13th PFMC Workshop 2011. 5.12

In-situ measurement of hydrogen isotope retention using high heat flux plasma generator with ion beam analysis

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Outline of this talk

- Background
- Motivation

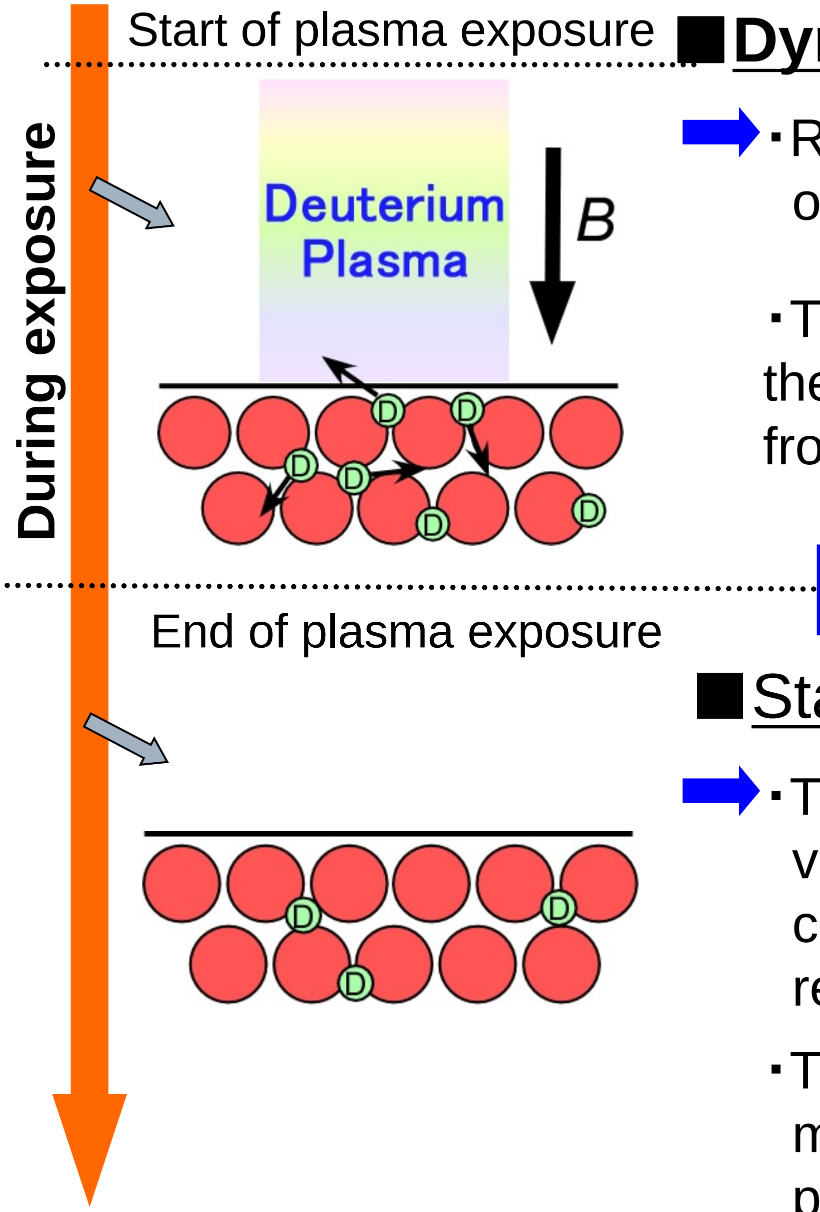
  Dynamic retention and related issues

  Previous studies and technical issues
- Experimental

  Newly developed experimental device: PS-DIBA
- Experimental Results

  In-situ measurement by using PS-DIBA
- Summary

Static and dynamic retention



■Dynamic Retention

➡ ・Retention within the material by the effect of the hydrogen flux.

・The hydrogen atoms have the mobility in the materials, so that they can be released from PFC after plasma termination.

Dynamic Retention≠Static Retention

■Static Retention

➡ ・The hydrogen atoms are trapped in atomic vacancies, voids, dislocation loops and crystal grain boundary, and sometimes retained as hydrogenated products.

・Those hydrogen atoms are trapped in the material and not released even after the plasma termination.

Background

- The dynamic retention leads to several effects, such as hydrogen recycling and net erosion of plasma-facing surfaces.

Important issues related to dynamic retention

- Optimization of fueling
- Flux dependence of chemical sputtering

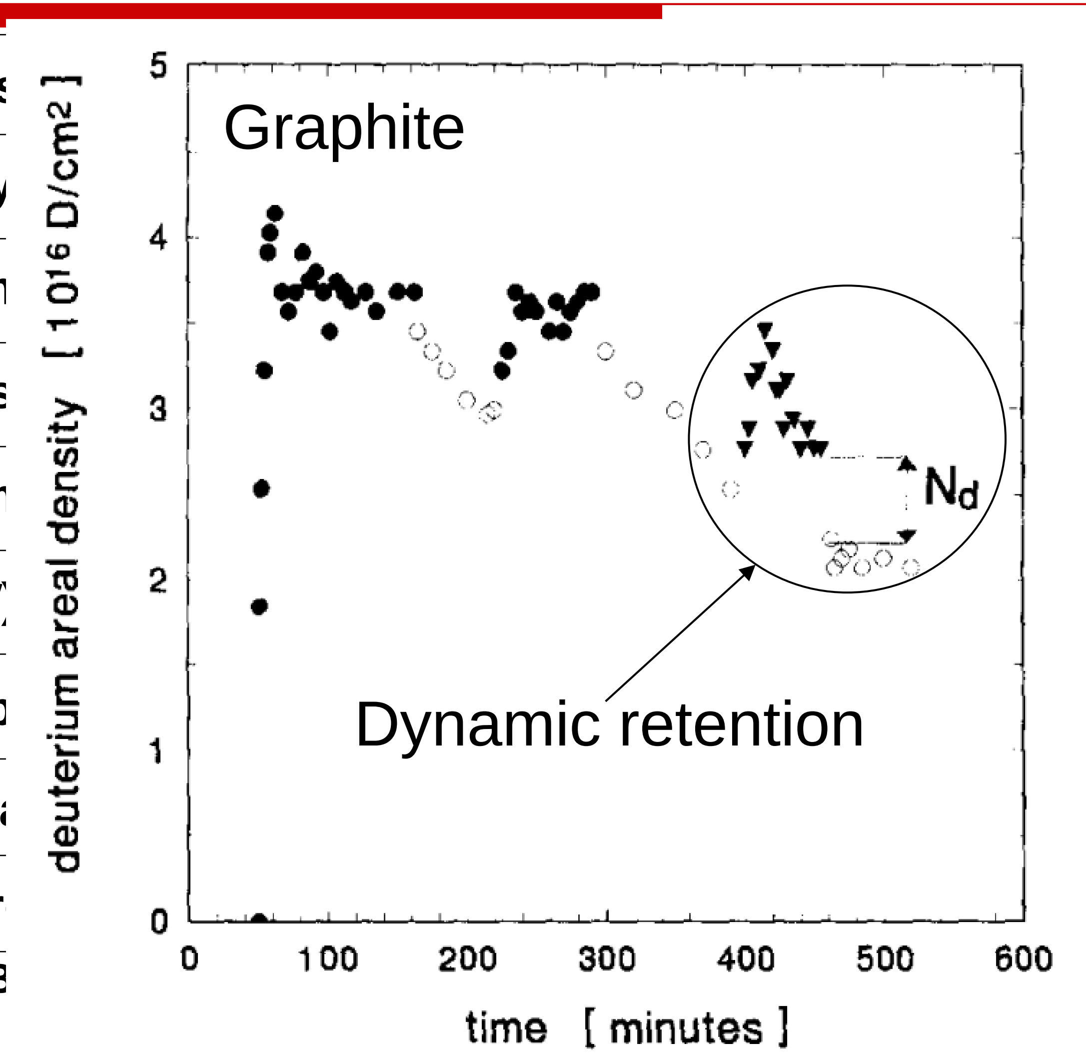
In-situ measurement of hydrogen retention during plasma exposure is necessary.

