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In-Vessel Tritium Inventory in Fusion DEMO Plant at JAERI

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Tritium Issues in Fusion Power Plant

Tritium inventory in fusion power plant relates

- Tritium inventory control
(Accountancy of T production and consumption,
Waste management)

- Source term for safety assessment
(Accidental and normal T release)

- Design basis of tritium processing plant
(Water detritiation system of cooling system,
T removal method from materials)

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Knowledge on tritium inventory is essential to safety and economical design of the fusion power plant

Objective and Outline

OBJECTIVE

- To estimate in-vessel tritium inventory in the Fusion DEMO reactor designed by JAERI
- To clarify critical tritium issue on inventory reduction or on tritium inventory control in DEMO

OUTLINE

- Clarification of difference of specification concerning T inventory issues between DEMO and ITER
- Evaluation of T inventory in DEMO
  - •analytical method •analytical conditions •analytical results
- Characterization of feature of T inventory issues in DEMO

Difference of basic specification between DEMO and ITER on T issues

Basic parameters		ITER	DEMO
Reactor operation	Fusion power	0.5 GW	3 GW(1 GWe)
	Operation	Pulse operation	Steady operation (75%/year)
	Coolant temp.	Low (<450K)	High (600~700K)
Fuel cycle	T consumption	~17 gT/day	~450 gT/day
	T production	negligible	~500 g/day(TBR=1.1)
	Site T inventory	~3 kgT	<3 kgT
Material selection	PFC	W/Be/CFC/Cu	W/F82H
	Structure	SS316/Water	F82H/Water
	BLK	various	Solid breeder /Water

H. Nakamura, Japan-US WS on Fusion Power Plant in participant of EU, 2005,Jan.11-13

T Inventory in ITER and DEMO

	ITER	DEMO
T in T plant	~1 kgT	**Same with ITER**
T in PFC	~1 kgT (0.35 kgT) Mainly in Co-deposition layer	**How much amount of T? Mainly ?**
T in coolant	<2 gT (mainly from Be FW) T concentration <<10 Ci/L*	**How much amount of T? Where from mainly? (There is rough estimation from BLK region)**
T in BLK	TBD (Maybe negligible)	**How much amount of T? (There is rough estimation)**
Key issue on T inventory	**Only the co-deposition of carbon and tritium is a critical problem in ITER.**	**What is the critical issue on T inventory in DEMO?**

*Based on the safety handling experience of tritiated water in CANDU reactor.

Evaluation of Tritium inventory in DEMO

Evaluation method

Tritium inventory evaluation

- Classified the DEMO into several in-vessel components
- One dimensional analysis for simplification
- Combined tritium transport and thermal transport analysis for one-dimensional analytical system (TMAP5 code)

Tritium transport

$$\frac{\partial C(x,t)}{\partial t} = -\frac{\partial J(x,t)}{\partial x} + \gamma C(x,t) + S(x,t)$$

$$J(x,t) = -D_{eff}(T)\left(\frac{\partial C(x,t)}{\partial x} + \frac{C(x,t)Q^*}{kT^2}\right)$$

C(x,t):T concentration, *S*:T source
J:diffusion flux, *γ*:decay constant
D_{eff}:Effective diffusivity,
*Q**:heat of transport t ,

