Agenzia nazionale per le nuove tecnologie,
l'energia e lo sviluppo economico sostenibile

Tritium migration pathway and role of the coolant purification system

Technical meeting on Plasma Physics and Technology Aspects of the Tritium Fuel Cycle for Fusion Energy

13 October 2022

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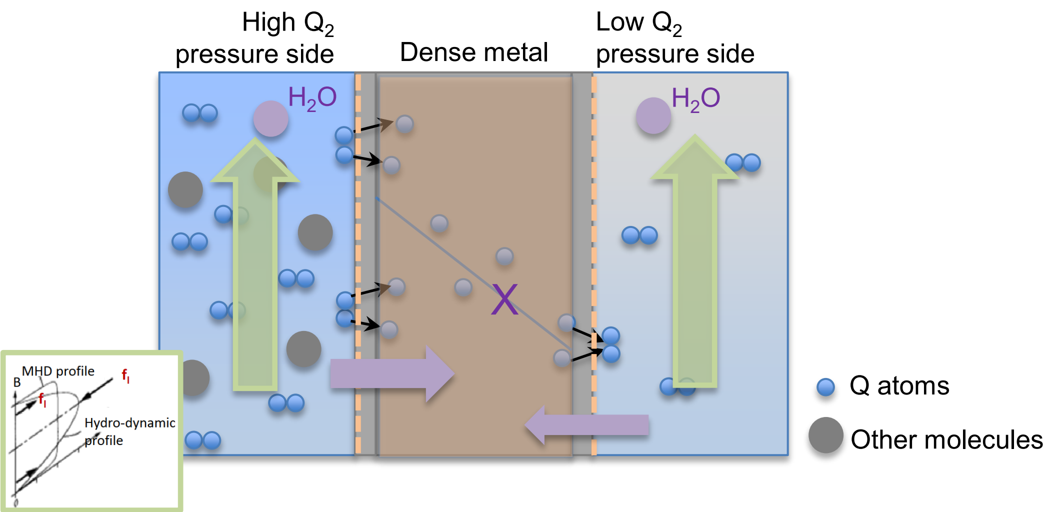
Basics on permeation

Hydrogen permeation through dense metal is a serial process which includes several steps:

- Diffusion of Q_2 molecules
- Physical adsorption of molecules on high pressure side
- Dissociation into metal surface
- Atomic diffusion by concentration gradient
- Recombination on metal surface
- Molecular desorption in gas phase
- Diffusion of Q_2 molecules



Materials

- Surface condition (i.e., oxide layer)
- Bulk defects (i.e., vacancies, interstitials, impurities, etc.)

Dynamic of the fluid

- Diffusion + convection (advection)
- Liquid metal (LiPb) + magnetic field → Magneto Hydrodynamic (MHD) effect

Others

- Chemical equilibrium btw. Q_2 and other components
- Co-permeation (or back permeation) → non-linearity in the diffusion gradient

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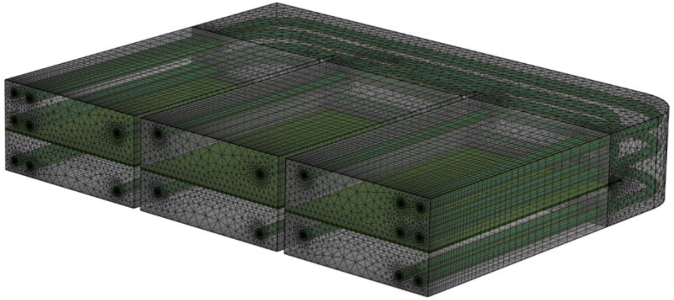
Q = H, D, T

Basics on permeation

Depending on the complexity and the extension of the problem, the permeation models can reach different levels of details

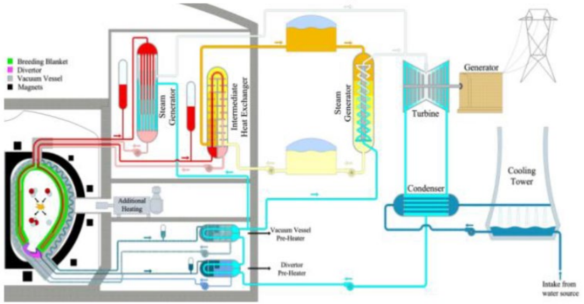
Unit Level



- ❑ Accurate description of the permeation phenomemon (physics and geometry)
- ❑ Limited extension

Output: tritium concentration profile to support the blanket design

System Level

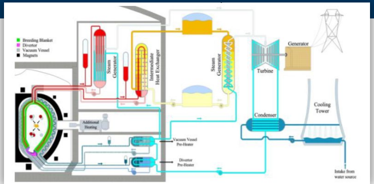


- ❑ Less accurate description of the permeation problem
- ❑ Very large extension

Output: tritium inventory and release (permeation and leaks) to support the design of several systems

Basics on permeation

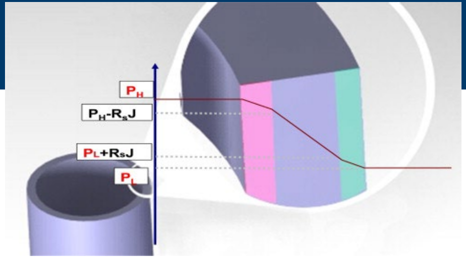
Models a system level



- ❑ Permeation is driven by the slowest phenomenon

Surface-limited: the permeation rate depends on the dissociation and recombination constants (**σ**k) and is proportional to p^1

Diffusion-limited: the permeation rate depends on solubility (S) and diffusivity (D) inside the bulk and is proportional to $p^{0.5}$



Unified permeation models $(\sigma k, D, S)$ *proportional to* p^n

- ❑ "Database" (scientific literature) of hydrogen transport parameters for breeder blanket and steam generator functional materials (RAFM = Reduced Activation Ferritic Martensitic Steel, like Eurofer or Incoloy)

Table 1: Overview of the most relevant & recent papers on hydrogen permeation through structural materials (inverse chronological order)

