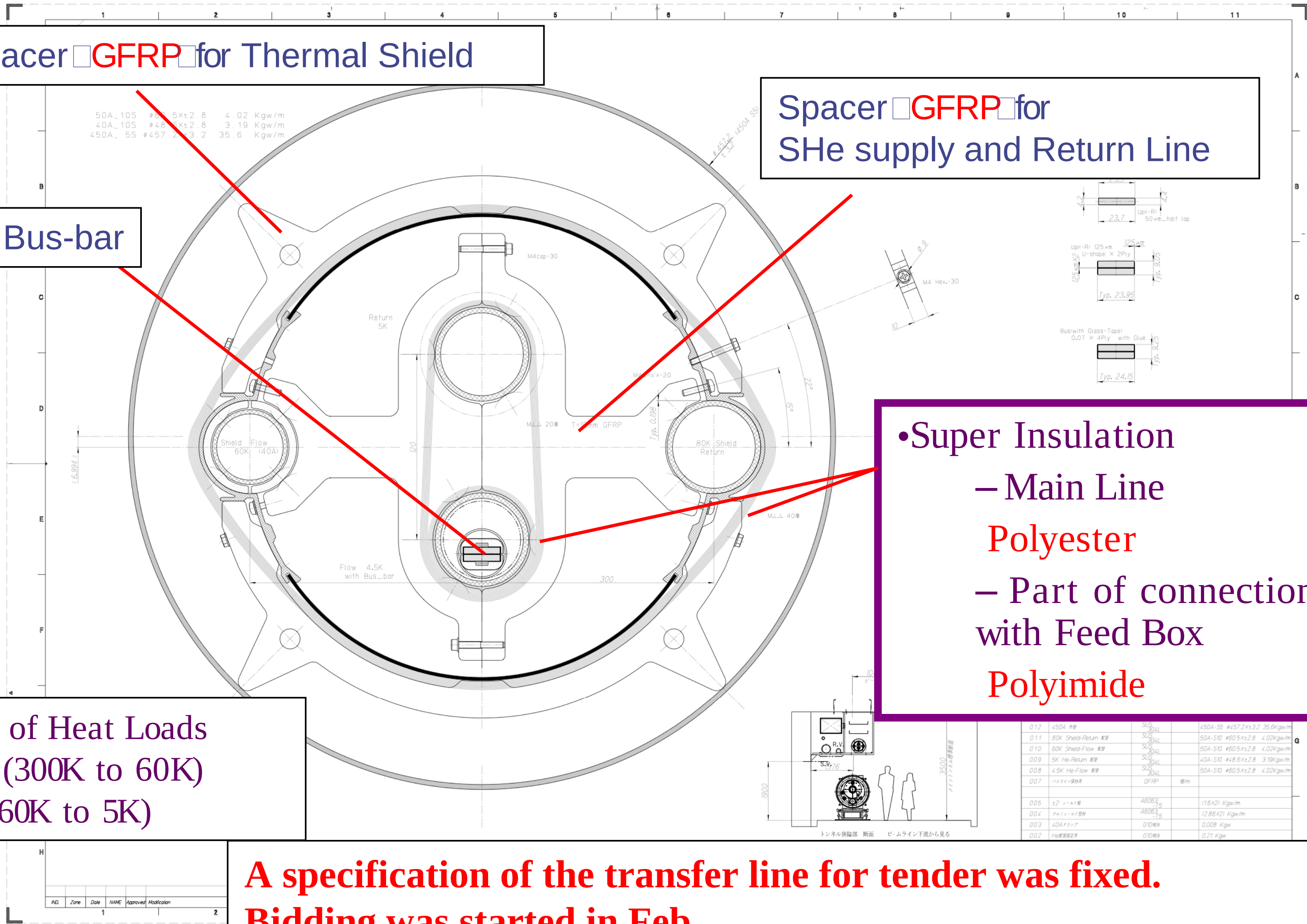
Variable Relief Pressure
by reference pressure

Pre-cooling: 1.2 MPa
In Operation: 0.45 MPa



P >Pin= Close
P <Pin= Open

Cross section of the Transfer Line



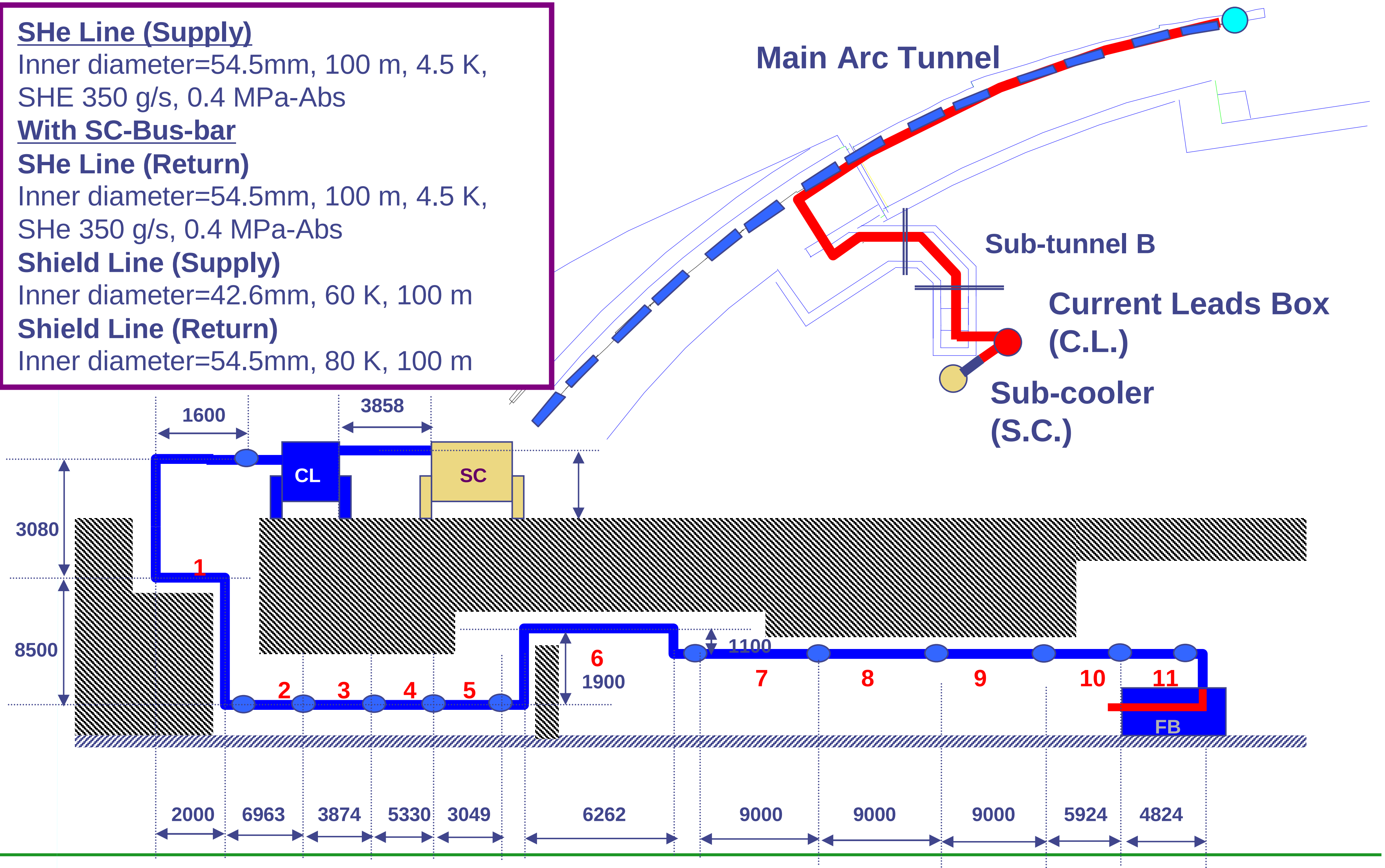
- •Super Insulation
  - – Main Line
    Polyester
  - – Part of connection with Feed Box
    Polyimide

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.

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



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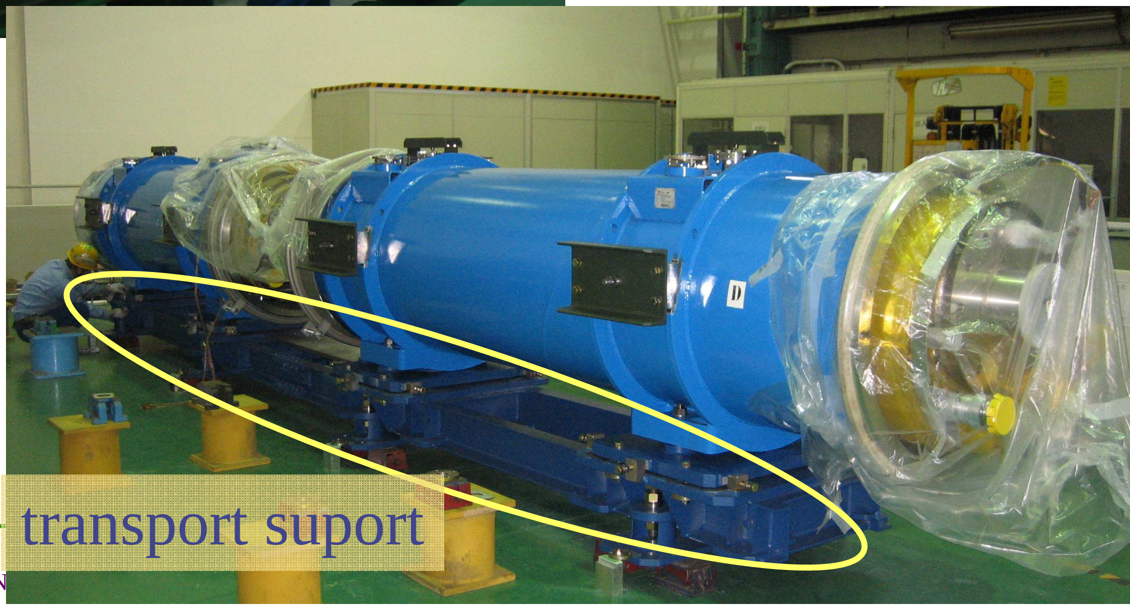
Status on SCFM

- In our project plan, thirty two SCFMs products for T2K.
- All of the SCFMs are testd using with holyzontal cryostat in KEK.
- In this time, twenty eight SCFMs have finished performance test without serious troubles.
- These magnets install in the tunnel with cryostats.
- Left four SCFMs will be done performance test until mid of 2008.
- These four SCFMs will use as reserve magnet.

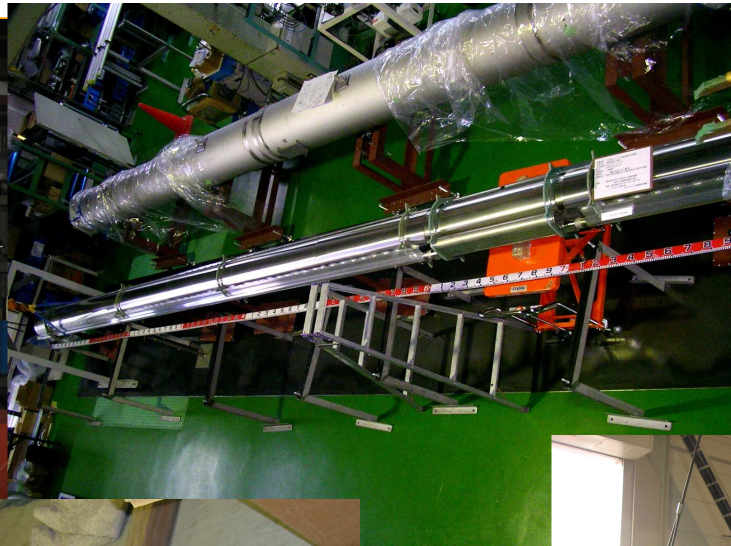
Cryostat Assembly



Status on Dublet Cryostat

Twelve cryostats are completed, and installed in the tunnel.
Left two cryostats and two reserved cryostats are
now under production at Mitsubishi Electric Co..

Status of Transfer Line



Production of Transfer line
was started on end of 2007

First of four units of transfer line were delivered for KEK.

These units will be installed in the tunnel on this July.

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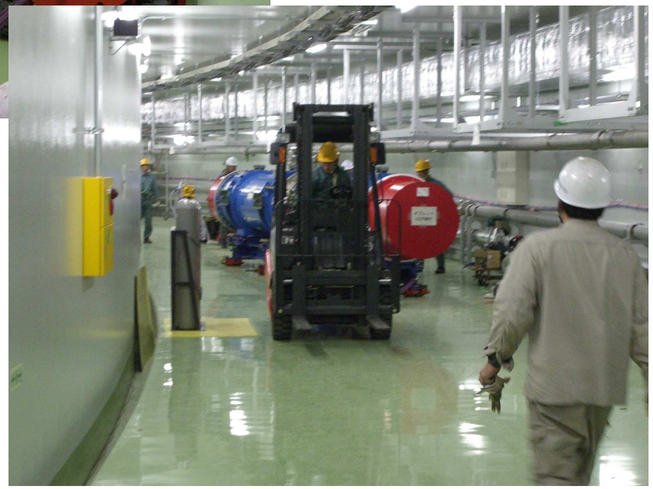
Status on Doublet Cryostat (1)



On 8th Feb. 2008, installation work of
the doublet cryostats were started I
n the tunnel at Tokai.
The above photograph shows the cryostat
into the tunnel by crane.
Left three photographs show
the first cryostat in the tunnel.

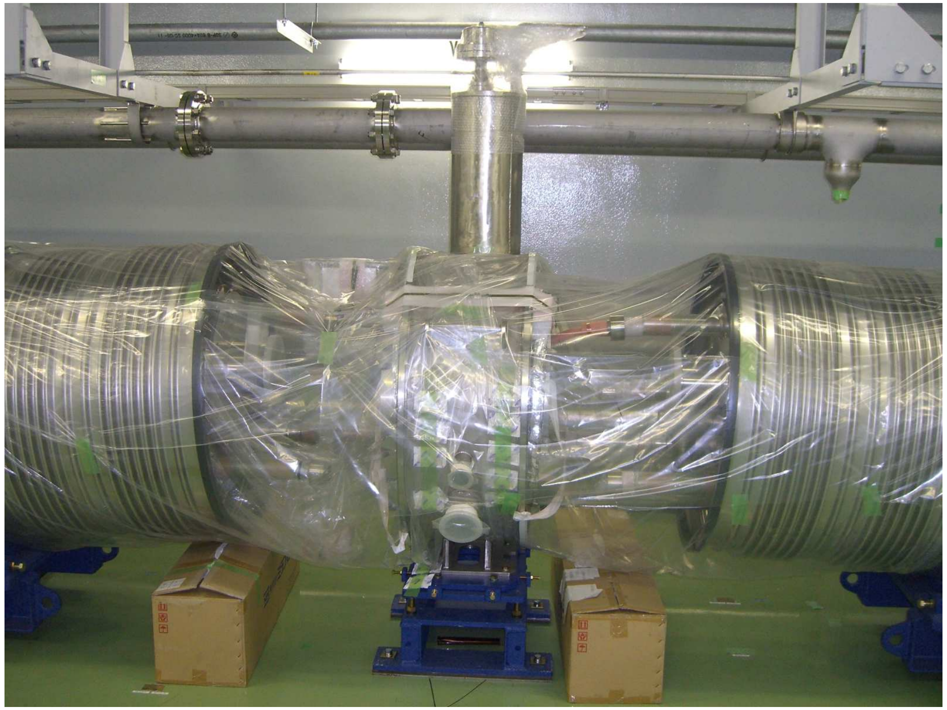
Status on Doublet Cryostat (2)

Doublet cryostats in the tunnel.

eleven doublet cryostats (11/14) were set on the beam line.

The cryostats were tighten by bolts.

Status on Quench Valve Cryostat



Four Quench Valve inter-connect cryostats were transferred in to the tunnel

Three Quench Valve inter-connect cryostats were set on right position in the system.

Status on other component

Quench pressure relief lines were installed in the tunnel.
The lines will be connected with quench relief valve cryostat and stack.

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Summary

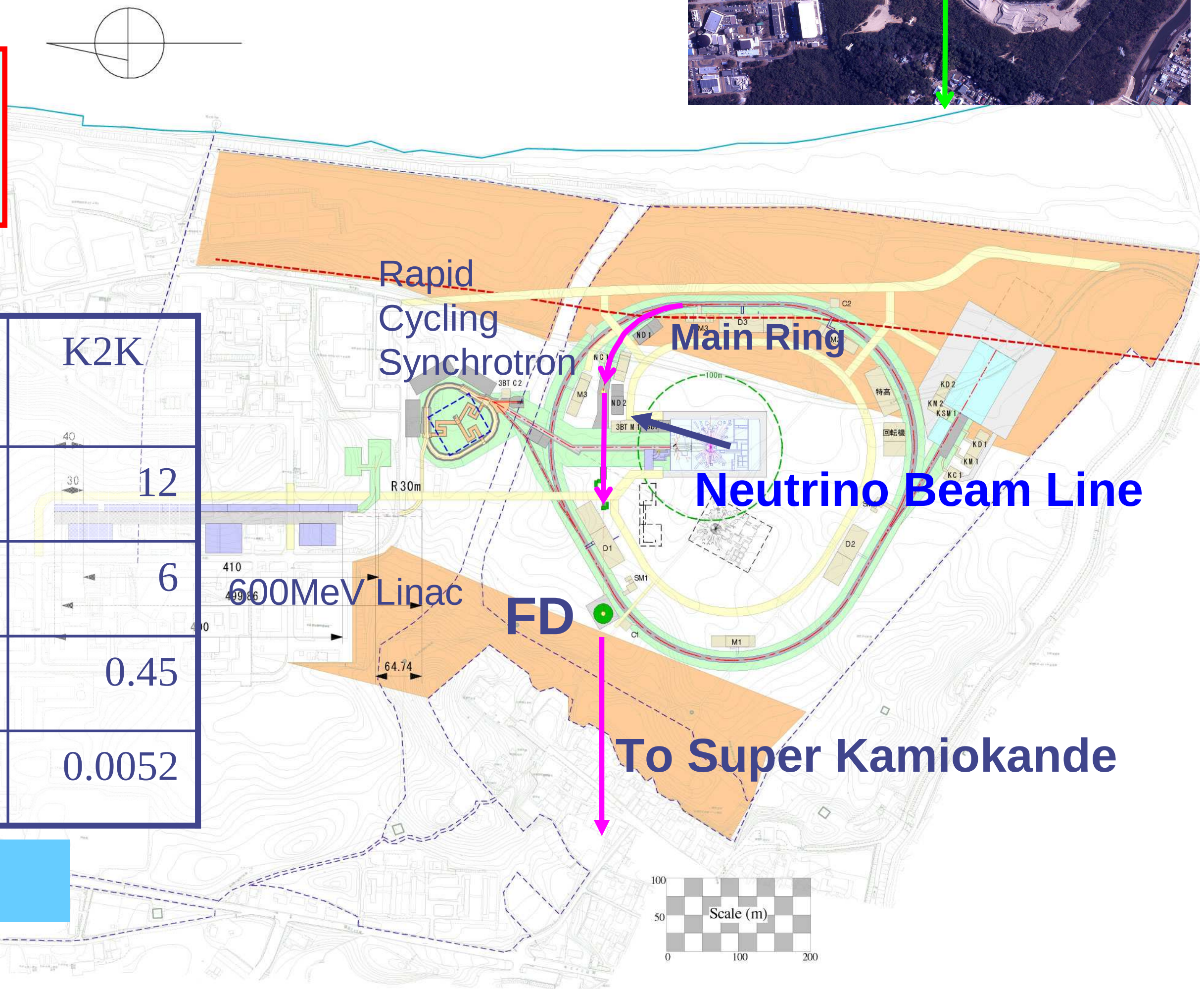
- Twenty eight SCFMs have finished performance test without serious troubles.
- Twelve doublet cryostats have been completed, and installed in the tunnel.

