HITACHI
Inspire the Next

# 1/3rd Century Challenged Ultra-High Voltage Applications

## - Progress of Neutral Particle Beam Injection Device Technology for Fusion Reactor

December 14, 2018
Hitachi, Ltd. Healthcare Business Unit
Fusion and Accelerators Department
Hiroyuki Kawakami

Innovating Healthcare,
Embracing the Future

HITACHI
Inspire the Next

# Contents

# 1. Record & Latest Up-date of NBTF (1) Outline

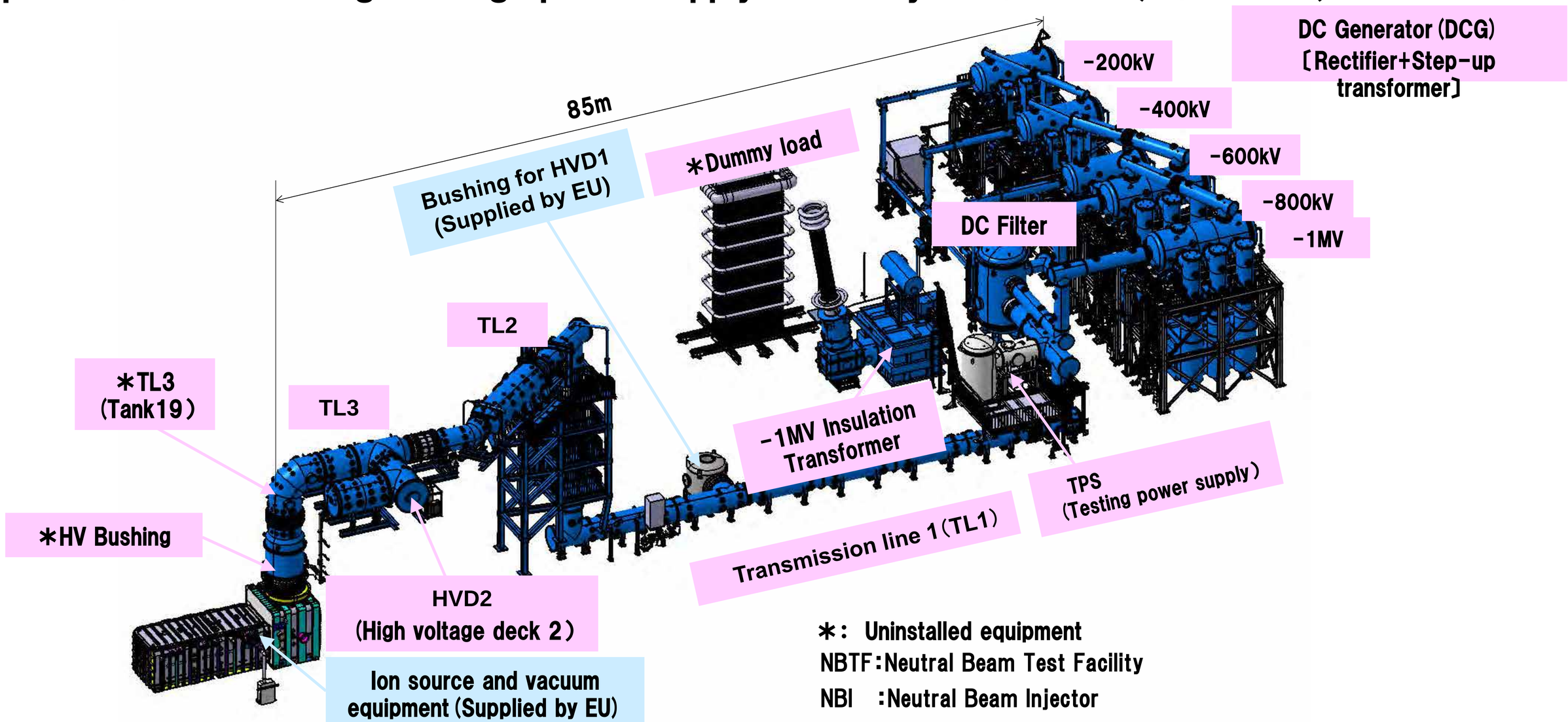
HITACHI
Inspire the Next

NBI (Neutral Beam Injector) for ITER: Generate negative ion beam of 40A@1MeV for 1 hour by accelerated negative ion with DC-1MV ultra high voltage power supply.

NBTF for verification test of beam acceleration technology for ITER is under installation @ Padova Italy.

Japan supplies major high voltage equipment after DC generators (Shown below in Pink color)

Supplied DC 1MV Ultra high voltage power supply much beyond JT-60U (DC-500kV)




＊: Uninstalled equipment
NBTF:Neutral Beam Test Facility
NBI :Neutral Beam Injector

Ultra high voltage power supply system of NBTF(Neutral Beam Test Facility)
(Equipment supplied by Japan) Installed at RFX Laboratory @ Padova Italy

# 1. Record & Latest Up-date of NBTF (2) Site Situation

HITACHI
Inspire the Next

**Order of NBTF received in 2012, and completed manufacturing of 16 tanks in five years.**
**NBTF equipment through TL3 Tank18 installed. Site withstand voltage test started.**

【TL2 Tank3 (Core snubber)】

【High voltage bushing of Ins. Transfomer】

【DC Filter, DCG, Connecting TL】

【TL2 Vertical tanks & support frame】

【TL1 tanks in TL pit】


【TL1 tanks @ entrance of TL pit 】

# 1. Record & Latest Up-date of NBTF
## (3) Withstand voltage test

HITACHI
Inspire the Next

Acceptance test of NBTF @ RFX site started prior to European equipment.
Withstand voltage test with TPS (Testing Power supply) @ RFX site;
Performed twice and passed successfully.
Three more tests planned.
①1st Test (Sep. 12-13): For DC Filter through DC Generators (DCG)#1-#5
•Condition of Withstand voltage test:
5 hour @ DC-1060kV, Repeated test @ DC-1060～-1265kV (5 times)
②2nd Test (Nov. 12): For Transmission line 1～2～3 & HVD2 (High voltage deck 2)
•Condition of Withstand voltage test: 1 hour @ DC-1200kV


Team of 2nd withstand voltage test


Photo of 2nd withstand voltage test

# 1. Record & Latest Up-date of NBTF
## (4) Overcome Challenge: ①Pressurized vessels

HITACHI
Inspire the Next

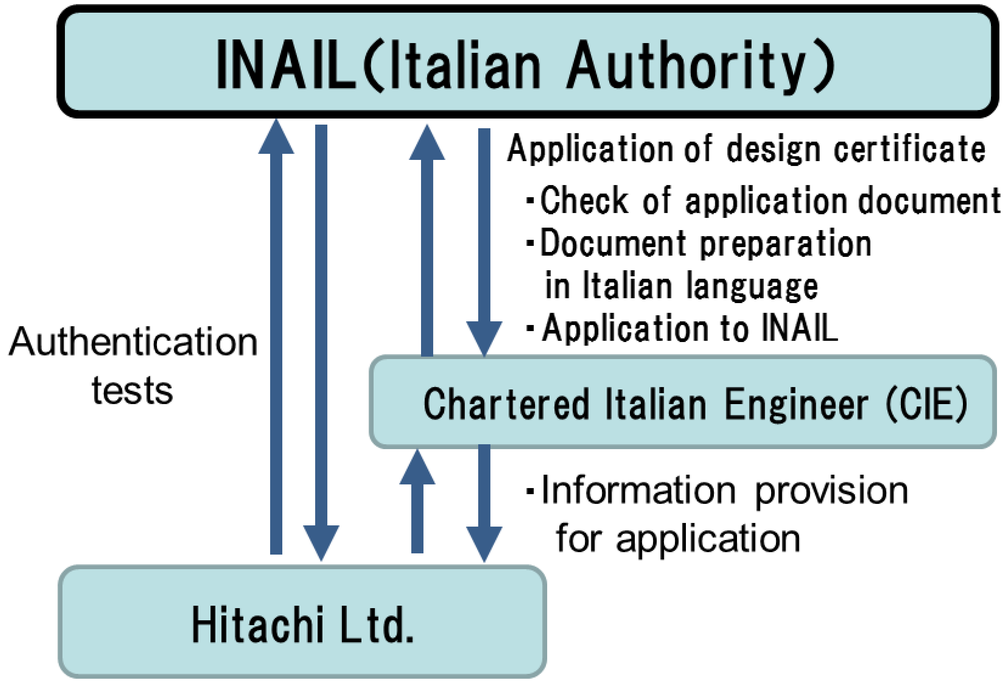
## ■Applied Italian standard Raccolta-VSR
## Redesigned the resin pressure vessel due to a unique application procedure.

