Ultrahigh Vacuum for High Intensity Proton Accelerators:
– Exemplified by 3 GeV RCS in the J-PARC –

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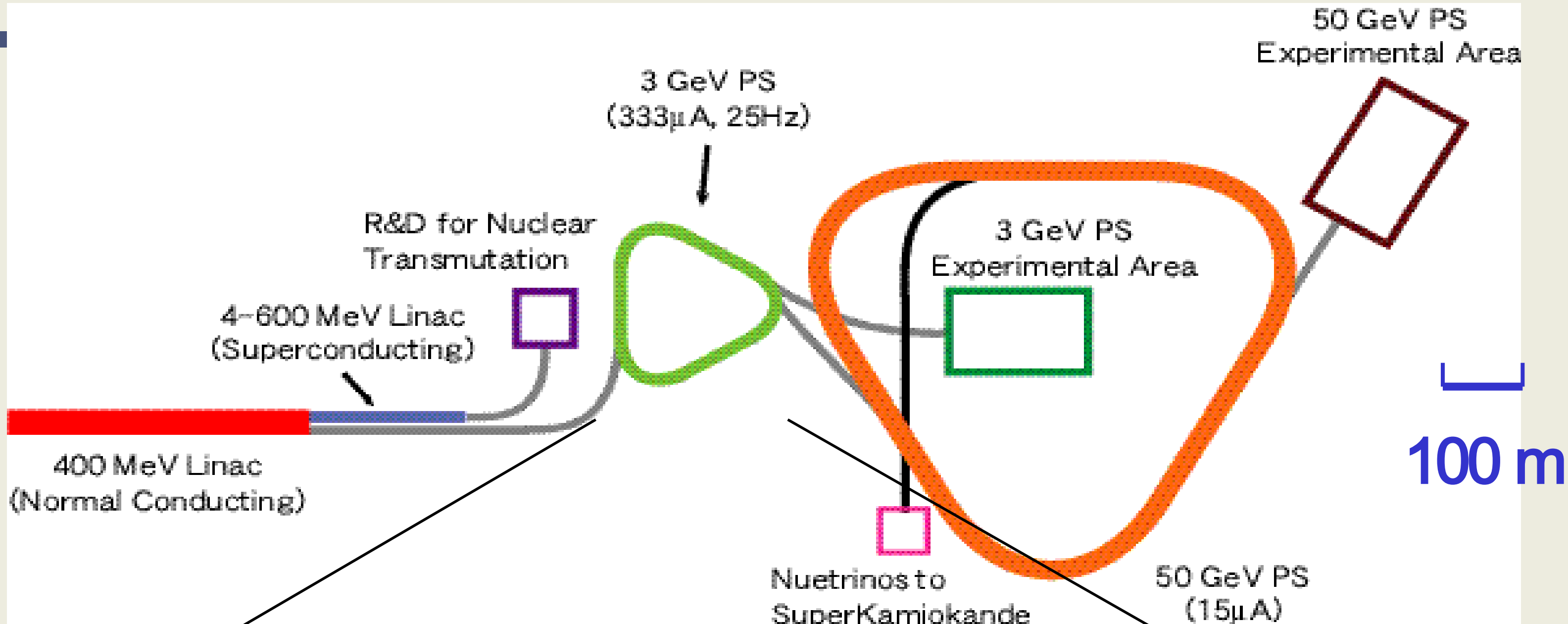
Contents

1. Main Features of the RCS
2. Requirements for the Vacuum System of the RCS
3. Outline of the Vacuum System
4. Research and Development
   - *A Few Topics*

5. Performance
   - *Pump-down Characteristics*
   - *Outgassing during Beam Operation*
   - *Machine Troubles since Oct. 2007*
   - *Examination after the Earthquake at 11th Mar. 2011*
6. Summary

Main Features of the RCS



Features of the RCS

Circumference	**348.333 m**
Injection Energy	**181 MeV (400 MeV)**
Extraction Energy	**3 GeV**
Repetition Rate	**25 Hz**
Output Beam Power	**(1 MW)**

