# A SURVEY OF PRESSURE VESSEL CODE COMPLIANCE FOR SUPERCONDUCTING RF CRYOMODULES

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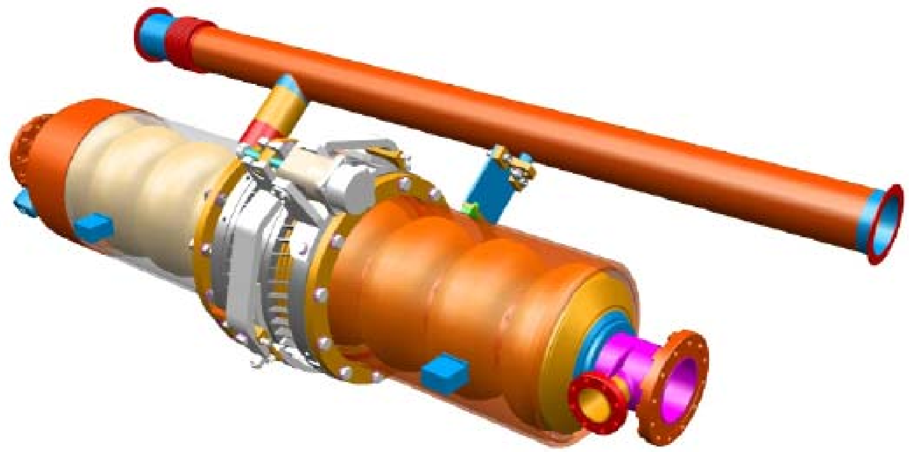
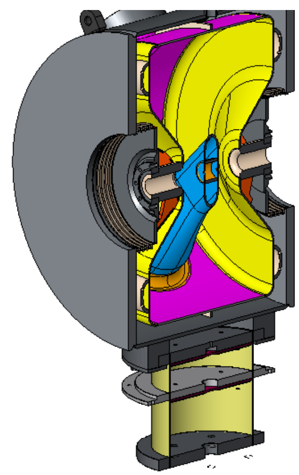
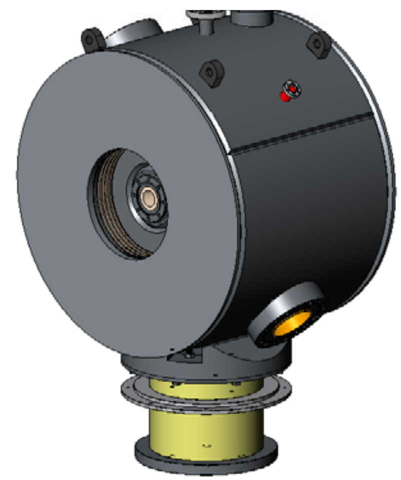
# SRF Technology

- Physics laboratories around the world are developing niobium superconducting radio frequency (SRF) cavities for use in particle accelerators.
- These SRF cavities are typically cooled to low temperatures by direct contact with a liquid helium bath, resulting in at least part of the helium container being made from pure niobium.

