1st NIFS-CRC International Symposium and 1st Korea-Japan Workshop on "Edge-Plasma and Surface Component Interactions in Steady State Magnetic Fusion Devices“ NIFS, 21-22 May 2007

Multiscale Phenomena of Plasma-Wall Interaction in TRIAM-1M

M. Sakamoto, M. Ogawa[1], H. Zushi, K. Takaki[1], M. Tokitani[2], K. Tokunaga, N. Yoshida,Y. Higashizono[3], Y. Nakashima[3], M. Miyamoto[4], K. Sasaki[1], B. Rajendraprasad[1], K. Nakamura, K. Hanada, K.N. Sato, H. Idei, M. Hasegawa, S. Kawasaki, H. Nakashima, T. Fujiwara, A. Higashijima

Advanced Fusion Research Center,
Research Institute for Applied Mechanics, Kyushu University

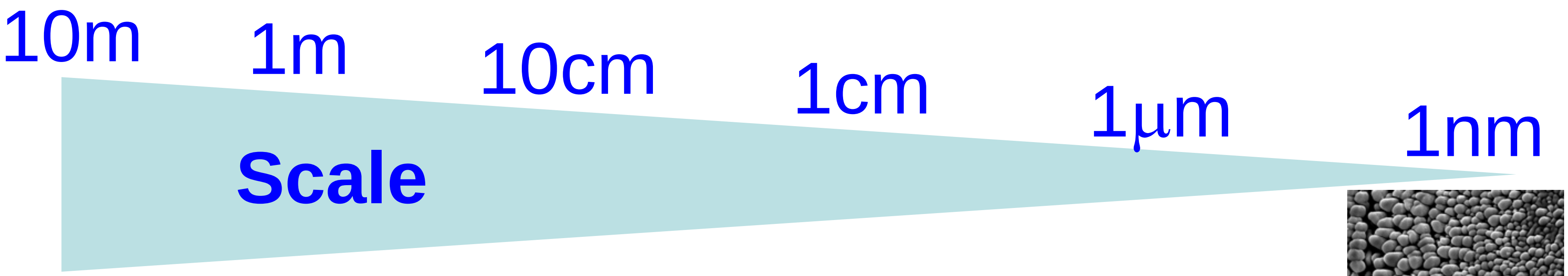
1 Interdisciplinary Graduate School of Engineering Sciences,
Kyushu University
2 National Institute for Fusion Science
3 Tsukuba University
4 Shimane University

Contents

- Introduction
- Wall Recycling Structure
- Global Particle Balance
- Hydrogen Retention in Co-deposits
- Impact of an interval time between discharges
- Summary

Multiscale Phenomena in PWI

It is important to understand various phenomena related to the plasma-wall interaction from macroscopic and microscopic viewpoints



Particle balance

Neutral transport

Impurity transport

Re-deposition

Local recycling

Local heat load

Dust

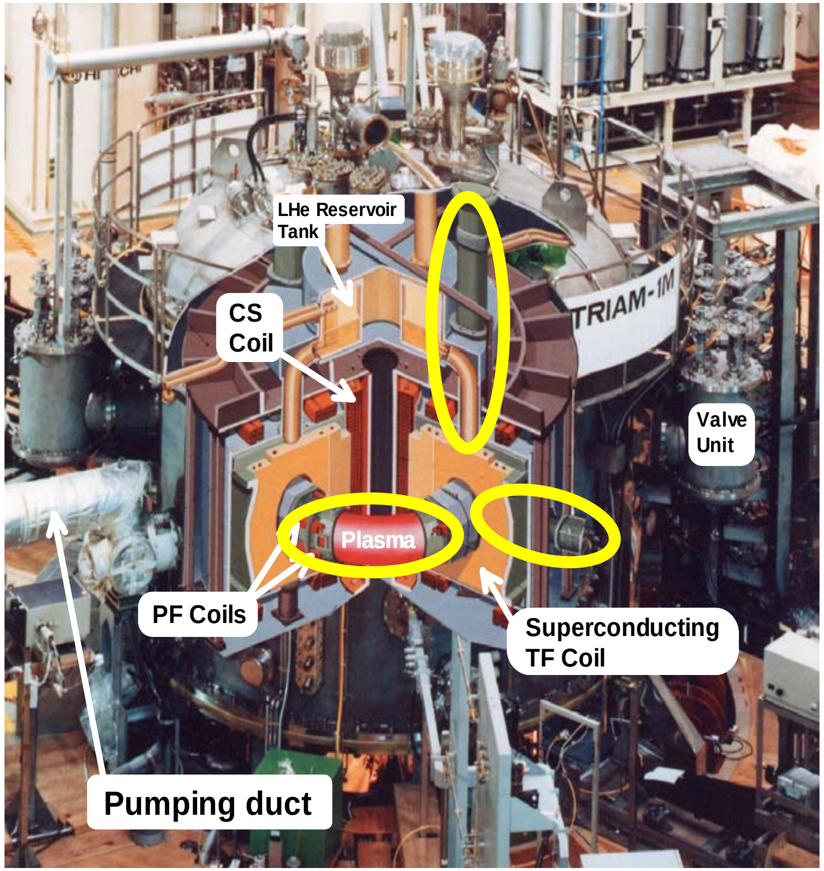
Co-deposits

Fine structure

Sputtering

Radiation damage

TRIAM-1M Tokamak



Bird's-eye view of TRIAM-1M

Major radius	0.84 m
Minor radius	0.12 m
Toroidal field	8 T **(Steady State)**

TF coils : Nb_3Sn (superconductor)

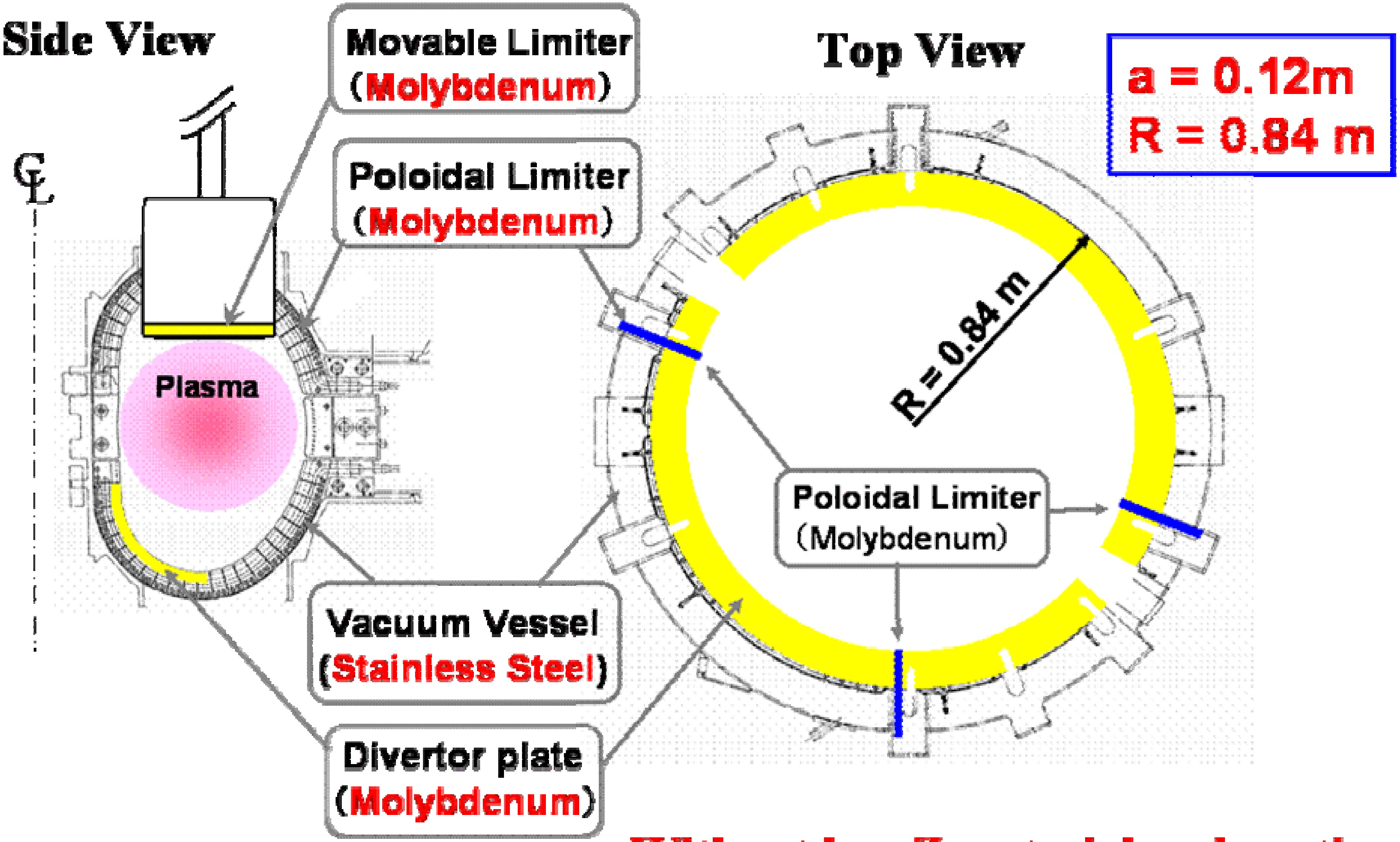
PF coils : Cu (normal conductor)

Plasma facing components: High Z

Wall Conditioning:

(1)Baking of extension ports
and then
(2) ECR discharge cleaning for PFCs

All of the PFMs are made of metals



Movable Limiter (Molybdenum)

Poloidal Limiter (Molybdenum)

Vacuum Vessel (Stainless Steel)

Divertor plate (Molybdenum)

Poloidal Limiter (Molybdenum)

