WPPRD-LMD 2021: PoliTo contribution

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This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Outline

- Aim of the work
- Overview of the modelling strategy
- FP8 activities completed in 2020
- Work program and status of 2021 activities
- Perspective for 2022 (and beyond)

Aim of the work

- LM **erosion** →
  - beneficial vapor shielding of the target …
  - … **but** possibly excessive **core plasma cooling/dilution**

- Target, SOL and core plasma must all be included in a **self-consistent model** to:
  - Analyze LMD experiments in tokamaks (→ interpretation, model calibration and validation)
  - Assess compatibility with EU DEMO plasma scenario and support LMD design

Aim: to develop the necessary knowledge and tools to simulate the EU DEMO plasma in the presence of an LMD using a state-of-the-art edge plasma code (SOLPS-ITER) coupled to a core transport code (ASTRA).

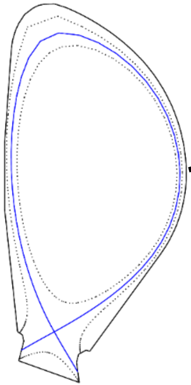
Overview of modelling strategy

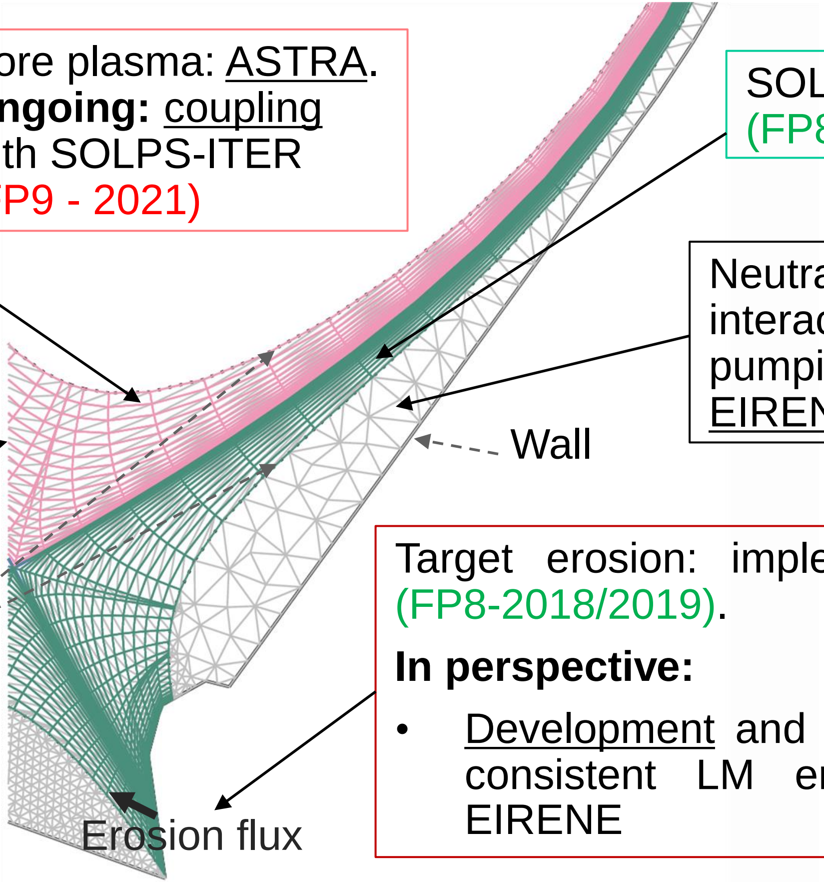
Pedestal: <u>B2.5</u> with adjusted transport coefficient profiles to reproduce ETB (FP8 – 2018/2019)

Core plasma: <u>ASTRA</u>. **Ongoing:** <u>coupling</u> with SOLPS-ITER (FP9 - 2021)

SOL plasma: <u>B2.5</u> (FP8 – 2018/2019)

Neutral transport, interaction with plasma, pumping/redeposition: <u>EIRENE</u> (FP8 – 2020)





Target erosion: implemented in B2.5 (FP8-2018/2019).

