High Pressure Gas Safety Code for ILC Cryomodule

2022/1/26 TTC meeting

Modified for 2022/2/15 IDT-WG2 SRF group meeting

KEK CASA Kensei Umemori

Outline

- High Pressure Gas Safety regulation
  - ✓Introduction
  - ✓Refrigeration safety regulation
  - ✓Material (Nb, NbTi, Ti/SUS clad)
  - ✓Pressure test
  - ✓Welding efficiency
- Summary

Reference

H. Nakai, “High pressure gas safety regulations in Japan for SC cavities and cryomodules”, TTC2008@DESY

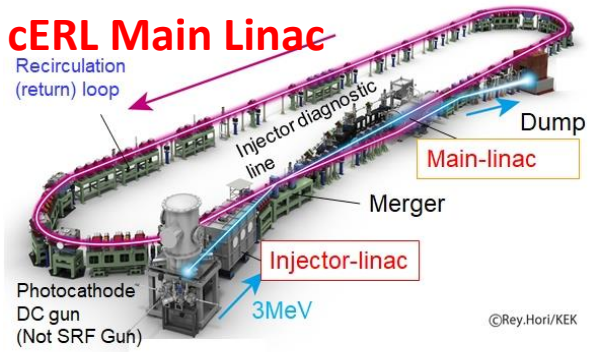
K. Umemori, “High pressure gas safety regulation in Japan”, ILCX2021

KHK = Kohatsu-Gas Hoan Kyokai
= The High Pressure Gas Safety Institute of Japan
KHK is a specialized institute ensuring high pressure gas safety.

