Licensing of the IFMIF/EVEDA Cryoplant and SRF Linac

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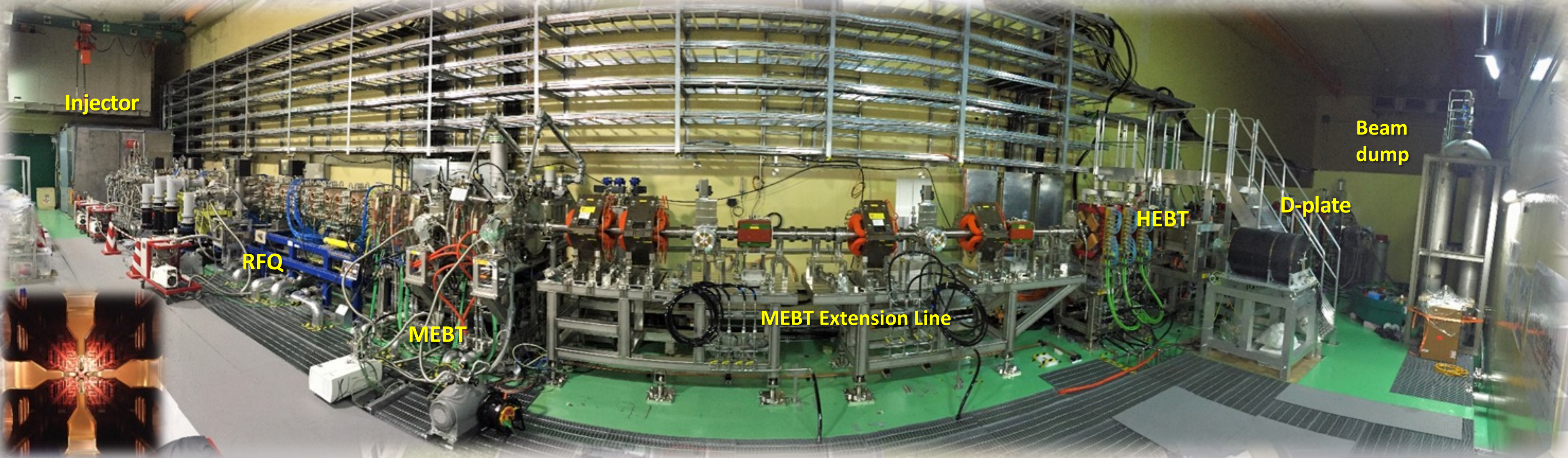

Linear IFMIF Prototype Accelerator (LIPAc)

Rokkasho Fusion Institute (BA Site)

Contributors

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Outline

Scope of Application in SRF Linac and cryoplant

SRF Linac and HWR Cavity

Cryoplant

Licensing of SRF Cavity in Japan

Licensing Strategy

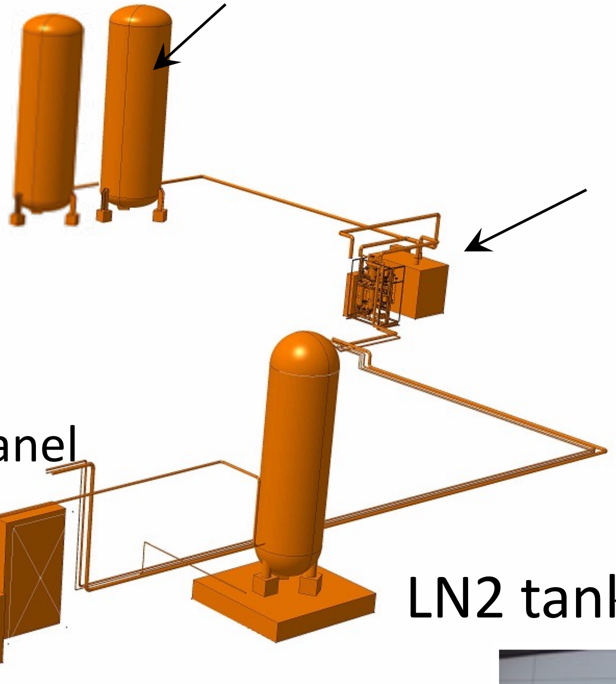
HWR Application

Summary and Future Schedule

Cryoplant & SRF System

Cold box(103W, 52 *l*/h) &
He Dewar (2000 *l*)

He GAS Buffer Tank: 50m^{3}x2



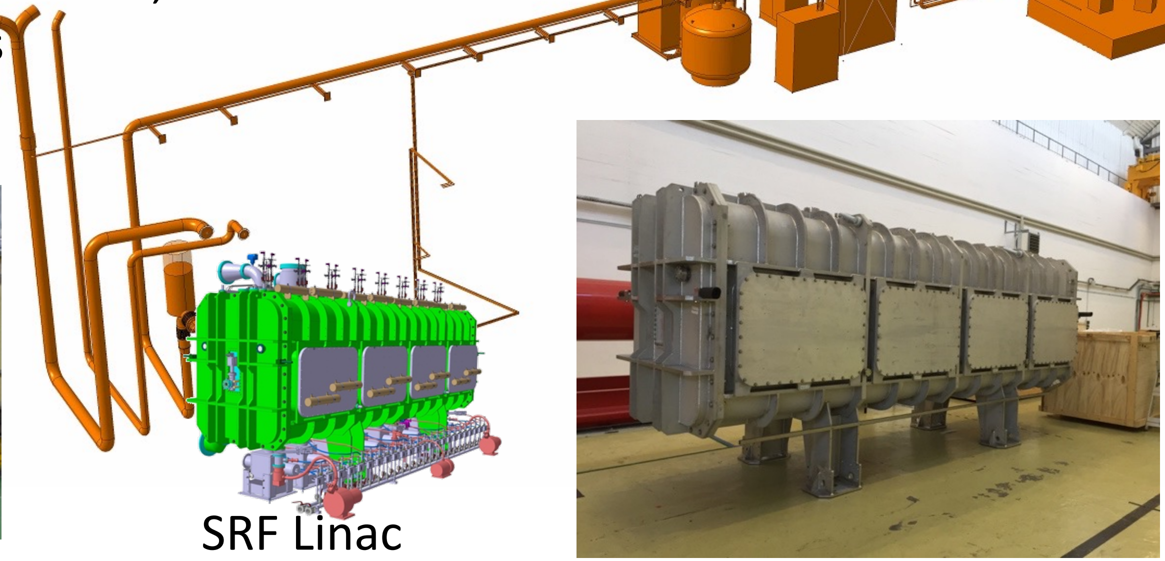
Cold Box, Dewar,
Room Temperature Valve Panel

