Techniques of tritium decontamination on plasma-facing walls in DEMO

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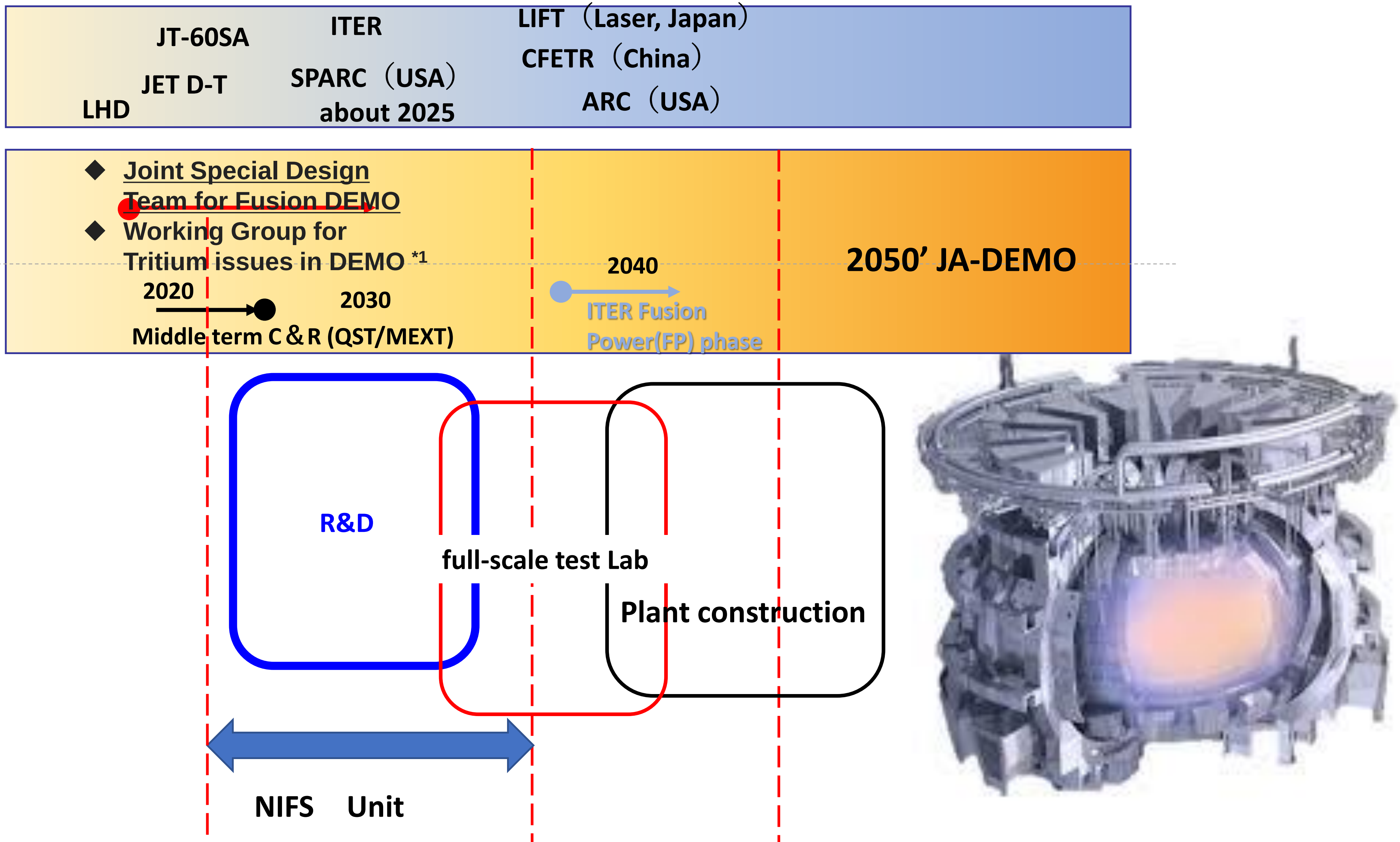
- **Background**
- **Tritium removal in the plasma chamber of DEMO**
- **Monitoring methods of remained T in vessel**

This work is supported by JSPS-CAS Bilateral Joint Research Projects (GJHZ201984 and JPJSBP120197202), and QST collaboration works.

13 Oct. 2022, IAEA TM, IAEA Headquarters

Research/Development toward Fusion Plant



Ref：QST

DEMO researching works in JAPAN

- **<u>JA-DEMO (QST)</u>** QST

<u>Joint Special Design Team for Fusion DEMO</u> in QST

JA-DEMO team made the **<u>action plan (total 75 pages in 2017),</u>** which details issues for the collaboration works and their objective of researching works.

https://www.fusion.qst.go.jp/rokkasyo/ddjst/index.html

- **<u>Researching project is reconstructed into 11 UNITS (NIFS)</u>**

Details of the UNIT is presented at the International Toki Conference (ITC)-31, Remote conference, 2022 Nov.8 – Nov.11

https://itc.nifs.ac.jp/

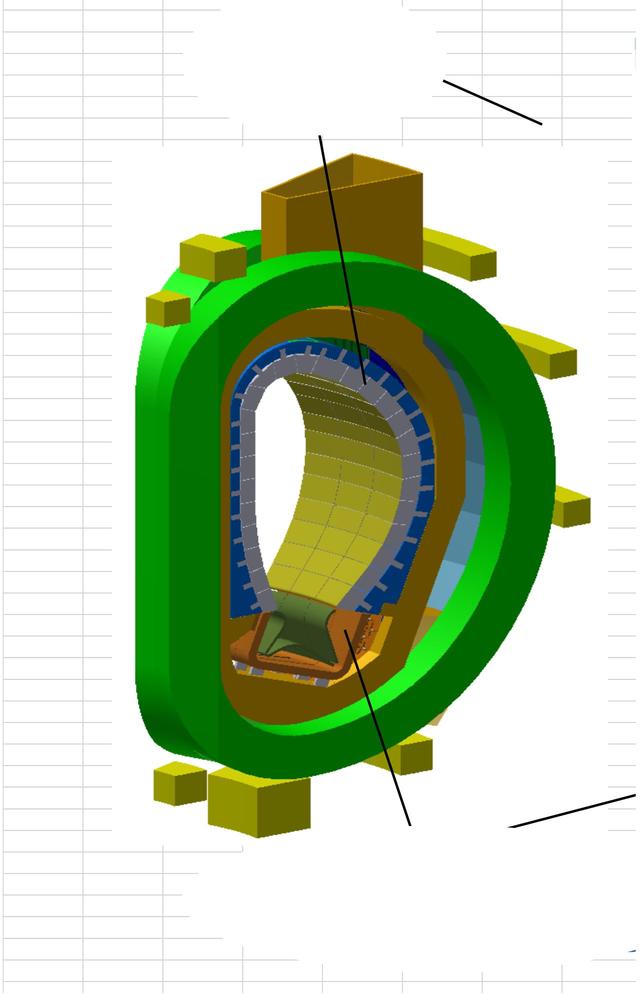
(registration is required by Oct.23, free)

Motivation of Tritium decommissioning

Action plan in Joint JA-DEMO team

"7. Fuel cycle system"

- **Design of fuel system**
- **Safety engineering and development for Tritium**



- R&D of Tritium decommissioning is required to get a license of the agreement for starting the periodic maintenance.
- At present, the amount of limitation to doing the vacuum vent is not determined yet.
- But to show **methods of T decontamination** is important. The method by the team (researchers and related companies) contributes to one of the DEMO creation policies of the Japanese government.

1) Safe working conditions for Machines (with Humans?) at the maintenance
   To keep low-level irradiation in the tokamak hall
2) High purity tritium recovery for their cycle in a closed plasma chamber.
   Recovered T by vacuum pump can be used for direct recycling pass

T removal on the surface in plasma chamber

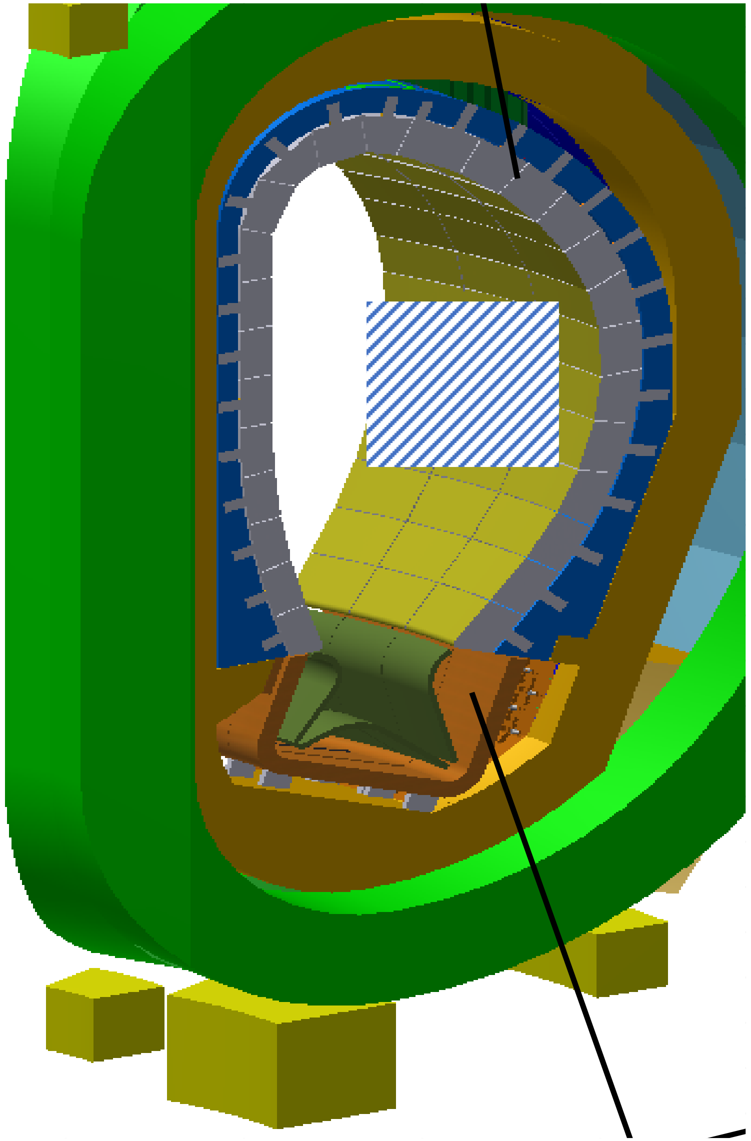
Agreement of license for **starting the periodic maintenance.**