In perspective:

- <u>Development</u> and <u>validation</u> of self-consistent LM erosion model in EIRENE

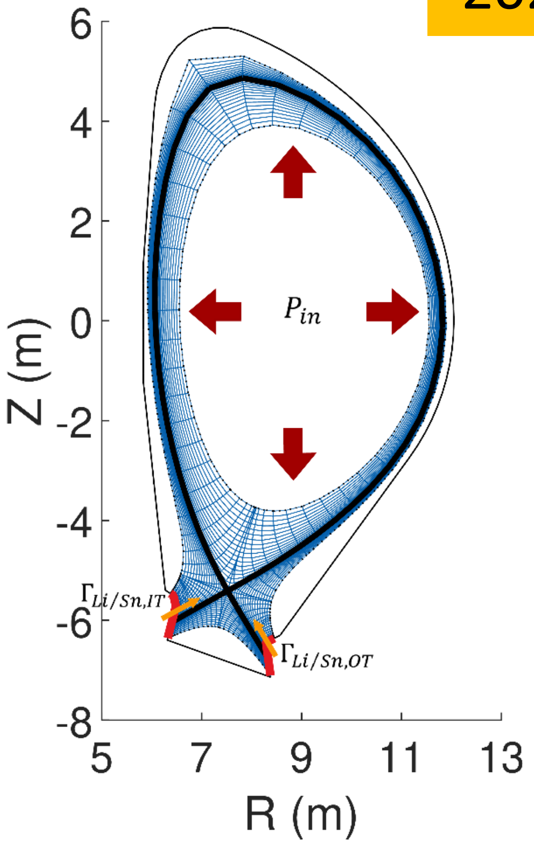
<u>SOLPS-ITER (B2.5 + EIRENE)</u> simulation domain

Overview of FP8 activities

SOLPS-ITER simulations (I)

2020

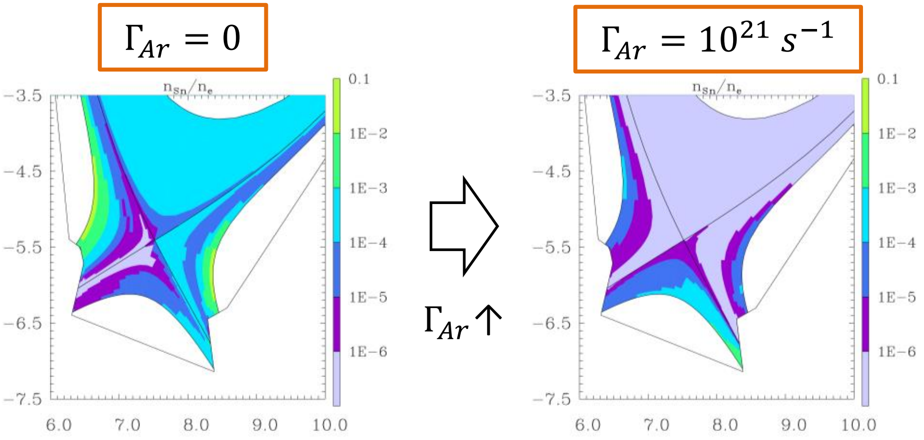
- Simulations for EU DEMO with CPS-based LMD (Li/Sn), including self-consistent target erosion (fluid model for neutrals) and Ar seeding.
- Modeling refinements:
  - Target erosion model:
    - Considered most recent ENEA PFC design for Sn
    - Included thermal sputtering for Li
    - Considered prompt redeposition of evaporated particles
  - Ar seeding:
    - Full set of ionization states for Ar in the place of simplified bundled charge → more accurate calculation of radiated power
    - Completed parametric scans

