Assessment of Tritium Extraction and Removal System's Design Parameters for the DEMO-HCPB Breeding Blanket

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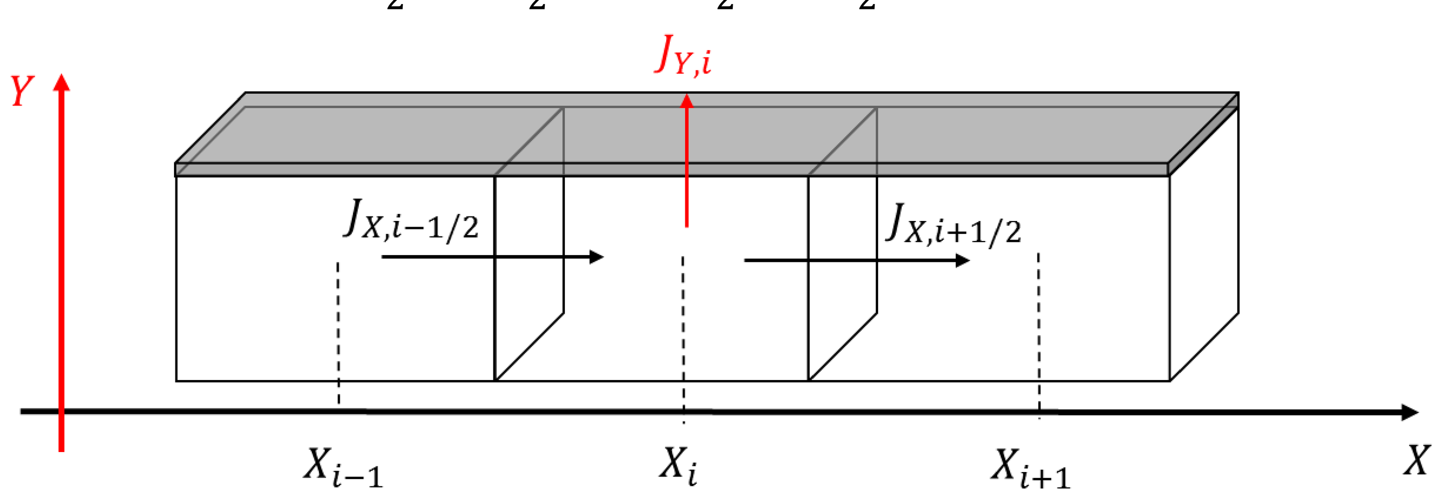
Abstract & Motivation to the work

- The tritium handling (generation, accumulation, extraction and parasitic losses) in an FPP like DEMO → important for a safe and economically-viable operation.
- HCPB BB: tritium extraction carried by a helium purge gas (PG) doped with hydrogen.
- The PG mass flow rate and the composition influence size of TERS, and plant inventories and permeation losses. → A system analysis approach is needed.
- FUS-TPC+ code → a modular and flexible Simulink frame.
- A set of parametric studies on PG mass flow rate and composition performed.