- However, these phenomena remain relatively poorly understood, primarily due to the lack of proper plasma-surface analyses except for a few devices.

Previous studies for in-situ measurement

Plasma s	RF helicon[3]
Ion energy	10-500
Electron tem	1-10
Electron dens	<10^{17}-10^{18}
Sample tem	300-800
Ion flux(Γ_i	10^{20}-10^{22}
Samp	molybdenum
Ion beam a	NRA,RBS,ERD
Dynamic r	25% up

[1] E … Wright JNM2007



For next step PWI studies

- **Relevant to divertor condition ➡ n_e~10^{19-20} m^{-3} and T_e<10 eV**
- **ITER divertor materials ➡ tungsten (W)**

Purpose of this study

We have developed a new device **Plasma Surface Dynamics with Ion Beam Analysis** (**PS-DIBA**) to investigate the dynamic interaction property using Nuclear Reaction Analysis (NRA) and Rutherford Back-Scattering (RBS).

◇Compact and powerful plasma source → DC discharge using lanthanum hexaboride (LaB_6)

◇Samples → ･ITER R&D tungsten ･isotropic graphite (IG-110U)

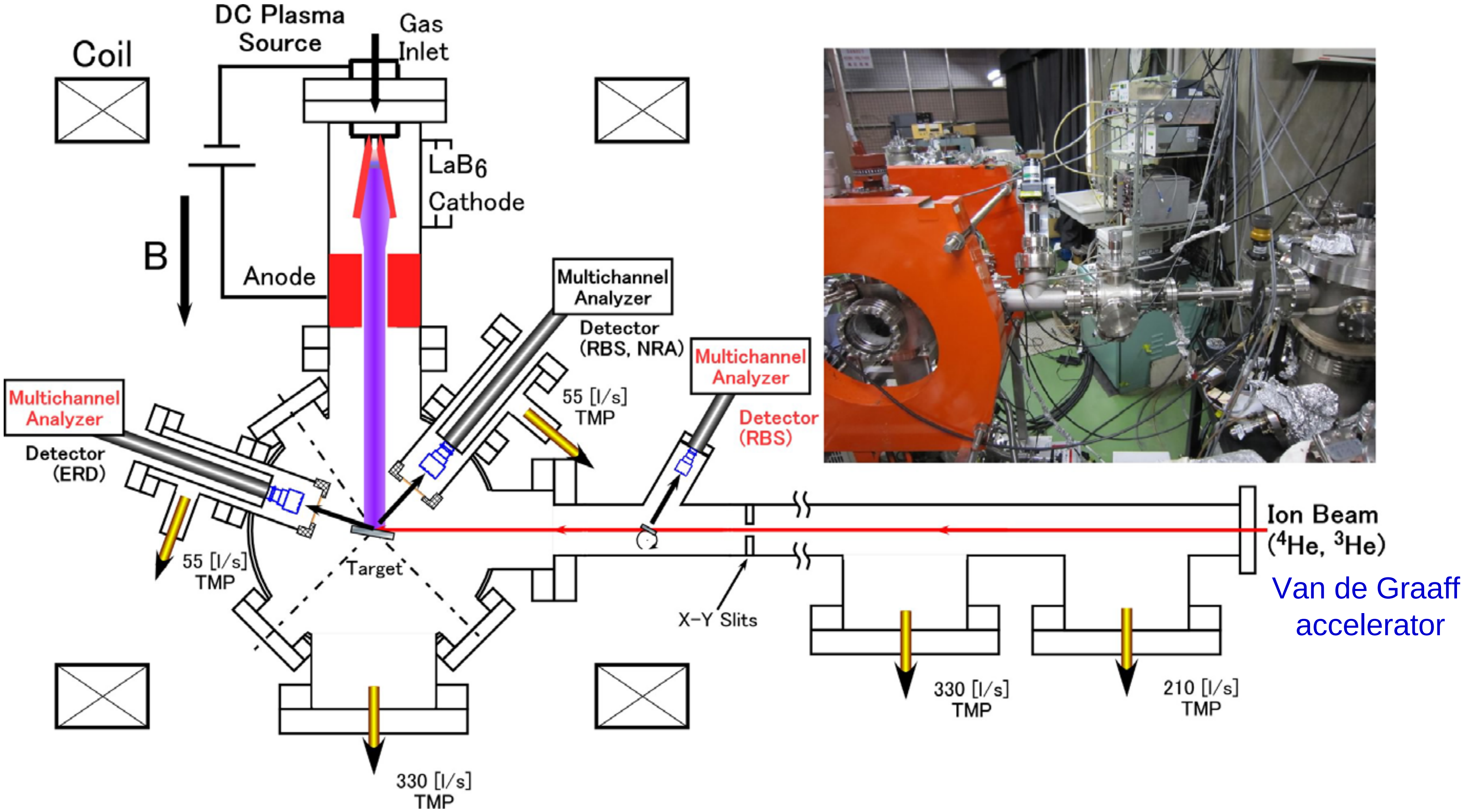