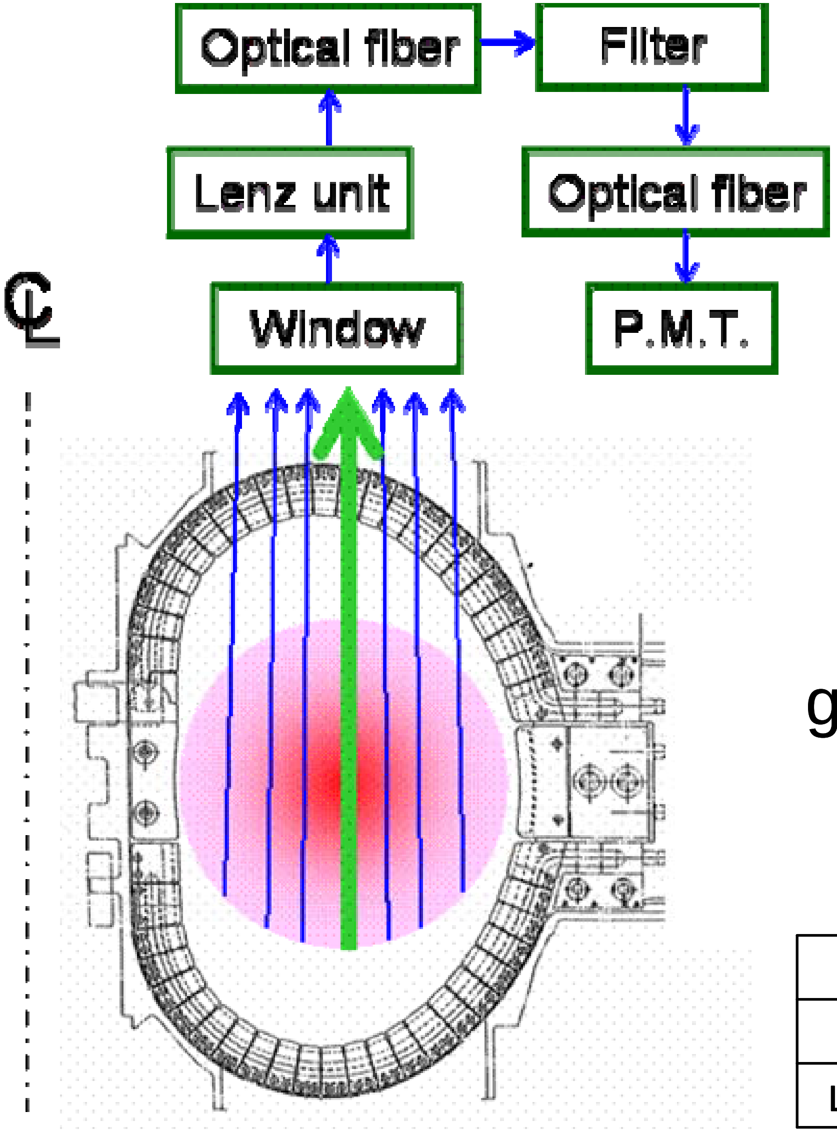
a = 0.12m
R = 0.84 m

Without low Z material and coating

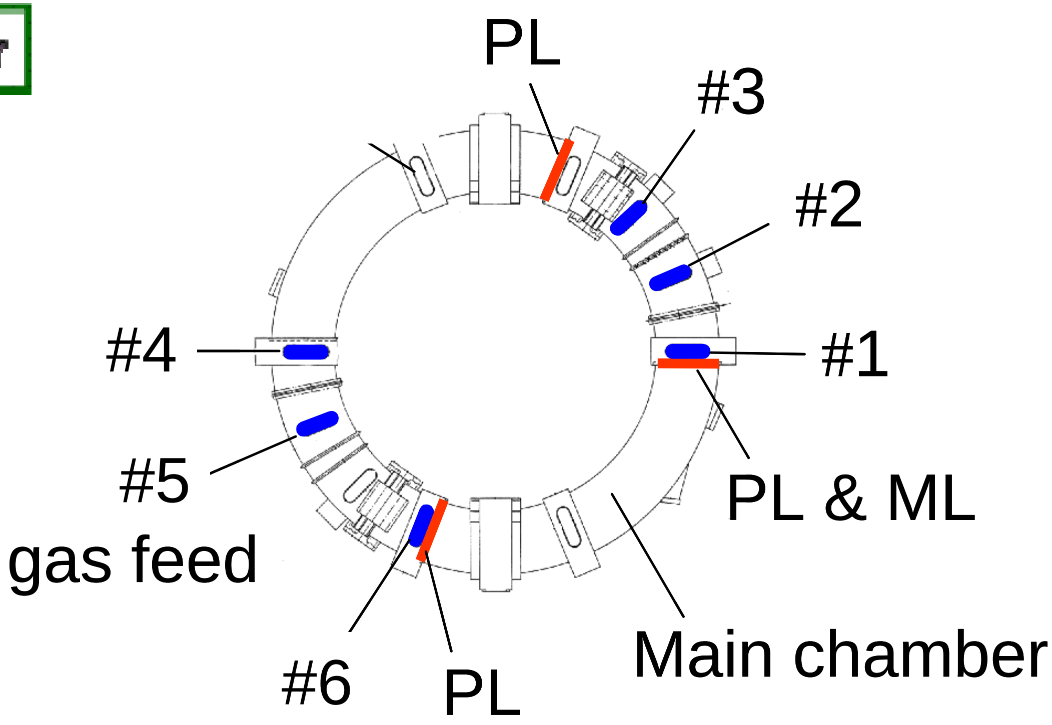
Contents

- Introduction
- **Wall Recycling Structure**
- Global Particle Balance
- Hydrogen Retention in Co-deposits
- Impact of an interval time between discharges
- Summary

Measurement system for Hα profile



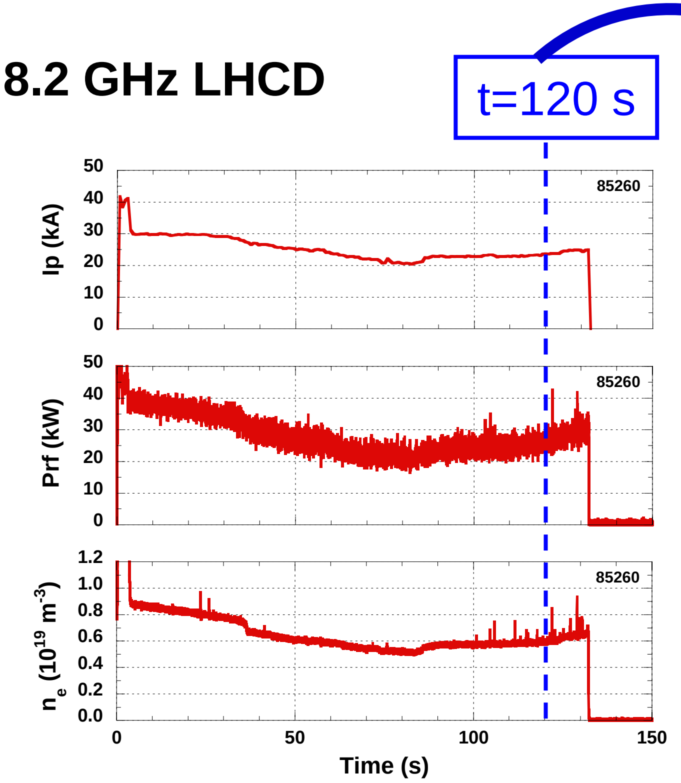
Toroidal Profile of Hα intensity is measured at 6 positions.

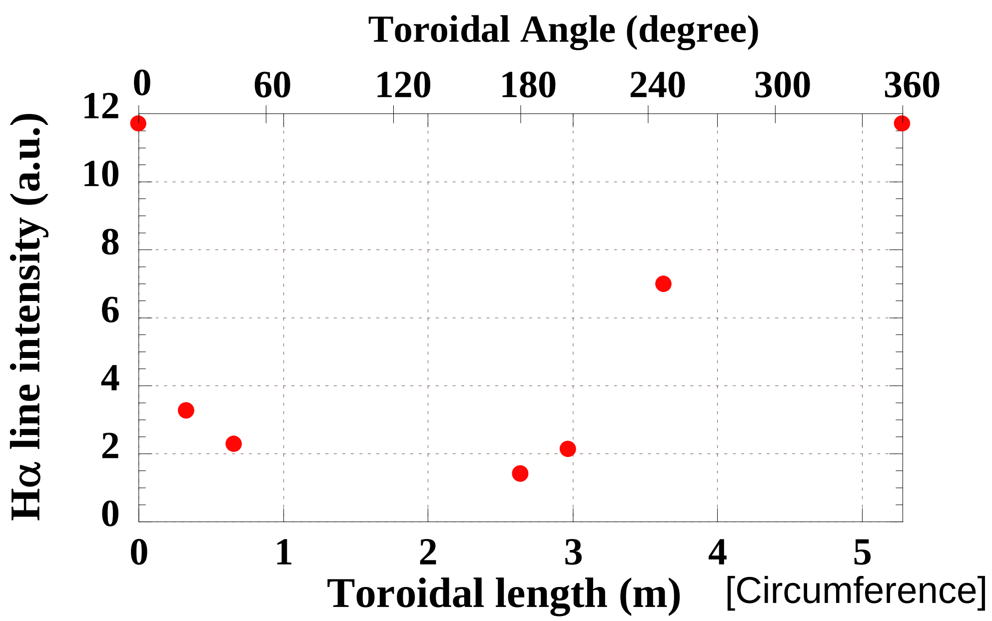


#	1	2	3	4	5	6
Φ	0	22.5	45	180	202.5	247.5
L (m)	0	0.33	0.66	2.64	2.97	3.63

Toroidal profile of Hα intensity

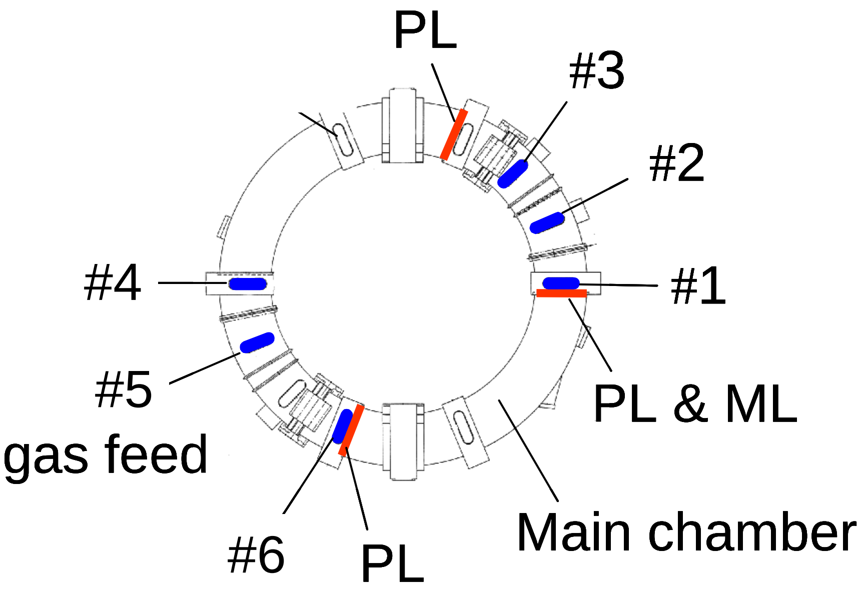
8.2 GHz LHCD



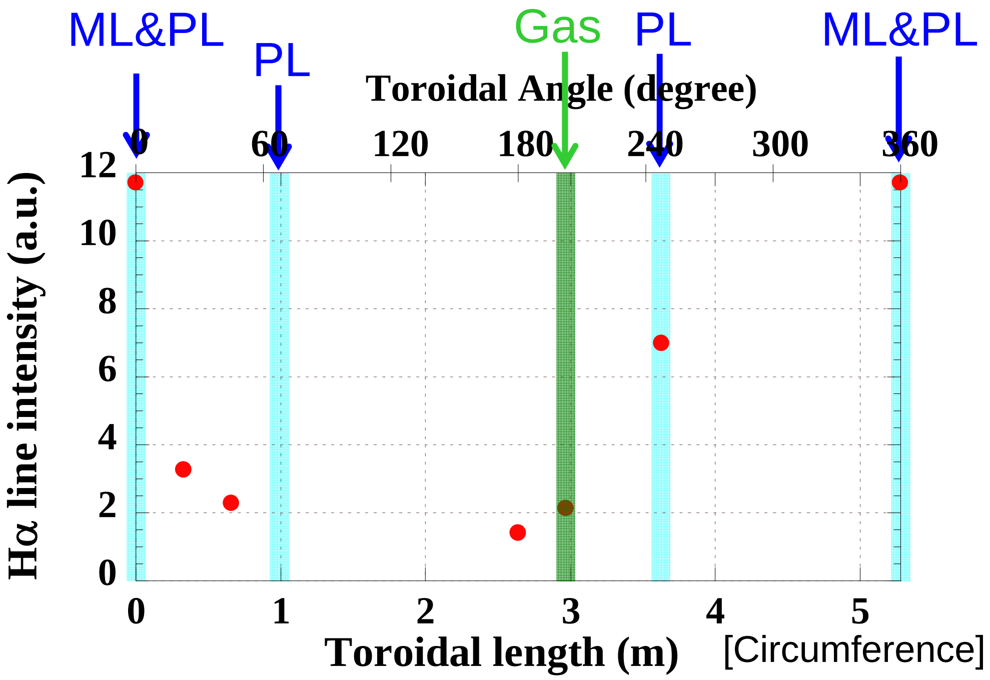


Data at the latter phase of the discharge is used to reduce an effect of gas puff on the toroidal profile.