Thermal transport

$$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (\kappa \nabla T) + S_h$$

ρ:density, C_p:heat capacity, T:temp.,
κ:thermal conductivity, S_h:Heat source

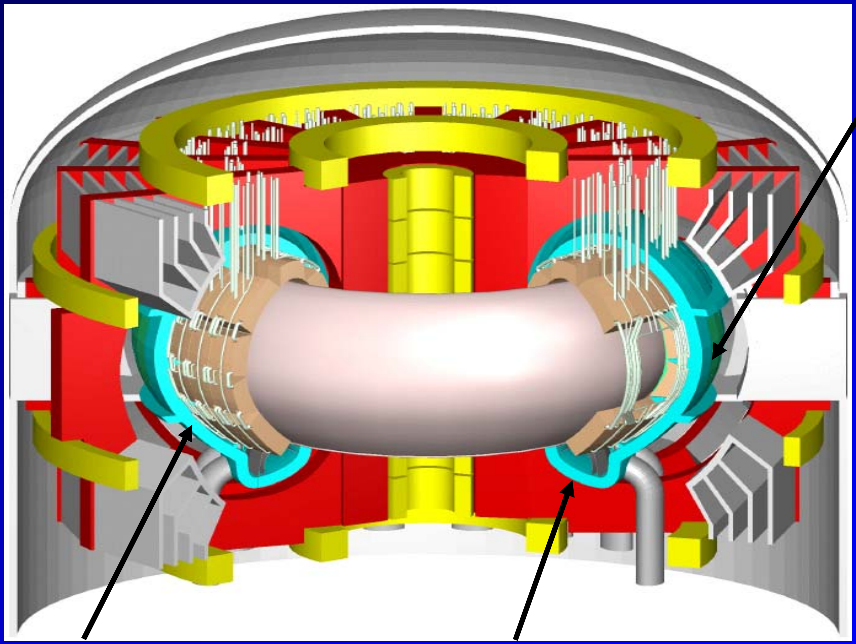
To solve tritium inventory using above analytical system
- Operational conditions (heat load, particle load,etc.)
- Tritium transport properties (Diffusivity, Solubility etc.)