He Compressor Unit +
Oil Removal System

LN2 tank

Main Cryogenic Transfer Line,
Safety lines, GHe lines

SRF Linac

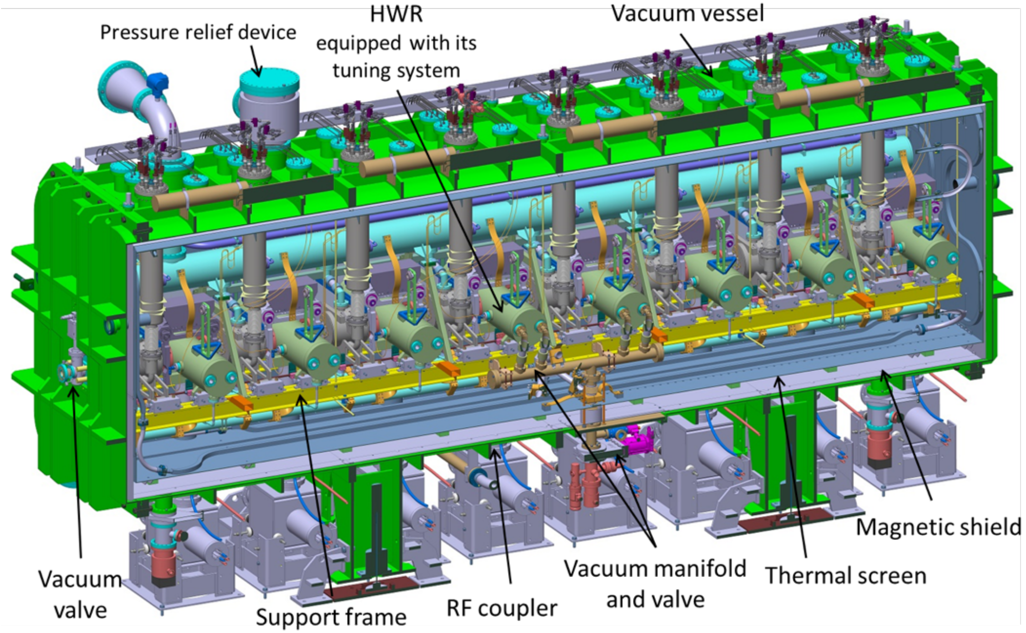


SRF Linac and Cavity

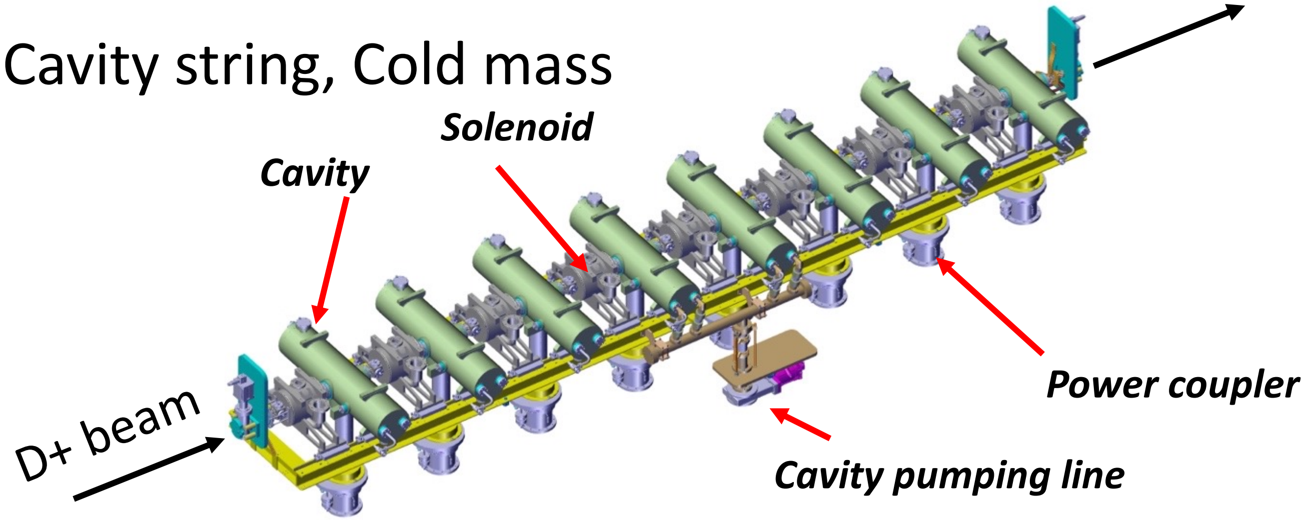
SRF linac

accelerate a 125 mA D^+ beam in CW operations from 5 to 9 MeV

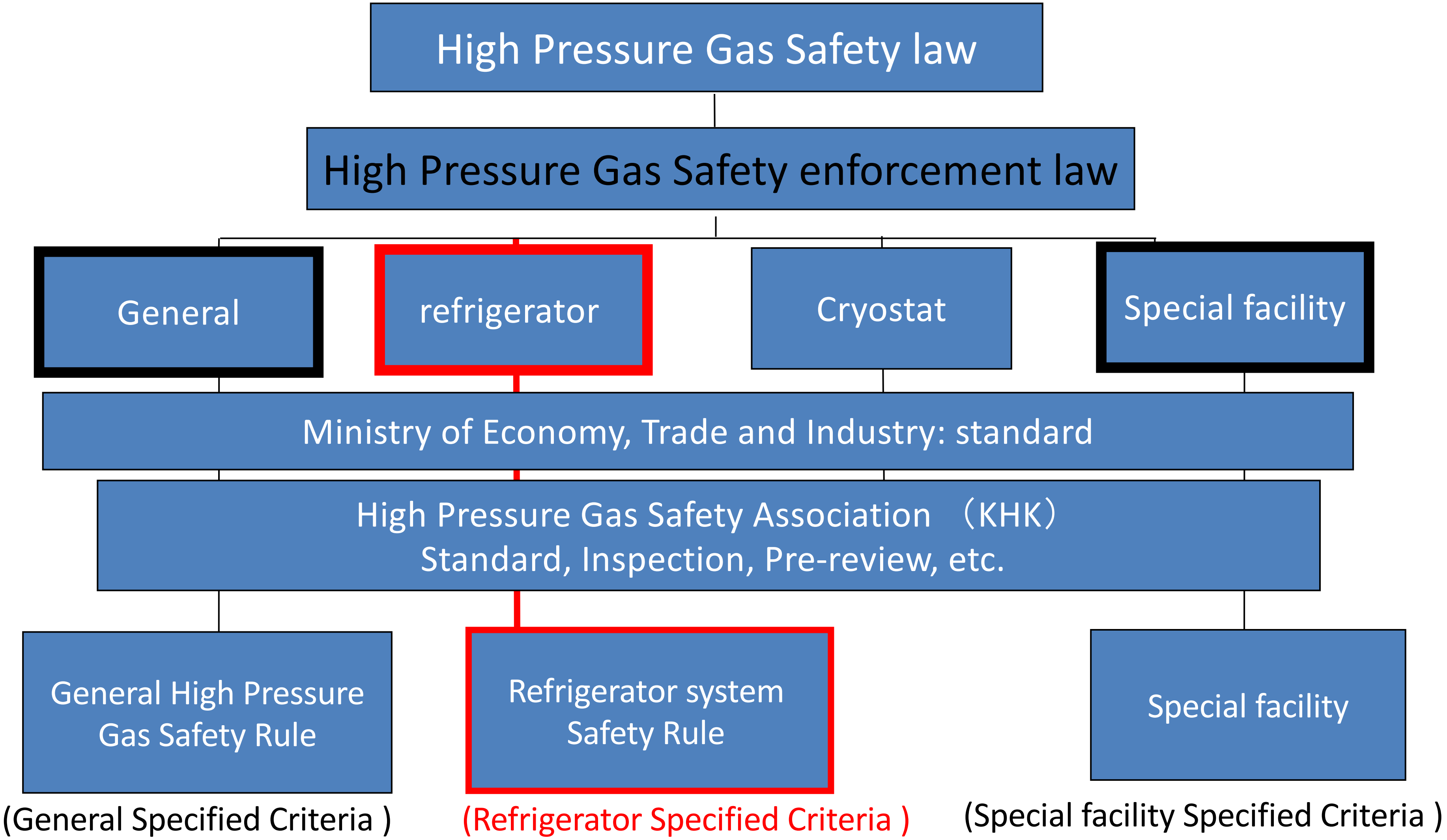
- ✓ LIPAC SRF Linac: full-scale and operational cryomodule
- ✓ Transport and accelerate D^+ beam from 5 MeV up to 9 MeV
- ✓ 6 m long, 3 m high and 2.0 m wide, 12.5 tons
- ✓ 8 superconducting HWRs working at 175 MHz and at 4.45 K
- ✓ 8 Power Couplers
- ✓ 8 Solenoid Packages as focusing elements
- ✓ Reference for the realization of the IFMIF



Cavity string, Cold mass



High Pressure Gas Safety Regulation in Japan



General & Refrigeration Regulation in Japan

	General High Pressure Gas Safety Regulation	Refrigeration Safety Regulation