Requirements for the Vacuum System in the RCS

- *1 MW Beam Power*
- *25 Hz Repetition*

↓

(1) To Minimize Exposure of Operators to Radiation

(2) To Keep the Pressure during Beam Operation in UHV

(3) To Fast Pump Down

(4) To Avoid the Eddy Current Effect

How to fulfill the requirements

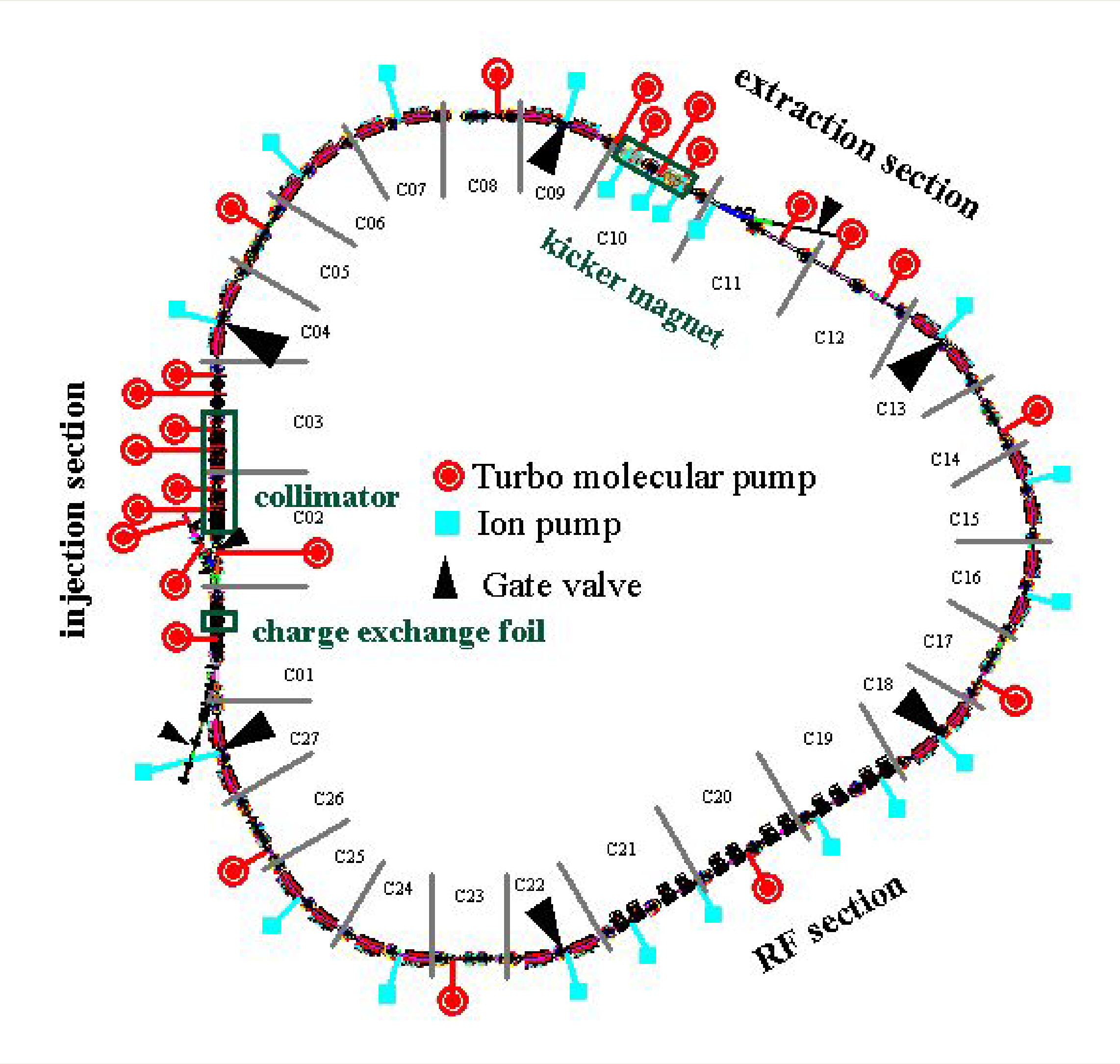
To Minimize Exposure of Operators to Radiation
To Keep the Pressure during Beam Operation in UHV
To Fast Pump Down
To Avoid the Eddy Current Effect

↓

-Radioactive resistance to vacuum components
-Materials with small residual radioactivity
-TMP for evacuating the ring during beam operation
-Vacuum-firing to reduce gases in wall materials

-Ceramic ducts to avoid eddy current effect

Schematic Configuration of Vacuum System



Vacuum Components

- Ceramic Ducts (108)
  ---180 m in total length---
- Ti Ducts & Bellows(186)
  ---170 m in total length---
- Pump
  TMP 24, SIP 20
- Gate Valve 9
- Gauges BA 17,
  CCG 44, Pirani 44
- Other Components
  - Collimator System
  - Kicker Magnet
  - Chamber for injection and extraction

Research and Development

Newly Developed Components

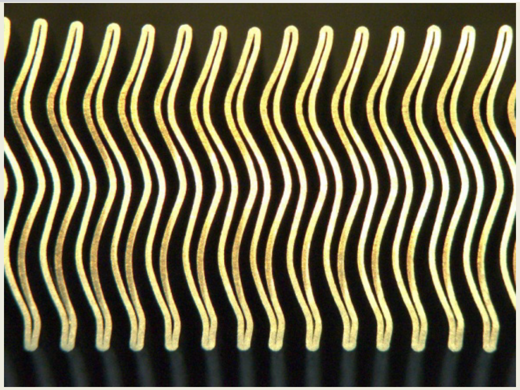
-Large Scale Ceramic Ducts
-Large Scale Ti Bellows
-TMP with Radioactive Resistance
-Vacuum Chambers at Beam Junction
-Cable and Connector

New Techniques

- Surface Treatment for Ti
Inner-surface Polish of Bellows
H-content reduction in the Bulk
-Vacuum Firing of Cu Blocks for Collimators
-Degassing of Ferrite Cores in Kicker Magnet

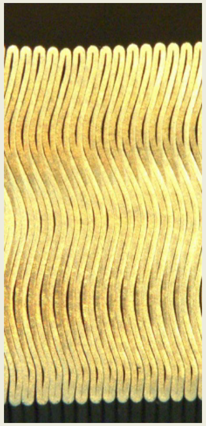
Large Scale Ti Bellows -1-

- Pure Ti
- Hydro-formed Bellows
  as Flexible as the Welded Ones
  Spring Rate : ~ 10 N/mm