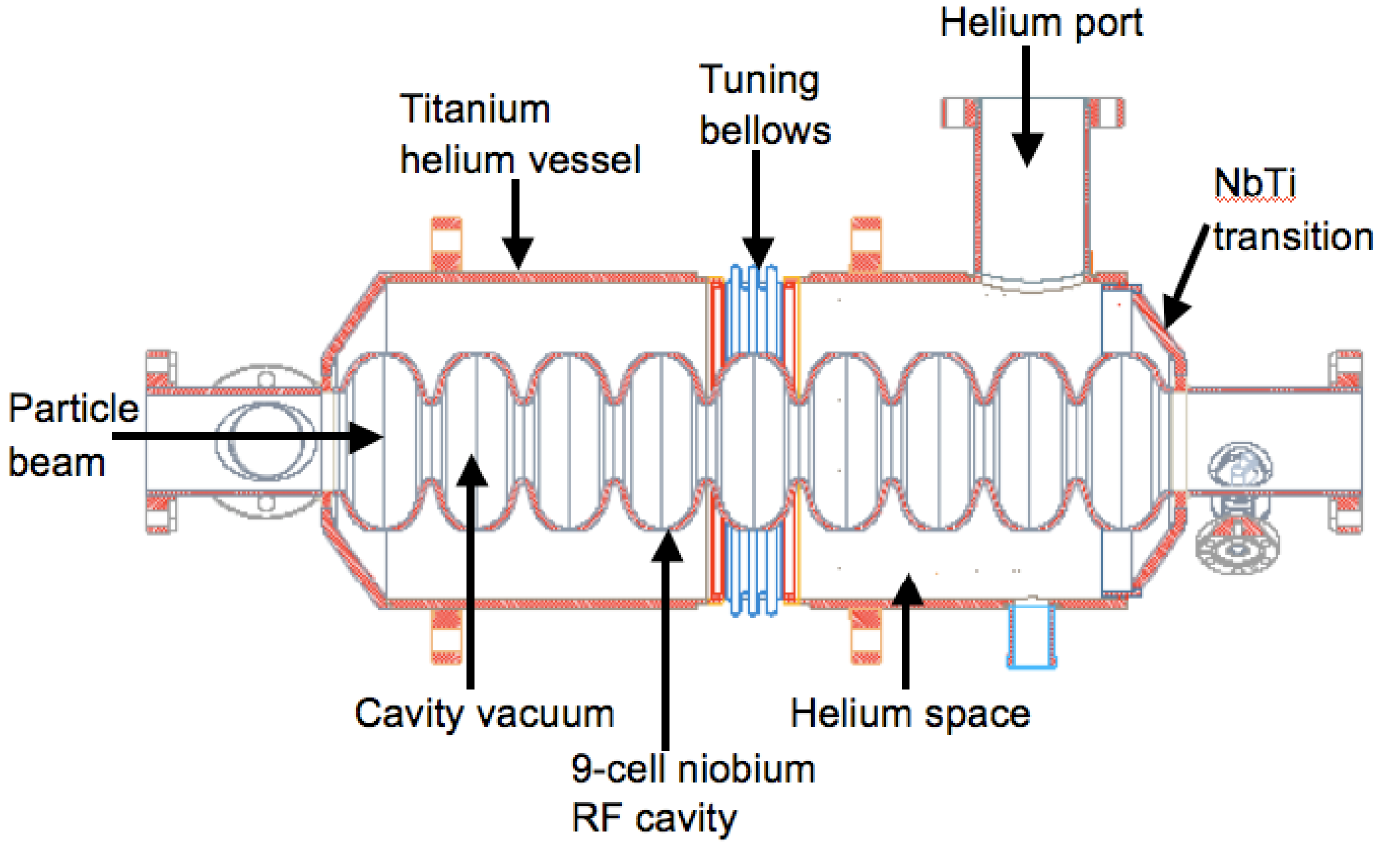






# Features of a dressed RF cavity

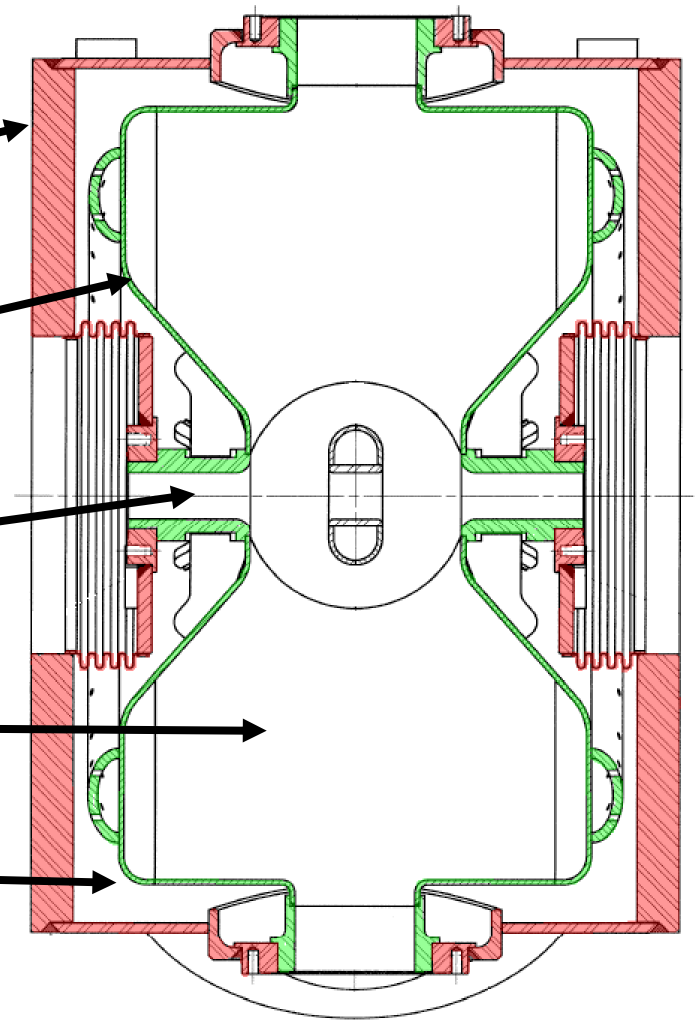
9-cell elliptical cavity
Niobium cavity under external pressure.
Helium vessel sees internal pressure.



