

Defining Operational Scenarios For DTT In Metallic Environment: A Modelling Study Of Core-Edge Dynamics And Plasma-Wall Interaction

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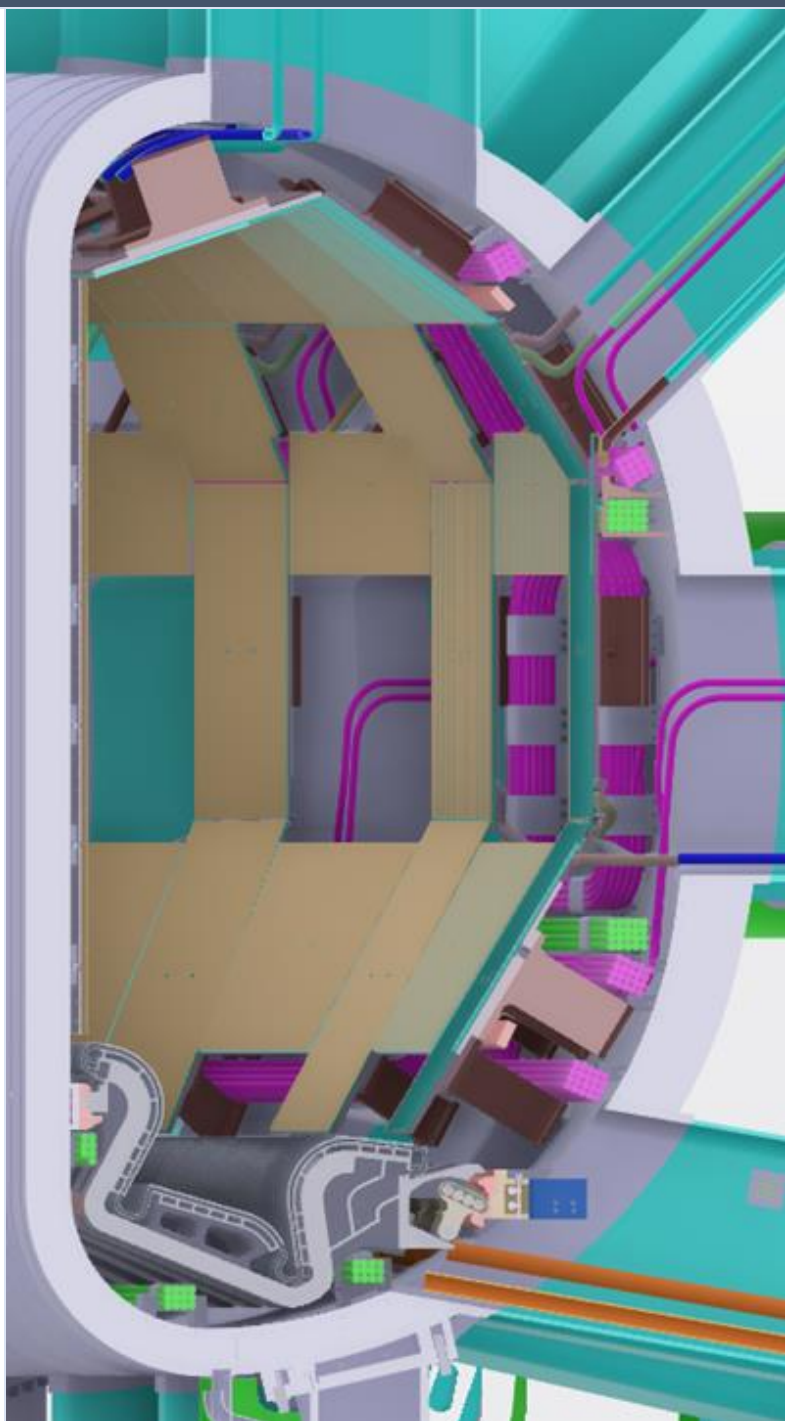
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BACKGROUND