Regulations in high pressure gas safety act

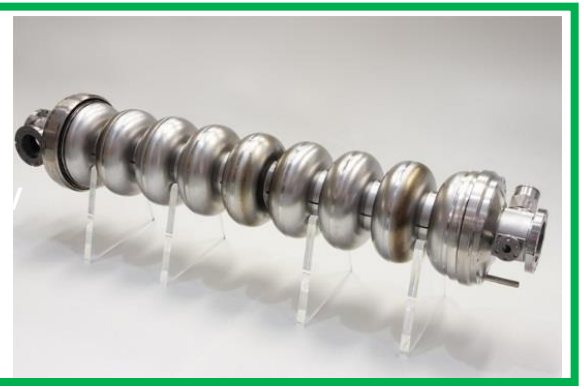
New HPGS regulation

Designated equipment inspection regulation



PV>0.004 [MPa m^3] => “Designated equipment” is required

General high-pressure gas safety regulation

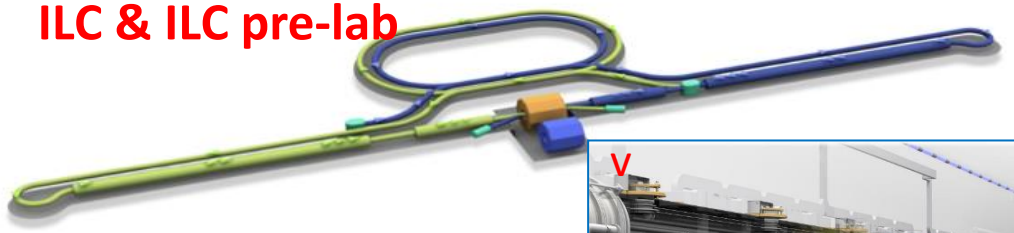


LPG(Liquefied petroleum gas) safety regulation

Industrial complex (kombinat) safety regulation

Refrigeration safety regulation

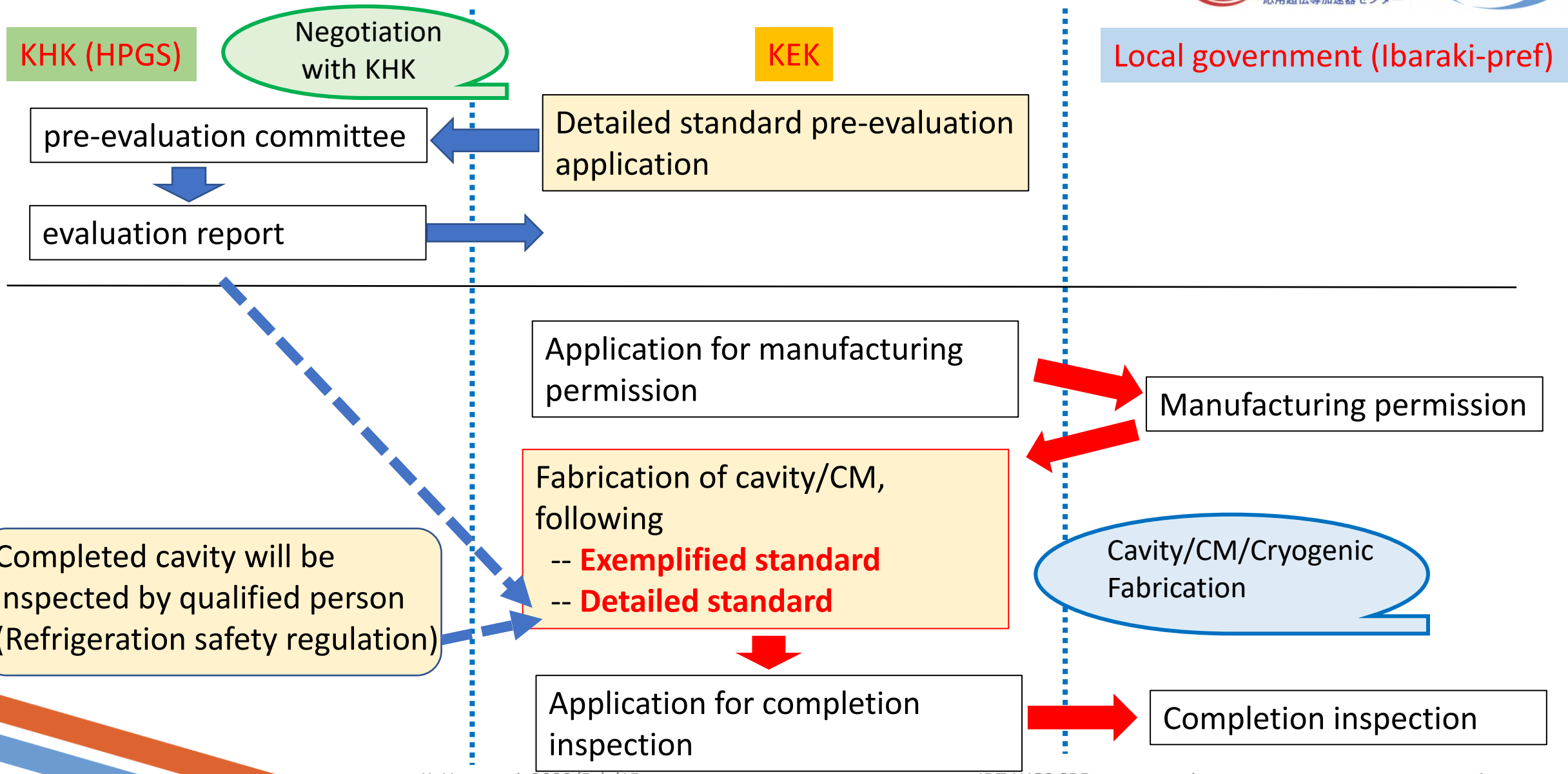
ILC & ILC pre-lab



etc…

For ILC & ILC pre-lab, we try to apply to refrigeration safety regulation.

Flow of cavity/CM/cryogenic construction



Application of special technical standard pre-evaluation

High pressure gas regulations

Conformity assessment to functionality standard

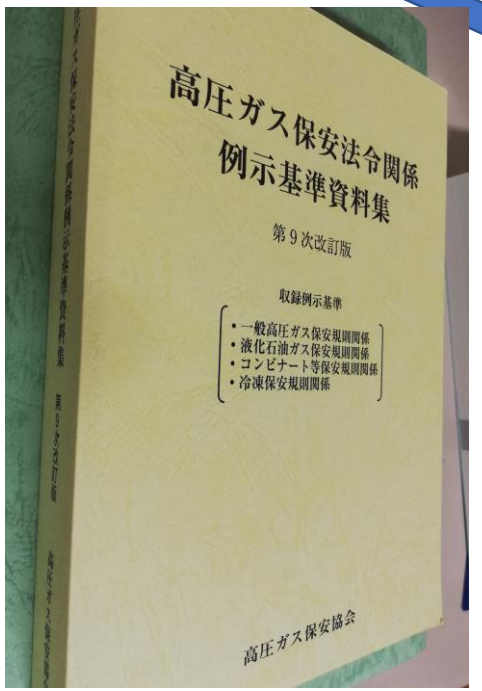
If the case not following to exemplified standards (for example, cavities)

Submit "**Special technical standard pre-evaluation application**" to KHK

Evaluation at **pre-evaluation committee** (KHK)

Issuance of **evaluation report** (KHK)

※ This process is done between **KHK** and KEK.



If the case following to exemplified standards (for example, piping etc.)