Toroidal profile of Hα intensity

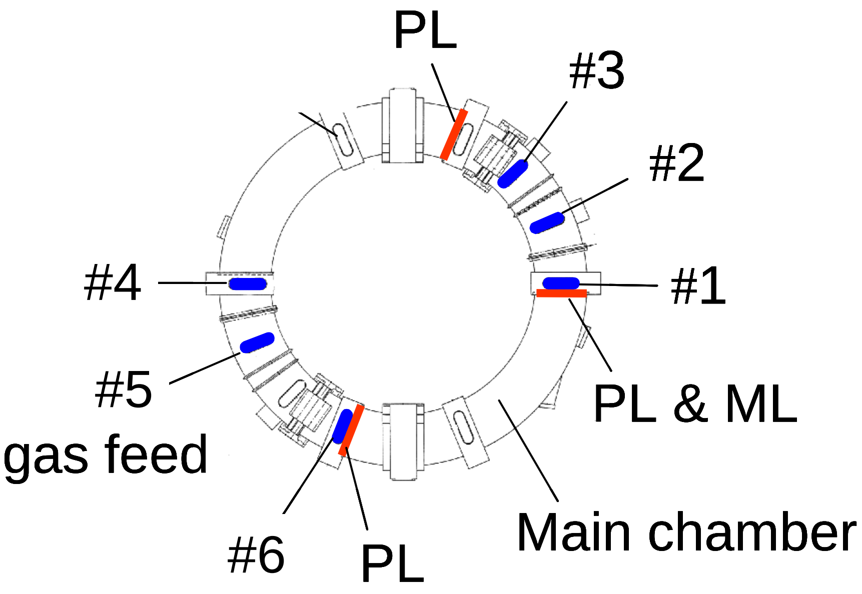


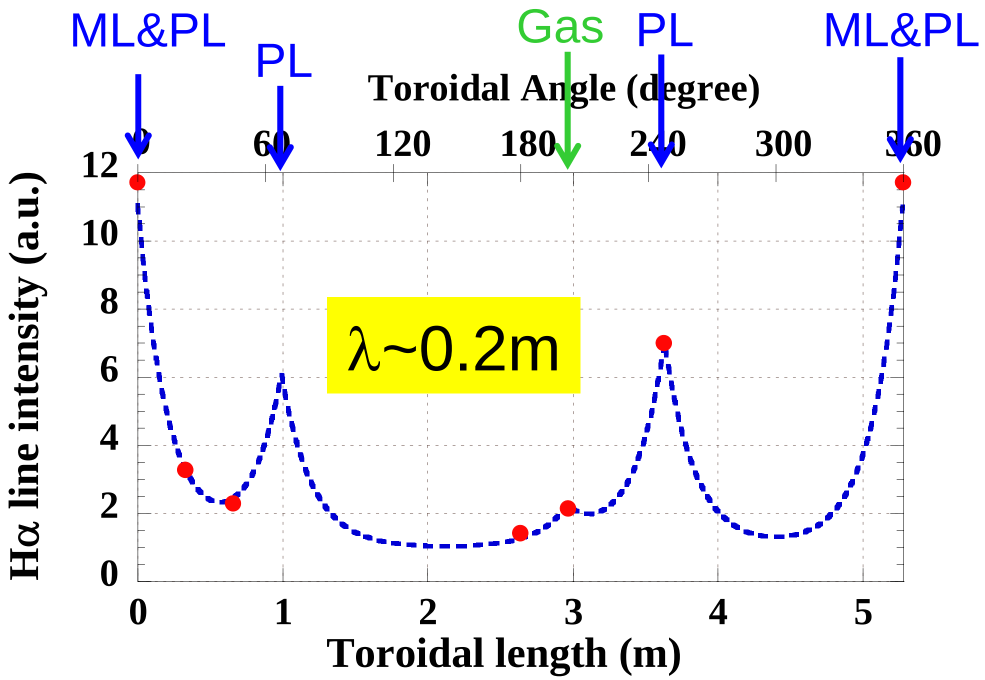
Wall recycling is enhanced at ML&PL



$$I_{H\alpha}(x) = P_{mc} + \sum_{i=1}^{4} P_i \exp\left[\frac{-\left|x - x_i\right|}{\lambda}\right]$$

Toroidal profile of Hα intensity





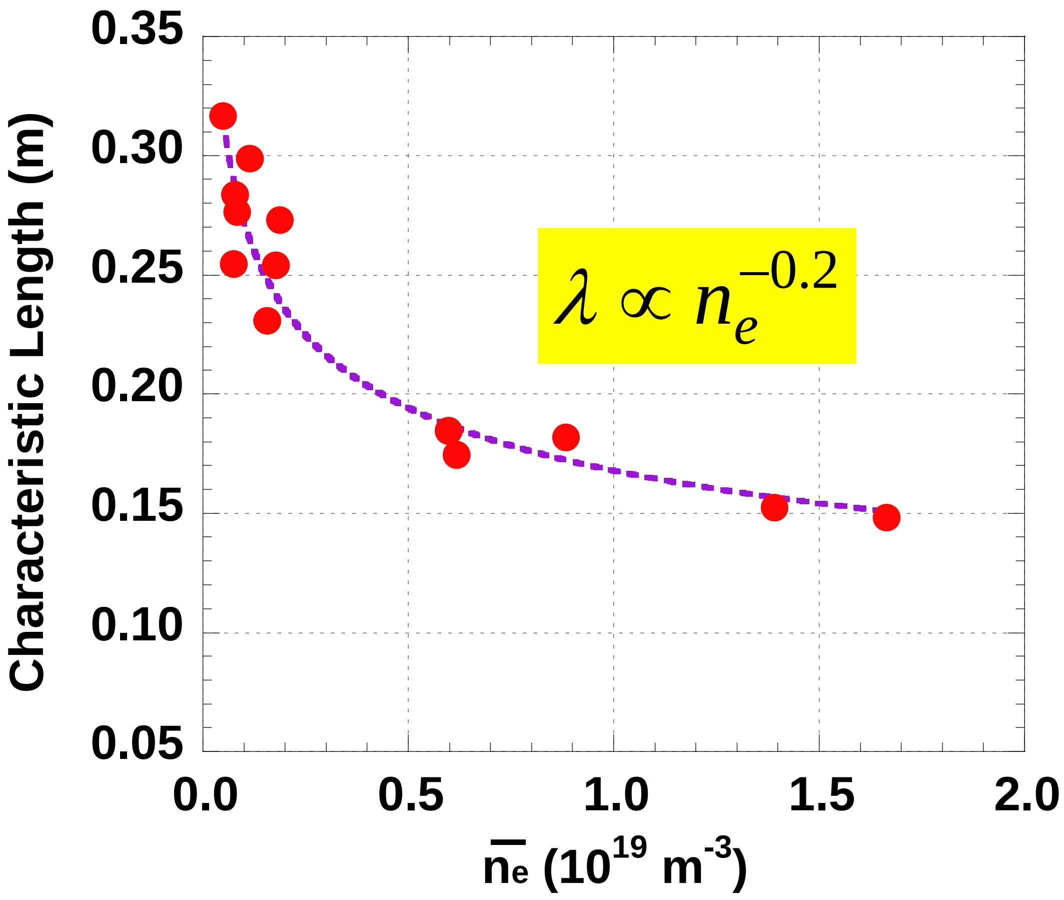
Almost all hydrogen is refueled by wall recycling. This means that recycling ratio is nearly unity. In another exp., the recycling ratio was more than 0.998.

[Ref.: M.Sakamoto et al. NF(2002)]

$$I_{H\alpha}(x) = P_{mc} + \sum_{i=1}^{4} P_i \exp\left[\frac{-|x-x_i|}{\lambda}\right]$$

Hydrogen recycling is localized within λ ~ 0.2m.