- DTT is a superconducting tokamak under construction in Frascati, designed to study power exhaust and plasma-wall interaction in a fully tungsten environment.
- In metallic devices, impurity control and heat flux management are critical for performances and reduce contamination.
- Integrated modelling (core+edge+PWI) need to define operational scenarios before machine start-up.
- Scenarios analysed:
 - Scenario A → reduced current and field, long pulse.
 - Scenario E → high-current, high-field, DEMO-relevant



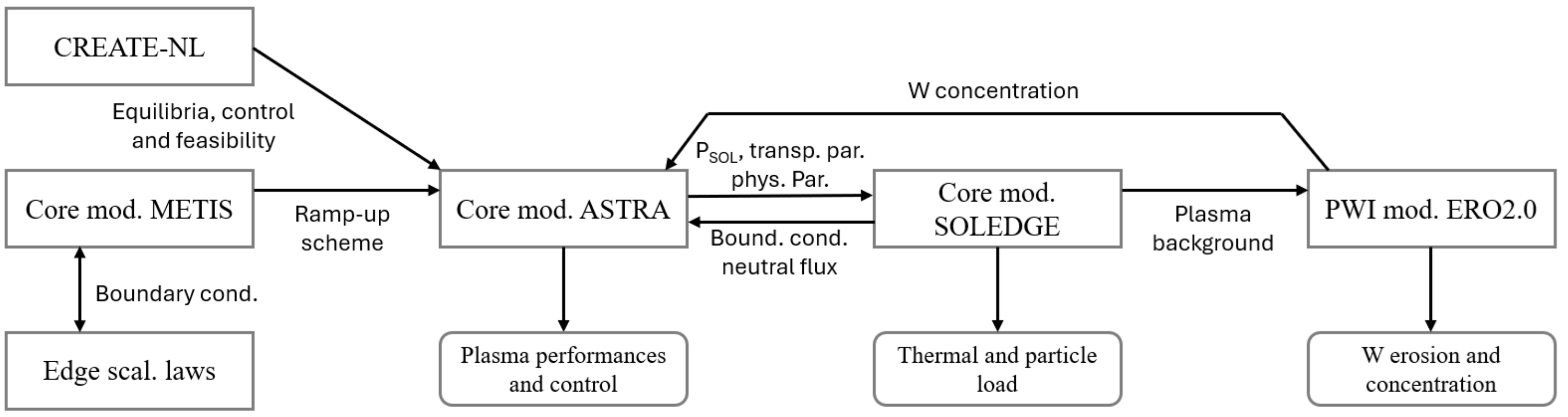
List of relevant plasma parameters for main DTT SN scenarios

	I _p (MA)	B _T (T)	P _{aux} (MW)	n _e (m ⁻³)	T _e (keV)	n _{e,sep} (m ⁻³)
Sc. A	2	3	7.2	9×10 ¹⁹	5	3.5×10 ¹⁹
Sc. C	4	5.85	20.2	14×10 ¹⁹	8	5.0×10 ¹⁹
Sc. E	5.5	5.85	45	19×10 ¹⁹	12	8.0×10 ¹⁹