Safety Management Structure	- Safety management structure is required. - Appointment of responsible persons for every watching shift	- Appointment of a responsible person for safety management - No safety management structure is required
Monitoring	- 24 hour monitoring is required.	- 24 hour monitoring is not required.
Facility Inspection	- Every year - Self inspection with disasembling	- Every three years
Licencing Application	- Whole factory, institute - Government (KHK)	- Each machine - Local Government
Configuration	- Opened & separate system & loop	- Closed system & loop with cryosystem
Facility	- Other SRF facility	- LIPAc, JT-60SA, LHD, Riken

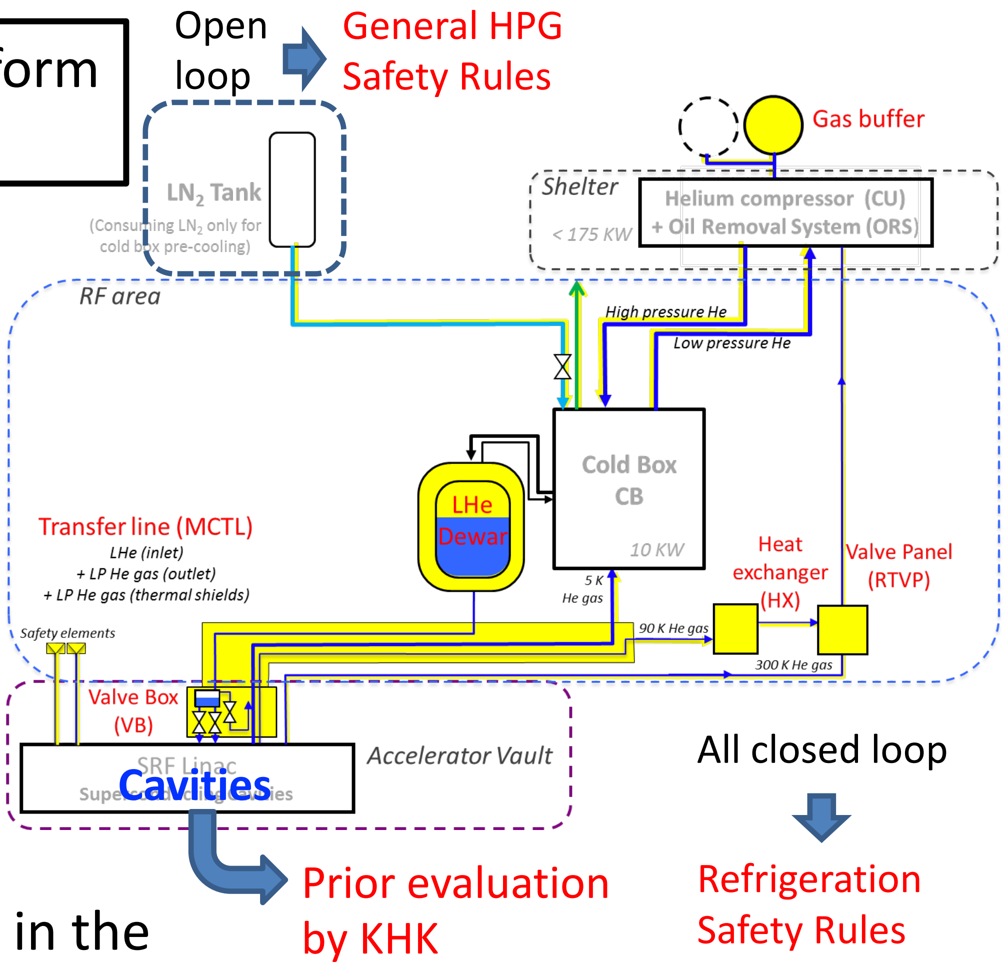
Licensing Strategy

Basically, Refrigeration Safety Regulation was applied in IFMIF/EVEDA

Some parts in the design and production of HWR cannot conform to the Specified Criteria of the Refrigeration Safety Rules.