- Requirements of T removal are areas on the facing regions.
- Separated scenario between the maintenance (this work) and irradiated waste of the thick tile blocks (~~Hot cell~~)

  >>It is not considered tile blocks.

- **The candidate temperature** for T removal is around the same as the device's operational temperature. And the controlled temperature gradient is slow, especially in superconducting(SC) magnetic confinement devices.
  - For example, the baking temperature setting in LHD is 95°C /15 hours

    >>To avoid heat transfer to SC



Tritium removal in the plasma chamber of DEMO

T removal method on the surface in plasma chamber (1)

3 methods are considered

1. Baking and heat decay

*Active temperature control by coolant is so slowly. Temperature of materials is shown as the balance between coolant ant heat decay.

O : Tritium profiles in the depth is changed by diffusion.

X : feed back control

O : for example, Model predictive control

- ✓ Some of thermal power plant is used for efficient fuel use
- ✓ Model of temperature control by heat decay

２. **Active wall conditioning** （glow, RF (IC, EC) wall conditionings w/ mag. Field) removal depth of the WS is 10-100nm

３． **Gas and Pressure Selections** (including small amounts of O, H2O）

T removal method on the surface in plasma chamber (2)

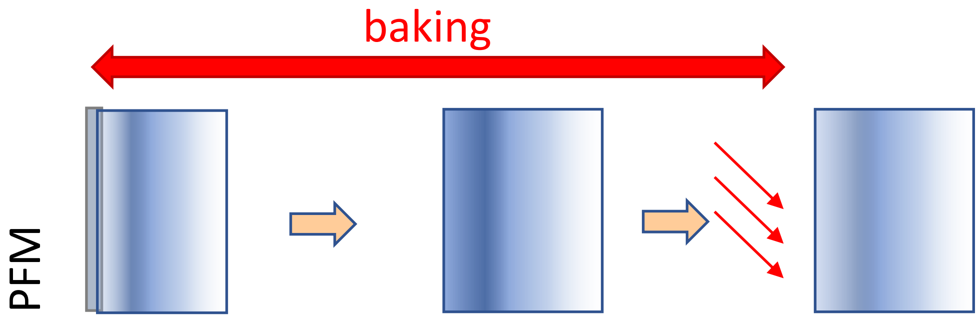
3 methods are considered

1. **Baking and heat decay**
2. **Active wall conditioning**
3. **Gas and Pressure Selections** (including small amounts of O, H2O)

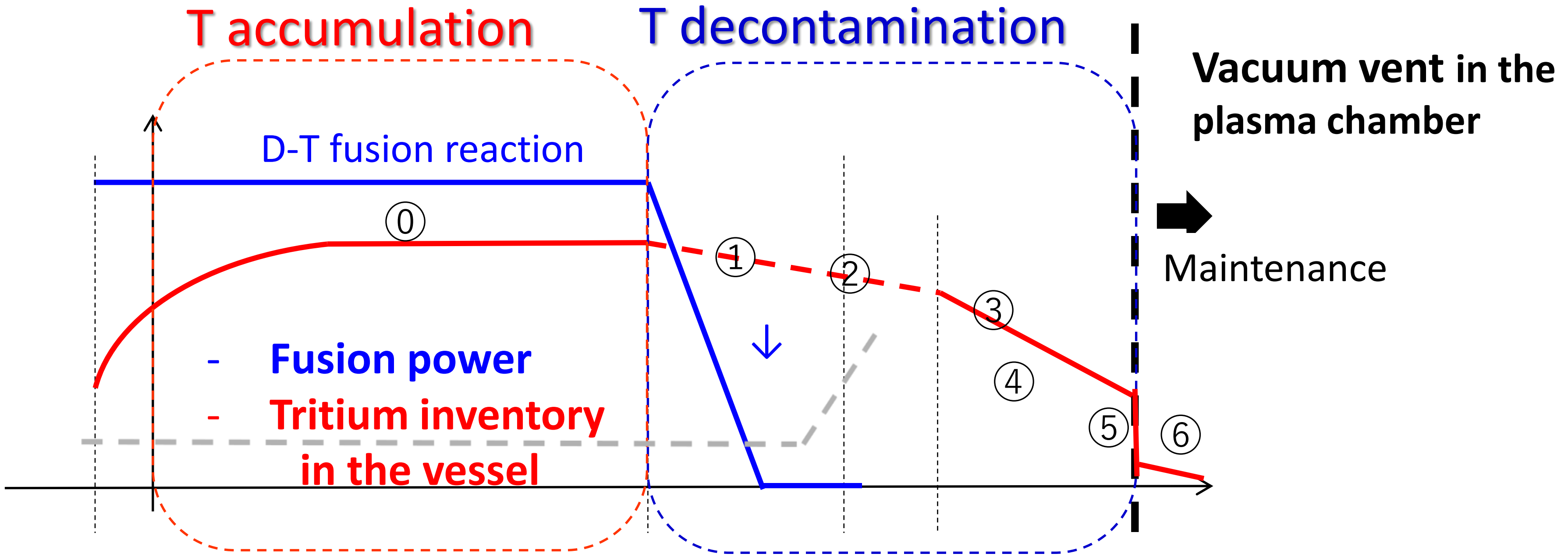
In actual operation, combine two or three methods

- Baking with Glow discharge is a standard method in Tokamak/Stellarator

- DEMO reactors require a short-term maintenance for power generation efficiency and power prices. For high-efficiency T decontamination, a combination is important.



General scenario from fusion operation to maintenance in the plasma chamber



⓪ D-T burning plasma

① Changing density to lower, for shot down. Gas puff is working

② Shot down plasma operation and stopping the gas puff (for plasma)

③ Temperature control between decay heat and coolant.

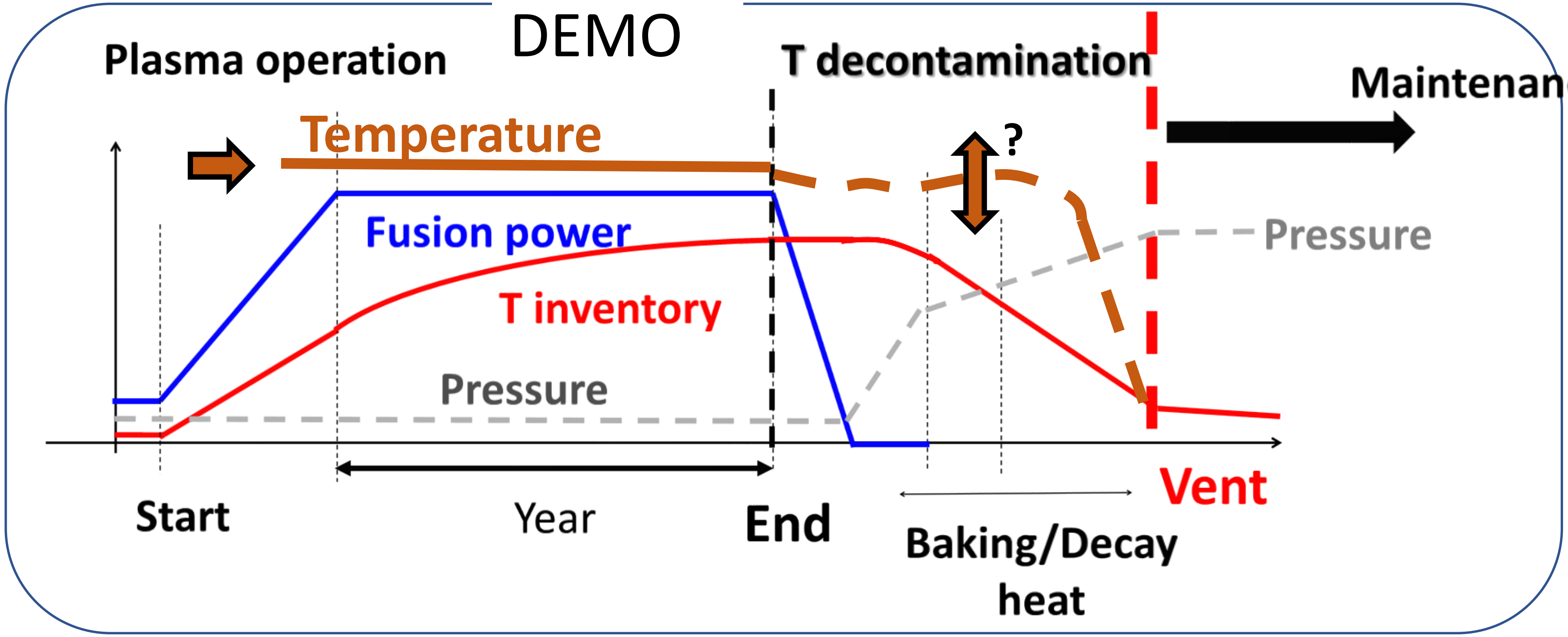
NOTE: A coolant control is required by Model Predictive Control