OBJECTIVES

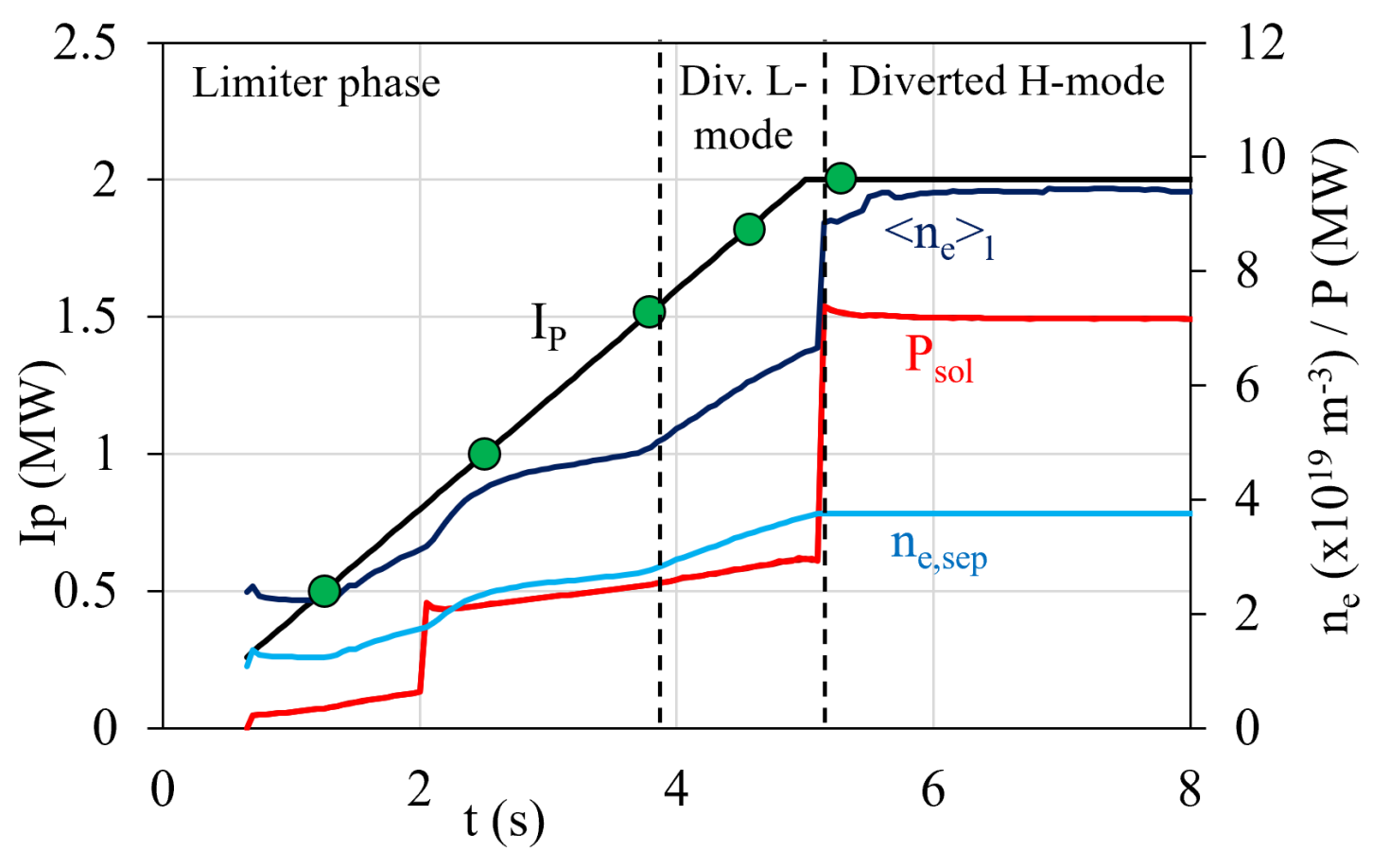
- Define and validate reference operational scenarios for DTT in a full-tungsten environment.
- Use integrated core-edge-PWI modelling to assess plasma performance and wall compatibility.
- Identify safe operational strategies (ramp-up and flat-top) that minimise impurity accumulation and erosion.
- Provide inputs for machine design optimisation (limiter/divertor geometry)