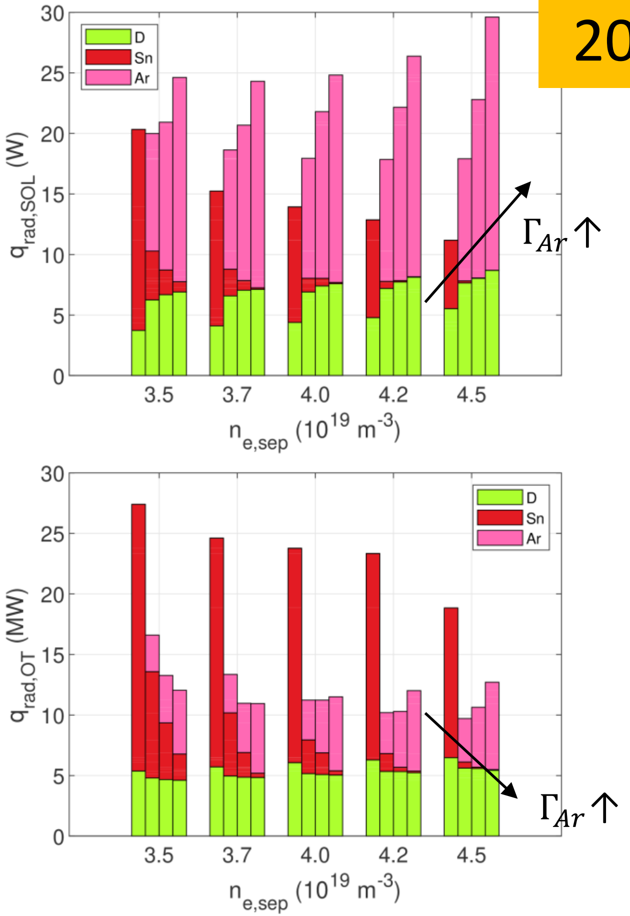


SOLPS-ITER simulations (II) - Ar seeding

2020

- Here show results for Sn (same study was performed for Li)
- Ar replaces Sn as SOL radiator →
  - LMD no longer operates in vapor shielding regime
  - Sn concentration in edge and pedestal dramatically reduced