### ◇Exemption of PED,
### Applied Italian Raccolta-VSR.

EU: ~~PED(Pressure Equipment Directive)~~

Italy: Raccolta-VSR

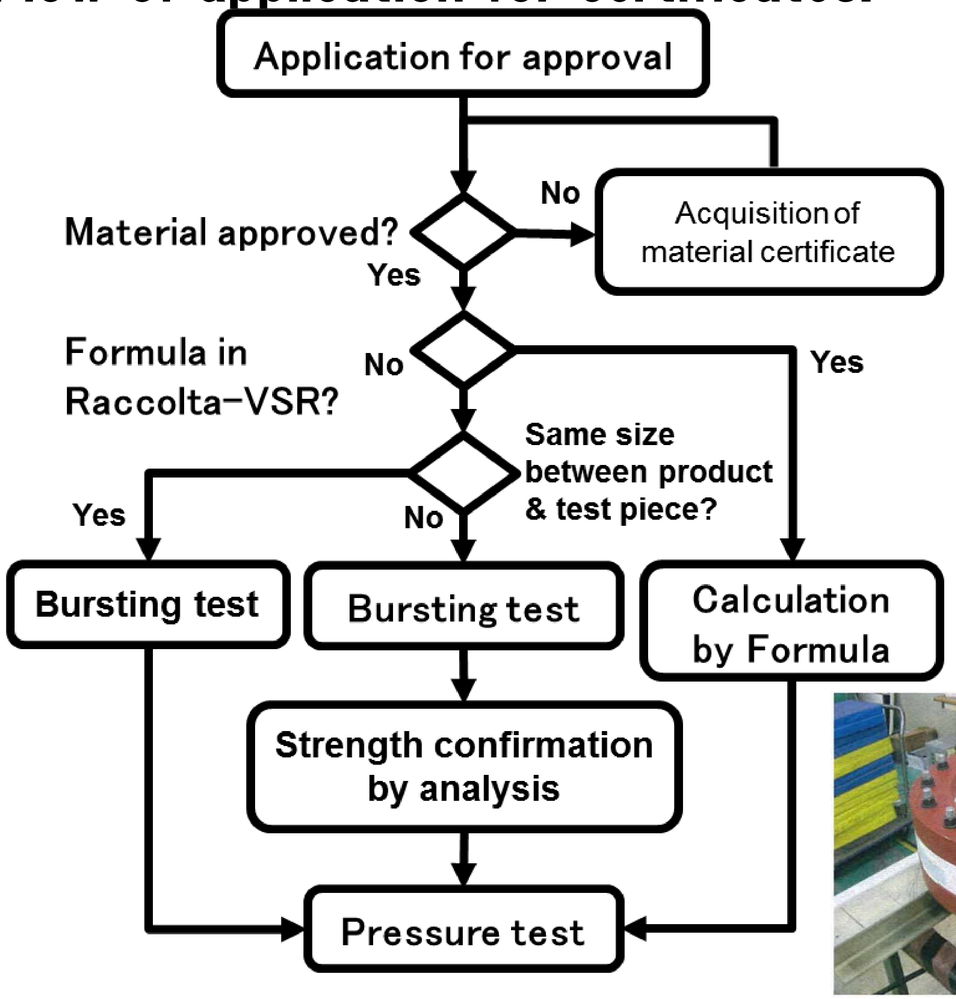
### ◇Application process of Raccolta-VSR




▪Only CIE can apply design certifications to INAIL.

INAIL : Istituto Nazionale per l'AssicurazioneContro Gli Infortuni Sul Lavoro

### ◇Flow of application for certificates.




Bursting test of plastic parts.

▪Bursting test is mandatory for resin or bellows that not applied calculation formula.

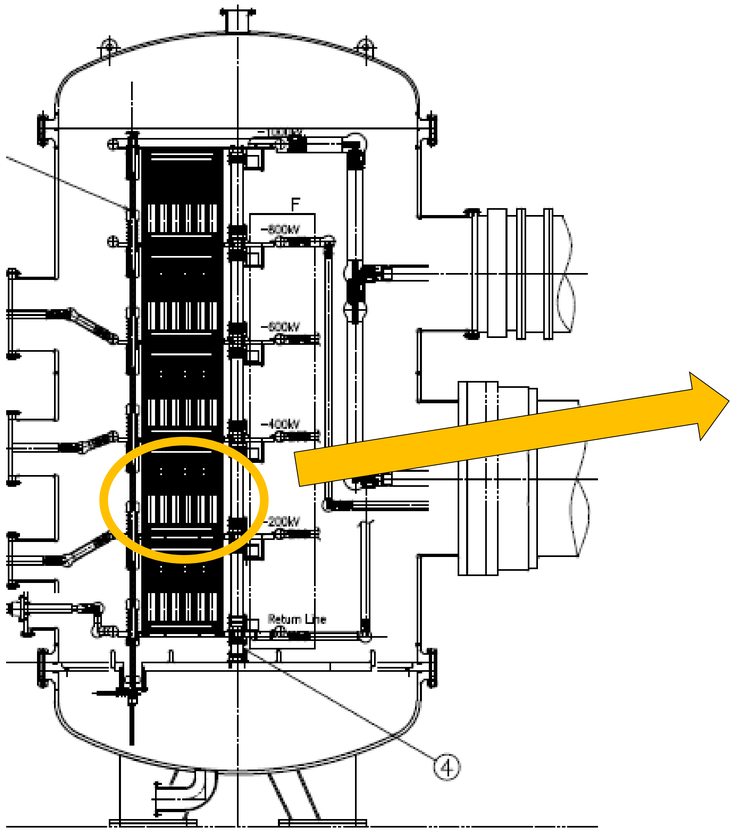
▪Pressure of bursting test is calculated by formula. Some cases needed redesign due to high testing pressure (5 -6 times of design pressure).

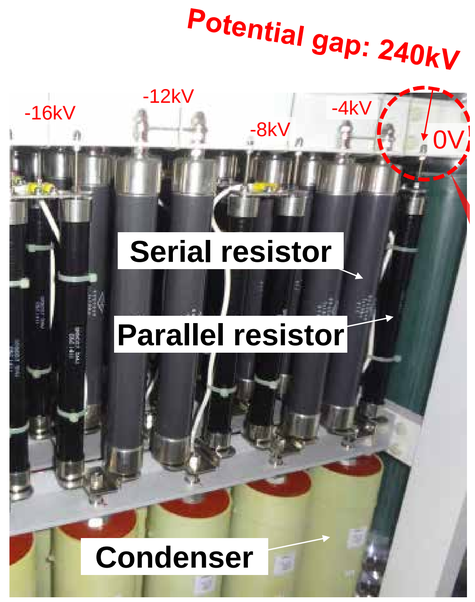
# 1. Record & Latest Up-date of NBTF
## (4) Overcome Challenge: ②Ensuring of electric insulation

HITACHI
Inspire the Next

■ Breakdowns at DC Filter

- Function : Reduction of voltage ripple after rectifying.
- Structure: Many parts of 200-1000kV potential assembled in limited space in DCF tank.




(a) Overview

Fig. 1 Location of breakdowns in CR units ( Potential shown for each unit level)

◇ Result: Position of breakdowns are on edges of washers lead of parallel resistors (0V: unit potential)
High electric concentration due to small size of these washers (φ10mm, M4) & salient shape at outside nut (φ8.1mm) make excessive of electric field concentration.

◇ Countermeasure: Material change of bolts to PEEK (insulation material) to eliminate electric field concentration at edge of washers. (Applicable positions)
Change of bolt material to PEEK on serial resistor arrays similarly.

# 1. Record & Latest Up-date of NBTF
# (4) Overcome Challenge: ③Potential fixing

HITACHI
Inspire the Next

## ■ Potential difference in HVD2 (High voltage deck2)

- **Function:** FRP & ceramic insulation pipes for water, gas, hot water in HVD2 with 200kV～1000kV insulation.
- **Structure:** Insulation pipes (3 -11 insulation pipes for each potential line) & metal pipes inside cylindrical pressurized vessel.

◇Delay of voltage rise among intermediate voltage pipe lines makes potential difference between them due to their own capacitances.

- Between flangs of insulation pipes & metal pipes and Tanks.