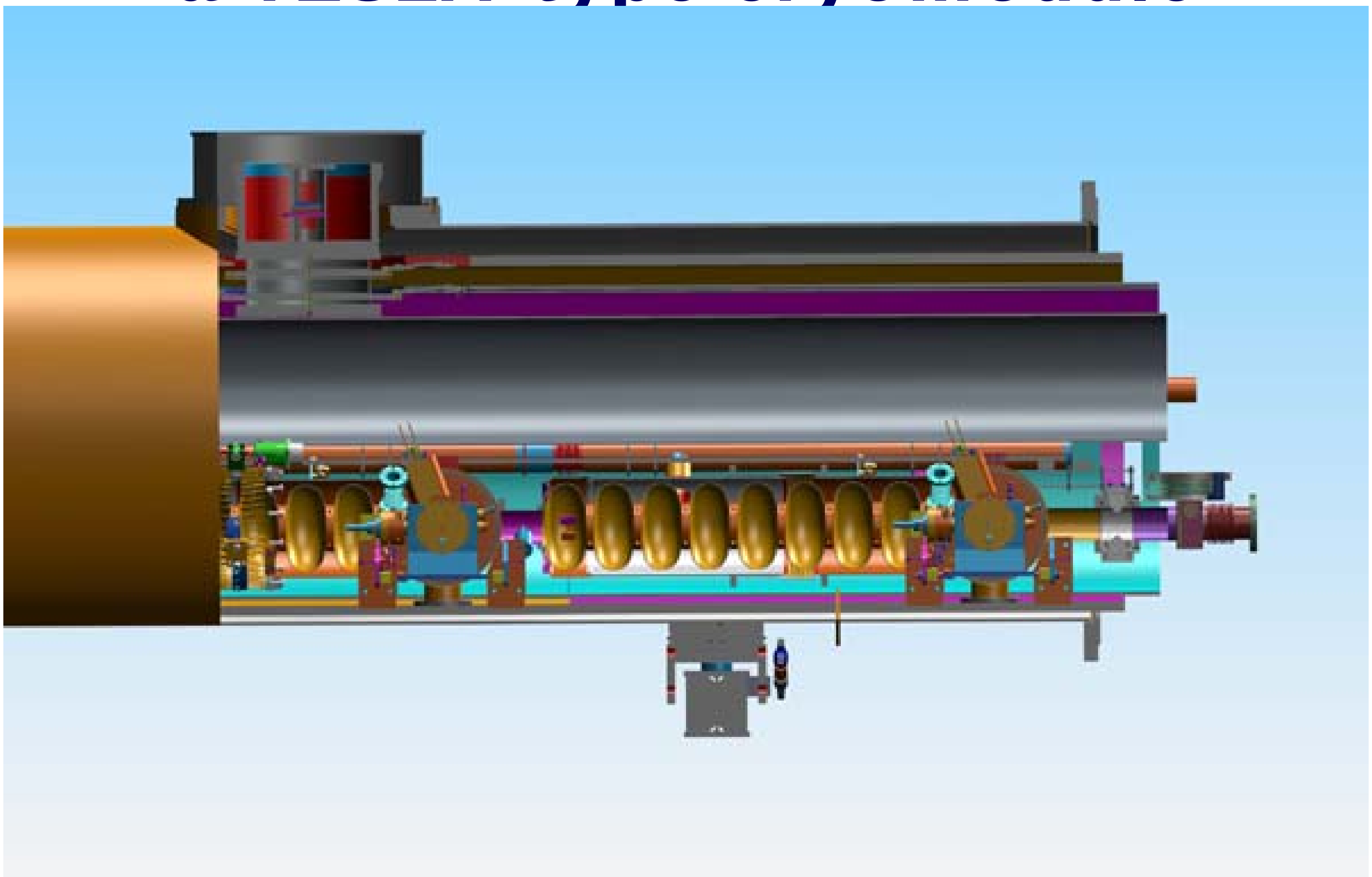
# Features of a dressed RF cavity

Single-spoke cavity
Niobium cavity under external pressure.