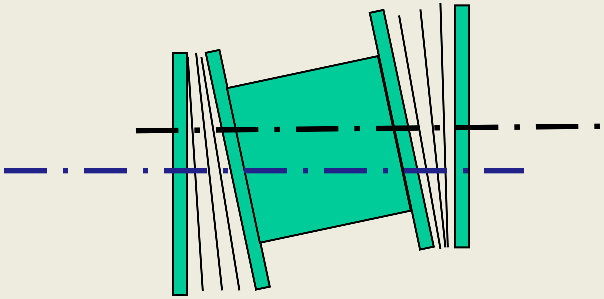


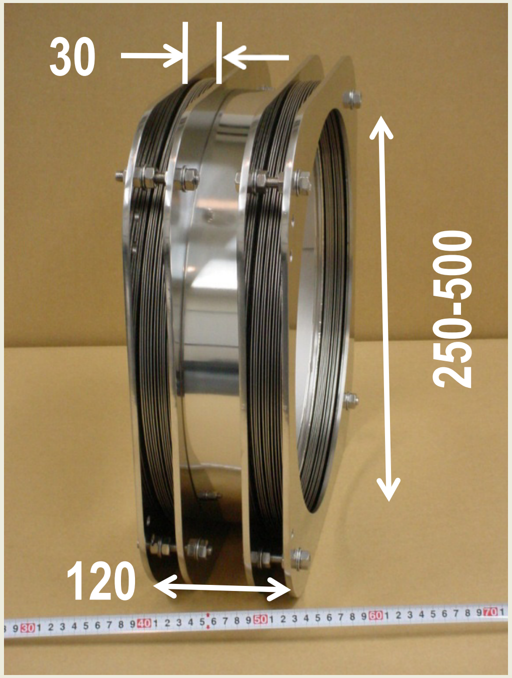
Free

Compressed



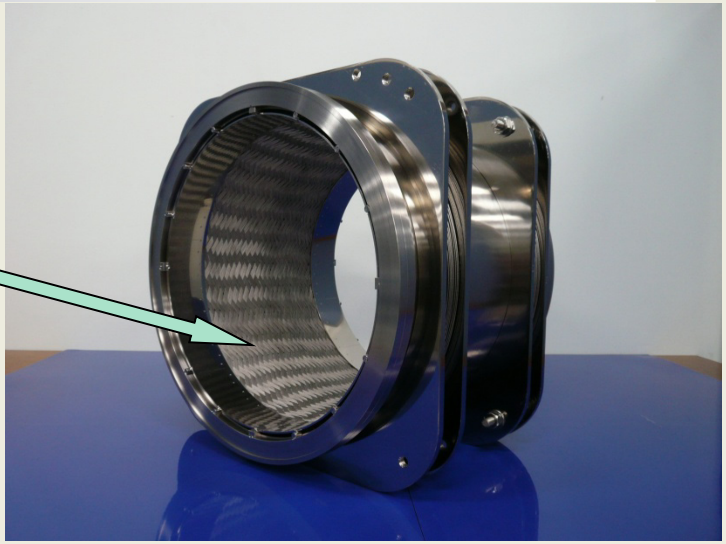
- Displacement
  - Axial : ±5mm × 2 = ±10 mm
  - Lateral: ~ 5 mm
  (Universal Joint:2 bellows + tube)