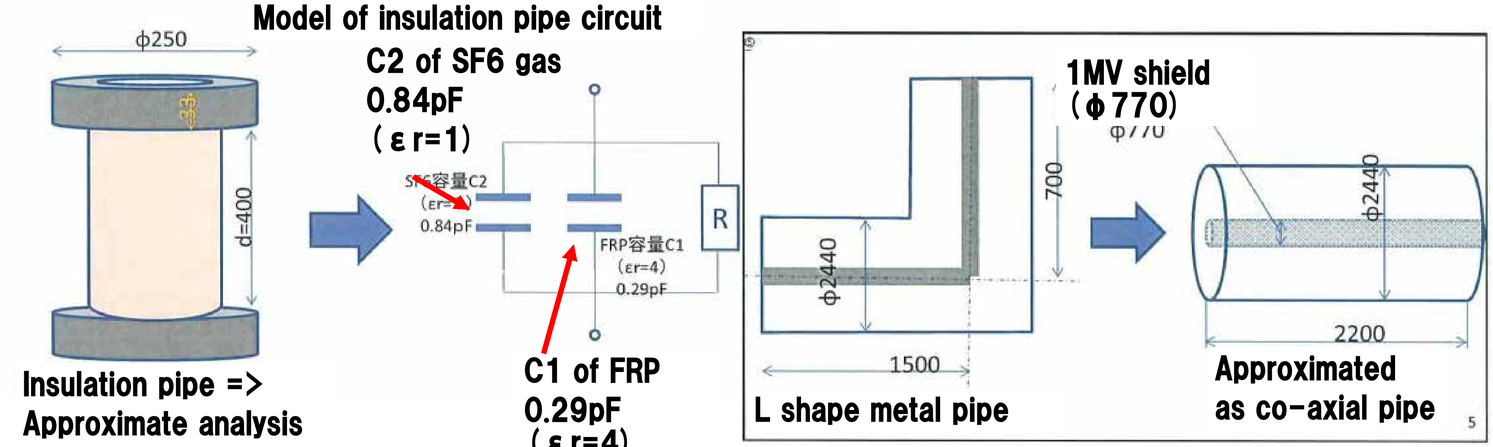



Fig. Capacitance of insulation & metal pipings

◇ Result

250kV potential difference generated on single ceramic pipe designed for 110kV insulation.

◇ Countermeasure:

To suppress potential difference by conductor connection between same potential parts in each intermediate pipe line.

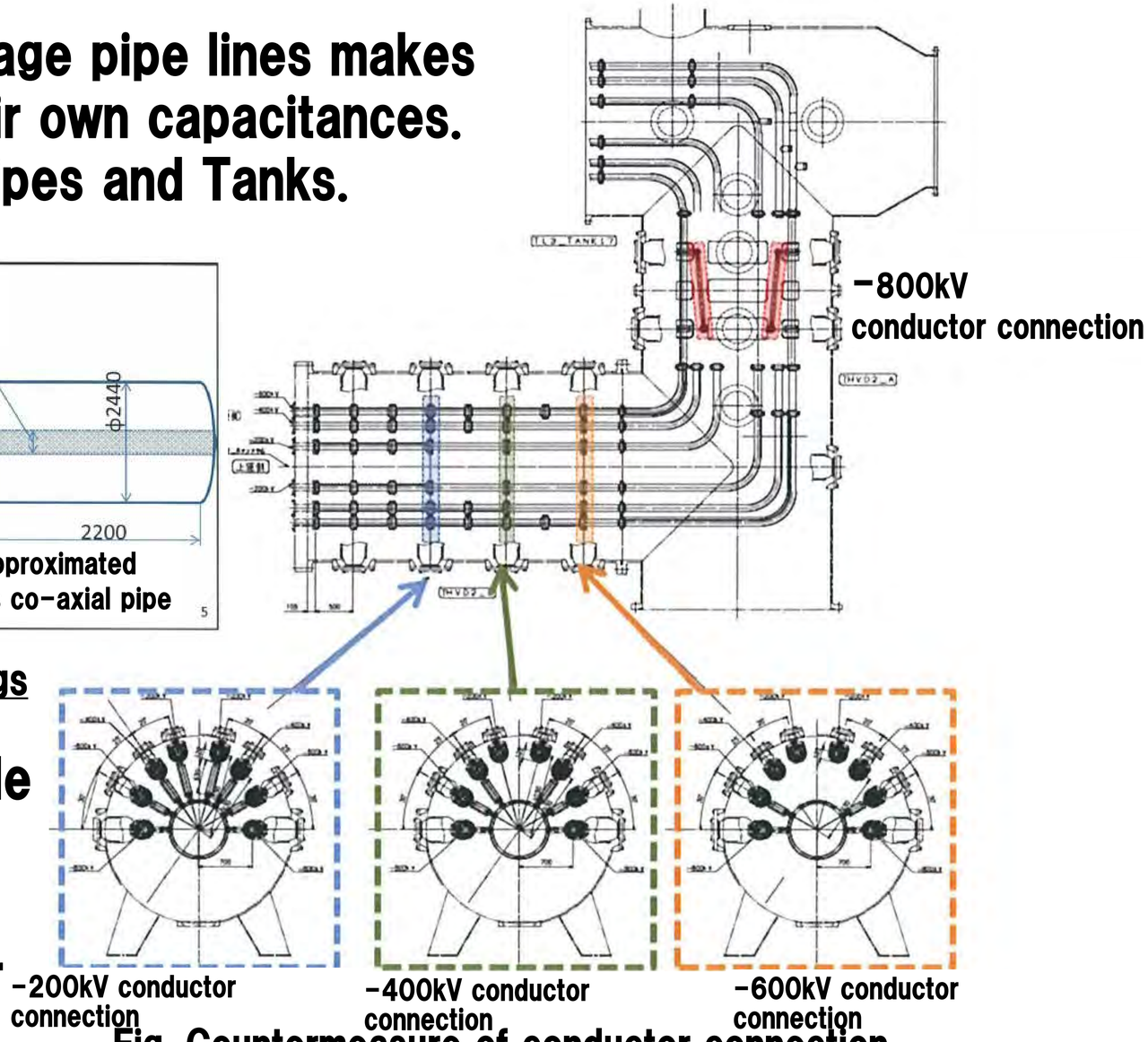
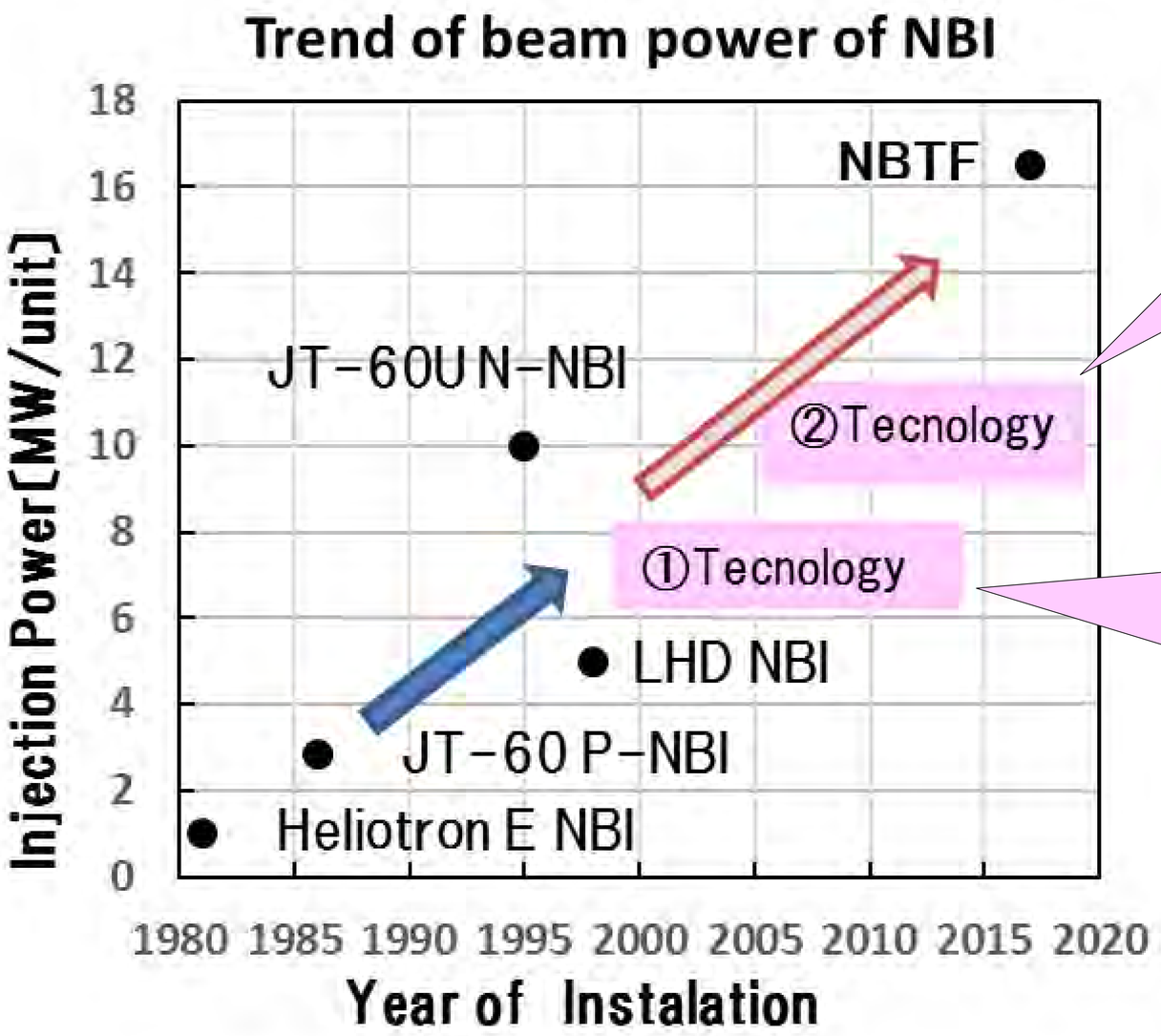



Fig. Countermeasure of conductor connection at same potential positions

# 2. History of development & manufacturing of NBI (1)

HITACHI
Inspire the Next

**Table shows a history of development & manufacturing of NBI systems. HITACHI started detail design work of Prototype NBI of JT-60 in 1978, and delivered NBI systems of Heliotron E/JT-60/LHD, then NBI system for NBTF in 2017.**




②Technology
- High Voltage part fully SF6 gas ducted.
- Improvement of Insulation material spec. (FRP 、Ceramic 、Epoxy resin 、ets.)