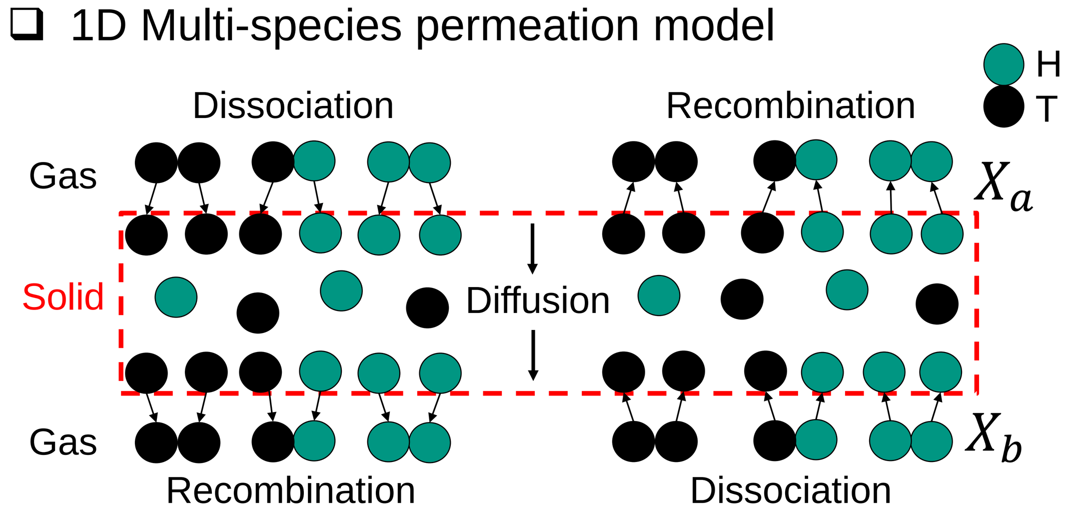
Tritium transport modelling

- Quasi 2D advection/diffusion time-dependent multi-species j transport solver, based on Finite Volume Method (FVM). X_i nodalization into discrete volumes. Local and global mass balance enforced.

$$V_i \frac{dC_{j,i}}{dt} = A_{X,i-\frac{1}{2}} J_{X,j,i-\frac{1}{2}} - A_{X,i+\frac{1}{2}} J_{X,j,i+\frac{1}{2}} - J_{Y,j,i} A_{Y,i} + \bar{S}_{j,i} + v_{j,i}$$



- 1D Multi-species permeation model



$$J_k = \sum_j a_{k,j}\left(J_{d,j} - J_{r,j}\right)$$

$$-D \left.\frac{\partial C_k}{\partial X}\right|_{X_{a/b}} = J_{k,a/b}$$

- Chemical reactions (e.g. isotope exchange → aA + bB ↔ cC + dD)

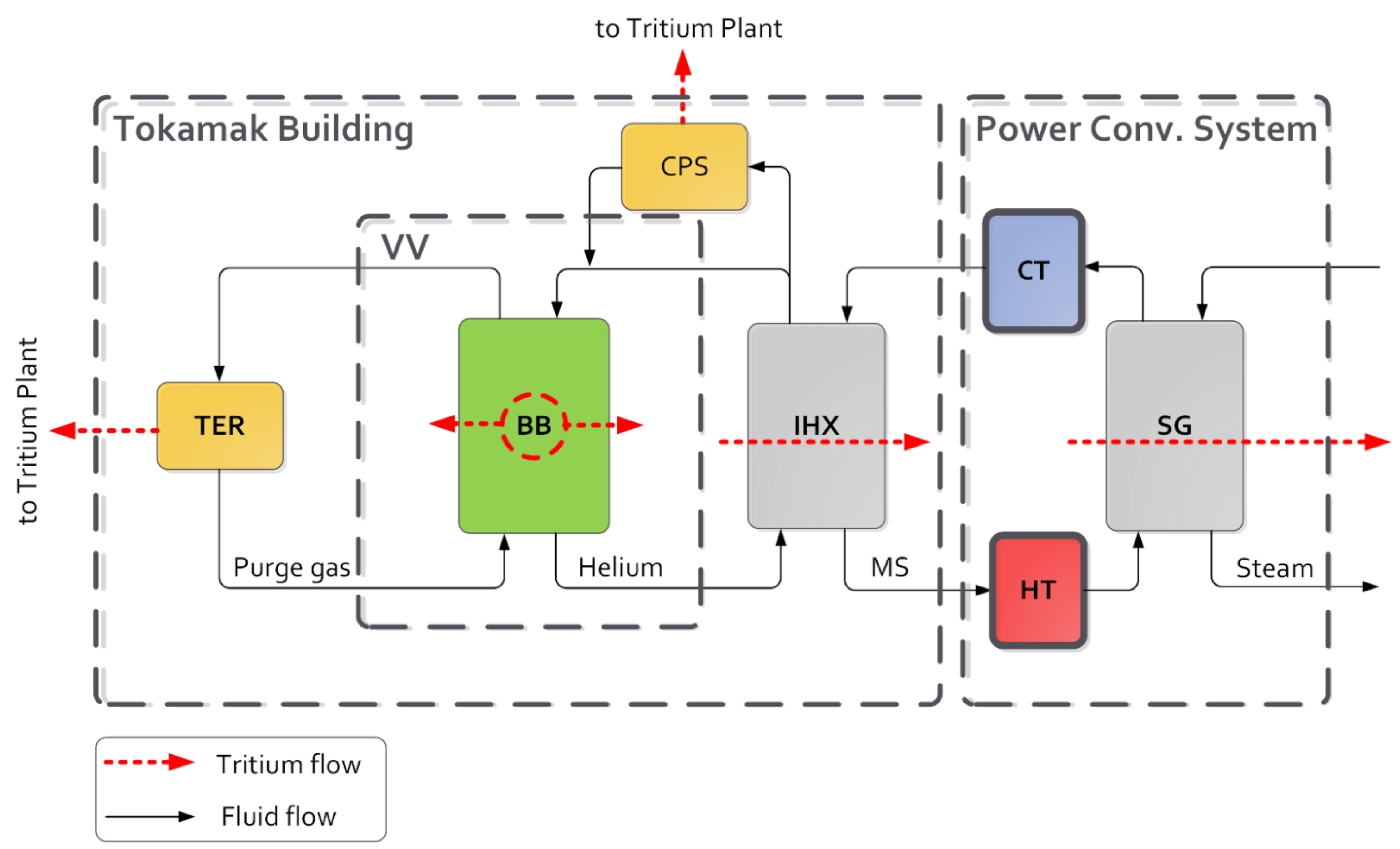
$$v = k_f [A]^a [B]^b - k_b [C]^c [D]^d = -\frac{1}{a}\frac{d[A]}{dt} - \frac{1}{b}\frac{d[B]}{dt} = \frac{1}{c}\frac{d[C]}{dt} = \frac{1}{d}\frac{d[D]}{dt}$$