④ T removal under vacuum condition

⑤ Monitor of retained T

⑥ Vacuum vent (more T removal by isotope exchange of H2O)

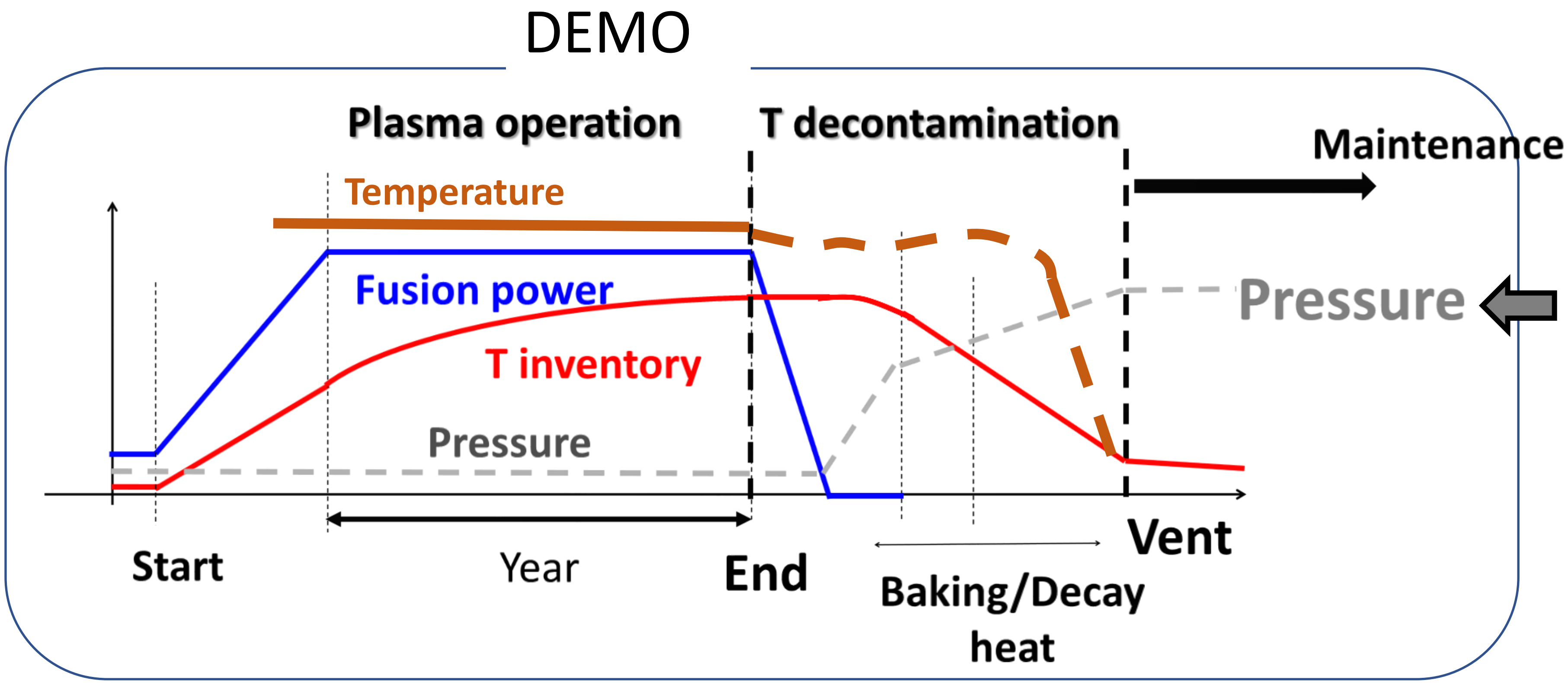
Temperature : Retained T decomissioning under vacuum condition



<Temperature>

- Temperature of blanket is controlled by cooling water/gas/material.
- Balance between decay heat and cooling system >> Material temperature
- Slow temperature changing of materials, due to **long (more than a few 100 m) and complex** cooling water tubes and systems
- In JA-DEMO, temperature in F82H (RAFM) has to keep below 350 ℃ due to pressed coolant water.

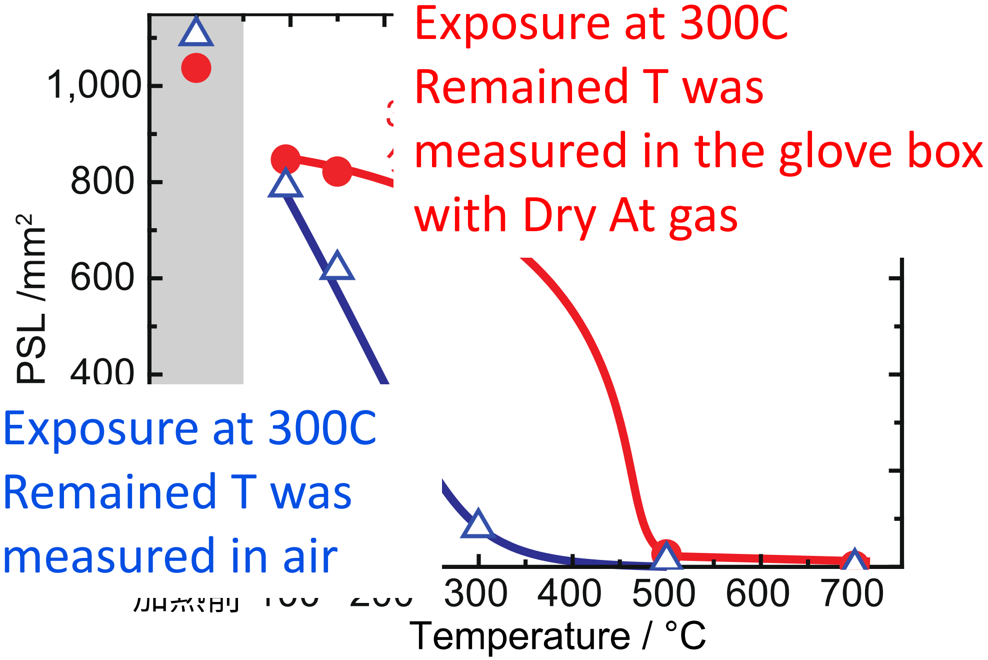
Pressure : T decomissioning under vacuum condition

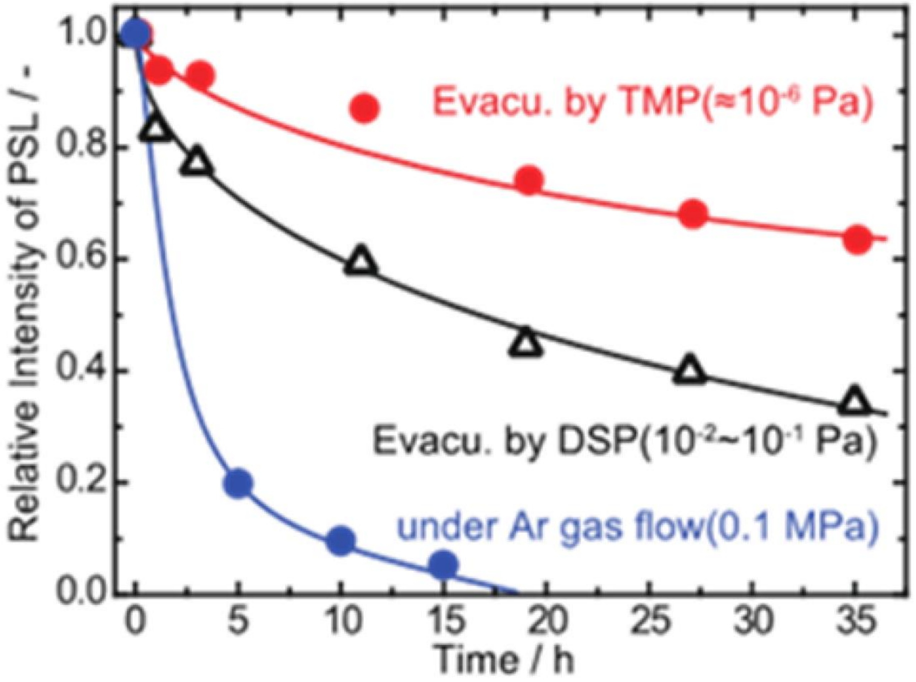


<Pressure>

- After stopping the fusion reactions, it can be selected by air pressure.
- Gas selection is also available for T removal
- In addition, wall conditioning operations

Air contamination / isotope exchange by H, H2O





<Experimental setup>
SS 316 specimen exposed to T gas (7％)
Surface T measured by T imaging plate in the glove box with Ar gas.
Removed T is released as HTO