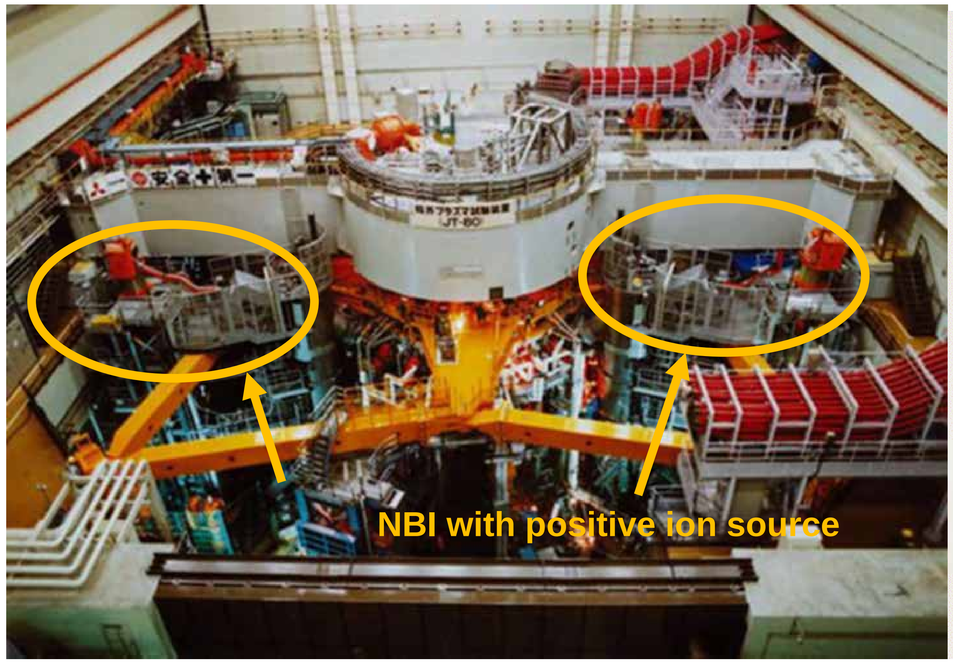
①Technology
- High Voltage part with SF6 gas duct
- Output control by low voltage side for N-NBI.
- High current & long pulse beam for LHD.

Fig. Progress of beam power of NBI (as designed)

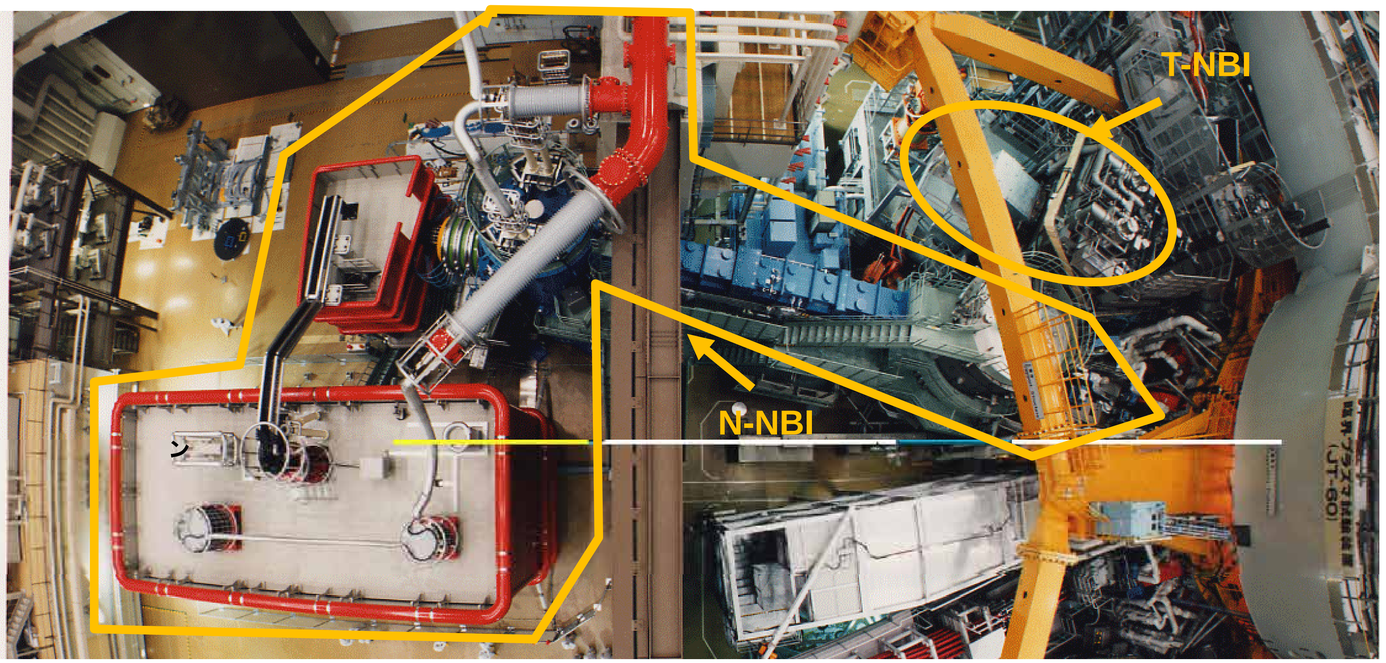
# 2. History of development & manufacturing of NBI
## (2) NBI system for JT-60

HITACHI
Inspire the Next

- Delivered 14 units of NBI in 1986, 2 units of T-NBI in 1992 with positive ion sources.
- Delivered one NBI with negative ion source in 1995(N-NBI).




View of NBI with positive ion source




View of T-NBI & N-NBI

■ Specifications of N-NBI (as designed)

- Beam energy : 500 keV
- Injection energy : 10 MW (each beam line)
- Kind of ion : $H^-$ / $D^-$
- Number of ion source : 2 units (each beam line)