Pre-built Simulink blocks for DEMO applications

- Generic 1D physical domain
- Permeator (Solid physical domain with surface flux)
- Pipe (Physical Domain + Permeator)
- Heat Exchanger (Pipe + Shell Fluid domain)

T permeation modelling of DEMO HCPB plant

- HCPB BB design concept (ceramic breeder, high pressure He coolant)
- Intermediate heat transfer system with molten salt energy storage
- Tritium extraction and removal based on low pressure He-H_2 purge gas)

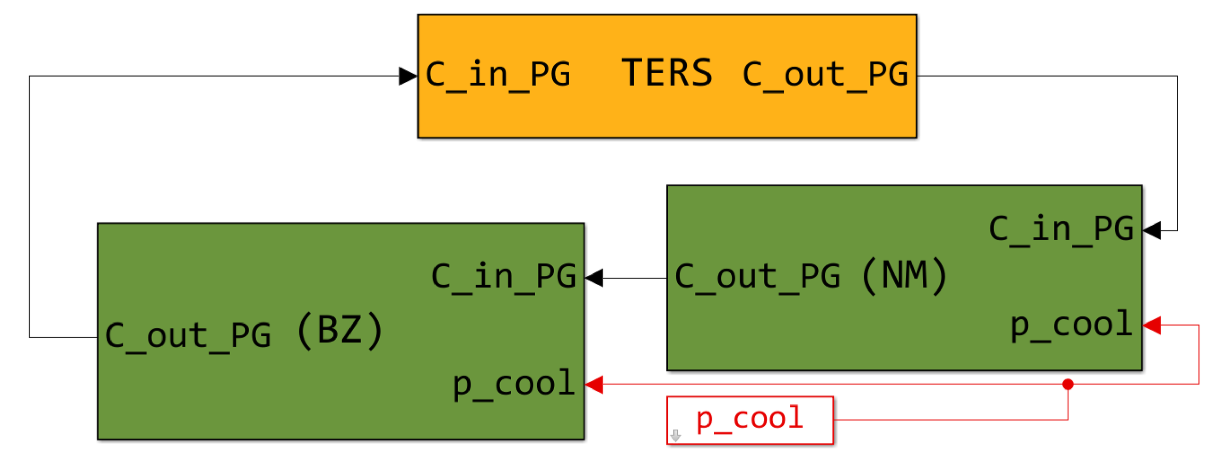


Major input parameters (DEMO 2017 baseline)

