Magnetic Shielding: Our experience with various shielding materials

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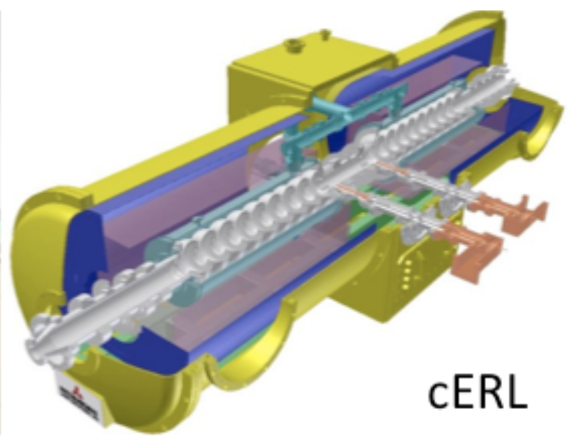

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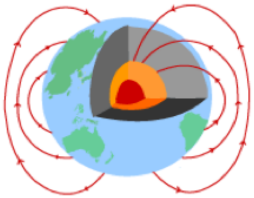
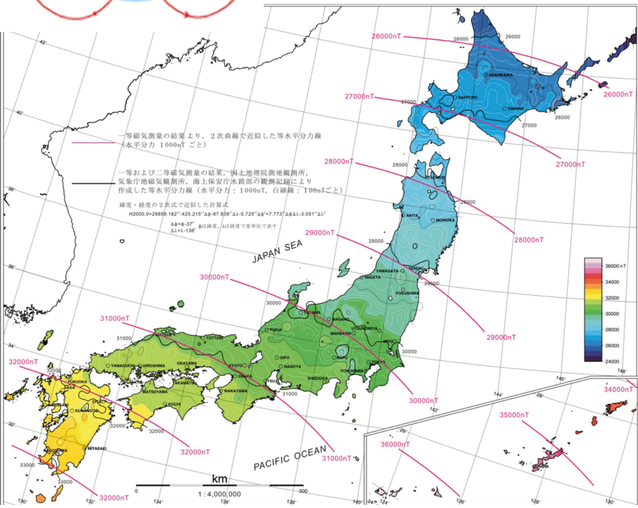
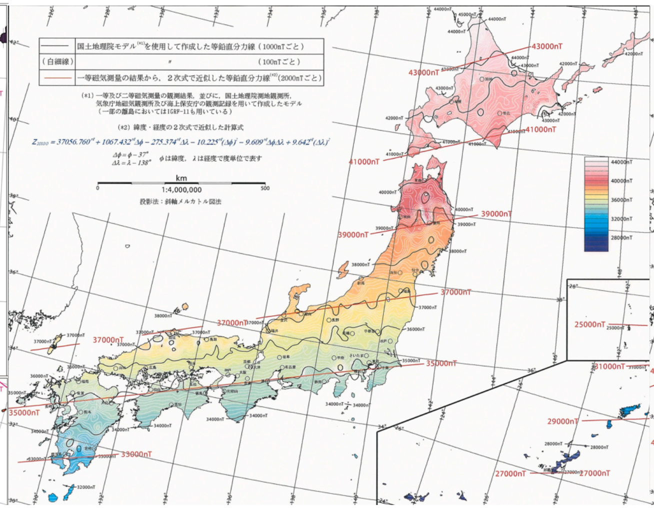
(1) Introduction

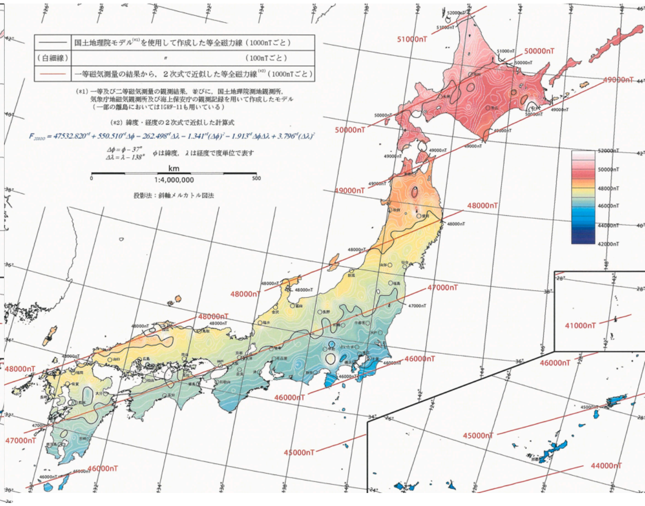
- Magnetic shielding is a key technology for superconducting RF cavities.
- The acceptable level of ambient magnetic field depends on factors such as operating RF frequency, acceleration gradient, operation mode (pulsed or CW) but it can be as low as a few mG.
- Shielding effectiveness at cryogenic temperature is important.



Ambient field:





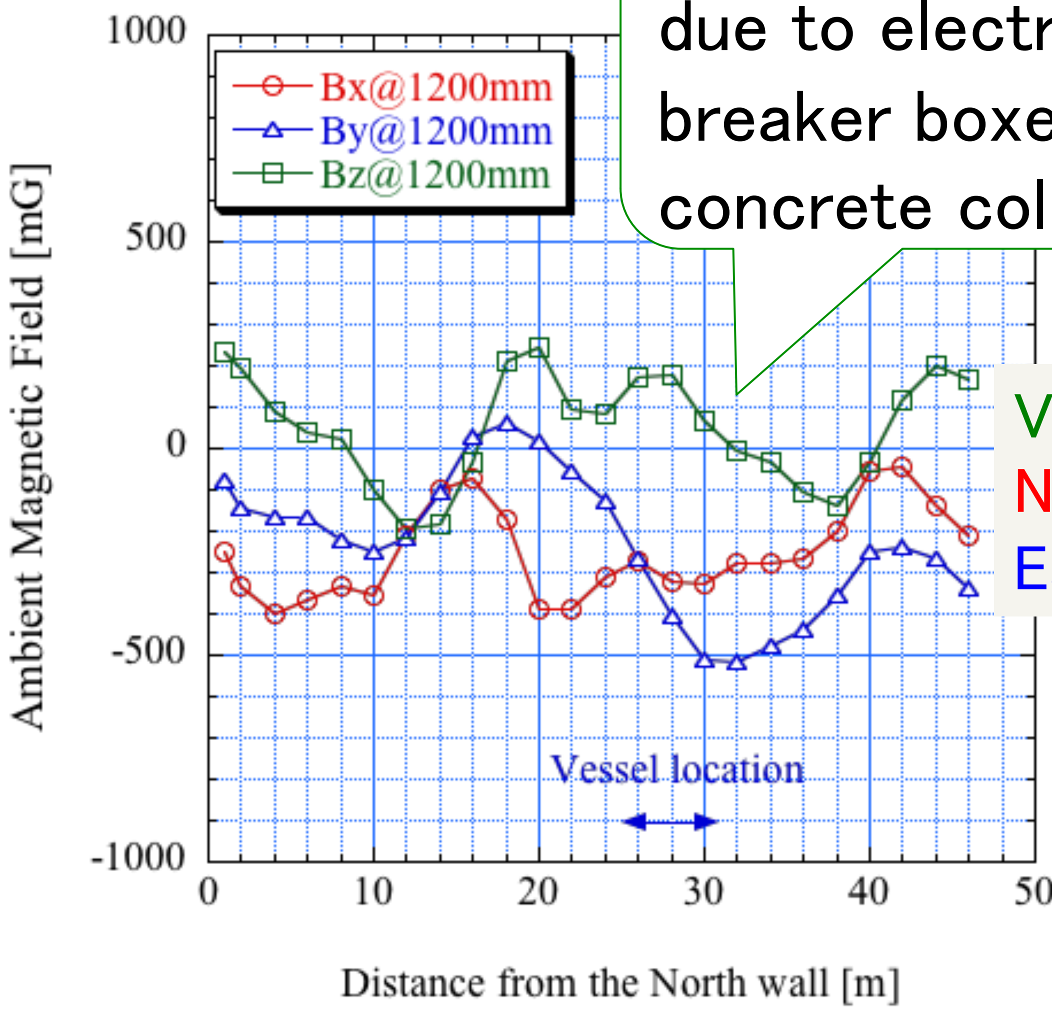


Earth's magnetic field: ~0.47 G in the open air around KEK.

