Multiphysics modelling for Tritium transport in the WCLL Breeding Blanket

R. Testoni[a], G. Ferrero[a], J. Dark[b], E. Hodille[c]

[a]Dipartimento Energia, Politecnico di Torino, Corso Duca degli Abruzzi 24 – Torino, Italy
[b] Massachusetts Institute of Technology – Plasma Science and Fusion Center – Boston, USA
[c] Commissariat à l'énergie atomique et aux énergies alternatives, IRFM/GCFPM - Saint-Paul-lez-Durance, France

Background

The **WCLL** is one of the breeding blanket concepts proposed by Europe in view of its DEMO reactor. The **multi-physics** of the system (Fig. 1), **multi-material** domains, and **complex blanket geometry** characterize some issues in the development of a tritium transport model. However, the **prediction of tritium** concentrations and **inventories** in the blanket and the quantification of the permeation rate from the lead-lithium into the coolant is of main interest, both to guarantee fuel self-sufficiency and from a safety viewpoint. In the years, the research activity conducted by the group carried out to development of a component level analysis focused on a simplified geometry of WCLL. **No experimental data** are currently available to validate the model in its complexity. Thus, **a code-to-code comparison** has been carried out focusing on fluid dynamics, heat transfer, diffusion effects and trapping effects (PoliTo and CEA groups). Then, the **3D model** has been enriched by including trapping, buoyancy, MHD and pulsed transient.

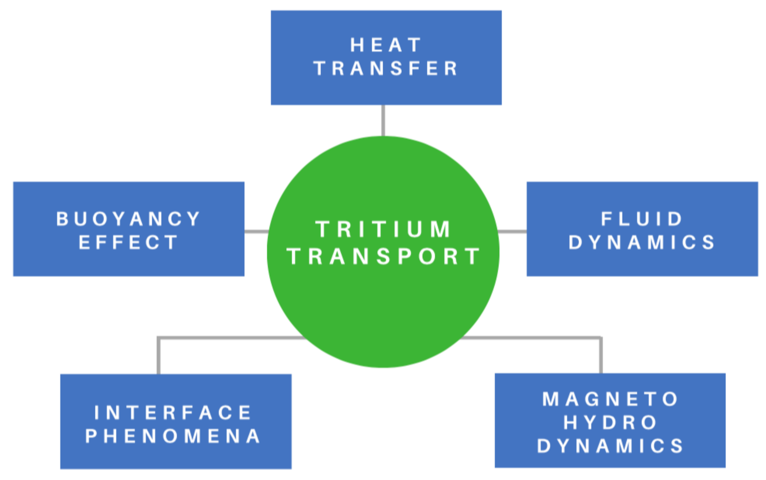
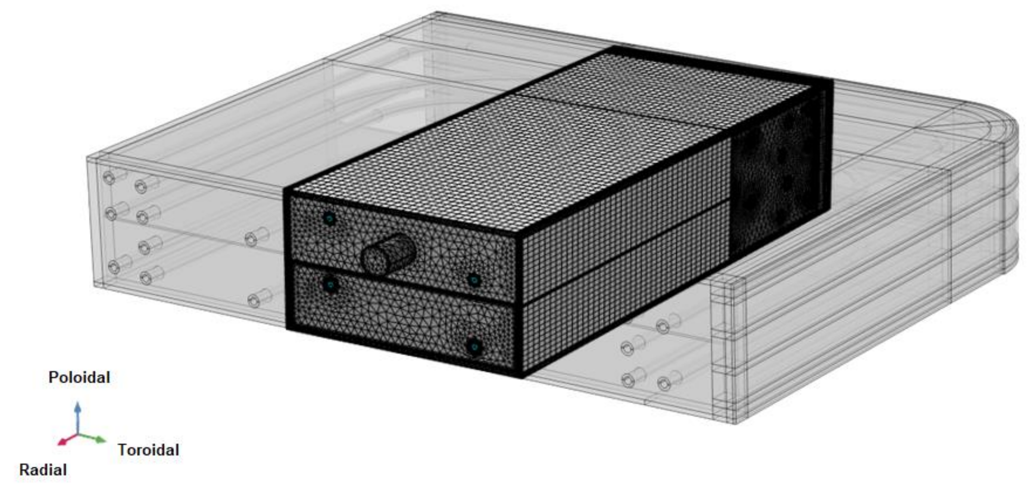
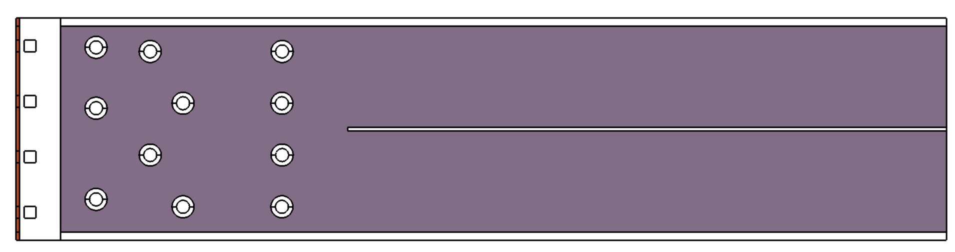


Fig. 1 Physics involved in the component level modelling.