First Author (Year) [Ref]	Interest – Main outcome
Calderoni (2011) [3]	Measurement of permeability on Incoloy for VHTR applications with H_2 diluted in He (tritium tests are also ongoing)
Esteban (2009) [4]	Measurement of permeation, diffusion, solubility and trapping in Glicop Al25 (ODS RAFM Cu rich alloy) and comparison with other Cu and Cu rich alloys, showing higher trapping due to ODS and alumina nanoparticules, but lower permeabilities compared to other RAFM
Esteban (2007) [5]	Measurement of permeation, diffusion, solubility and trapping in Eurofer and comprehensive comparison with literature
Takeda (2004) [1]	Measurements for Hasteloy with H and D, comprehensive comparision with literature, for application to HTR
Esteban (2002) [6]	Measurement of permeation, diffusion, solubility and surface rate constant for Incoloy 800 with bare or oxidised surfaces, showing effective barrier with oxide layer
Esteban (2002) [7]	Measurement of permeation, diffusion, solubility and trapping in Optifer and study of isotope effect with H and D
Esteban (2000) [8]	Measurement of permeability, solubility and diffusivity for Optifer with deuterium, and isotope extrapolation given full data for H, D, and T, comparison with other RAFM materials
Esteban (2000) [9]	Discussion of permeation regimes (surface-limited / diffusion-limited / intermediate), measurement of surface rate constant for Optifer with deuterium
Perujo (1997) [10]	Discussion of different measurement approaches (gas evolution or permeation), measurement of permeability, solubility and diffusivity for MANET II with H and D, discussion on oxidation of surfaces, measurement of surface constants with slightly oxidised surfaces
Perujo (1996) [11]	Measurement of surface rate constant for Inconel and 316L with tritium at low pressure (below 1 Pa), reference to other studies showing surface-limited permeation regime
Serra (1995) [12]	Theory / model of surface-limited regime, and measurement of surface rate constant for Manet, experiments show surface limited behaviour up to 10^4 Pa
Röhrig (1975) [2]	Review of high temperature alloys permeability values, and measurement over large pressure range, also studying water vapour effect

- ✓ Good agreement among the hydrogen transport parameters reported in literature
- • Missing data in "real" conditions (i.e., surface status, very low hydrogen pressure, etc.)

Outline

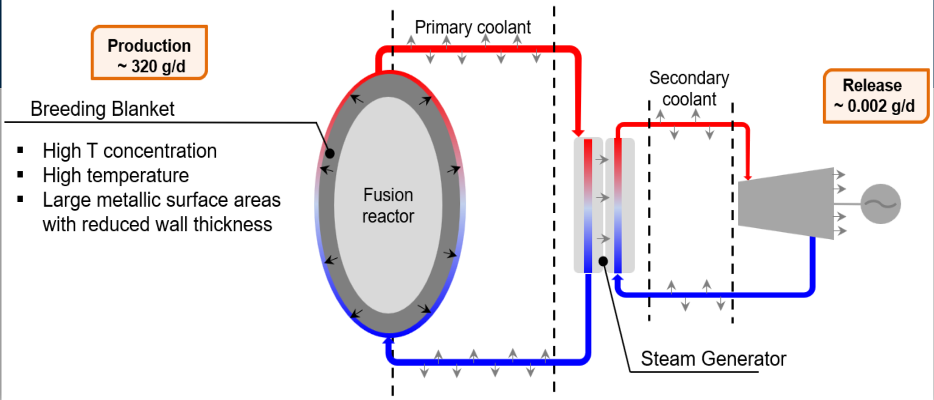
- The problem of Tritium migration in DEMO
- EDFA tasks (2012-2014)
  - FUS-TPC code
- EUROfusion (FP8) activities (2014-2018)
  - EcosimPro
  - Development of mitigation strategy to the Tritium permeation
    - Anti-permeation barriers
    - Coolant Purification System (CPS)
- KDII#2 activity (2018-2020)
  - Main results of the sensitivity analysis
- Conclusions

The problem of Tritium migration in DEMO

Two key requirements for DEMO are:

❖ The demonstration of the production of net electricity

❖ The tritium self-sufficiency



✓ need to guarantee an optimum heat transfer in both Breeder Blanket (BB) and Steam Generator (SG) regions

✓ achieve a Tritium generation rate of about 320 g $d^{-1(*)}$

✓ efficient Tritium Extraction and Recovery (TER) system, very limited Tritium losses

✓ …

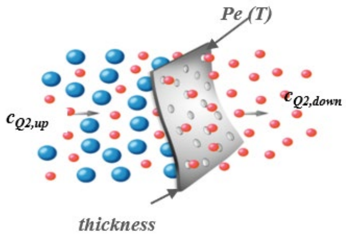
Large metallic surface areas characterized by thin wall operated at high temperature

\+

Elevated Tritium concentration

=

Perfect conditions to enhance the Tritium permeation!



(*) Value referred to a DEMO configuration having a fusion power of 2 GW operating continuously at full power day with a tritium breeding ratio of 1.05

A. Santucci et al., "The issue of Tritium in DEMO coolant and mitigation strategies", https://doi.org/10.1016/j.fusengdes.2020.111759

EFDA task (2012-2014)

1. Large literature review on:
   - State of the art and previous simulation works
   - Material data including anti-permeation barriers
   - Tritium extraction/removal processes in Processes in He, water, PbLi

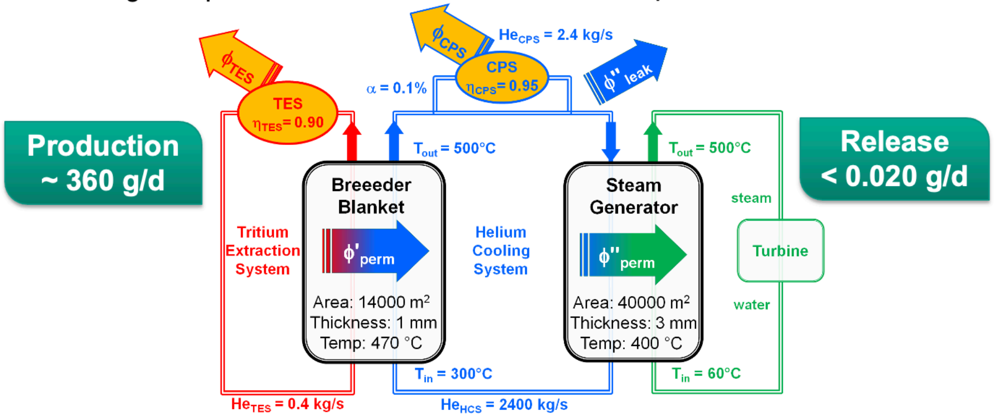
EFDA
EUROPEAN FUSION DEVELOPMENT AGREEMENT
EFDA-Power Plant Physics & Technology

Report for TA WP12-DAS-02	
Task Area:	DAS - Design Assessment Studies
TA Title:	In-vessel Components Design and Integration
IDM Reference:	EFDA_D_2L8QPK, v.0.1
Author(s):	D. Demange, R. Wagner (KIT-ITEP-TLK), F. Franza (KIT-INR) S. Tosti, A. Santucci (ENEA-Frascati), A. Ciampichetti (ENEA-Brasimone)