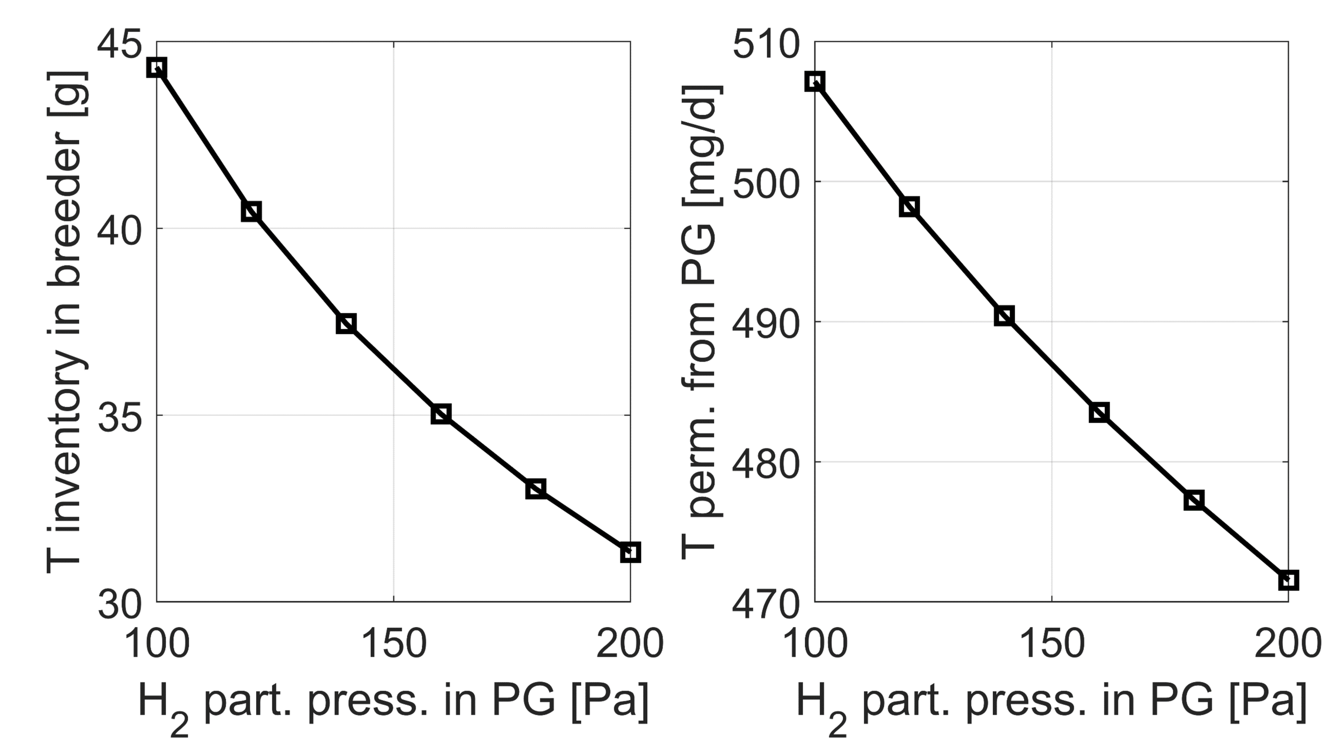
Parameter (unit)	Value
Tritium generation rate [g/d]	320
TER efficiency [%]	99.999
H_2 partial pressure in He purge gas [Pa]	200
He purge gas flow rate [kg/s]	0.497
Purge gas pressure [MPa]	0.2-0.3
T residence time in CB [hr] (EXOTIC-6)	$\tau \propto \exp\left(\frac{9729}{T}\right)\frac{1}{\sqrt{p_{H_2}}}$

Partial Simulink model for DEMO HCPB plant

- TER: Adsorption on Reactive & Cryogenic Molecular Sieve Beds
- BZ: T generation/Transport/Permeation through cooling structures
- NM: T generation/retention/permeation through cooling structures
- Assumption: fixed partial pressure from EcomsimPro calculation of H_2/HT/T_2 gas – coolant side



Effects of H_2 purge gas as doping on T inventories and permeation losses



Conclusion & Outlook

- Large impact on T inventory ($\tau_T \propto 1/\sqrt{p_{H_2,PG}}$) → + 50 %
- Moderate impact on T permeation rate:
- Extend to full DEMO plant (PHTS + IHX + SG + piping)
- Investigation of further TER design parameters (e.g. reduction of mass flow rate and steam doping of PG)

EUROfusion

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