Density dependence of λ



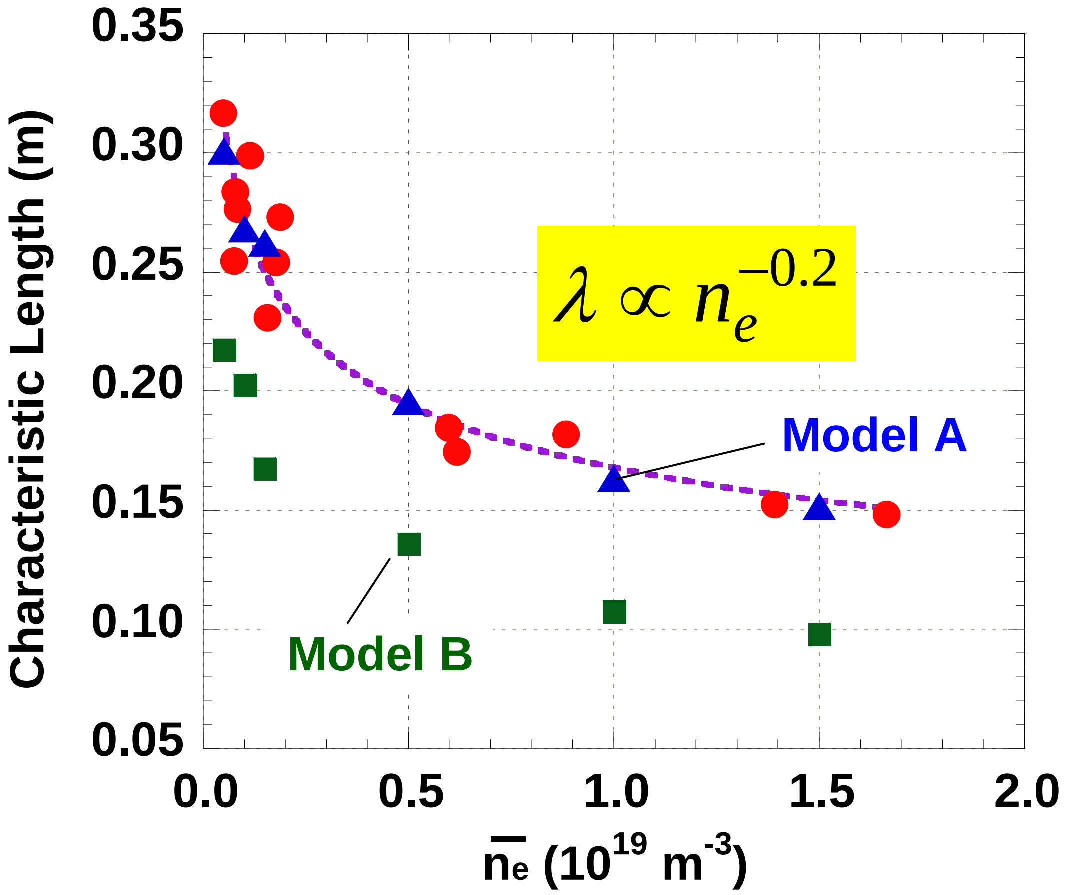
Density regime

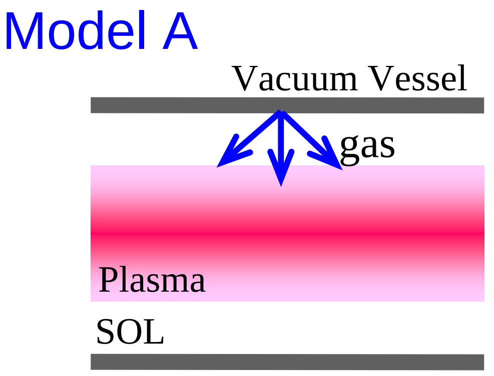
$$0.05\times10^{19} < \bar{n}_e < 1.5\times10^{19}\,m^{-3}$$

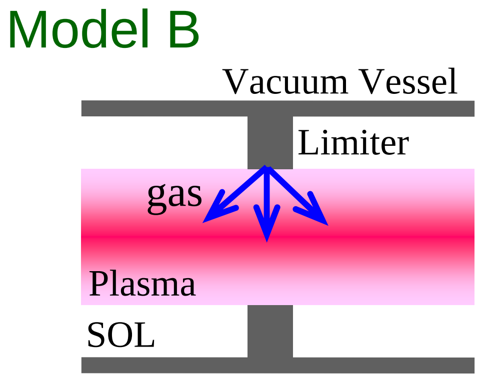
$$0.3 > \lambda > 0.15m$$

Although the density changes by 30 times, λ changes only twice.

DEGAS simulation

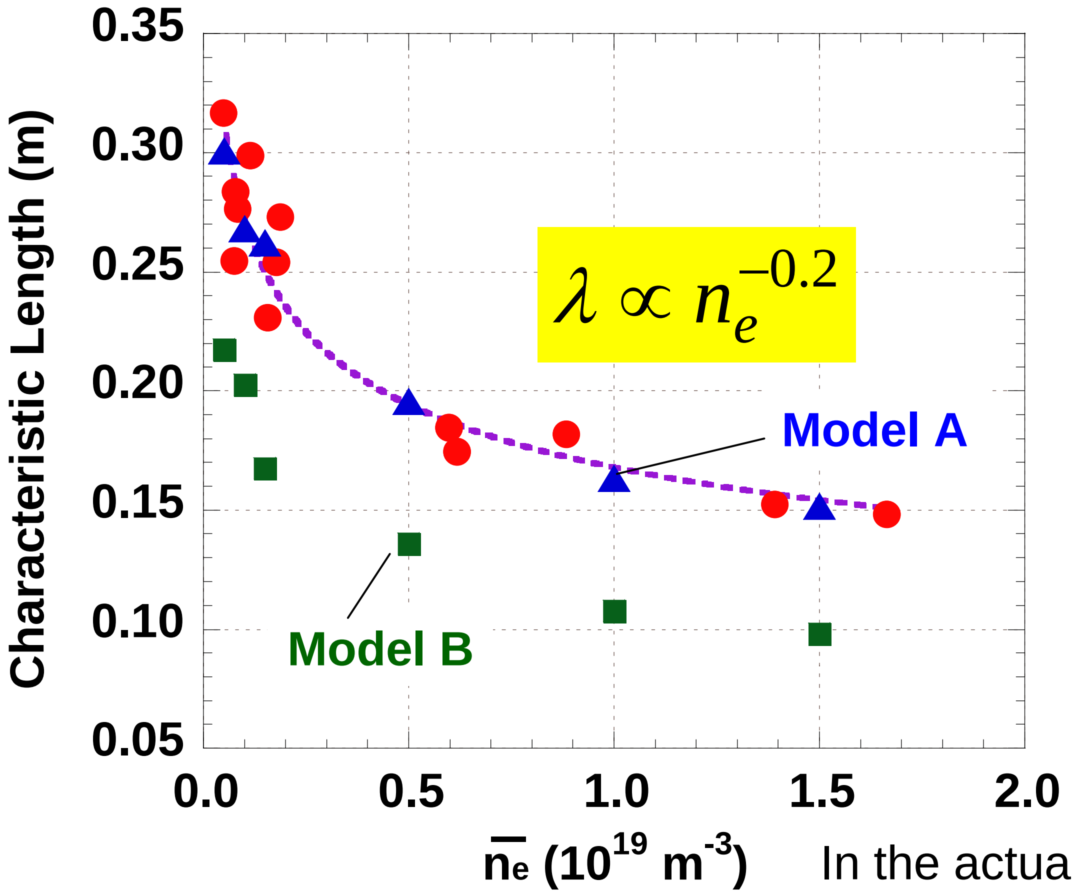


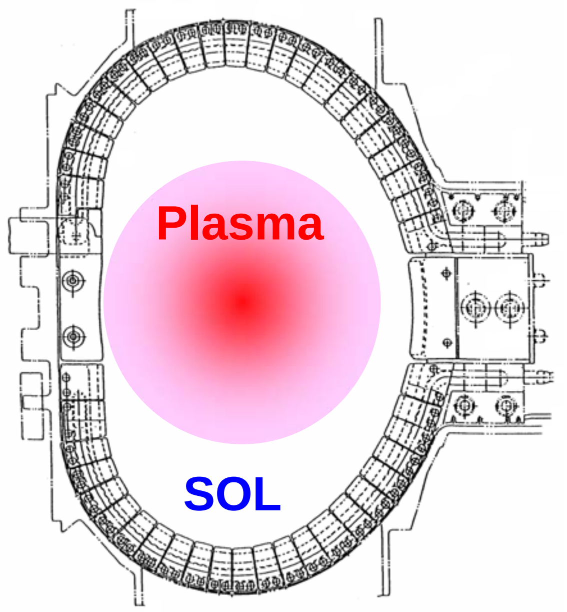




DEGAS simulation of the model A reproduces the exp. results.

Impact of SOL on the neutral transport





In the actual geometry, the limiter is D-shaped. Large SOL region exists above and below the plasma. Neutral transport is SOL seems to dominate the characteristic length of wall recycling structure.

Contents

- Introduction
- Wall Recycling Structure
- **Global Particle Balance**
- Hydrogen Retention in Co-deposits
- Impact of an interval time between discharges
- Summary

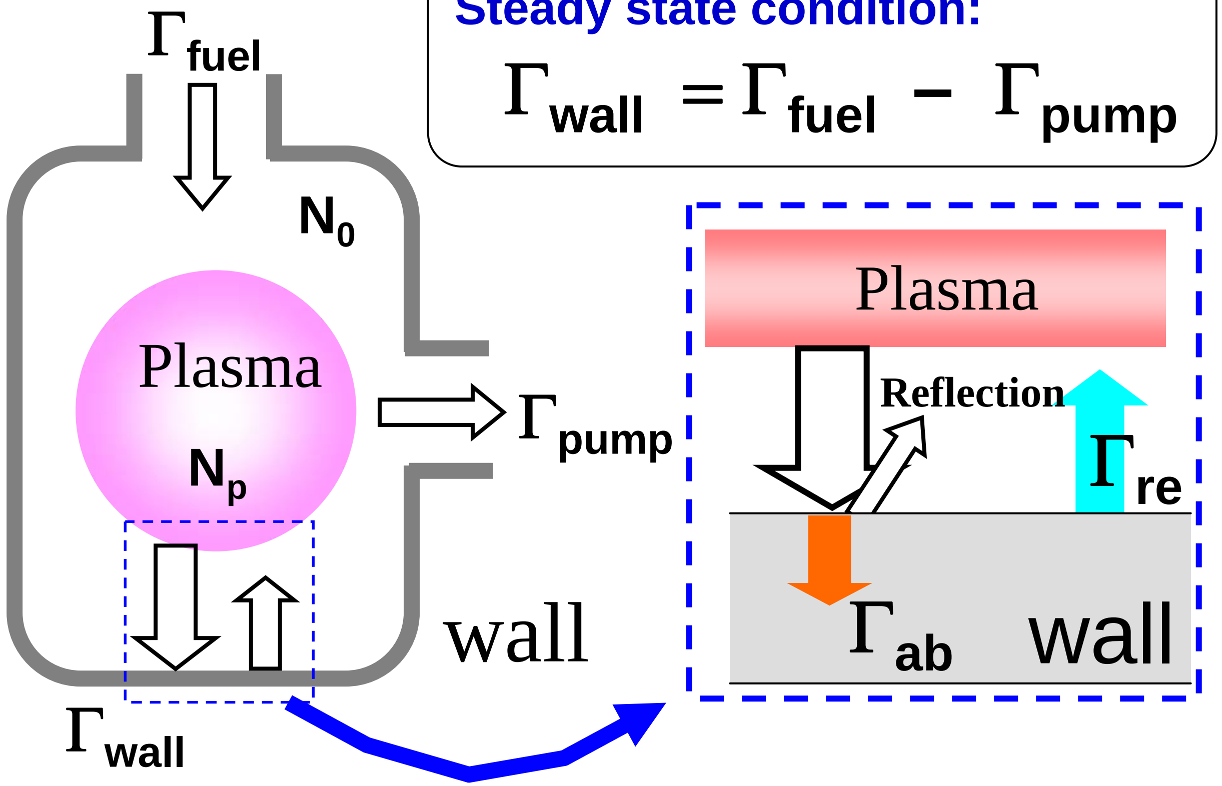
Particle Balance in Vacuum Vessel

$$dN_p / dt \; + \; dN_0 / dt \; = \; \Gamma_{fuel} - \Gamma_{pump} - \Gamma_{wall}$$

Γ_{fuel} : fueling rate, Γ_{pump} : pumping rate, Γ_{wall} : net wall pumping rate