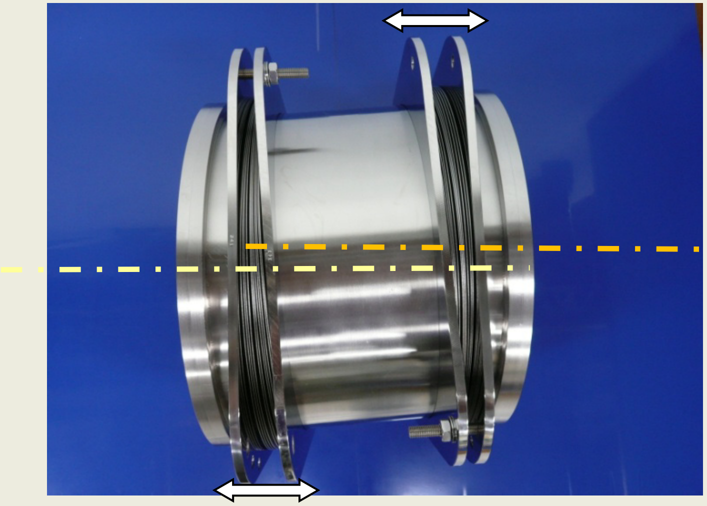


Large Scale Ti Bellows -2-

■ **New RF Contact**

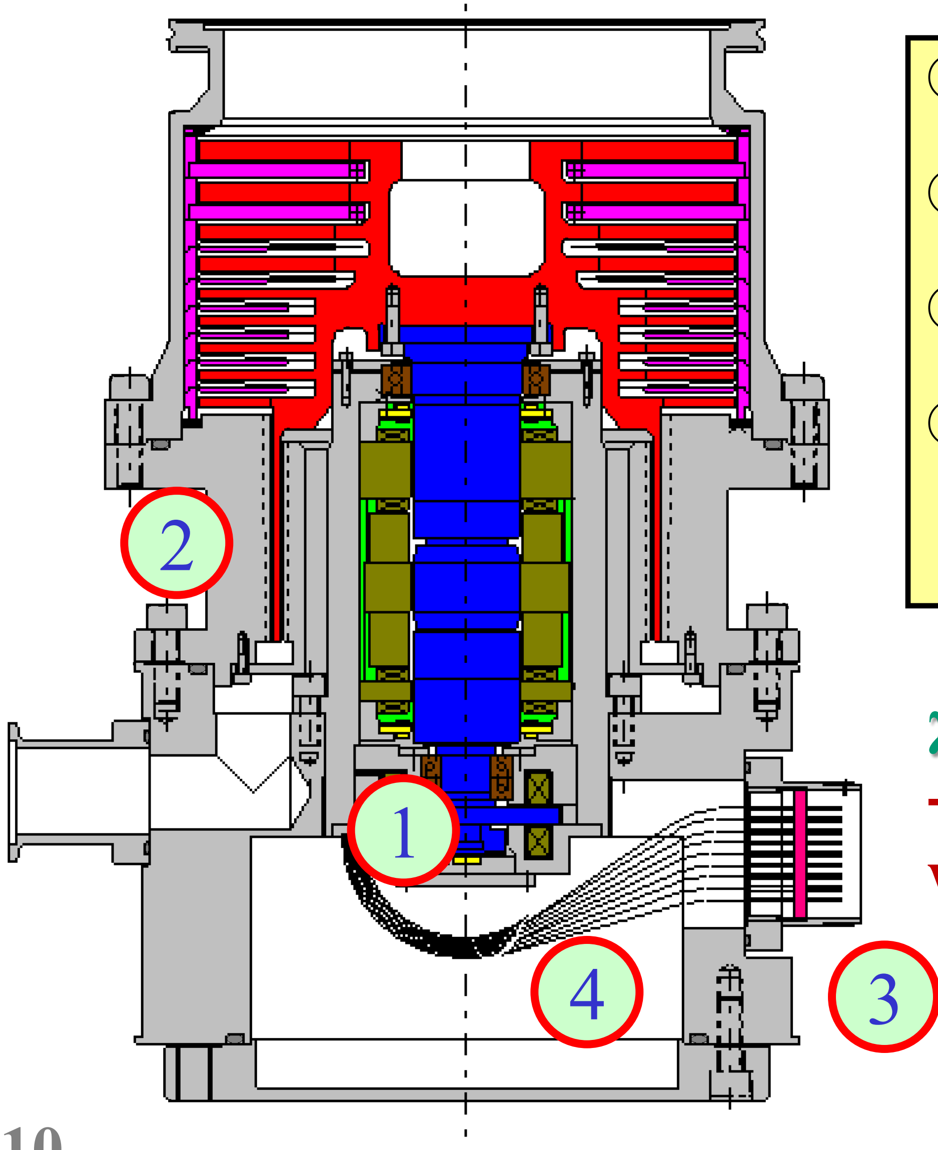


- Basket Made of Ti Braid (0.3 mm in diameter Ti wires)



Universal Joint

TMP with Radioactive Resistance



①: Speed sensor :
Hall sensor ⇒ Pick-up coil
②: Seal :
elastomer ⇒ metal
③: Hermetic seal :
rubber, resin, etc. ⇒ ceramics
④: Sheath material :
Teflon ⇒ PEEK

γ ray irradiation test for 3 years

- Good performance
with the absorbed dose > 75 MGy

Surface Treatment for Pure Ti

Out gassing Mechanism

- Thermal Desorption

- Particle Impact Desorption

- Chemical Reaction

If there are neither gases nor elements on the surface and/or near the surface

→ No Outgassing

What treatment for pure Ti ?

Surface Treatment for Pure Ti

neither gases nor elements on (near) the surface

(1) To Remove Surface Degraded Layer and To Make Surface as Smooth as possible

(2) To Reduce Gas Species (mainly H) in the Bulk
- Through Vacuum-firing

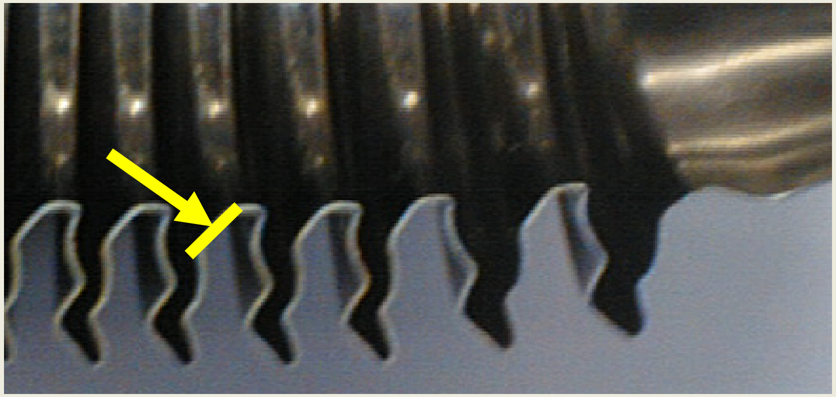
(3) To Introduce Chemically Stable Surface
- Dry treatment to form a thin amorphous oxide layer

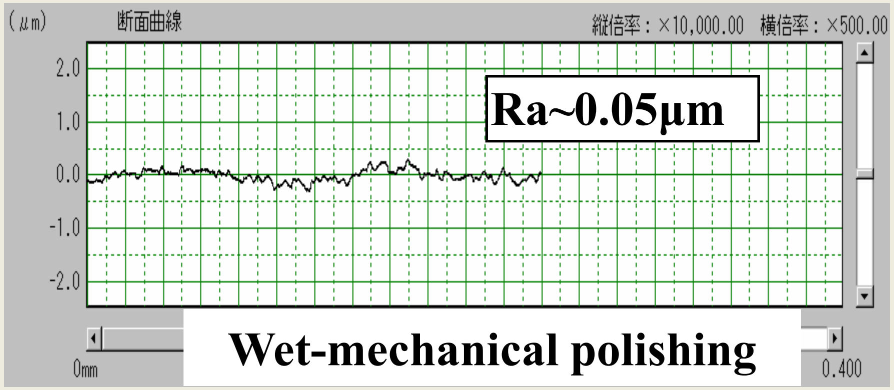
Surface Treatment for Pure Ti

(1) To Remove Surface Degraded Layer and To Make Surface as Smooth as possible

Chemical Polish : Ducts, Braid for RF contact

Wet-mechanical Polish : Bellows Inner Surface





Wet-mechanical polishing

Average Roughness Factor Ra < 0.2 μm

Surface Treatment for Pure Ti

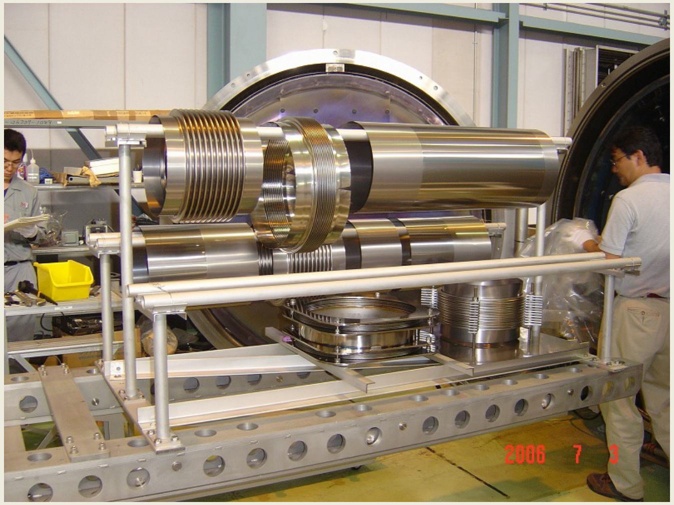
(2) To Reduce Gas Species (mainly H) in the Bulk