- The structure of the HWR is complicated.
- Some parts in the design and production of HWR cannot conform to the Specified Criteria of the Refrigeration Safety Rules.
- Basic consensus that the design and production shall conform to ASME Sec. VIII Div.1 (2010) from the viewpoint of international cooperation in IFMIF/EVEDA project.

Japanese High Pressure Gas Safety Law basically does not approve ASME criteria!



We request prior evaluation related to the critical items in the Specified Criteria of the Refrigeration Safety Rules to KHK.

ASME and HPGSL in Japan

- Cryogenic fluid inside the IFMIF cryomodule ➔ Must comply with the Japanese regulation: **High Pressure Gas Safety Law (HPGSL)**.
- Strategy negotiated some additional manufacturing tests with the Japanese authorities : design, fabrication and tests of all the cryomodule components according to **ASME BPVC** or **B31.3.**
- All licensed components are subject to Aomori Prefecture approval before installation of the cryomodule in Rokkasho. (especially cavities, such as material, structure, welding and inspection)

	Component	Licensing procedure	Code
Pressure Vessel	Cavities	YES – Pressure vessel	ASME BPVC Section VIII Div.1
	Phase Separator	YES – Pressure vessel	
	Solenoid vessels (CIEMAT)	YES – Pressure vessel	
Piping	Current leads assembly (CIEMAT)	YES – Pressure piping	ASME B 31.3
	Cryo-piping, thermal shield piping	YES – Pressure piping	
Cryostat	Vacuum vessel /thermal shield	NO – ΔP < 0,1 MPa	x

Pressure vessels as per ASME BPVC Sec. VIII Div.1 §U-1
Internal diameter > 6 in. (152 mm)

Piping as per ASME B 31.3
Internal diameter < 6 in.

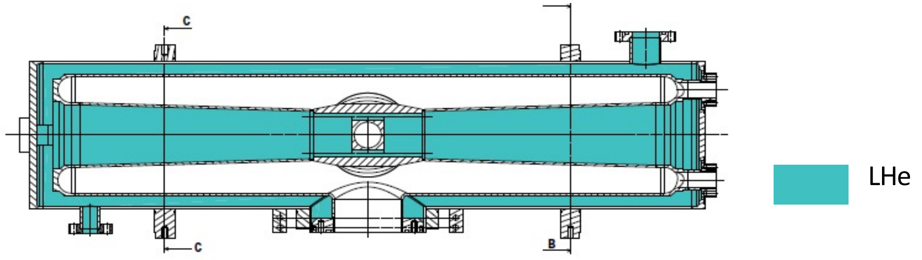
Japanese regulation

Vessel > 160 mm in inner dia.

Piping < 160 mm in inner dia.

Cavity Licensing

Cavities are considered « Pressure Vessel » as per ASME BPVC Section VIII Div.1. (LHe in the cavities)