Steady state condition:

$$\Gamma_{wall} = \Gamma_{fuel} - \Gamma_{pump}$$



Two roles of wall

$$\Gamma_{wall} = \Gamma_{ab} - \Gamma_{re}$$

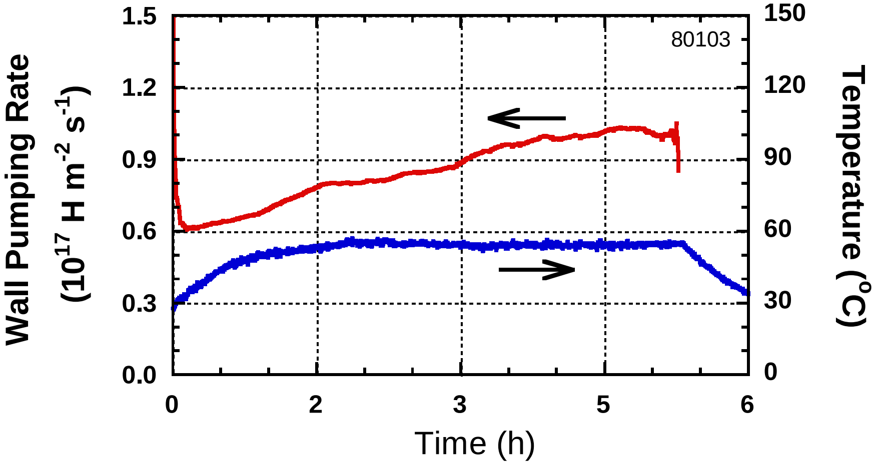
Positive : Sink

Negative : Source

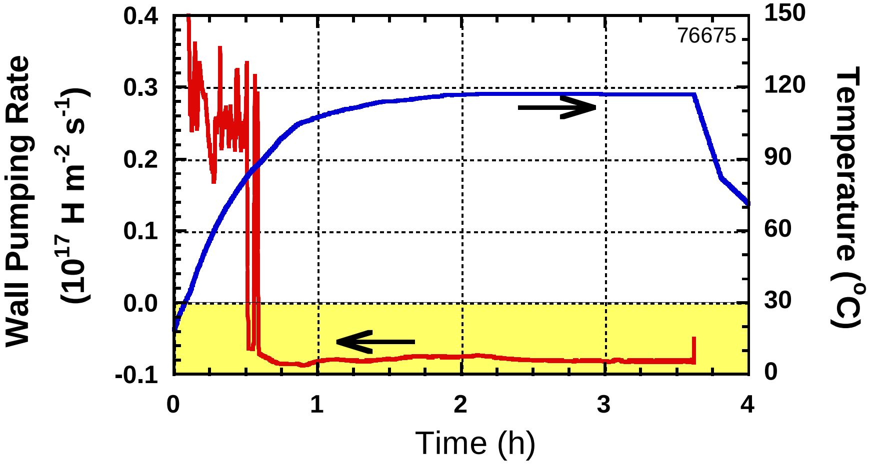
Γ_{ab}: H absorption

Γ_{re}: H re-emission

Impact of Wall Temperature on GPB

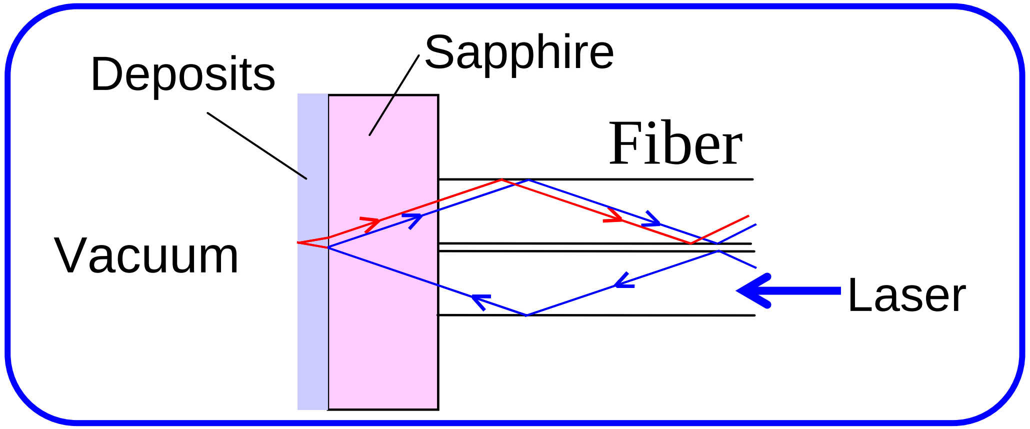

Low Temperature Wall

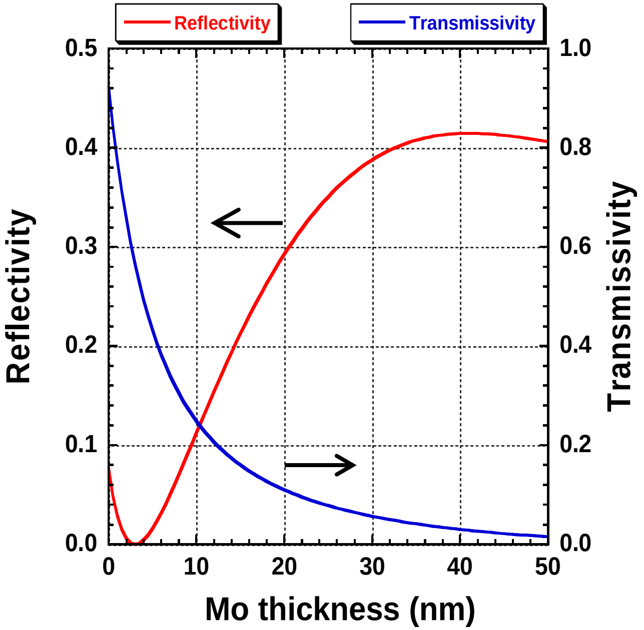
By using a movable limiter with good cooling capability, increase in the wall temperature was suppressed to less than 60 ^{o}C. No wall saturation can be seen.

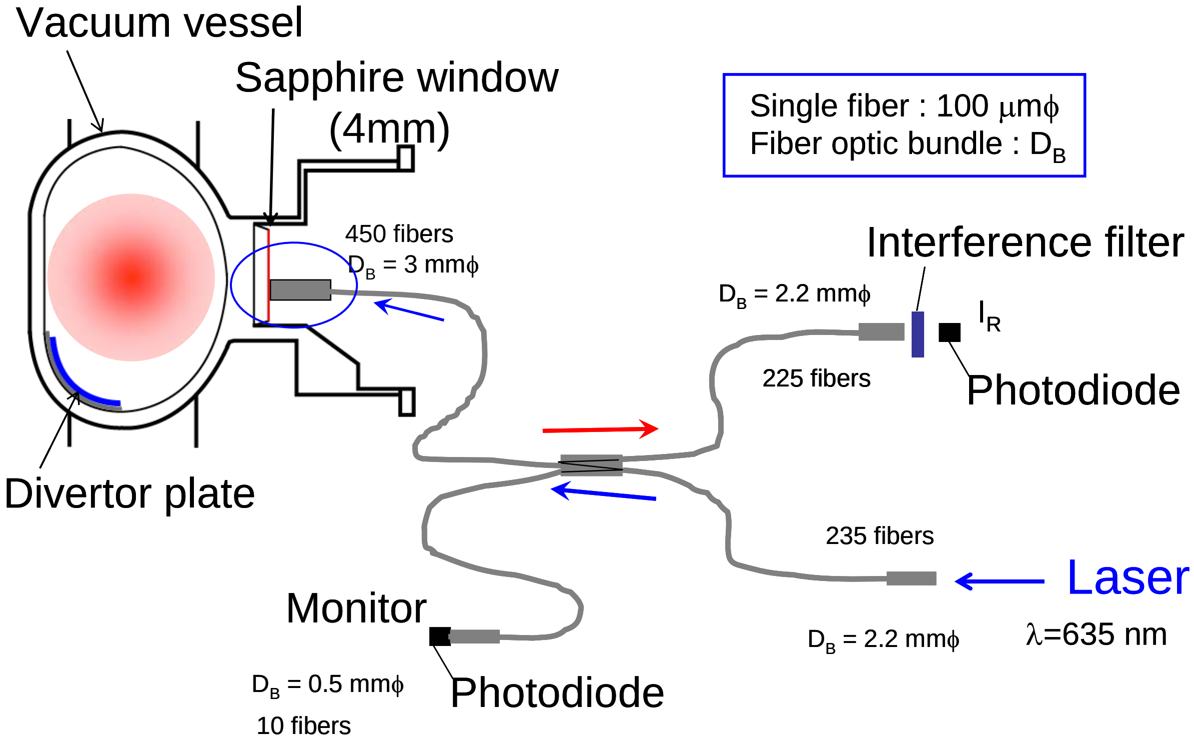

High Temperature Wall

Without the movable limiter, the wall temperature partly increased up to 120 ^{o}C due to heat load from the plasma. The wall pumping rate changed from positive to negative at t ~ 30 min.

In situ measurement of growth of deposited layer







Single fiber : 100 μmϕ
Fiber optic bundle : D_B

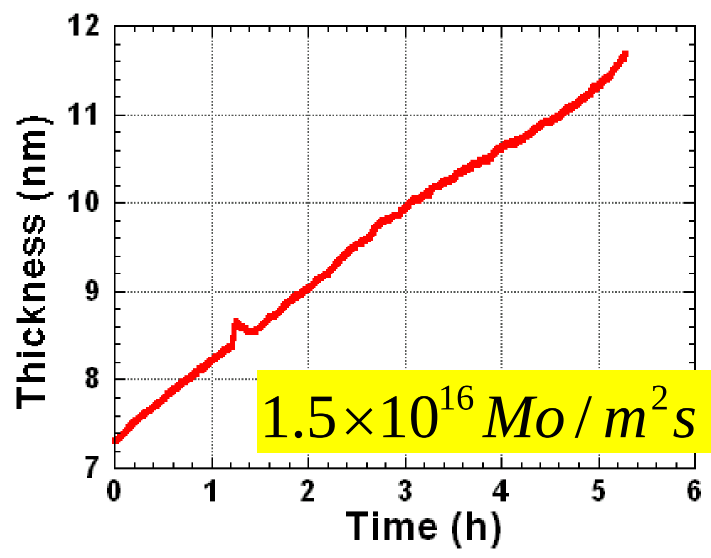
$$\delta = \frac{2\pi}{\lambda_0} n_1 2d \cos\phi \sim \frac{4\pi}{\lambda_0} n_1 d$$

$$r_1 = \frac{n_0 - n_1}{n_0 + n_1} \qquad r_2 = \frac{n_1 - n_2}{n_1 + n_2}$$

$$r = \frac{r_1 + r_2 e^{-i\delta}}{1 + r_1 r_2 e^{-i\delta}}$$

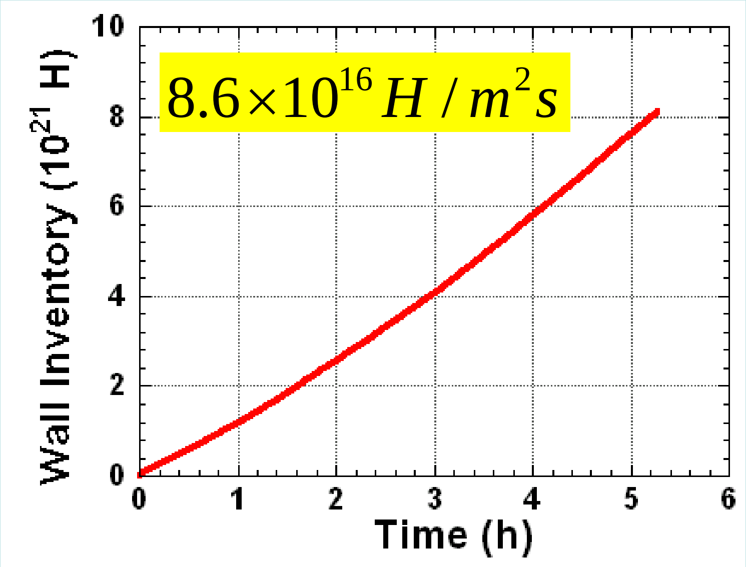
Continuous wall pumping related to codeposition

Growth of dep. layer



Time evolution of the thickness of the deposited layer.