- Not uniform though in the accelerator tunnel.
- Not the only source of ambient field in the tunnel.

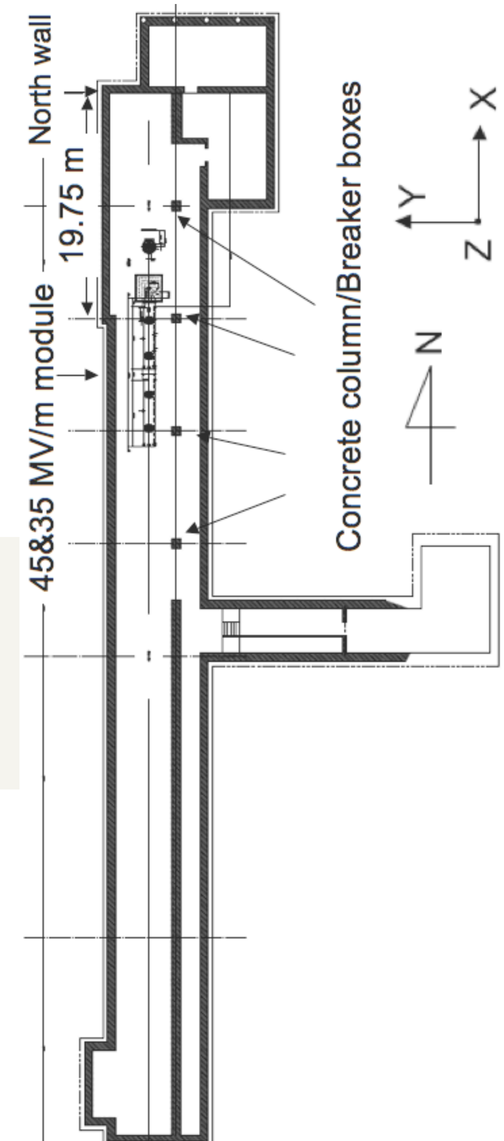
A factor of 100 reduction, from ~500 mG down to ~5 mG, is needed.

Ambient field: not uniform, changes directions

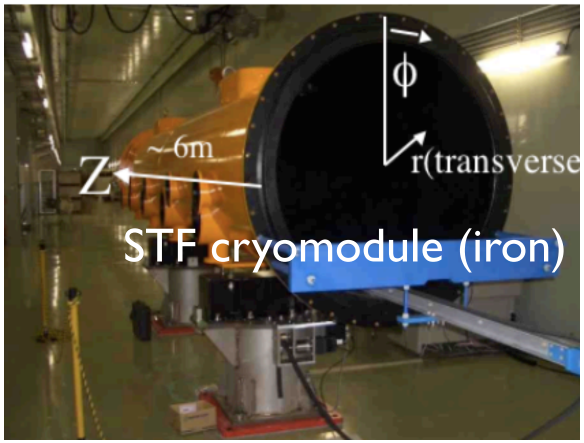


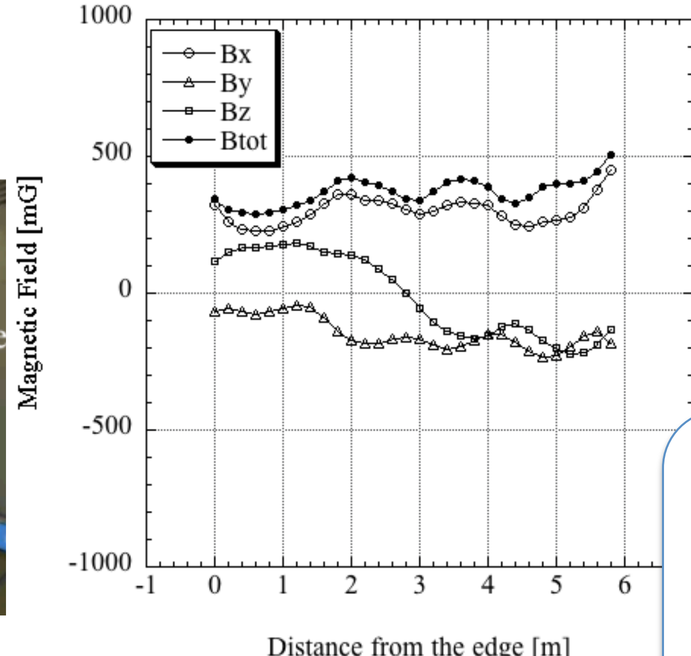
Periodic structure due to electrical breaker boxes and concrete columns.

Vertical
North−South
East−West



Ambient field: (iron) Cryomodule was magnetized

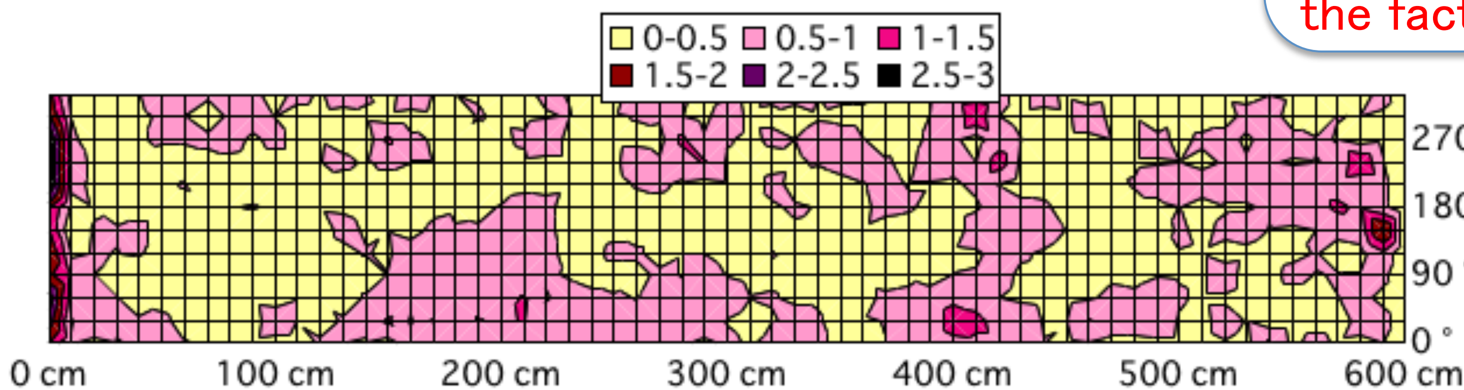




Magnetic field is NOT shielded in the iron vessel, but is instead enhanced!

Iron vessel surface was magnetized > 0.5 G over 50% of the area.

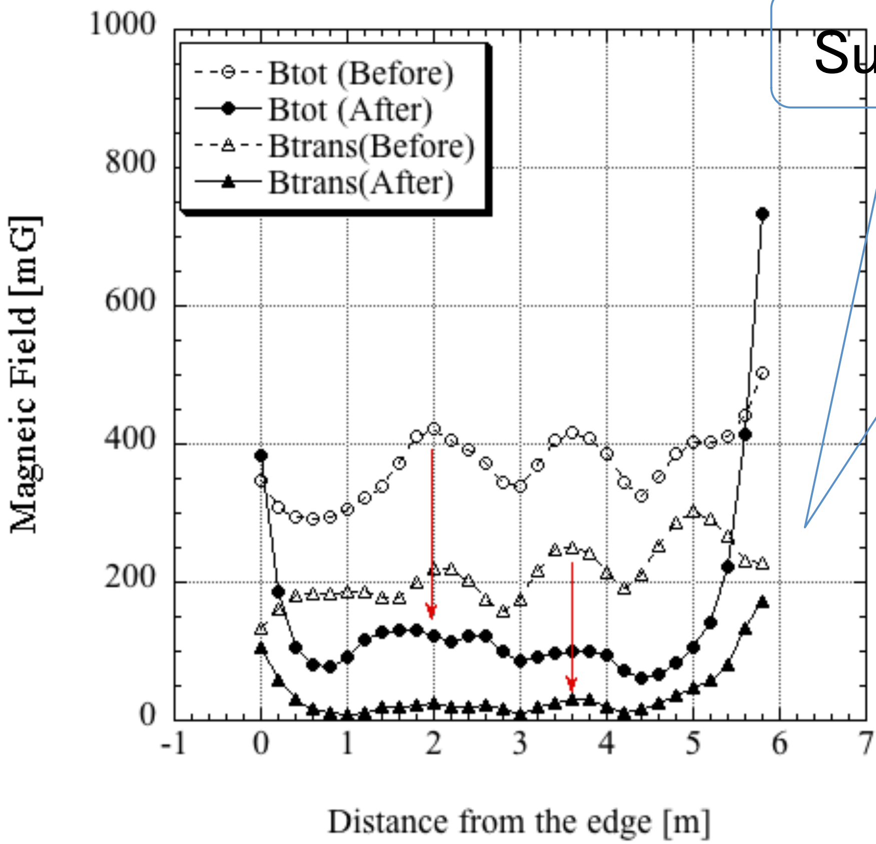
Magnetic crane hook at the factory, welding, etc.