In this presentation

◆Novel compact DC plasma source

◆Plasma-compatible ion beam assemblies

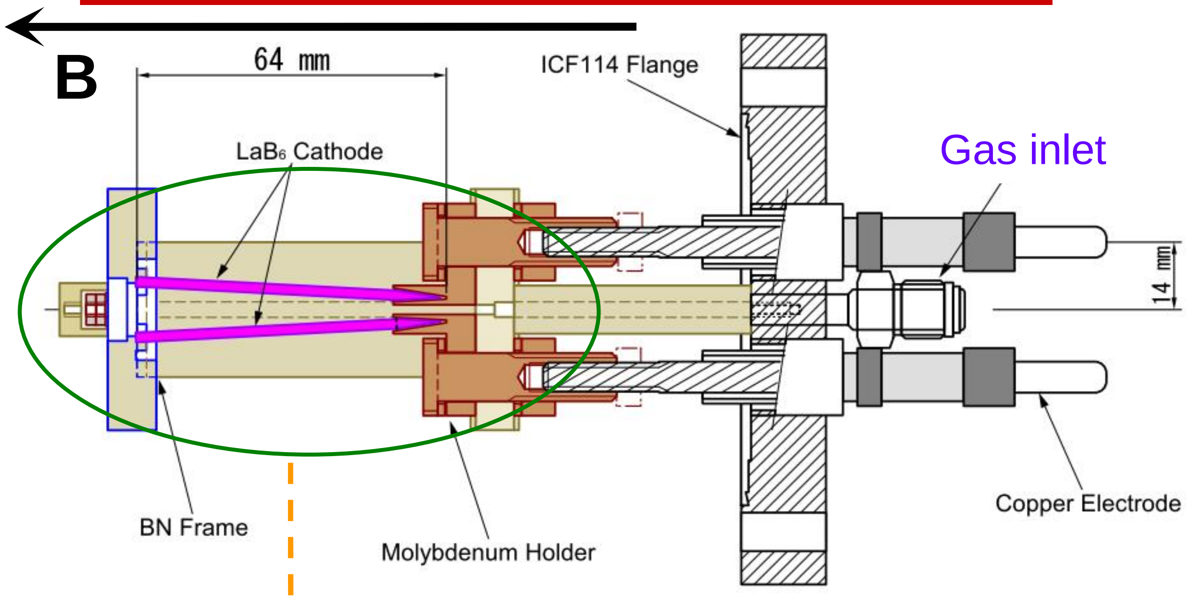
◆In-situ measurement of deuterium retention using PS-DIBA

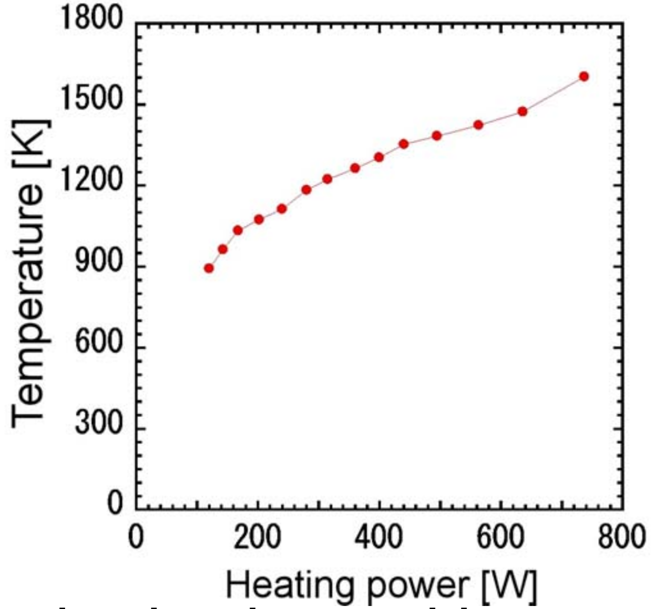
Plasma Surface Dynamics with Ion Beam Analysis (PS-DIBA)

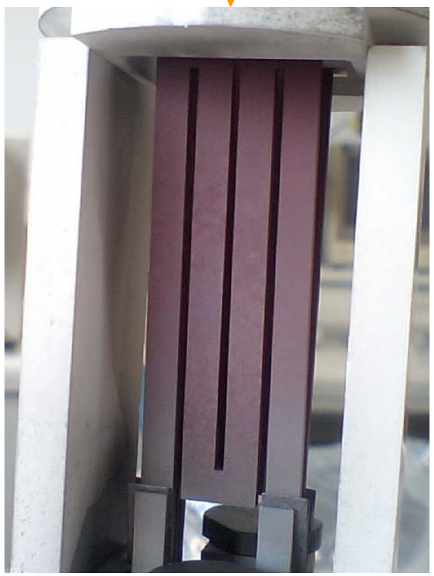


i) Compact and powerful plasma source
ii) Differential pumping to protect detectors and Van de Graaff accelerator
iii) Ion beam monitoring system during plasma exposure

Novel compact and powerful dc plasma source

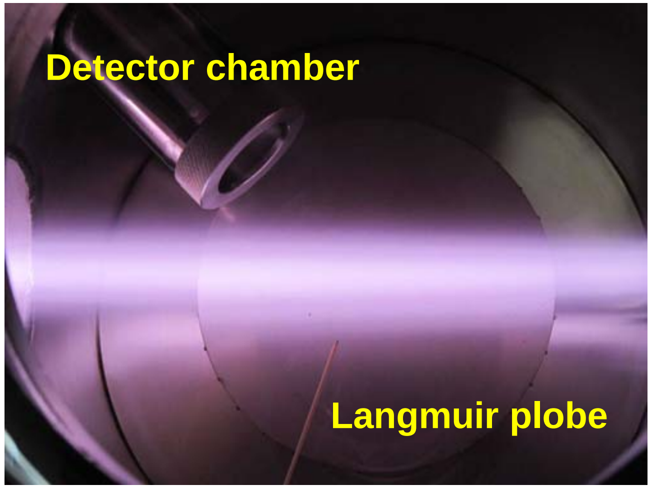






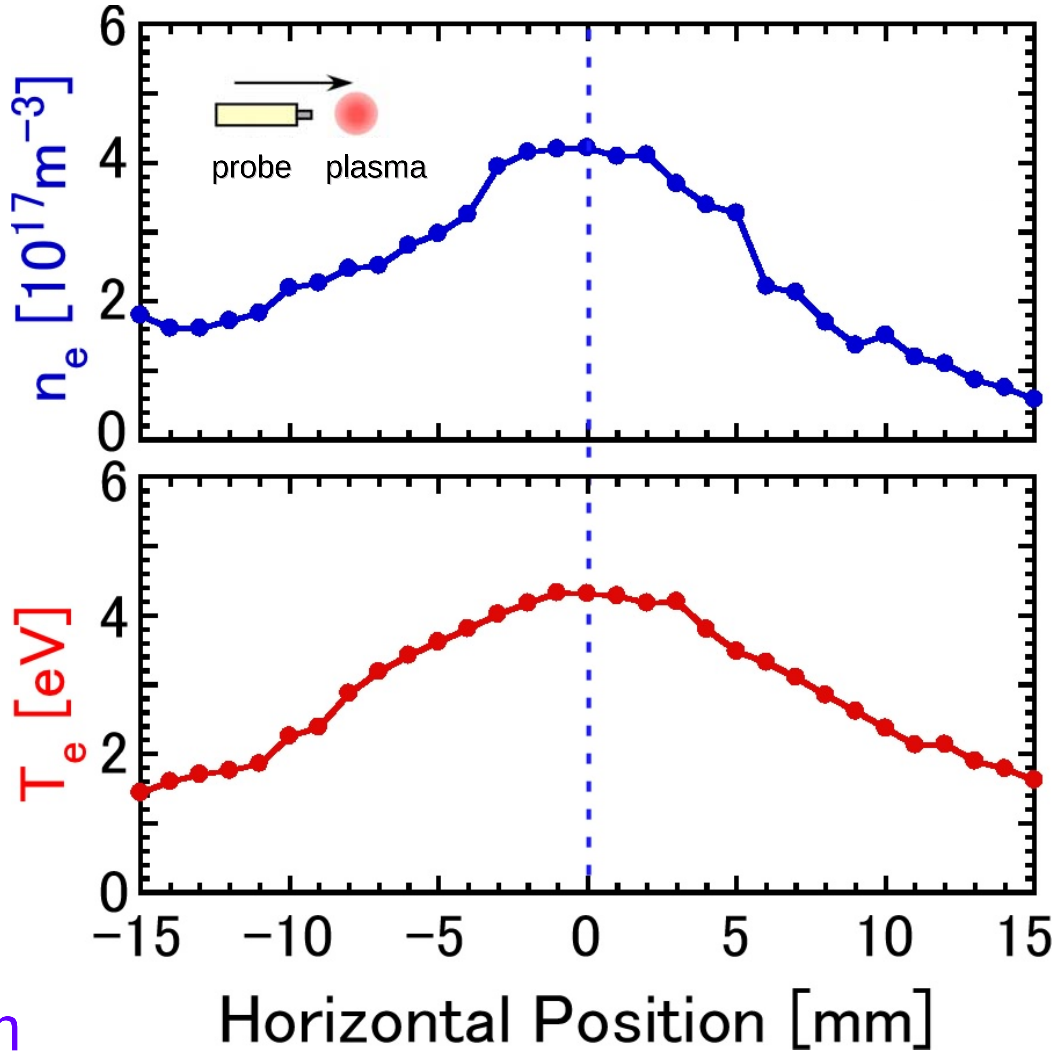
- Zigzag-shaped LaB_6 cathodes heated by direct Joule heating.
  - ➡ Efficient heating (1600 K at 730 W)
- Magnetic field is inclined to two cathode surfaces at a shallow angle.
  - ➡ Large effective cathode area
- Discharge gases are introduced between the two cathodes.
  - ➡ Efficient usage of neutral gas for discharge