  Left two doublet cryostats and two reserved cryostats are now under production at Mitsubishi Electric Co..
- Three quench relief valve cryostats and two corrector magnet cryostats have installed in the tunnel.
- First of four units of transfer line were delivered for KEK.

  These units will be installed in the tunnel on this July.
- A cold box manufactured by LINDE and components such as a Helium compressor will be delivered Tokai at mid of May 2008.

J-PARC project and Neutrino beam line

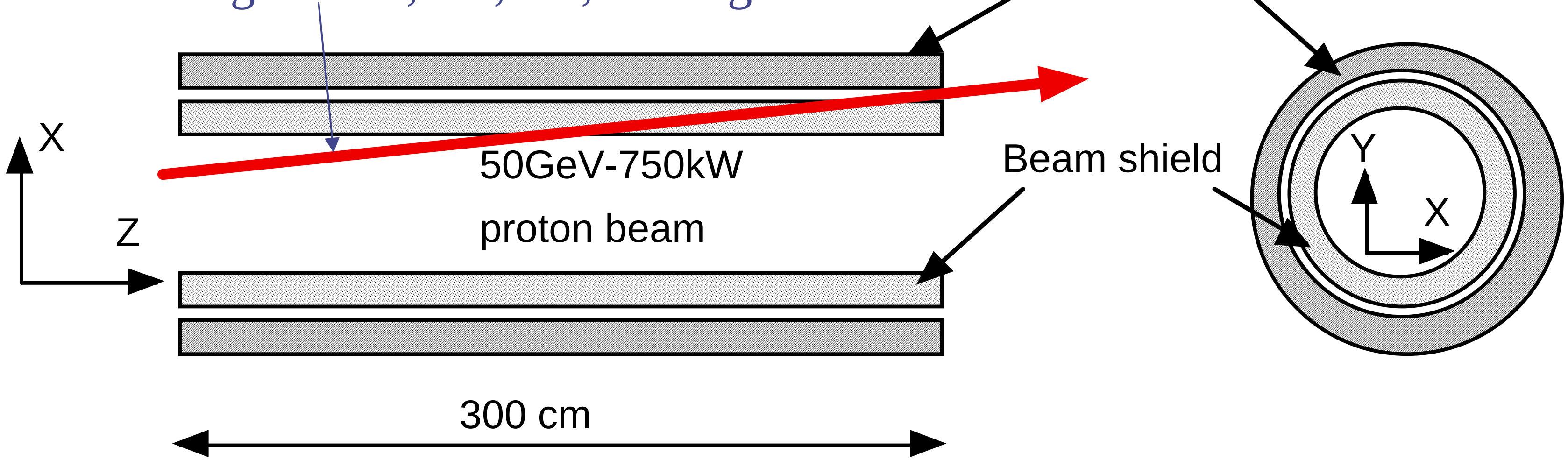
JAEA@Tokai-mura
(60km N.E. of KEK)



	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”

Incident angle = 0.1, 0.5, 1.0, 1.4 degs.

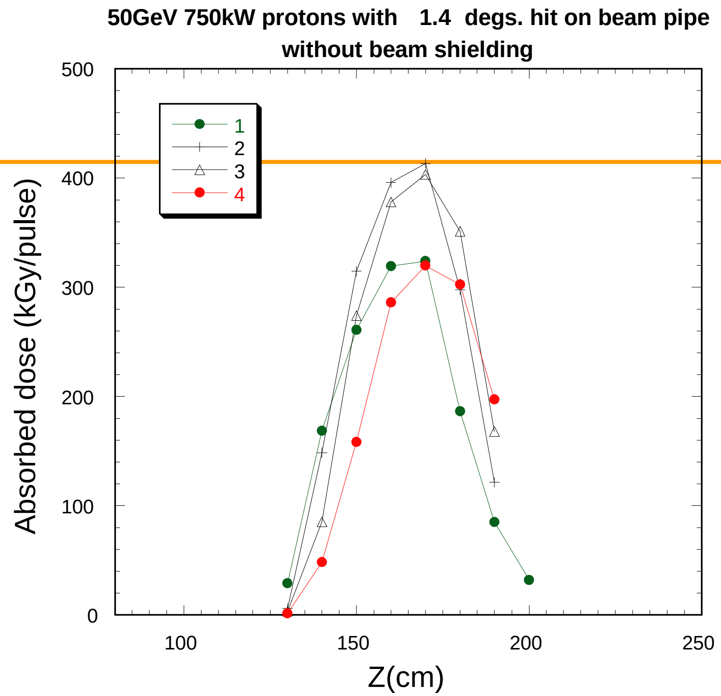


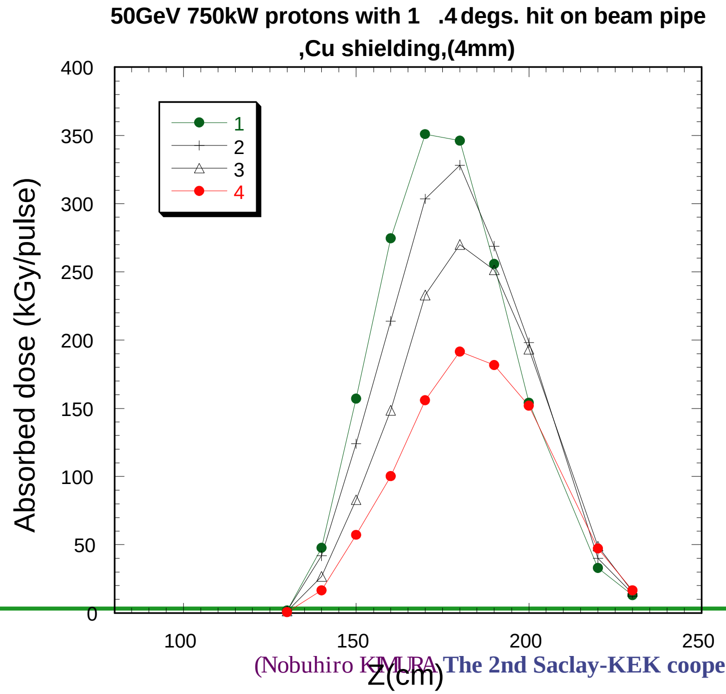
The beam is distributed uniformly rectangular area. dX=1cm,dY=2cm

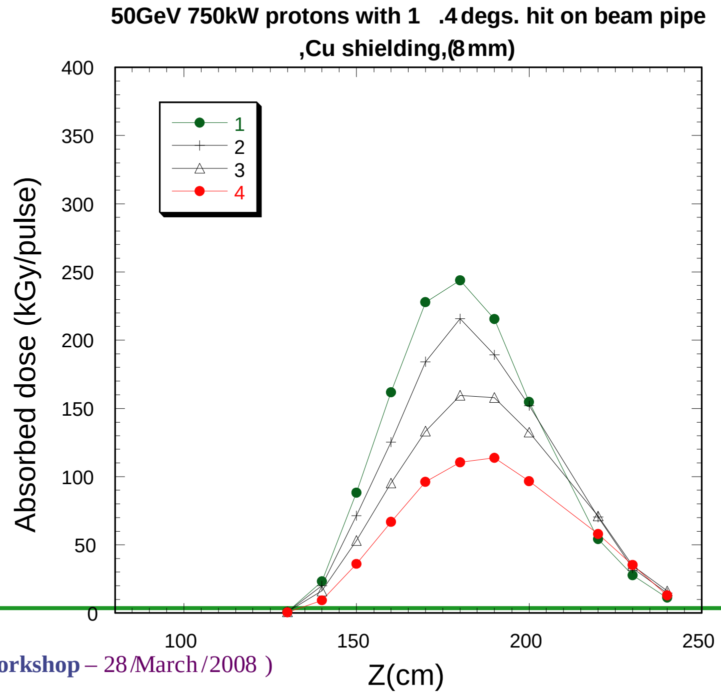
-	Beam shield	Beam tube
Material	Copper	Stainless
Radius (mm)	~74	76~84
Thickness(mm)	0, 4, 8, 10	8

Heat input

QuickTimeý Ç²
TIFFÅiLZWÅj êLí£ÉvÉçÉOÉâÉÄ
Ç™Ç±ÇÃÉsÉNÉ`ÉÉÇ¾å©ÇÈÇžÇ½Ç…ÇÕïKóvÇ-Ç□ÅB





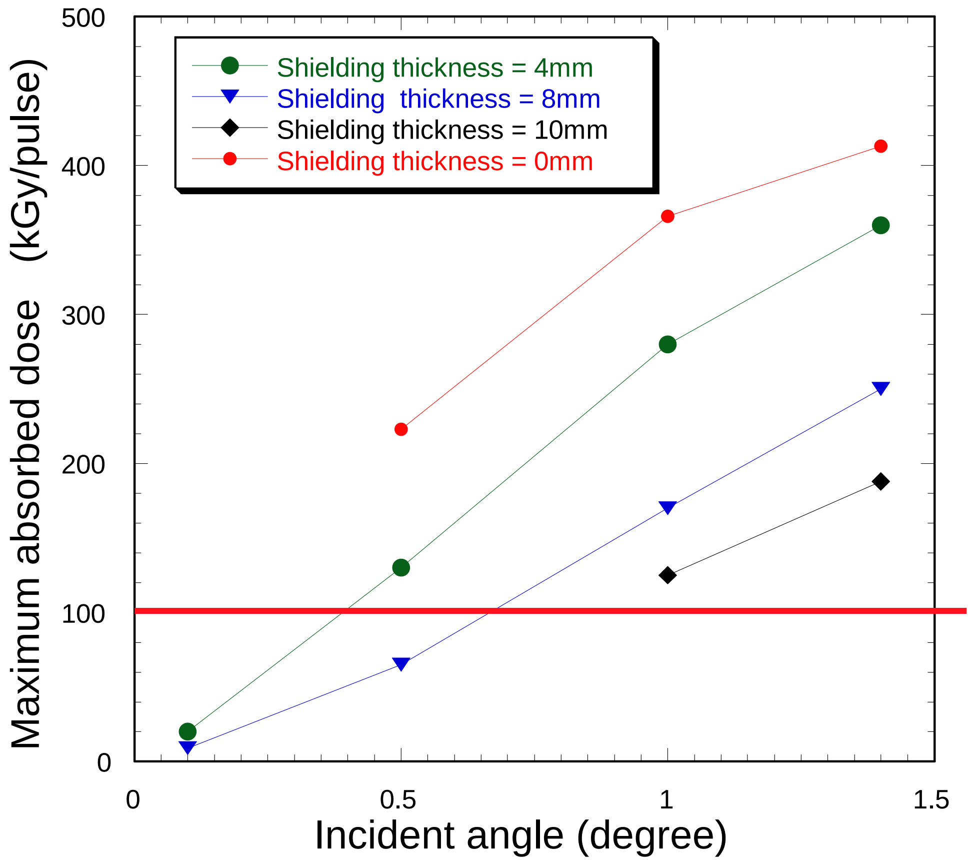


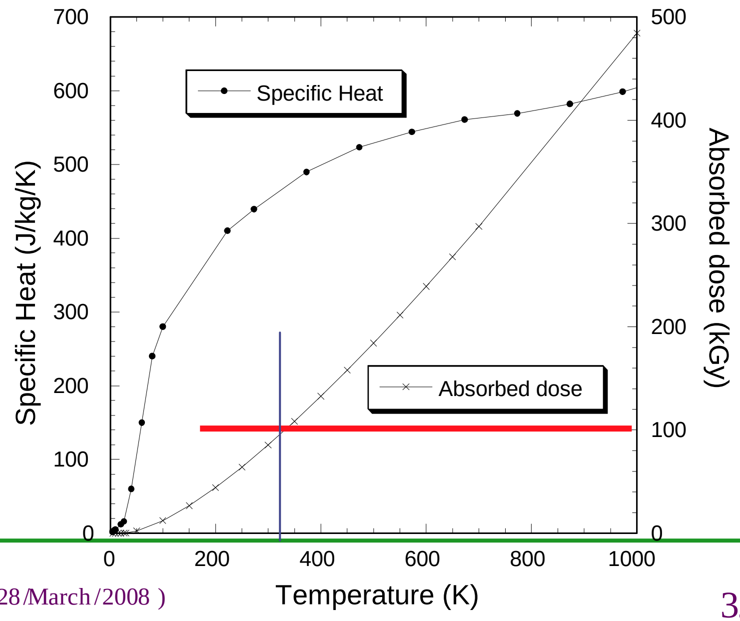
Simple estimation: $\sigma_{th} = \frac{2-\nu}{3(1-\nu)} \cdot E \cdot \int_0^T \alpha \cdot dT$

100kGy/pulse

$\sigma_{th} = 0.52\text{GPa}$

~ Tensile Strength @ 300K





[illegible]

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  - 10mm[illegible]

- [illegible]
  - [illegible]π
  - [illegible]130mm

    →[illegible]10mm

- [illegible]
  - [illegible]

[illegible]

- [illegible]
  - [illegible]
  - [illegible] π
    - [illegible]
  - [illegible]

  → [illegible]

[illegible]

[illegible]

[illegible]

–

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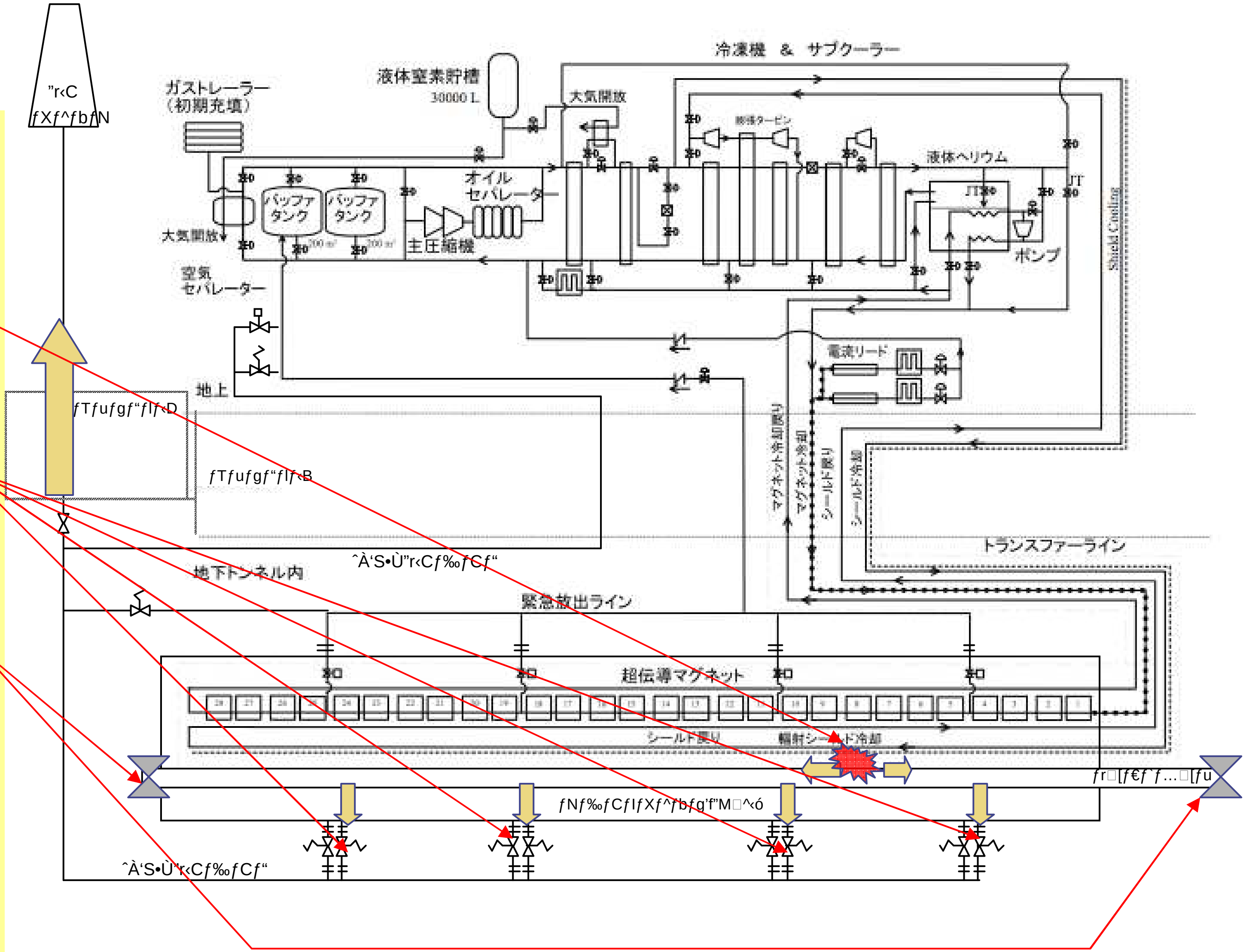
– 0.1MPa

– 50GeV

– 0.3MPa



[illegible]

- [illegible]
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- [illegible]
  - [illegible] 35msec [illegible]
  - [illegible] → [illegible]
  - [illegible] 1msec [illegible]
- [illegible]
  - [illegible] 0.1MPa
  - [illegible] 0.3MPa
  - [illegible]

[illegible]

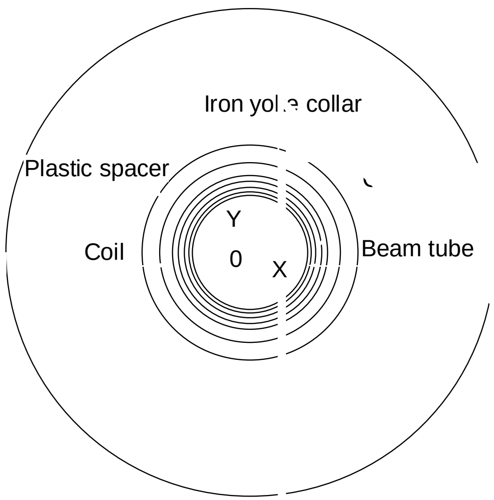
- [illegible]
  - MARS
  - 1 w/m, 4000 hr/year