Method of analysis



Representation of a WCLL breeder unit reference geometry (in gray) and the simulation domain (in dark) relative to the central outboard equatorial module.



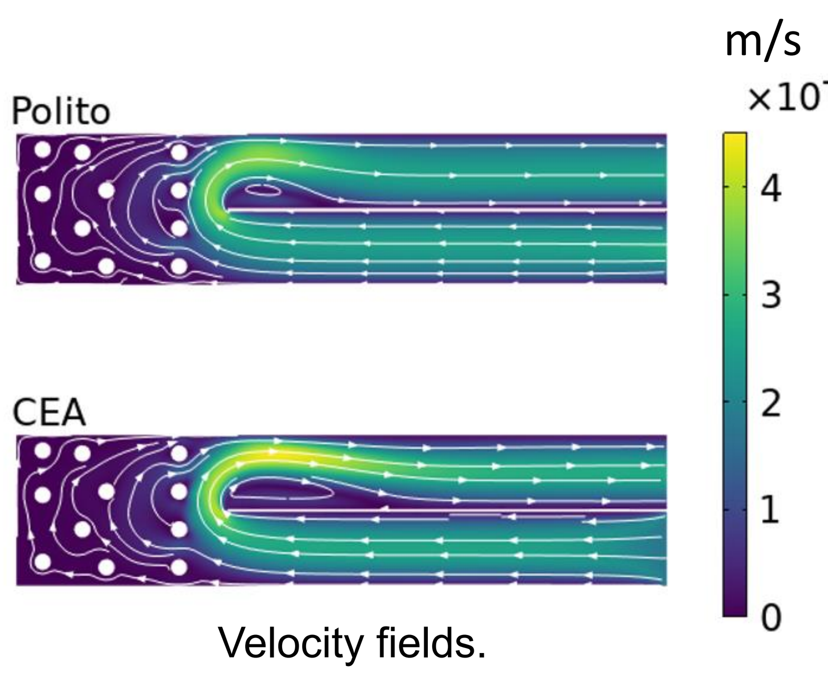
2D midboard slice employed for the code-to-code comparison

Assumptions:

- A **common input database** has been defined concerning materials properties and operational conditions.
- Volumetric power deposition and tritium generation rate has been provided by **neutronic analysis**.

Results

Code-to-code comparison between PoliTo and CEA



Velocity fields.

Material	PoliTO [atoms/m]	CEA [atoms/m]	Error %
Mobile EUROFER	$3.08 \cdot 10^{19}$	$3.12 \cdot 10^{19}$	1.3
Mobile Tungsten	$1.84 \cdot 10^{13}$	$1.99 \cdot 10^{13}$	8.2
Mobile PbLi	$2.83 \cdot 10^{21}$	$3.32 \cdot 10^{21}$	17.3
Trapped EUROFER	$7.94 \cdot 10^{18}$	$9.91 \cdot 10^{18}$	24.7
Trapped Tungsten	$1.62 \cdot 10^{14}$	$1.63 \cdot 10^{14}$	0.6
Total	$2.87 \cdot 10^{21}$	$3.36 \cdot 10^{21}$	17.1

Tritium inventory per meter of thickness for different materials

Code comparison:

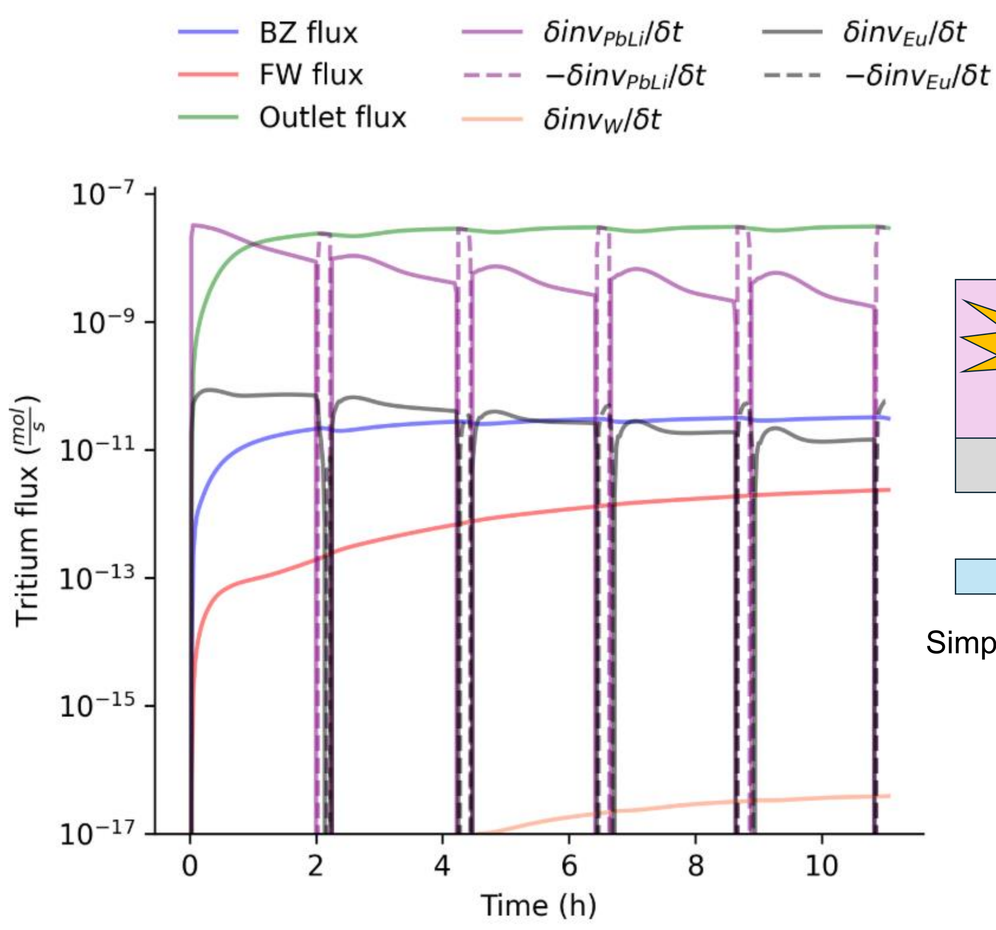
- A 2D code to code comparison has been carried out between PoliTO and CEA.
- Discrepancy on velocity fields is due to different inlet condition in the velocity setting into the two codes, and this contributes to the difference highlighted in the tritium inventories estimation.
- Some other discrepancies in the tritium inventories could be attributed to the different features of the two codes related to the setting of boundary condition (e.g. diffusion in liquid boundary layer between PbLi and Eurofer present in PoliTo code, and not in CEA one).

Despite the comparison involving a combination of different physics on a complex geometry, the qualitative behavior of the observed variables is similar, and a relative error of 17% has been found and it can be considered a suitable preliminary result.

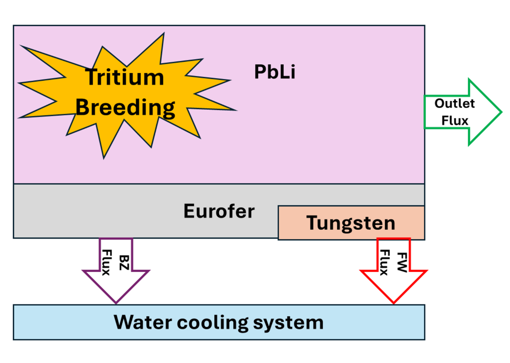
3D model WCLL BU model (PoliTo)

Main milestones of 3D model multiphysics implementation:

- 2017: heat transfer (fixed thermal heat flux at the FW) + fluid-dynamics without buoyancy + tritium transport phenomena including interface ones
- 2019: heat transfer (fixed thermal heat flux at the FW) + fluid-dynamics *with buoyancy* + tritium transport phenomena including interface ones
- 2021: heat transfer + *MHD* + fluid-dynamics with buoyancy + *volumetric heat generation rate* + tritium transport phenomena including interface ones + *tritium generation rate*
- 2023: heat transfer + MHD + fluid-dynamics with buoyancy + volumetric heat generation rate + tritium transport phenomena including interface ones + tritium generation rate + *pulsed operation condition*
- 2025: heat transfer + MHD + fluid-dynamics with buoyancy + volumetric heat generation rate + tritium transport phenomena including interface ones + tritium generation rate + pulsed operation condition + *trapping in structural materials*



Tritium balance: fluxes and time derivative of inventories during the first 5 pulses.



Simplified scheme of domains and fluxes.

Discussion:

- Modelling of Tritium transport in a 3D WCLL BU involving multi domains and Multiphysics has been carried out step-by-step.
- A consistent 3D model has been developed based on the available properties.
- Results have shown how all the physics involved have a no negligible impact in the estimation of tritium inventories. So, for an accurate analysis it is necessary to be able to validate the model.

To validate this kind of models, four aspects should be investigated more in details:

- time dependent behavior of velocity field,
- trapping behaviour under contemporary irradiation and hydrogen exposure,
- Eurofer recombination constant and surface properties with water,
- tritium permeation barriers.

Conclusions

- **Component level** modelling supports multiphysics analysis and is able to face the complexity of multi-domain systems like breeding blanket. It needs to be developed in parallel and as support of **system level** codes.
- The **issue** of the component level modelling is linked to the **lack of experiments** that should validate these models. Thus, effort on experimental campaigns should be focused both to investigate not again well understood physics and to support the modelling activity.
- The **collaboration** among the experts in different technical fields should be strongly supported in order to enhance the research and development of BB.

References

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