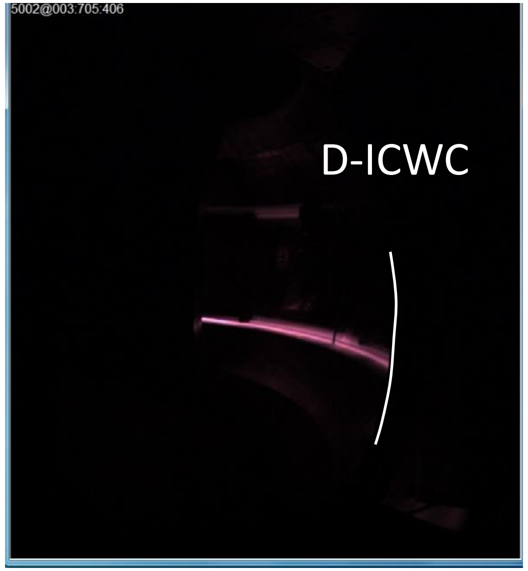
10^{-6}Pa：High vacuum（~plasma operation level）
10^{-1}Pa：Middle range (~wall conditioning level)
0.1MPa : Low vacuum (Ar gas)

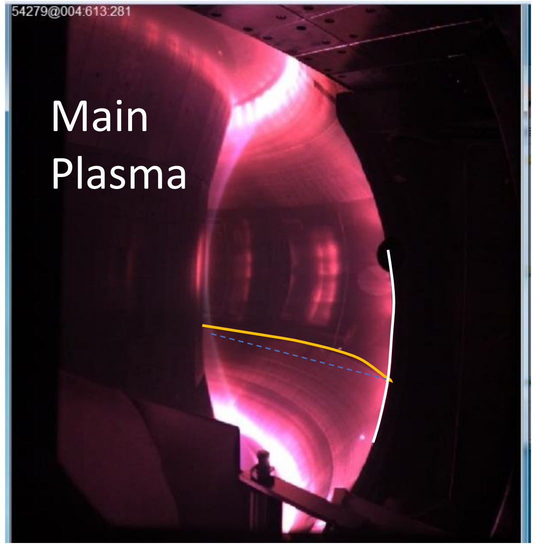
Surface tritium decontamination depending on atmospheric pressure evacuated by TMP or DSP or ambient pressure

Y. Torikai, N. Ashikawa；Report of LHD joint research program（FY 2017）

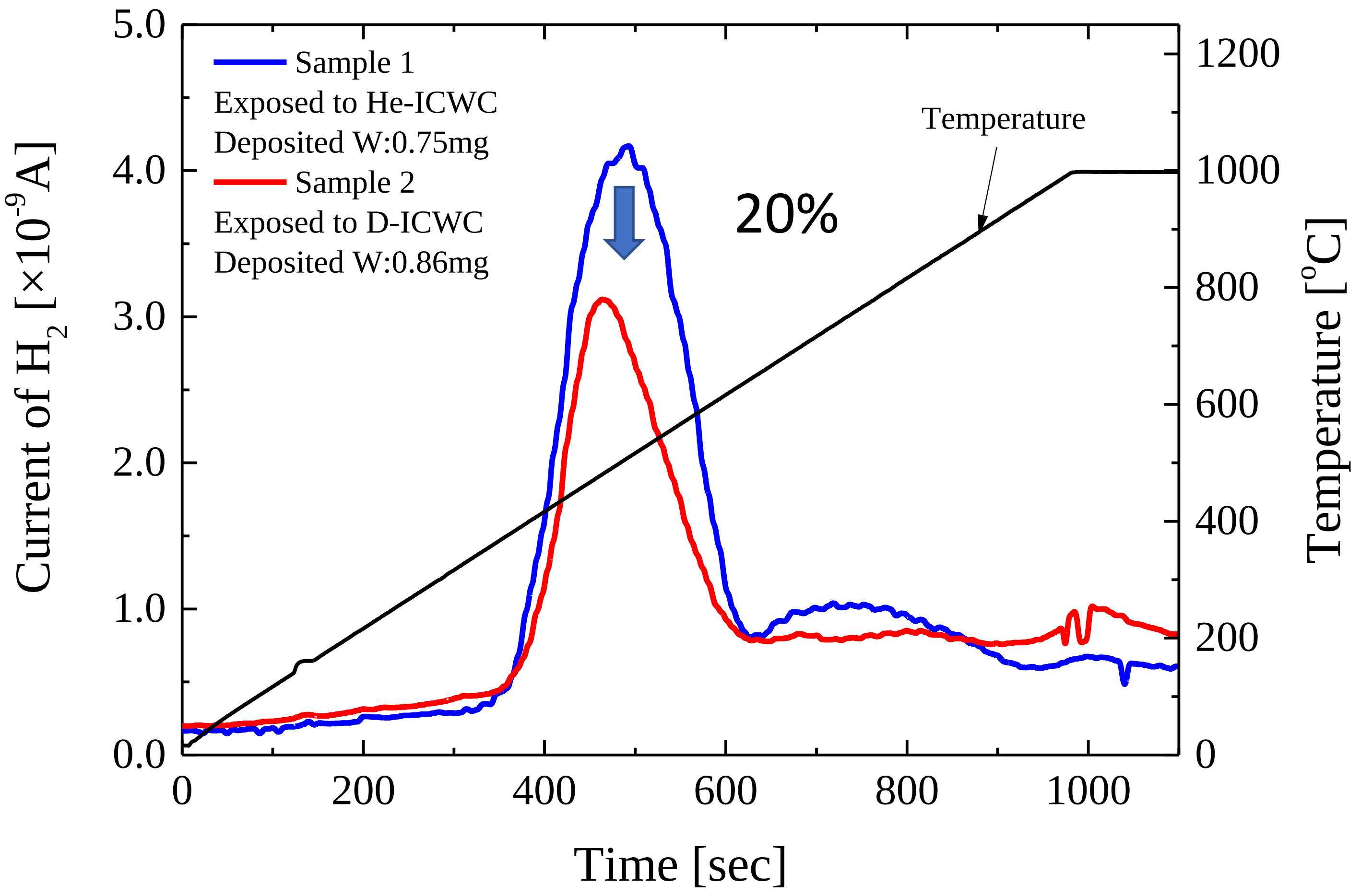
Experimental parameters in ICWC

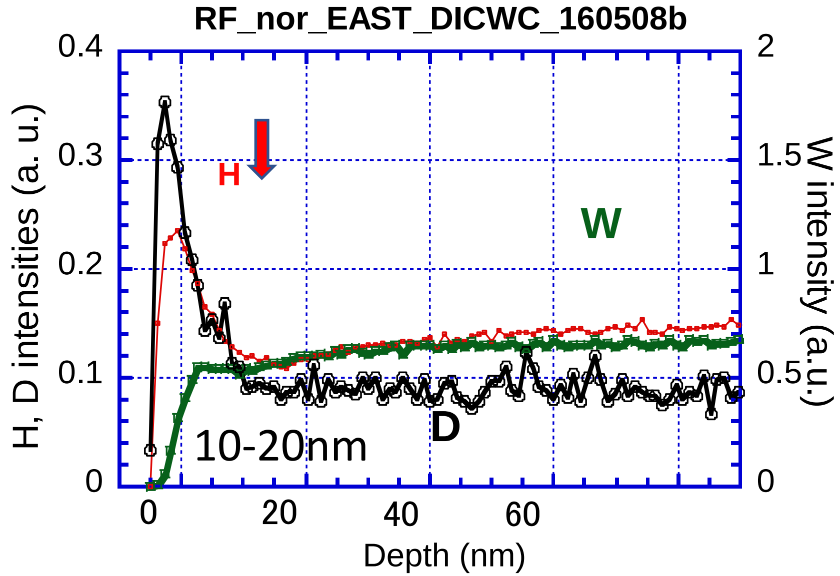
- EAST operates ICWC as the standard wall conditioning
- Working gas : D2, He, Total pressure : 5-6 x 10^{-2} Pa
- Operation time : 5 hours, (D2), 4 hours (He)
- Duty cycle : 0.5 s (on) / 3.5 s (off)
- RF input power 5 – 20 kW
- Magnetic field : Bt=1 T、 Bv=0T





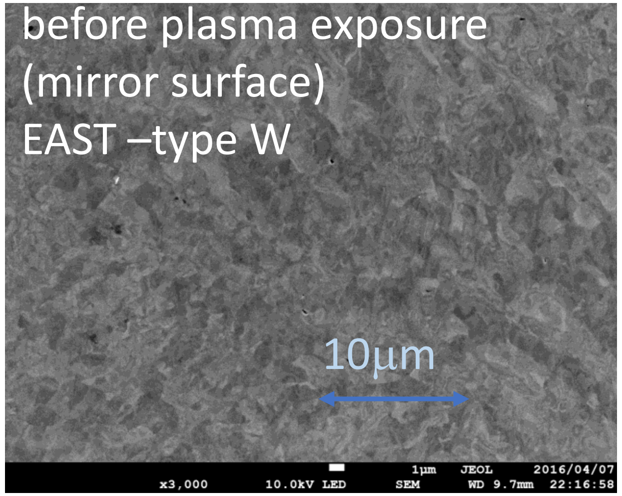
H2 retention after ICWCs on Dep.W (TDS)

