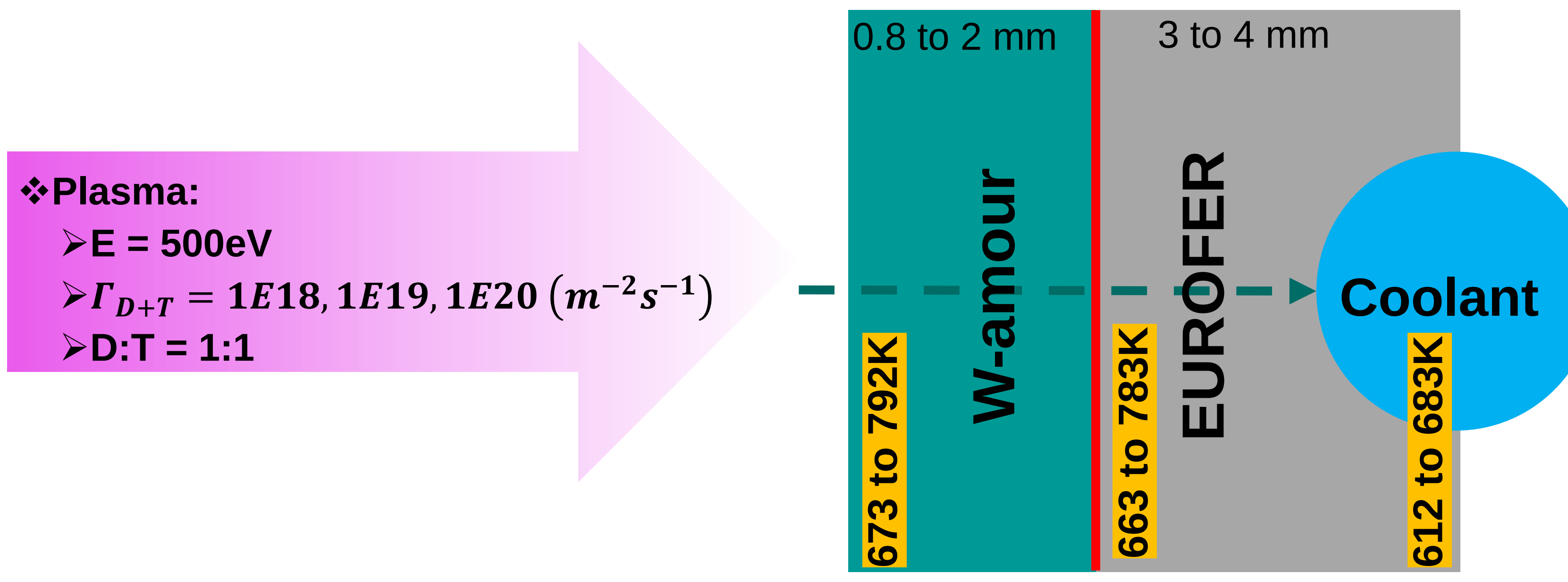
IMPLICATIONS OF T LOSS IN FIRST WALL ARMOR AND STRUCTURAL MATERIALS ON T-SELF-SUFFICIENCY IN FUTURE BURNING FUSION DEVICES

K. Schmid[1], T. Schwarz-Selinger[1], R. Arredondo[1], A. Theodorou[1], T. Pomella Lobo[2]
[1]Max-Planck-Institut für Plasmaphysik
[2]Institute for Neutron Physics and Reactor Technology (KIT)

ABSTRACT

- Future fusion reactors must breed enough T to sustain themselves and provide start up fuel for additional reactors
- T production is governed by “Tritium Breeding Ratio” TBR
- Displacement damage by fast fusion neutrons increases retention by orders of magnitude in W and EUROFER
- TBR is calculated including various sources and sinks for T
  - **Ignoring T trapping in n-damage defects underestimates first wall T sink**
- Using current experimental data on trapping in displacement damaged W and EUROFER:
  - **Compute T-loss probability in first wall**
  - **Compare to simple T-self-sufficiency requirements model**
  - **Derive time too T-self-sufficiency as first wall traps are saturated**
  - **Investigate inefficiency of pre-saturating wall with D due to isotope exchange**
- **Repeat simulations from [1] with refined, validated material data base**