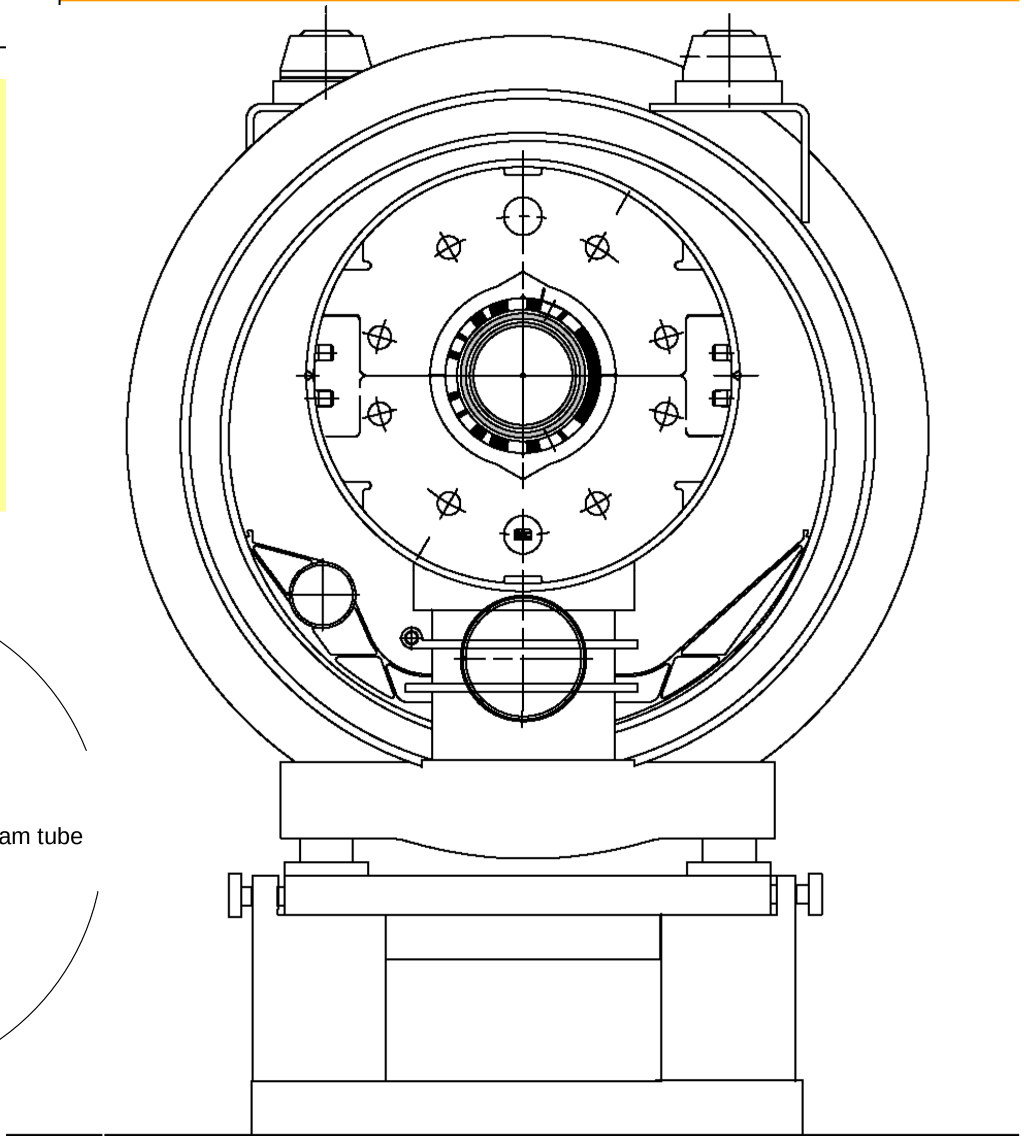
X

0 Z

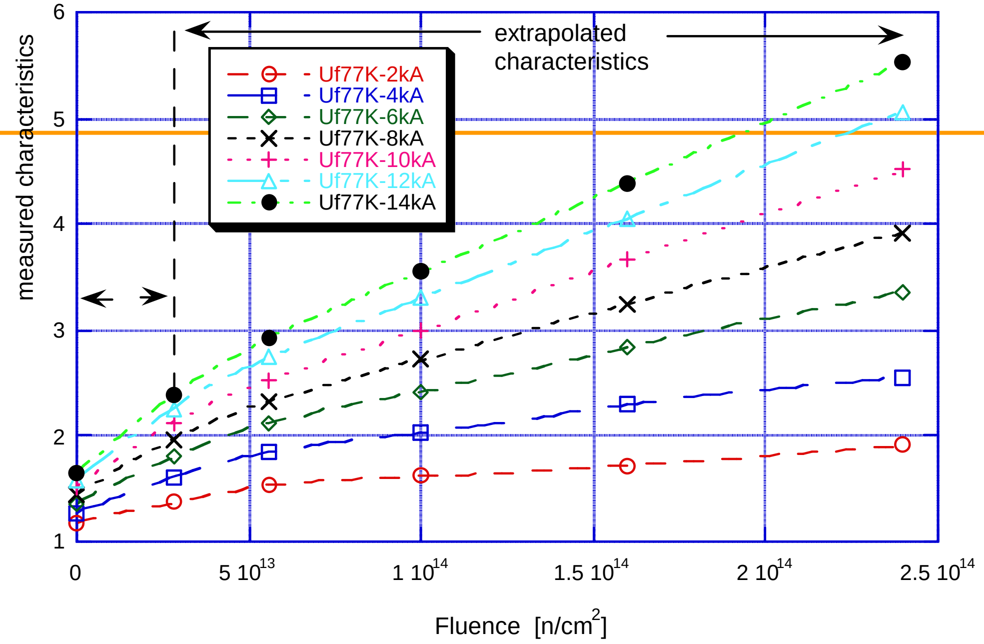
50GeV-1W/m

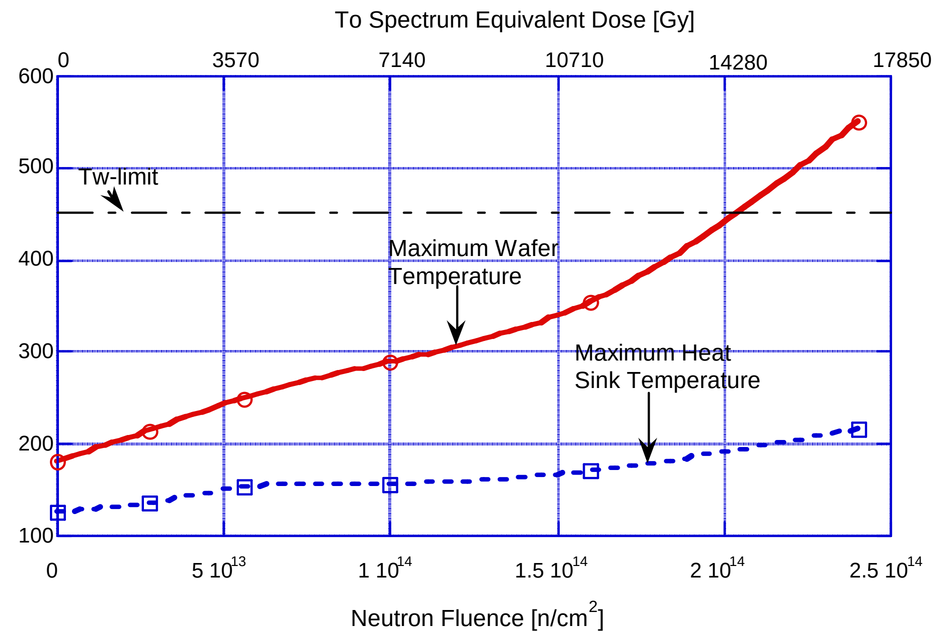
330 cm





Radiation to Cold Diode

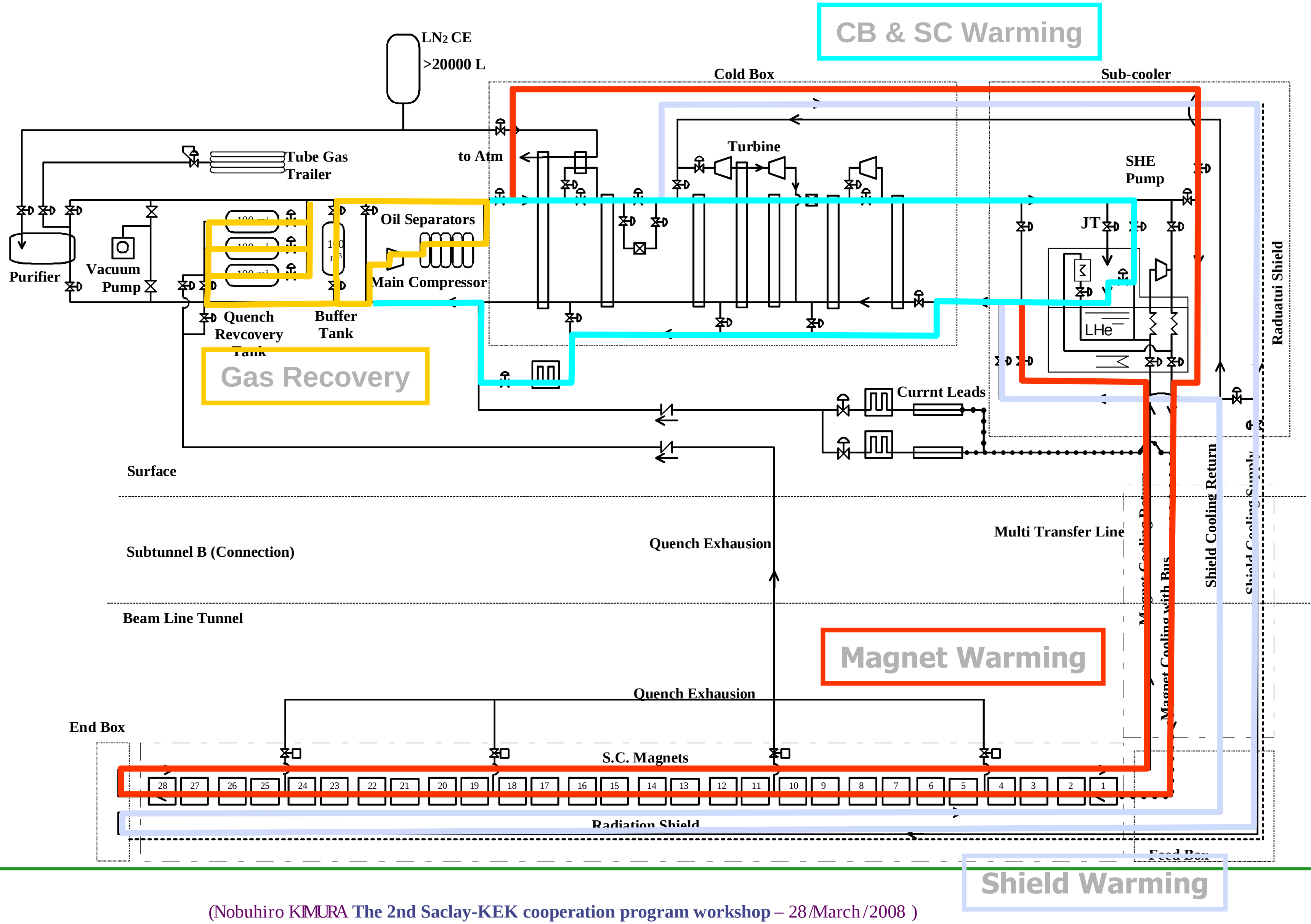




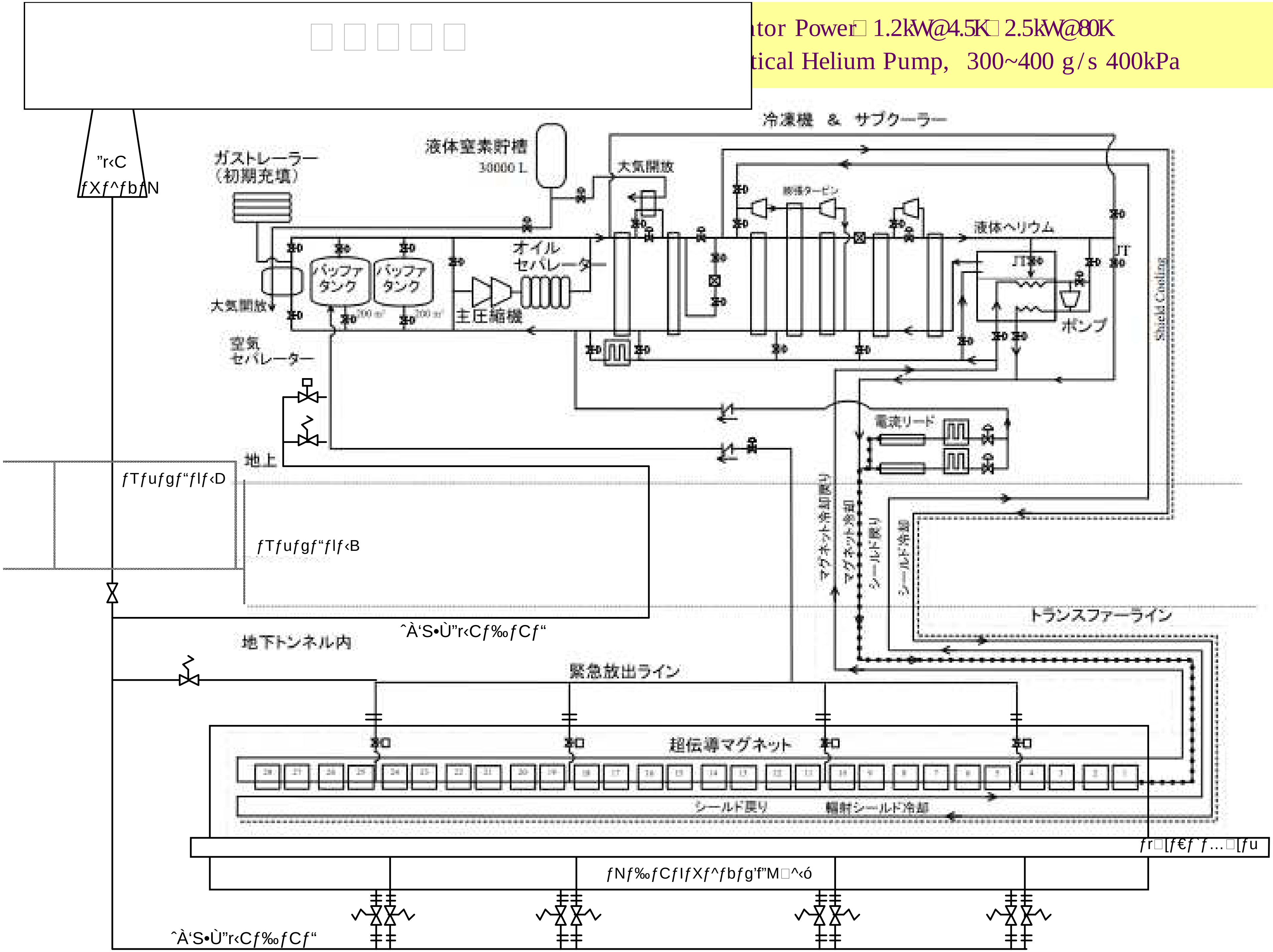
- Influence of Neutron to Cold Diode
  - Intensively studied at CERN by D. Hagedorn
    - Change Forward Voltage
  - Using LHC Arc Quad Assembly
    - 7.5kA Operation
    - Limit; 2• 10^{14} n/cm^{2}