Radial profiles of the electron density n_e and temperature T_e

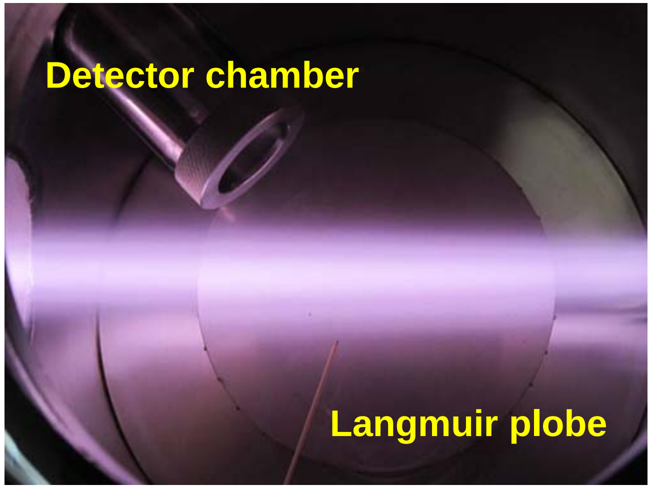


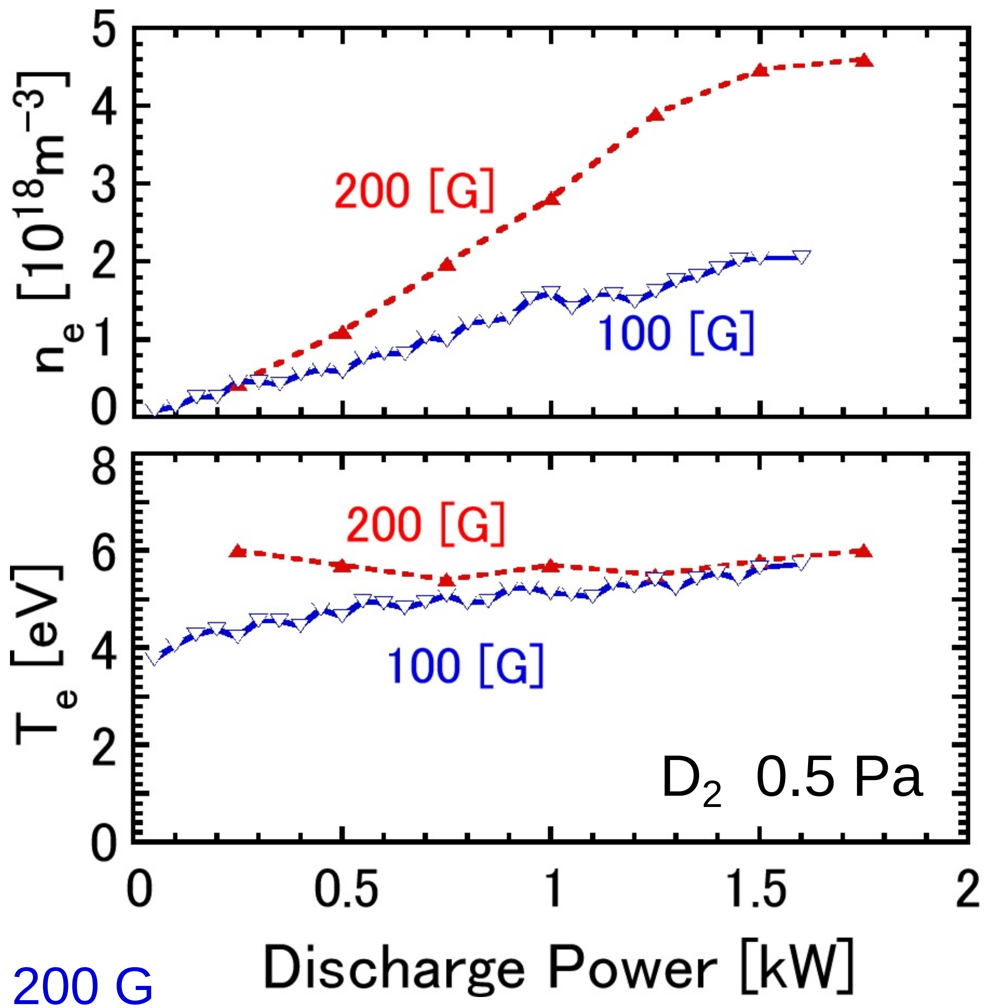
Discharge power	250 [W]
Gas	D_2
B-field	100 [G]
Pressure	0.5 [Pa]

Plasma diameter ~ 20 mm



Discharge power dependences of the electron density n_e and temperature T_e at a center of plasma column



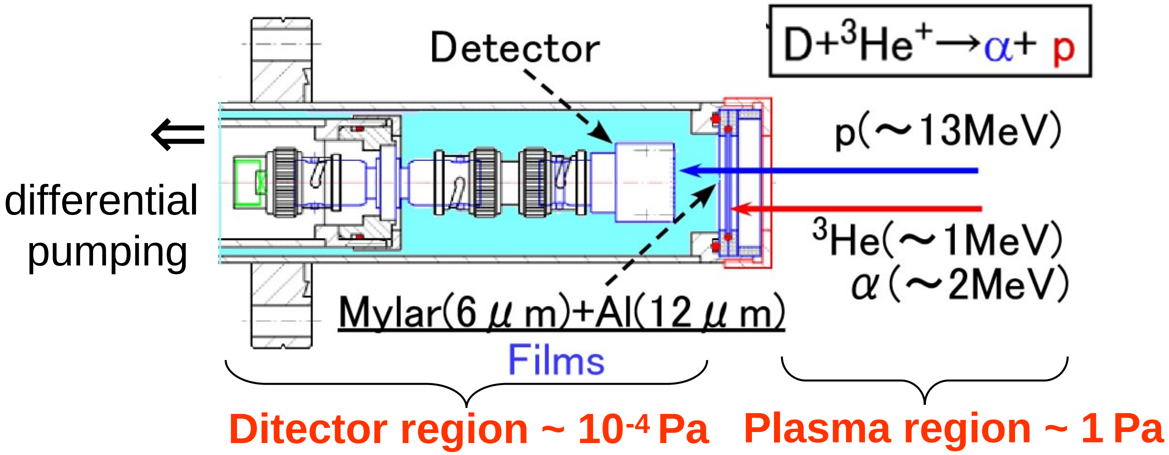


- Density is proportional to the discharge power.
- Electron temp. is almost constant around 5 eV.
- Higher *B*-field leads to higher density.