Tritium migration issue

Karlsruhe Institute of Technology

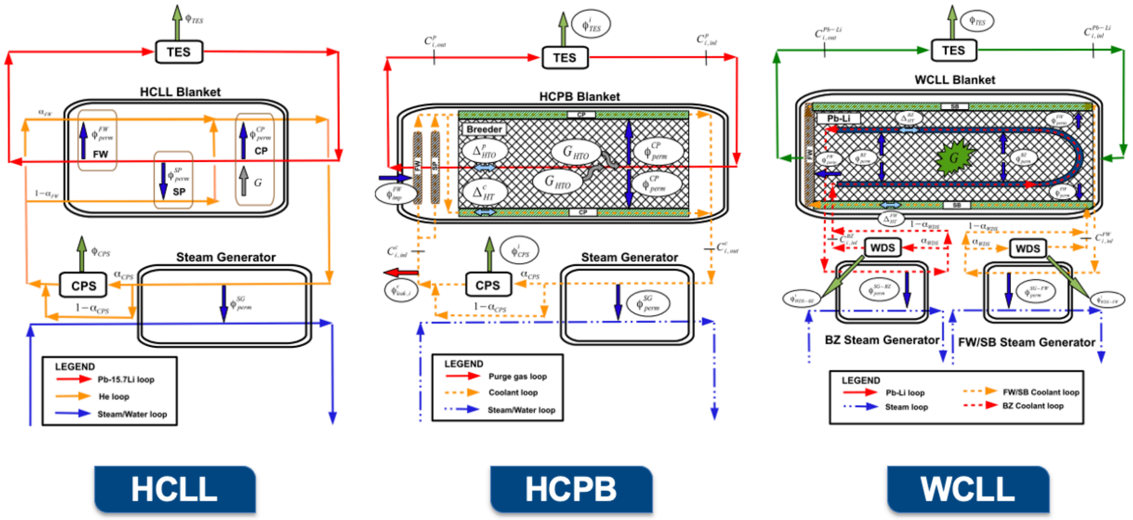
- Tritium permeation is high…
  - Large surface areas
  - Thin wall thickness
  - High temperatures
- Permeation mitigations
  - T extraction from blanket
  - T extraction from coolant
  - Anti-permeation barriers



EFDA task (2012-2014)

2. Development of a numerical tool using simplified model to simulate 3 blankets (HCPB, HCLL, WCLL) + parametric analysis

Sodium-Cooled Fast Reactors Tritium Permeation Code adapted for fusion (**FUS-TPC** under Matlab)



First example of a unified code for three DEMO blankets

F. Franza et al. *"A model for tritium transport in fusion reactor components: The FUS-TPC code", https://doi.org/10.1016/j.fusengdes.2012.01.002*
F. Franza et al., *"Tritium transport analysis in HCPB DEMO blanket with the FUS-TPC code", https://doi.org/10.1016/j.fusengdes.2013.05.045*
A. Santucci et al., "Impact of tritium solubility in liquid Pb-17Li on tritium migration in HCLL and WCLL blankets", https://doi.org/10.1109/SOFE.2013.6635438
A. Santucci et al., "Model improvements for tritium transport in DEMO fuel cycle", https://doi.org/10.1016/j.fusengdes.2015.05.050
D. Demange et al., "Tritium management and anti-permeation strategies for three different breeding blanket options foreseen for the European Power Plant Physics and Technology Demonstration reactor study", https://doi.org/10.1016/j.fusengdes.2014.04.028

EFDA task (2012-2014)

Main outcomes of the sensitivity analysis

Table 56: Compilation of different scenarios for WCLL

Regime BB	Regime SG	Sieverts	Eta TES	Eta WDS	Alpha WDS	Total T Inv.	T losses
			no-dim	no-dim	no-dim	[g]	[Ci/d]
DF [10]	DF [1]	SOLE	0.8	0.9	0.001	19.57	70.85
DF [10]	DF [1]	Reiter	0.8	0.9	0.001	23.29	618.86
DF [100]	DF [1]	SOLE	0.8	0.9	0.001	19.60	8.96
DF [100]	DF [1]	Reiter	0.8	0.9	0.001	25.11	158.93
DF [10]	DF [1]	SOLE	0.8	0.6	0.03	19.48	4.51
DF [10]	DF [1]	Reiter	0.8	0.6	0.03	21.31	82.34

Table 31: compilation of scenarios for HCPB

Regime BB	Regime SG	Eta TES	Eta CPS	Alpha CPS	Leakage	He leaks	SG perm.
		no-dim	no-dim	no-dim	no-dim	Ci/d	Ci/d
DF [20]	SL [clean]	0.95	0.95	0.01	0.044	0.02	10.1
DF [20]	SL [clean]	0.8	0.8	0.01	0.044	0.02	13.8
DF [20]	SL [clean]	0.8	0.8	0.007	0.044	0.03	18.9
DF [20]	SL [clean]	0.8	0.8	0.005	0.044	0.04	25.2
DF [20]	SL [clean]	0.8	0.8	0.01	0.80	0.40	13.8
DF [20]	SL [clean]	0.8	0.8	0.007	0.80	0.55	18.9

[PRF=Permeation reduction Factor]

Need of a Coolant Purification System

TES efficiency ≥ 80%

- On simulation works
  - Different design input data, assumptions, simplifications, etc.
- On materials
  - Large uncertainty in the tritium solubility value (i.e., Sieverts' constant) in LiPb (2 o.o.m.) → large impact on T permeation and inventory
  - Need of effective anti-permeation (anti-corrosion) barriers
- On processes
  - Efficient tritium extraction system (eta TER ≥ 0.8). Very demanding especially for T extraction from LiPb
  - Helium CPS, Technology for T recovery from He → He cooled fission can be relevant
  - Water CPS, T processing from water at large scale is energy consuming

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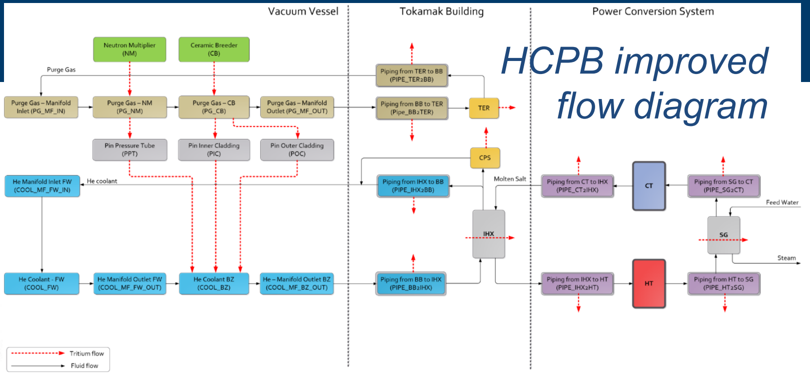
    - EcosimPro
    - Development of mitigation strategy to the Tritium permeation
        - Anti-permeation barriers
        - Coolant Purification System (CPS)
- KDII#2 activity (2018-2020)
    - Main results of the sensitivity analysis
- Conclusions