- Through Vacuum-firing

Duct(4 mm^t) : 750ºC × 8 h

Bellows(0.3 mm^t) }
Braid(0.3 mm$^{\Phi}$) } 650ºC × 8 h

↓

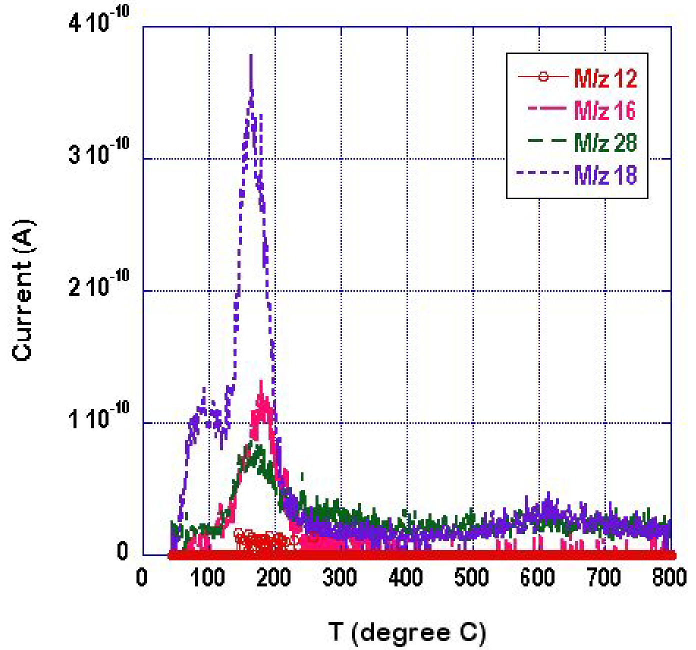


H-content

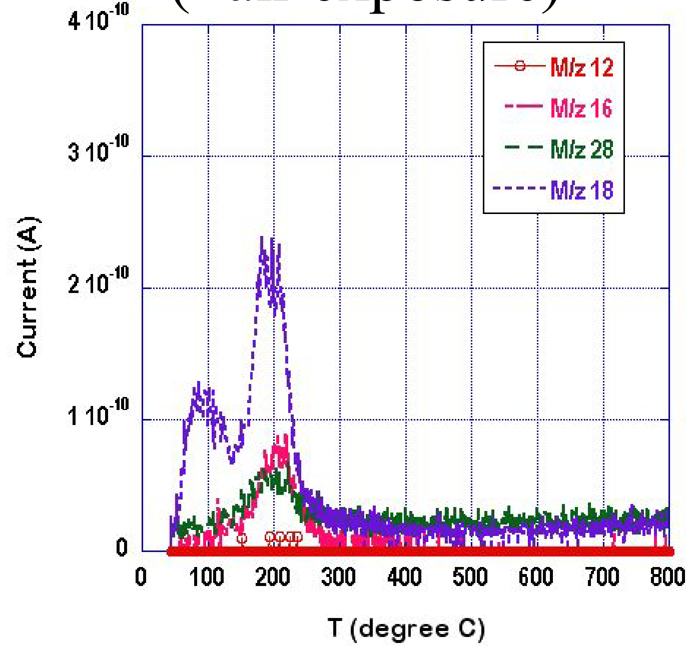
~10 ppm → < 1 ppm (wt)

Effect of vacuum-firing : TDS Spectra

CP (+air exposure)



CP + 650(degree C)
(+air exposure)