Helium vessel sees internal pressure.



# Cutaway view of cavity within a TESLA-type cryomodule



# Safety/compliance issue

- In the U.S., Europe, and Japan, these helium containers and part or all of the RF cavity fall under the scope of the local and national pressure vessel rules.
- Thus, while used for its superconducting properties, niobium ends up also being treated as a material for pressure vessels.
- For various reasons, it is not possible to completely follow all the rules of the pressure vessel codes for most of these SRF helium vessel designs

# Issues for code compliance

- **Cavity design that satisfies level of safety equivalent to that of a consensus pressure vessel code is affected by**
  - » use of the non-code material (niobium),
  - » complex forming and joining processes,
  - » a shape that is determined entirely by cavity RF performance,
  - » a thickness driven by the cost and availability of niobium sheet,
  - » and a possibly complex series of chemical and thermal treatments.
- **Difficulties emerge pressure vessel code compliance in various areas**
  - » Material not approved by the pressure vessel code
  - » Loadings other than pressure
    - Thermal contraction
    - Tuning
  - » Geometries not covered by rules
  - » Weld configurations difficult to inspect

# Exceptional vessels

- In the U.S., the Code of Federal Regulations (10 CFR 851 Appendix A Section 4C) allows national laboratories to use alternative rules which provide a level of safety greater than or equal to that afforded by ASME Boiler and Pressure Vessel Code when the pressure code cannot be applied in full.
- Similarly, in Europe and Japan, methods exist for handling exceptional cases like these vessels made partly from niobium.

# General solution

- **In applying ASME code procedures, key elements demonstrating the required level of design safety are**
  - » the establishment of a maximum allowable stress
  - » And for external pressure design, an accurate approximation to the true stress strain curve
- **Apply the ASME Boiler and Pressure Vessel Code as completely as practical**
  - » Exceptions to the code may remain
  - » We have to show the risk is minimal
- **Satisfy the requirement for a level of safety greater than or equal to that afforded by ASME code.**
- **Fermilab, Brookhaven, Jefferson Lab, Argonne Lab, and others in the U.S. have taken a similar approach**

# Fermilab has developed a standard and guidelines for vessels which cannot fully meet the pressure vessel code

- **Design drawings, sketches, and calculations are reviewed and approved by qualified independent design professionals.**
- **Only qualified personnel must be used to perform examinations and inspections of materials, in-process fabrications, non-destructive tests, and acceptance tests.**
- **Documentation, traceability, and accountability is maintained for each pressure vessel and system, including descriptions of design, pressure conditions, testing, inspection, operation, repair, and maintenance.**

# Brookhaven and Jlab

- **Engineers at Brookhaven, Advanced Energy Systems (AES) and Stony Brook University have analyzed cavity vessel stresses in accordance with ASME code rules in order to satisfy code requirements.**
  - » Allowed stress is 2/3 of yield where yield is based on material certifications provided from BNL to the supplier.
  - » Weld samples are tested per code, i.e. tensile, guided beam test, Charpy at room temperature and 77 K. No testing below 77 K due to heat input from testing giving inaccurate results.
  - » They have applied this approach also to the Cornell SRF cavity design "CESR-B", which is now used in several particle accelerator facilities around the world.
- **Jefferson Lab established an allowable stress of 29 MPa (4200 psi) based on 2/3 of yield strength of softest batch of material.**
  - » Relying on operational experience.
  - » Acceptance based on peer review and adherence to 10 CFR 851.