Apply exemplified standards to fabrication

※ This process is basically done by **local government.**

※ Special technical standard

Direct translation is "Detailed standard"

Our(KEK or my) challenge for HPGS

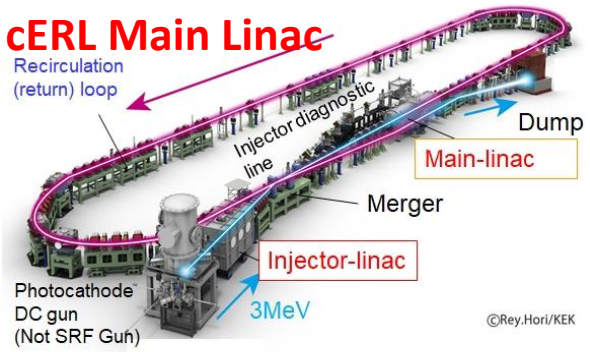
※ HPGS = High Pressure Gas Safety

- New regulation
  - General high-pressure gas safety regulation ⇒ Refrigerator safety regulation
- Cavity and CM design
  - STF cavity / CM ⇒ TESLA cavity / ILC CM
- Material (Mechanical test)
  - Higher temperature heat treatment
  - MG(Medium Grain), LG(Large Grain)
  - New material : NbTi(55%), Ti/SUS clad joint
- International collaboration
  - Japan(Asia), Europe, U.S.
  - Possibly unified application and unified procedure
- Multiple vender
  - Multiple Nb vender
  - Multiple fabrication vender

Regulations in high pressure gas safety act

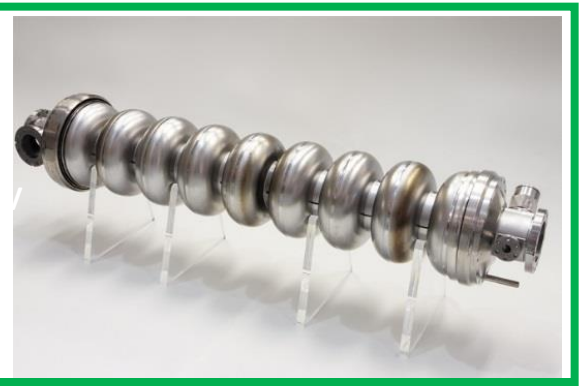
New HPGS regulation

Designated equipment inspection regulation



PV>0.004 [MPa m^3] => “Designated equipment” is required

General high-pressure gas safety regulation

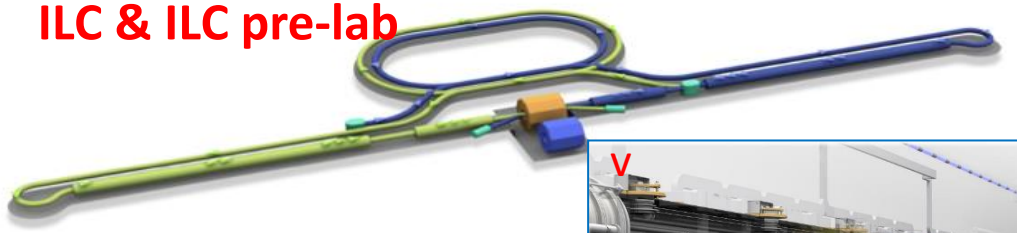


LPG(Liquefied petroleum gas) safety regulation

Industrial complex (kombinat) safety regulation

Refrigeration safety regulation

ILC & ILC pre-lab



etc…

For ILC & ILC pre-lab, we try to apply to refrigeration safety regulation.

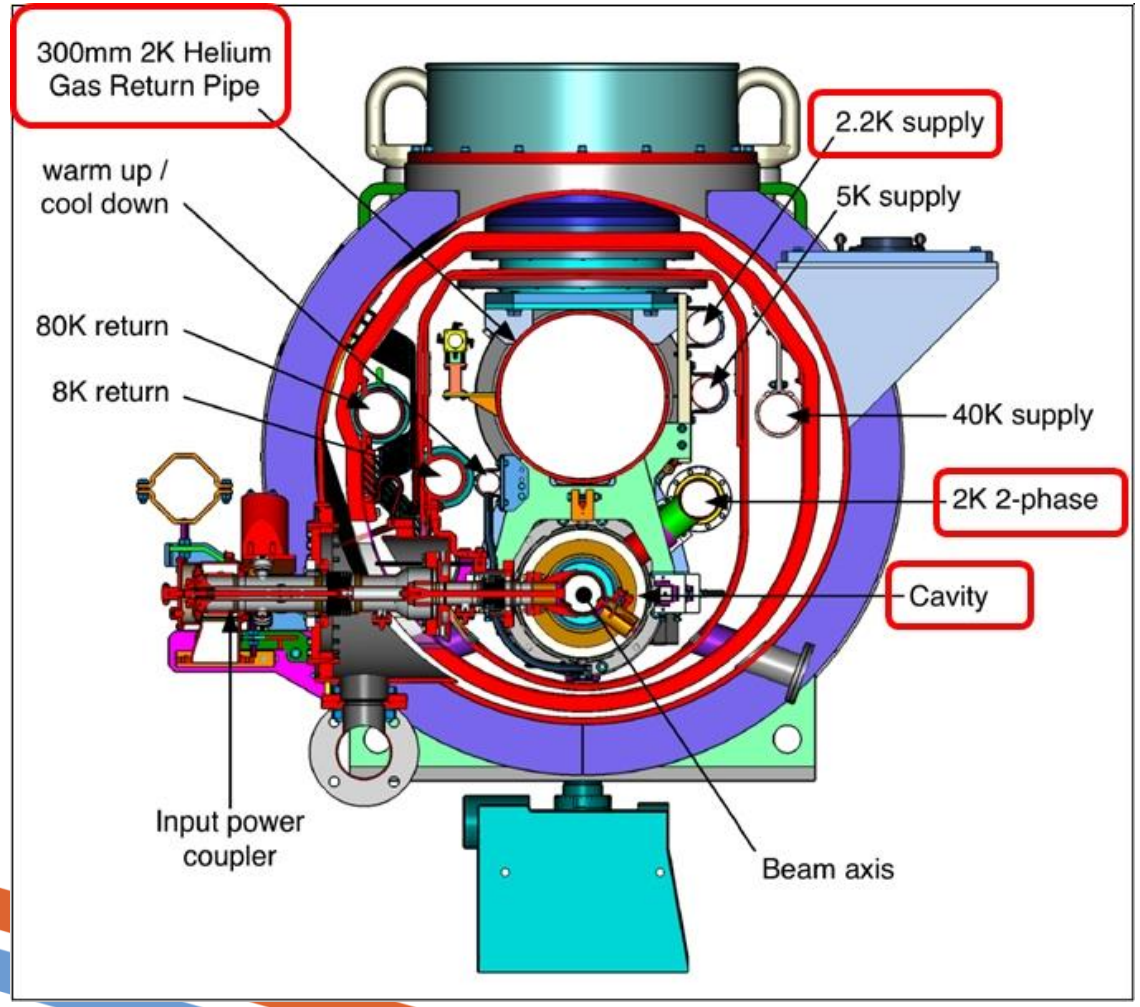
Comparison between general high-pressure safety and refrigeration safety regulation