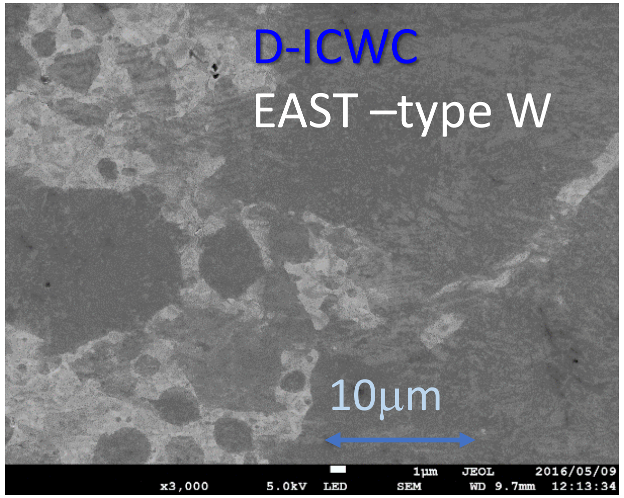




- **Initial hydrogen** was implanted by RF sputtering during productions of dep.W layer
- H2 removal rate by D-ICWC is higher than that by He-ICWC

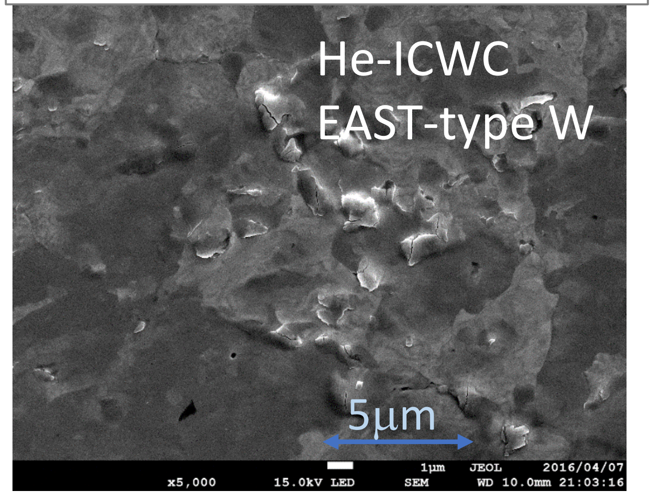
Wall conditioning : Surface morphologies in ICWC, EAST



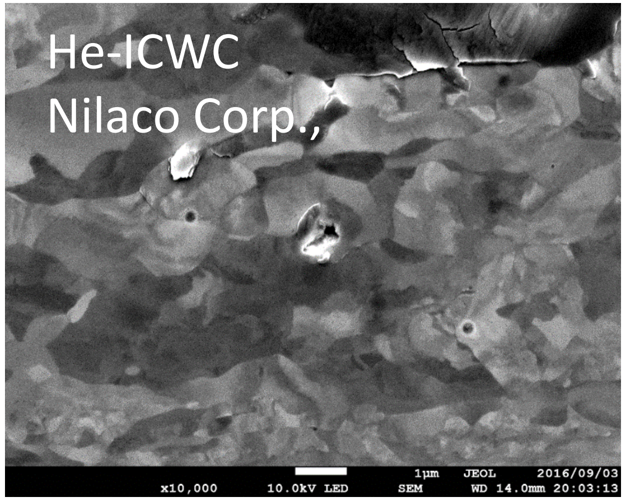


Surface on W bulk had peeling damages by He-ICWC.

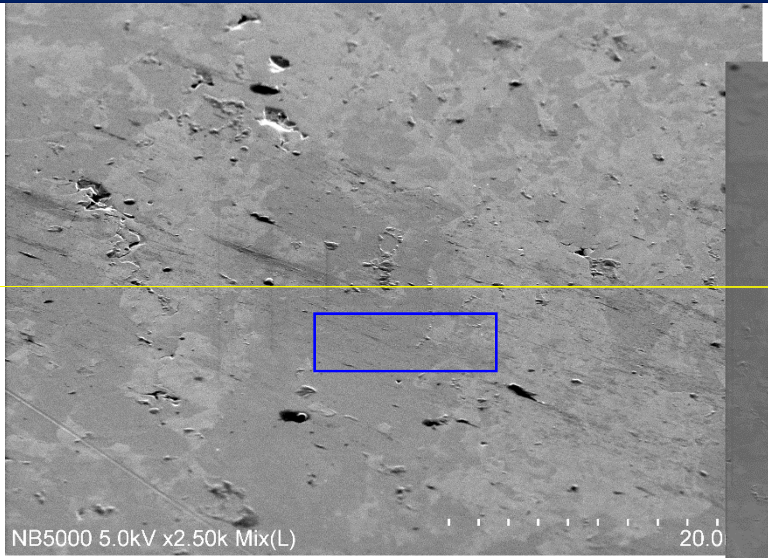
He-ICWC

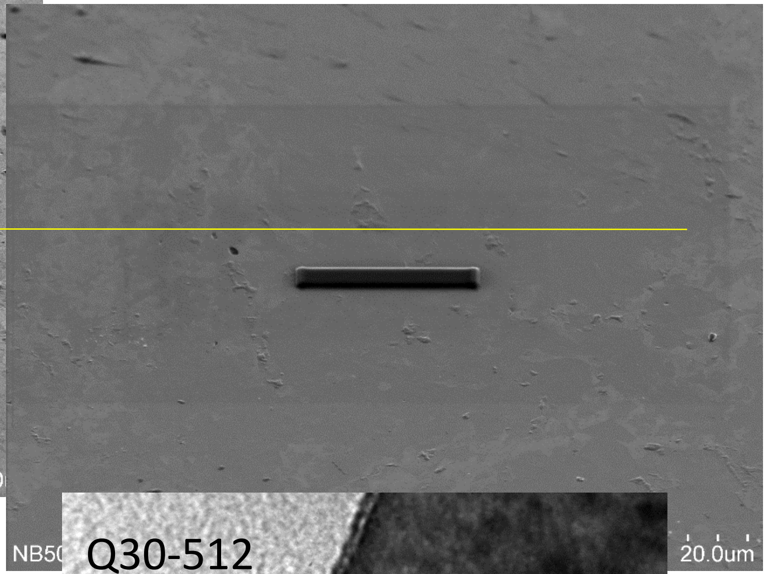


Peelings of 2-3 micron diameters are observed on surfaces

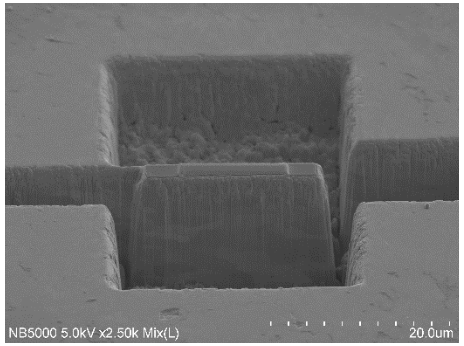


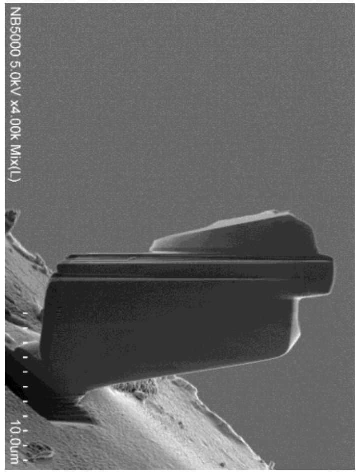
FIB Process on W after He-ICWC

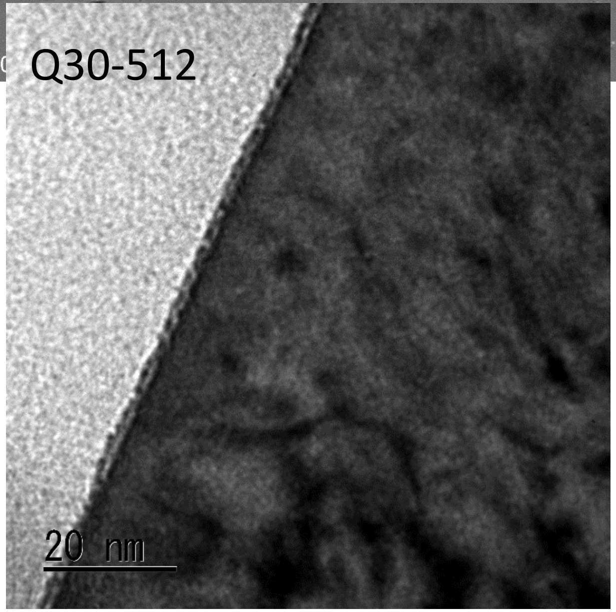




A position of thin layer is approximately into blue rectangle.