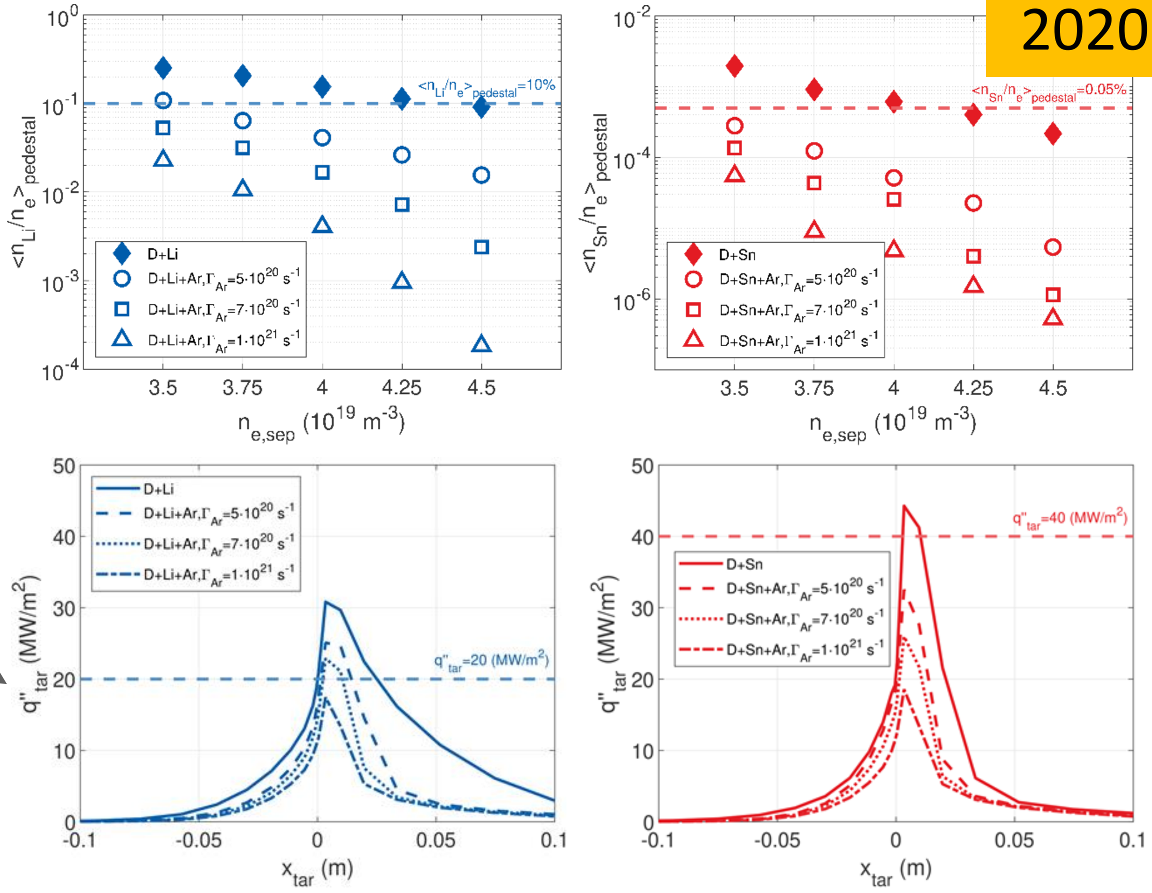




SOLPS-ITER simulations (III): Li vs. Sn

2020

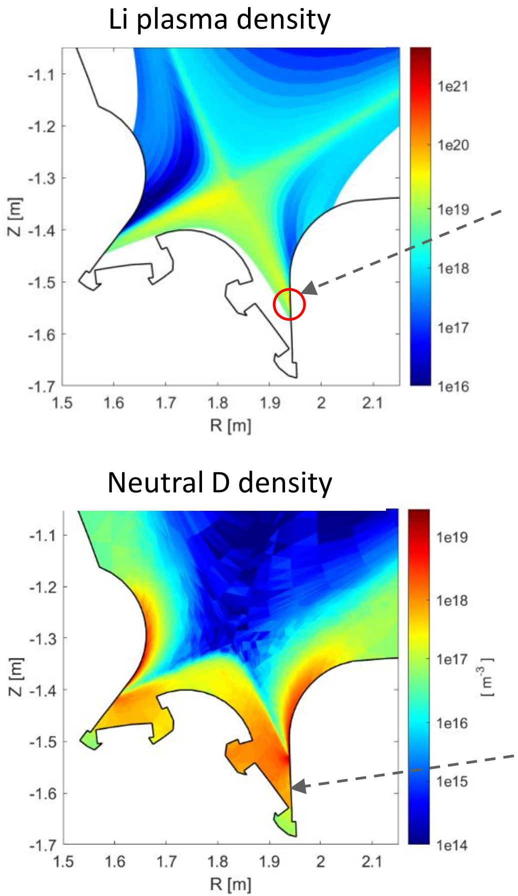
- Operational window significantly widened thanks to Ar seeding, for both Li and Sn, in terms of:
  - Core plasma contamination (but need more detailed assessment → couple to ASTRA in FP9)
  - Target peak heat flux (to be compared to power handling capability of different LMD designs)



Simulations with kinetic neutrals

2020*

- Kinetic model for the neutral species (EIRENE) needed to:
  - Extend neutral domain up to physical wall → assess effectiveness of baffling (for Li)
  - Account for pumping and condensation
- EU DEMO simulations:
  - Start from existing simulations performed by F. Subba in WPPMI [IDM report 2N3L2S] with D+He+Ar and kinetic neutrals
  - Add Li/Sn to the simulations, including source from target erosion and sink from pumping and condensation on FW
  - Generate new meshes and repeat simulations for increased divertor closure
  - Simulations are currently running…
- DTT simulations (smaller machine → faster convergence) to test the modelling strategy



Li emission simulated by puffing from the target with specified flow rate

Mesh for kinetic neutrals extends up to physical wall → account for pumping / condensation

*Activity completed in 2021 (deliverable due by 30/06)