  ~ 4.5×10^{18} m^{-3} at 1.8 kW and 200 G

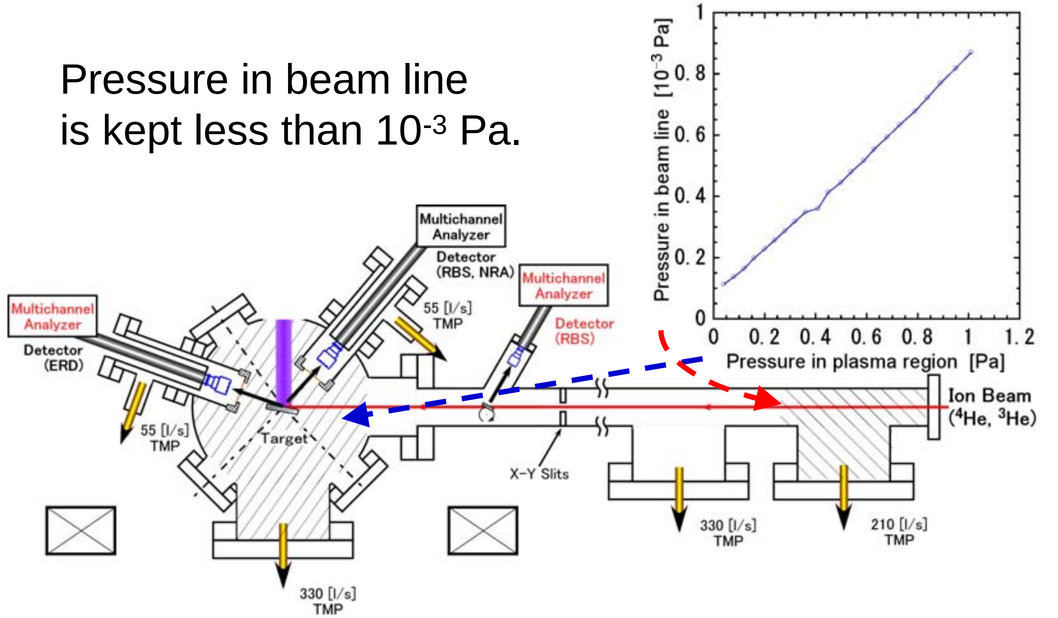
Capability of magnetic coils ~ 1.4 kG ➡ $>10^{19}$ m^{-3}

Differential pumping to protect detectors and Van de Graaff

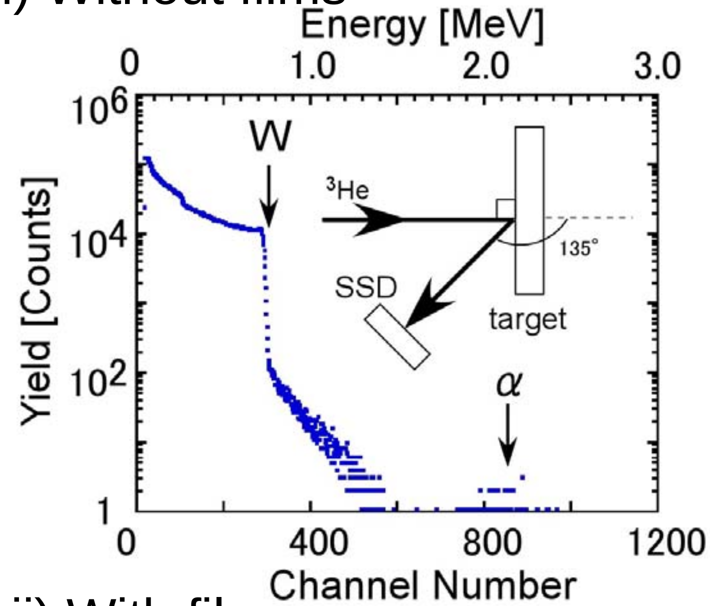


- Ditector region is sealed by mylar film to maintain high vacuum state and Al film is used to repel plasma photons.
- Protons in NRA can be detected through the films.

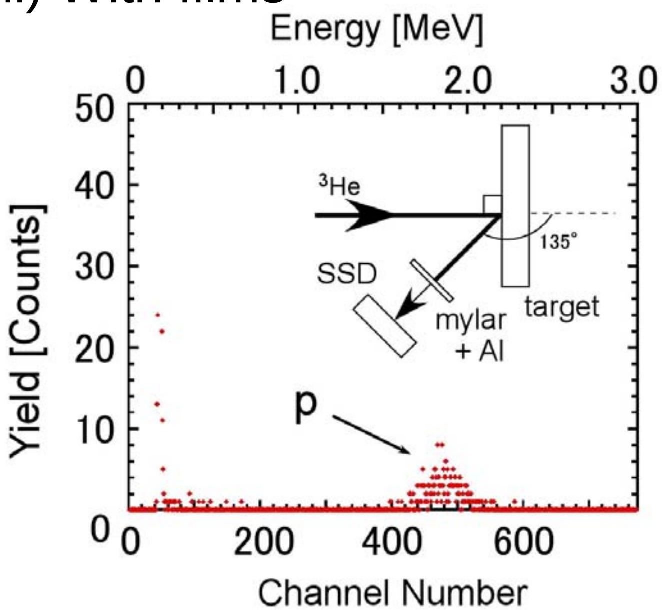
Pressure in beam line is kept less than 10^{-3} Pa.