METHODOLOGY



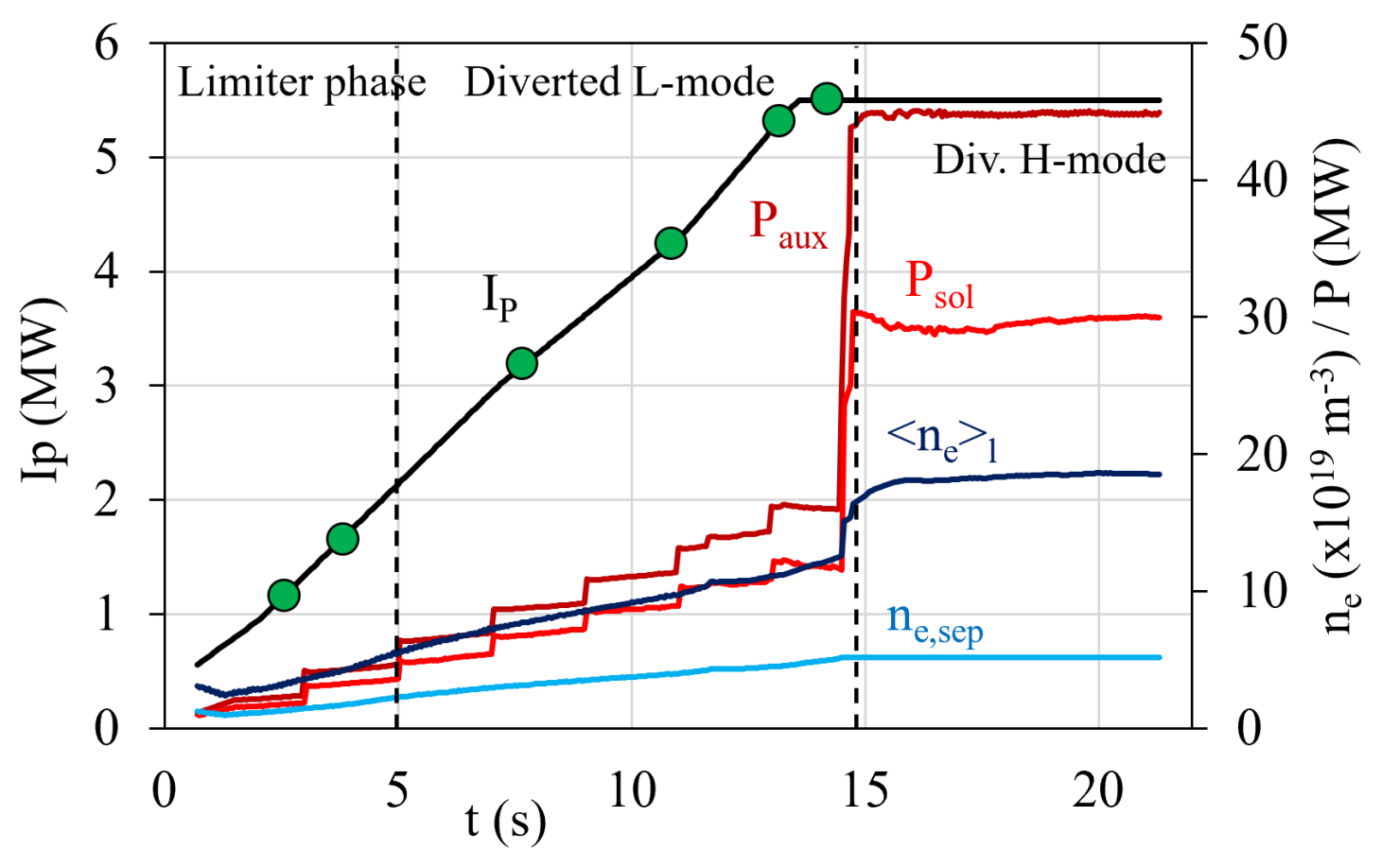
Scheme of the integrated modelling methodology applied