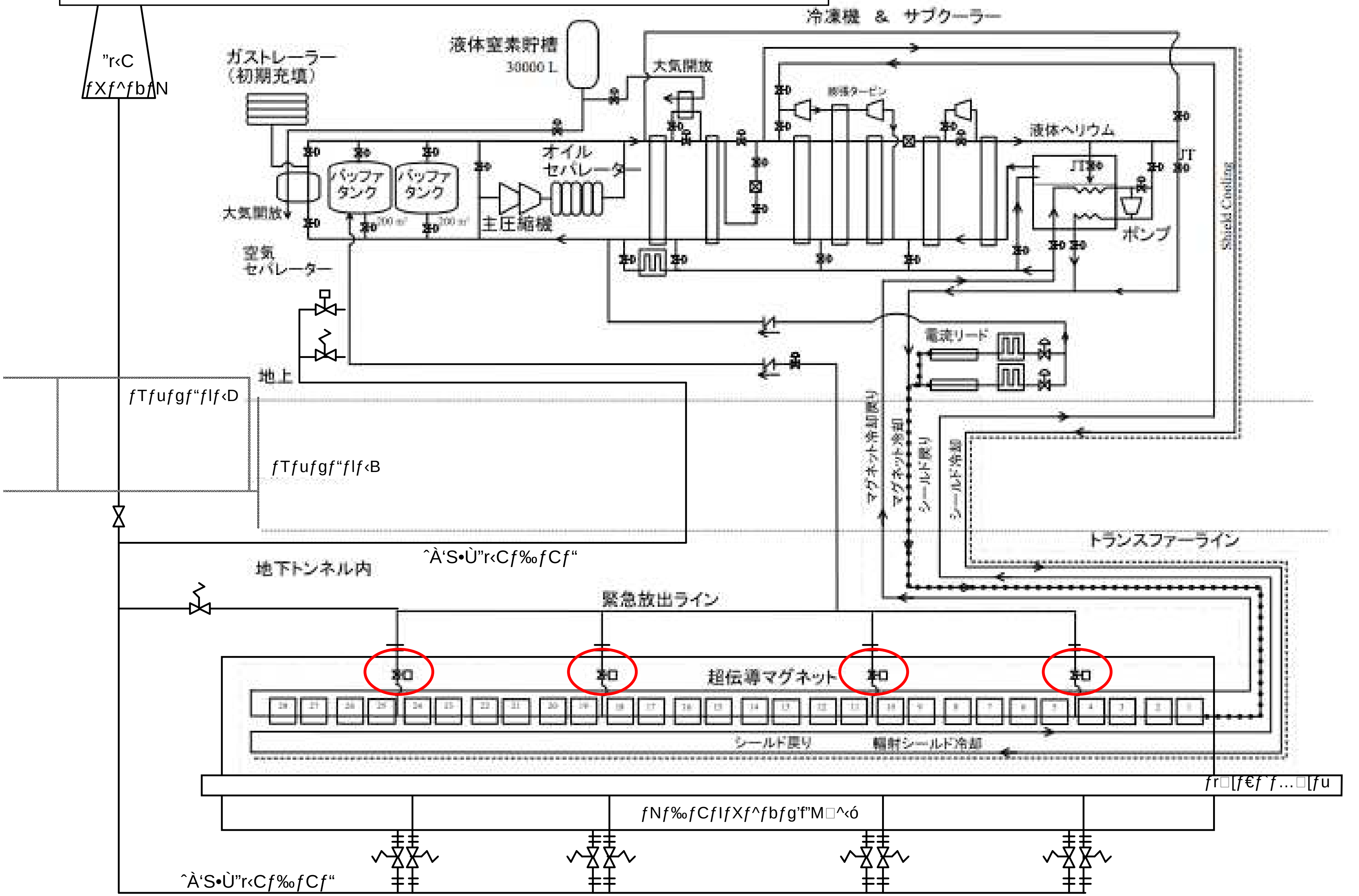
Courtesy D.Hagdorn

5. Operation - Warming



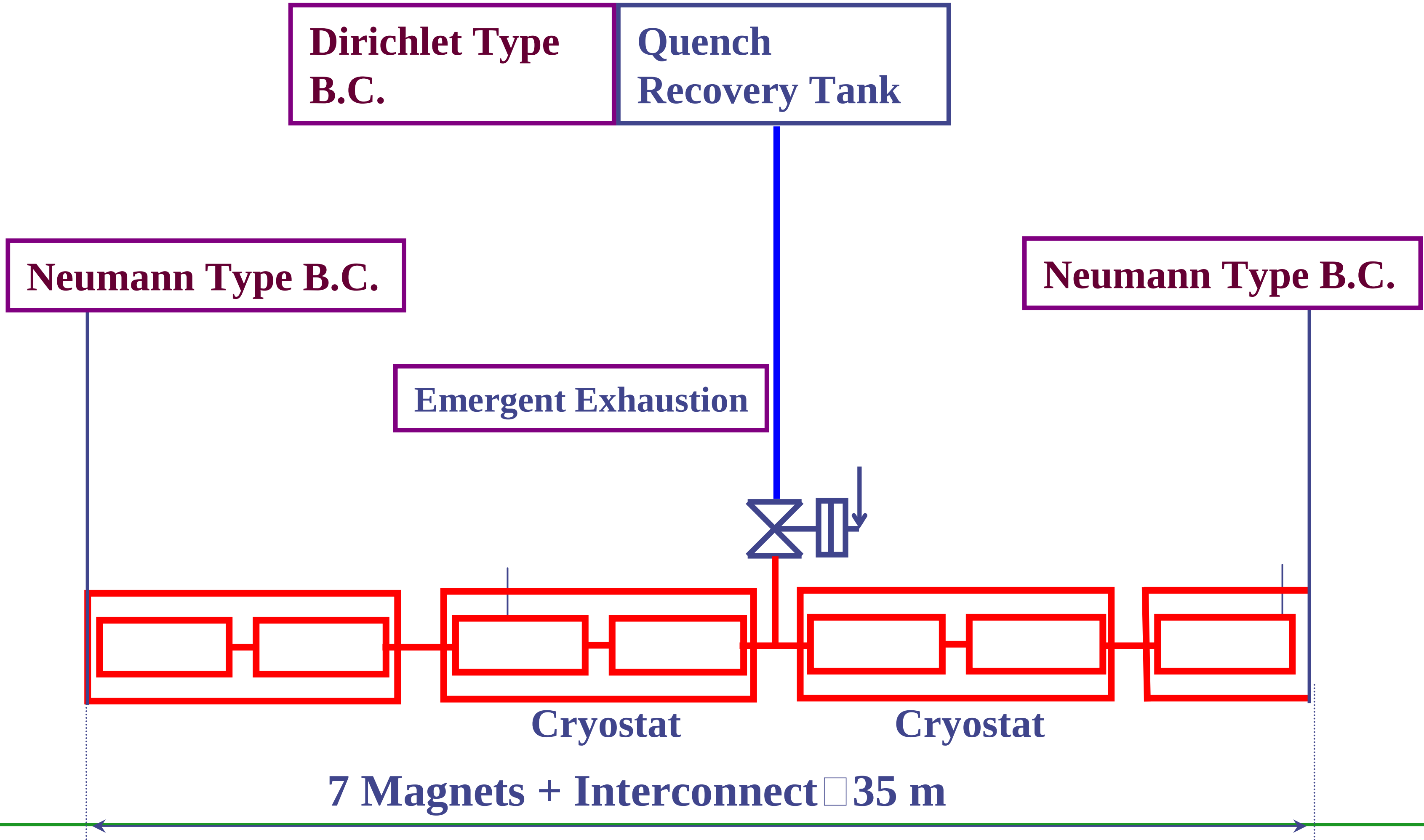
ator Power 1.2kW@4.5K 2.5kW@80K
tical Helium Pump, 300~400 g/s 400kPa

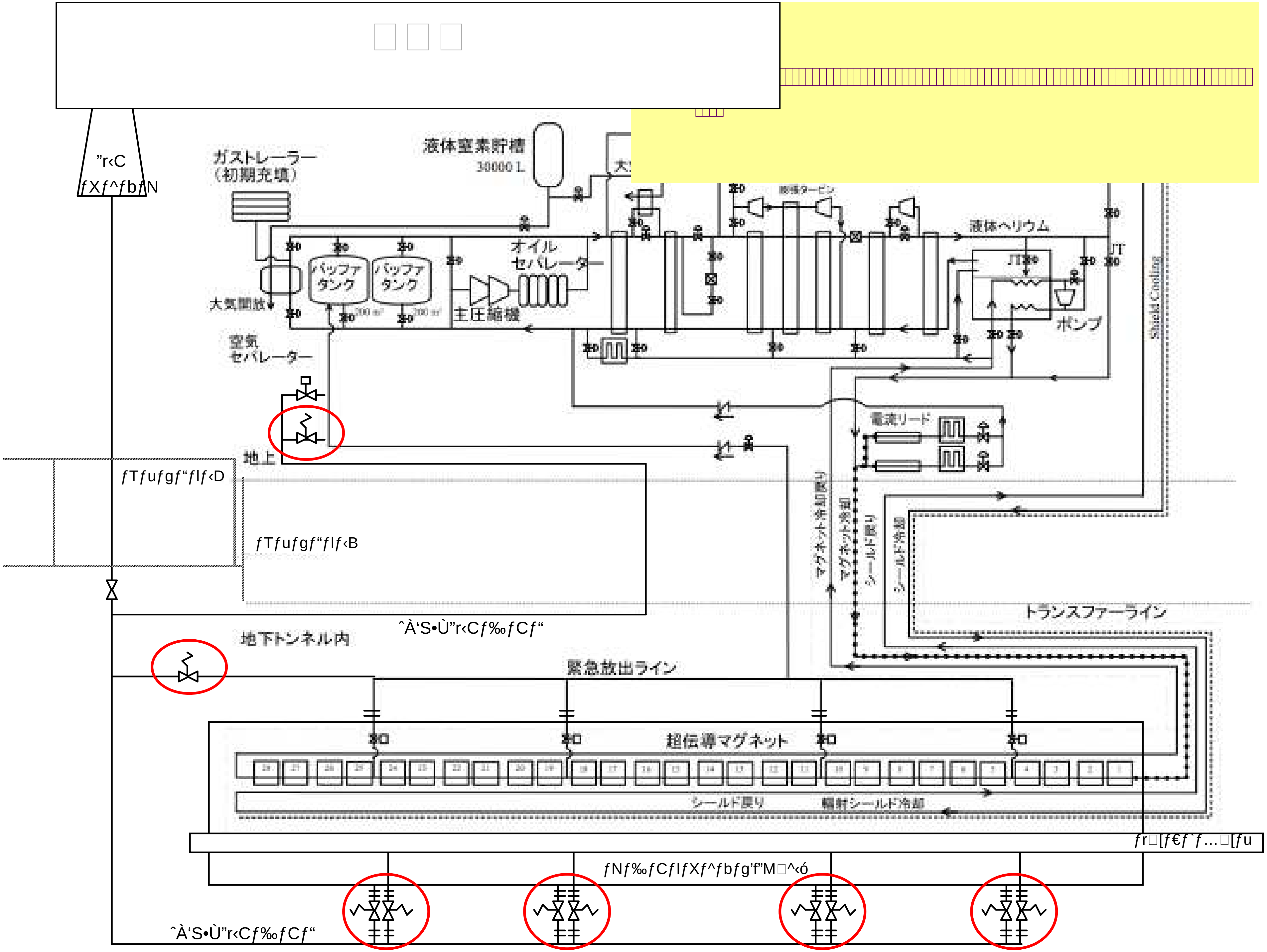




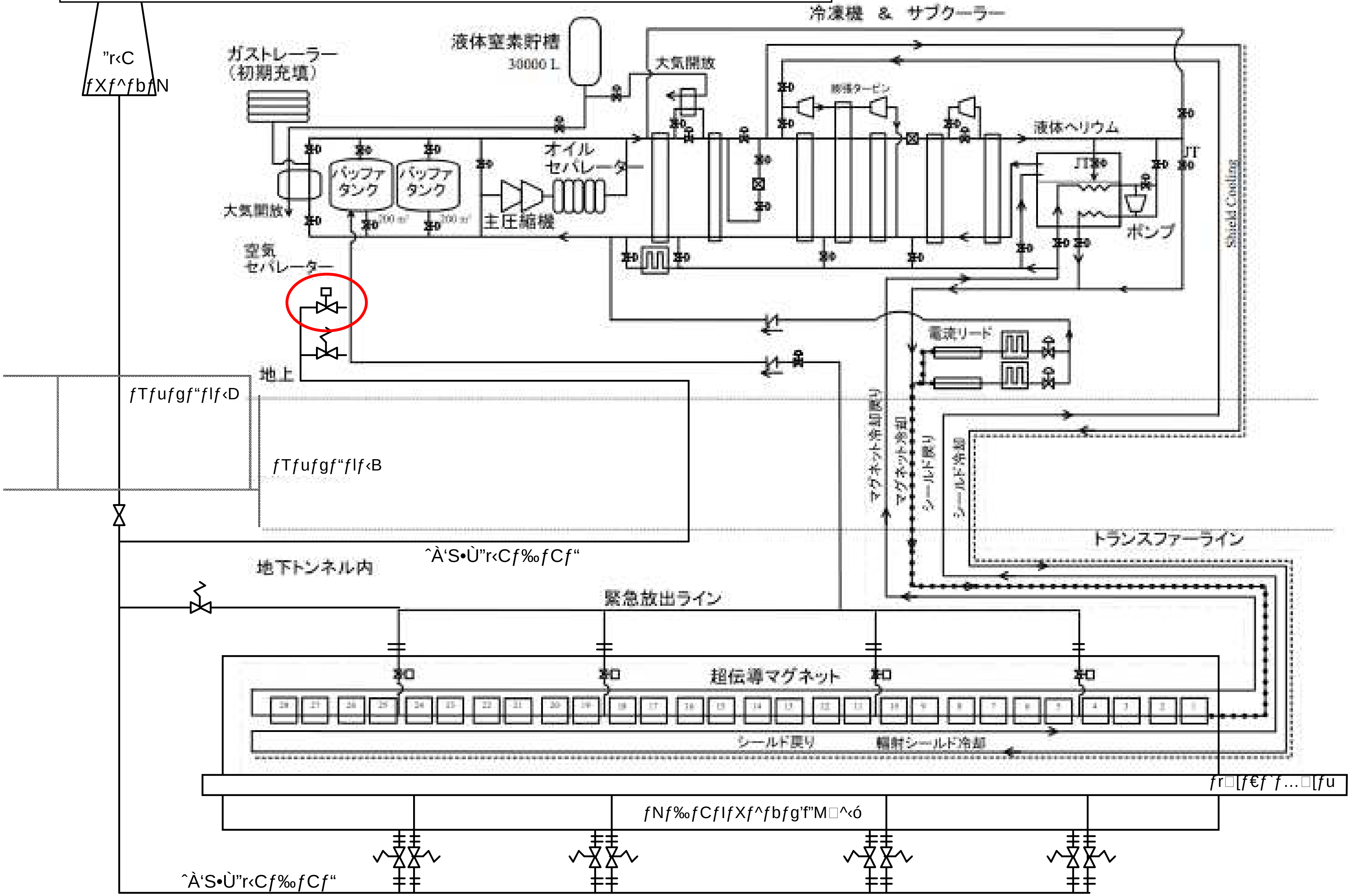
冷凍機 & サブクーラー
液体窒素貯槽
30000 L
ガストレーラー
（初期充填）
大気開放
バッファ
タンク
200 m³
オイル
セパレーター
主圧縮機
空気
セパレーター
膨張タービン
液体ヘリウム
JT
ポンプ
Shield Cooling
電流リード
マグネット冷却戻り
マグネット冷却
シールド戻り
シールド冷却
トランスファーライン
地上
地下トンネル内
緊急放出ライン
超伝導マグネット
シールド戻り
輻射シールド冷却

Strict analytical model

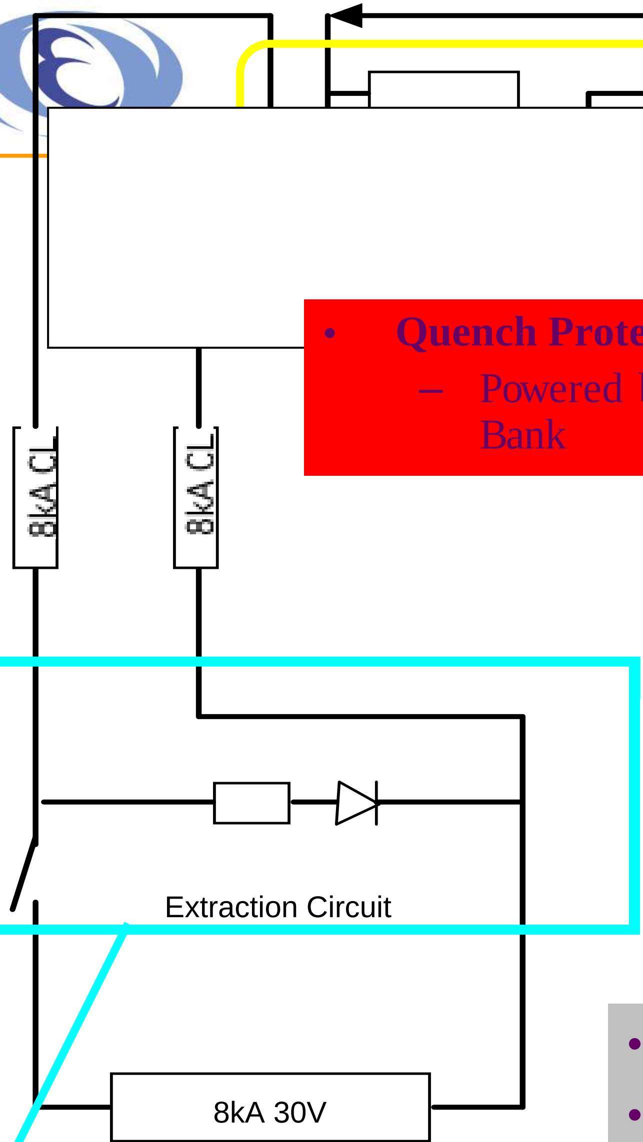




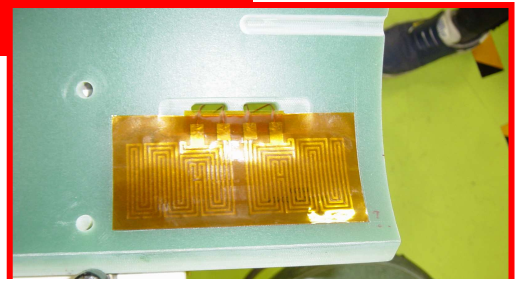
液体窒素貯槽
30000 L
ガストレーラー
（初期充填）
大気開放
バッファ
タンク
バッファ
タンク
200 m³
200 m³
オイル
セパレーター
主圧縮機
空気
セパレーター
膨張タービン
液体ヘリウム
JT
ポンプ
Shield Cooling
電流リード
地上
マグネット冷却戻り
マグネット冷却
シールド戻り
シールド冷却
トランスファーライン
地下トンネル内
緊急放出ライン
超伝導マグネット
シールド戻り
輻射シールド冷却



”r‹C ƒXƒ^ƒbƒN
ガストレーラー（初期充填）
液体窒素貯槽
30000 L
大気開放
冷凍機 & サブクーラー
膨張タービン
液体ヘリウム
バッファタンク
バッファタンク
200 m³
200 m³
オイルセパレーター
主圧縮機
大気開放
空気セパレーター
JT
JT
ポンプ
Shield Cooling
電流リード
地上
ƒTƒuƒgƒ“ƒlƒ‹D
ƒTƒuƒgƒ“ƒlƒ‹B
マグネット冷却戻り
マグネット冷却
シールド戻り
シールド冷却
トランスファーライン
ˆÀ‘S•Ù”r‹Cƒ‰ƒCƒ“
地下トンネル内
緊急放出ライン
超伝導マグネット
シールド戻り
輻射シールド冷却
ƒNƒ‰ƒCƒIƒXƒ^ƒbƒg’f”M
ˆÀ‘S•Ù”r‹Cƒ‰ƒCƒ“



- **Quench Protection Heater**
  - Powered by Capacitor Bank



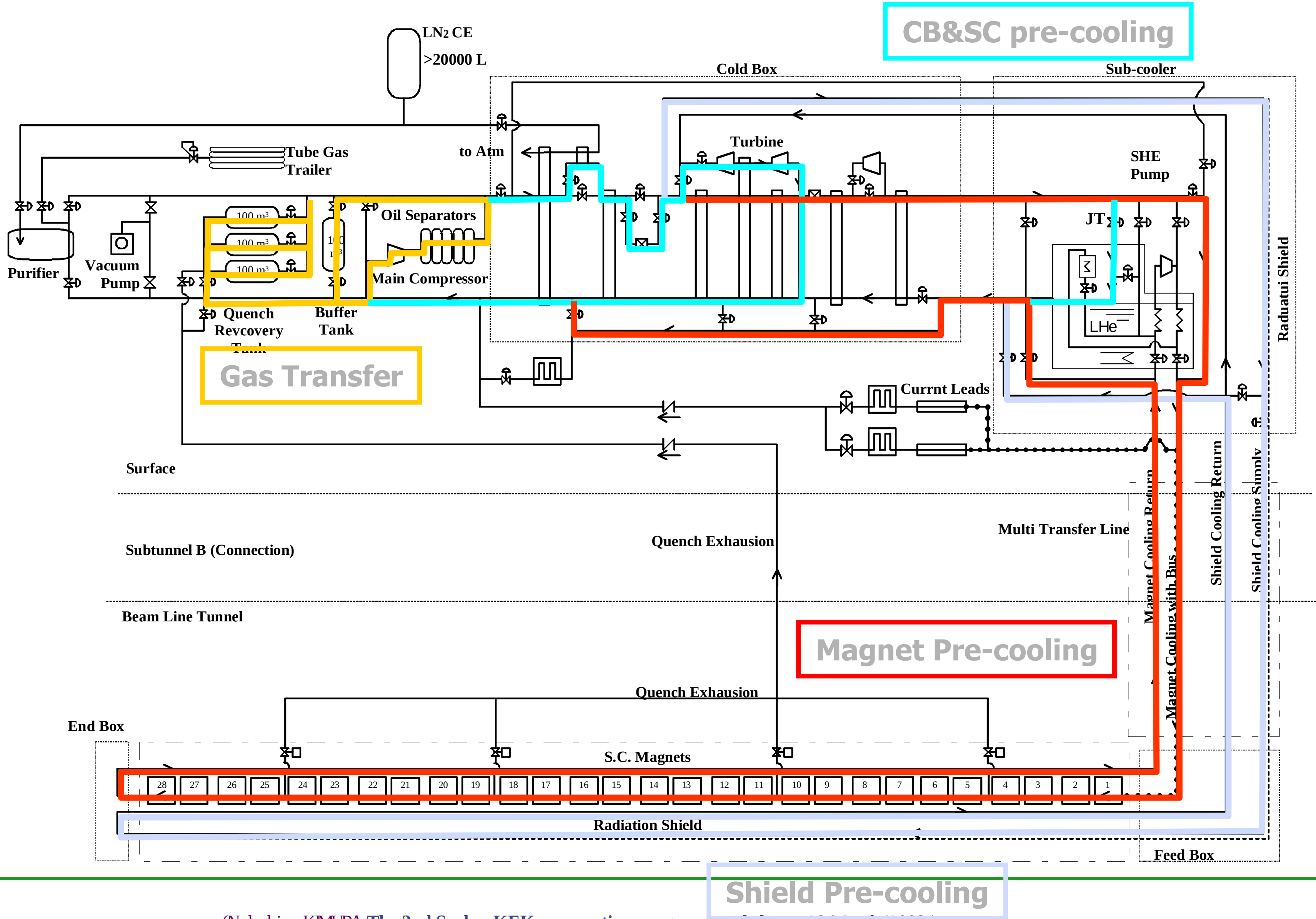
- **Cold Diode**
  - Turn On Voltage: 6V
  - Forward Voltage: 1V