He bubbles are not observed

Surface damages by He-ICWC

LHD : SS316

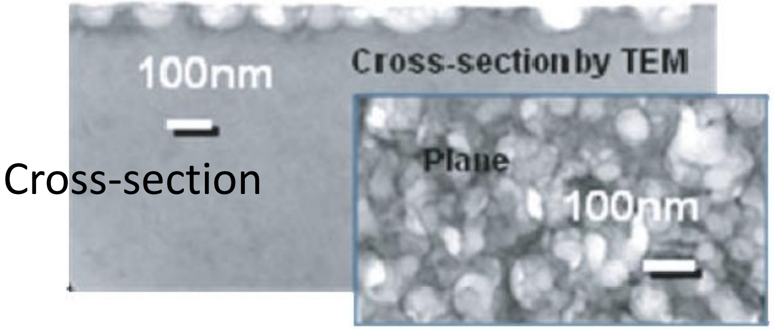
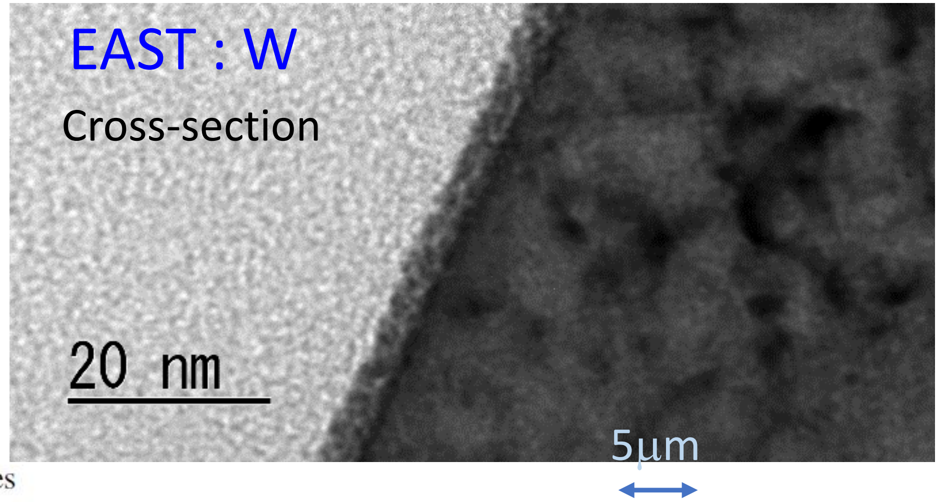


Fig. 3 Plan and cross-sectional view of TEM bright field images of thin SS sample exposed to the He ICWC.

- Material: **Stainless steel 316**
- He-ICWC : 30-80keV, 3 x 10^5 [s-1, cm-2] in LHD[1], ne=1x10^{16}/m^3 @CO_2 laser[3].
- Large He bubbles of 100 nm were observed measured by TEM.

[1]N. Ashikawa et al., PFR (2011), [3]N. Ashikawa et al., FED (2006)

EAST : W



- **Material: W bulk**
- He-ICWC : Te=15eV, ne=5x10^{14}/m^3 @fast harmonic floating probe[4]
- He bubbles were not clear measured by TEM.

[4]Y.W. Yu, Private communication

He bubble formation at Temp and fluence dependence

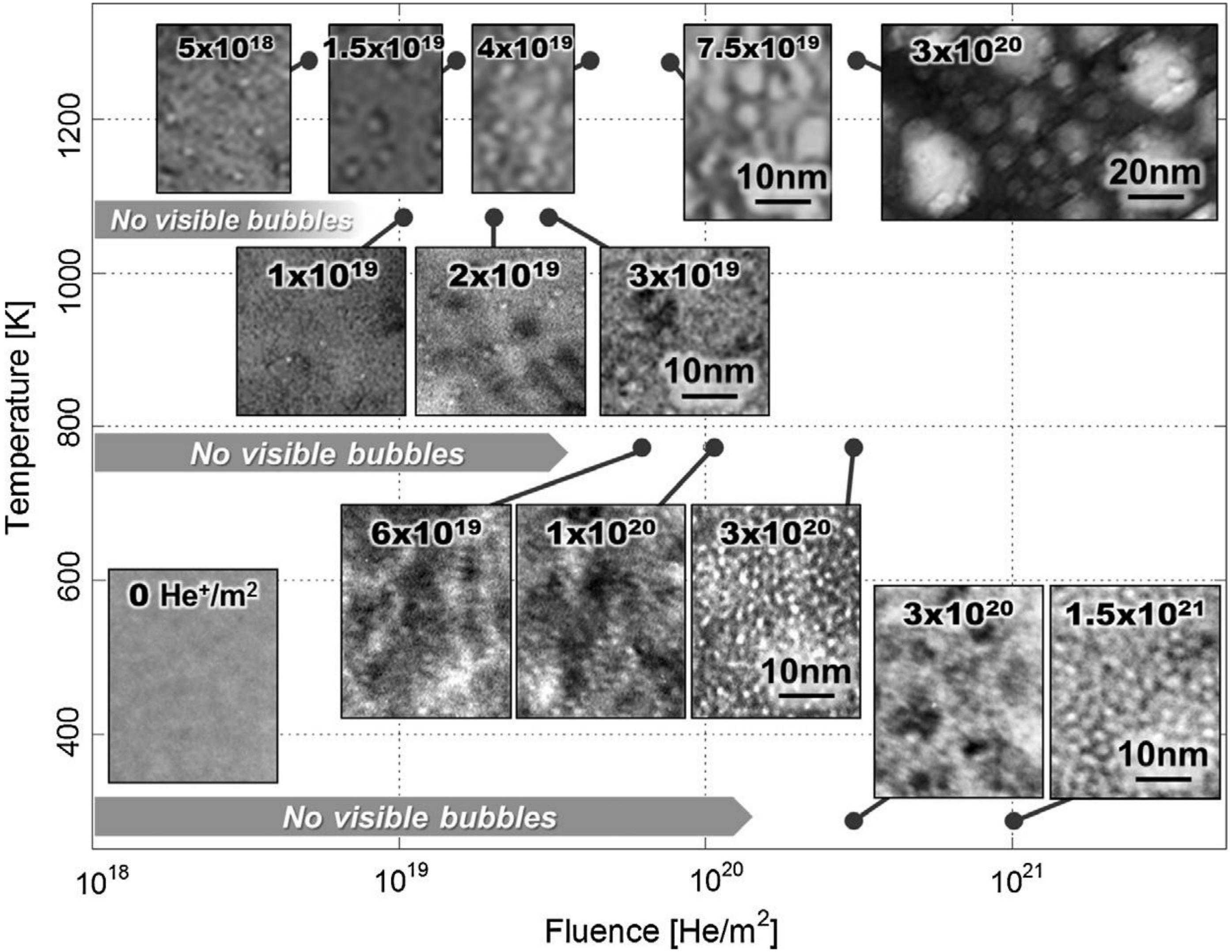


Fig. 3. The microstructural evolution of W under irradiation at constant temperatures of 293, 773, 1073, and 1273 K. M.Miyamoto (JNM(2015))