# Another possibility with certain geometries -- cavity not part of pressure boundary

- **SNS (Oak Ridge National Lab)**
  - » Doing their own material testing, abandoned pursuit of material-based Code case for now.
  - » Redesigning their cryomodule vacuum vessel to serve as the external containment per Code Interpretation VIII-1-89-82 – the heat exchanger tube sheet analogy.
- **ATLAS linac upgrade (Argonne National Lab)**
  - » Quarter wave cavity -- design nozzles and define the pressure vessel boundary such that the non-code material (niobium) is just contained within the pressure vessel but not part of the pressure boundary
  - » Following slide

# Argonne / Meyer Tool code-stamped helium vessel

- **SCRF quarter wave cavity LHe Vessel for the ANL Atlas Linac upgrade being welded at Meyer Tool**
- **Niobium all excluded from the pressure boundary by means of stainless nozzles and stainless vessel**
- **Vessel approved by authorized inspector and code-stamped**
- **Ed Bonnema (MTM), Joel Fuerst (ANL)**

# Japanese and German labs

# DESY (Hamburg, Germany)

**slides from Axel Matheisen, DESY, which were taken from a presentation at the 2011 TTC meeting in Milan, Italy**

from Axel Matheisen

# Who is who according to PED

Define “who is who”

**Manufactures-** Takes the risk for safe design

Responsible for safety for pressure vessel

Can/ has to fix sequences, materials and tests ..

for a safe product.

**But guides the whole production and**

**is the only one that can produce replicas of the product !**

**Manufacturing enterprise (fabricator)-**

Has to hold and guaranty all qualification's requested by the manufacturer

Hast to follow strictly the directives of manufacturer

Has to deliver all data from production requested.

**“Customer” location defines the PED code to be applied**

from Axel Matheisen

# PED handling of the DESY / XFEL cavities

**PED Module B / B1 for the XFEL Cavities**

- DESY is defined as the manufacturer
- Fabricate a “test piece” (pre production welding test acc. to ISO 15613) for destructive tests
- Manufacture n Cavities with notified body on place and do non destructive testing on them (DCV - RCV cavities for XFEL Cavity production)
- Set up PMA material for materials (as in use) and follow this PMA strictly!

  (PMA= Particular Material Appraisal Acc. PED(97/23/EC) annex I, Sec 4.2)
- Note: The niobium parts of the cavity are treated as a heat exchanger.
- Perform a pressure test on completed cavity for each cavity build