Field map of the inner surface of the iron vessel

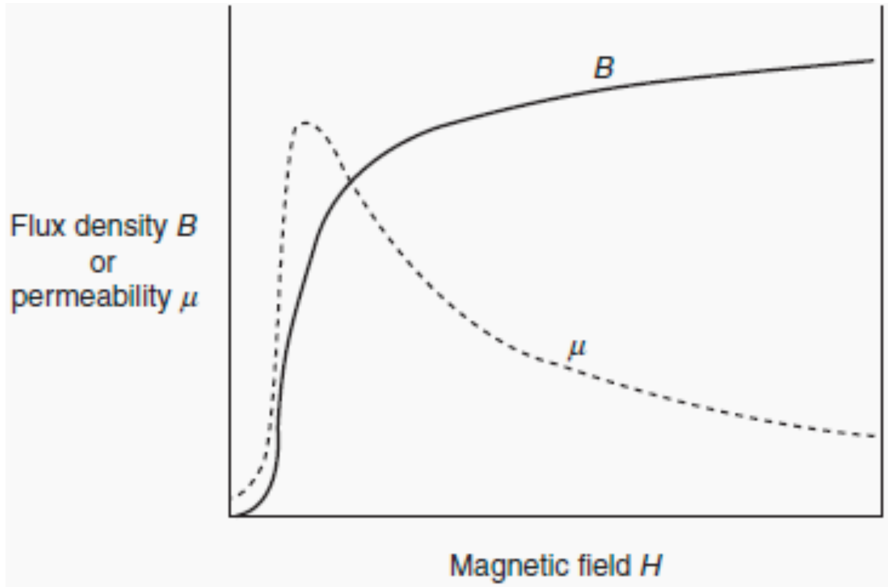
Ambient field: Cryomodule degaussed

- In the case of an iron vessel:
  - Make sure that the vacuum vessel is not magnetized during its fabrication. Degaussing may be needed.



Successfully Degaussed!

(2) Permeability measurements



CEA-Saclay and KEK have been measuring permeability of various shielding materials in the framework of the "France – Japan Particle Physics Laboratory (FJPPL)" Collaboration.

Our goal is to find a good (enough) shielding material for cryogenic use.

(2) Permeability measurements

- We measured permeability (μ) at RT and LHe (& sometimes at LN2) temperatures of various shielding materials.
- We see degradation in performance at cryogenic temperature, with measured permeability being lower than the "catalog" value for most of the materials.

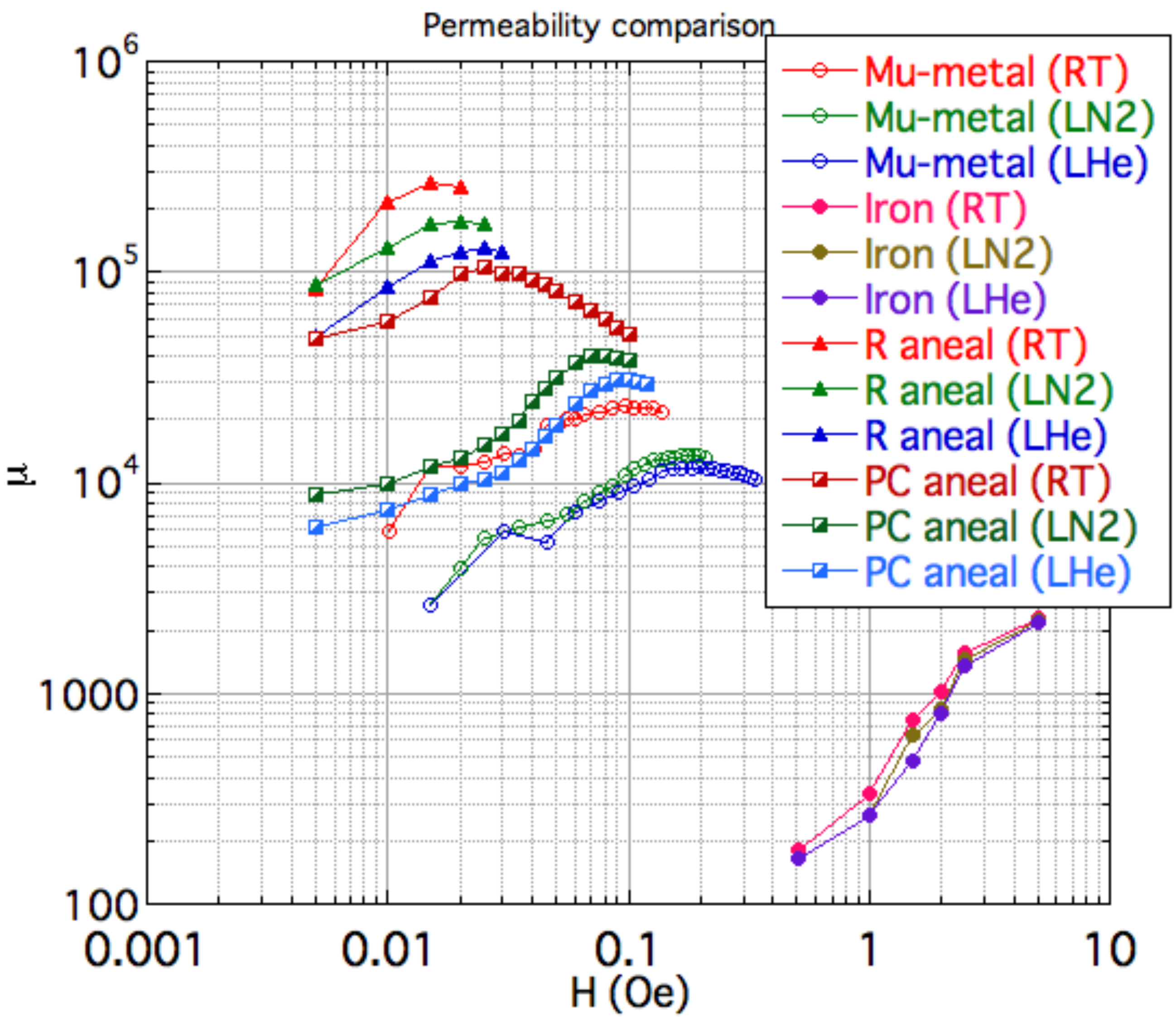
Measurement at LHe temperature

(2) Permeability measurements

Examples of materials evaluated by KEK

Material	Provided/prepared by
Permalloy “R”	Tokin
Permalloy “PC”	Tokin
Mu-metal	Off the shelf
Iron	Nippon Steel & Sumitomo Metal
FINEMET	Hitachi Metals
Cryoperm 10(TESLA)	VACUUMSCHMELZE /TOKIN
VDM	VDM/Ohtama
Cryoperm 10	VACUUMSCHMELZE /Amuneal
A4K	ArcerlorMittal/Amuneal
Cryophy	ArcerlorMittal
Cryophy	ArcerlorMittal/Ohtama