are necessary

Classified In vessel components in DEMO for T inventory analysis

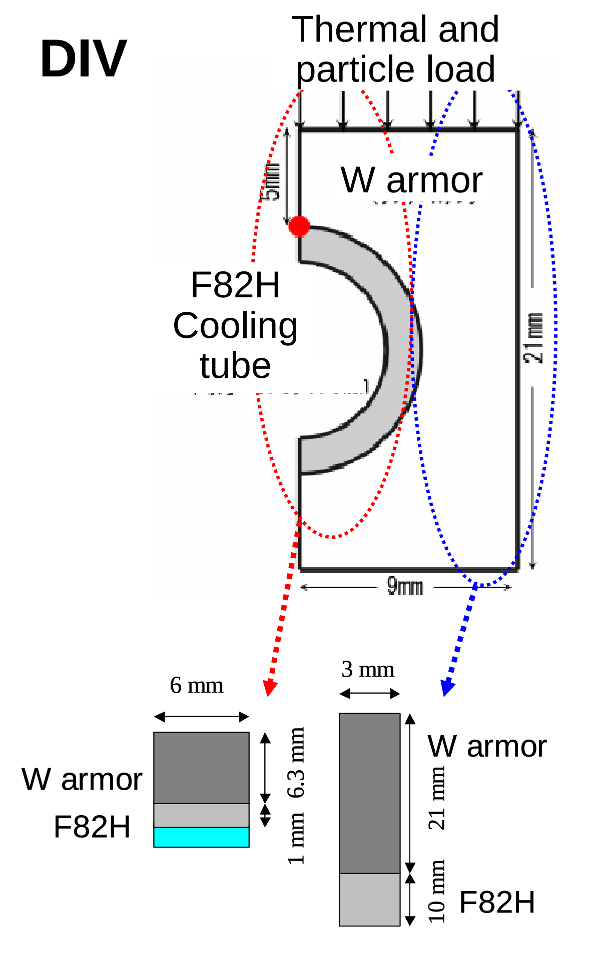
DEMO components were classified into

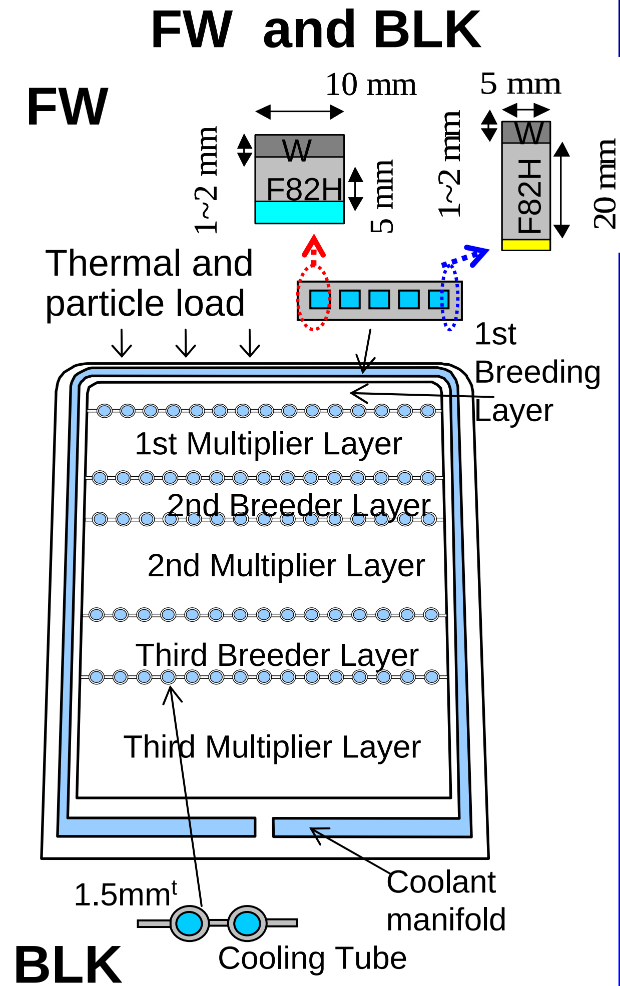
- PFC
  Divertor (DIV), **First wall(FW)**
- **Blanket(BLK)**
- **Structure material (VV)**
- **Coolant**

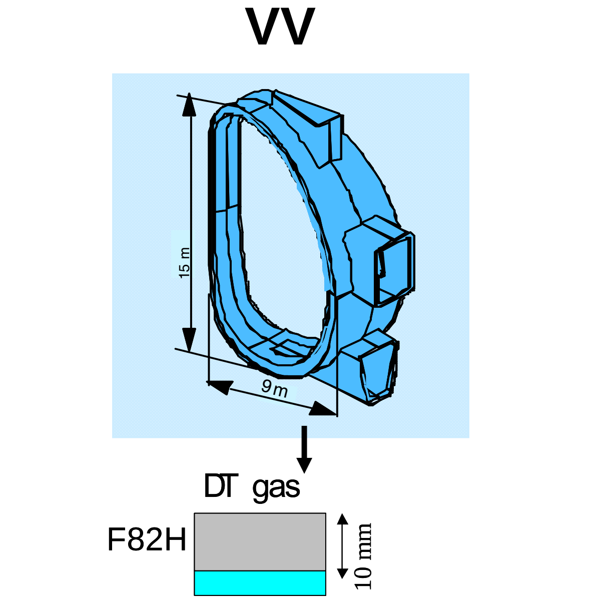


In-vessel component in DEMO

Detail of classified in-vessel components in DEMO







Coolant

T inventory in coolant is evaluated by permeation from the components

Operating conditions of the in-vessel components of DEMO

DIV

	Thermal load (heat flux/Temp.)		Particle Load	
	PFC	coolant	Flux	Range
DEMO	7/1273	473	3×10^{23}	2.5nm

VV

	Thermal load (heat flux/Temp.)		Particle Load
	Inner surface	coolant	T Pressure
DEMO	0/333	333	1 Pa

FW

	Thermal load (heat flux/Temp.)		Particle Load	
	PFC	coolant	Flux	Range
DEMO	0.6/773	603	3×10^{21}	2.5nm

BLK

	Thermal load (heat flux/Temp.)		Particle Load
	Cooling tube	coolant	T Pressure
DEMO	633~653	633~653	1Pa (H_2, T=1%)

Unit of parameters Heat flux: $MW/m^2/s$, Temp.: K, Flux:$DT/m^2/s$

Surface area and base materials of in-vessel components in DEMO

	DIV		FW		VV		BLK cooling tube*	
Area/material	200 m^2	W/F82H	700 m^2	W/F82H	~800 m^2	F82H	8000 m^2	glass/F82H