Wall Inventory



Time evolution of the wall inventory in 5 h 16 min discharge. No wall saturation can be seen.

Continuous codeposition can be expected.

Contents

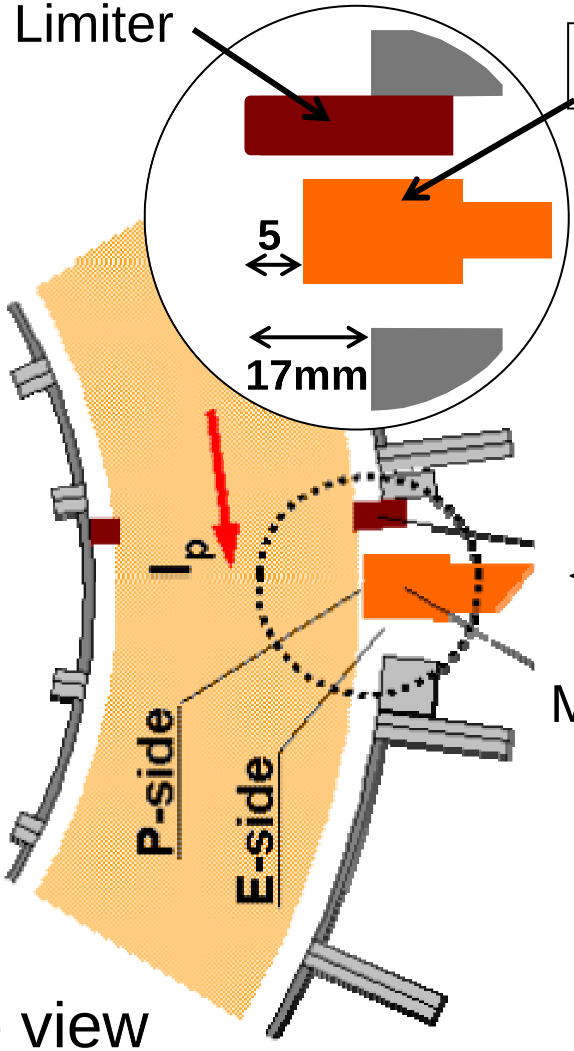
- Introduction
- Wall Recycling Structure
- Global Particle Balance
- **Hydrogen Retention in Co-deposits**
- Impact of an interval time between discharges
- Summary

Hydrogen retention & microstructure of co-deposit

Limiter

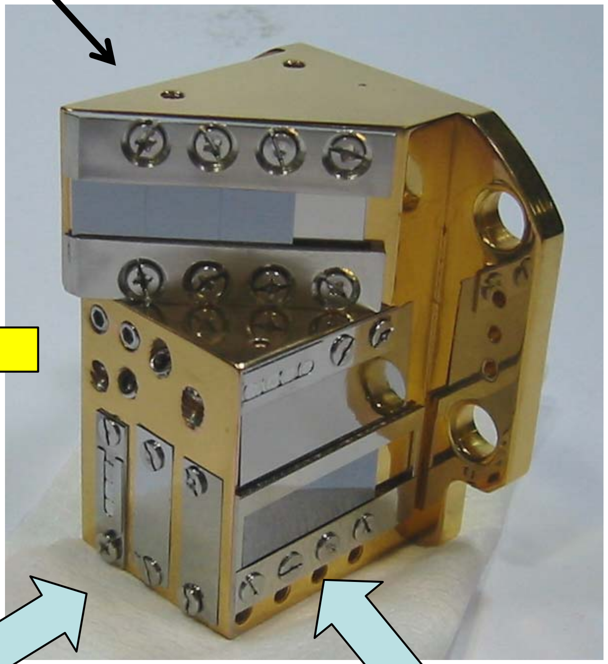
Material Probe

Analysis: RBS, ERD, TEM



Material Probe

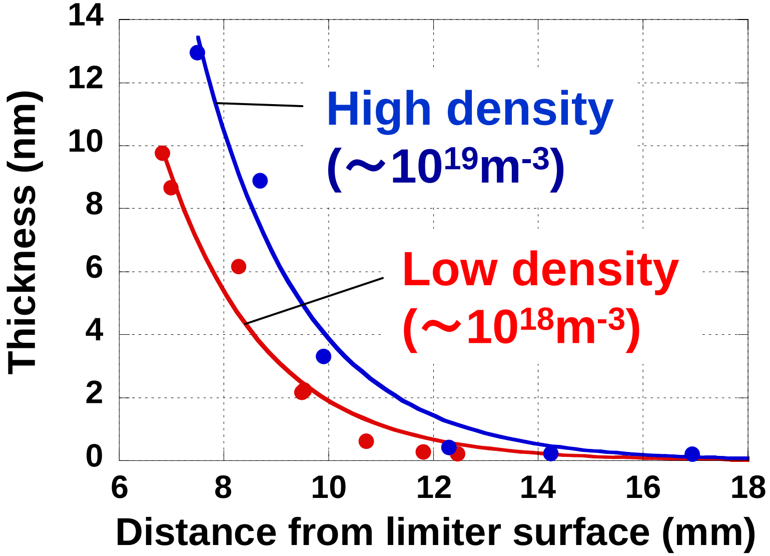
Top view



P-Side

E-Side

Hydrogen retention & microstructure of Mo deposit

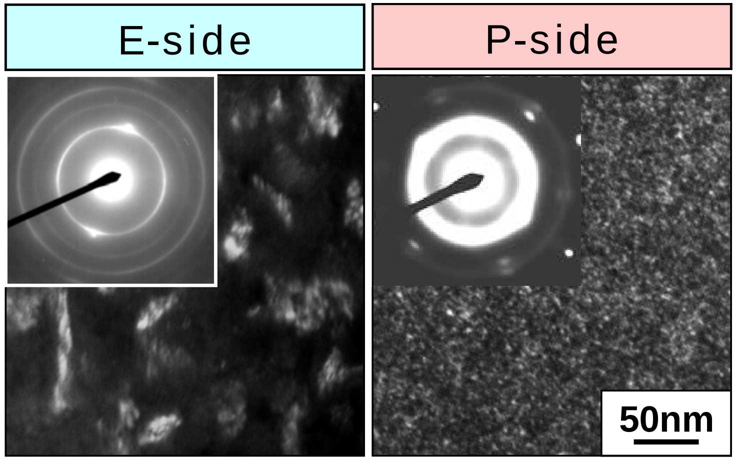


High density (10^{19} m^{-3})
H/Mo ~ 0.17 @ E-side (8mm)
H/Mo ~ 0.15 @ P-side

Low density (10^{18} m^{-3})
H/Mo ~ 0.04 @ E-side (8mm)
H/Mo ~ 0.10 @ P-side

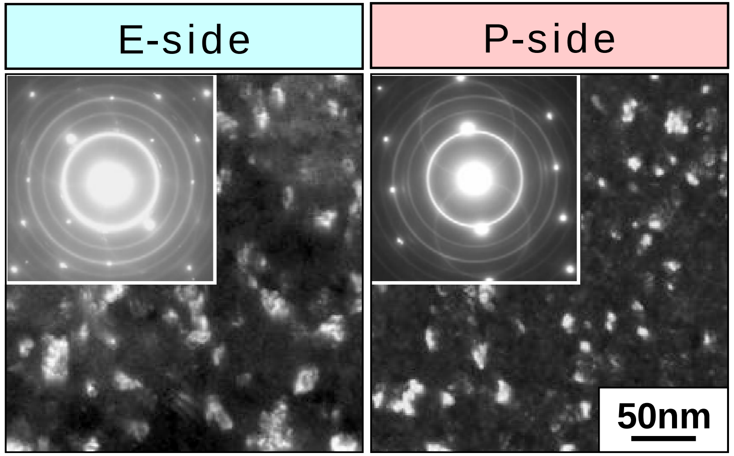
Codeposition of hydrogen with sputtered Mo makes a substantial wall pumping.

●Low density (n_e~$10^{18}m^{-3}$), 4320s



bcc, 10-20 nm **fcc, ~1 nm**

◆High density (n_e~$10^{19}m^{-3}$), 407 s



bcc, 10-20 nm **bcc, 10-20 nm**

Summary of material probe results and GPB

	Low density (~$1\text{x}10^{18}$ m^{-3})		High density(~$1\text{x}10^{19}$ m^{-3})		note
	E-side	P-side	E-side	P-side	
Structure	bcc	fcc	bcc	bcc	
Grain size	10-20nm	1-2nm	10-20nm	10-20nm	
Mo depo. Rate	$3.6\text{x}10^{17}$ Mo/m^{2}s	$6.4\text{x}10^{16}$ Mo/m^{2}s	$1.7\text{x}10^{18}$ Mo/m^{2}s	$2.3\text{x}10^{18}$ Mo/m^{2}s	x=8mm @E-side
Γ_{wall}(MP)	$1.3\text{x}10^{16}$ H/m^{2}s	$6.4\text{x}10^{15}$ H/m^{2}s	$2.9\text{x}10^{17}$ H/m^{2}s	$3.5\text{x}10^{17}$ H/m^{2}s	
Γ_{wall}(GPB)	$2\text{x}10^{16}$ H/m^{2}s (HTW) $8.6\text{x}10^{16}$ H/m^{2}s (LTW)		$4.0\text{x}10^{17}$ H/m^{2}s		Whole wall surface Is used. (S =5 m^2)

- M. Sakamoto et al., Nuclear Fusion, 42 (2002) 588.
- M. Sakamoto et al., Nuclear Fusion, 442 (2004) 693.
- M. Miyamoto et al., J. Nucl. Mater. 337-339 (2005) 436-440
- M. Tokitani et al., 12th ICFRM, J. Nucl. Mater. (in press)