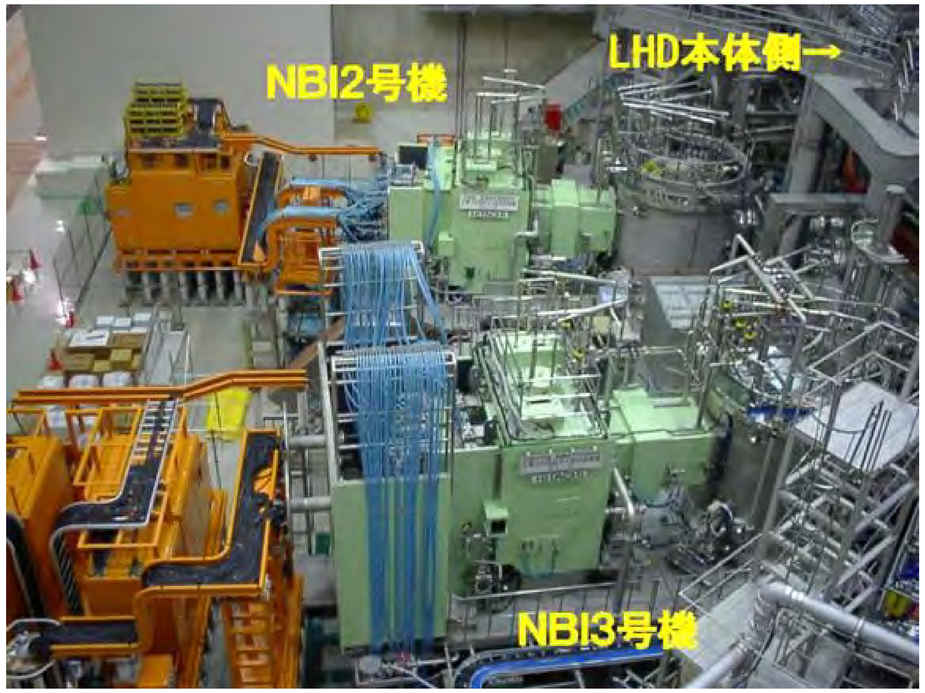

View of beam line of N-NBI

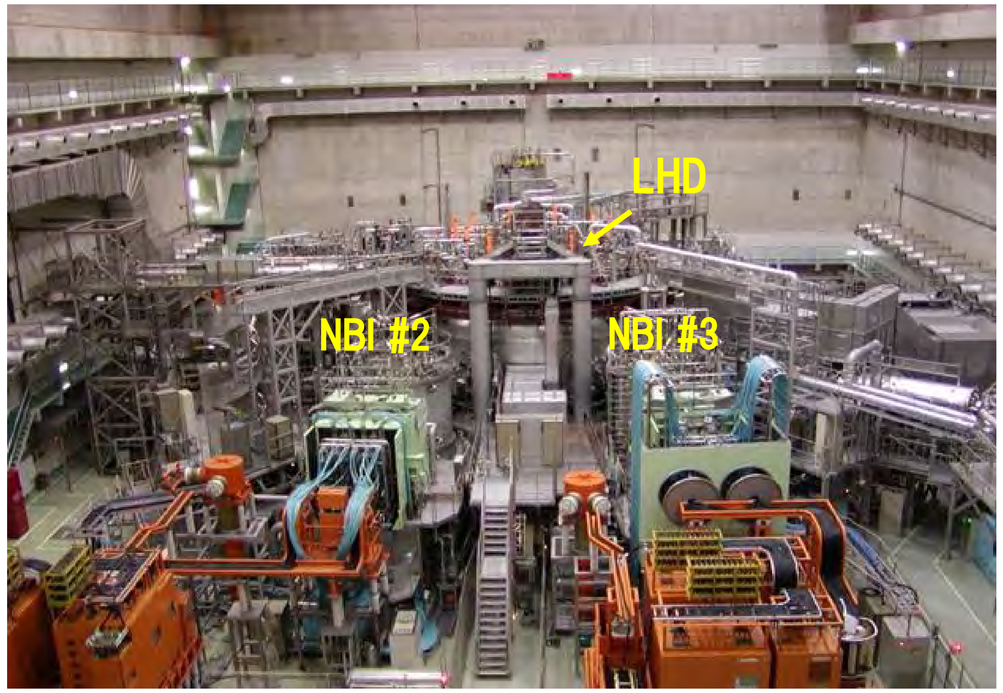
✱Pictures provided by National Institutes for Quantum and Radiological Science and Technology (QST)

# 2. History of development & manufacturing of NBI
## (3) NBI system for LHD

HITACHI
Inspire the Next

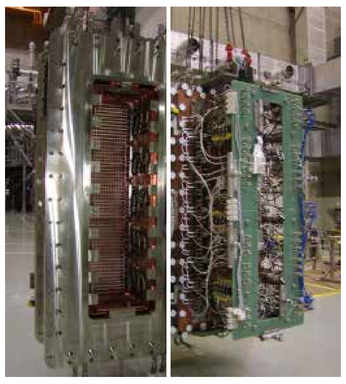
- Delivered NBI with negative ion source #2 in 1998, NBI #3 in 2001 for LHD. (N-NBI)
- Delivered NBI with positive ion source #4 in 2005, NBI #5 in 2010 for LHD.



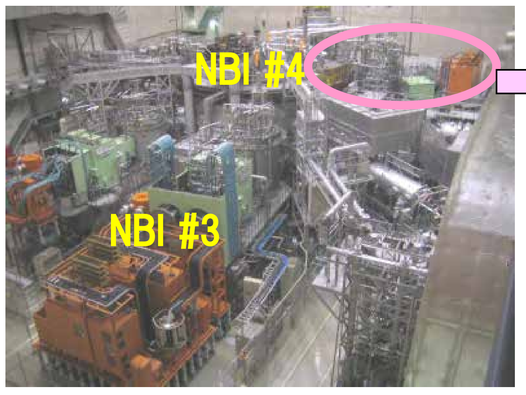



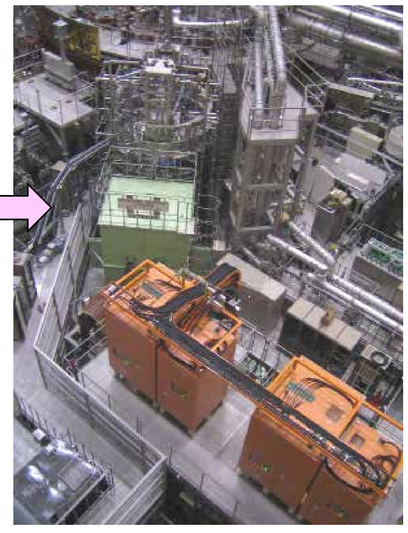

View of NBI #2 & #3 of LHD

■ Specifications of N-NBI of LHD (as designed)
- Beam energy : 180 keV
- Injection energy : 5 MW($H^-$)
  (each beam line)
- Kind of ion : $H^-$ / $D^-$
- Number of ion source : 2 units
  ( each beam line)



Negative ion source of LHD



View of NBI #4 of LHD

＊Pictures provided by National Institute for Fusion Science (NIFS)

# 3. Development of Ion Beam Technology
## (1) Ion Beam Milling system

HITACHI
Inspire the Next

**Feature : Large size bucket type ion source (φ580mm dia.), For magnetic head manufacturing system**

### ■Principle of Ion beam milling

Ion beam extracted from large size bucket type ion source is hit to substrate, then particles on surface are sputtered from substrate and digged.

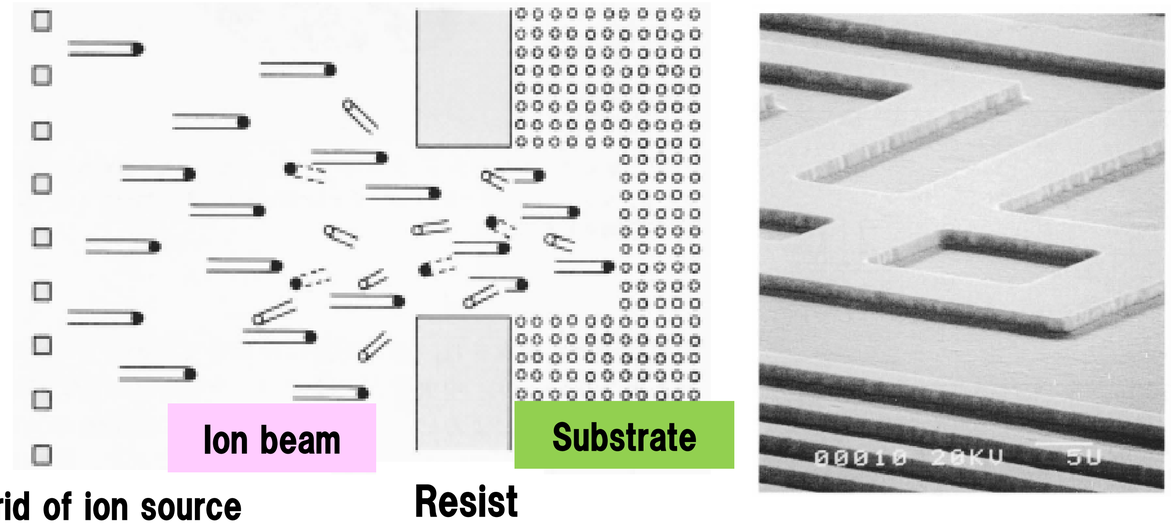
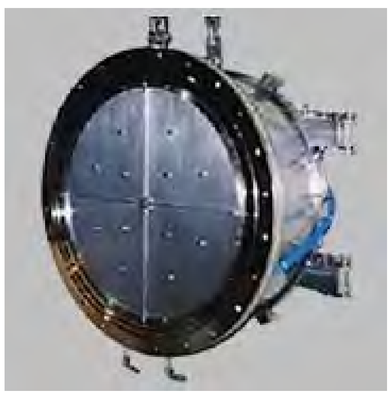





Fig Principle of ion beam milling　　Milling sample

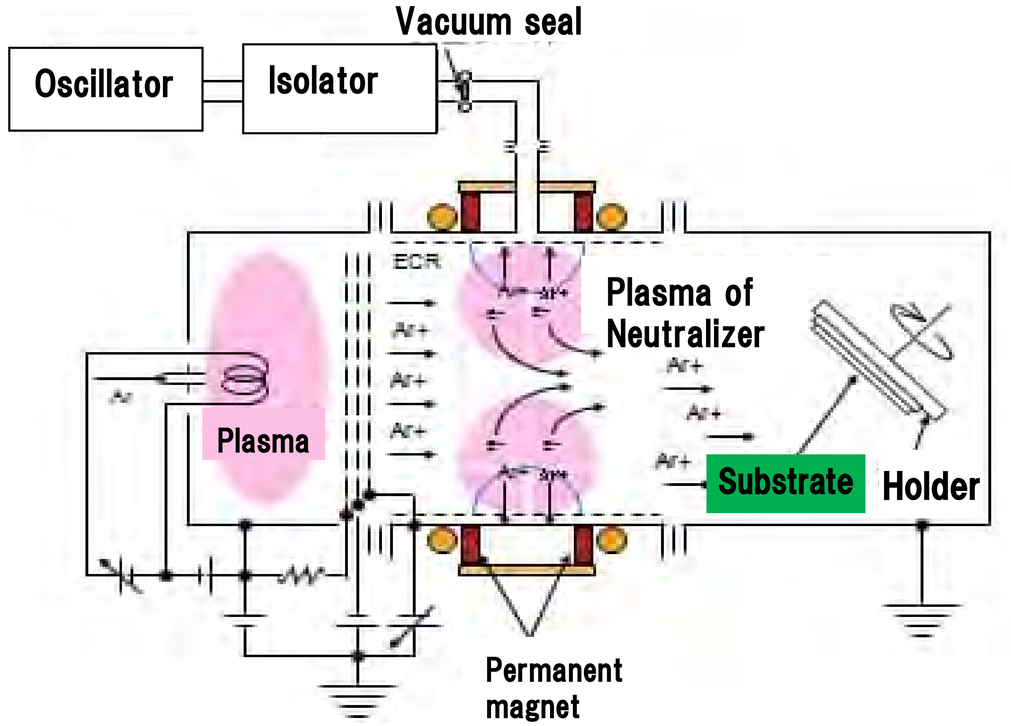
### ■Large size bucket type ion source



View of bucket type ion source

Specifications:
- Grid size : φ580mm
- Beam aperture: Multi-aperture type
- Beam divergent angle : < 05°
- Beam current: > 1mA/cm2
- Source gas : Ar,CF4 etc.