i) Without films



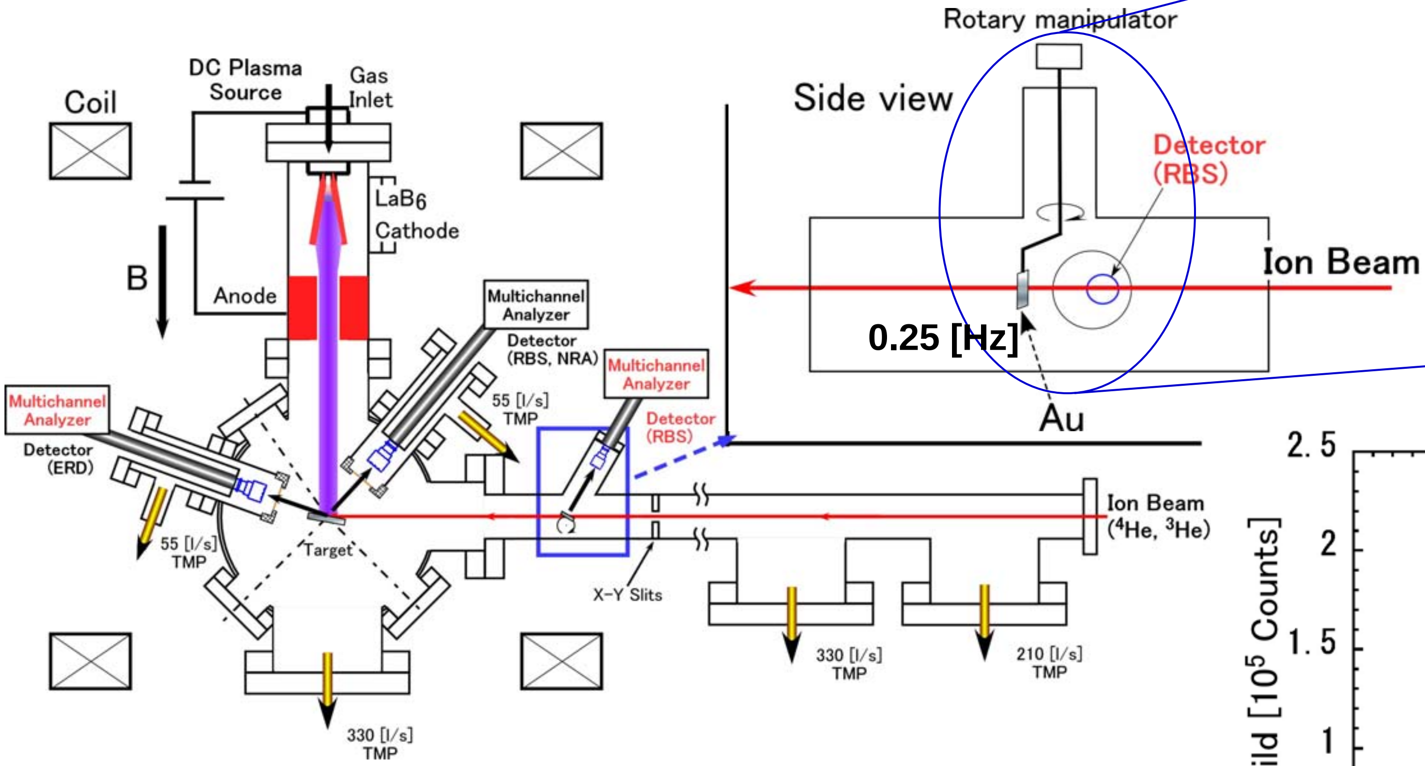
ii) With films



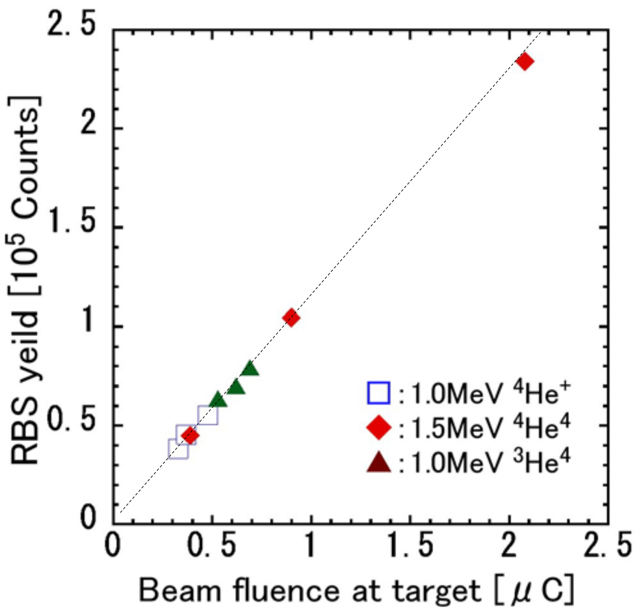
Ion beam monitoring system during plasma exposure

It is impossible to measure the ion beam current at samples during plasma exposure.

To monitor the beam current, a rotating gold plate (Au) was installed in the beam line as a beam chopper.



- Beam fluence [μC] at target is proportional to monitor yield [Counts] by Au plate.
- Capable of measuring ion beam fluence during plasma irradiation



Time dependence of deuterium retention of isotropic graphite

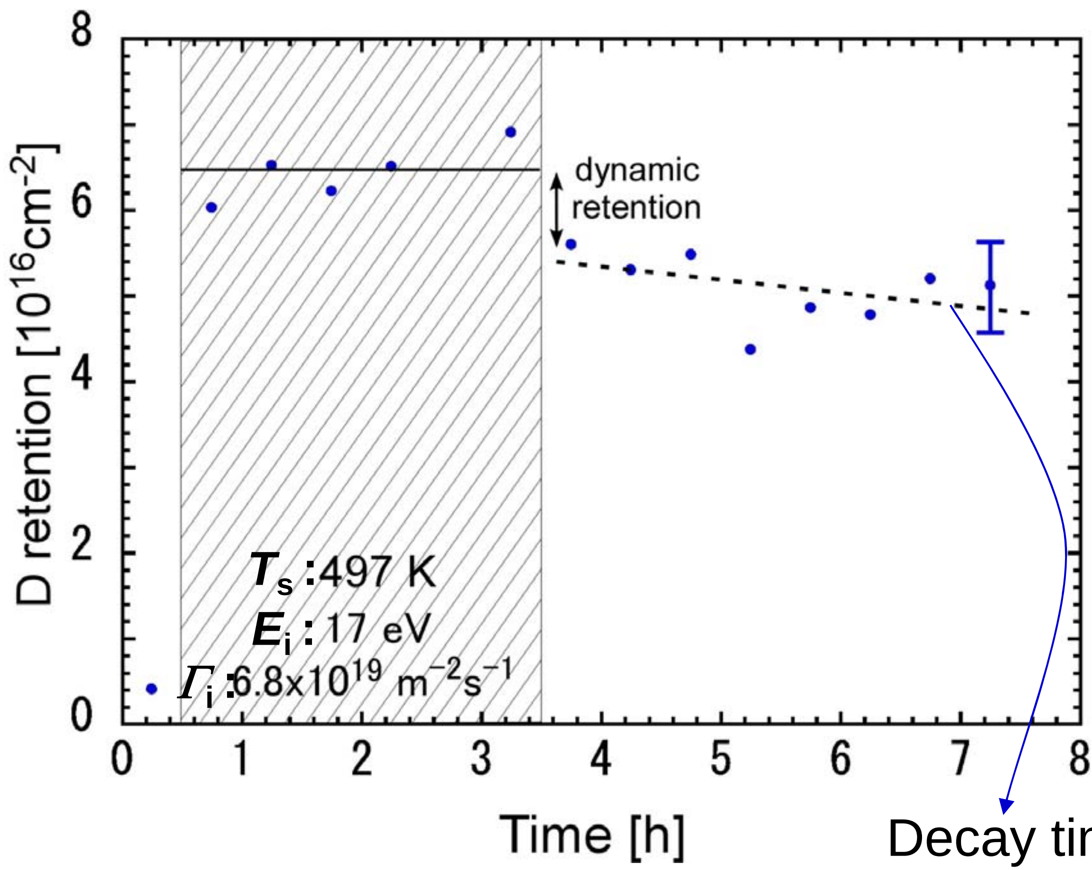
sample : isotropic graphite (IG-110U)

◇Ion beam

Ion beam energy : 0.7 [MeV]
Ion species : $^3He^+$
Beam current : 1～10 [nA]
Measurement time : 1800 [s]

◇Plasma parameter

Discharge power : 50 [W]
B - field : 100 [G]
Discharge gas : D_2
Pressure : 0.48 [Pa]
Irradiation time : 10800 [s]



Decay time = 31±4 [h]

- Decreased by ~20 % just after the end of plasma irradiation
  ⇒Dynamic retention
- Deuterium retention decreases slowly after plasma termination.