Item/Process	General high-pressure gas regulation	Refrigerator safety regulation
System	Open / closed loop	Only closed loop
Inspection of completed cavity	Inspection by KHK	Inspection by qualified person
Expiration date of inspection pass	3 years	(Basically) no limitation
Operation	Security staff (with license) must be resident	No need of security staff
Maintenance Regular inspection	Security inspection with prefectural office (once/year) + self inspection (> once/year)	Self inspection (> once/year) Unannounced inspection by prefectural office
Change category	Possible to change to refrigerator safety regulation	Impossible to change to general high-pressure gas regulation

CM design

Design of ILC cryomodule

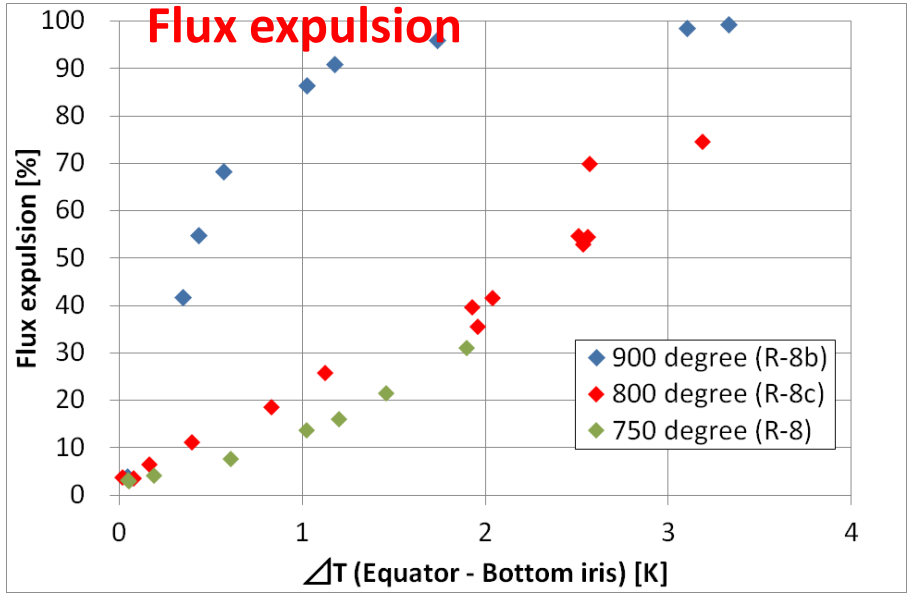
2K line

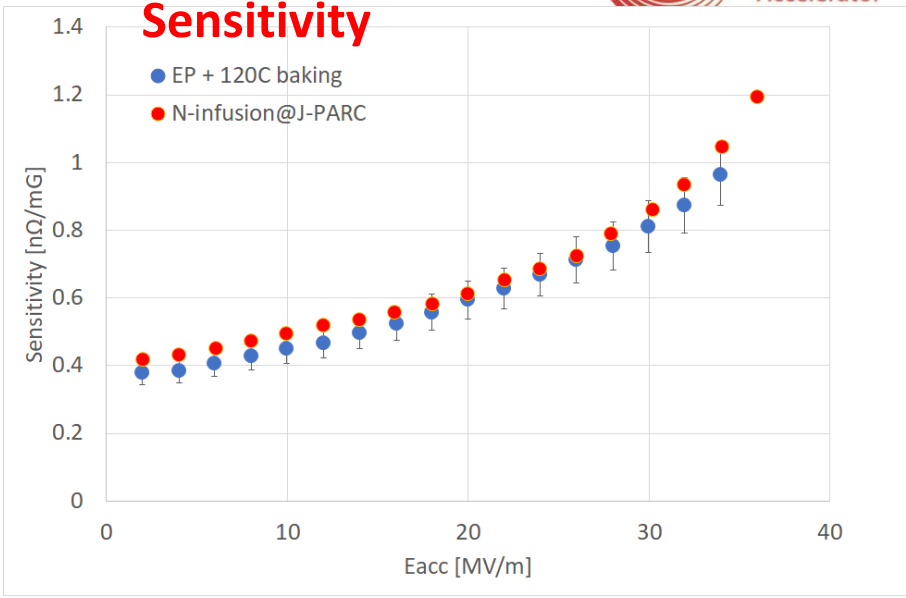


	Diameter	Design temperature	Operation temperature	Design pressure (Abs)	Operation pressure (Abs)
He gas return pipe	300 mm	2(?) ~ 300 K	~ 2K	Max. 2 bar	0.03 bar
2.2K supply line	60.2 mm	2 ~ 300 K	5 ~ 300 K	Max. 2 bar	???
2 phase pipe	69 mm	2 ~ 300 K	~ 2K	Max. 2 bar	0.03 bar
He jacketed cavity	240 mm	2 ~ 300 K	~ 2K	Max. 2 bar	0.03 bar
5K supply line	56.1 mm	5 ~ 300 K	5 ~ 8 K	Max. 20 bar	3 ~ 4 bar??
8K return line	69.9 mm	5 ~ 300 K	5 ~ 8 K	Max. 20 bar	3 ~ 4 bar??
High temp. shield supply line	72.0 mm	40 ~ 300 K	40 ~ 80 K	Max. 20 bar	3 ~ 4 bar??
High temp. shield return line	79.4 mm	40 ~ 300 K	40 ~ 80 K	Max. 20 bar	3 ~ 4 bar??
Pre-cooling line	38.9 mm	5 ~ 300 K	???	???	0.03 ~ 1.5 bar

Nb material

Higher temperature heat treatment





- Even perfect flux expulsion is difficult in ILC cryomodule, part of expulsion can help to reduce cryogenic loss and operation cost.
- Higher temperature heat treatment is desired (900 deg C?).
- But, mechanical strength might become weaker.

Request, Question

- If you(LCLS-II?) have data of temperature dependent mechanical strength, I would like to see it. It should be very much helpful for us.
- How to treat different vendor's Nb material, maybe different mechanical property?