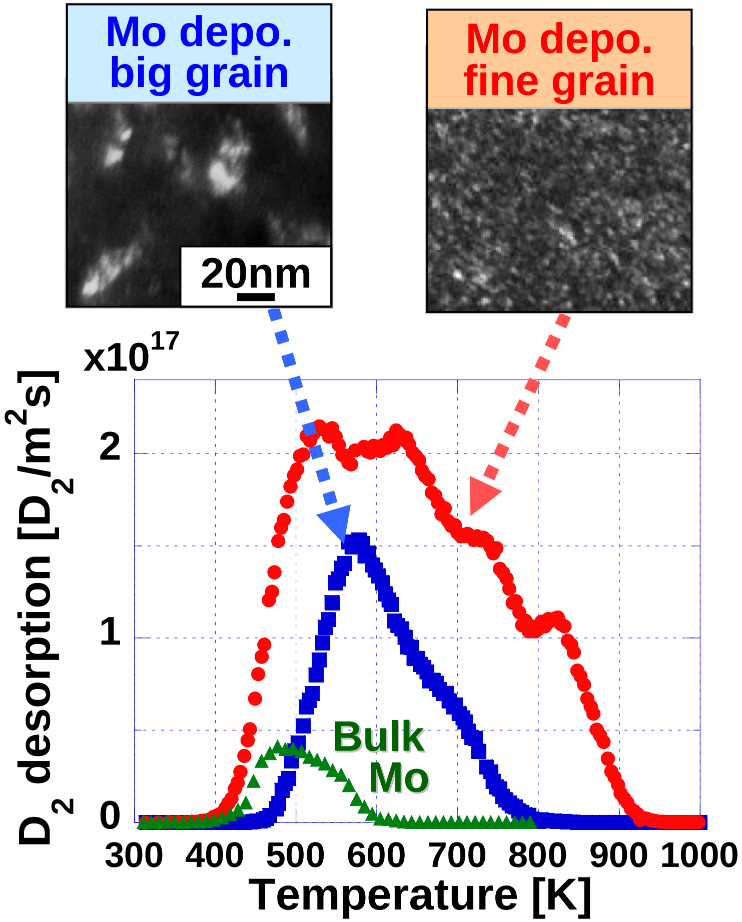
Summary of material probe results and GPB

	Low density (~$1\text{x}10^{18}$ m^{-3})		High density(~$1\text{x}10^{19}$ m^{-3})		note
	E-side	P-side	E-side	P-side	
Structure	bcc	fcc	bcc	bcc	
Grain size	10-20nm	1-2nm	10-20nm	10-20nm	
Mo depo. Rate	$3.6\text{x}10^{17}$ Mo/m^2s	$6.4\text{x}10^{16}$ Mo/m^2s	$1.7\text{x}10^{18}$ Mo/m^2s	$2.3\text{x}10^{18}$ Mo/m^2s	x=8mm @E-side
Γ_{wall}(MP)	$1.3\text{x}10^{16}$ H/m^2s	$6.4\text{x}10^{15}$ H/m^2s	$2.9\text{x}10^{17}$ H/m^2s	$3.5\text{x}10^{17}$ H/m^2s	
Γ_{wall}(GPB)	$2\text{x}10^{16}$ H/m^2s (HTW)		$4.0\text{x}10^{17}$ H/m^2s		Whole wall surface Is used. (S =5 m^2)
	$8.6\text{x}10^{16}$ H/m^2s (LTW)				

- **M. Sakamoto et al., Nuclear Fusion, 42 (2002) 588.**
- **M. Sakamoto et al., Nuclear Fusion, 442 (2004) 693.**
- **M. Miyamoto et al., J. Nucl. Mater. 337-339 (2005) 436-440**
- **M. Tokitani et al., 12th ICFRM, J. Nucl. Mater. (in press)**

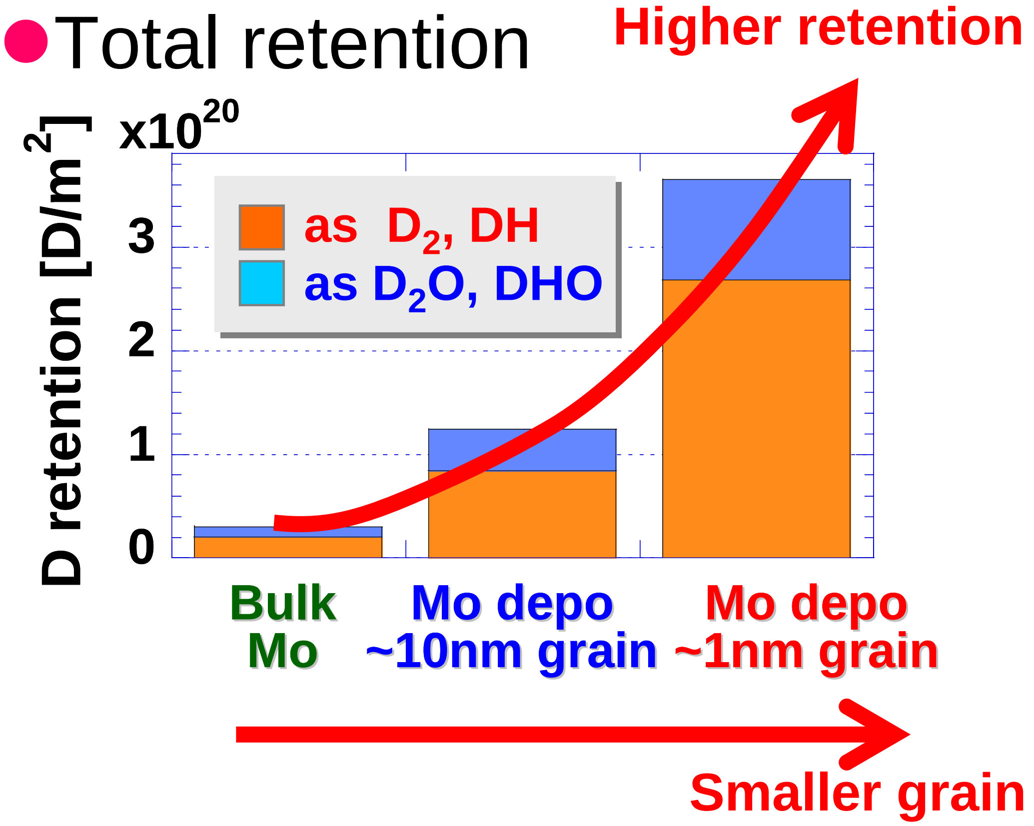
Impact of grain size on hydrogen retention

D_3^+ with 6keV is implanted to Mo bulk and Mo deposits.



Thermal desorption spectra
Fluence : 1×10^{21} D/m^2

● Total retention



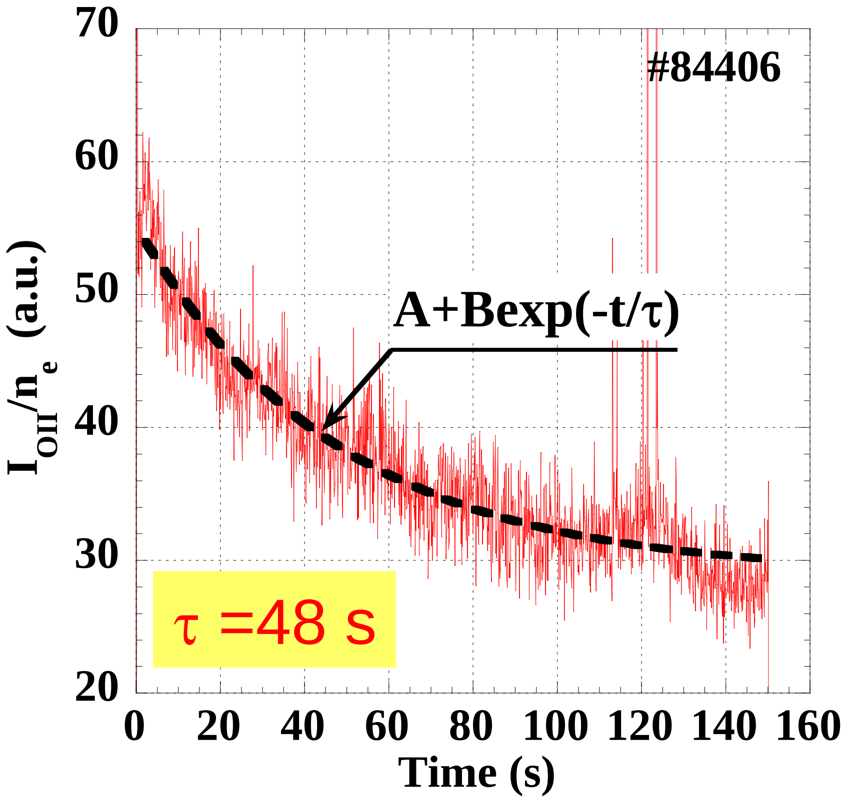
Note that the deposits with fine grains were made in a little oxygen atmosphere.

Contents

- Introduction
- Wall Recycling Structure
- Global Particle Balance
- Hydrogen Retention in Co-deposits
- **Impact of an interval time between discharges**
- Summary

Impact of a repetition of discharges on wall condition is shown focusing on oxygen impurity behavior