* Y.Kosaku et al., Fusion Sci. Technol.,41 958 (2002)

T Transport properties of in- vessel components materials

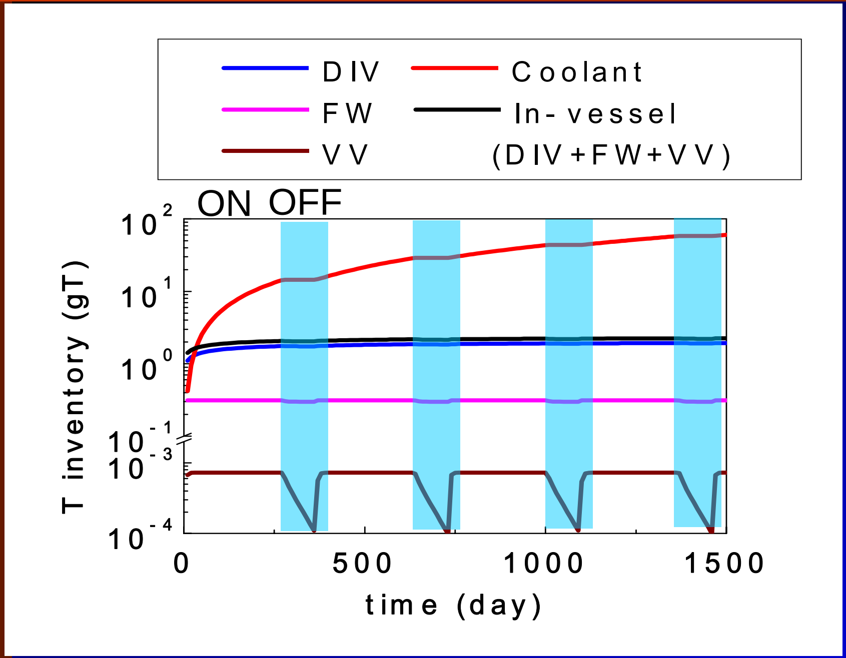
	Tungsten	F82H
Effective Diffusion coefficient (m^2/s)	$6.74\times10^{-8}\exp(-0.73eV/kT)$[*1] 10times larger in plasma facing region[*2]	$1.07\times10^{-7}\exp(-0.15eV/kT)$ $/(1+2.9\times10^{-8}\exp(0.58eV/kT)$[*5] 10times larger in plasma facing region[*2]
Solubility ($atoms/m^3/\sqrt{Pa}$)	$1.83\times10^{24}\exp(-1.04eV/kT)$[*3]	$6.21\times10^{23}\exp(-0.28eV/kT)$[*5]
Recombination coefficient (m^4/s)	$7.1\times10^{-18}\exp(-0.81eV/kT)$[*4]	$9.4\times10^{-26}\exp(-0.12eV/kT)$[*6]

* Irradiation effect was not considered in this evaluation

*1 H. Nakamura et al., JNM **297**(2001)285, *2 H. Nakamura et al., JNM **313-316** (2003) 675
*3 R. Frauenfelder, J. Vac. Sci. Technol. **6** 388 (1969) ,
*4 R. A. Anderl et al., Fusion Technol. **21** 745 (1992)., *5 E. Serra et al., JNM **245** (1997) 108,
*6 M. Enoeda et al., JAERI-tech 2001-078,

Analytical result (1)

Transient T inventory in DEMO operation



Time evolution of tritium inventory in the components and coolant during DEMO operation (except BLK).

DIV:1μm W coating on the cooling tube

FW: 1mm W coating

- Tritium inventory in the components and permeation into the coolant will reach at saturation level and steady state within one year operation of DEMO, respectively, while permeation in ITER will not reach steady state even after 3 years operation*

- Tritium inventory and permeation in DEMO is quite faster to reach steady state than the ITER case due to steady state operation, higher operation temp. and ferritic steel (F82H) structure.