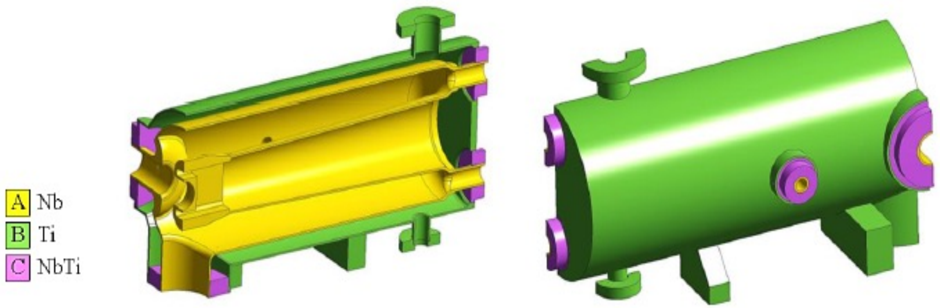


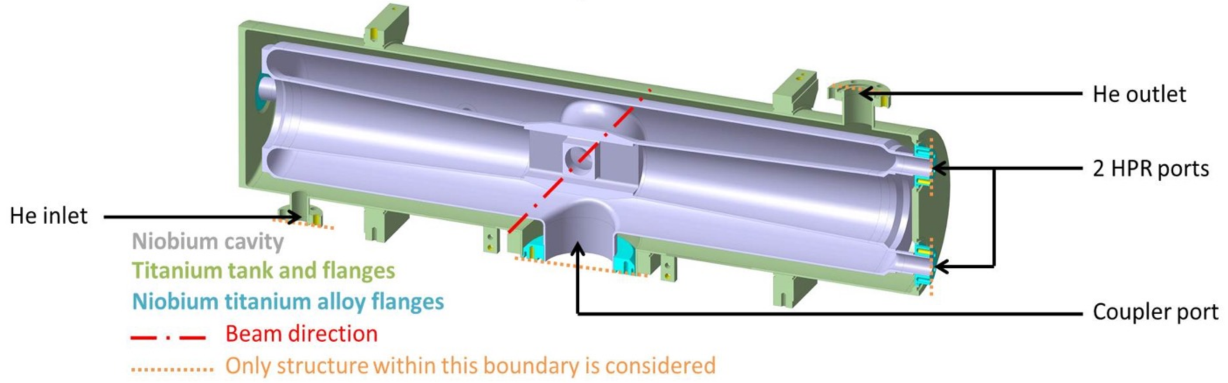
Materials: Nb , NbTi and Ti

Nb and NbTi are not listed in ASME BPVC also Japanese Standard

\+

Complex geometry





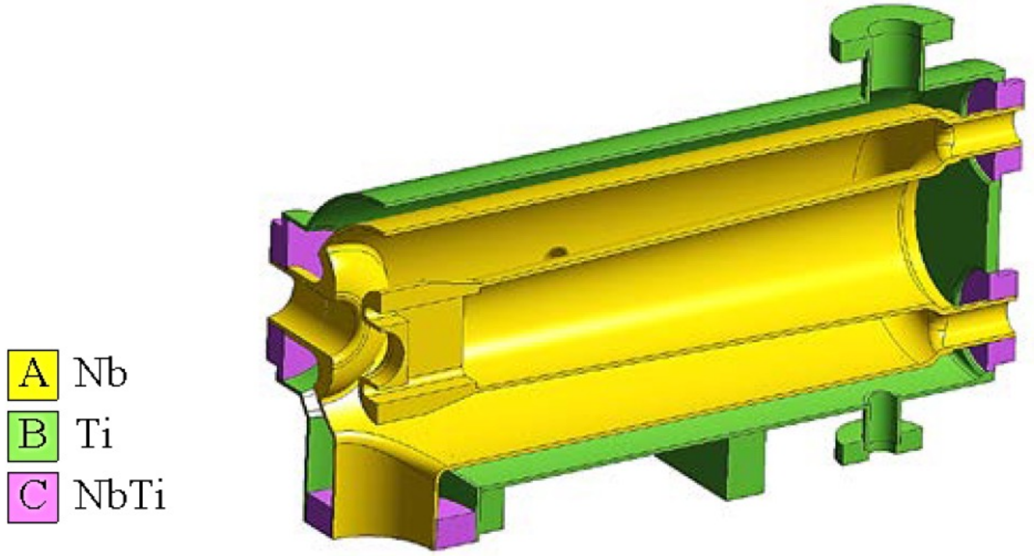
- Necessity to perform several analytical calculations + numerical simulations: stress analysis with finite element method, calculation of stresses in welded flanges…
- Tests samples for Nb, NbTi and Ti to determine tensile properties and Charpy impact energy at 4.45K.
- Application form submitted to KHK (High Pressure Gas Safety authority in Japan) for the cavities prior to Prefecture approval. This application form was officially approved in March 2016 (licensing procedure started in Dec. 2013).

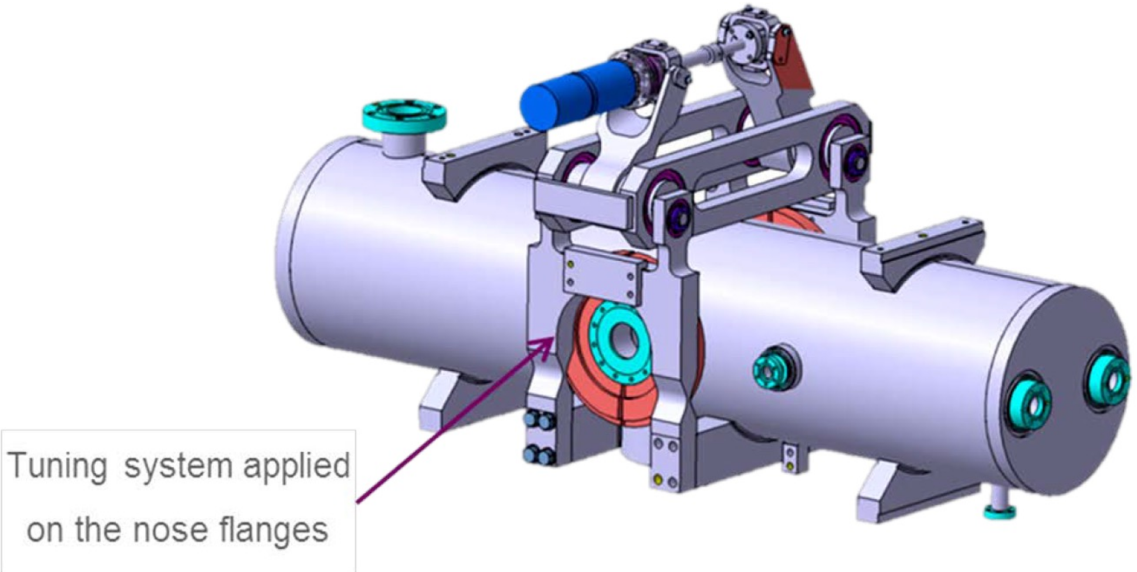
Outline for KHK Application

- Ti tank for storing LHe
- Nb cavity installed in LHe
- Flange made of NbTi to connect Nb cavity and Ti Tank

A vessel of integration by welding stored LHe related to refrigerant equipment with a refrigeration capacity of more than 20 tons.

Pre-evaluation of detail application
In addition to pressure, in order to demonstrate the performance as an accelerator, a compression force is applied to deform the Nb cavity up to 0.3 mm in the beam axis direction .