Safety analysis (I) - Methodology

2020

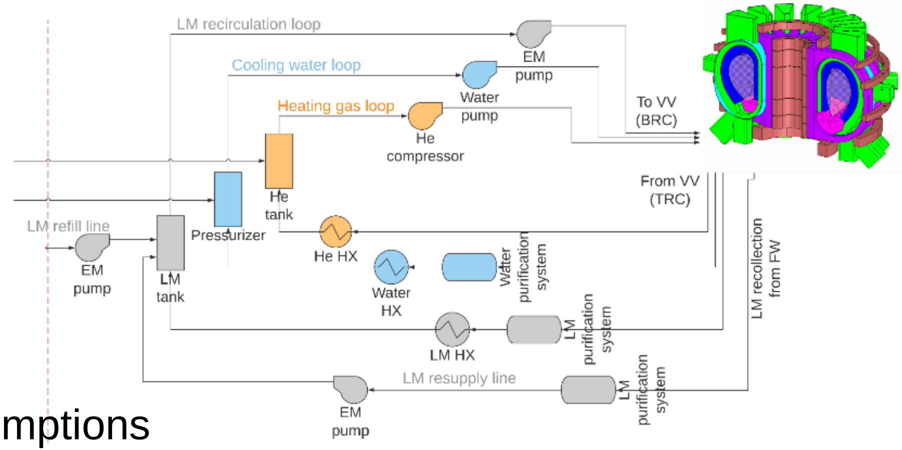
FFMEA methodology

Subdivision of systems into functionally independent subsystems → Identification of system main functions, operational states and failure modes → Analysis of functional failure modes, effects, detectability and safeguards → Identification of PIEs

- Plant Breakdown Structure (PBS)
- Functional Breakdown Structure (FBS)
- FFMEA table compilation

Setup of the LMD safety analysis

- Analysis in **normal operation** conditions;
- Consider only **internal events**;
- **Battery limits** included:
  - in-vessel components
  - LM recirculation / purification loop
  - LM cooling/heating systems
- Where design information is incomplete, assumptions on main components (see fig.)



Safety analysis (II) – Conclusions

- Functional safety analysis performed on an LM divertor (preliminary design)
  - Implementation of proposed methodology → **better understanding** of the analysed system safety issues
  - List of PIEs and description of possible consequences → input for deterministic analysis

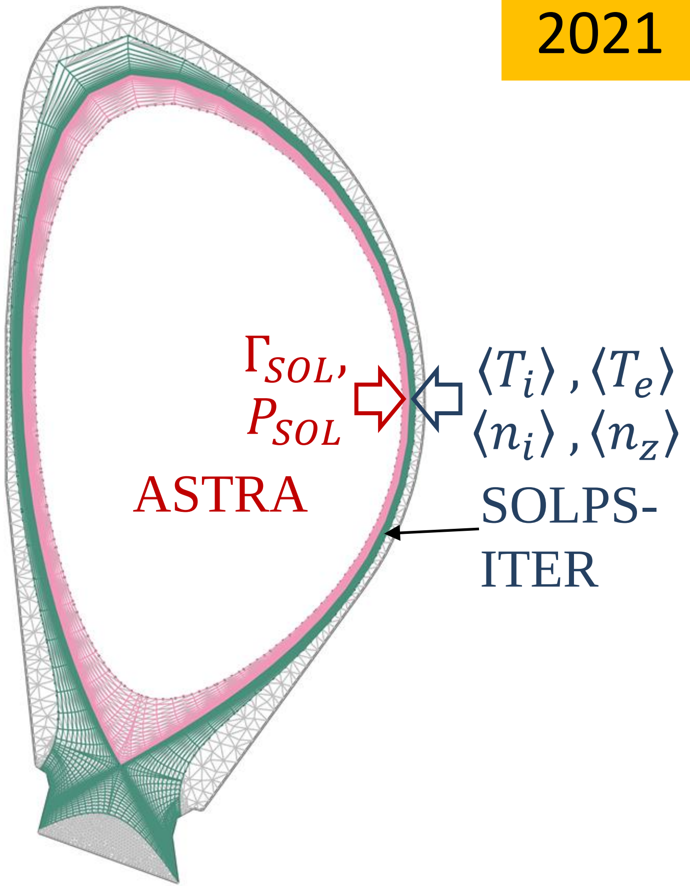
- Safety analysis results can support design development
  - Some accidental scenarios (e.g. water ingress in VV) are more severe in case Li is used instead of Sn
  - System **modularity** limits the damage in case of accidental scenario but increases the frequency