(2) Permeability measurements



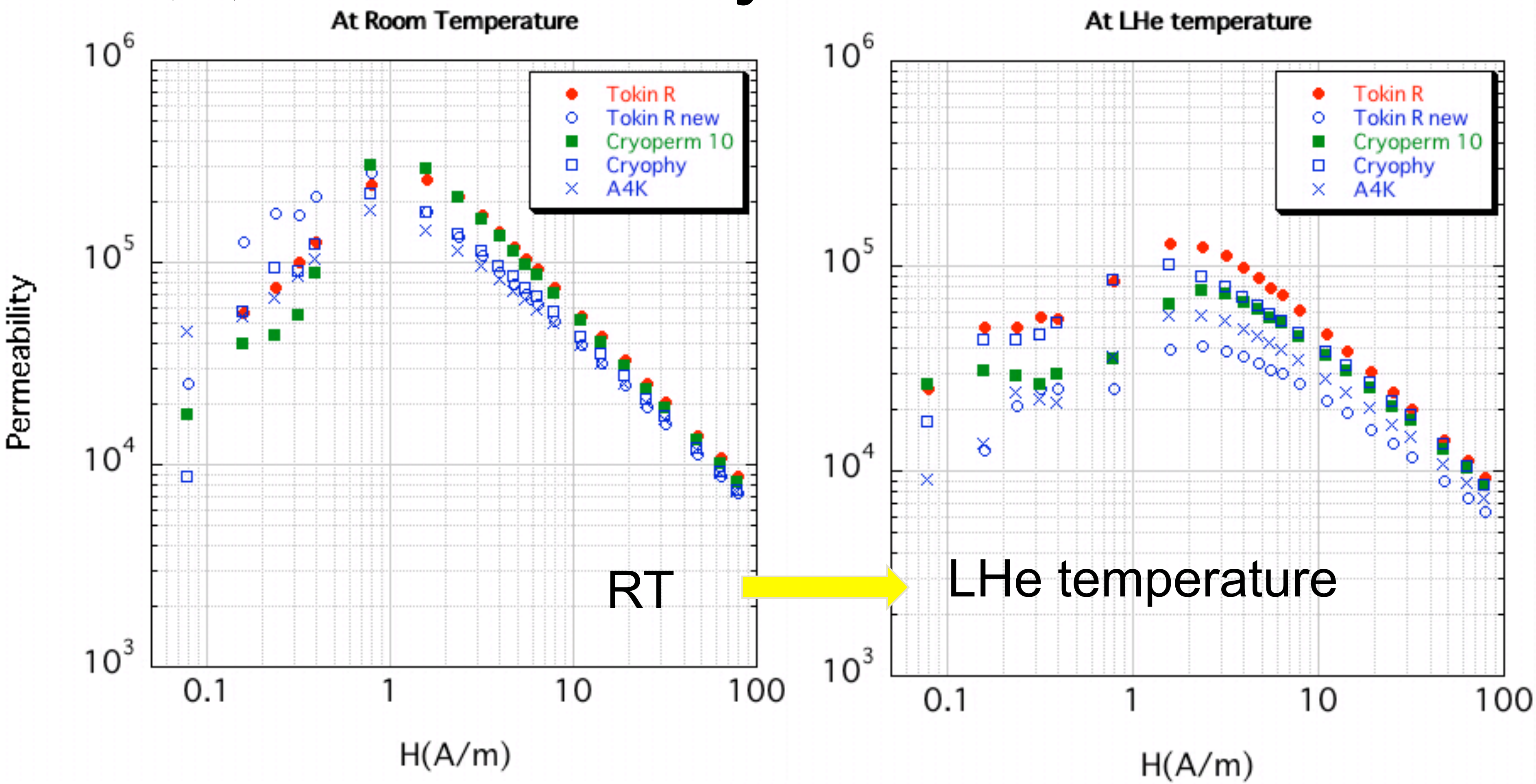
Comparison (1):
Among various shielding materials

Iron ~ 1000
Mu-metal ~ 10000

Tokin R Permalloy-PC ~100000

at RT,LN2,LHe temperatures.

(2) Permeability measurements



Comparison (2):Among materials for cryogenic use (μmax˜ 100000)
Tokin R, Tokin R new, Cryophy, Cryoperm 10, A4K

(2) Permeability measurements

Characteristics of materials for cryogenic temperature use that we found are:

- higher permeability than standard materials such as Permalloy-PC.
- μ_{max} of some samples stays higher than 10^5 at LHe temperature though some samples did not reproduce the catalog μ_{max} value at LHe temperature.

  Possible reasons:

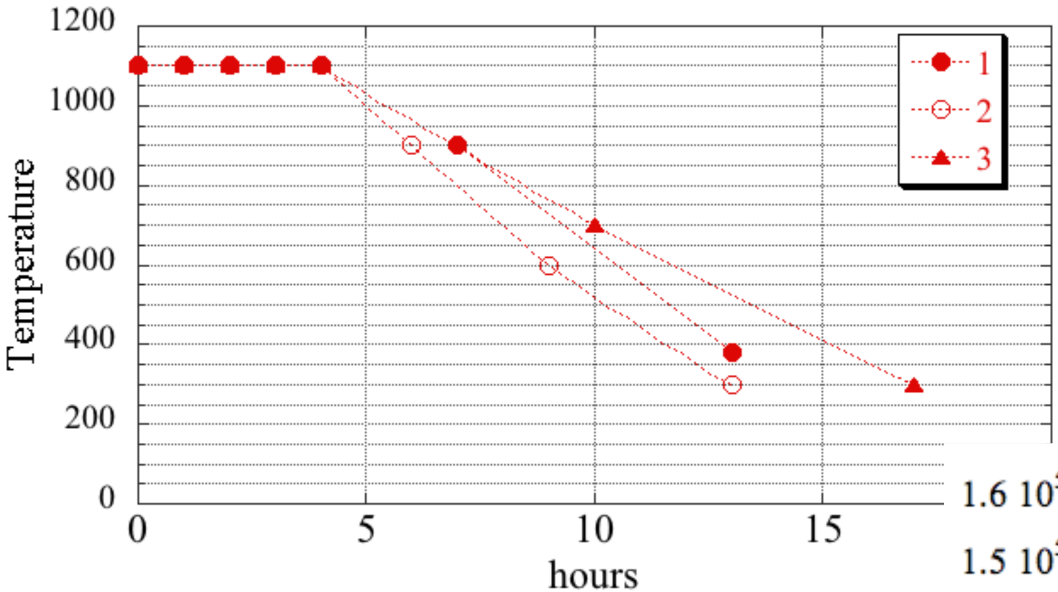
  Sample-to-sample variation (ingredients)

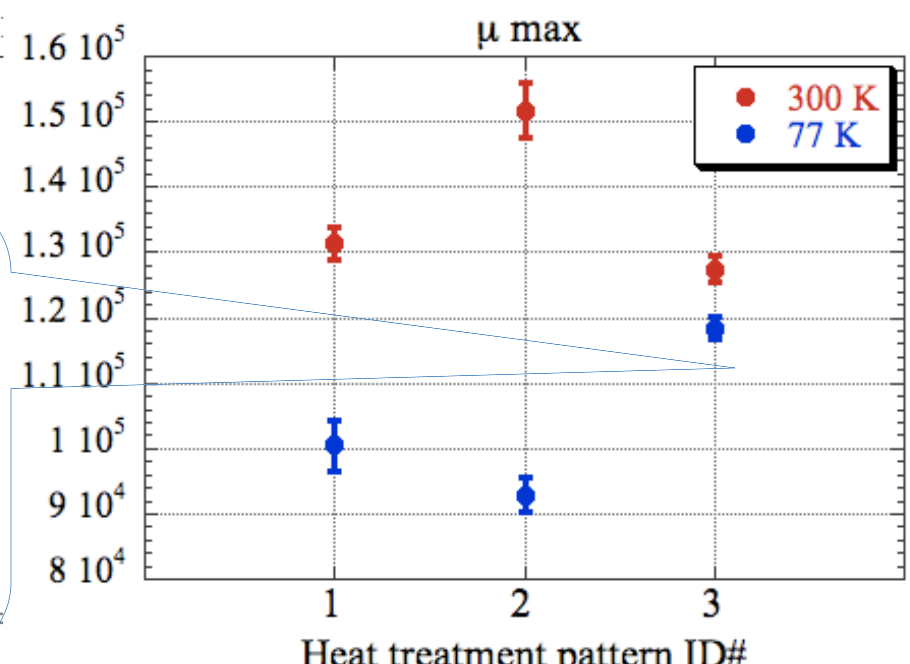
  Improper annealing

  Unwanted mechanical stress added
- The external magnetic strength that gives μ_{max} is lower than standard materials. This is suitable for shielding low ambient magnetic fields such as the earth magnetic field.