### ■ Outline of ion beam milling system




### ■ View of ion milling system

＊Pictures provided by Hitachi High-Technologies Corp. and Y.A.C. BEAM Co., Ltd.

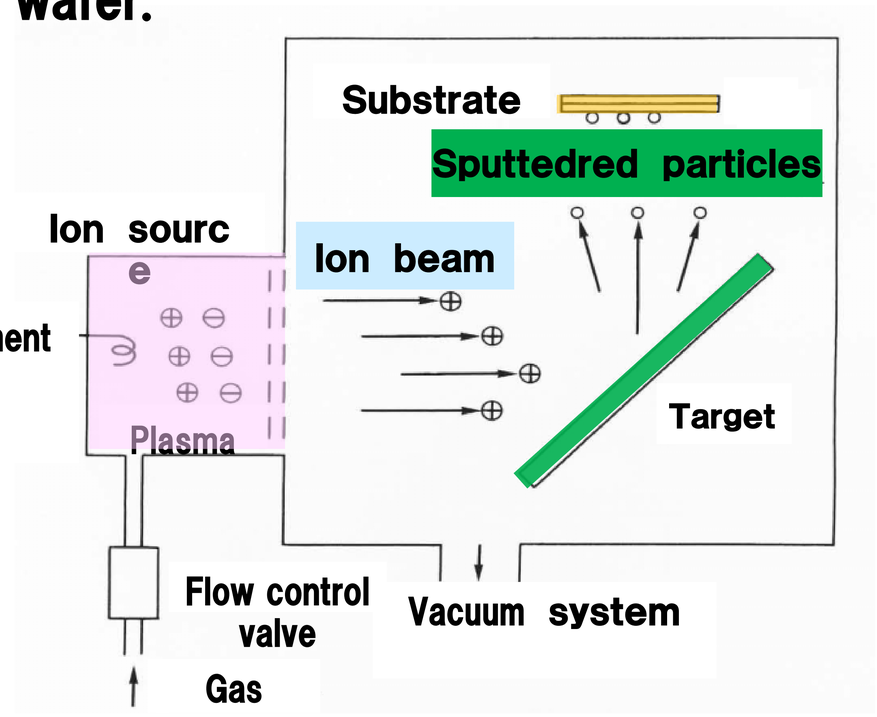
# 3. Development of Ion Beam Technology (2) Ion Beam Sputtering system

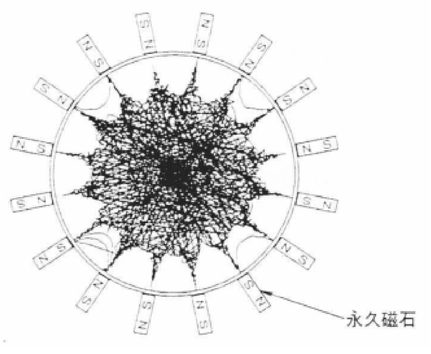
HITACHI
Inspire the Next

## Feature : Sputtering system with complex functions, For research thin-film deposition system

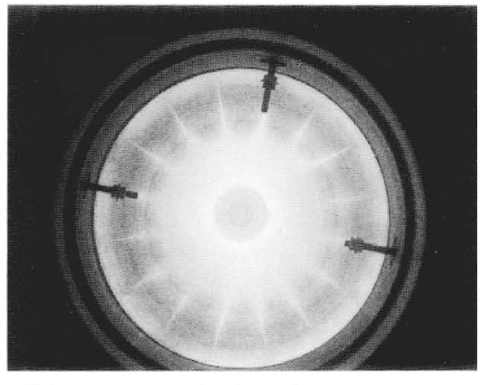
### ■Principle of ion beam sputtering

Ion beam extracted from ion source is hit to target, then sputtered particles are deposited on wafer.



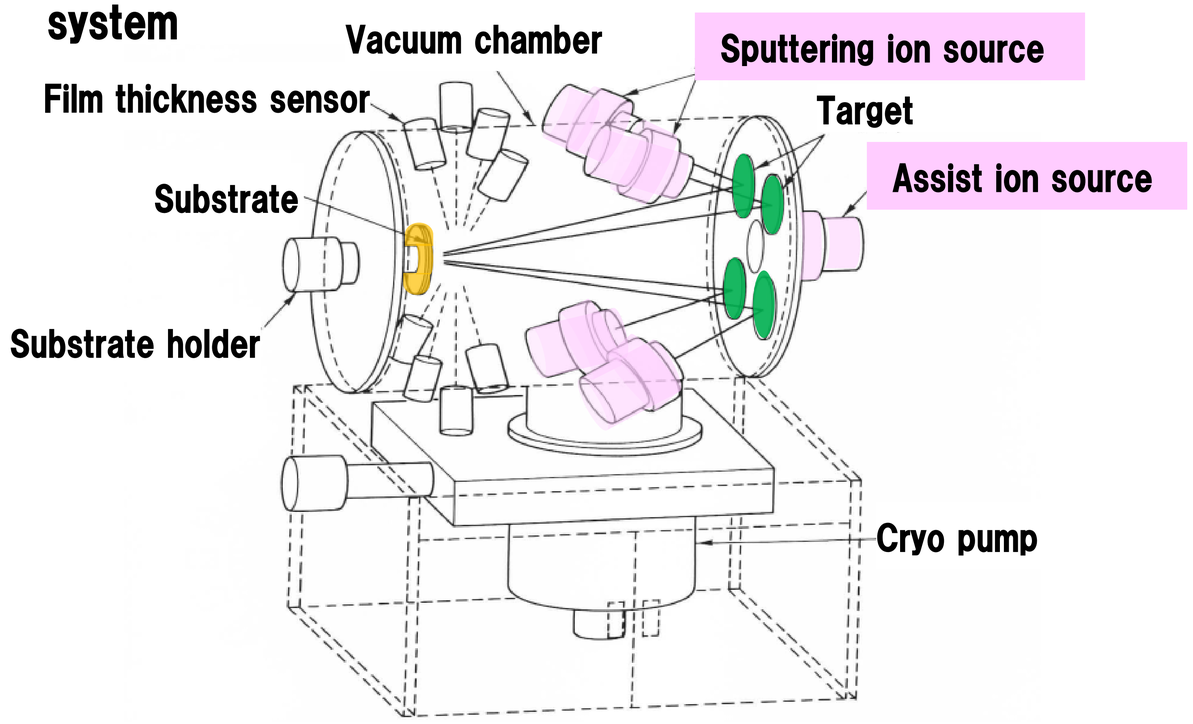




Locus simulation of electrons of bucket type ion source

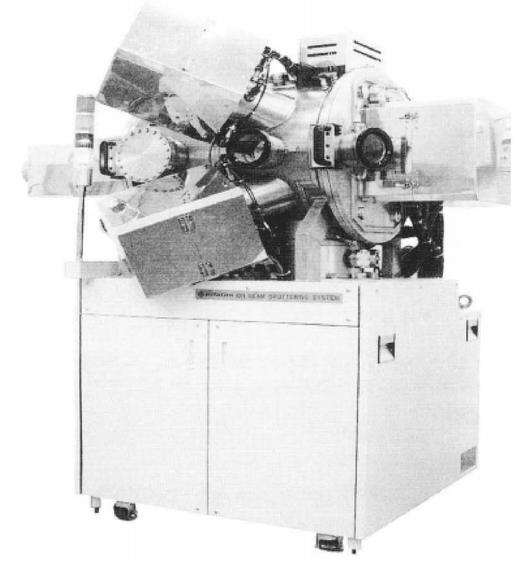


Plasma of Bucket type ion source

### ■Outline of multiple & simultaneous ion beam sputtering system




### ■ View of multiple & simultaneous ion beam sputtering system



Specifications:
- Sputtering ion source：4 units
  Bucket type, 1.2kV x 100mA
- Assist. ion source：1 unit,
  Bucket type, 100V～1.2kV
- Target size：φ6 inch x 4 targets
- Substrate size ：φ3 inch x 1
- Uniformity of sputtered film ：＜ ±2%