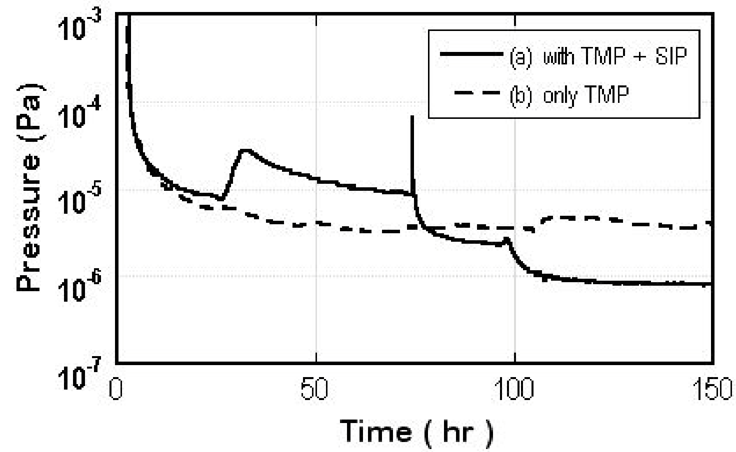


→ **By means of Vacuum firing**

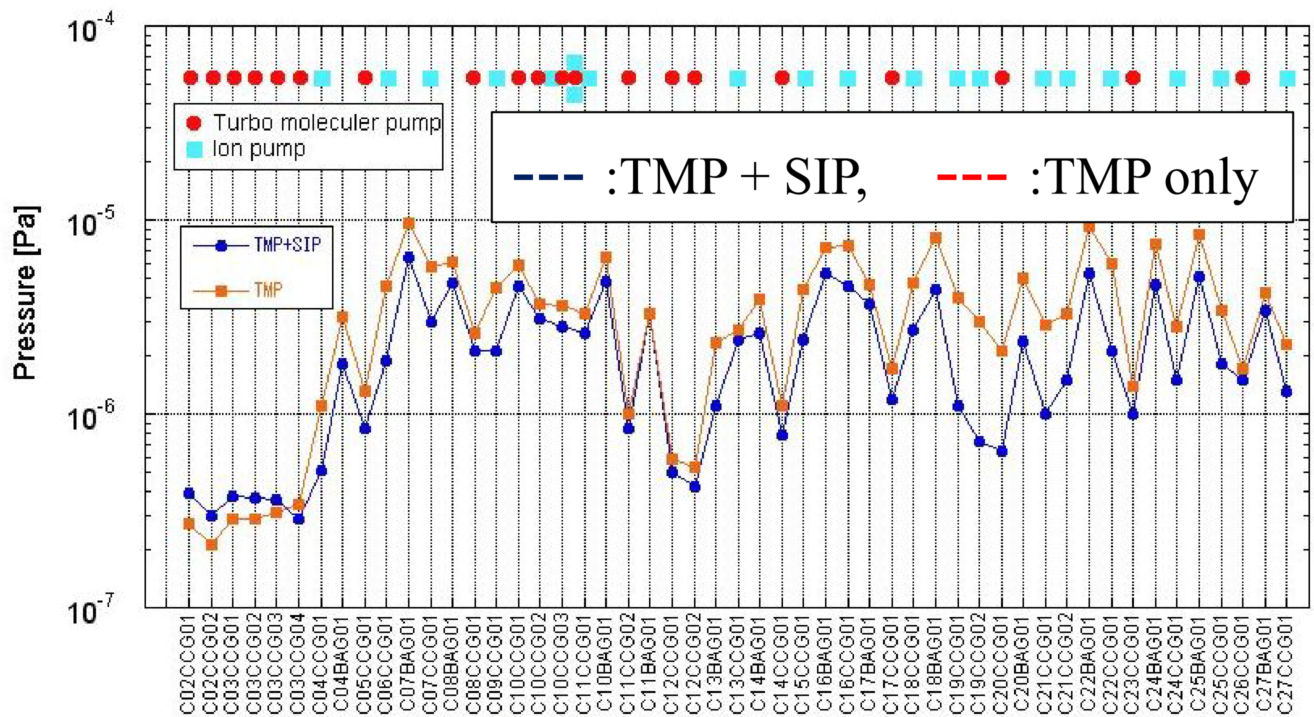
C, O content (including adsorption) rather decease

Performance : Pump-down Characteristics

- **Fast Pump-down**
  - **- Preparation in 2 days**
- **Outgassing Rate**
  - **- ~ 10^{-8} Pam/s (without bake)**



- Oct. 2007 ~ Sep. 2008
TMP:24 SIP:20
- Oct. 2008 ~
TMP:24
(SIP: no use)