(3) Effects of heat treatments

Cooling rate





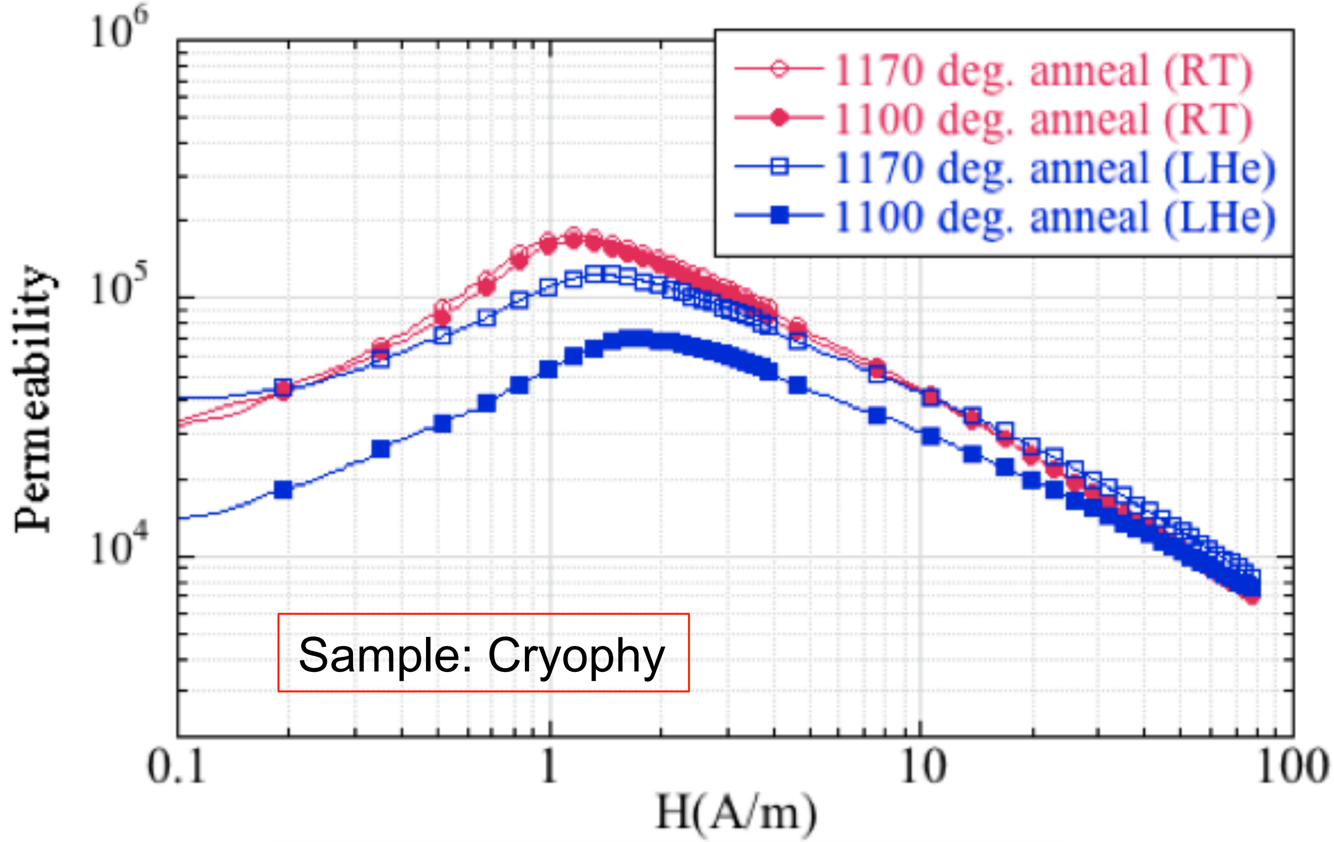
Heat treatment pattern 3(▲, the slowest cooling rate) resulted in the highest permeability at LN2 temperature, ~20% higher than with the other patterns.

SRF

(3) Effects of heat treatments

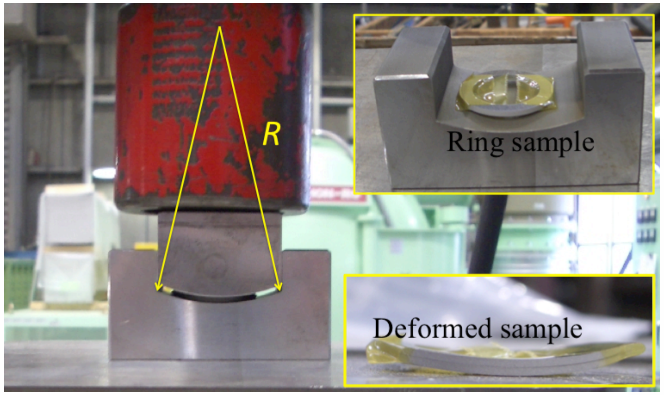
Maximum temperature (1170°C&1100°C)

The sample was annealed at 1170°C, as recommended by the supplier, using a small oven dedicated to experimental use.



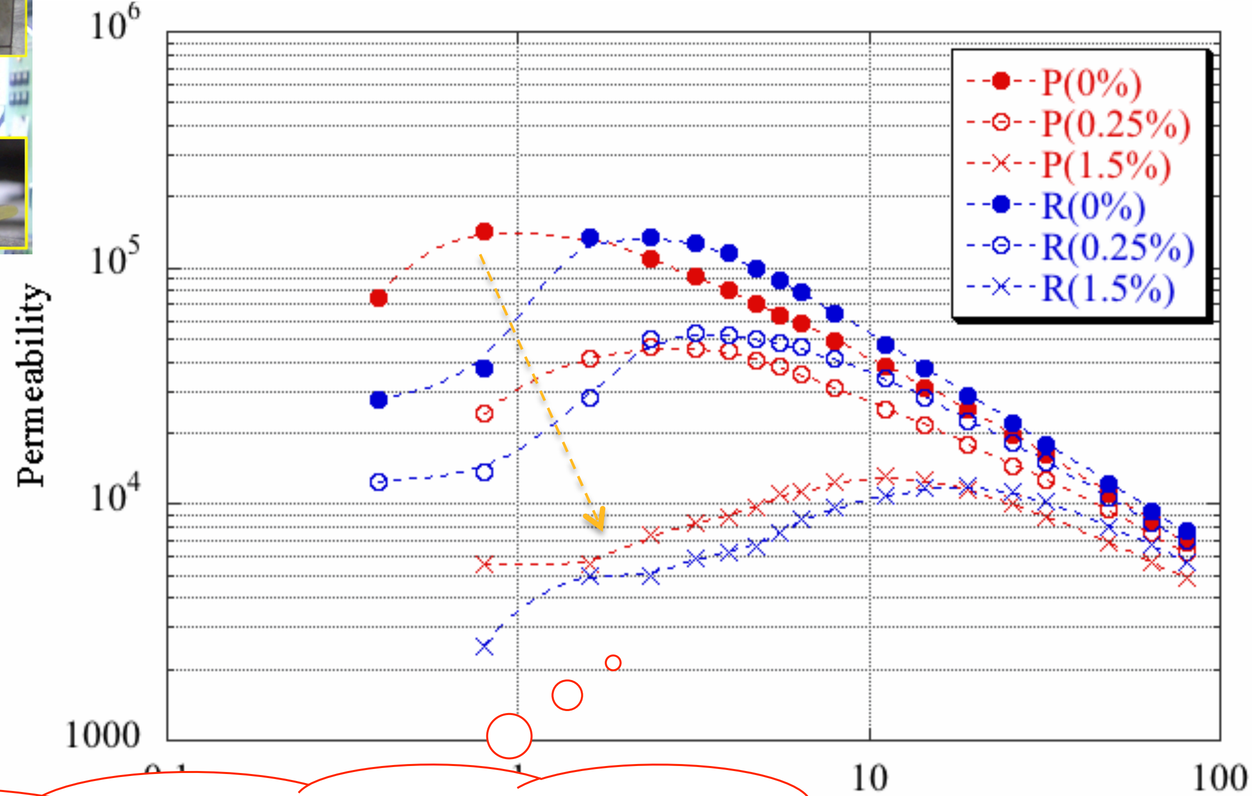
The maximum annealing temperature in a pure and dry hydrogen environment could not exceed 1100°C due to safety restrictions at the manufacturer.