Deuterium retention of tungsten during plasma exposure

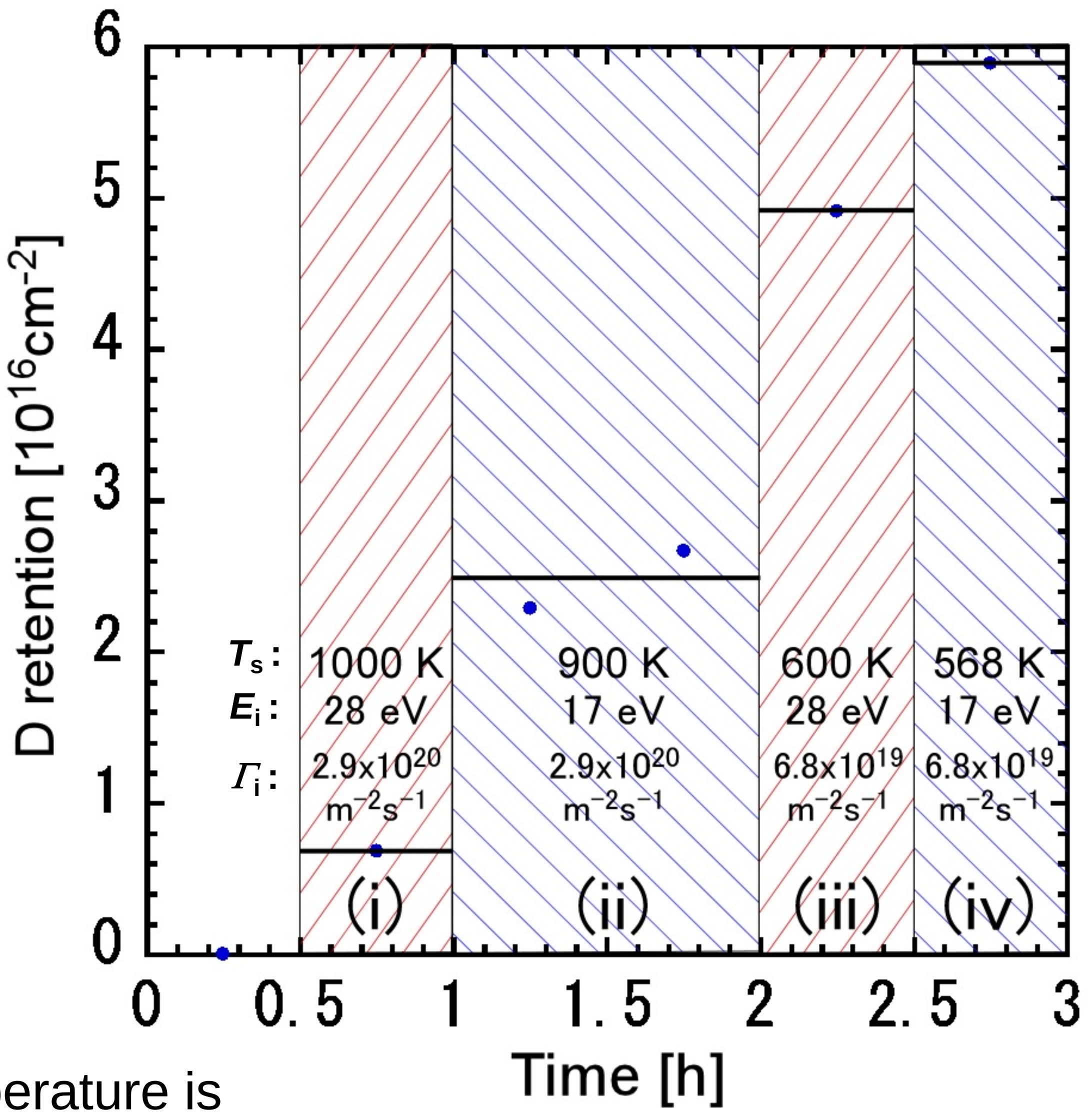
sample：ITER R&D W

◇Ion beam

Ion beam energy：0.7 [MeV]
Ion species：$^{3}He^{+}$
Beam current：1～10 [nA]
Measurement time：1800 [s]

◇Plasma parameter

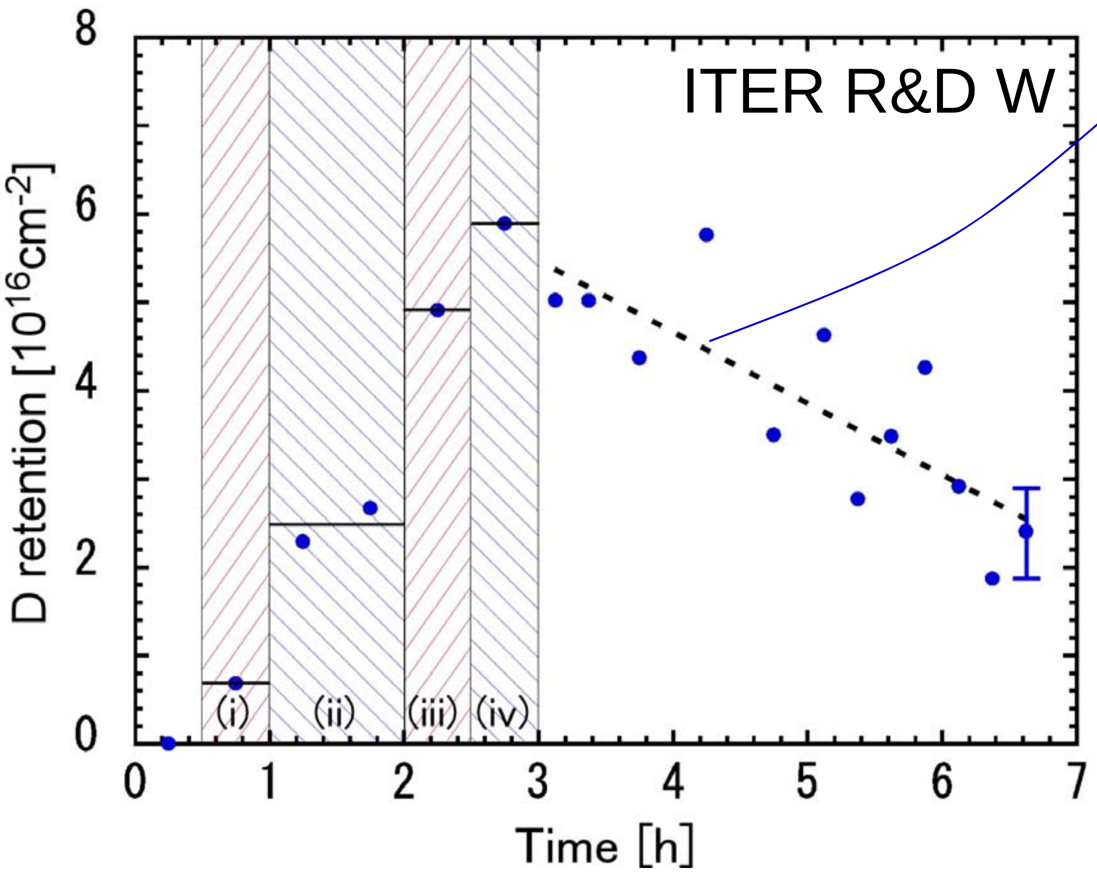
Discharge power：50, 250 [W]
B - field：100 [G]
Discharge gas ：D_2
Pressure：0.48 [Pa]
Irradiation time：9000 [s]