- **Dump Circuit**
  - Protect Cold Diodes and SC Bus Bars
  - Time Constant: 10 sec

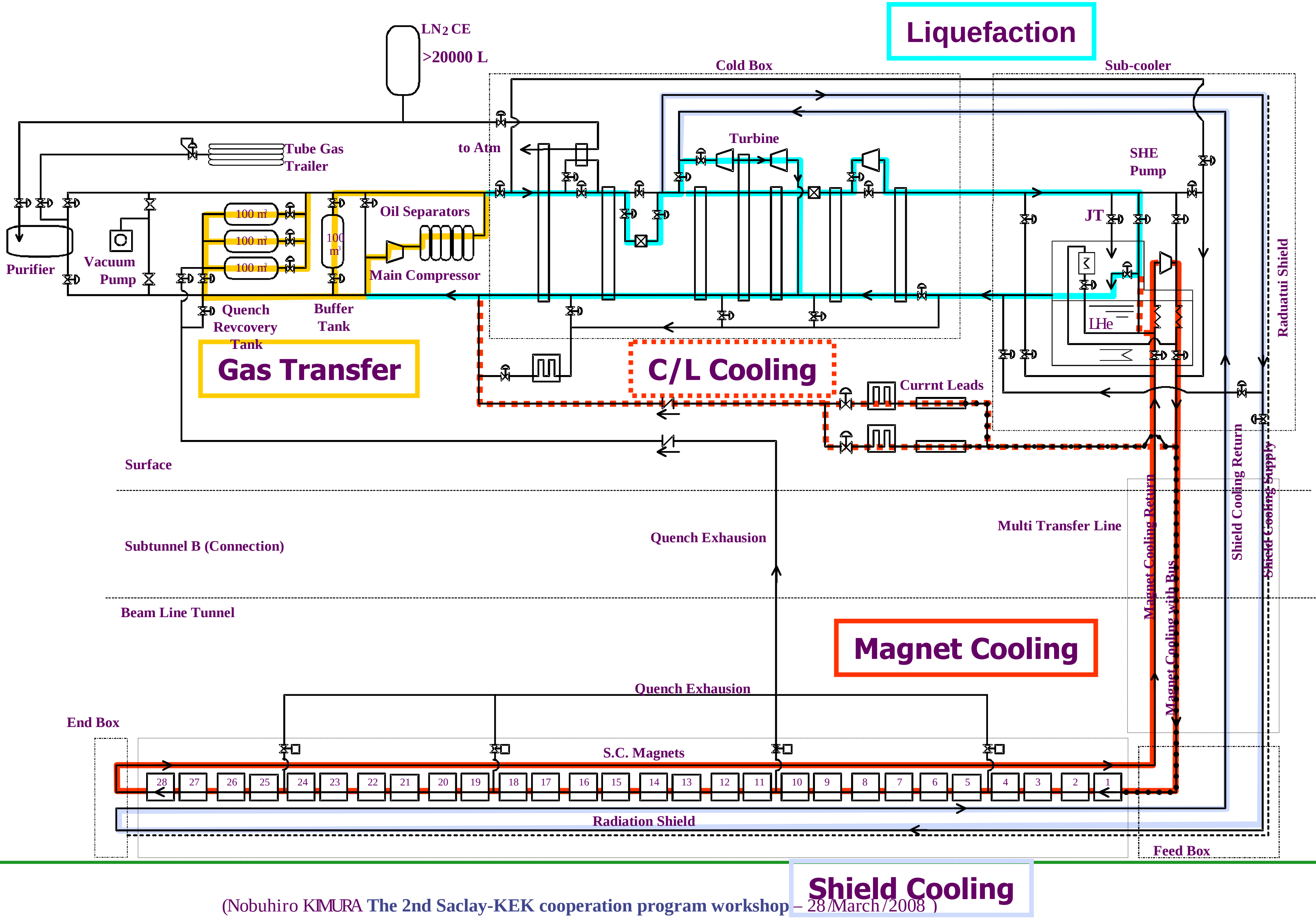
Summary of Load (Magnet & Transfer Lines) to Cryogenic System

	4.5 K Level	Remarks	80 K Level	Remarks
Coolant	SHe	4.5 K□0.4 MPa	He Gas	60□100 K, 1.2 MPa
Heat Load Estimation	336 W	Including beam loss of 150 W transfer line of 55 W	1419 W	Including transfer line of 440 W
Current Lead	1.0 g/s	8000A	-	
+ 20 % Contingency	403 W + 1.1 g/s		1703 W	
Cold Mass	204 ton	Iron basis	6.8 ton 2.5 ton	Aluminum basis Iron basis
+ 10 % Contingency	225 ton	Iron basis	7.5 ton 2.8 ton	Aluminum basis Iron basis
Inventory	3550 ℓ		1620 ℓ	
+ 10 % Contingency	3900 ℓ		1780 ℓ	
Pressure Drop	84 kPa	300 g/sec, 4.5 K, 0.4 MPaAbs	36 kPa	40 g/sec, 80 K, 1.35 MPa
Design Pressure	>1.4 MPa(G)		>1.4 MPa(G)	

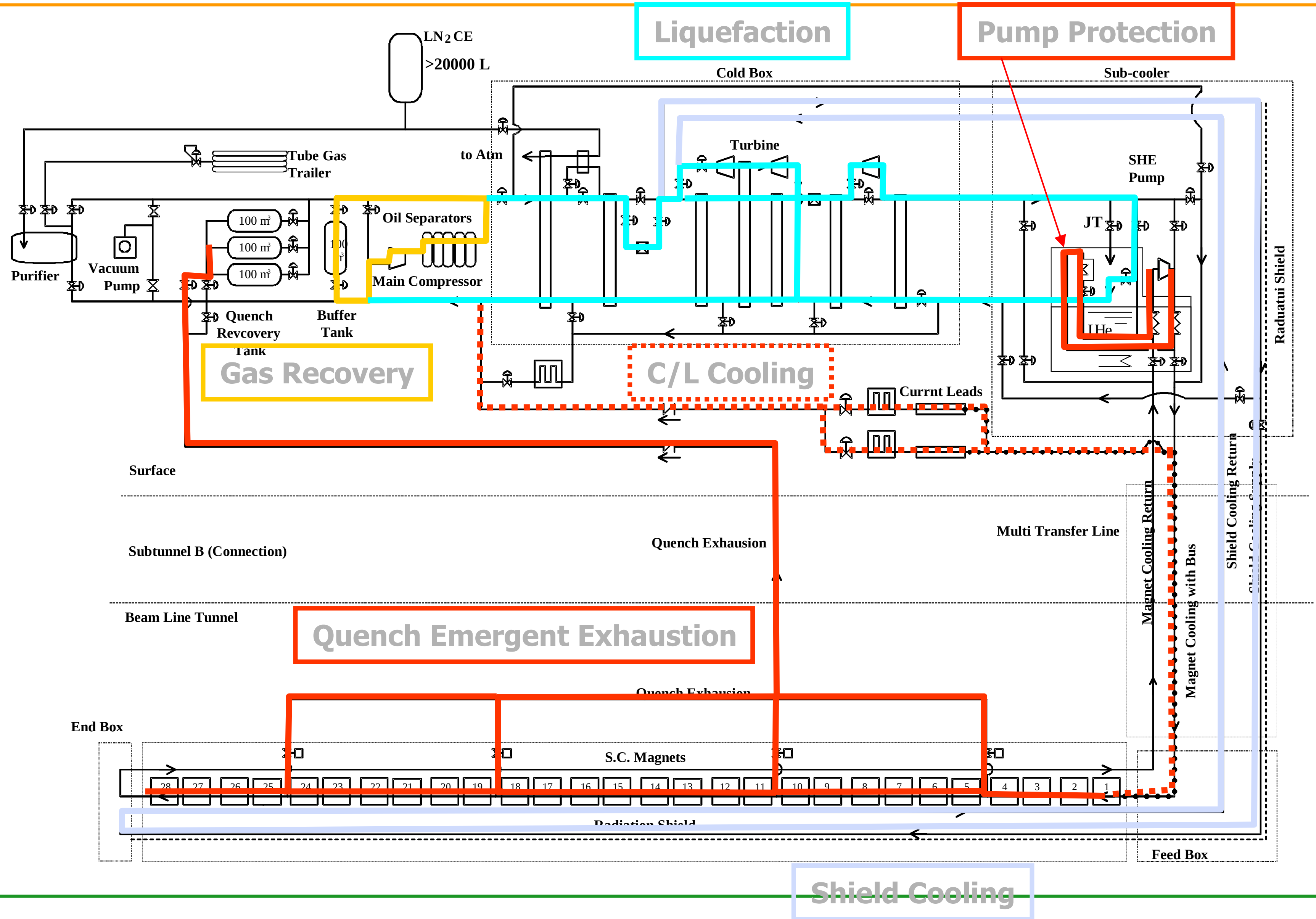
Operation – Pre-cooling



Operation – Magnet Excitation (Steady state)



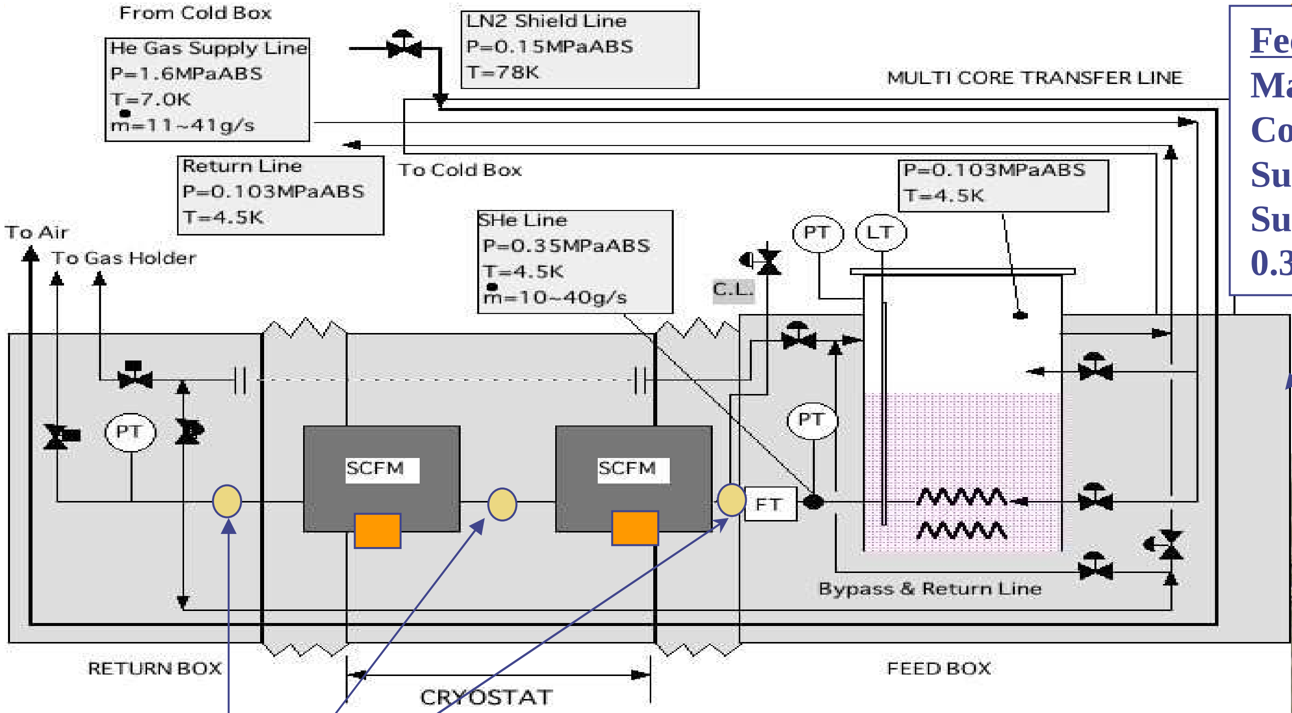
Operation - Quench



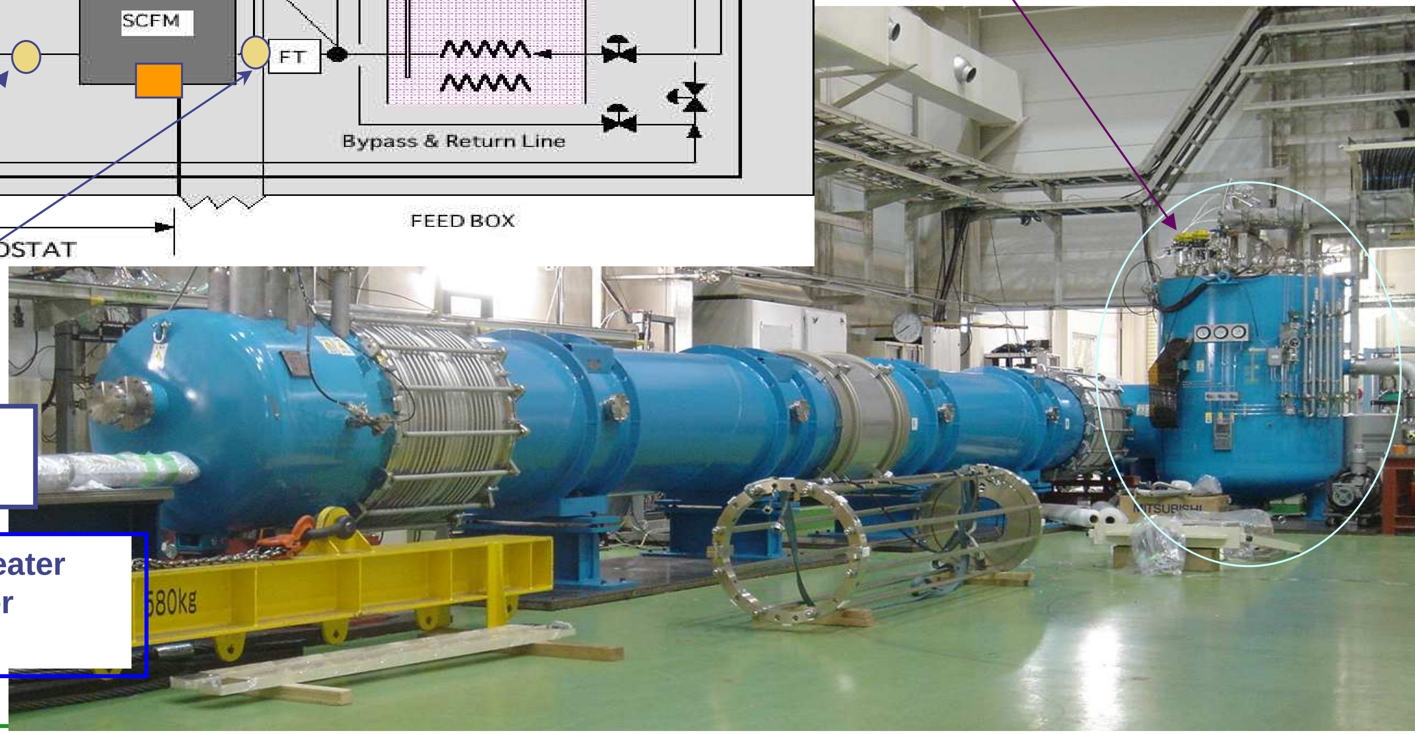
Schedule

	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

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



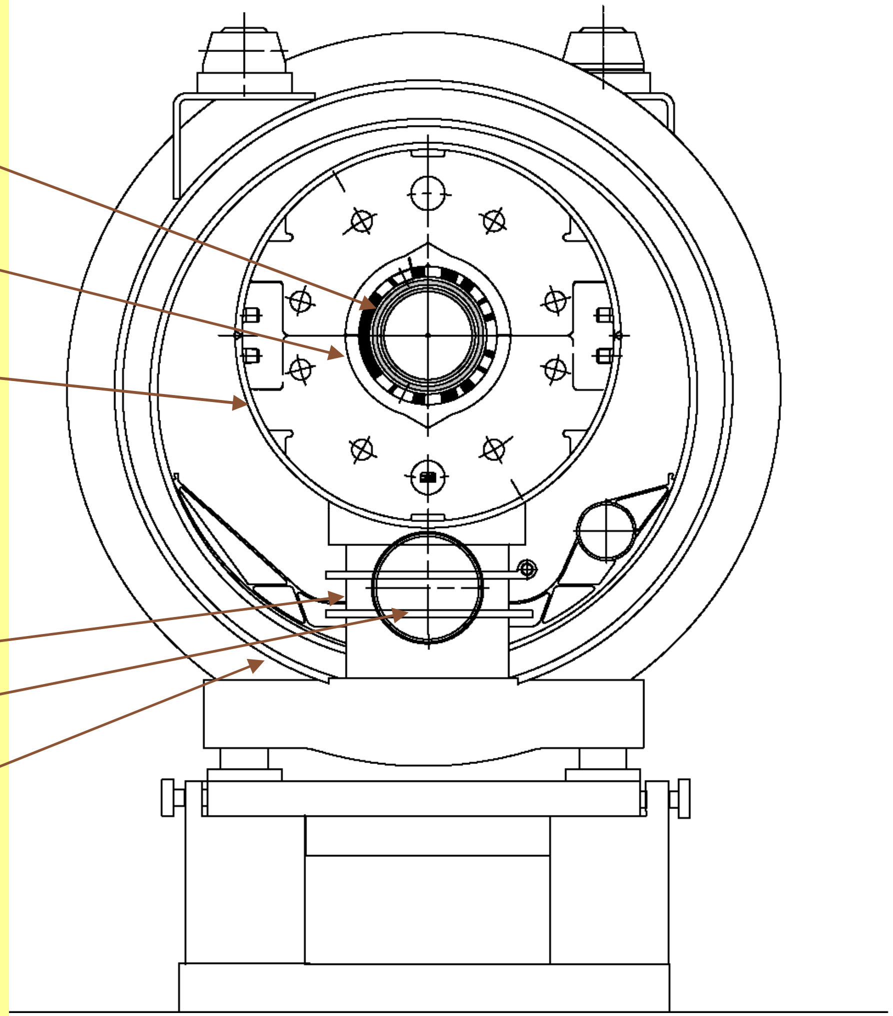
Temperature censor (Lake Shore, Cernox)

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

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..

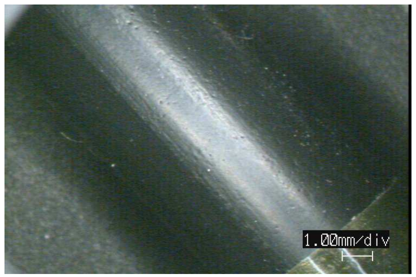
New Elastomer seal have been tested up to Dose=9.1 MGy with γ ray source.