Nb material

MG(Medium Grain)/LG(Large Grain) Nb

A. Kumar 「Mechanical properties of directly sliced medium grain niobium for 1.3 GHz SRF cavity」, SRF2021, MOPCAV004

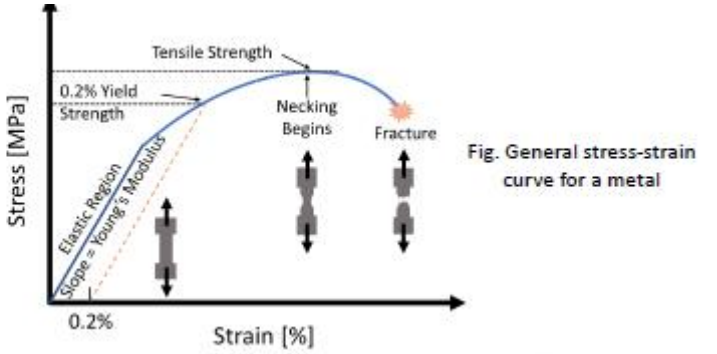


Fig. General stress-strain curve for a metal

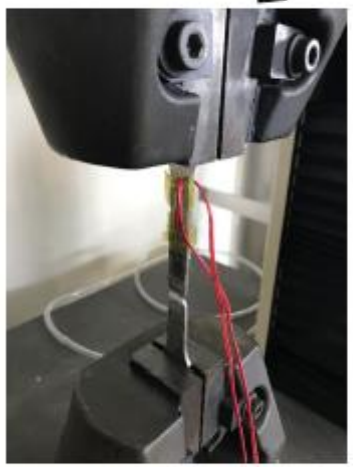


Fig. Room temperature tensile testing

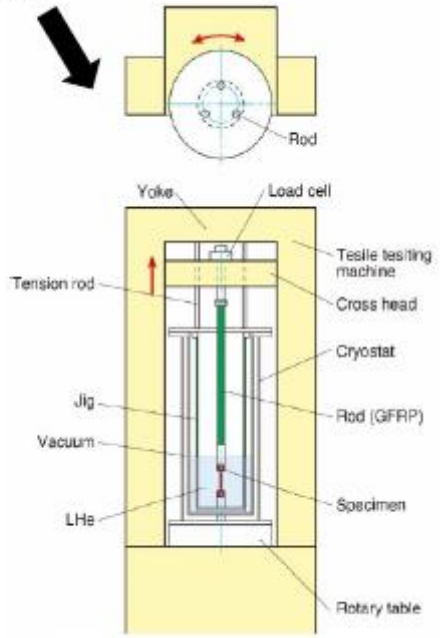


Fig. Tensile testing in liquid helium

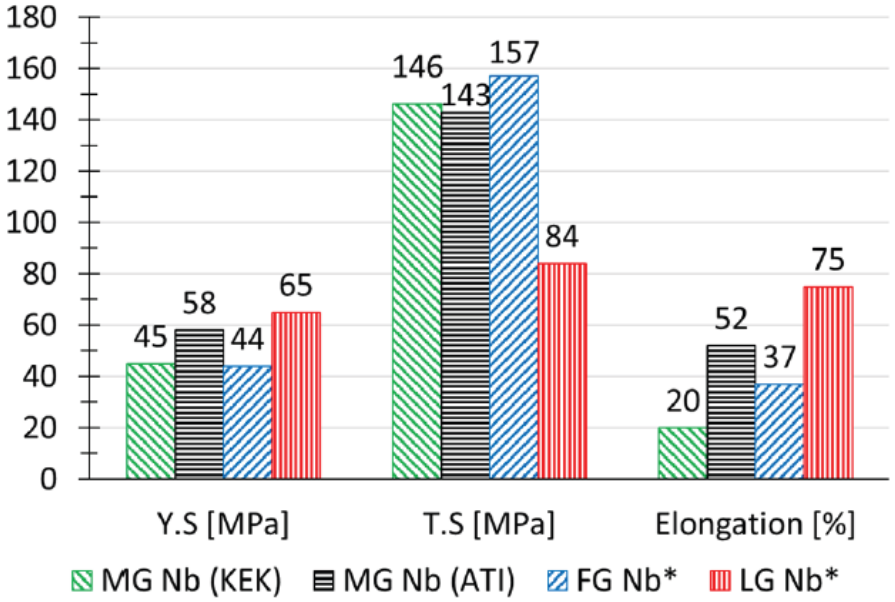


Figure 9: Comparison of mechanical properties of MG Nb with FG Nb and LG Nb at room temperature.

- Mechanical strength of MG is similar to FG Nb. ⇒ maybe possible to apply HPGS
- Tensile strength of LG is lower than FG.

Request

If you(JLAB?) have experience to pass the LG against HPGS, could you please kindly let me know how did you do that?