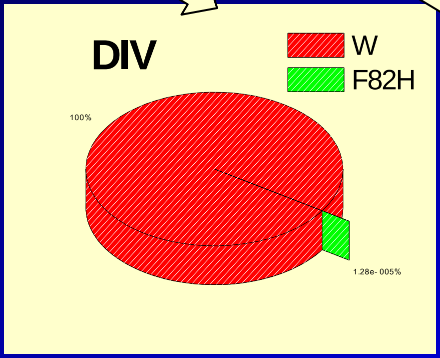
*H. Nakamura et al., JAERI-Research 2003-024 (2003). and JNM 329-333 (2004) 183

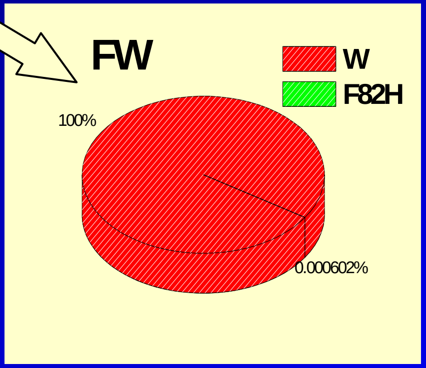
Analytical result (2)

T inventory in in-vessel components

Tritium inventory in the components at saturation level
(Those results didn't include neutron irradiation effect)

DIV	FW	BLK	VV
~1.5gT	~0.3gT	~1.2 gT* (Li_2O case)	~mgT





Breakdown of T inventory in materials for DIV and FW

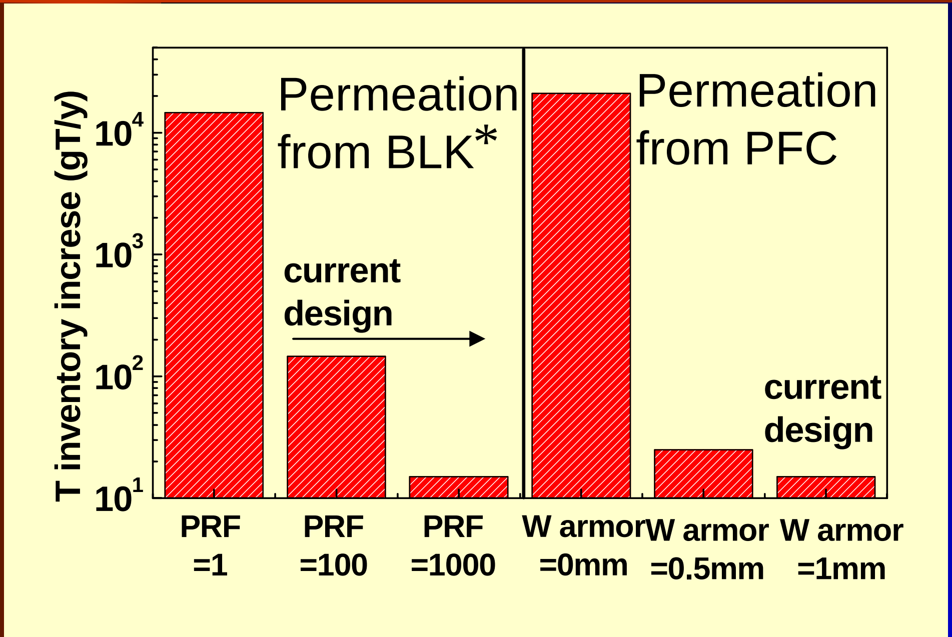
- Tritium in the components mainly exists in the DIV (armor region) and BLK.

- Total T inventory in the in-vessel components is ~gT. It is negligible smaller than ITER case(1.2kgT) due to carbon free PFC in DEMO.

Tritium inventory in the components will not be a critical issue in DEMO

* M. Enoeda et al., Nuclear Fusion, **43** 1837 (2003)

T inventory in coolant(1)



Annual T inventory increase in the coolant from PFC (DIV and FW) and BLK for various permeation reduction barrier

PRF:Permeation Reduction Factor

W armor: W armor thickness on FW

- T inventory in coolant strongly depends on the permeation reduction effect of coatings on components surface.