Temperature control for coolants in DEMO

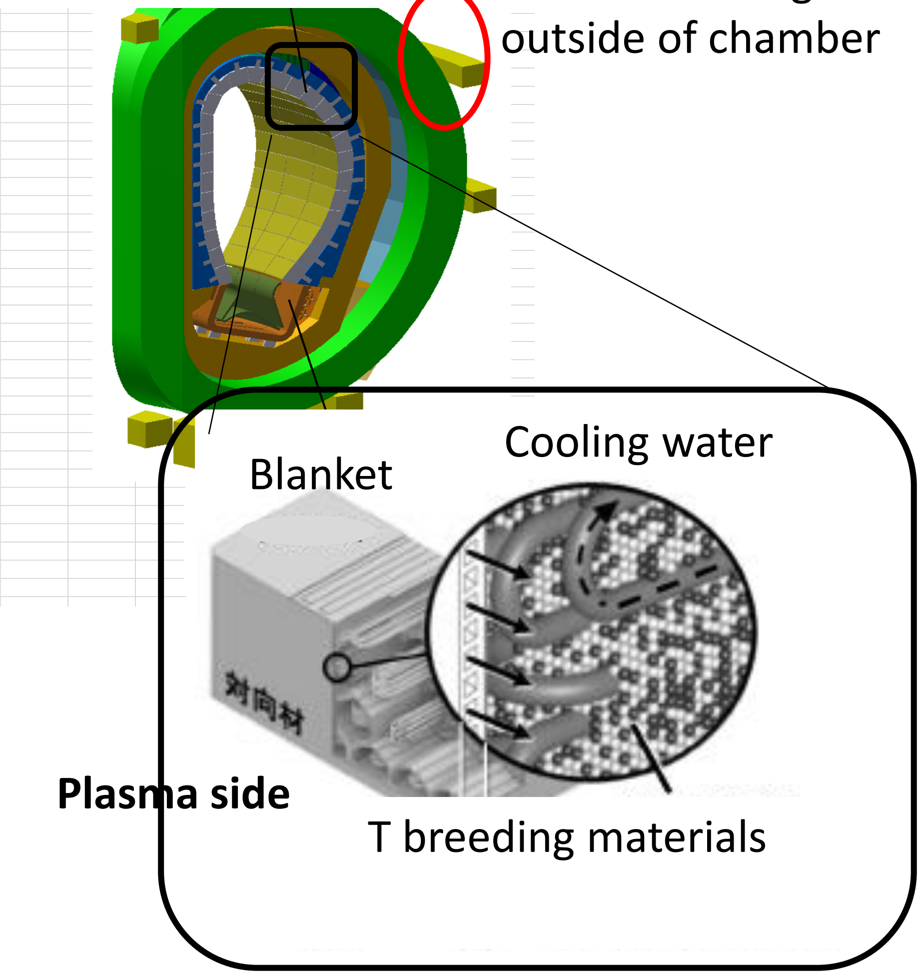
Upper limit for structural material：

550℃（Ferritic steel）

Target temperature during plasma operation：

300-350℃

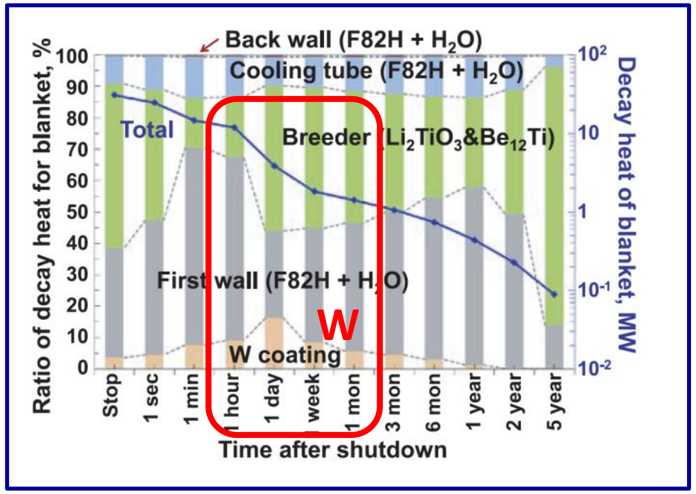
Actuator setting at outside of chamber



Decay heat

increases from 1 hour to 3 months for W

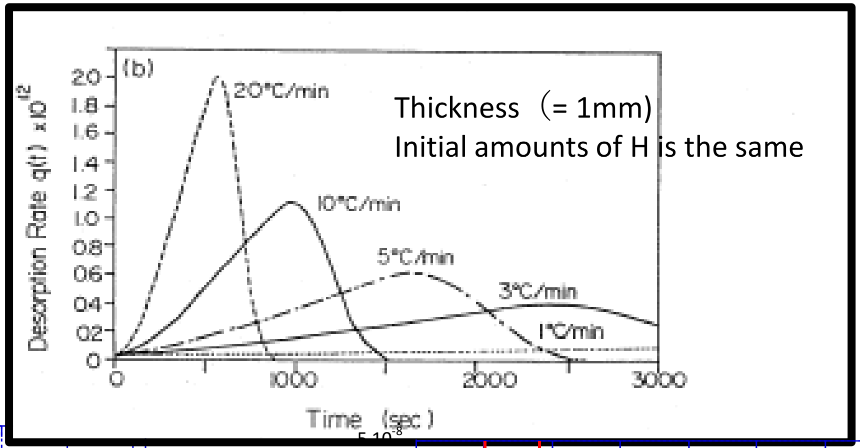
Target material：W

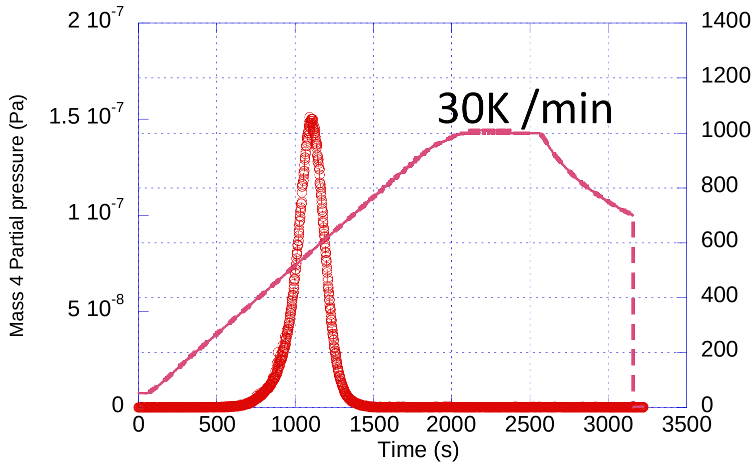


Y. Someya et al., Plasma and Fusion Research (2012).

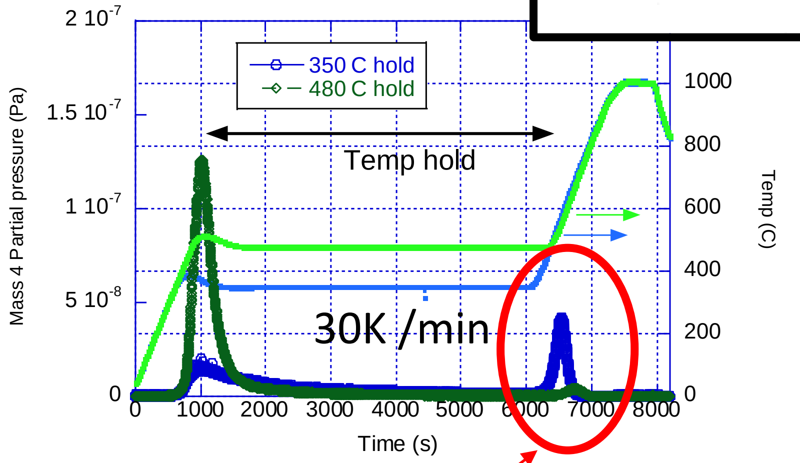
Demonstration of Temp history in DEMO condition in LAB

Material：W
D plasma exposure （80eV, 5 E25 D/m^2)
Target temperature under Plasma irr. ：200℃



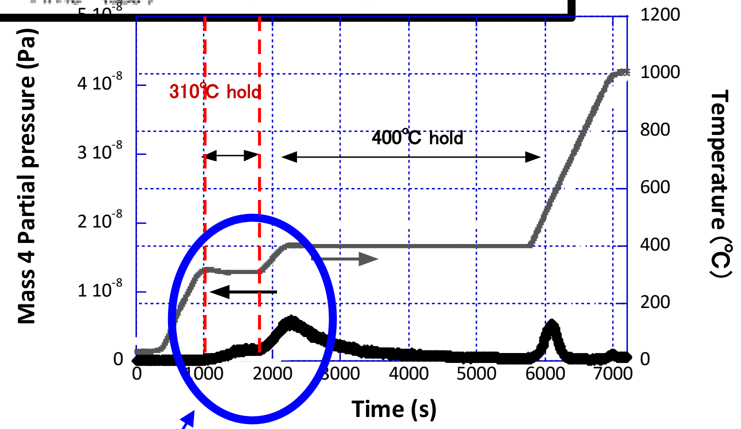


Thermal desorption



Isothermal desorption

Remained amounts after isothermal desorption



Isothermal desorption

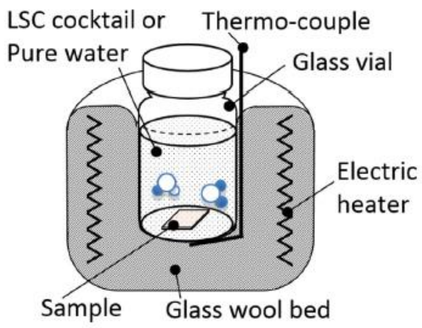
By pre-temp setting at 300 ℃, keeping low temp. gradients is planned.

- Deuterium implanted by D plasma on W can be desorption using the isothermal desorption of 350℃. But a higher temperature, such as 480 ℃ is more effective. W with Fe irr., which is demonstrated as neutron demonstration is the higher remaining of D at 350 ℃

Monitoring methods of remained T in vessel

Useful technique for tritium detection from soaked specimens in cocktail (LSC)

- Long-term released T from the specimen is observed for a safety monitoring



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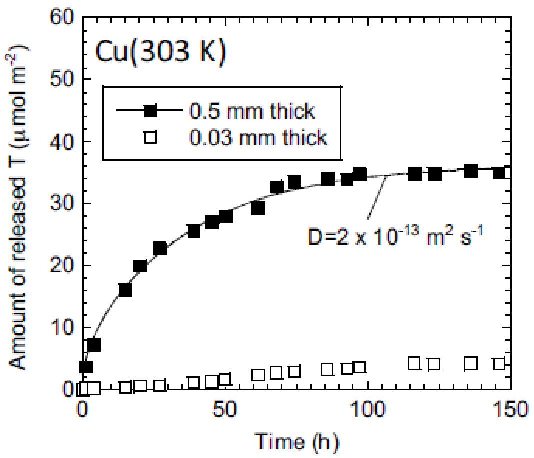
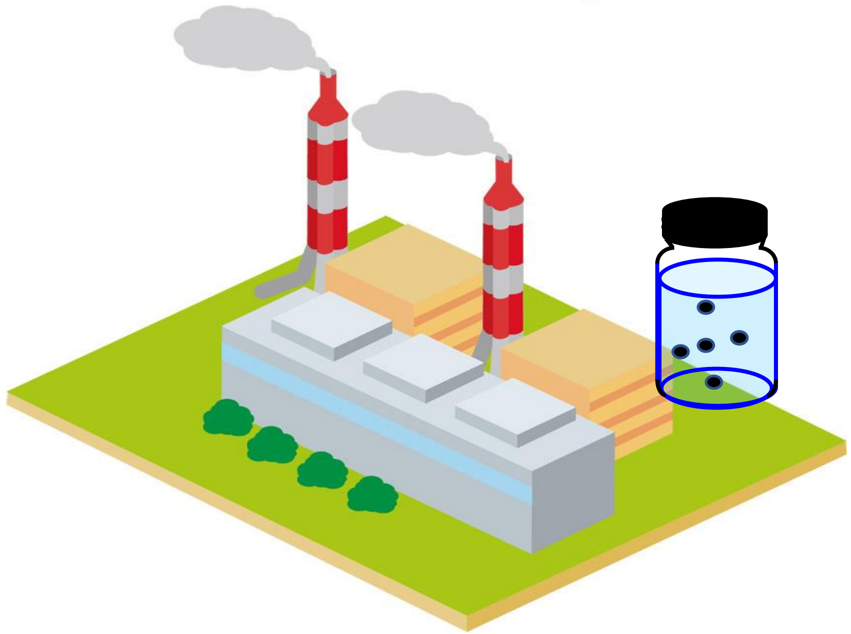


Fig. 3. Tritium (T) release curve from plate of pure Cu with different thickness of 0.5 mm and 0.03 mm at 303 K.