New material

NbTi(55%), Ti/SUS clad

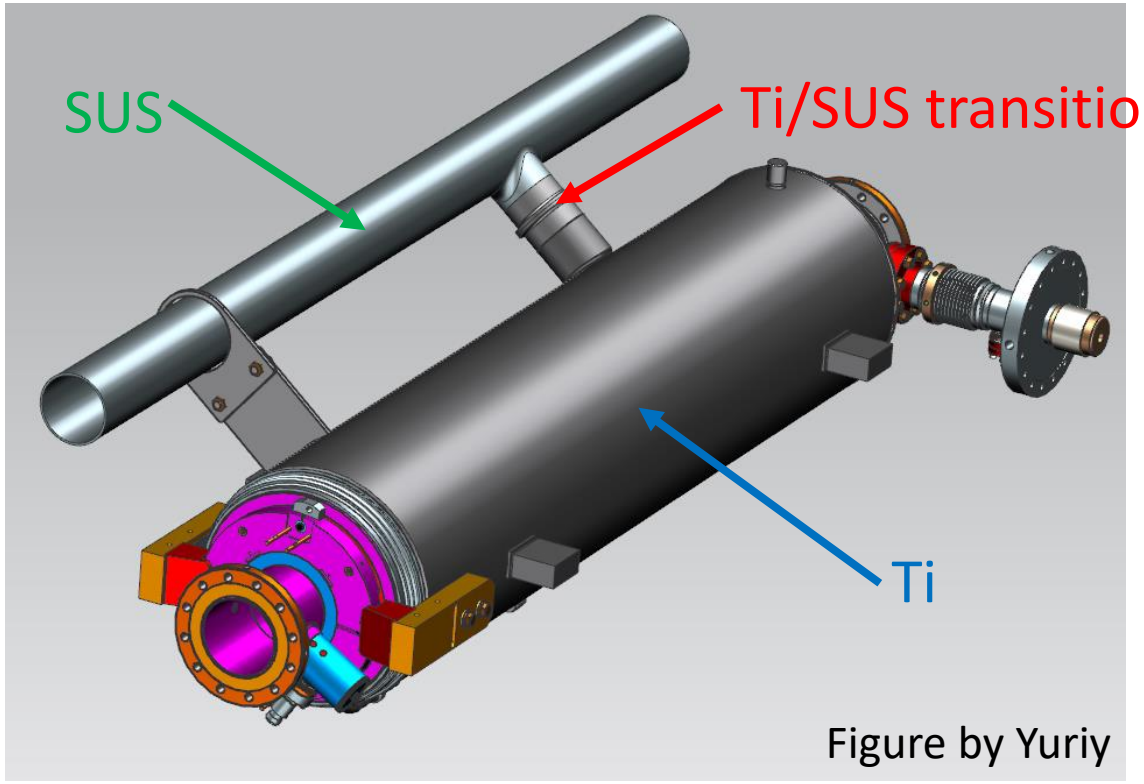
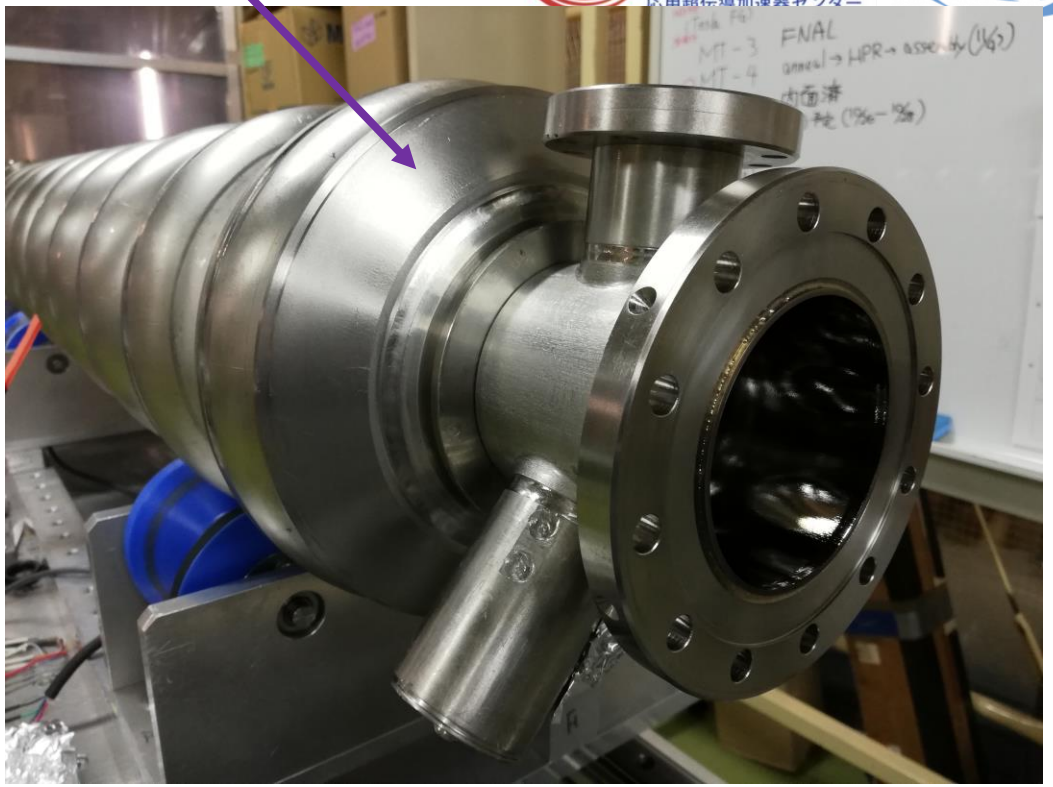


Figure by Yuriy



- We had mechanical data for NbTi(47%), but not for NbTi(55%).
- Consider to use Ti/SUS transition at chimney and pre-cooling line.