SIMULATION GEOMETRY



Plasma:
- **E = 500eV**
- $\boldsymbol{\Gamma_{D+T} = 1E18, 1E19, 1E20\ (m^{-2}s^{-1})}$
- **D:T = 1:1**

0.8 to 2 mm

3 to 4 mm

W-amour

EUROFER

Coolant

673 to 792K

663 to 783K

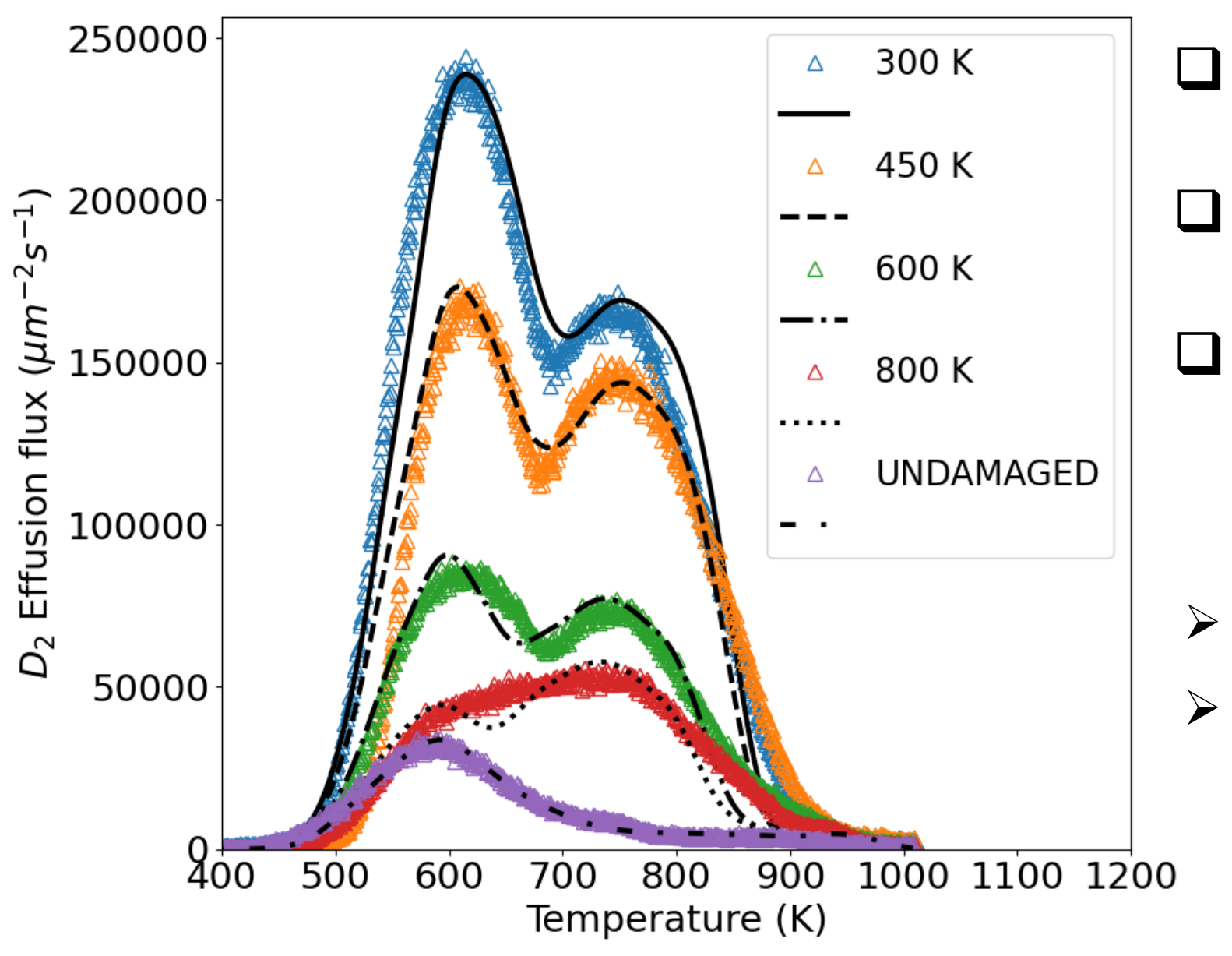
612 to 683K

SIMULATION SETUP

- Model simultaneous transport of D, T through W layer on EUROFER
  - **Mimic HCPB[5] and WCLL[4] blanket concepts**
  - **W armor layer on EUROFER structural material connected to coolant**
  - **Blanket concepts differ in amor thickness and thus T-gradients**
- Simulations use TESSIM-X code [6,7] in 1D linear geometry
- Diffusion limited boundary conditions on W inlet side
- Diffusion or surface limited boundary conditions on EUROFER/coolant side

MODEL PARAMETERS FOR W

- Re-fit data from “*M. Pečovnik et al Nucl. Fusion 60 (2020) 036024*”
  - **Produce single set of fit parameters for all temperatures**
  - **Only vary trap concentration with temperature**
  - → **Experimentally verified set of transport parameters for displacement damaged W at 300 to 800K**