(4) Effects of mechanical strain



The degree of strain is evaluated by the parameter ε, defined as $\varepsilon = \Delta t / 2R$, where Δt and R are the thickness of the sample and the radius of the curvature of the template blocks, respectively.

Permeability of two types of materials P and R measured at the room temperature.



Significant decrease in permeability due to deformation

(4) Effects of mechanical strain

When dropped（~ 1m height)
Permeability is reduced by a factor of 2!

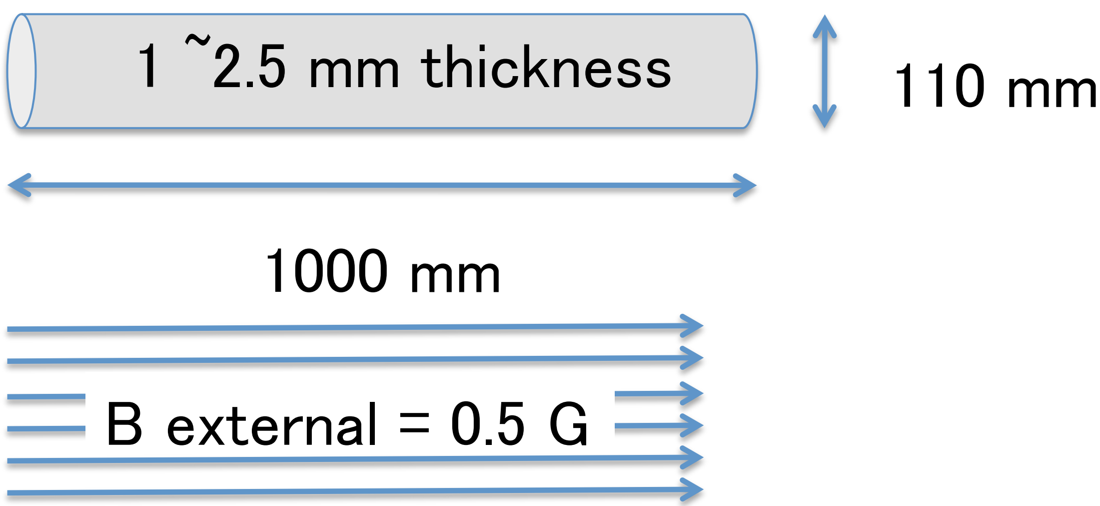
“Drop test” by Amuneal, shown by J. Plouin

So handle with care to make the maximum use of the high-μ (often expensive) material.

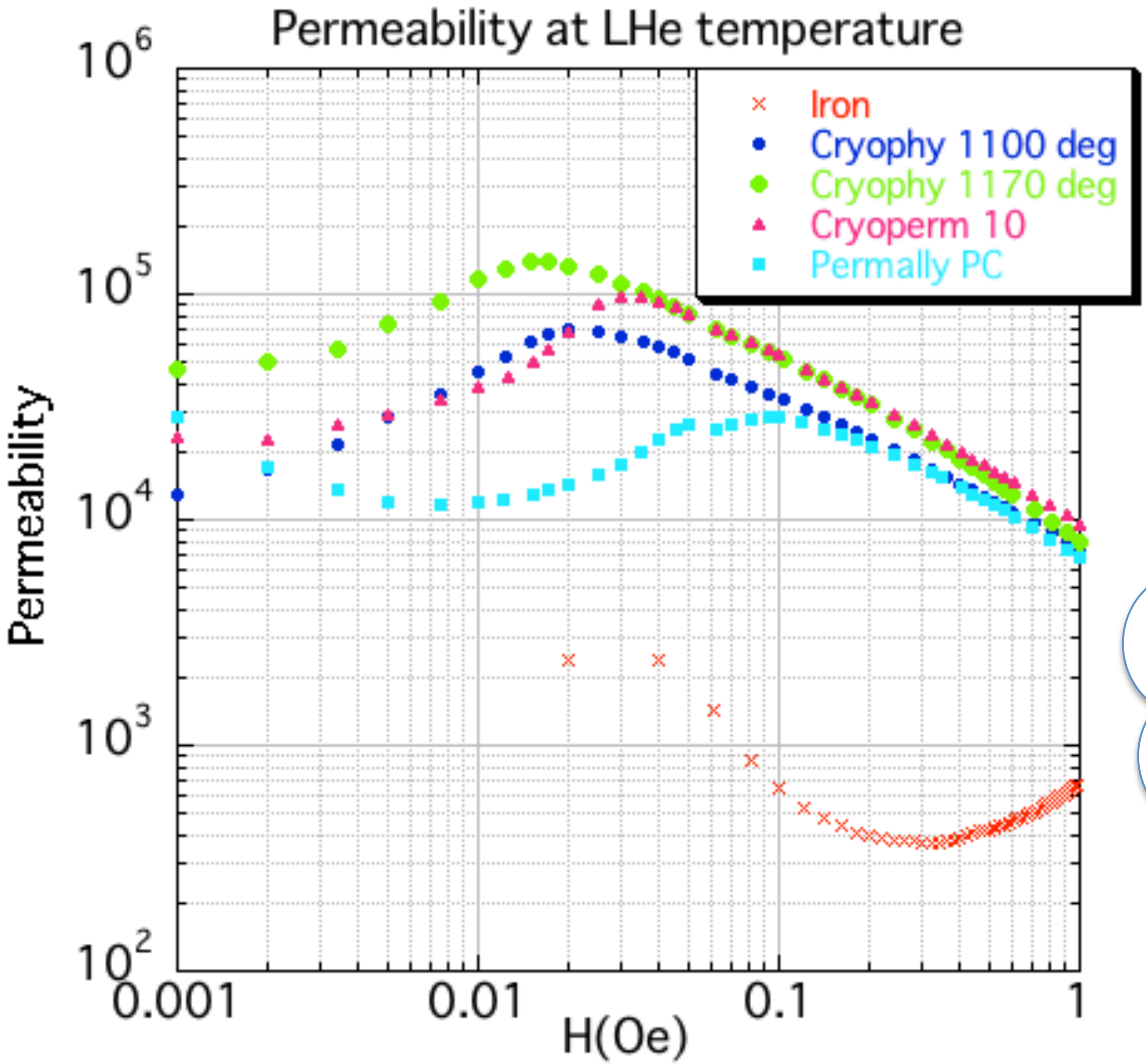
(5)Shielding effectiveness

We see there is a difference in permeability among various materials.

How much effect does permeability have on the shielding?