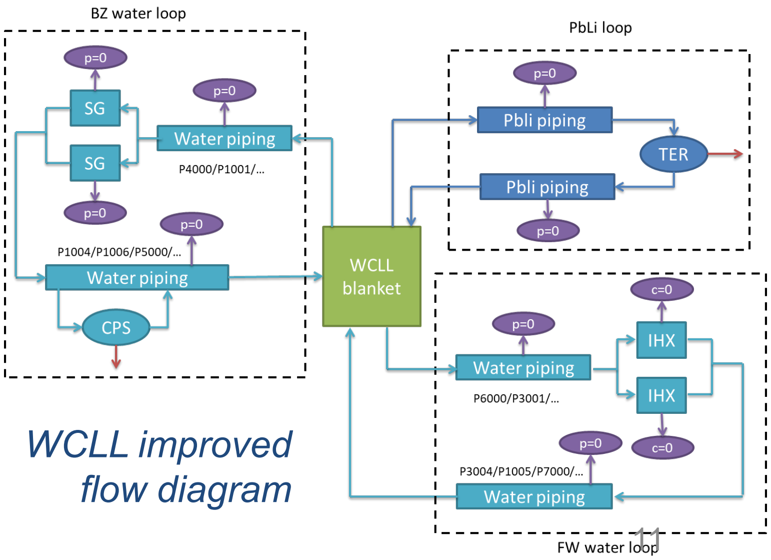
EUROfusion (FP8) activities (2014-2018) - EcosimPro



The tritium transport analysis at system level has been implemented in Model implemented by CIEMAT using the object-oriented modelling software EcosimPro

Laboratorio Nacional de Fusión
Ciemat

- ✓ Integration of the secondary coolant (IHX and/or SG)
- ✓ Tritium permeation through pipes into rooms
- ✓ Introduction of H_2, HT, T_2 co-permeation
- ✓ Effect of doping agent (i.e., H_2 and H_2O) in purge gas and in primary coolants
- ✓ Updated design



Uncertainty of the tritium transport property in the molten salt (HITEC salt) used in the IHX

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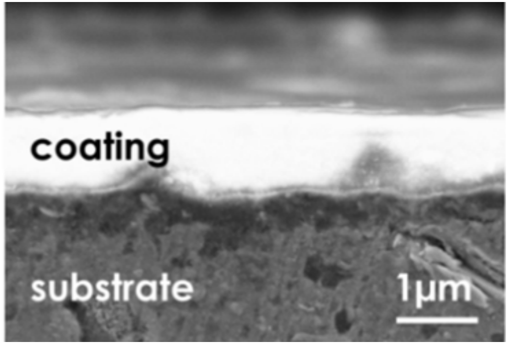
EUROfusion (FP8) activities (2014-2018) – mitigation strategy to the Tritium permeation

About the strategy to mitigate tritium permeation, two main activities are carried out

✓ Anti-permeation barriers
(i.e., dedicated coatings or natural oxide layer)

$$PRF = \frac{J_{Q_2,bare}}{J_{Q_2,coated}}$$

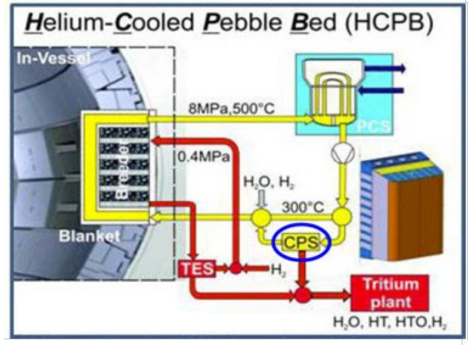


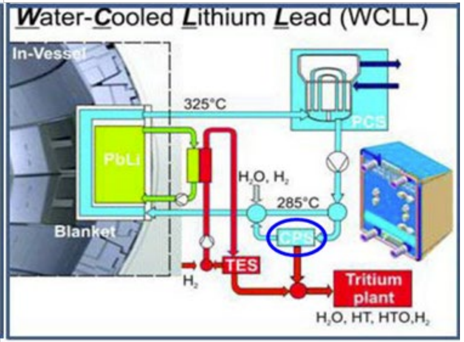
Taken from D. Iadicicco et al., Efficient hydrogen and deuterium permeation reduction in Al_2O_3 coatings with enhanced radiation tolerance and corrosion resistance, Nucl. Fusion 58 (2018) 126007

✓ Coolant Purification System (CPS)

$\alpha_{CPS} \rightarrow coolant\ fractiony\ inside\ CPS$

$\eta_{CPS} \rightarrow CPS\ efficiency$

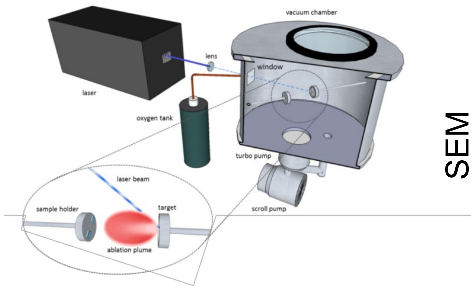




EUROfusion (FP8) activities (2014-2018) – mitigation strategy to the Tritium permeation

Development of anti-permeation barriers

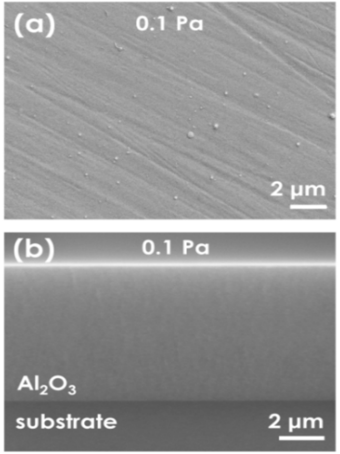
Mainly Al_2O_3 coatings deposited with different techniques (PLD: Pulsed Laser Deposition and ALD: Atomic Laser Deposition)



PLD: Pulsed Laser Deposition

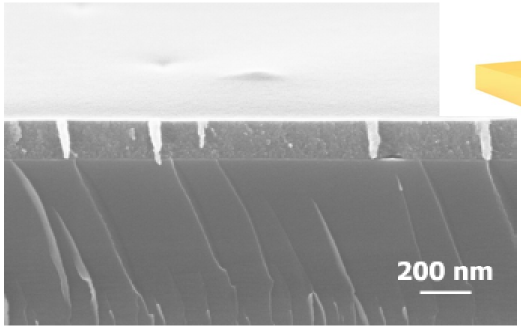
SEM surface

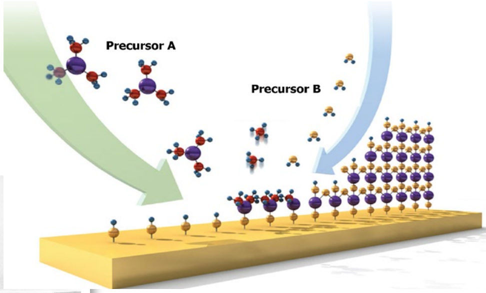
SEM cross-section



ALD: Atomic Laser Deposition

SEM cross-section of ALD Alumina film grown at 177°C.