- Ti/SUS clad material is really new material for low temperature application in Japan.

Request

Your information for NbTi, Ti/SUS clad is very much welcome!

Pressure test

Pressure-resistant test

Requirement from the regulation

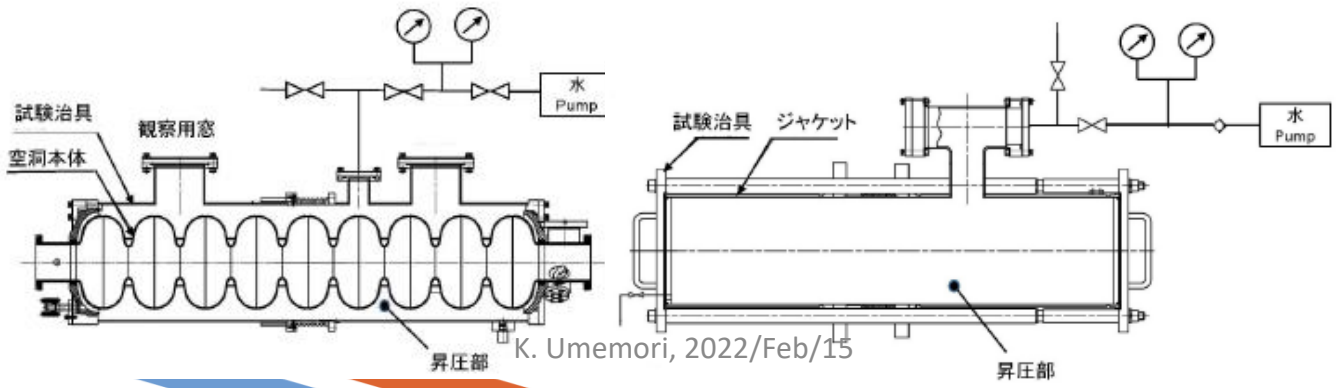
After completion of He jacketed cavity, pressure and tightness test is required with