T. Otsuka et al., Fusion Engineering and Design 113 (2016) 227

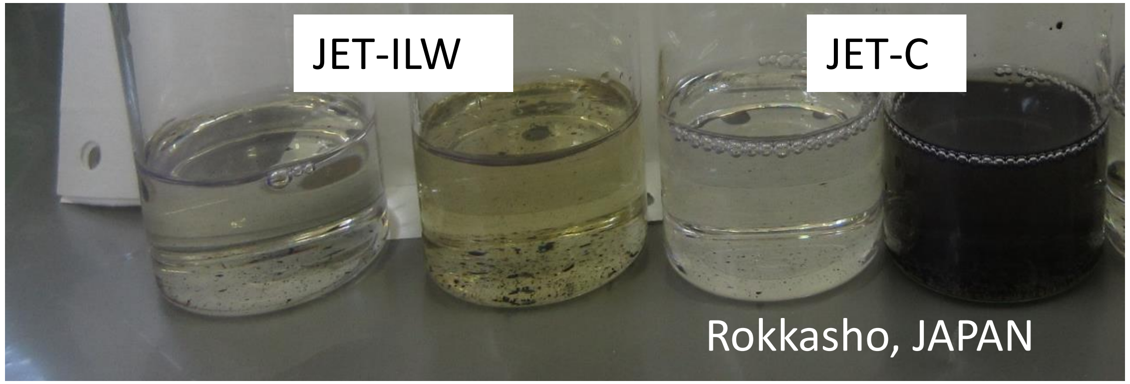


LSC analyzer

- Simple preparation is done on site, such as hot arias. Optimization of bottle and treatment machine are required

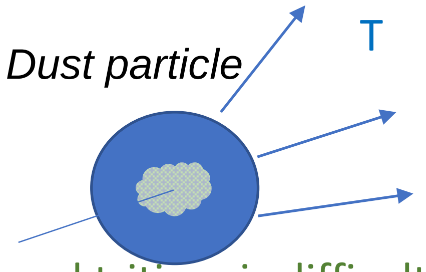
(irradiated specimens is stored in a cocktail bottle)

Tritium of soaked dust particles in cocktail measured by Liquid Scintillation Counting (LSC) method



- Quick measurement with quantification is available.
- Small amounts of dust particles less than 15mg is required to obtain without color quenching.
- In the case of **JET-C and –ILW**, dust particles are remained in the cocktails with solutions (as shown in the photo).
- Detected tritium was released **on the surface of dust particles**

In JET and ITER, the treatment of specimens should be taken by the remote handling(RH) system.
The processes of taking out specimens from vacuum vessels and set analyzers by LSC method can be operated by RH.



Detection of Internal tritium is difficult

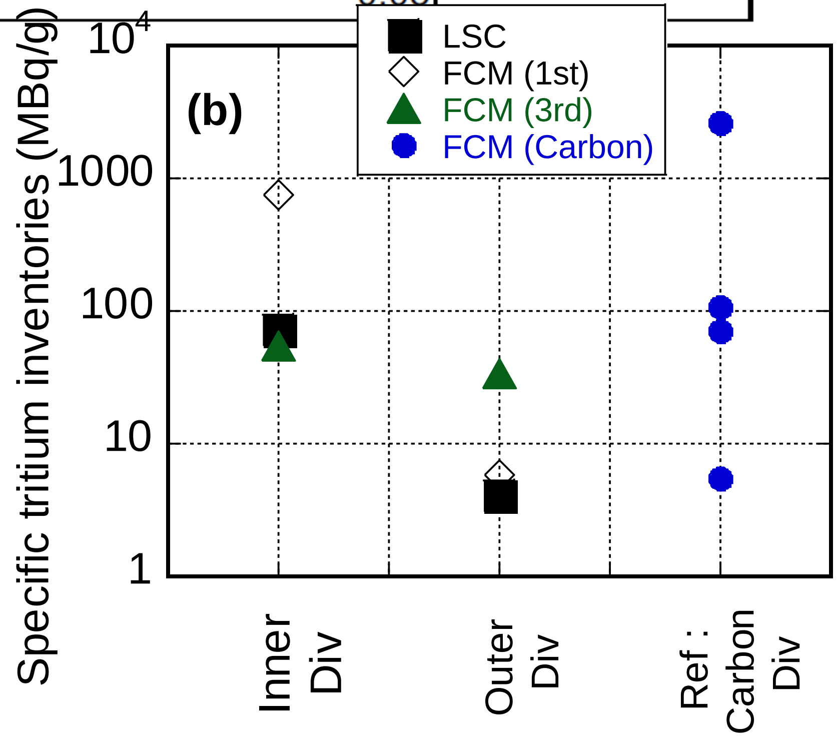
T amounts by FCM vs LSC

divertor

JET Final report (2020)

Campaign	Locations	Shipped amounts to QST (g)	Total amounts (g)
JET-C	Inner divertor tiles	6.36	245
	Carrier ribs	3	
	Outer divertor tiles, and base carrier	4.61	
	Inner and Outer louvres	6.03	
JET-ILW1	Inner divertor tiles	0.14	1
	Outer divertor tiles	0.01	
JET-ILW3	Inner divertor tiles	0.14	1
	Outer divertor tiles	0.05	

The full combustion method (FCM), as data of accurate T amounts, and LSC data are compared. A good agreement for order estimation is obtained

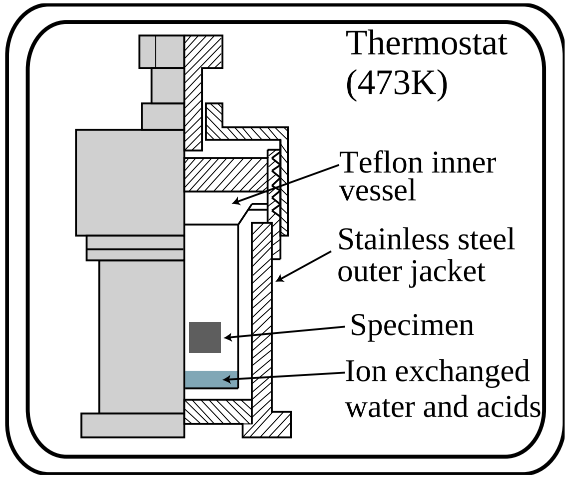


N. Ashikawa, Y. Torikai et al., NME (2020)

Measurement of tritium in tritium contaminated materials

❖ Autoclave or acid hydrolysis method

Tritium contaminated materials, such metal, alloy and dust, are introduced in an autoclave vessel with small amount of water or acid solutions. Specimens are heated at 473K in a thermostat. Tritium in specimens are moved to water or tritium contaminated materials are dissolved into acid together with tritium. Tritium in liquids are measured by liquid scintillation counter.
** This method has proposed to measure tritium in JT-60 vacuum vessel and LHD specimen to check the clearance level of tritium in the vessel.

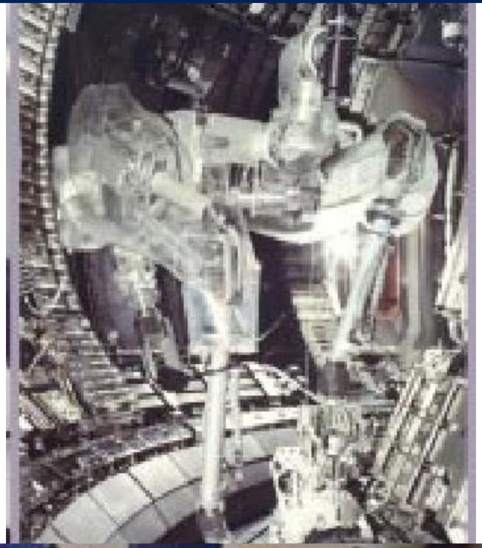


The vessel is designed for a maximum pressure of 15 MPa and maximum temperature of 500 K.

RACE in UKARA

Taking out specimens

HOT CELL



Analyzers for hot materials in the hot lab

・Target specimens (bulk or dust) set in the cocktail bottle(LSC) or Autoclave **in the tokamak hall**

・Transport to hot LAB

・Analyses is done **in the hot LAB.**

Conclusion

- ✓ In JA-DEMO team, T decommissioning research works are required for the safe working conditions for Machines at the maintenance and the high-purity tritium recovery for direct cycle pass in a closed plasma chamber.

- ✓ Based on the three T-removal methods, DEMO reactors require short-term maintenance for power generation efficiency and power prices.

- ✓ For high-efficiency T decontamination, a combination is important. The isothermal desorption method is proposed to demonstrate tritium decontamination under vacuum conditions by heat decay in DEMO.

- ✓ For monitoring methods of retained T using materials under the vacuum conditions, two methods, LSC and Autoclave, are shown.