Outgassing during Beam Operation

After a long-time shutdown

- Small amount of outgassing

According to the operation time

- Outgassing decreases

and

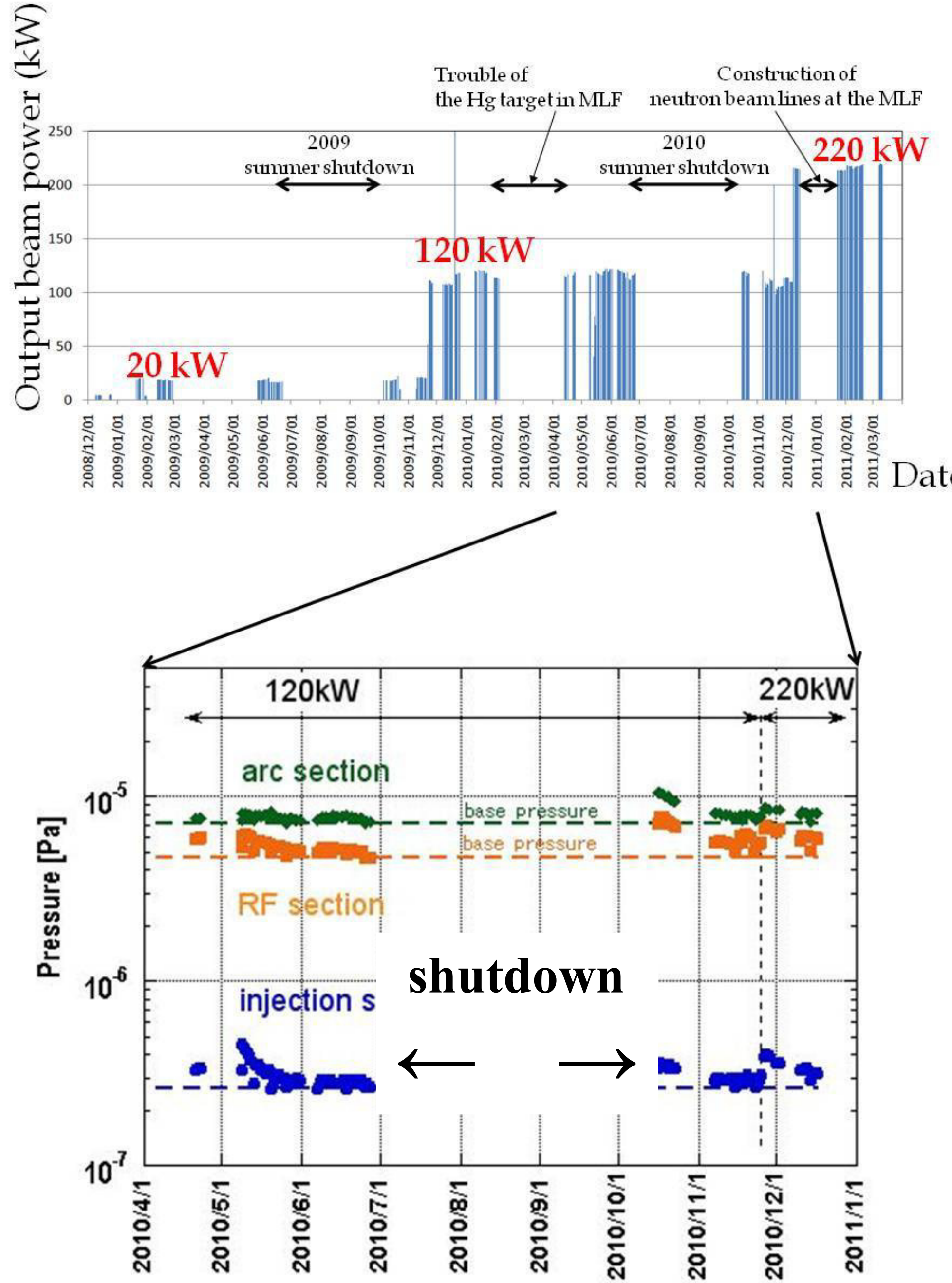
- pressure reaches to

the base pressure everywhere

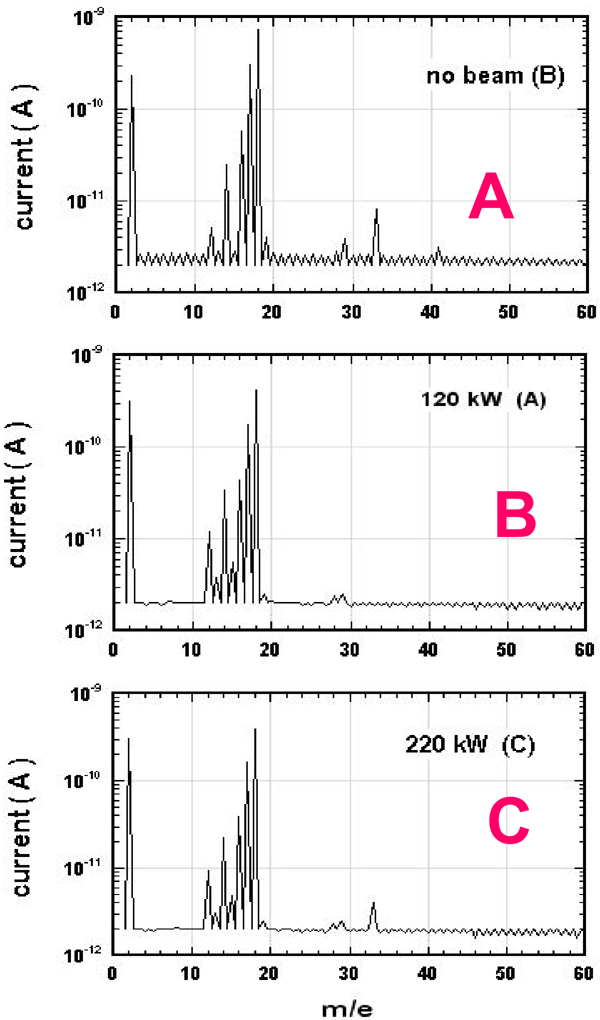
Outgassing with beam

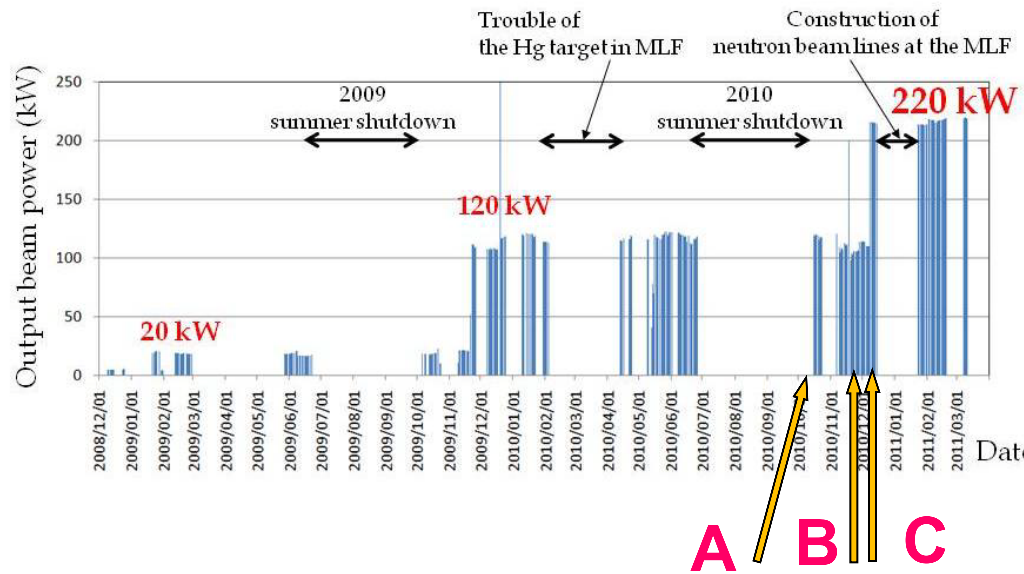
(up to 220 kW)

→ Negligibly small



Outgassing during Beam Operation





Comparison of spectra

between B (120 kW) and C (220 kW)

-Little difference

between A(no beam) and B,C (220 kW)

-Beam conditioning effect

-No obvious outgassing during beam op.