Dose=9.1 MGy

Dose=0.34 MGy

Dose=2.6MGy

Dose=0 MGy

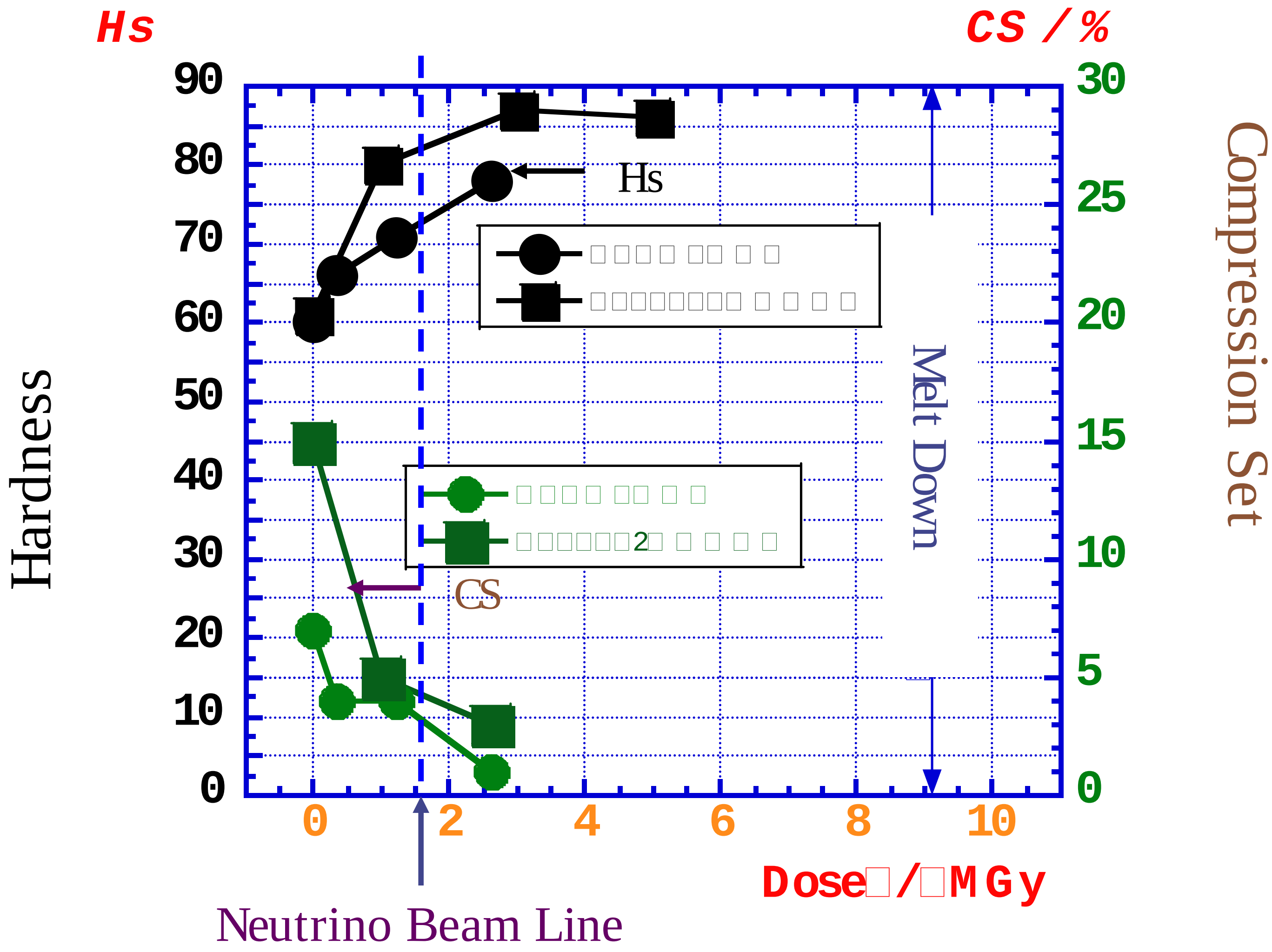


Dose=1.2MGy

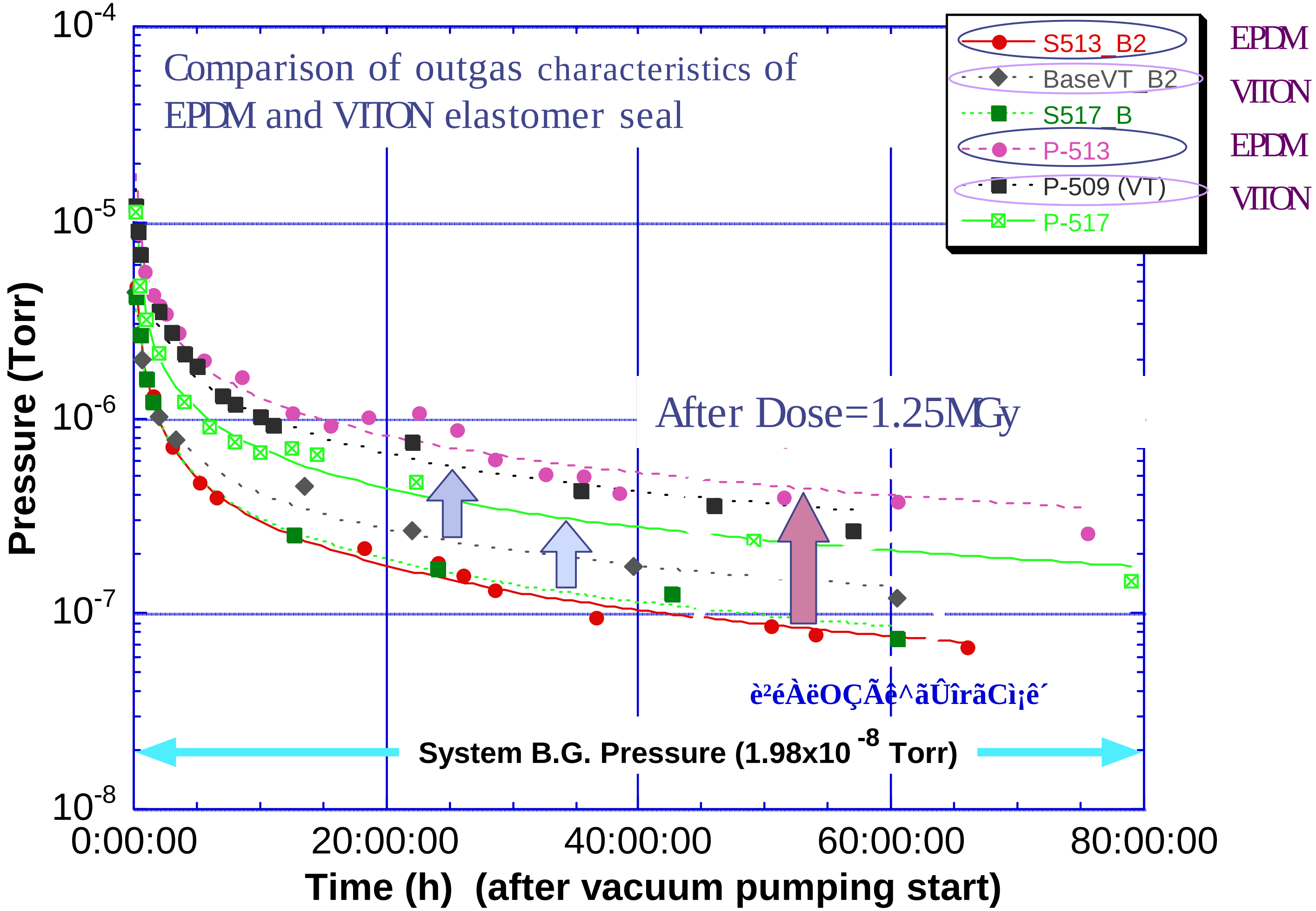
Blank

Dose=0 MGy

Hardness and Compression set



Outgas Characteristics of EPDM Elastomer Seal



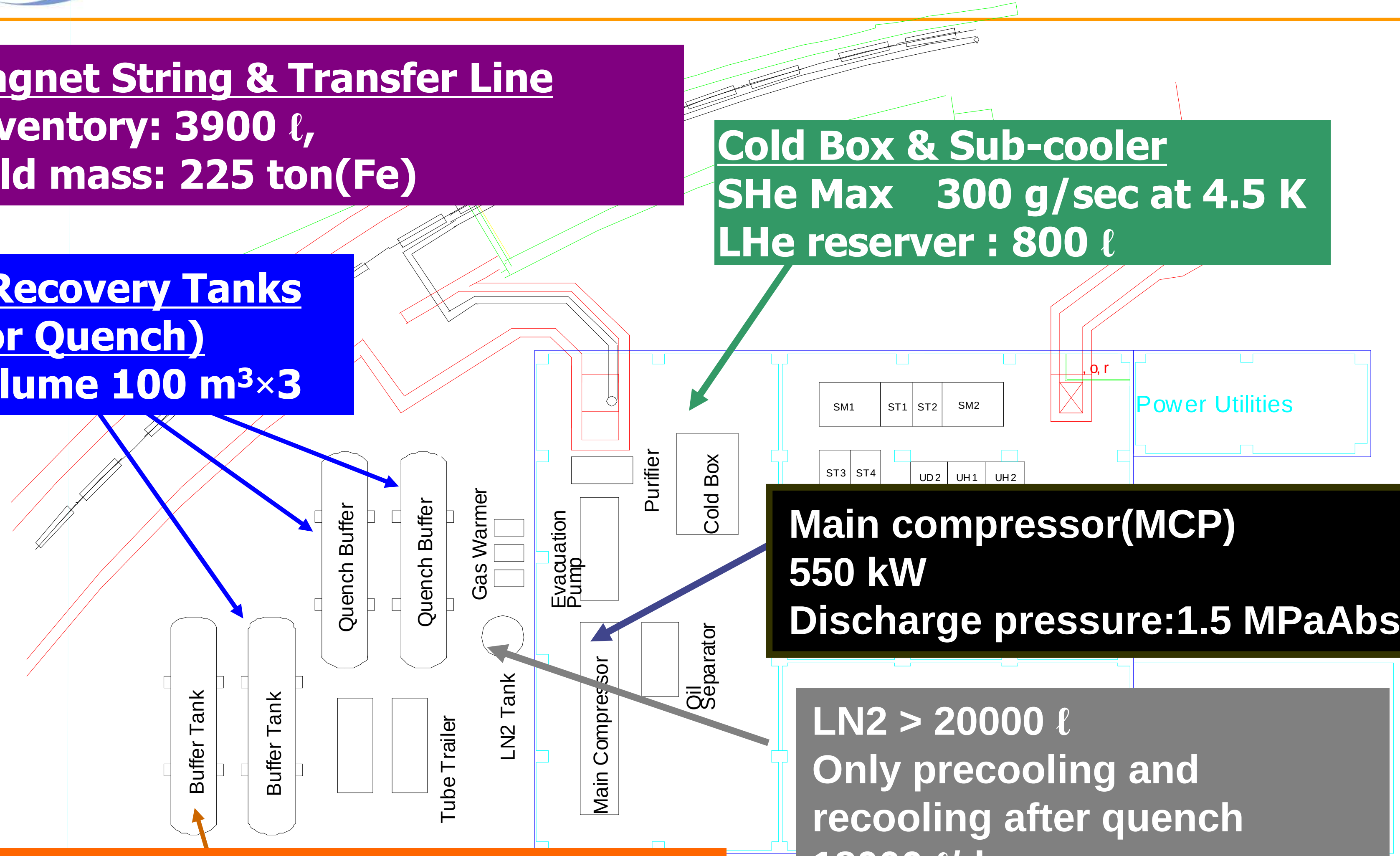
It is confirmed that new EPDM type elastomer seal can be used up to Dose=1.2 MGy.

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

Quench Release Analysis

OKAMURA Takahiro
takahiro.okamura@kek.jp

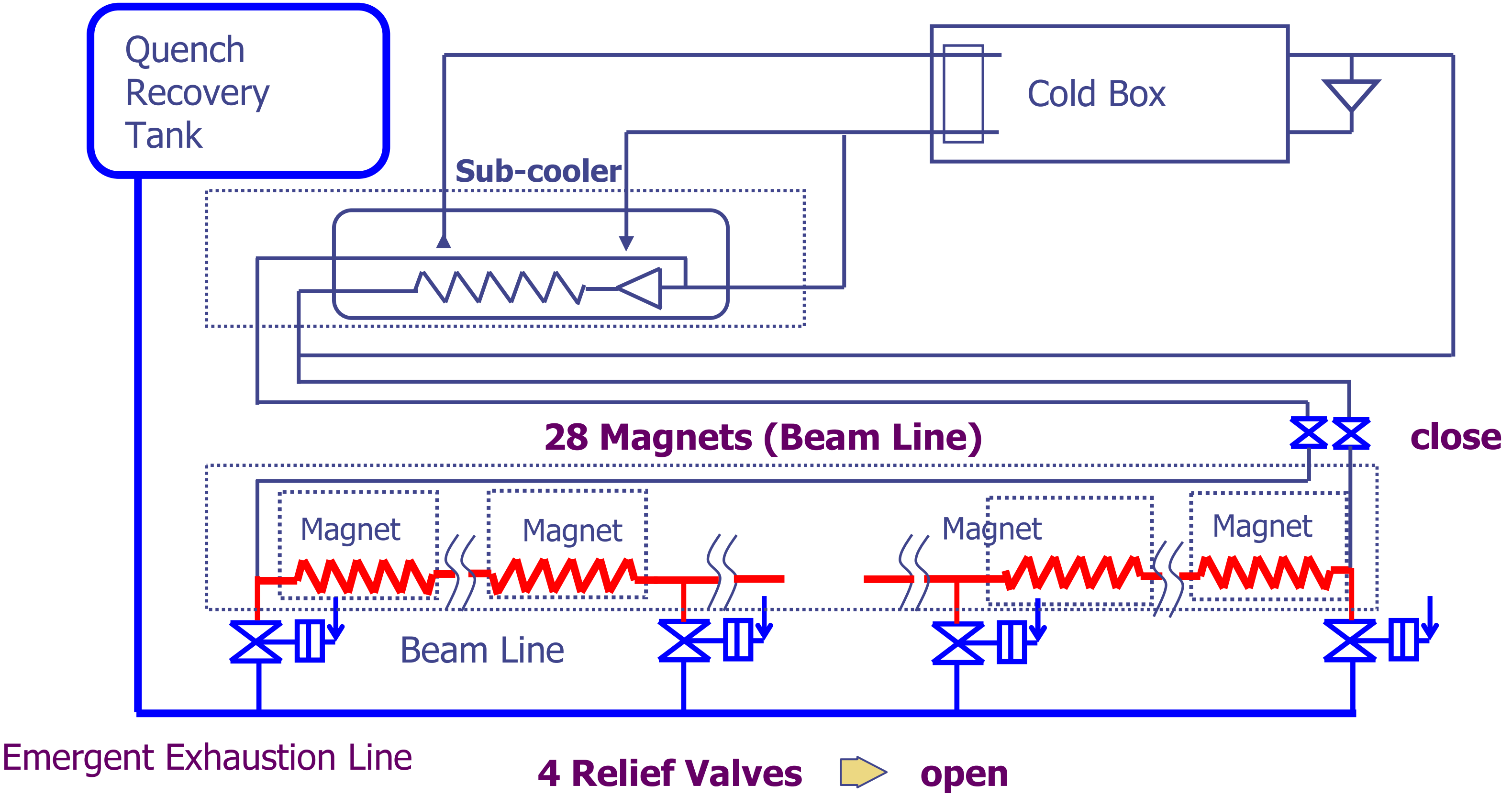
Contents

Conceptual diagram of quench release

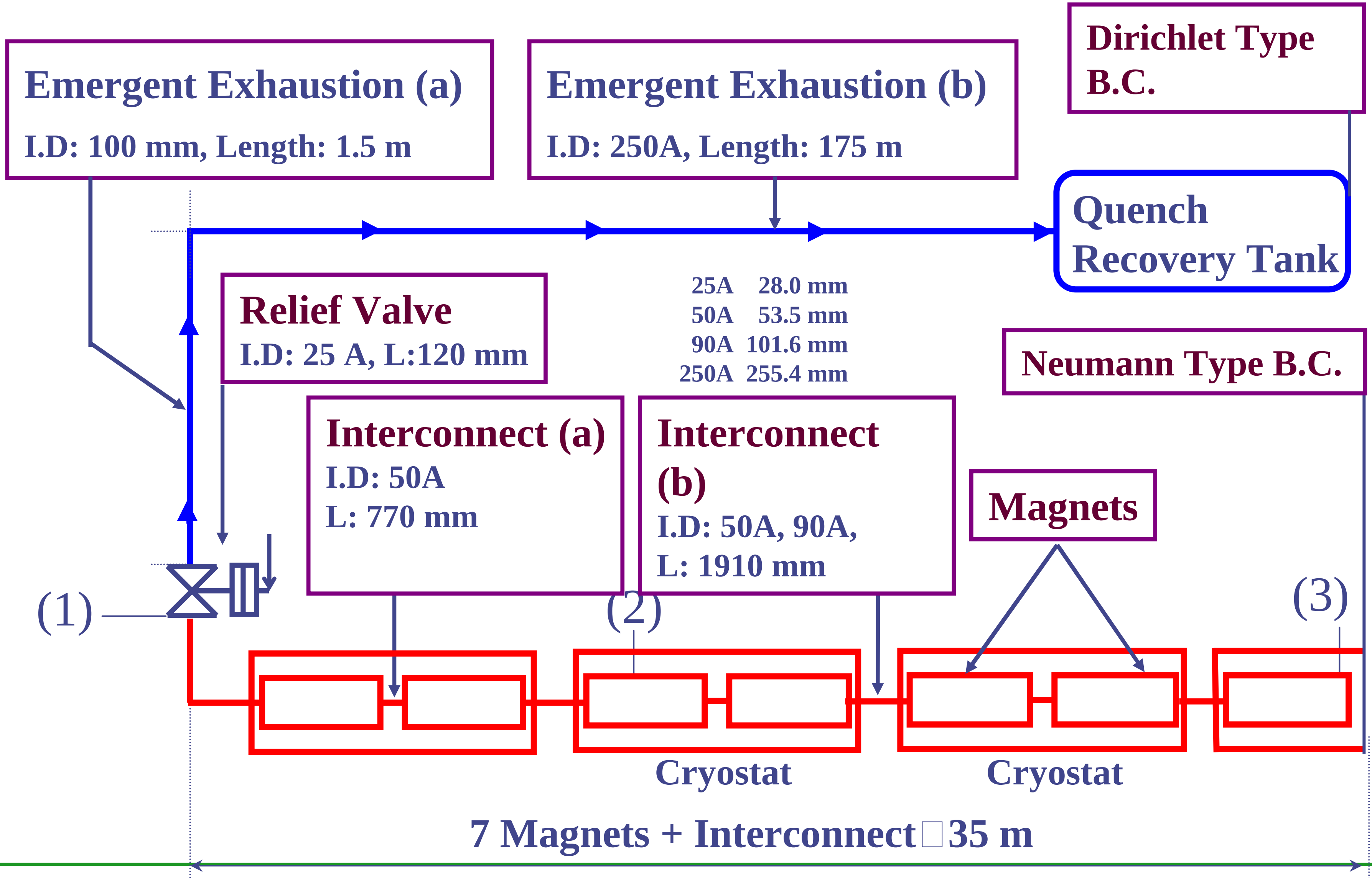
Allowable pressure of SC magnet system: 2.0 MPa