- 1.5 times pressure by water (liquid), or
- 1.25 times pressure by gas with additional RT/PT tests

※ But we can not do pressure test by water, also can not do RT/PT tests

Our solution (for the case of STF cavity)

- Apply 1.5 times(3 bar) water pressure test for cavity (w/o He jacket).
- Apply 1.5 times(3 bar) water pressure test for He jacket (w/o cavity).
- Apply 1.25 times (2.5 bar) gas pressure test for completed jacketed cavity. PT is applied only to Ti-Ti TIG welding joint.



Question

- What procedure is applied for pressure test at Europe and U.S.?
- Gas? Water?
- How much pressure?

Welding efficiency

This factor only applied for the refrigeration safety regulation, not for general gas high-pressure regulation.

- For butt welding, following welding efficiency factor is defined.

Fraction of radiation transmission test against total welding length	Welding efficiency factor
100 %	1.0
Less than 100 %, and more than 20 %	0.95
Less than 20 %	0.7

- Above welding efficiency factor is used as follows.

$Pm \leqq S \times$ (welding efficiency factor)
$PL \leqq 1.5 \times S \times$ (welding efficiency factor)
$PL + Pb \leqq 1.5 \times S \times$ (welding efficiency factor)
$PL + Pb + Q \leqq 3 \times S \times$ (welding efficiency factor)

Pm: Primary general membrane stress
PL: Primary local membrane stress
Pb: Primary bending stress
Q: Secondary stress
S: Design stress strength

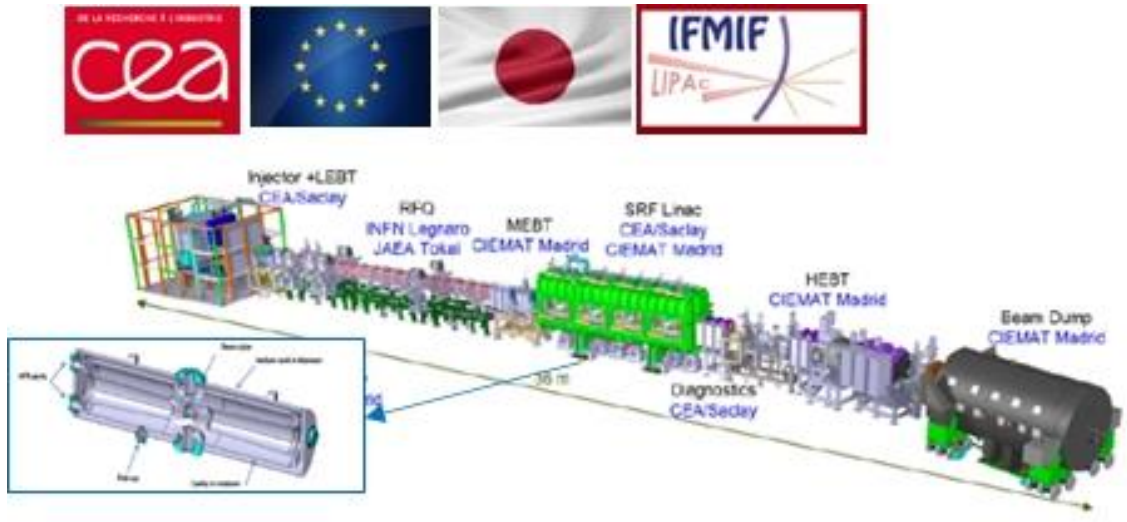
Question

- Does welding efficiency applied also in ASME and/or EN?

International collaboration on HPGS

- If applying foreign procedure is out of exemplified standards, it has to be treated as “detailed standard”, which require discussion/negotiation with KHK.

- Application for IFMIF QWR at Aomori-prefecture by QST is very good reference to apply HPGS by using ASME regulations.
- But anyway, we are not familiar with ASME and EN.
- At present, I do not have much information about European regulations.



Question

- Are the requirement of ASME and EN similar or different?
- Are procedures applied for Euro-XFEL and LCLS-II similar or different?
- Any information are welcome!

Summary

- We have been struggling with High Pressure Gas Safety Act in Japan.
- Many changes exist.
  - Regulation, Material, Cavity type, International unification, etc.
- Your support and help are essential and very much welcome.