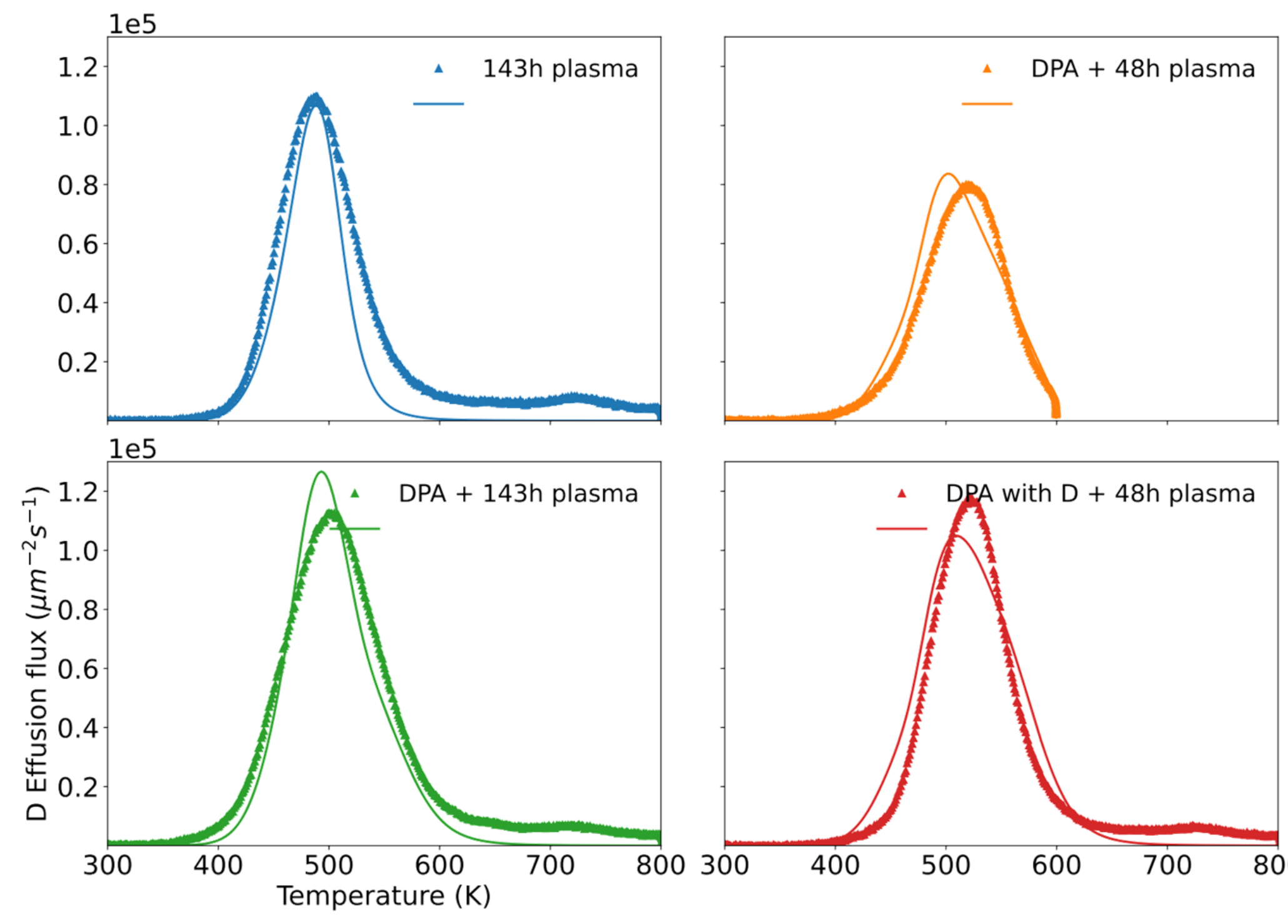


- ☐ **Damage W at 300 to 800 K**
- ☐ Sequential loading with 300eV D at 450K
- ☐ TDS & NRA to detect D-containing defects

- **Use 800K data for HCPB**
- **Use 600K data for WCLL**

MODEL PARAMETERS FOR EUROFER

- D-retention data of displacement damaged EUROFER from [2]
  - **Experiment suggests strong increase in retention with displacement damage**
  - **Displacement damage created at room temperature anneals at ~600K**
  - **Intrinsic defects do not anneal up to 800K**
- Transport parameters for D in EUROFER from [3]
  - **Modeling suggests very weak traps 0.9 and 1.1 eV de-trapping energy**
  - **Strong surface limit for gas phase uptake**
- **TESSIM-X fit to available experimental data on damage EUROFER:**



- **Damage EUROFER at 300 K**
- „Gentle“ D-loading at 370 K
- TDS & NRA to detect D-containing defects

- More experiments are needed for EUROFER
- → Displacement damage at high T

SIMPLE T-SELF-SUFFICIENCY MODEL

- Must breed more T than is lost in wall for given TBR

$$\Gamma_{Inject} = \Gamma_{Burn} + p_{trap}(t)\Gamma_{Wal}$$

→ Compensate T loss by burn and wall sink

$$\Gamma_{Burn} = p_{Burn}\left(\eta_{Pellet}\Gamma_{Inject} + \eta_{Recycle}\Gamma_{Wall} \times \left(1 - p_{trap}(t)\right)\right)$$

→ Burn T from pellets and recycling (i.e. non trapped T)

$$\Gamma_{Bred} = (TBR - 1)\Gamma_{Burn}$$

$$\Gamma_{Trap} = p_{trap}(t)\Gamma_{Wal} \qquad \int_0^{\Delta t}\Gamma_{Trap}(t)dt < \int_0^{\Delta t}\Gamma_{Bred}(t)dt$$