# 3. Development of Ion Beam Technology
# (3) Oxygen Ion Beam Implantation system

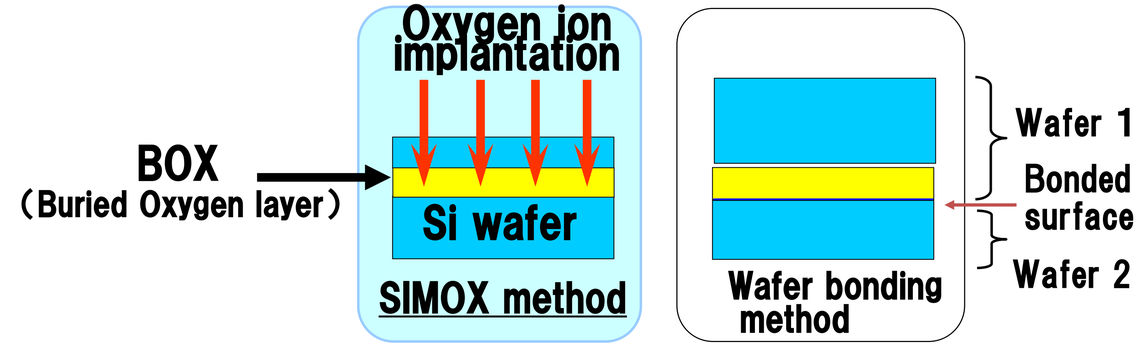
HITACHI
Inspire the Next

( Feature : High current Oxygen ion beam (Max 100mA) , For semiconductor wafer manufacturing system )

## ■ Production method of SOI wafer

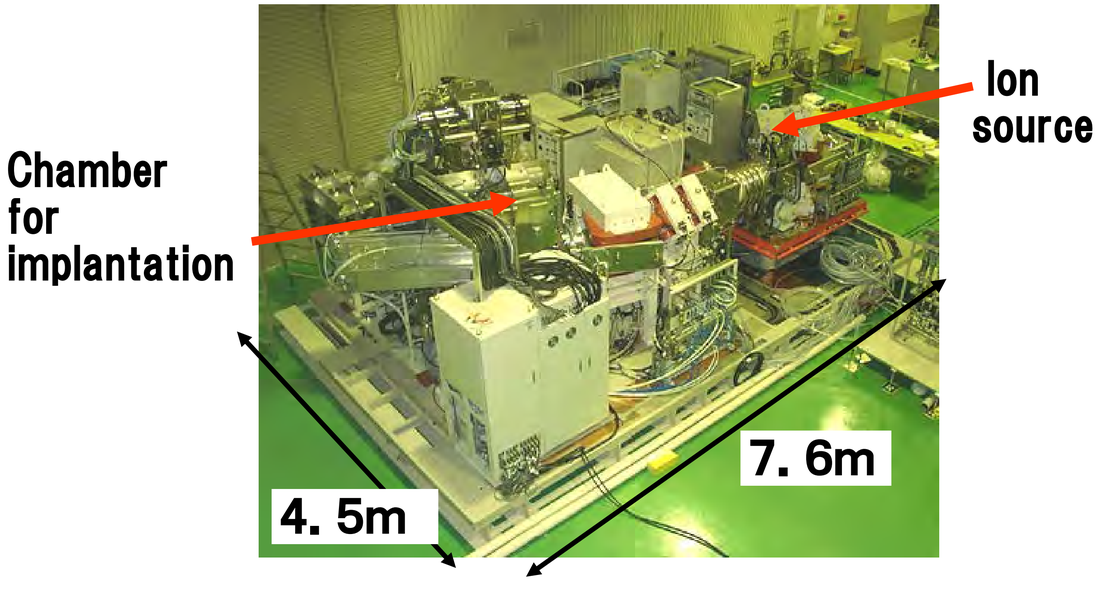
( SOI : Silicon on Insulator )