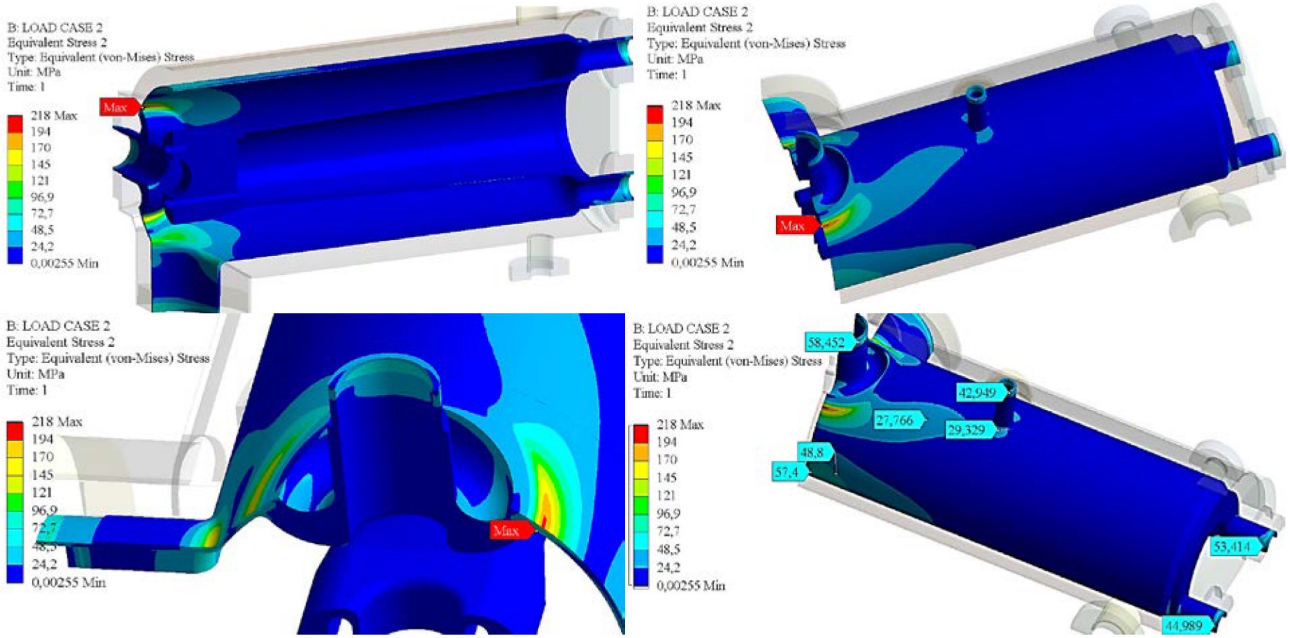


HWR cannot conform to JA regulation

Some parts in the design and production of HWR cannot conform to the Specified Criteria of the Refrigeration Safety Rules.

- Complex structure
- Design and manufacture in accordance with ASME Sec. VIII Div.1 (2010) of international standard.
- Designed and manufactured in European standards with different test methods and standards in Japan.

stress analysis by FEM →



-269 degC and under tuning
(8,000N compressive force is applied on the welded parts)

Japanese High Pressure Gas Safety Low basically does not approve ASME criteria!

➡ We request prior evaluation related to the 12 items in the Specified Criteria of the Refrigeration Safety Rules to KHK.

KHK pre-reviews following items before manufacturing

non-conformity items against Specified Criteria of the Refrigeration Safety Rules

5. Pressure Test
6. Air Tightness Test
19. Design Pressure
20. Materials for Refrigerant Facility
21. Ultrasonic Test for materials
22. Weld Efficiency
23. Strength of vessels and pipes
24. Welding
25. Stress Removal
26. Structure and Process of vessels
27. Mechanical Test for Welded Parts
28. Nondestructive Test for Welded Parts

Example: Verification of material safety

Refrigeration Safety Rules

The Half Wave Resonator in the Superconductive Accelerator will use Niobium, Niobium Titanium and ASTM specified Titanium. However, Niobium, Niobium Titanium and ASTM specified Titanium are not the materials specified in the Specified Criteria.

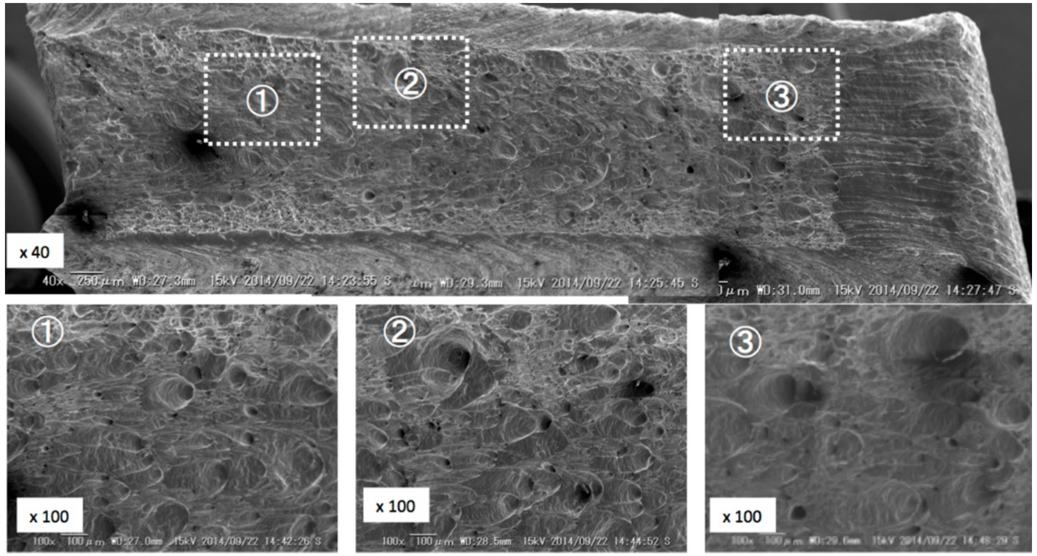
We carried out the tensile strength test and the fraction observation test at RT and -269 degC. We demonstrated the results of material safety by QST.

(Base metal of Niobium and Niobium Titanium) ex.

- The lowest value of 0.2% proof stress measured after the heat treatment at RT is 59 N/mm2, which satisfies 40 N/mm2 of the guaranteed value. Also, 0.2 % proof stress increases at -269degC.
- The lowest value of tensile strength measured at RT after the heat treatment is 171N/mm2, which satisfies 95N/mm2 of the guaranteed value. Also, tensile strength increases at -269degC.
- The lowest value of elongation measured at -269 degC is 14.5 %.
- From above, it is concluded that Niobium is can be used at LHe temperature.

it was confirmed that the fracture surface was 100 % dimple and ductile fracture by the fraction observation conducted with SEM on a fractured tensile specimen tested at -269degC of the LHe temperature condition.

Nb cross-section after tensile test at -269degC



Summary of verification of material test & calculation

items	Evaluation
a. Pressure test	Non-destructive inspection based on ASME
b. Material	We confirmed by references, performed tensile / Charpy test for weldings.
c. Allowable tensile stress	We confirmed that 0.2% proof stress, tensile strength, and elongation satisfy the standard values in 3 cases: no consideration of thermal stress, consideration of thermal stress, and consideration of compressive force. We confirmed that the fracture surface is ductile.
d. Longitudinal elastic modulus	We measured the values and reference data, evaluated from past results.
e. Welding efficiency	We confirmed that ASME's welding efficiency is a safer evaluation.
f. Strength calculation	evaluation of corrosion, 3D finite element method analysis applied to 3 load conditions. Confirmed that generated stress is below allowable value for 17 stress evaluation lines. Buckling analysis was performed. Implemented and confirmed a margin of 3 or more.
g. Welding	welding efficiency considering non-destructive inspection, evaluated from past results.
h. Mechanical test	Evaluated with ASME test piece instead of JIS test piece. Evaluated for safety.
i. Non-destructive test	ASME non-destructive inspection is adopted. Past performance is also evaluated.