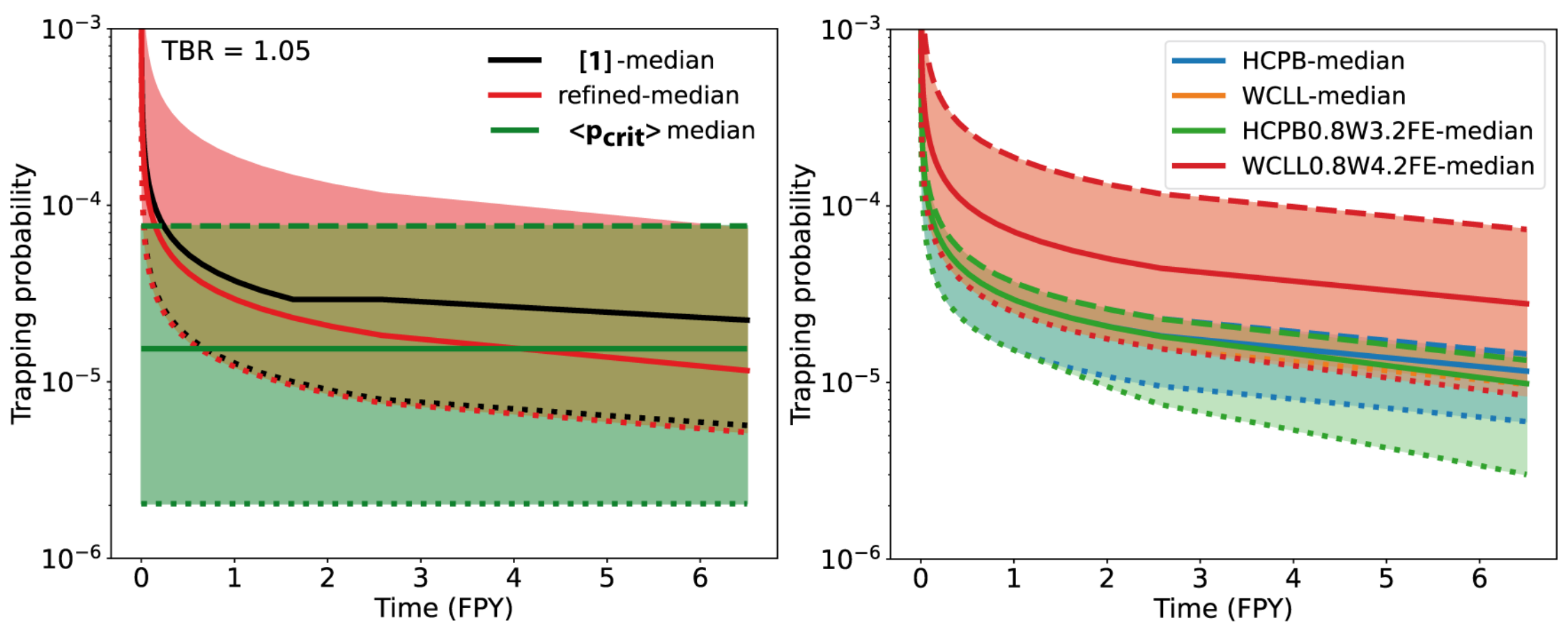
→ Breed more T from burn than is lost in wall sink

$$\langle p_{trap}\rangle = \frac{\int_0^{\Delta t} p_{trap}(t)dt}{\Delta t} < p_{Crit} = \frac{1}{1 + \frac{1}{\eta_{Recycle}\, p_{Burn}(1 - TBR)} - \frac{\eta_{Pellet}}{\eta_{Recycle}}\frac{TBR}{TBR - 1}}$$