D. Iadicco et al. Fusion Engineering and Design 146 (2019) 1628–1632
P. Munoz et al. Journal of Nuclear Materials 512 (2018) 118-125
D. Iadicicco et al. Nuclear Fusion 58 (2018) 126007

The coatings (ALD better than PLD) show:

- ✓ Continuous and homogeneous structure
- ✓ Absence of defects, pinholes or cracks

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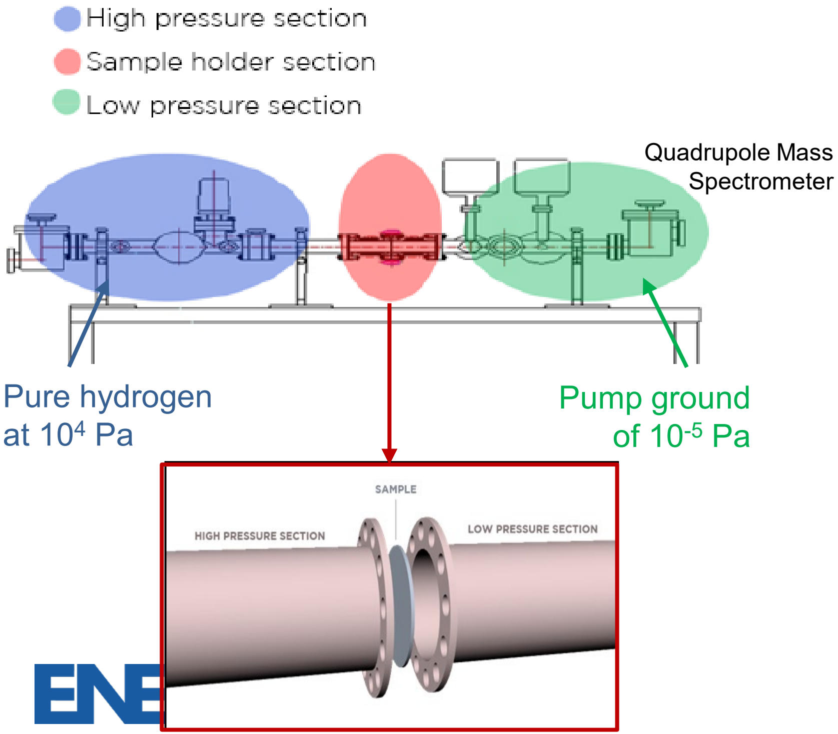
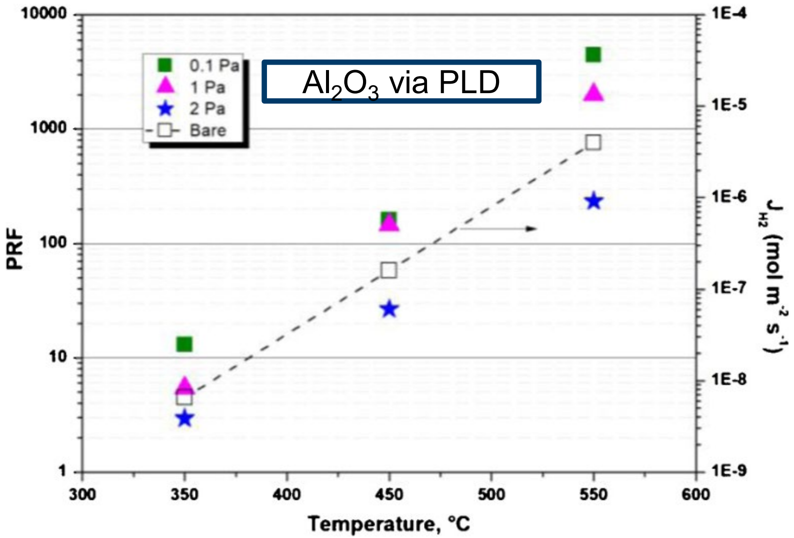
EUROfusion (FP8) activities (2014-2018) – mitigation strategy to the Tritium permeation

Development of anti-permeation barriers

H_2 permeation tests at ENEA-Brasimone



H_2 permeation flux in EUROFER 97 bare sample goes from 6.5×10^{-9} mol m^{-2} s^{-1} at 350°C up to 4×10^{-6} mol m^{-2} s^{-1} at 550 °C

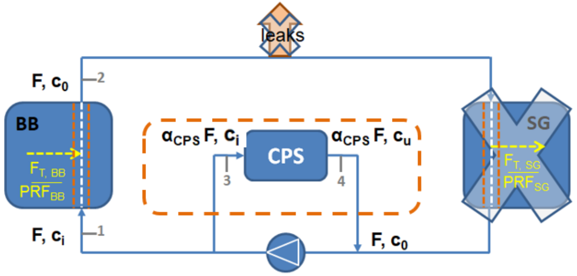


- Deposition capability in complex shapes
- Effectiveness under neutron irradiation

EUROfusion (FP8) activities (2014-2018) – mitigation strategy to the Tritium permeation

Coolant purification system

A fraction of the primary coolant (α_{CPS}) is routed inside a dedicated system, the CPS, for removing tritium with a certain efficiency (η_{CPS})



Tritium mass balance in coolant

$$\alpha_{CPS}F = \frac{F_{T,p}/PRF_{BB}}{\eta_{CPS}\left(c_0 - \frac{F_{T,p}/PRF_{BB}}{F}\right)}$$

- α_{CPS}: coolant fraction to be processed inside the CPS
- η_{CPS} : CPS efficiency
- $F_{T,p}$: tritium permeation rate from blanket into coolant
- PRF_{BB}: the Permeation Reduction Factor
- c_0: the allowable tritium concentration in coolant

Coolant flow rate inside the HCPB-CPS

Input	Value
η_{CPS}	0.9
$F_{T,p}$, g/d	0.36
PRF_{BB}	1
c_0	5×10^{-9} (*) (*) corresponding to an HT partial pressure in He-coolant of 4×10^{-2} Pa

$\alpha_{CPS}F = 1.3$ kg s^{-1}

Coolant flow rate inside the WCLL-CPS

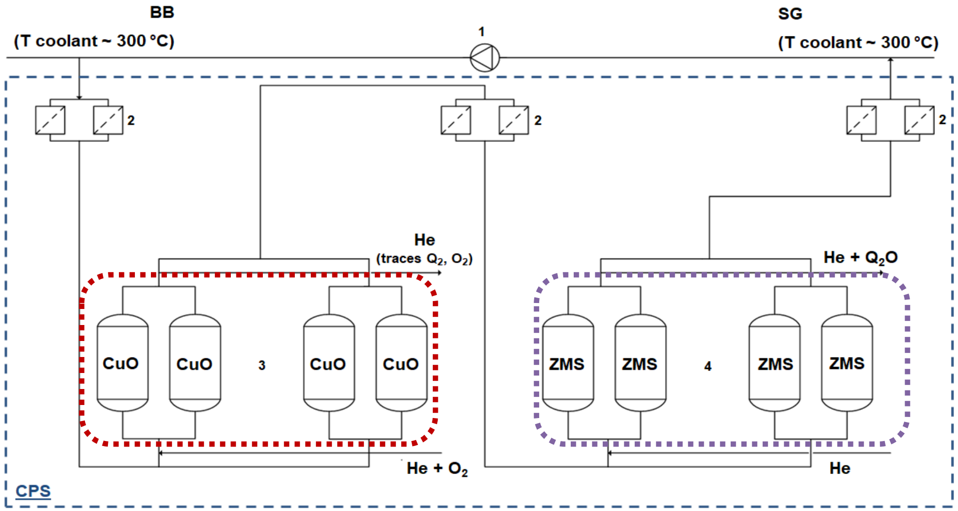
Input	Value
η_{CPS}	0.9
$F_{T,p}$, g/d	42.93
PRF_{BB}	100
c_0	3×10^{-6} (*) (*) corresponding to a T concentration inside water coolant of 1.85×10^{11} Bq kg^{-1} (5 Ci kg^{-1})