For speeding up & low power consumption of semiconductor

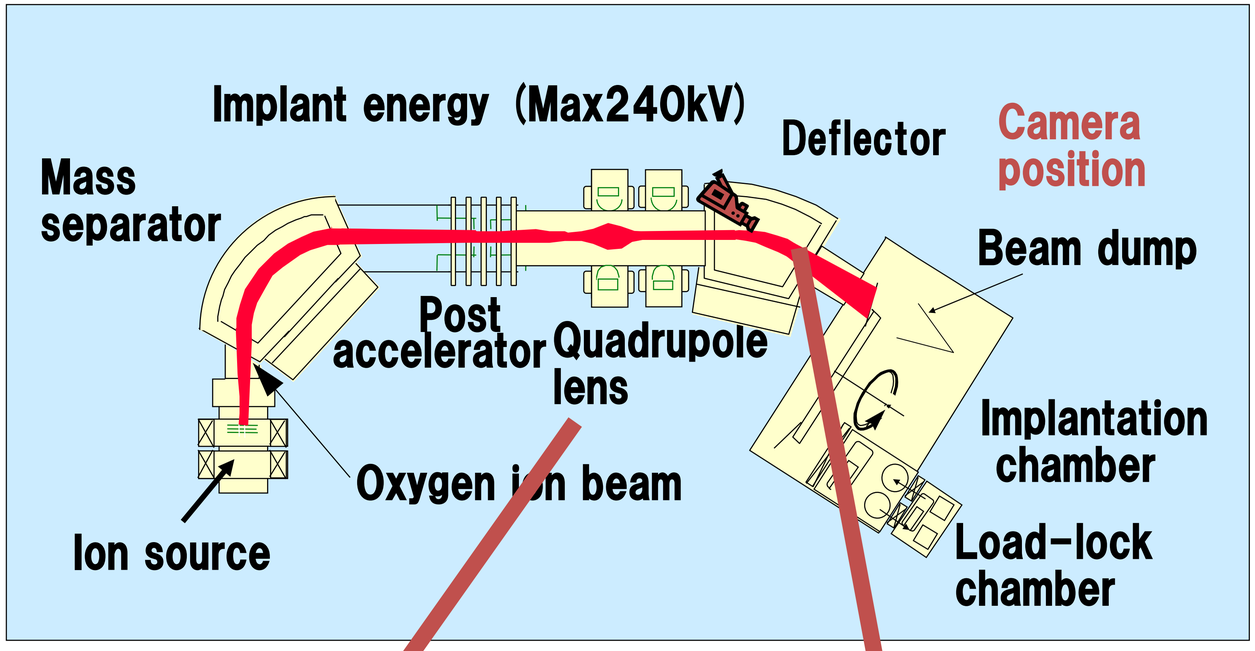


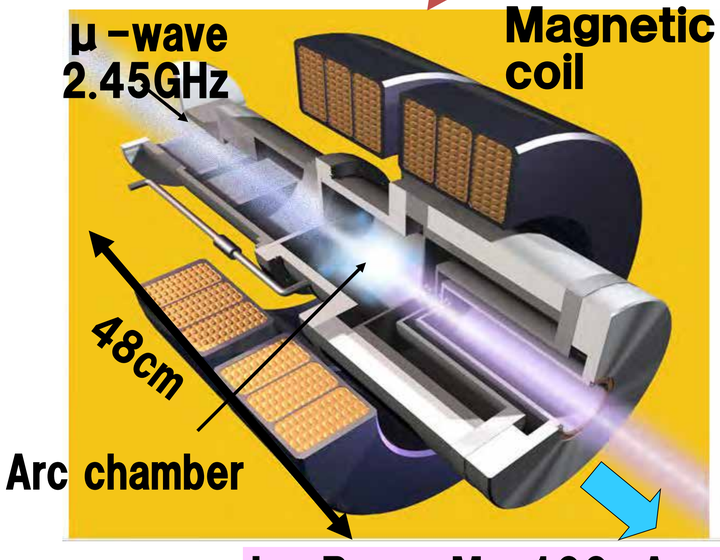

SIMOX : Separation by Implanted Oxygen

## ■ Outside view of oxygen ion beam implantation system

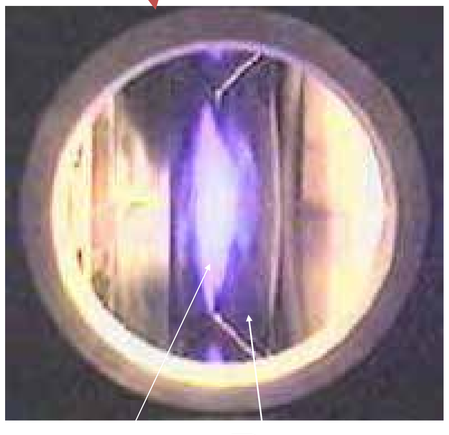



## ■ Configuration of Oxygen Ion Beam Implantation system




Ion Beam: Max100mA

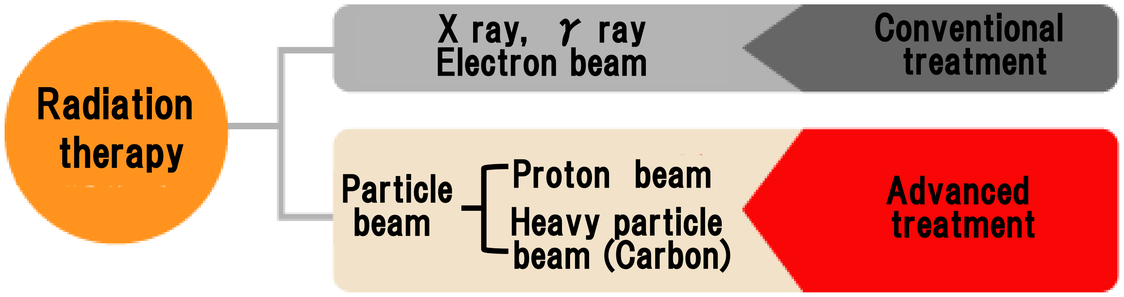


# 3. Development of Ion Beam Technology
# (4) Proton Corpuscular Beam Treatment system

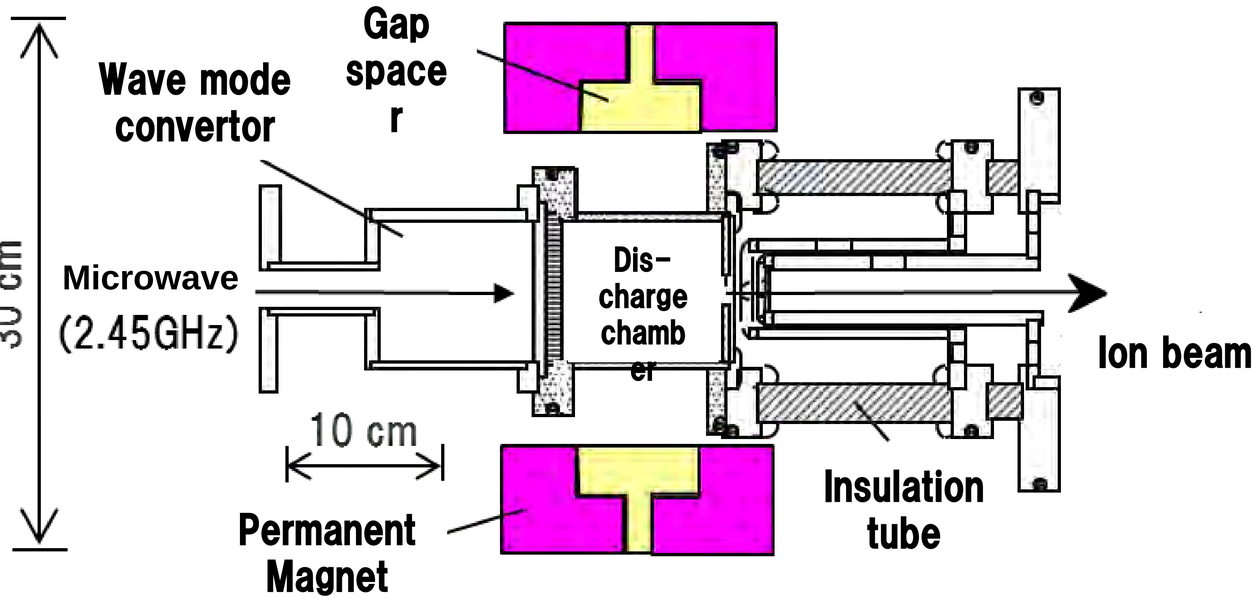
HITACHI
Inspire the Next

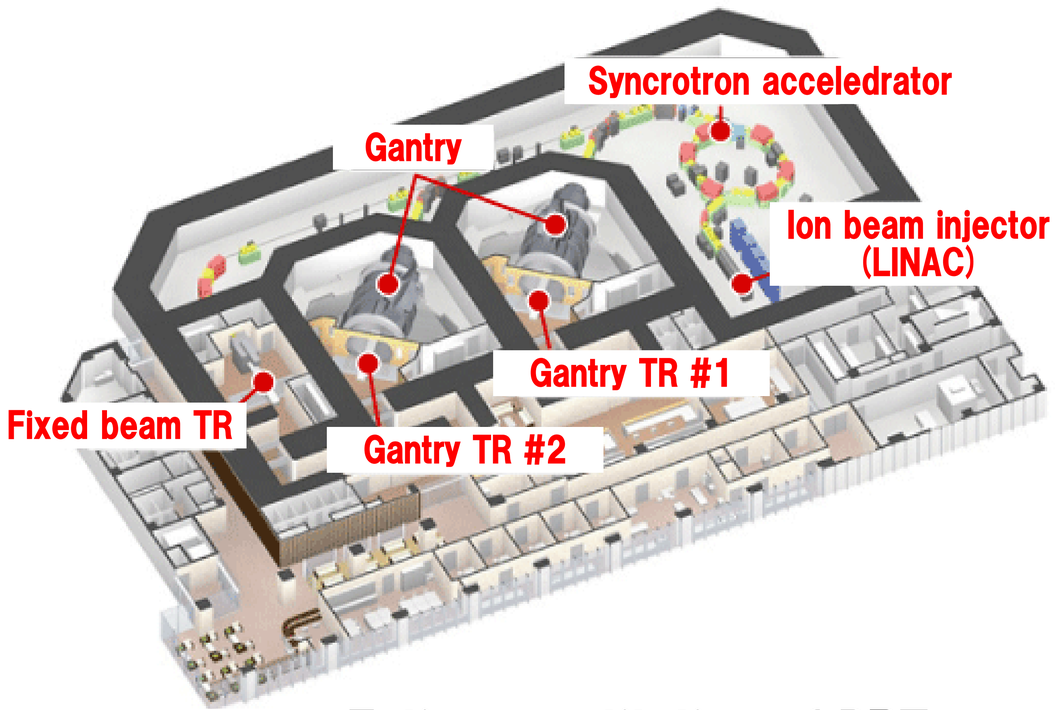
## 〔Feature: High reliable ion source with easy maintenance Work, Medical application 〕

■Proton Corpuscular Beam Treatment system (PBT) has much in common with Nuclear Fusion experimental systems as Electromagnetic applied equipment & Large scale Scientific system.




■Structure of Ion source for PBT

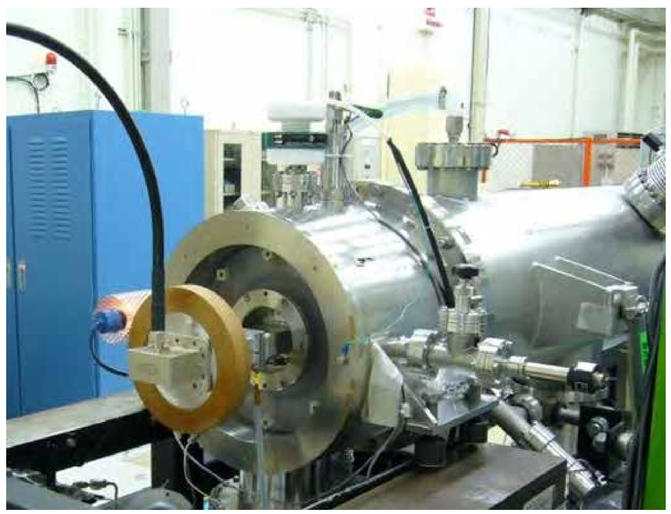



TR: Treatment room

**Entire constitution of PBT**

■View of ion source for PBT



**Specifications:**
- Aperture size: 5mm
- Plasma grid: 30 kV
- Deceleration grid: −2 kV
- Ground grid: 0 kV
- Max current: 63 mA
- Pulse width: 400 μs
- Repeat frequency: 20 Hz
- Micro wave power: 1.3 kW

# 4. Summary

HITACHI
Inspire the Next

(1) Progress of site instauration work & withstand voltage test of NBTF
Under collaboration with RFX & QST, NBTF site work is on schedule.
Hitachi supports these site works with dispatched Hitachi's technical advisors (TA).

(2) Achievements of NBI development/manufacturing and deployment for ITER project
Since detailed design work in 1978, Hitachi has been contributed to development & manufacturing of following NBI systems more than 30 years.
NBI systems for: Heliotron E, JT60 prototype unit, JT-60, JT-60U (T-NBI, N-NBI), LHD (#2～#5) and NBTF for ITER.

(3) Application development of ion beam technology
Ion Beam technology derived from NBI development applied to industrial equipment.

⇒Hitachi will contribute to promote development of nuclear fusion technologies from now on.

# Innovating Healthcare, Embracing the Future

HITACHI

Inspire the Next