$\frac{\int_0^{\Delta t} p_{trap}(t)dt}{\Delta t}$ **= Computed by TESSIM-X**

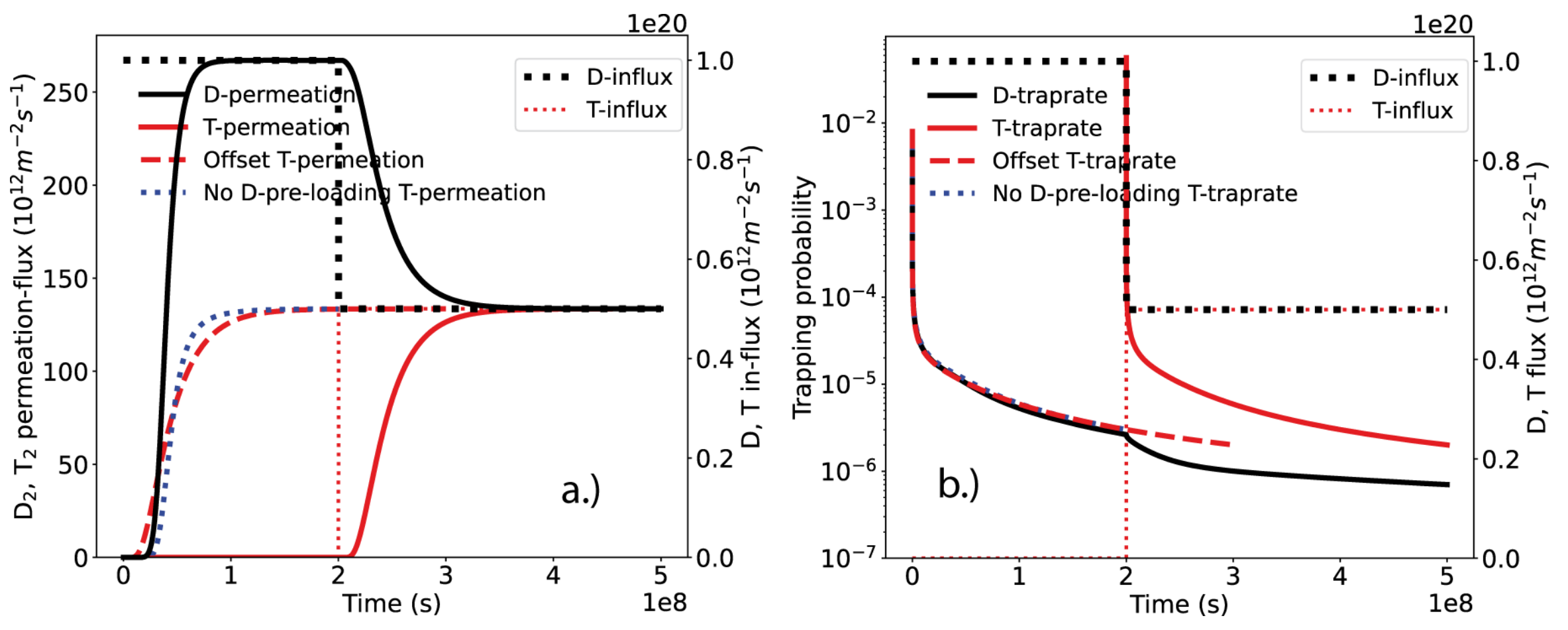
T-SELF-SUFFICIENCY

- Compute $\langle p_{trap}\rangle$ using TESSIM-X for a range of parameters
  - **Vary cooling concepts /temperatures: HCPB vs WCLL**
  - **Vary particle influx**
  - **Vary boundary conditions**
- Compare to p_{Crit} from simple T-self-sufficiency model
  - **Depending on parameters it takes up to 6 fpy to reach T-self-sufficiency**
  - $\langle p_{trap}\rangle$ **time evolution is dominated by W-armor layer**
  - **Thin W-armor and hot (HCPB) wall reach T-self-sufficiency fastest**



ISOTOPE EXCHANGE

- Investigate influence of pre-saturating wall with D
  - **Expose wall to 100% D**
  - **After break through to coolant switch to D:T = 1:1**
  - **Compare retention and** $\langle p_{trap}\rangle$ **to non pre-saturated case**
- Pre-saturating with D leads to slightly faster break through to coolant
- Isotope exchange is very efficient at these high temperatures
  - $\langle p_{trap}\rangle$ **is unaffected by pre-saturating wall with D**
  - **T-retention is unaffected by pre-saturating wall with D**
- → **Sponge effect [8] does not work due to isotope exchange**



CONCLUSION