-Current design of DEMO

FW: W coating (~mm) is necessary for the reduction of erosion of ferritic steel

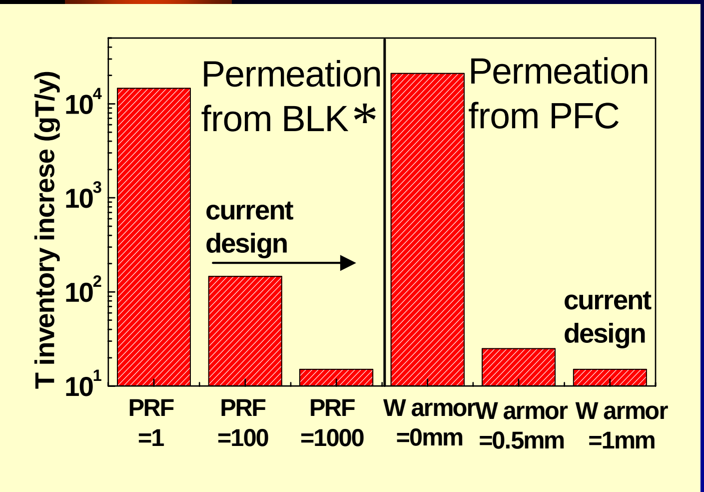
BLK: 100 or more PRF is expected by the glassy coating on the cooling tubes**

- In current design of DEMO, T in the coolant is mainly attributed to permeation from BLK region.

* Y.Kosaku et al., Fusion Sci. Technol.,41 958 (2002)

** M. Enoeda et al., JAERI-tech 2001-078 (By Nakamichi)

T inventory in coolant(2)



Annual T inventory increase in the coolant from PFC (DIV and FW) and BLK for various permeation reduction barrier

- Without permeation barrier, annual T inventory increase in the coolant will be tens kgT/y.
- Water detritiation system (WDS) can not recover such amount of tritium from cooling water even in the R&D target for DEMO.
- It means tritium will run out within one month operation of DEMO.
- It is not acceptable !!
- At least PRF=100 is required to maintain the T concentration in the coolant below 10 Ci/L/year (within R&D target of WDS capacity)

Tritium permeation reduction is a critical issue in a viewpoint of the tritium inventory control at DEMO

T Inventory in ITER and DEMO

	ITER	DEMO
T in PFC	~1.2 kgT Mainly in Co-deposition	**~1.5 gT Mainly in W armor of DIV**
T in coolant	<2 gT (20 years) mainly from Be FW	**~tens kgT/y (worst case) <200 gT/y (target value)**
T in BLK	TBD (Maybe negligible)	**~1.2 gT Mainly in the breeder**

In ITER,
- Only the co-deposition issue is a critical issue

In DEMO

-Tritium inventory in the component (PFC and BLK) will be negligible, since there are no carbon materials.

- Tritium inventory in the coolant will be a critical issue without permeation reduction method.

Uncertainties and Further analysis

We could identify the critical issue on T inventory in DEMO. There are still uncertainties, however.

Uncertainties

- T transport properties in the permeation reduction coating materials (Key issue for PRF in BLK region)
- Neutron irradiation effect on T transport properties in the DEMO components materials (Durability of coating and inventory enhancement)
- T transport mechanism at the interface between cooling tube and coolant

Further analysis

- Further evaluation in BLK region
- Evaluation of tritium migration into the secondary coolant
- Modification of evaluation with resolved uncertainties

Summary

- In-vessel tritium inventory in the JAERI-DEMO has been evaluated under the current design and operational conditions

- Based on the obtained results, the feature of tritium inventory in DEMO has been characterized by comparing with that in ITER

- Analytical results indicated that tritium inventory in in-vessel components will be negligible in DEMO.
  However, the tritium inventory in the coolant in DEMO is much greater than that in ITER.

- Establishment of tritium permeation reduction technique into the coolant is a critical issue in a viewpoint of tritium inventory control.