Requirement from KHK: Create PQR and WPS, implement and record welding test of actual cupon, perform heat treatment, limit number of cooling cycles

Outline of Applicable Detailed Criteria for Refrigerator Regulation
IFMIF/EVEDA Half Wave Resonator for Superconducting Accelerator

1 Overview of the High Pressure Gas Facility of IFMIF
2 Description of Content of Applicable Detailed Criteria
- 2.1 Pressure Test
- 2.2 Weld efficiency
- 2.3 Materials used in the refrigerant facility
- 2.4 Use range of materials
- 2.5 Allowable Tensile Stress of Materials
- 2.6 Modulus of longitudinal elasticity of materials
- 2.7 Thickness of each part of the vessel (1)
- 2.8 Thickness of each part of the vessel (2)
- 2.9 Welding for nozzle stubs, strengthen materials, and etc.
- 2.10 Mechanical Tests for Welded Parts
- 2.11 Non-Destructive Tests for Welded Parts

3 Past Record
4 Drawings
5 Attachment
6 Reference

Licensing of SRF Cavity in KHK

Completed in 18th March, 2016

２８高機第５５号
平成２８年３月１８日

国立研究開発法人日本原子力研究開発機構
青森研究開発センター（国際核融合エネルギー研究センター）
所長　飯塚　幸治　殿

高圧ガス保安協会
会　長　市　川　祐　三

詳細基準事前評価書

平成２７年６月４日付け原機（青管）０２０をもって申請がありました件については、「冷凍保安規則の機能性基準の運用について（平成 13・03・23 原院第 4 号）」に基づき事前評価を行いましたので、下記のとおり評価結果を通知します。

なお、留意事項欄に特別に記載した事項については、製造又は使用に当たり十分に留意してください。

記

1．高圧ガス設備等の製造者	名　称	ETTORE ZANON S.p.A.
	所在地	36015 Schio VI-Italy-via Vicenza 113, Italy
2．高圧ガス設備等が設置される事業所	名　称	国立研究開発法人日本原子力研究開発機構 青森研究開発センター（国際核融合エネルギー研究センター）
	所在地	青森県上北郡六ヶ所村大字尾駮字表舘 2 番地 166

3．適用すべき詳細な技術基準の内容

(1) 評価項目

	通達　冷凍保安規則の機能性基準の運用について（平成 13・03・23 原院第 4 号）別添「冷凍保安規則関係例示基準」の
耐圧試験	5.(1)ロに規定される耐圧試験以外の耐圧試験の採用
材料	20.1(5)及び 20.2 に規定される冷媒設備に用いる材料以外の冷媒設備に用いる材料の採用
許容引張応力	20.4(3)に規定される材料の許容引張応力以外の材料の許容引張応力の採用
縦弾性係数	20.9 に規定される材料の縦弾性係数以外の材料の縦弾性係数の採用
溶接効率	22.に規定される溶接効率以外の溶接効率の採用
強度計算	23.1.2 並びに 23.2, 23.4, 23.6 及び 23.10 に規定される容器及び配…器及び配管の強度等の採用
溶接	24.9(2)に規定される溶接以外の溶接の採用
機械試験	27.3(2),27.6(2)及び 27.7 に規定される溶接部の機械…採用
非破壊試験	28.1(4)並びに 28.2, 28.8, 28.9 及び 28.12 に…試験以外の溶接部の非破壊敷試験の採用

(2) 設備の種類と概要

本申請対象である半波長空洞は、ビーム加速方…ームを 5MeV から 9MeV まで加速させる超伝導加速器を構成する容器で…リウムを貯めるチタン製の槽（以下「チタン槽」という。）、液体ヘリ…の空洞（以下「ニオブ空洞」という。）及びニオブ空洞とチタン槽を接…のフランジから構成される。

種類	…圧力容器類「…超伝導加速器用半波長空洞」　８基	
		ニオブ空洞
使用流体	毒性ガス又は可…ス以外のガス（液体へ…ウム）	（真空）
処理容積（㎥/day（標準状態））	—	
貯蔵能力（ｔ）	—	
内容積（ｍ³）	０．０１８／基	

（１／３）

設計圧力（MPa）	０．０５＋０．１０１３	－０．０５－０．１０１３
設計温度（℃）	－２６９～＋３０	－２６９～＋３０
図面番号	JEAE-F4E-CEA.SRF0001 rev4　使用材料一覧及び設計仕様　(1/3)～(3/3) 3200.0.000.000 Rev.1　Half Wave Resonator-LIPAc SRF-Linac　Cavity with Helium Tank 3200.1.000.000 Rev.4　Half Wave Resonator-LIPAc SRF-Linac　Niobium Cavity 3200.2.000.000 Rev.0　Half Wave Resonator-LIPAc SRF-Linac　Helium tank - integration to cavity scheme	

(3) 内容の評価

３．(1) に示す評価項目に対し、次の(a) ～(i)に示す内容の確認等を行っており、妥当と評価する。

(a) 耐圧試験

耐圧試験を気体を用いる耐圧試験とする場合、次に示す非破壊試験が要求されるが、これらの非破壊試験を設計仕様での非破壊試験の検査割合に基づいて検査することに対して、次の①及び②の対応を講じるとしていること。

- 放射線透過試験を行うものとして設計された長手継手に係る突合せ溶接部の、全長についての放射線透過試験
- 周継手に係る溶接部及び放射線…行なわないものとして設計された溶接部についての浸透探傷試験

① 全長についての放射…様の検査割合の適用について
設計仕様での検…験であるニオブ－ニオブ溶接部に対し、長手継手の全長について放射…記の対応を示していること。
・例示基…方法の確認試験を ASME Sec.IX(2010) Article II に準拠して実施し…いる。
・…よる耐圧試験の実績も十分にある。
…に講じるとしている。
…傷試験の省略について
…で、放射線透過試験を行わないとしているニオブ及びニオブチタンに係る溶接部に…験が必要となるが、不純物の混入を防止する必要性から下記の対応を示していること。
…チタン溶接部は、設計仕様の検査割合で全長について浸透探傷試験を実施するとしている。
…に引き続いて同一の条件で別個に溶接して製作する機械試験板の溶接部に対し、放射線透過試…び浸透探傷試験を実施し、溶接部の健全性を確認するとしている。