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

Determination
of Geometric Parameter
I.D. of Relief Valve



Simulation Model



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

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

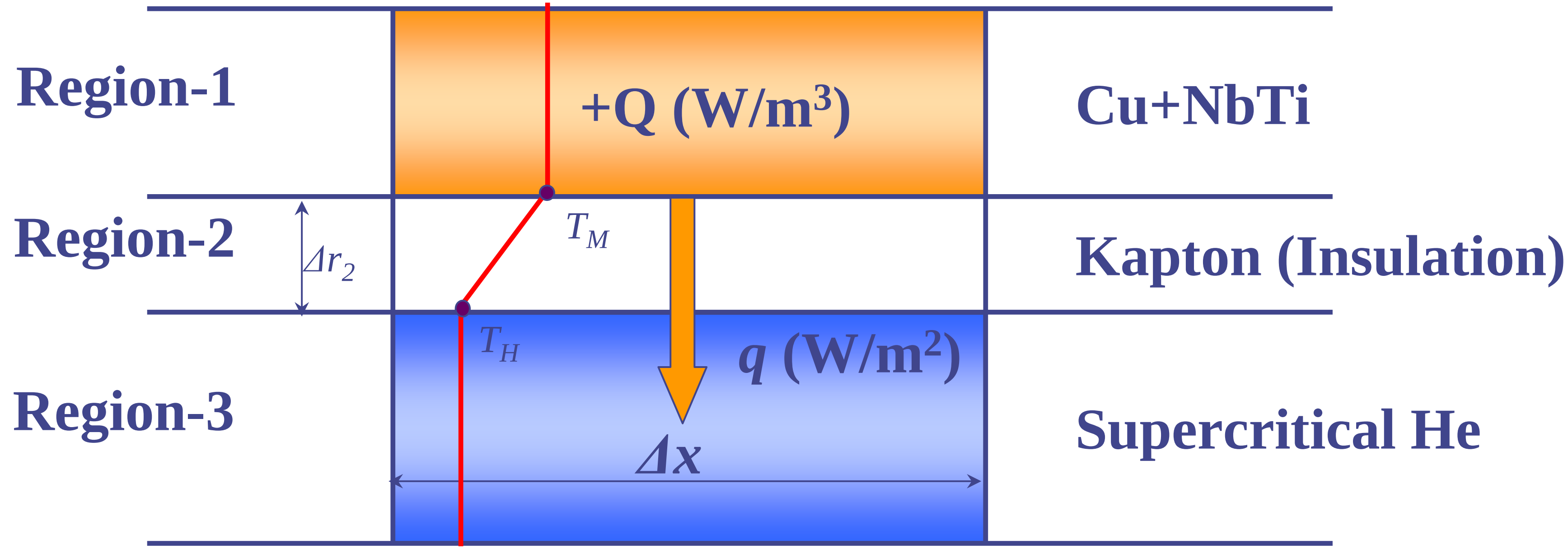
Mass, Momentum, Energy are directly coupled.
(Semi-Implicit Pressure Based Scheme)

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



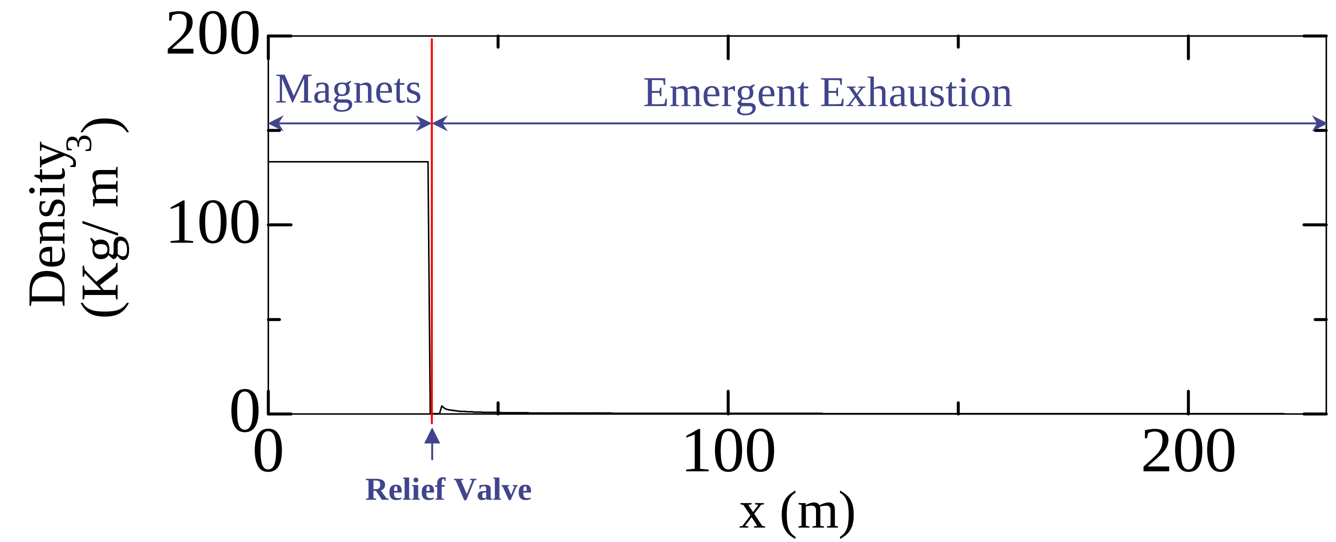
Region-1: Energy Balance Equation

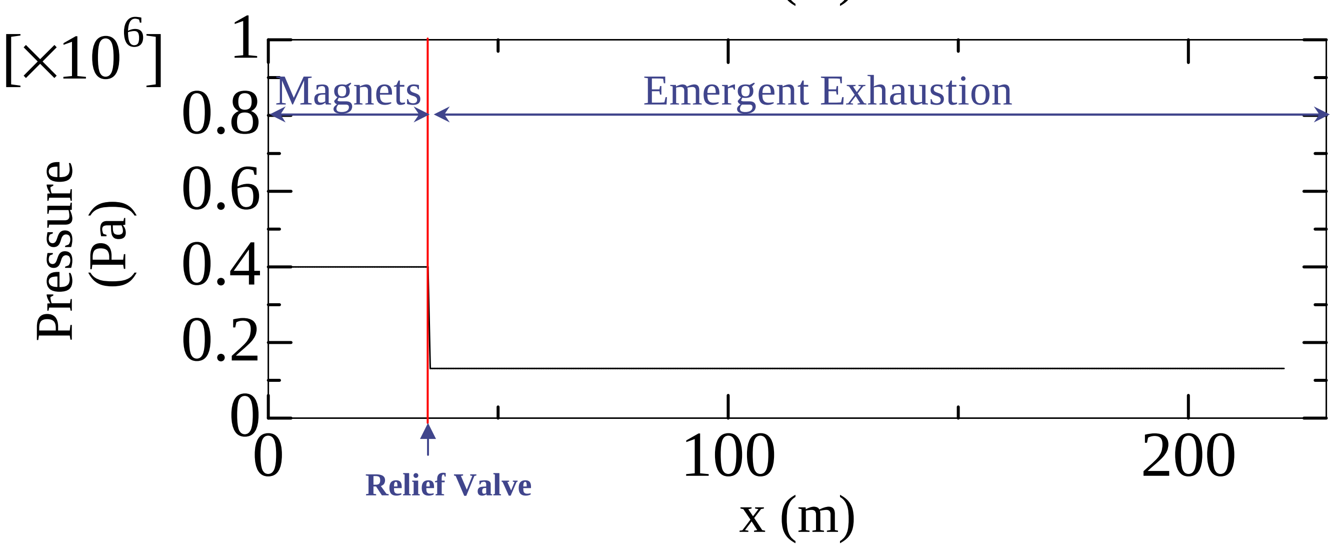
$$\rho c_p \frac{\partial T_M}{\partial t} \Delta V = Q \Delta V - q \Delta S \ , \qquad q = \lambda_K \frac{T_M - T_H}{\Delta r_2}$$

Heat Generation term from Magnet to SHE

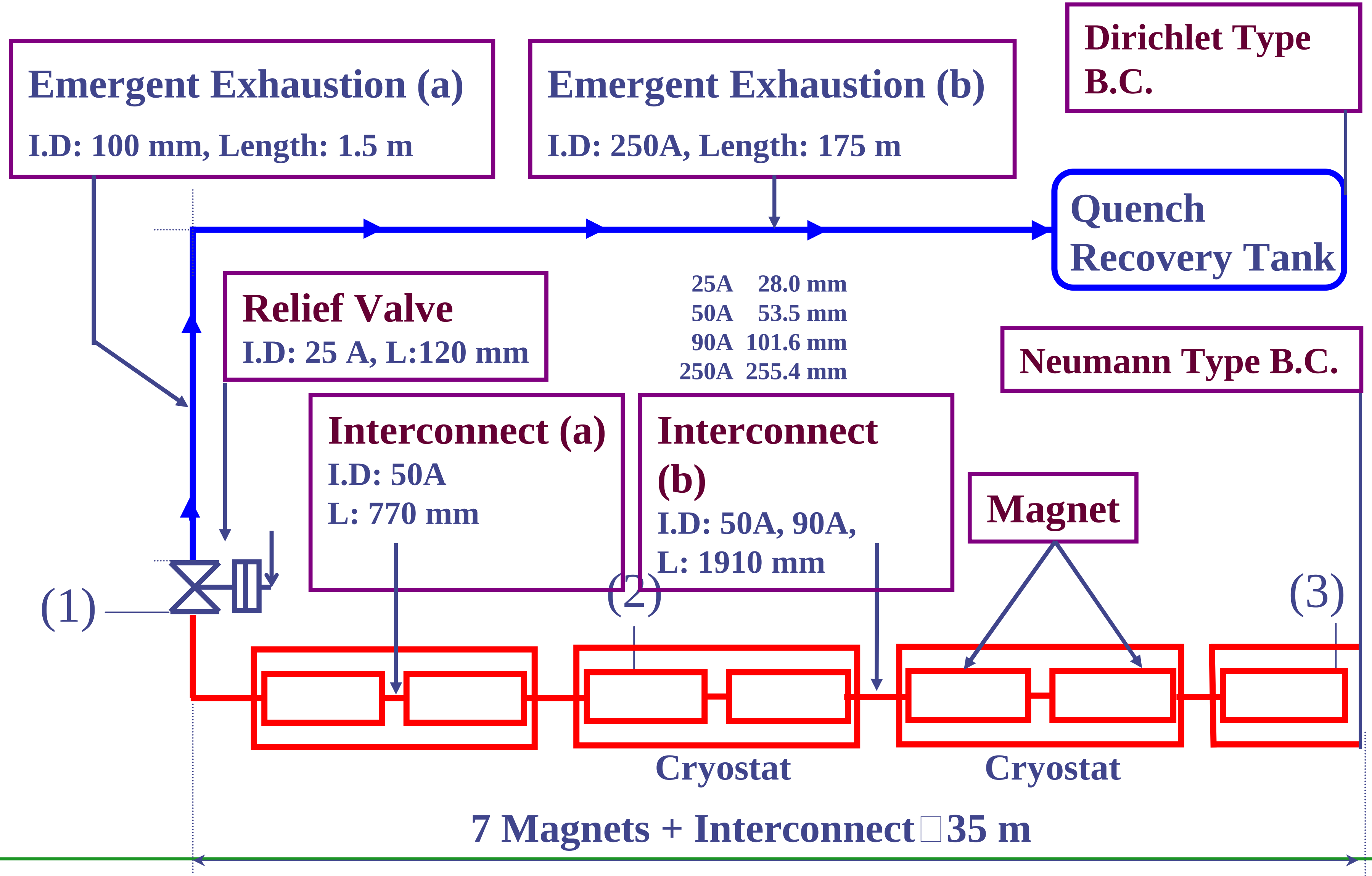
$$\dot{Q} = \frac{q \Delta S}{\Delta x}$$