- Repeat T-self-sufficiency estimates from [1] including T-wall-sinks due to neutron damage with refined and experimentally validated material data bases
- Results are qualitatively similar: It takes up to 6 fpy to sufficiently saturate traps with T based on simple T-self-sufficiency model
- Hot wall (HCPB) with thin W layer performs best
- Isotope exchange makes pre-saturating defects with D useless
- Possible solution: avoid the need for saturating n-damage generated traps in the wall by increasing recycling
  - ☐ E.g. Castellated wall surface with increased out-diffusion through side faces
  - ☐ E.g. Open porosity by He-pre-irradiation [9]

[1] R. Arredondo, et al., Nuclear Materials and Energy 28 (2021) p. 101039
[2] K. Schmid, et al., Nuclear Materials and Energy (2023) Vol. 34 p. 101341
[3] K. Schmid, et al., Nuclear Materials and Energy (2023) Vol. 36 p. 101494
[4] E. Martelli, et al., Int. J. Energy Res. 42 (2018) . 27
[5] F. Hernández, et al., Fusion Eng. Des. 124 (2017) . 882
[6] K. Schmid, et al., J. Appl. Phys. 116 (2014) 134901
[7] K. Schmid, M. Zibrov Nucl. Fusion 61 (2021) 086008
[8] B. Deng et al, Nucl. Fusion 51 (2011) 073041
[9] Miyamoto M. et al. 2015 J. Nucl. Mater. 463 333

Poster No.: TEC-MTL-1971
IAEA-FEC 2023 London

*Corresponding author:
Klaus.Schmid@ipp.mpg.de

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.