…た、JIS 規格に基づく放射線透過試験及び浸透探傷試験の試験方法に替えて ASME Sec.Ⅷ Div.1(2010)に規定される非破壊試験の方法を採用するとしているが、ASME Sec.Ⅷ Div.1(2010)は世界で広く利用されており、実績も十分にある検査方法であることより、問題はない。

(b) 材料

半波長空洞の使用材料一覧を表 1 に、各材料の機械的性質を表 2 に、化学成分を表 3 に示すが、当該材料を設計温度 -269 ～+30 ℃で使用することに問題のないことを、次の①～③により確認していること。

表 1　使用材料一覧

材料の種類	材料規格	材料の略称	使用部位
ニオブ	ASTM B393-09 Type 5 (UNS No.R04220) 相当材	ASTM B393 相当材	ニオブ空洞本体
	ASTM B391-03 Type 1 (UNS No.R04200) 相当材	ASTM B391 相当材	ニオブ空洞のパイプ部分
ニオブチタン	ASTM B348-10 Grade 36	ASTM B348 Gr36	フランジ
チタン	ASTM B265-10 Grade 2	ASTM B265	チタン槽
	ASTM B348-10 Grade 2	ASTM B348 Gr2.	

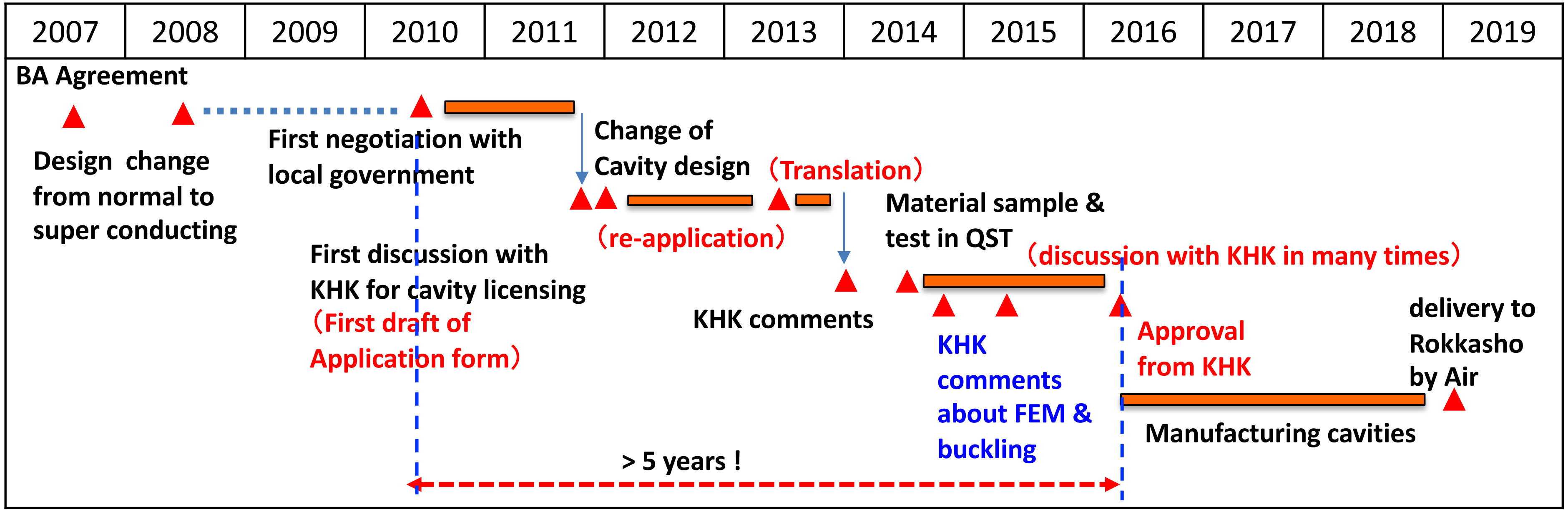
表 2　機械的性質（常温における規格値又は保証値）

	0.2%耐力 (N/mm^2)	引張強さ (N/mm^2)	伸び (%)
ASTM B393 相当材 及び ASTM B391 相当材	40 (注)	95	15 (注)
ASTM B348 Gr36	410	450	10
ASTM B265 及び ASTM B348 Gr2	275	345	20

(*) ASTM B393-09 Type 5 及び ASTM B391-03 Type 1 の 0.2%耐力及び伸びの規格値は、それぞれ $50N/mm^2$、30%であるが、ニオブ空洞の特性を達成するため不純物（ニオブ以外の成分）を極力抑えているため、保証値としている。

History of licensing of cavities

Since EU side cannot respond to Japanese licensing, QST had to respond instead of EU in long-term negotiation.



(1) Basic stress analysis and draft application form in English by CEA.
(2) Application preparation for Japanese regulation is in charge of QST (submitted calculation from CEA was translated into Japanese and attached as reference material).
(3) Response to requirements from KHK as needed (material testing is conducted by QST).
(4) Significantly added required items from KHK for application to refrigeration laws.
(In addition to Nb, NbTi, Ti material special approval, container pipe strength, welding efficiency, weld strength test, transmission flaw test, etc.)
(5) Cooperation of Japanese manufacturers for buckling calculation.

Summary

1. Cavity approval was obtained from KHK in 2016, and the production of eight identical cavities was completed. They have already delivered in Rokkasho. It took more than 5 years to get permission.

2. The accelerator cavity permission in Japanese refrigeration laws was for the first time. Cleared complex processes in Japanese regulation.

3. Cryoplant approval was obtained from Aomori Prefecture and installed in Rokkasho site. There is no problem with the trial operation. Final approval will be after the loop is complete with SRF Linac installed.

4. Cryomodule assembly already started at a clean room in Rokkasho Institute constracted by QST. However, due to delays in the production of solenoid coil vessels and COVID-19, full assembly will be expected to shift after lifting immigration restrictions.

5. After the cryomodule completion, it will be integrted into the cryoplant loop, and Aomori Prefecture will permit for the change of licensing. After that, cooling test will become possible.

Future Schedule

1. Cryomodule assembly at Rokkasho in 2022. After that, Carry into accelerator building.

2. Applying to Aomori Prefecture for a change of licensing to connect the cryoplant and cryomodule as one refrigeration LHe loop.

3. Aomori Prefecture officials will confirm the cavity, solenoid coil vessel, and phase separator pressure vessel in documents and on-site.

4. Cryogenic cooling test of the cryomodule will start after change of licensing.