$\alpha_{CPS}F \sim 45$ kg h^{-1}

EUROfusion (FP8) activities (2014-2018) – mitigation strategy to the Tritium permeation

Helium CPS: pre-conceptual design

1st Proposal: scale-up of the ITER process



Legend
1. HCS main compressor unit
2. Filters
3. CuO beds unit
4. Zeolite Molecular Sieve beds unit

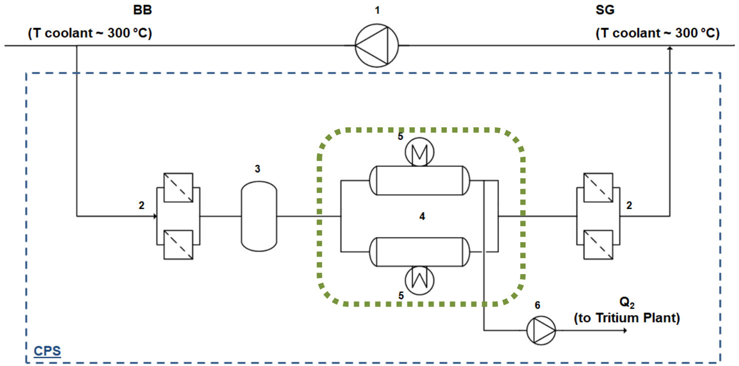
- ✓ Large, but feasible, size of the beds (CuO + ZMS)
- ✓ Impact of the H_2 content in He-coolant on the time before regeneration → $p_{H2} \leq 300$ Pa

EUROfusion (FP8) activities (2014-2018) – mitigation strategy to the Tritium permeation

Helium CPS: pre-conceptual design

2nd Proposal: based on Non-Evaporable Getters (NEGs)

	Sieverts' parameters		Embrittlement limit q_e (torr l/g)	Temperature T (K)			
				573		773	
Getter alloy	A	B		K(T) Torr/(torr l/g)^2	q_0(T) (torr l/g)	K(T) Torr/(torr l/g)^2	q_0(T) (torr l/g)
ST707	4.8	6116	20	1.338E-06	14.98	7.726E-04	0.62
ST101	4.82	7280	20	1.303E-08	151.74	2.524E-05	3.45
ZAO	5.76	7290	~100	1.090E-07	52.46	2.134E-04	1.19



Legend

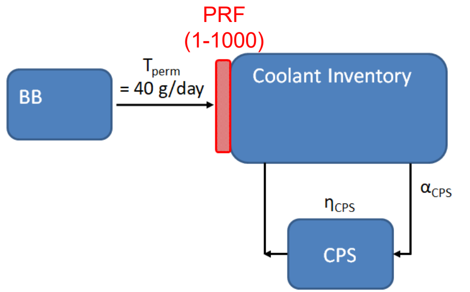
1. HCS main compressor unit
2. Filters
3. Non regenerable getters
4. NEGs beds
5. Heaters
6. External pump

✓ Among the NEGs, the ZAO alloy is the most suitable for He-CPS application

EUROfusion (FP8) activities (2014-2018) – mitigation strategy to the Tritium permeation

Water-CPS: pre-conceptual design

Case 1) Water-CPS in-line



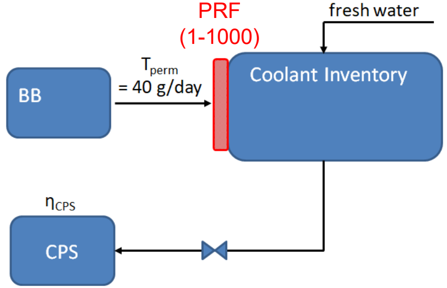
Allowable Tritium concentration in water coolant based on CANDU experience between 5-10 Ci kg^{-1}

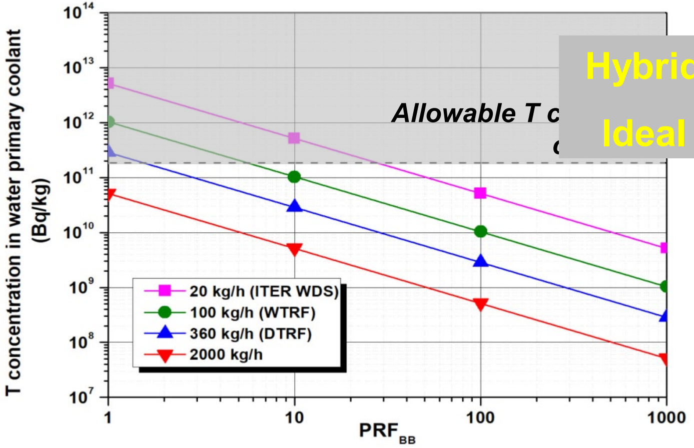
1.85 × 10^{11} Bq kg^{-1} (or 5 Ci kg^{-1})