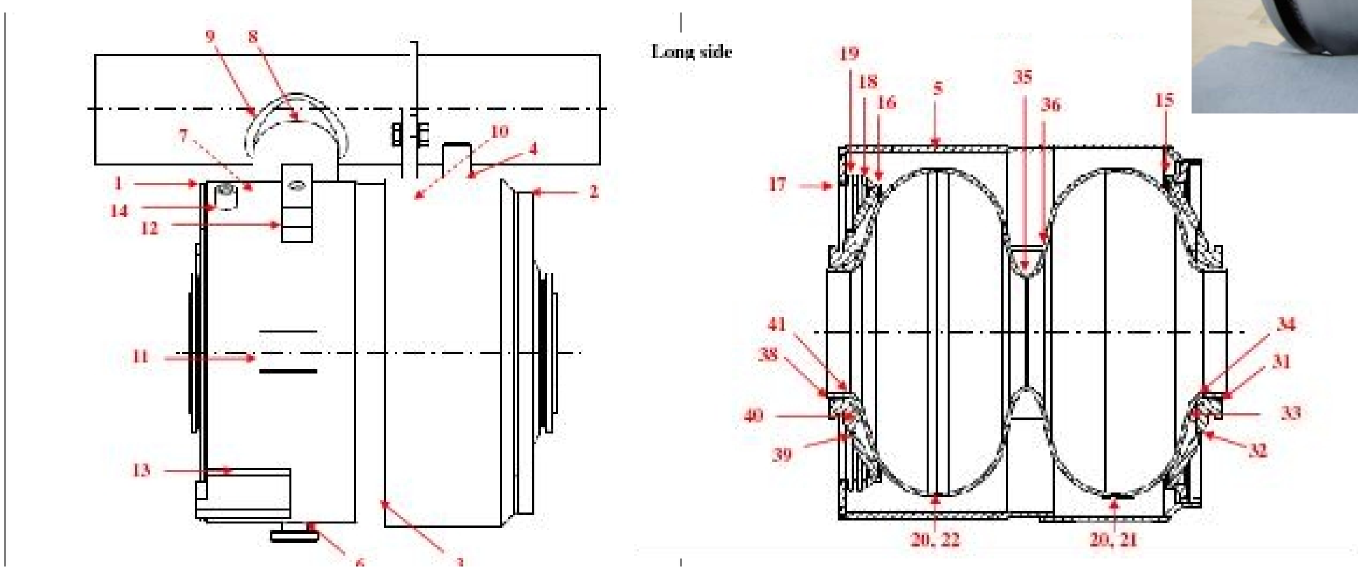
from Axel Matheisen

# PED handling of the DESY / XFEL cavities

XFEL/028

**Test piece / Prüfstück "Cavity in Heliumtank"**

Qualification based on pre-production welding test according ISO 15613
Qualifizierung aufgrund einer vorgezogenen Arbeitsprüfung gemäß ISO 15613