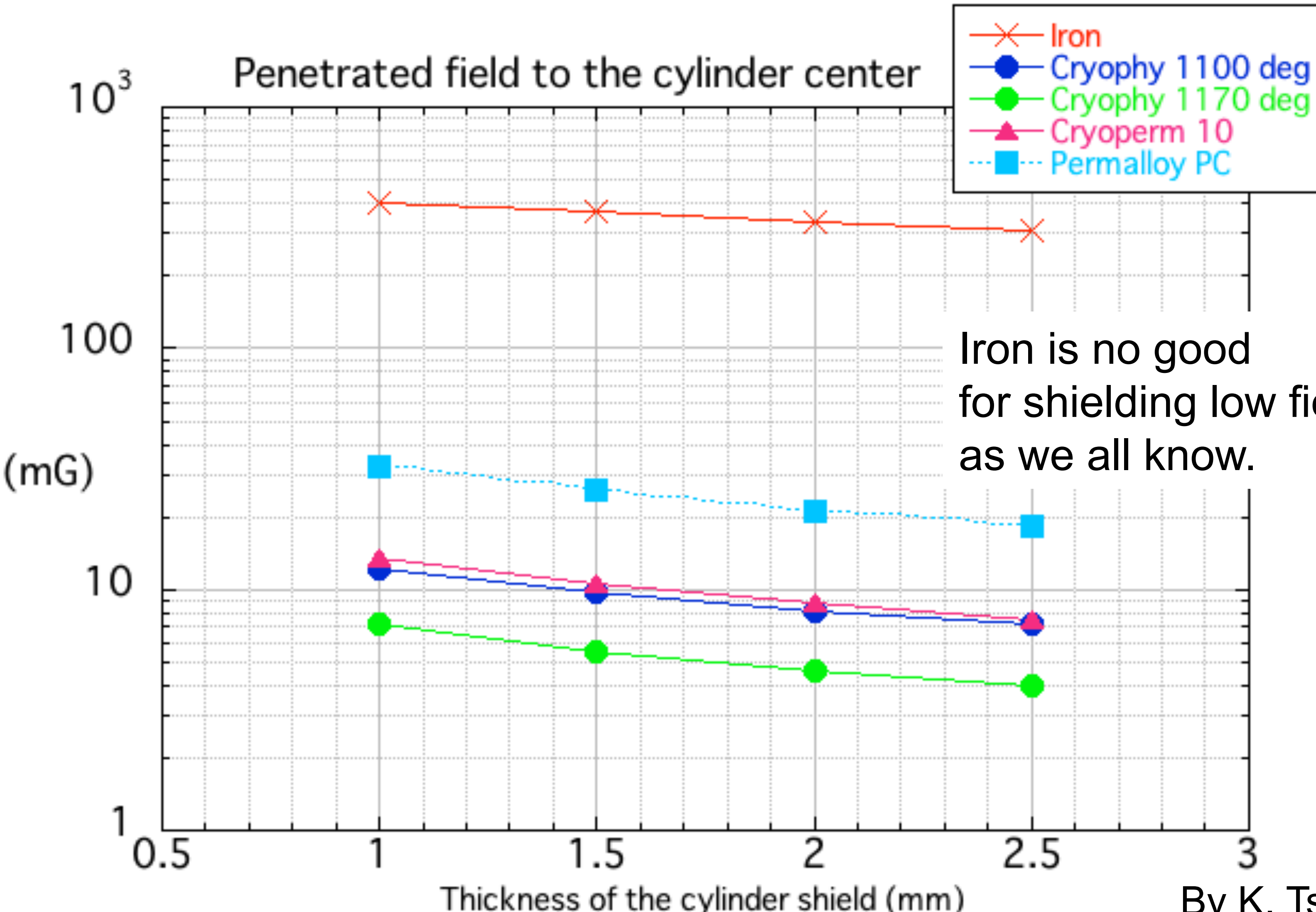
(5)Shielding effectiveness



μ@LHe data used for calculation

Penetrating field inside the cylinder model?

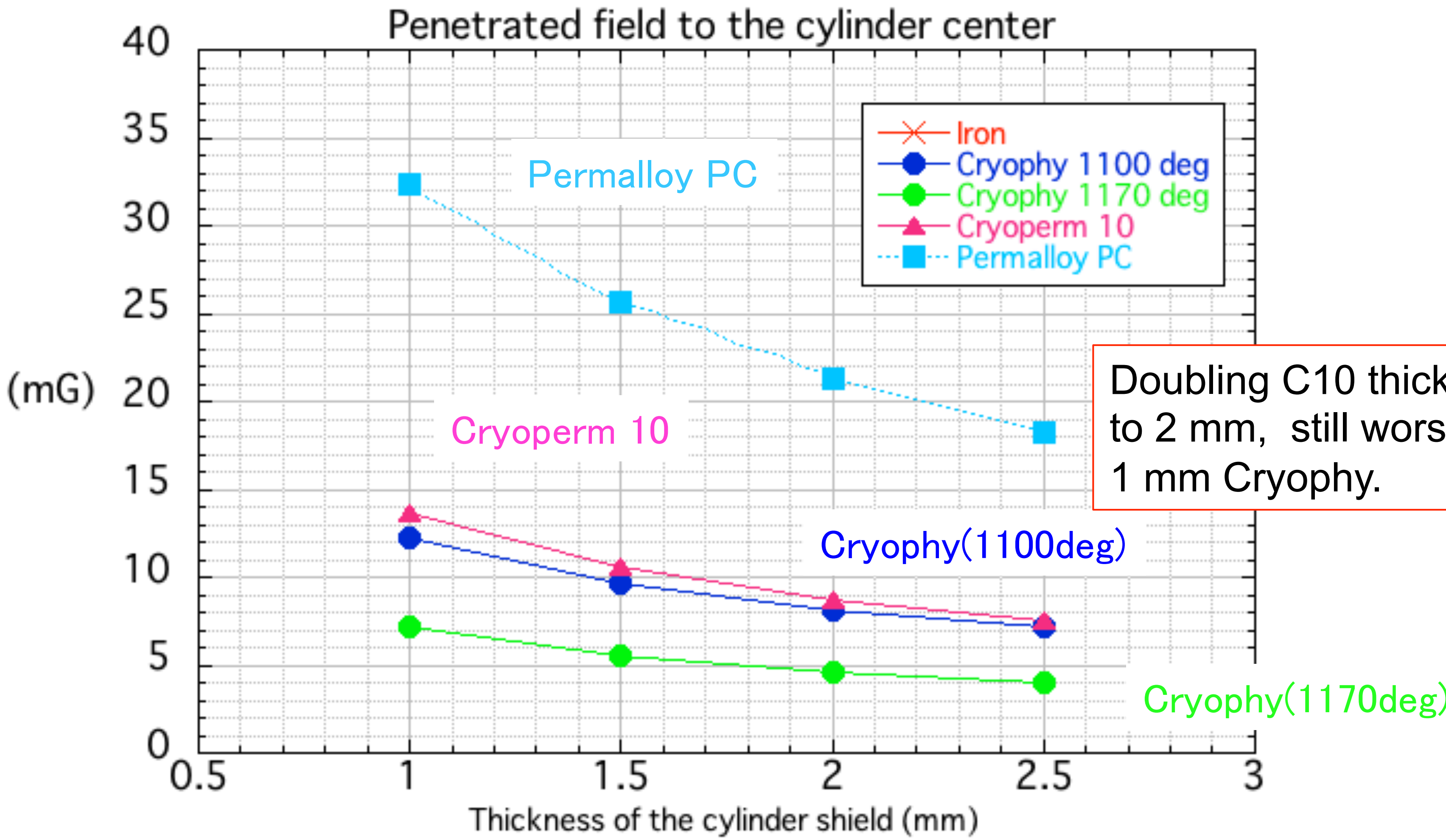
(5)Shielding effectiveness



Iron is no good
for shielding low fields,
as we all know.

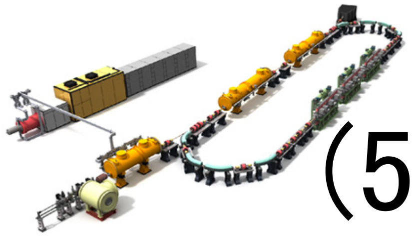
By K. Tsuchiya

(5)Shielding effectiveness



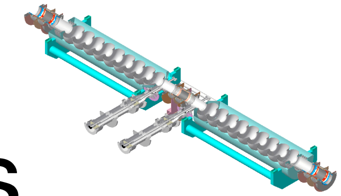
Doubling C10 thickness to 2 mm, still worse than 1 mm Cryophy.