(Still) under discussion with Safety group

See V. Narcisi poster

Case 2) Water-CPS off-line

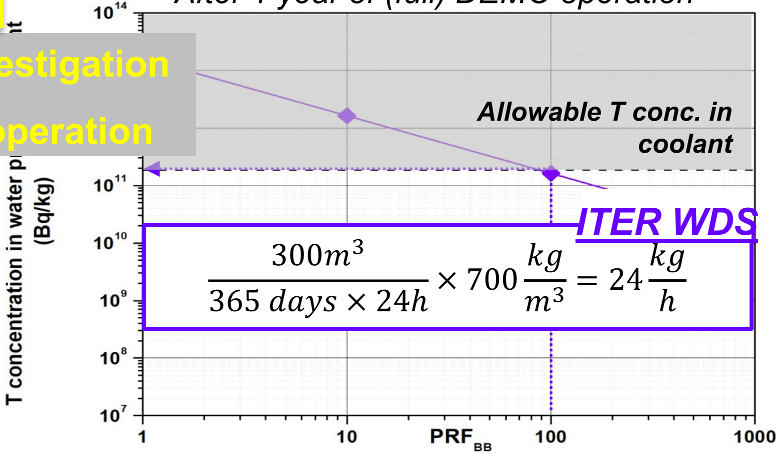




Hybrid solutions under investigation

Ideal sequence of DEMO operation

After 1 year of (full) DEMO operation



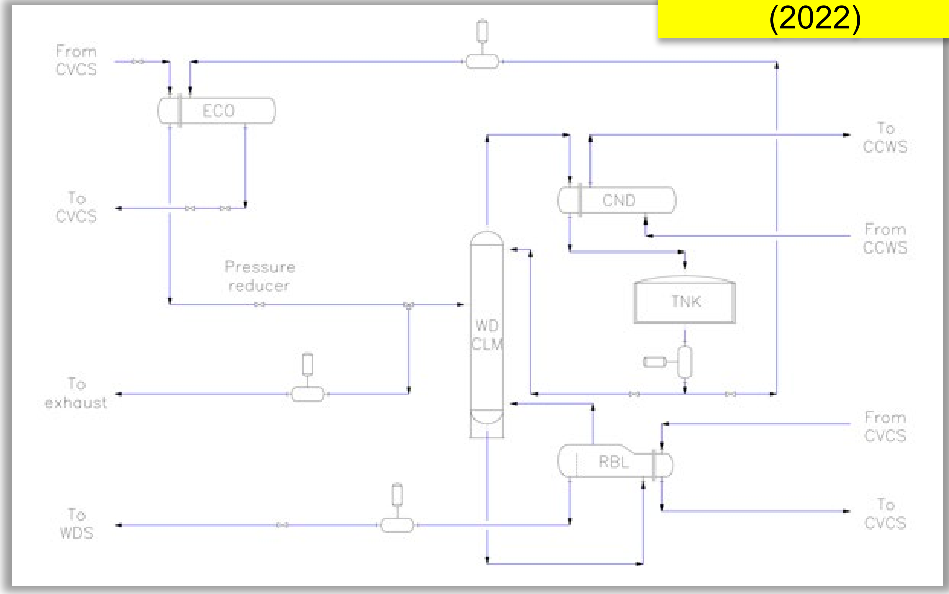
$$\frac{300m^3}{365\ days \times 24h} \times 700\frac{kg}{m^3} = 24\frac{kg}{h}$$

EUROfusion (FP8) activities (2014-2018) – mitigation strategy to the Tritium permeation

<u>Water-CPS: pre-conceptual design</u>

Water Distillation

V. Narcisi activity (2022)



- Packed column with Sulzer CY Gauze Packing
- Operative pressure: 10 kPa
- Anti-permeation barrier with PRF 100
- Tritium content in feeding flow rate: 5 Ci kg^{-1}
- Tritium content in bottom stream, sent to WDS: 100 Ci kg^{-1}

KDII#2 activity (2019-2020)

Scope of the Key Design Integration Issue (KDII) #2:

Addresses some specific issues of the design of breeding blanket and ancillary systems related to the use of helium or water as a coolants for the blanket and impact on the overall plant design

Methodoly for the Tritium migration issue:

- ❑ Collect input from different plant designers (Breeding Blanket, Tritium Extraction and Recovery, Coolant Purification system, Anti-permeation barriers, Primary Heat Transfer System, Power Conversion System, etc.)
- ❑ Identify a reference scenario and suitable ranges for the sensitivity analysis
- ❑ Perform tritium simulation analysis at system level (EcosimPro) with the most updated plant architecture
- ❑ Analise the simulation results with respect to some “Operating Limit”

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EFDA_D_2P2X46

Key Design Integration Issue #2
Summary Report 2020

Date: 07/10/2022
IDM number: EFDA_D_2P2X46

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A. Spagnuolo et al. “Key Design Integration Issue #2 Summary Report 2020”, IDM number: EFDA_D_2P2X46
A. Spagnuolo et al., “Integrated design of breeding blanket and ancillary systems related to the use of helium or water as a coolant and impact on the overall plant design”, https://doi.org/10.1016/j.fusengdes.2021.112933

KDII#2 activity (2019-2020)

WCLL

Reference case

Table 4. WCLL DEMO 2017 baseline [12].

Parameter (unit)	WCLL Case-0
CPS by pass flow rate [kg/h]	0
TER efficiency [%]	80
T permeation rate through the FW [mg/d]	0
PRF in BB [-]	100
H_2 partial pressure [ppm]	8
PRF in PbLi loop[-]	1
Leak rate at the SG/IHX [gal/d] [51]	0

Parametric scan

Table 6. Sensitivity matrix for WCLL DEMO 2017 bas...

Case ID	Parametric scan		
	Parameter (unit)	Min/ Intermediate	Max
1	CPS by pass flow rate [kg/h]	20	360
2	TER efficiency [%]	80	95
3	T permeation rate through the FW [mg/d]	0	20
4	PRF in BB [-]	1	1000
5	H_2 partial pressure [ppm]	8	100
6	PRF in PbLi loop[-]	100	1000
7	Leak rate at the SG/IHX [gal/d] [51]	3	5

Updated plant architecture

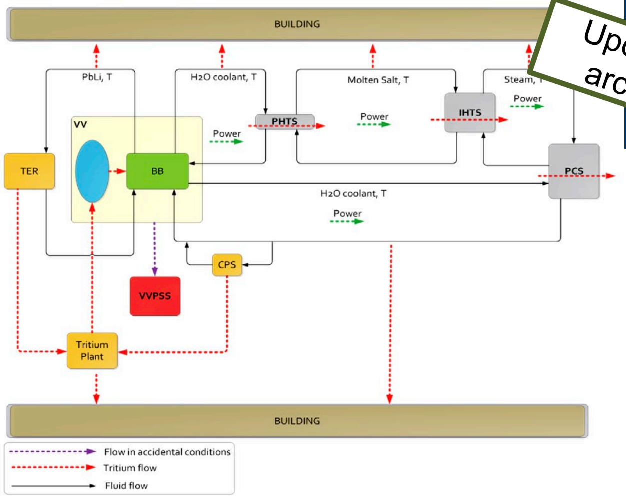

Fig. 2. Schematic drawing of the tritium and heat removal paths of the Water-cooled DEMO architecture.

Legend

BB: Breeding Blanket
CPS: Coolant Purification System
IHTS: Intermediate Heat Transfer System
PCS: Power Conversion System
PHTS: Primary Heat Transfer System
TER: Tritium Extraction System
VVPSS: Vacuum Vessel Pressure Suppression System

Vacuum Vessel | Tokamak Building | Power Conversion System

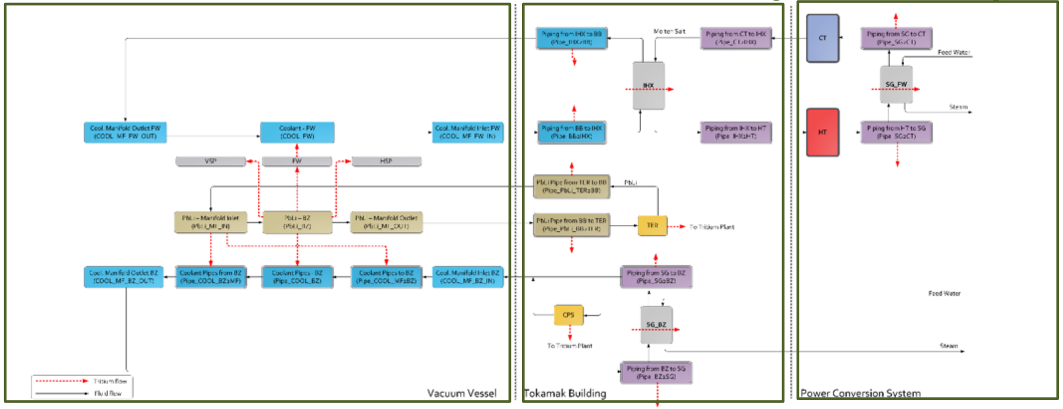

Figure 9. WCLL Breeding Blanket Schematic of Tritium Flow.