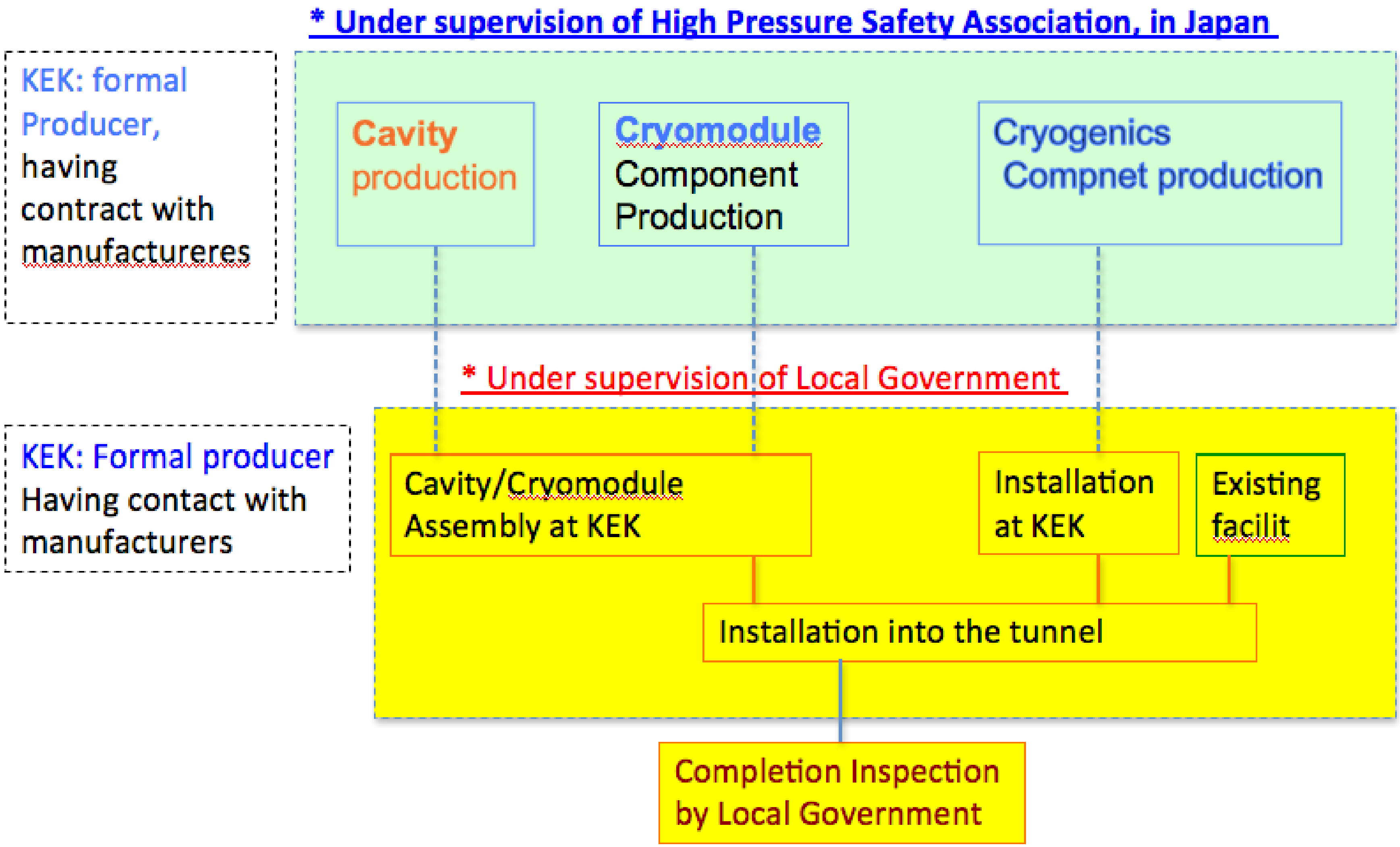



# KEK (Tsukuba, Japan)

**slides from Akira Yamamoto, KEK, which were taken from a presentation at the 2011 TTC meeting in Milan, Italy**

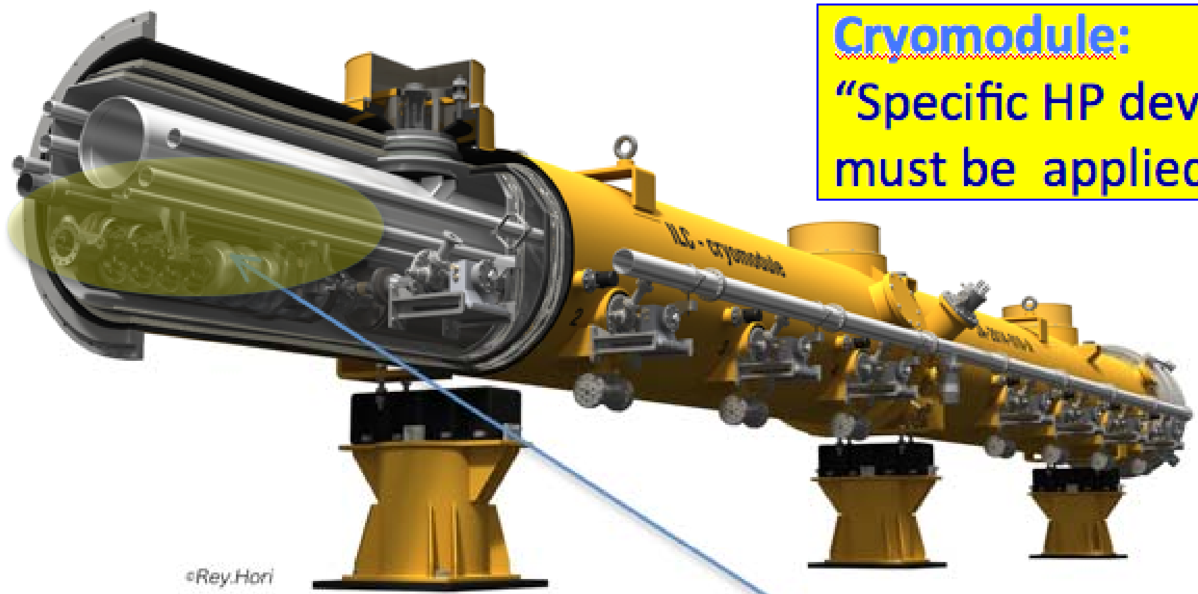
From Akira Yamamoto

# Formalities in HP Code Actions



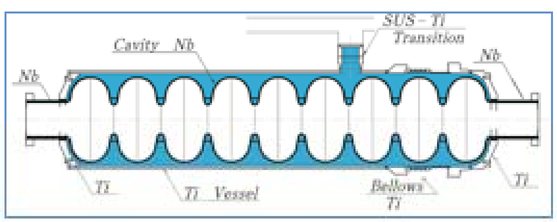
From Akira Yamamoto

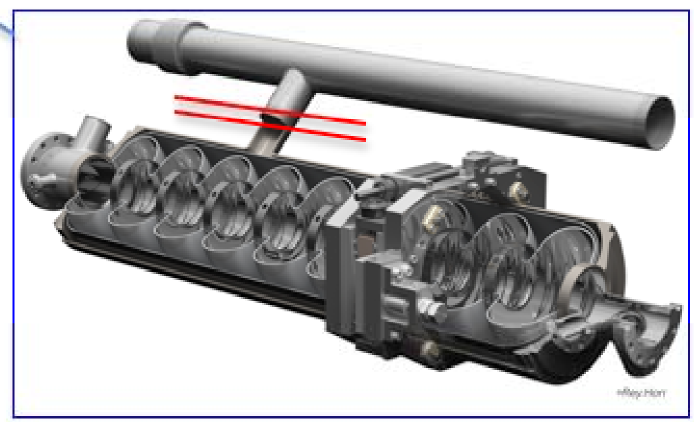
# Category of HP Regulation




**Cryomodule:**
"Specific HP device regulation" must be applied

**9-Cell Cavity unit**
May be treated as "a device", if
PV value may be **below the threshold PV = 0.004**

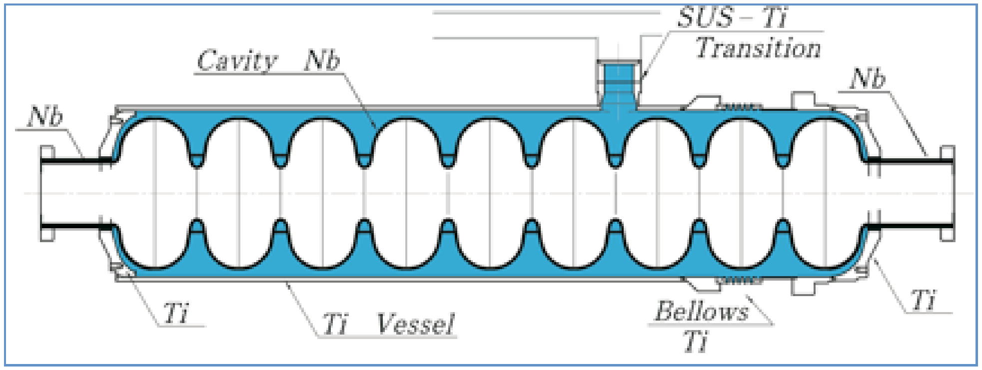


From Akira Yamamoto

# Advantages with the Category of Ordinal Device at PV < 0.004

- **Special permission required:**
  - » Ti: at T < – 196 C
  - » Nb: not listed for special permission
- **Process and inspection with HP code simplified**
  - » Material mechanical evaluation prior to production process required,
  - » HP code test (Pressure, and leak test) only required in the completion process,
- **Subject for further investigation**
  - » If the 2–phase pipe to be included in the cavity category or to be included in the cryomodule?
  - » Can we convert material at the boundary; Ti to SUS (including joint).



# Conclusions

- **Niobium, niobium-titanium, electron beam welding, and other features required for the proper function of superconducting RF cavities create problems with respect to pressure vessel codes in all regions of the world**
- **With significant effort, laboratories have found various ways to provide levels of safety equivalent to the applicable code rules**