・Deuterium retention is mainly determined by sample temperature *T*s.

・Precise control of surface temperature is required independently plasma condition.

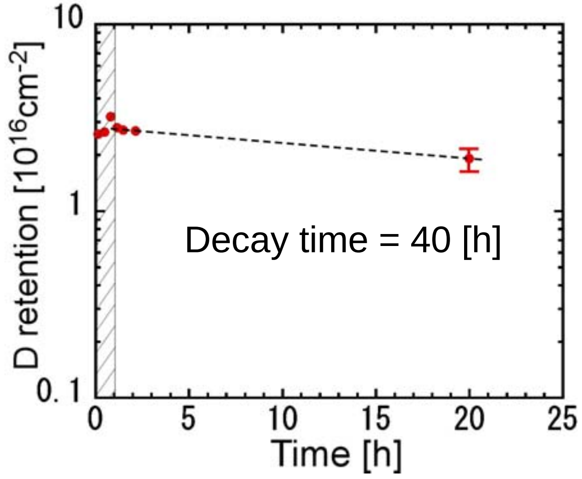
Deuterium retention of tungsten after plasma termination



Decay time = 4.0±0.8 [h]

- Decay time of deuterium retention of ITER R&D W is much shorter than that of isotropic graphite (IG-110U).
- Need to care about post-measurement of deuterium retention of W.

Preliminary result for powder metallurgy W (PM-W)



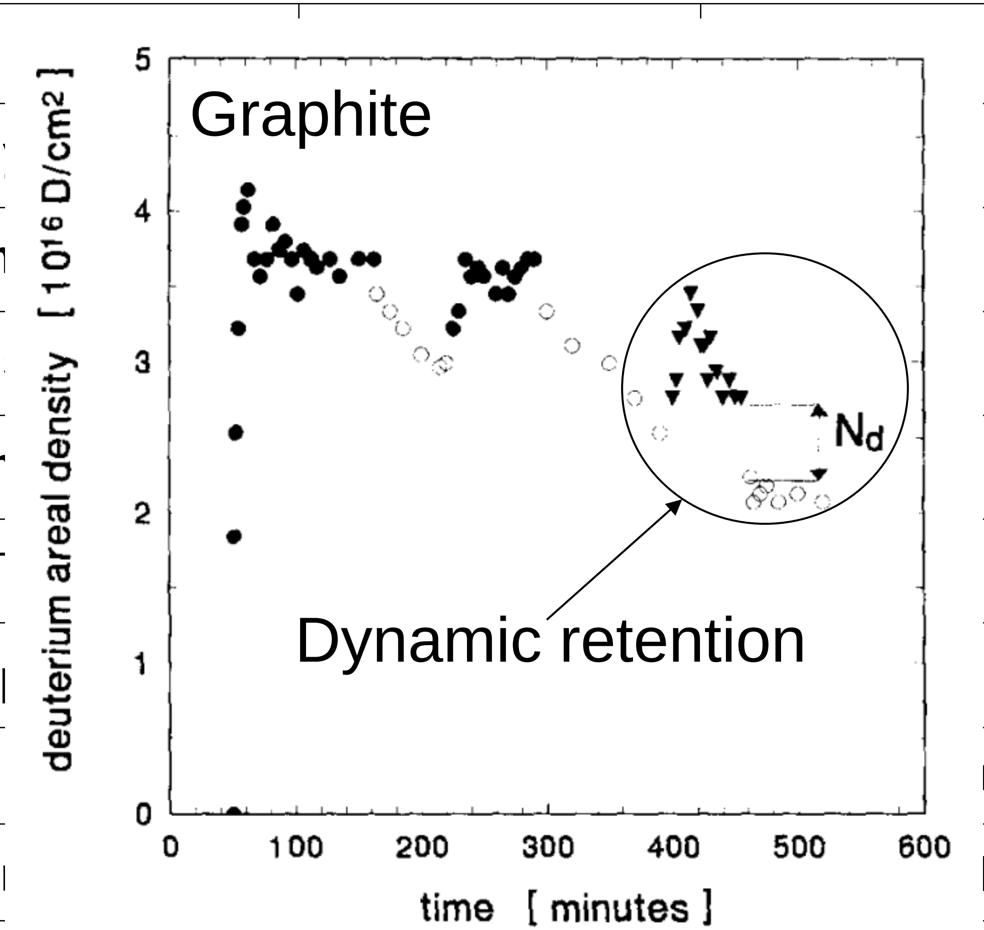
- Decay time could be different depending on manufacturing methods for W.

Summary

- Plasma Surface Dynamics with Ion Beam Analysis (PS-DIBA) device developed to investigate the dynamic retention during deuterium plasma exposure.
- Novel dc plasma source by using direct heated lanthanum hexaboride (LaB6) cathode can generate high density deuterium plasma with an electron density of 4.5×10^{18} m^{-3}.
- Deuterium retention on W and graphite targets was investigated during and after plasma irradiation.
- Deuterium retention of the isotropic graphite (IG-110U) increased just after the plasma irradiation started, and was almost constant during the irradiation. It decreased by approximately 20 % just after the end of plasma irradiation and slowly decreased with a decay time of 30 hours.
- The deuterium retention of ITER R&D tungstens mainly determined by sample temperature. Decay time of deuterium retention of ITER R&D W (4 hours) is much shorter than that of isotropic graphite. On the other hand, the decay time of PM-W could be longer than that of ITER R&D W, meaning the decay time depends on its manufacturing method.

Previous studies for in-situ measurement

Plasma	Magnetron [3]
Ion energ	100-300
Electron ten	120-140
Electron den	$<10^{21}$
Sample ter	370-870
Ion flux(*I*	$<10^{22}$
Sam	graphite
Ion beam	NRA,RBS
Dynamic	20% up



[1] G.M. Wright JNM2007 [2] M. Langhoff JNM1997 [3] B. Emmoth JNM1997

For next step PWI studies

Relevant to divertor condition ➡ n_e~10^{19-20} m^{-3} and T_e<10 eV

ITER divertor materials ➡ tungsten (W)