Core modelling Sc. A



Scenario A ramp-up and flat top scheme derived with ASTRA

Core modelling Sc. E



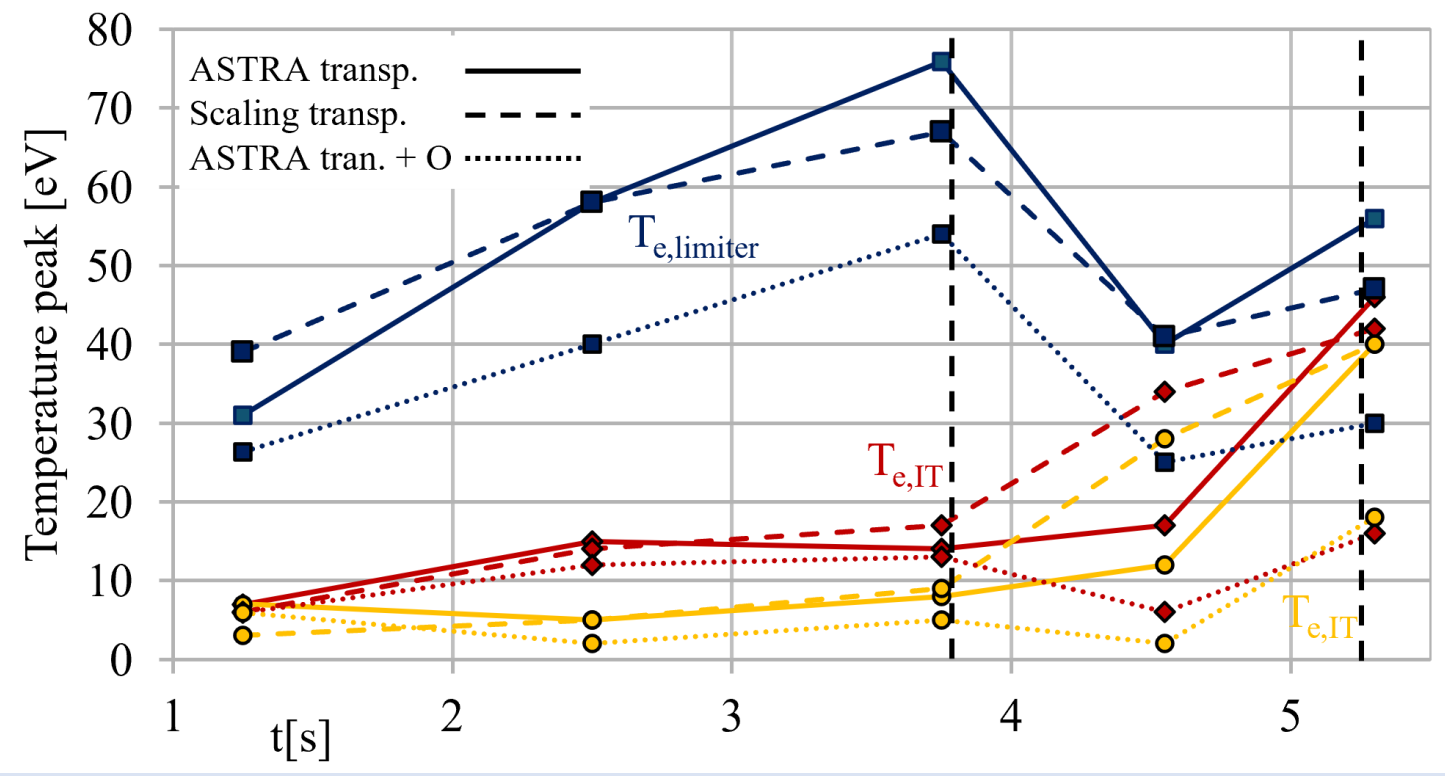
Scenario E ramp-up and flat top scheme derived with ASTRA

- A ramp-up scheme has been developed for scenarios A and E that is capable of achieving the nominal machine performances see Bonanomi et al. Nucl. Fus. (2024)
- This scheme guarantees a flat top duration in H mode of 30/40 seconds for scenario E and more than 100 seconds for scenario A.
- This solution was achieved by anticipating the formation of the X-point while remaining within the magnetic field generation and control limits specified by CREATE-NL.
- The transport parameters estimated by ASTRA at the plasma edge are similar to those obtained from existing scalings for scenario A in all phases of the discharge, while they overestimate those of the scalings for scenario E.
- It assumed c_w=10⁻⁵ -> For validation see PWI section