- **These methods involve taking some very conservatively low values for niobium yield strength due to heat treatments and uncertainty, and doing analysis and quality assurance inspections in accordance with code rules as much as possible**
- **Treating the vacuum vessel as the primary containment volume or excluding the niobium material from the pressure boundary definition may be feasible in some cases**

# References from our paper


1. ASME Boiler and Pressure Vessel Code, 2007 edition.
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3. Federal Register/Vol. 71, No. 27/Thursday, February 9, 2006/Rules and Regulations, PART 851 – Worker Safety and Health Program.
4. J. Theilacker, et. al., "Guidelines for the design, fabrication, testing, installation, and operation of SRF cavities," in *Advances in Cryogenic Engineering*, 55B, 2010. edited by J.G. Weisend II, et al., American Institute of Physics, Melville, NY, 2010, pp. 1223-1230.
5. Fermilab ES&H Manual (FESHM) Chapter 5031.6, Rev. 07/30/10, "Dressed Niobium SRF Cavity Pressure Safety"
6. Technical Division Technical Note TD-09-005, "Guidelines for the Design, Fabrication, Testing and Installation of SRF Nb Cavities"
7. Directive 97/23/EC of the European Parliament and of the Council of 29 May 1997 on the approximation of the laws of the Member States concerning pressure equipment (PED)
8. C. Astefanous, et. al., Design and Analysis of SRF Cavities for Pressure Vessel Code Compliance, *Proceedings of 2011 Particle Accelerator Conference*, New York, NY, paper TUP269
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10. J. Mammosser, SNS (Oak Ridge National Lab), private communications