Initial Conditions

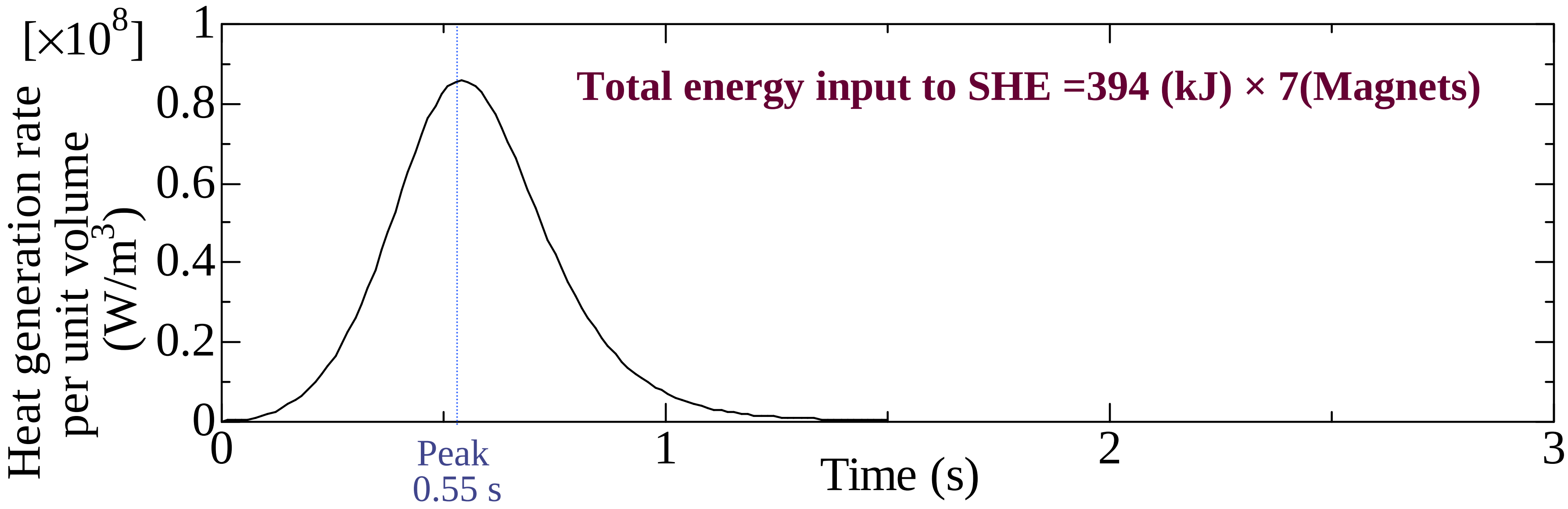


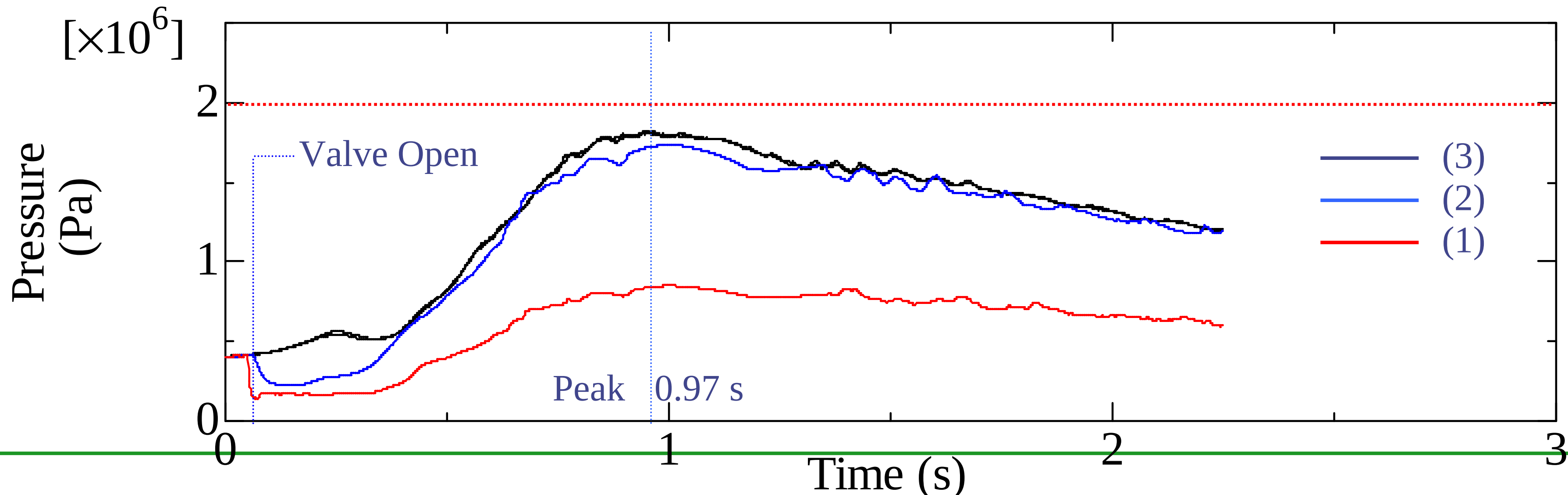


Simulation Model

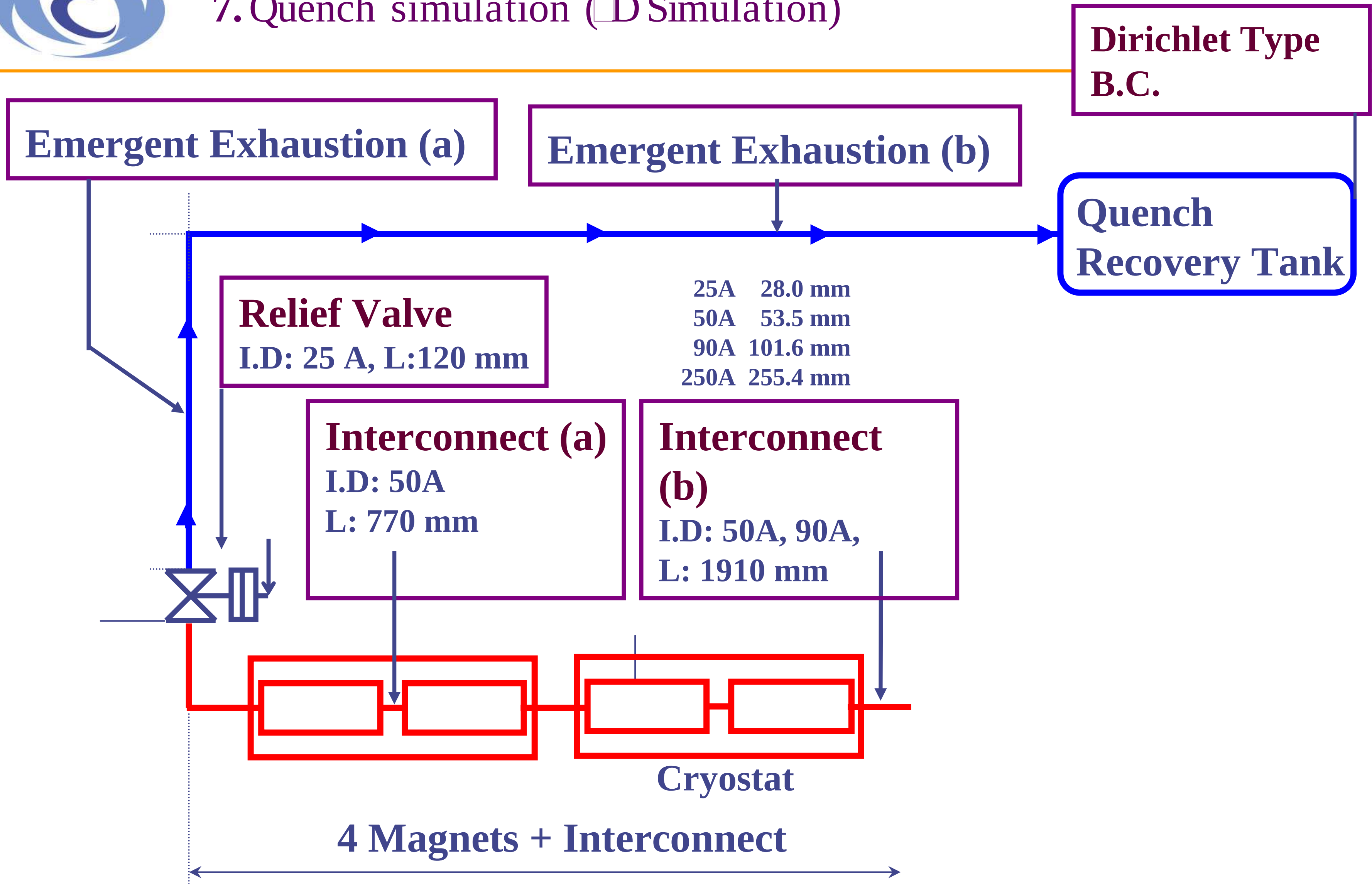


Highlight Result





7. Quench simulation (□D Simulation)



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**

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

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

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

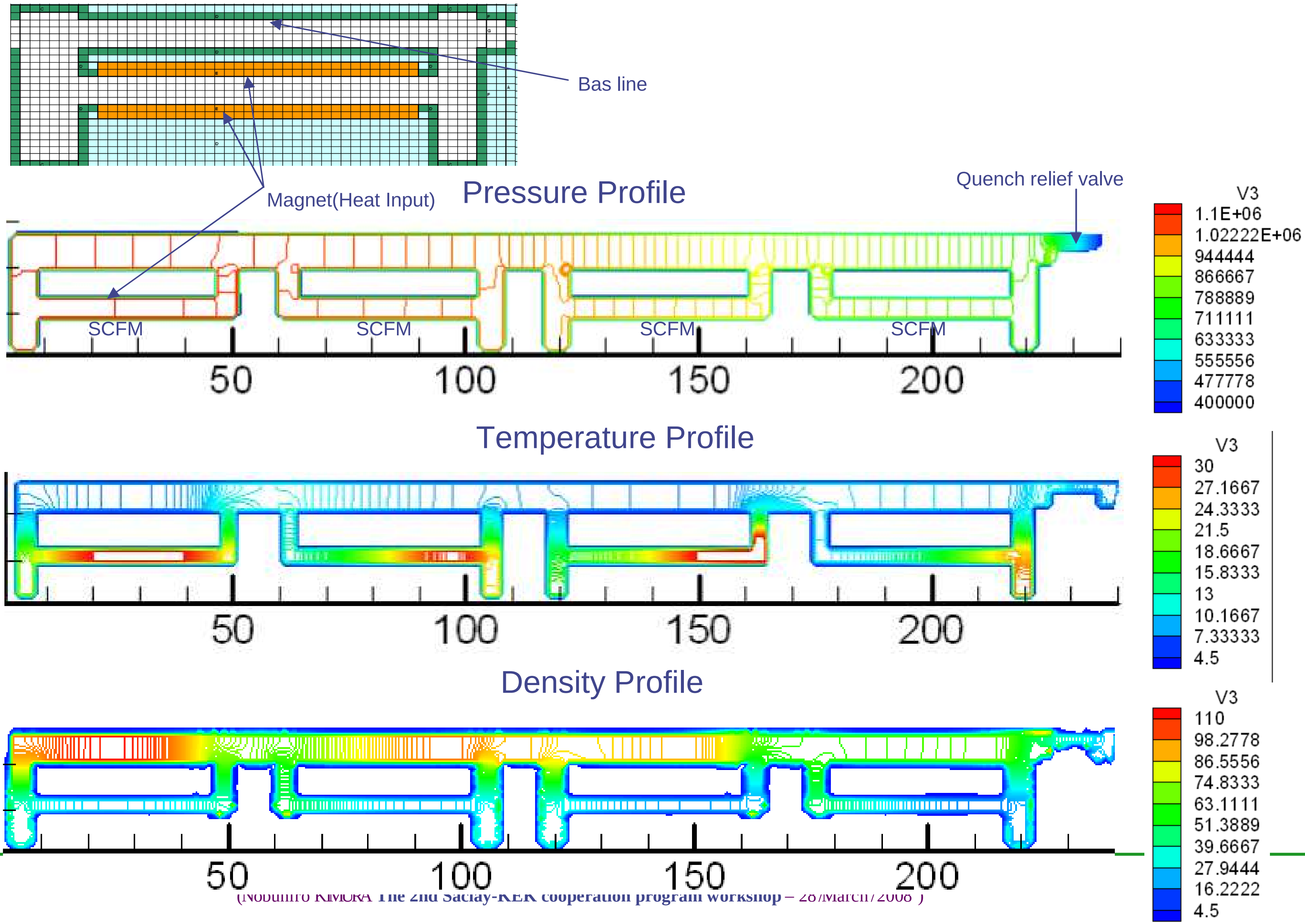
$$de = \left(\frac{1}{\varphi \rho}\right) dp - \left(\frac{c^2}{\varphi \rho} - \frac{p}{\rho^2}\right) d\rho$$

where

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

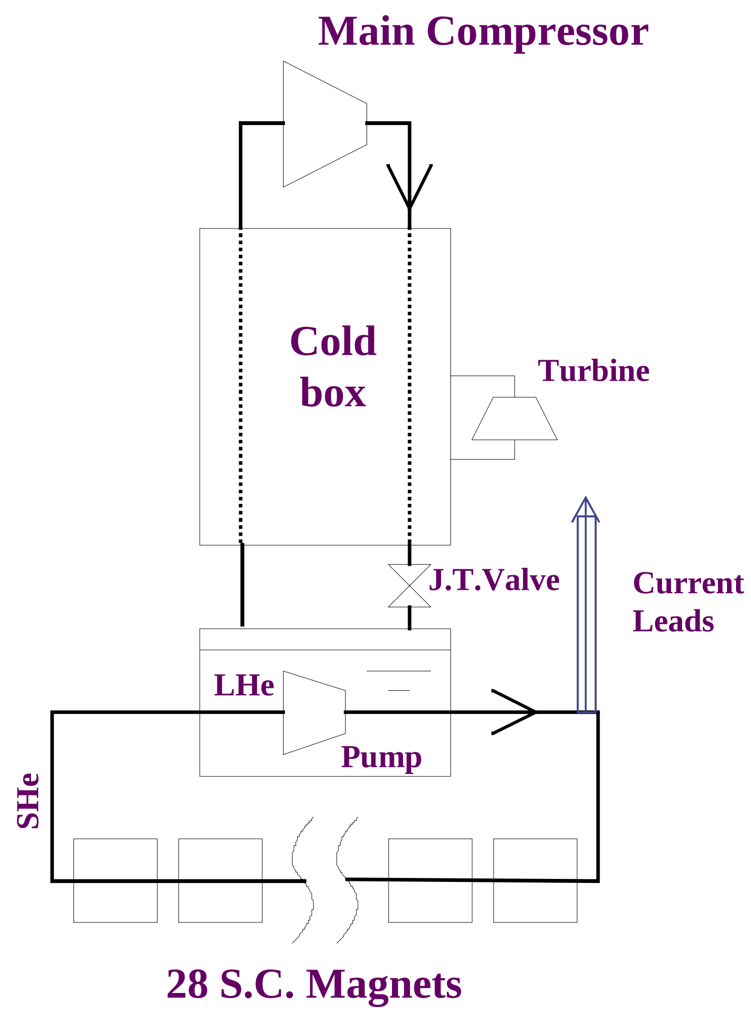
- **Method: FVM+Pressure Based Scheme**
- **Coordinate: BFC**

7. Simulation Results at 4/4 Magnets Quench



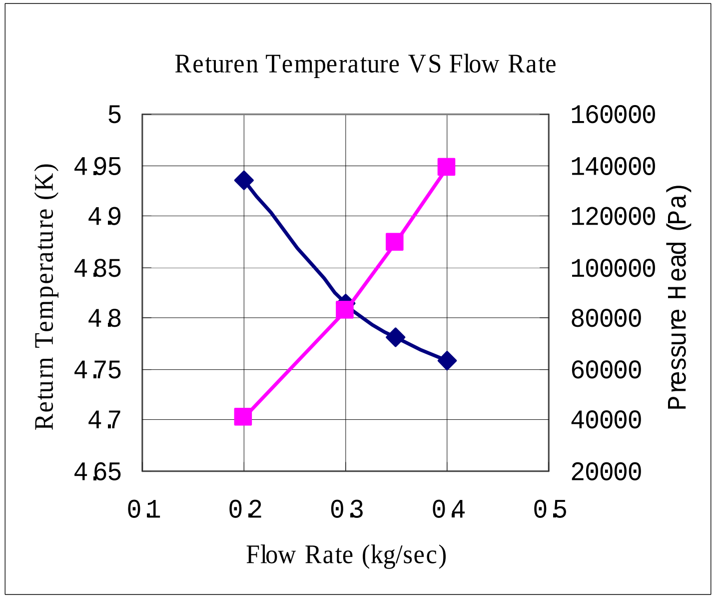
Required Cooling Capacity

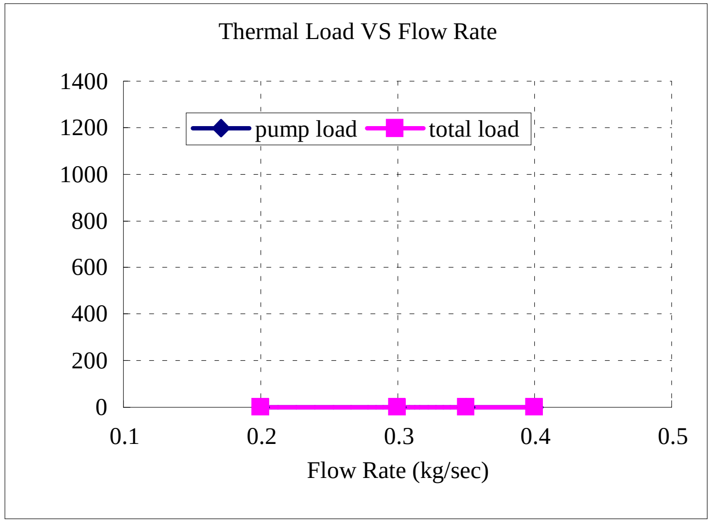
SHe Flow Rate	max 300 g/s
SHe Condition	0.4 MPa(A), 4.5 K
SHe Return	4.9 K
Thermal Load to SHe Flow	410 W
Pressure Head of SHe	85 kPa
Current Lead cooling gas	1.1 g/s (1 pair)
Shield Temperature	60□100 K
Shield Cooling	Cold Helium Gas
Thermal Load to Shield Line	1710 W
Shield Cooling Gas Condition	Not 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





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

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

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

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

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

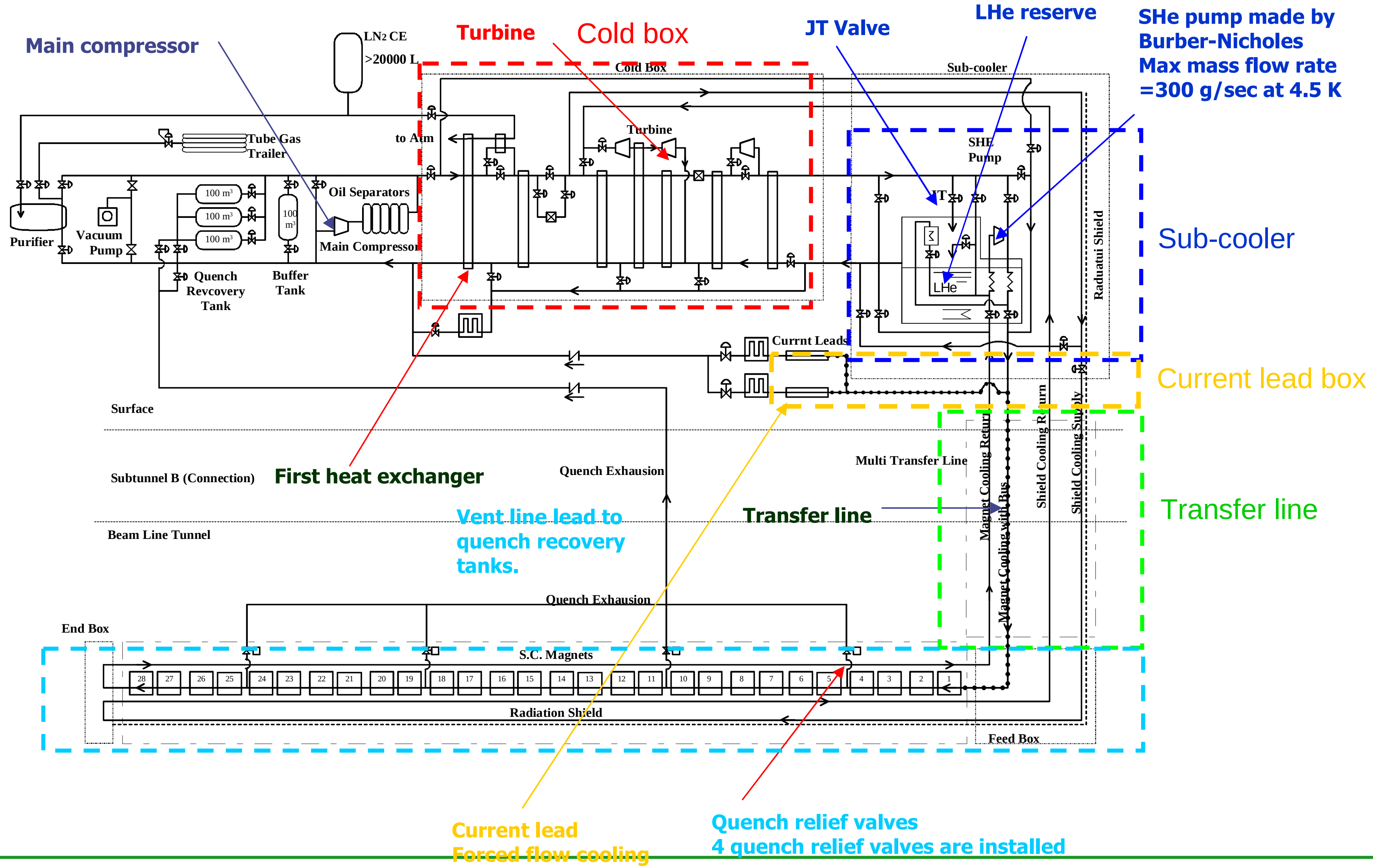
Mass-flow rate is controlled to be 300 g/s at the maximum.

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.

Conceptual Flow Diagram



Summary

- A new Implicit Continuous-fluid Eulerian code for SHe venting simulation has been developed

  by means of 1 & 2 Dimensional Heat transfer model.

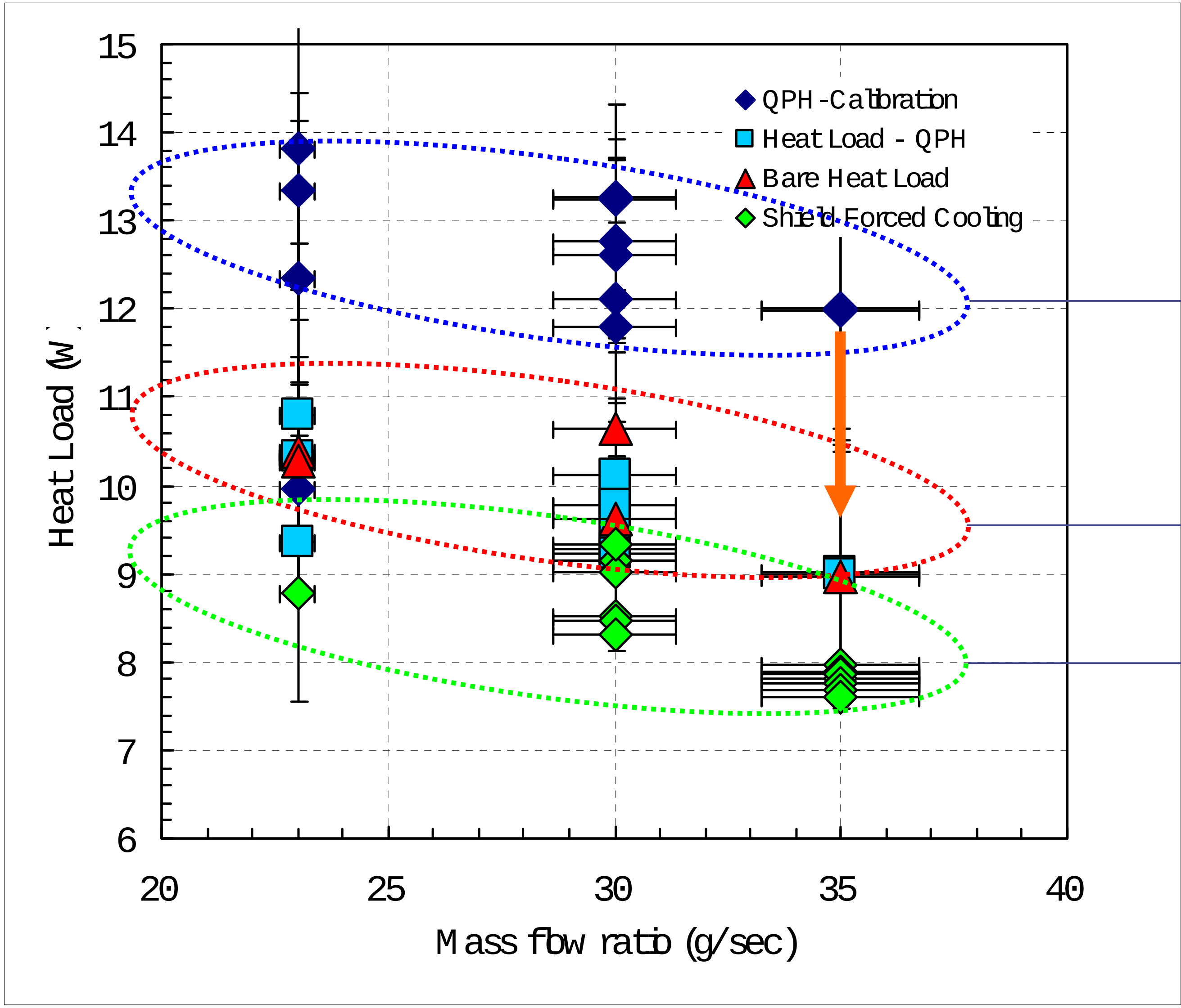
- Maximum Pressure is about 1.8 MPa

  and lower than allowable pressure of the magnet

  under the present relief valve

  and emergent exhaustion line design conditions.

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