Machine troubles

Component	Problem
1 of 24 Backing Pump	Stop due to the rust of the spring for preventing air back streaming
3 of 20 Ion Pumps (Oct.2007~Sep. 2008)	Trip-ups due to communication error between controller and main PC
3-5 of CCG	Sometimes no ignition

There have been no serious problems since Oct 2007.

- There have been no problems related to TMPs.

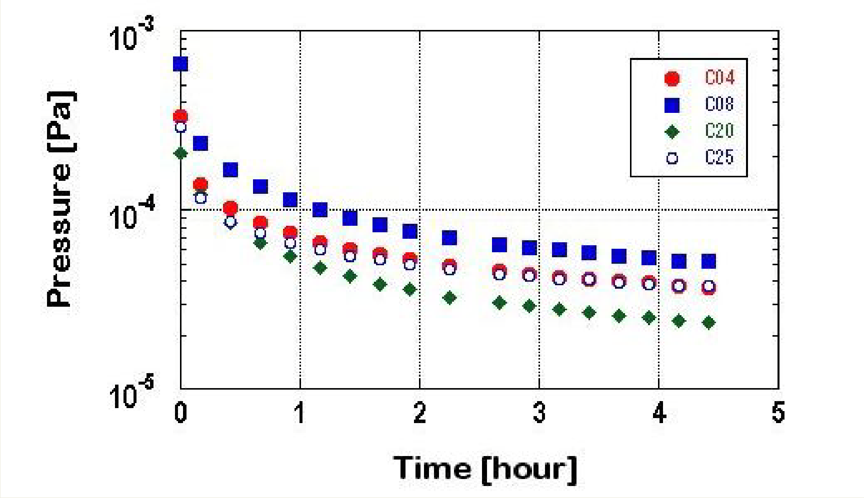
Status after Big Earthquake at 11th Mar. 2011

***Simple inspection*:**

- **no damage**
- **no vacuum leak**

Pumping test

using temporary power supply



As soon as the permanent electric-power is supplied, we will inspect the whole system thoroughly and start evacuating the ring

Summary

1. Main Features of the RCS

2. Requirements for the Vacuum System

- To Minimize Exposure of Operators to Radiation
- To Keep the Pressure during Beam Operation in UHV
- To Fast Pump Down

3. Outline of the Vacuum System

- Main pump : TMP with Radioactive Resistance
- Pure Ti component, Thorough Heat-treatment

4. Research and Development

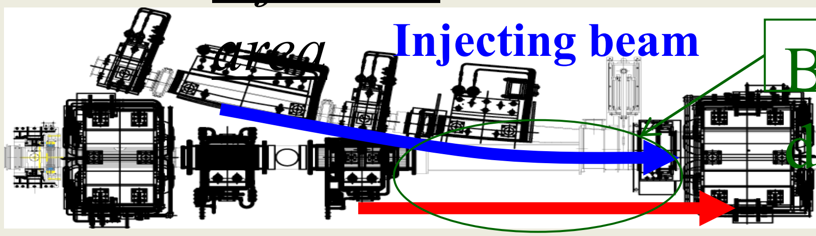
5. Performance

- No serious machine trouble, Fast Pump-down (in 2 days)
- Little outgassing with beam operation up to 220 kW

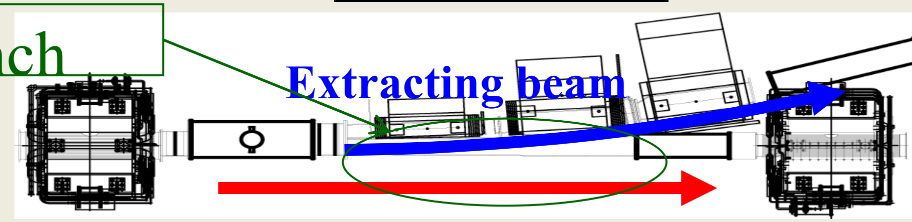
Branch duct for beam injection and extraction

Branch ducts are installed in the septum magnets for beam injection and extraction.

Injection area

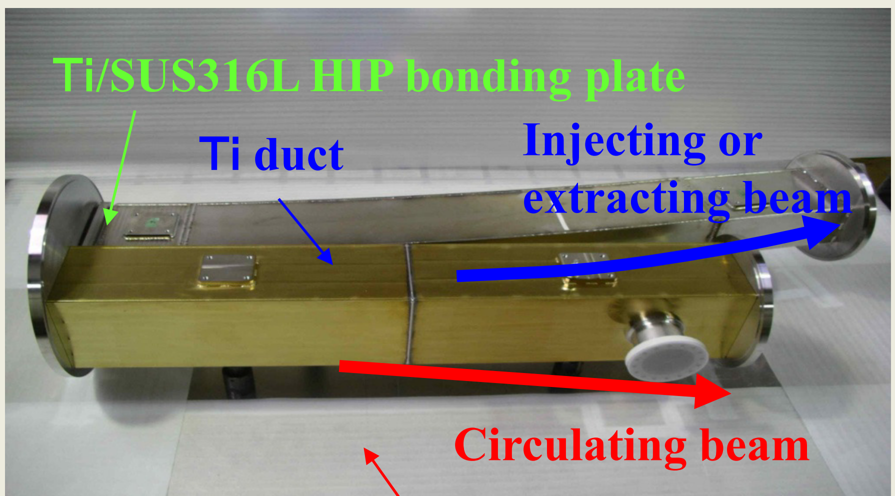


Extraction area



☐ In septum magnet;
Titanium duct

- Beam is bended
- Nonmagnetic material
- Titanium is adopted (J-PARC common specification)



☐ Out septum magnet
EM stainless duct

- Beam goes straight
- Magnetic material (to suppress the leakage field)
- ES stainless is adopted (RCS original specification)