By K. Tsuchiya

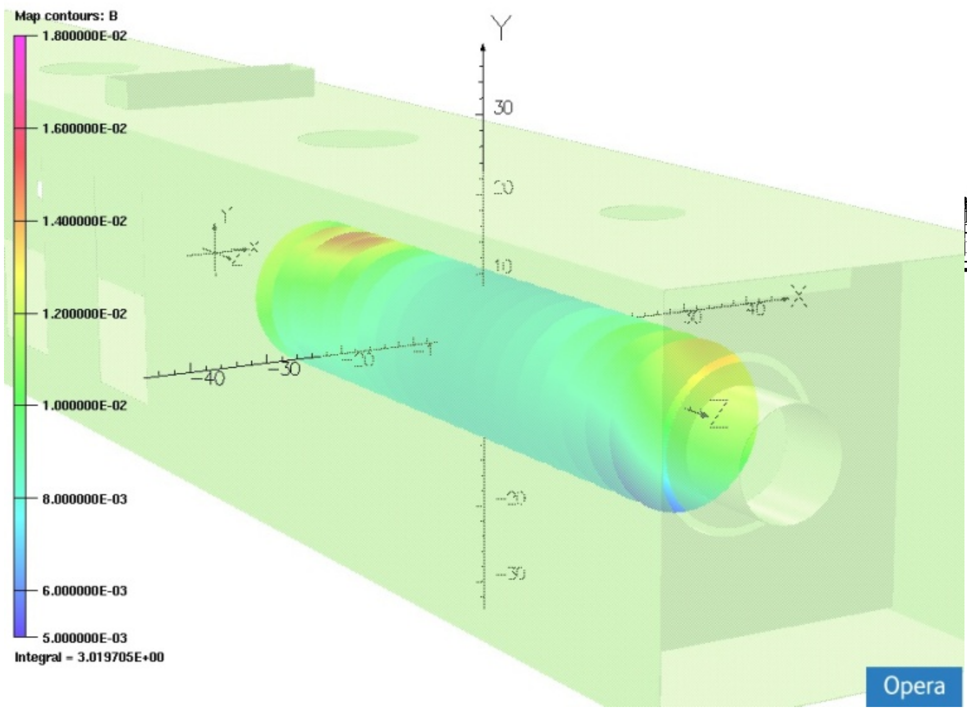


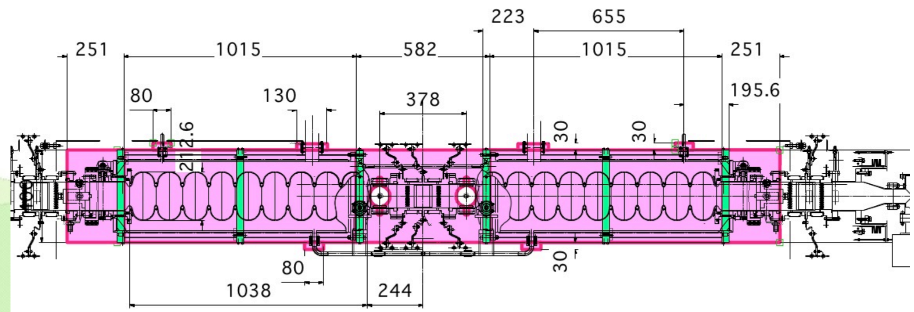
コンパクトERL：ERL加速器の原理実証機 © Rey Hori

(5)Shielding effectiveness



cERL Main Linac Cavity system

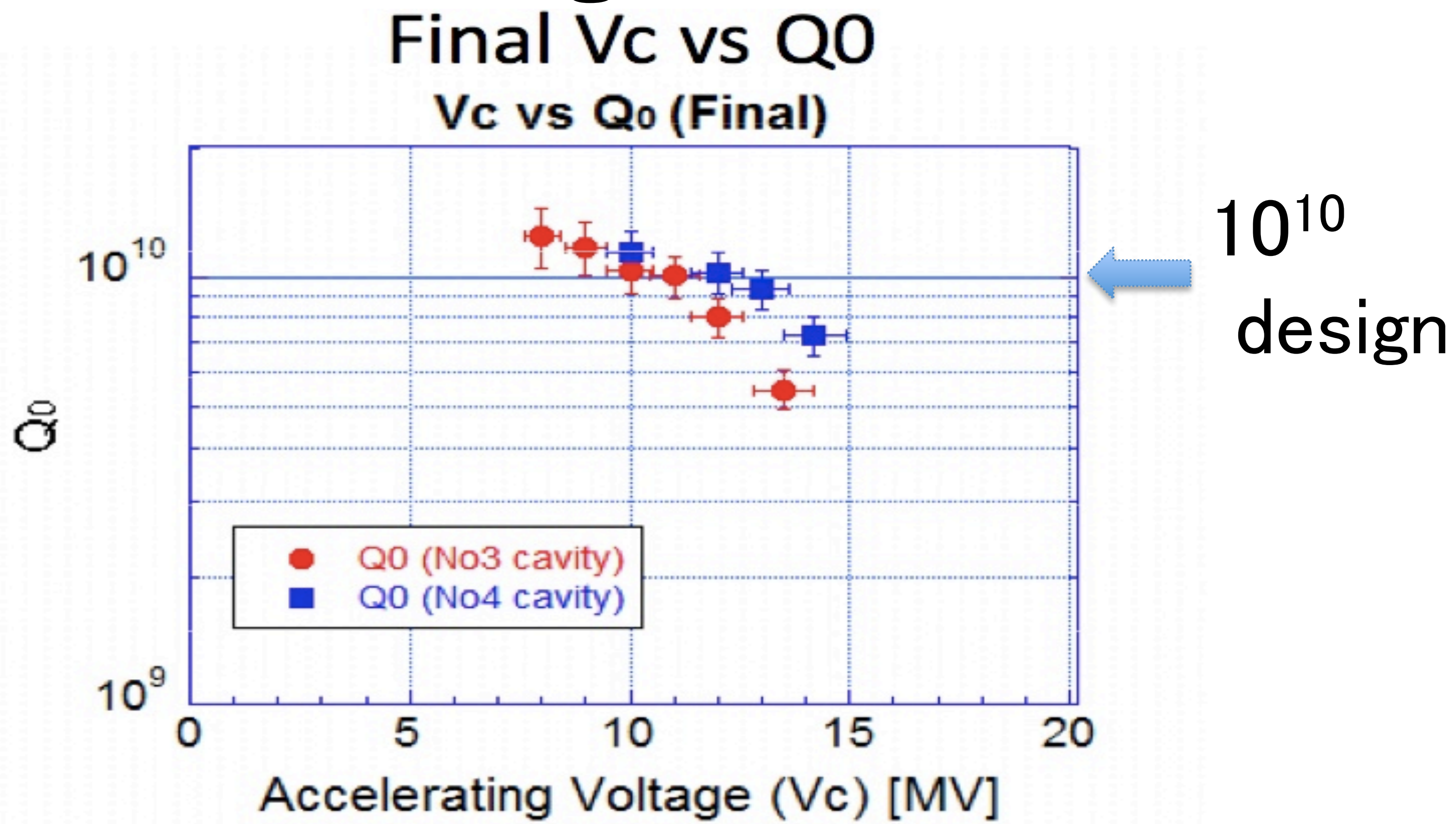




We chose Cryophy for cERL ML system. CEA-Saclay also chose Cryophy for XFEL.

Simulation results using Cryophy data @ LHe temperature (annealed @ 1100°C). The color scale on the left corresponds to the magnetic field inside the cavities, 18 mG being the maximum.

(5)Shielding effectiveness



High Power Test Results from H. Sakai

➔see Thursday oral presentation THIOC02 @ 10:45

The Q_0-value exceeded the design value of 10^{10}

This indicates that the magnetic shield kept the ambient magnetic field to a level of 10 mG at cryogenic temperature, agreeing with the simulation.

(6) Summary & additional info

- Among the materials evaluated, Cryophy gave the highest permeability at LHe temperature.

- Shielding materials are very delicate. When installing the shield, avoid adding mechanical stress unless you can anneal them in-situ.

- Attention should be paid to the annealing process (maximum temperature, cooling rate, and so on). Stick to the supplier's recipe.

(6) Summary & additional info

Cryophy is more expensive than permalloy PC

When buying 300 kg of them in Japan, it is a factor of 2 more expensive than permalloy PC.

But doubling the thickness of permalloy PC does not shield the ambient field as well as Cryophy.

➔choosing a material with higher permeability is better than adding more lower-grade material.

It really depends on the tolerance on the ambient field.

➔10 mG? A few mG?

Choose the material wisely.

A clear understanding of the required tolerance on the ambient magnetic field is needed!

Collaboration with CEA/Saclay in the framework of FJPPL (France-Japan Particle Physics Laboratory)

Future plan

From Juliette Plouin – FRIB Magnetic shield workshop Mar. 6, 2013

- Measure permeability of the same sample at CEA and KEK at room temperature and cryogenic temperature and make a comparison and evaluate possible systematic errors between the two groups. CEAs collaboration with CERN may give more data to be compared.
- Continue to investigate possible causes for the performance degradation of the shielding material at the cryogenic temperature.
- Development of a quality control method, suitable for use in mass production.

Our goal is to contribute to a shielding material database that the community can share.