ACKNOWLEDGEMENTS

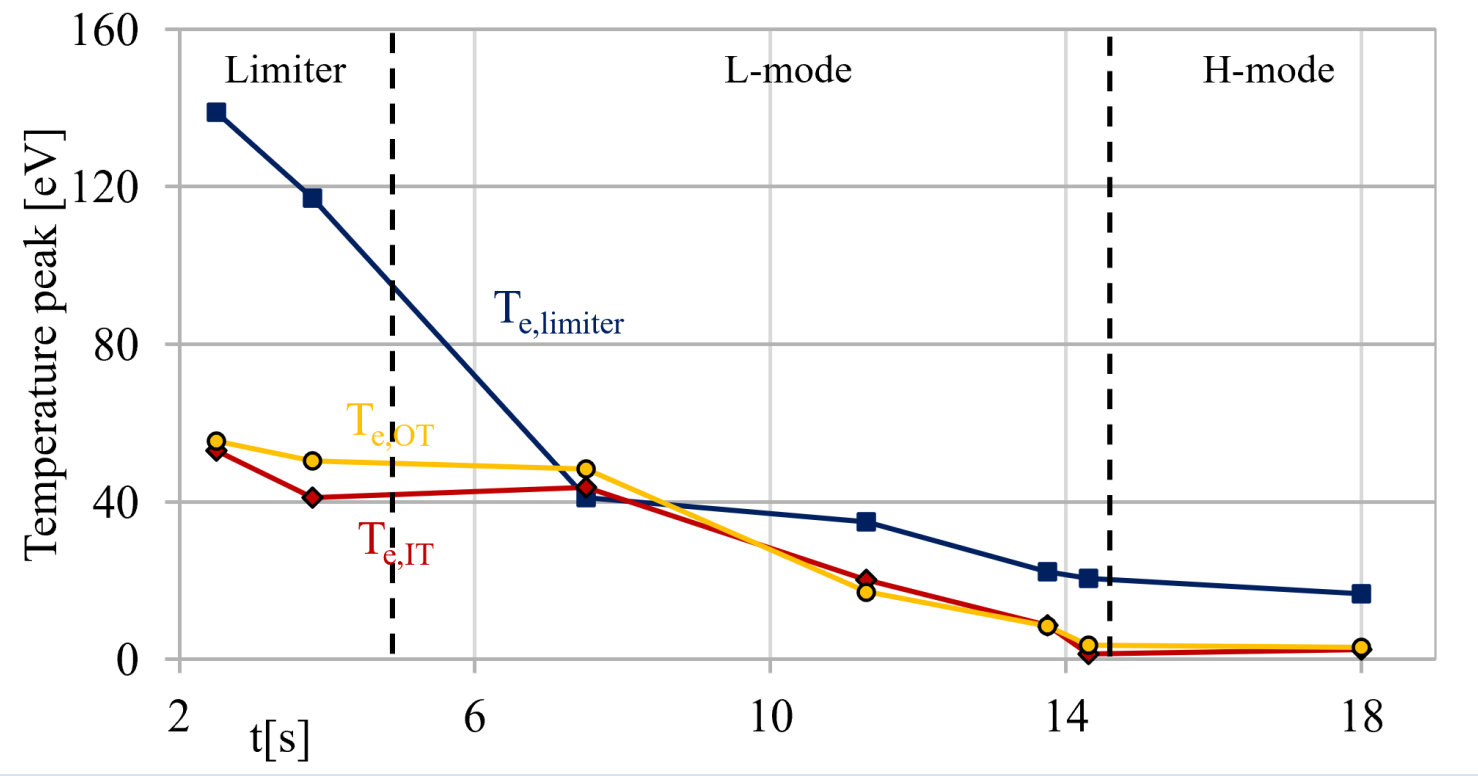
- This work was performed using the Eni S.p.a. HPC4 Supercomputing Cluster.