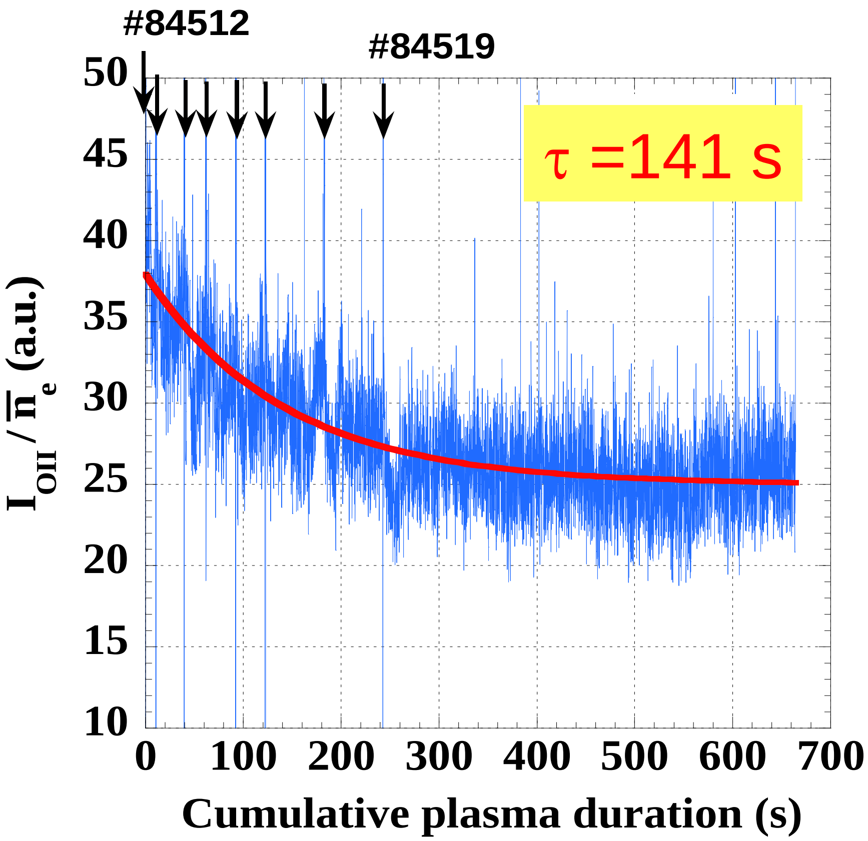
Single long duration discharge

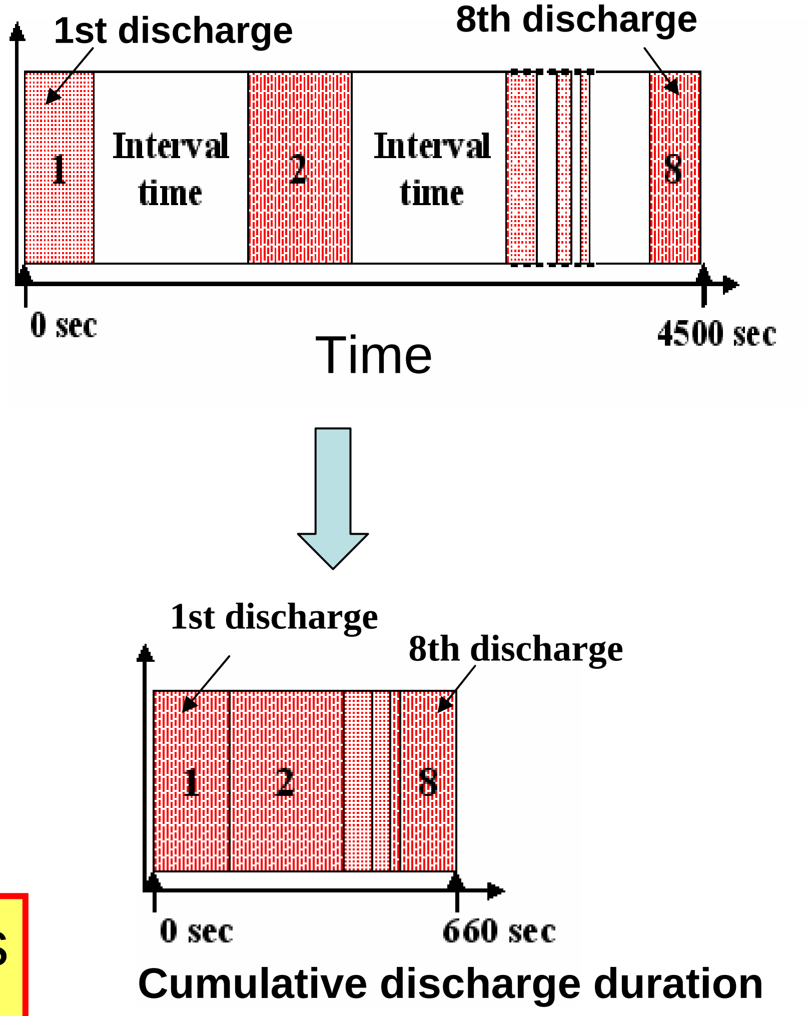


Oxygen concentration of the wall surface gradually decreases during the discharge.

Note that the data were obtained in the initial phase of the campaign.

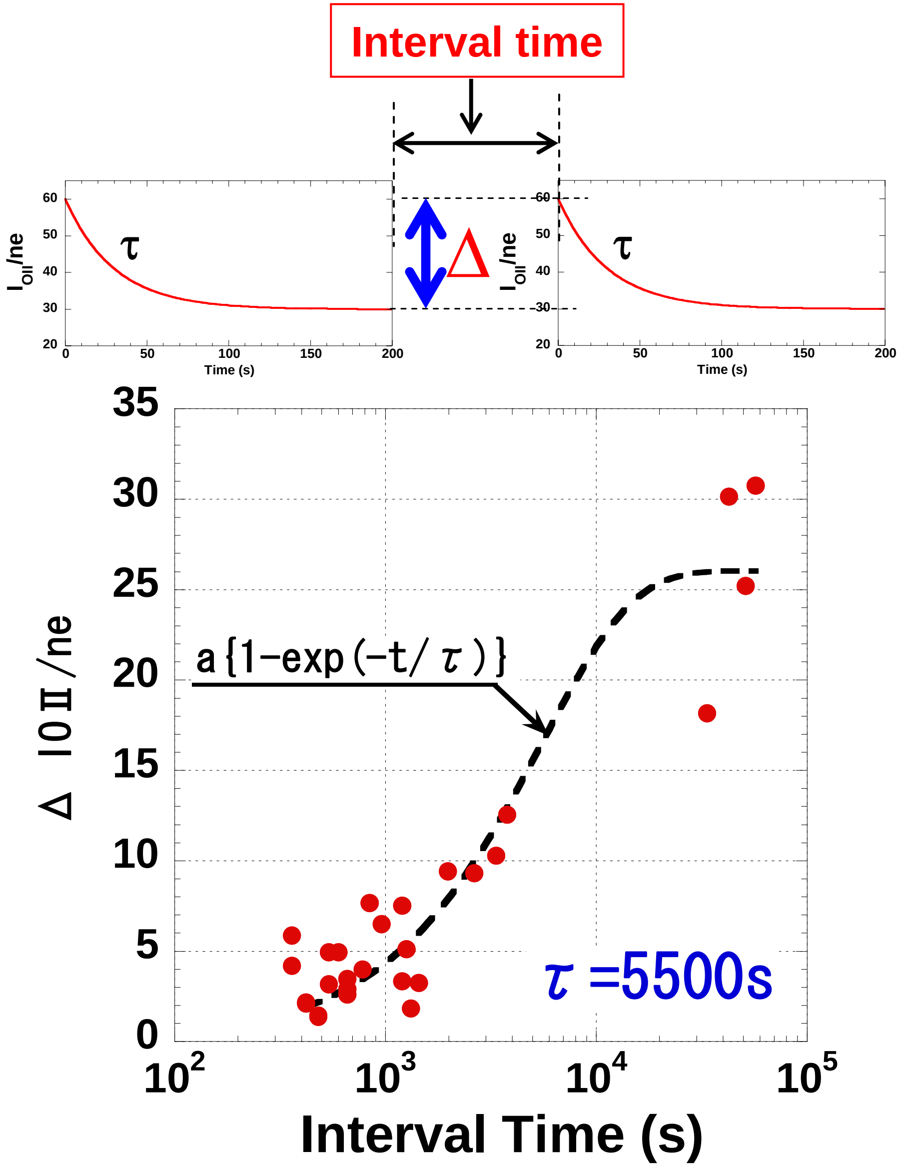
Oxygen behavior in the case of a repetition of discharges





The time constant τ is about 3 times longer than that of a single one.

Oxygen concentration on the wall surface increases during the interval time between discharges



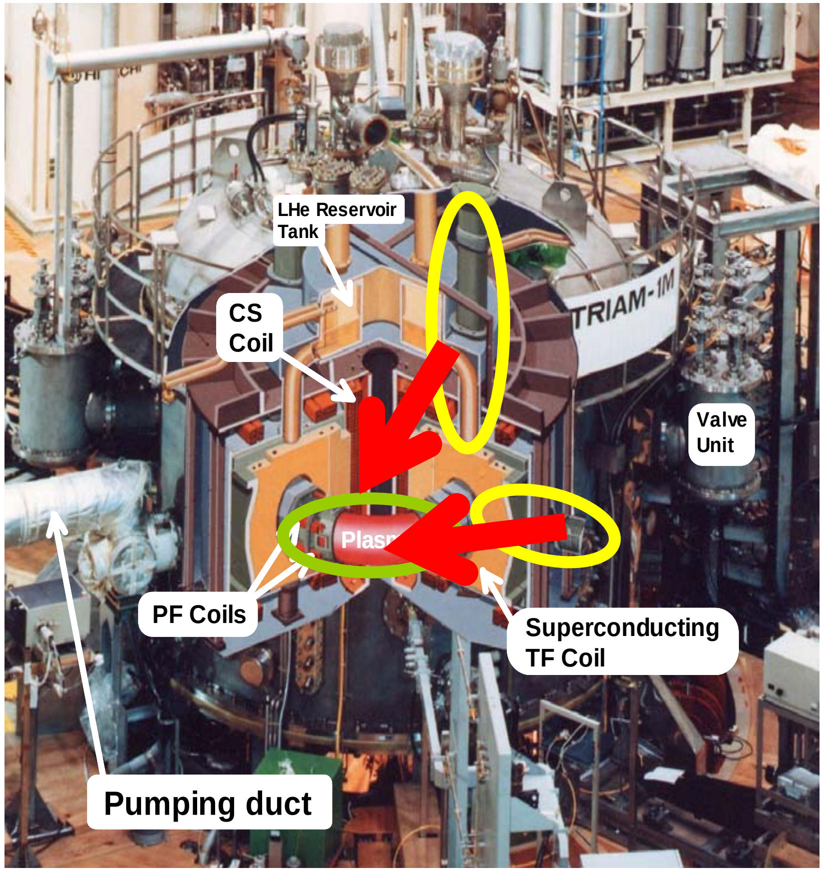
Langmuir adsorption equation

$$\frac{d\theta}{dt} = \frac{s(1-\theta)}{\sigma_m}\left(\frac{v}{4}\right)n - \frac{\theta}{\tau_a}$$

$$\Delta\theta = (1-\theta_0)\{1-\exp(-t/\tau)\}$$

K. Akaishi, J. Plasma Fusion Res. 79(2003)518.

Oxygen comes from the surface which does not face the plasma during the interval time



Bird’s-eye view of TRIAM-1M

Wall Conditioning:

(1)Baking of extension ports

and then

(2) ECR discharge cleaning for PFCs

H_2O should come from the extension ports during the interval time.

Summary

PWI phenomena have been studied from macroscopic and microscopic viewpoints in long duration discharges on TRIAM-1M.

(1) Wall recycling is localized within λ~0.3m. λ is proportional to $n_e^{-0.2}$. Neutral transport in SOL should dominate the characteristic length λ.

(2) Global wall pumping rates were estimated using a particle balance model in the case of LTW and HTW.

(3) Wall temperature is a key to dominating a wall role: particle sink or particle source.

(4) Codeposition of hydrogen with eroded metal makes a substantial wall pumping. H/Mo is comparable to that of carbon.

(5) Capability of hydrogen retention depends on a grain size of the deposits. Oxygen strongly affects the structure formation of the deposits.

(6) The wall condition continues to change not only during the discharge but also during an interval time between discharges. As for some PWI issues, a summation of short discharges can not reproduce a single long discharge.