KDII#2 activity (2019-2020)

HCPB

Table 5. HCPB DEMO 2017 baseline [6...

Reference case

Parameter (unit)	HCPB Case-0
CPS by pass flow rate [kg/s]	3
CPS efficiency [%]	90
Partial pressure in He coolant [Pa]	0
He purge gas flow rate [kg/s]	0.497
TER efficiency [%]	80
T permeation rate [mg/d]	3.5
He coolant leakage frequency [% inventory/yr]	4
PRF in IHX [-]	100
Molar fraction of steam in purge gas [%]	0
Leak rate at the IHX[kg/h] [51]	0

Table 7. Sensitivity matrix for HCPB DEMO 2017 baseline [6...

Parametric scan

Case ID	Parametric scan		
	Parameter (unit)	Min/ Intermediate	Max
1	CPS by pass flow rate [kg/s]	2	4
2	CPS efficiency [%]	80	95
3	Partial pressure in He coolant [Pa]	1	300
4	He purge gas flow rate [kg/s]	0.25	0.497
5	TER efficiency [%]	80	98
6	T permeation rate [mg/d]	0	60
7	He coolant leakage frequency [% inventory/yr]	0	36.5
8	PRF in IHX [-]	1	1000
9	Molar fraction of steam in purge gas [%]	0	4
10	Leak rate at the IHX[kg/h] [51]	0.024	0.34

Updated plant architecture

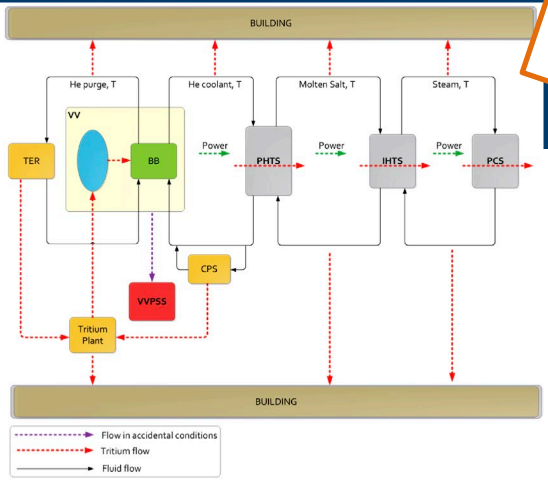

Fig. 5. Schematic drawing of the tritium and heat removal paths of the Helium-cooled DEMO architecture.

Legend

BB: Breeding Blanket

CPS: Coolant Purification System

IHTS: Intermediate Heat Transfer System

PCS: Power Conversion System

PHTS: Primary Heat Transfer System

TER: Tritium Extraction System

VVPSS: Vacuum Vessel Pressure Suppression System

Vacuum Vessel

Tokamak Building

Power Conversion System

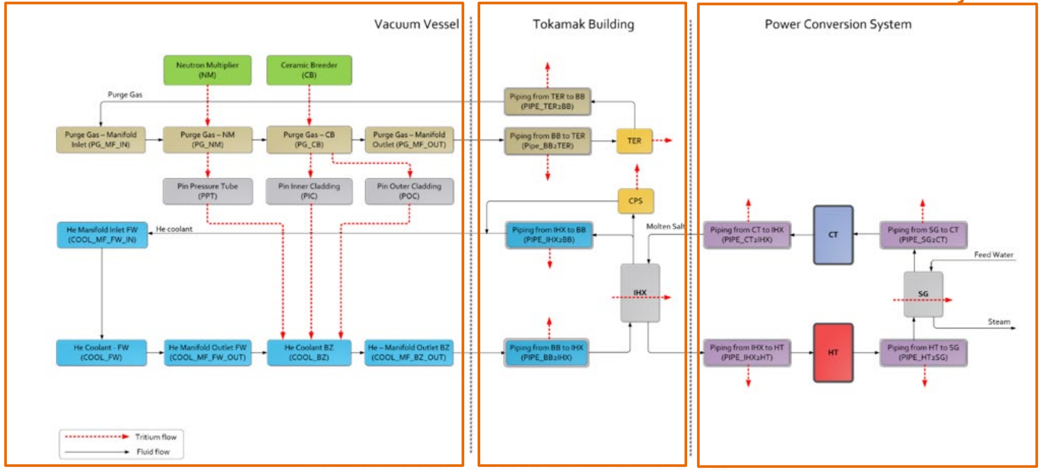

Figure 10. HCPB Breeding Blanket Schematic of Tritium Flow.

KDII#2 activity (2019-2020)

Operating limit description	Limit value*	Notes
Release in Tokamak building	**1 [g/y]**	This limit is posed on the environmental releases to the Stack. However, in this work, it is conservatively used to compare the results in term of permeation rates from the PHTS and TER piping into the Tokamak building.
Threshold to activate the Detritiation System (DS)	**10^8 [Bq/m^3]**	The limit for serving a room by the DS system depends on the concentration of tritium per volume inside the room. In ITER the threshold to switch from Heating Ventilation and Air Conditioning (HVAC) to DS is 1×10^8 Bq/m^3. (ITER_D_35YGFT v1.2). In DEMO, the same threshold for DS intervention is assumed.
Threshold for nuclear classification of the secondary/intermediate systems according to Equipment Sous Pression Nucléaire (ESPN) Directive	**370 [GBq]**	Equipment is considered nuclear equipment if: ○ It is submitted to the Pressure Equipment Directive (PED); ○ Provide confinement of radioactive nuclides for at least one of its normal operating conditions. This means that if secondary/intermediate system is not ESPN, the activity of any secondary/intermediate system component (vessels, not piping) should be kept under 370 MBq (10 mCi) during normal operation. The activity of tritium, ^{16}N and ^{17}N are divided by a factor 1/1000 according to ESPN rules, allowing consequently an increase of the total contamination of secondary/intermediate systems to 370 GBq (10 Ci).

** For a complete explanation of the values assumed for the different operating limit, please refer to:*
A. Spagnuolo et al. "Key Design Integration Issue #2 Summary Report 2020", IDM number: EFDA_D_2P2X46

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Conclusions

- Tritium migration is an important issue in DEMO
- Main contributors to the problem have been identified and activities to mitigate this issue are in placed
- Relevant experiments are on going in the FP9 to:
    - Reduce the uncertainty in the Sieverts constant in LiPb
    - Measure the Tritium permeation under “more DEMO relevant conditions” (i.e., presence of steam, co-permeation, oxidized surface, etc.)
- Tritium properties in molten salt (HITEC) still require proper investigation

Thank you!

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