Work program for 2021-2022

ASTRA + SOLPS-ITER coupling (I)

2021

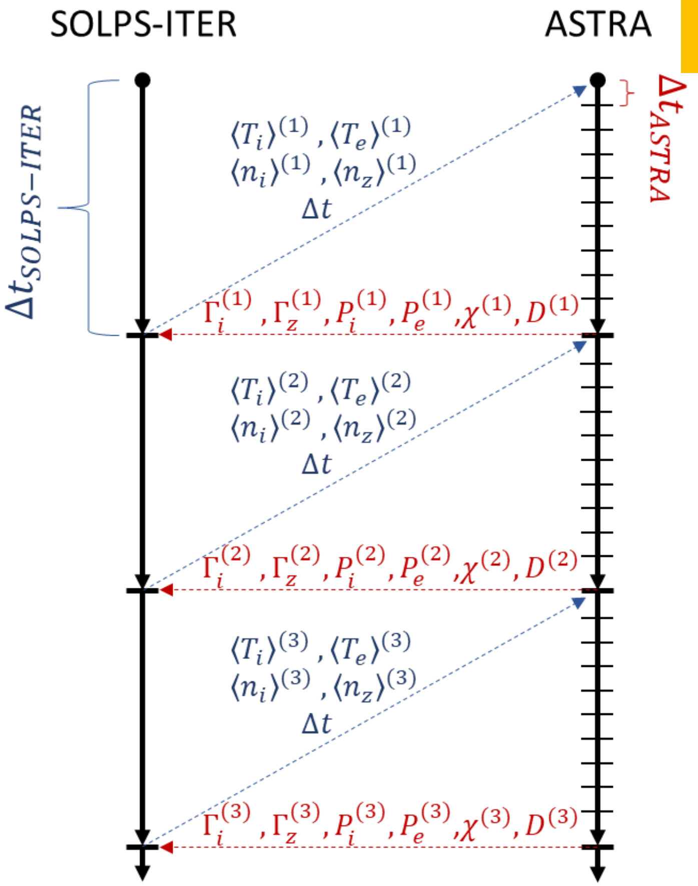
- Aim: to assess the effect of impurities on core plasma performance and the feedback on the power entering the SOL → integrated EU DEMO scenario with liquid Sn divertor
- Strategy: SOLPS-ITER up to pedestal region, ASTRA for core region
- Work program for 2021:
    1. Identification and implementation of coupling scheme between ASTRA and SOLPS-ITER (*collaboration with ASTRA developers – Dr. E. Fable / IPP Garching*)
    2. Extensive testing



ASTRA + SOLPS-ITER coupling (II)

2021

- Coupling strategy: synchronized time advance with data exchange on shared memory location (time as iteration variable)
  - SOLPS: flux-averaged temperatures and densities.
  - ASTRA: power and particle fluxes + transport coefficients for the pedestal region
- Implementation: C routine using semaphores (caller)
  - Called by SOLPS-ITER via ad-hoc Fortran interface
  - Calls ASTRA as a library, regulates semaphores



Integrated EU DEMO scenario with Sn

2022

- Following developments in 2021, run integrated simulations to characterize an EU DEMO scenario with liquid Sn divertor:
  - Interact with other WPs to update input data (e.g. vessel shape, fueling and pumping strategy, etc.)
  - Rely on previous experience from COREDIV simulations
  - Assess core plasma compatibility and closed loop requirements
- Improve erosion/deposition model in EIRENE:
  - Target emission profile consistent with the impinging power/particle fluxes (so far, done in B2.5 fluid neutral model but not in EIRENE kinetic model)
  - Species-specific pump for Sn on FW → simulate condensation

Perspective beyond 2022

Support to experimental campaigns

Context:

- Experiments in **AUG** (module insertion) and later in **COMPASS-U** and **DTT** (full divertor) are foreseen in FP9
- **Integrated plasma simulations** can support design and interpretation of experiments requires

Proposed activities:

- Apply **SOLPS-ITER + ASTRA** to support the design and interpretation of the experimental campaigns foreseen in **AUG**, **COMPASS-U** and **DTT**

Thanks for your kind attention.

Comments or Questions?