Edge modelling Sc. A



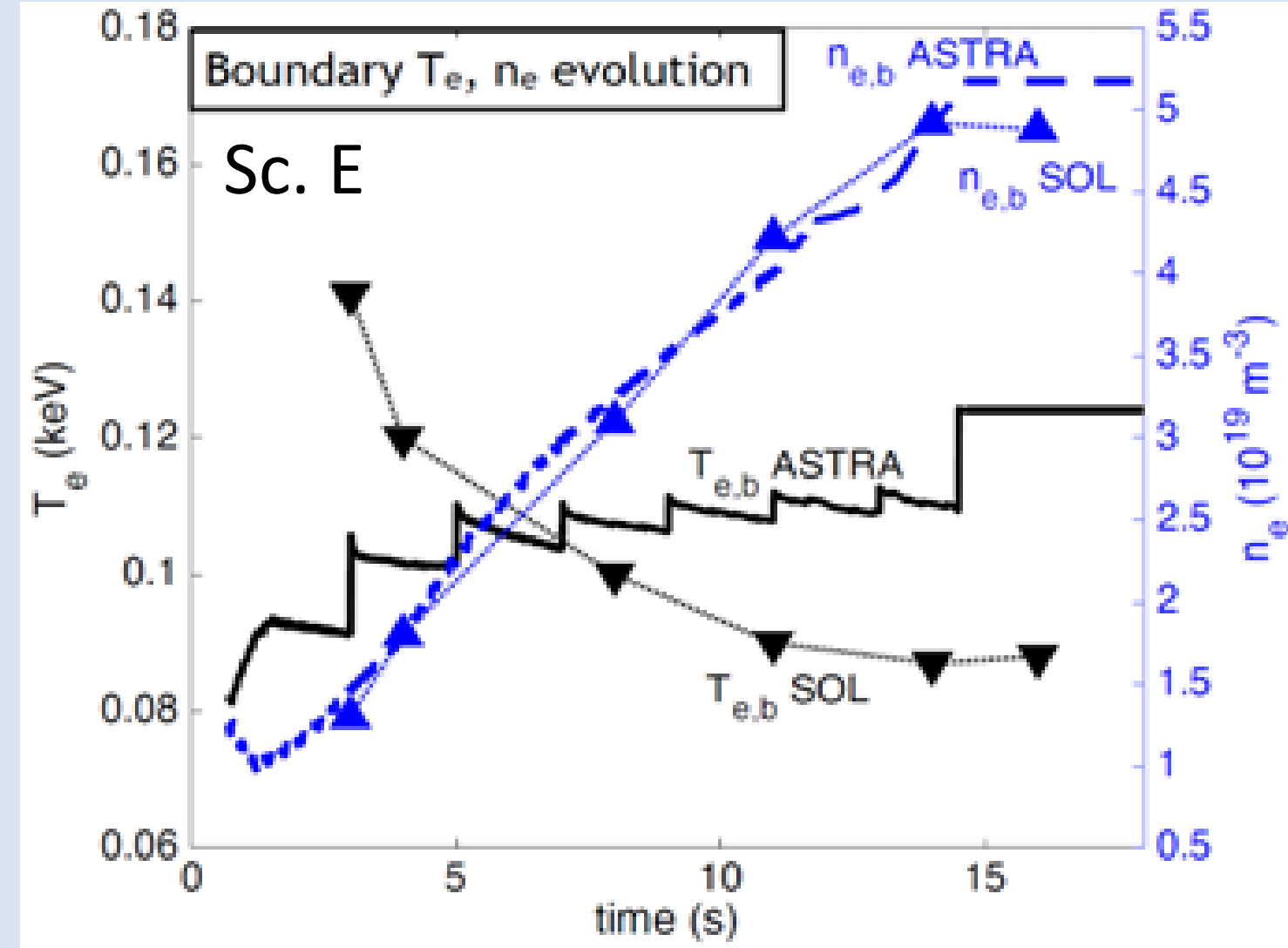
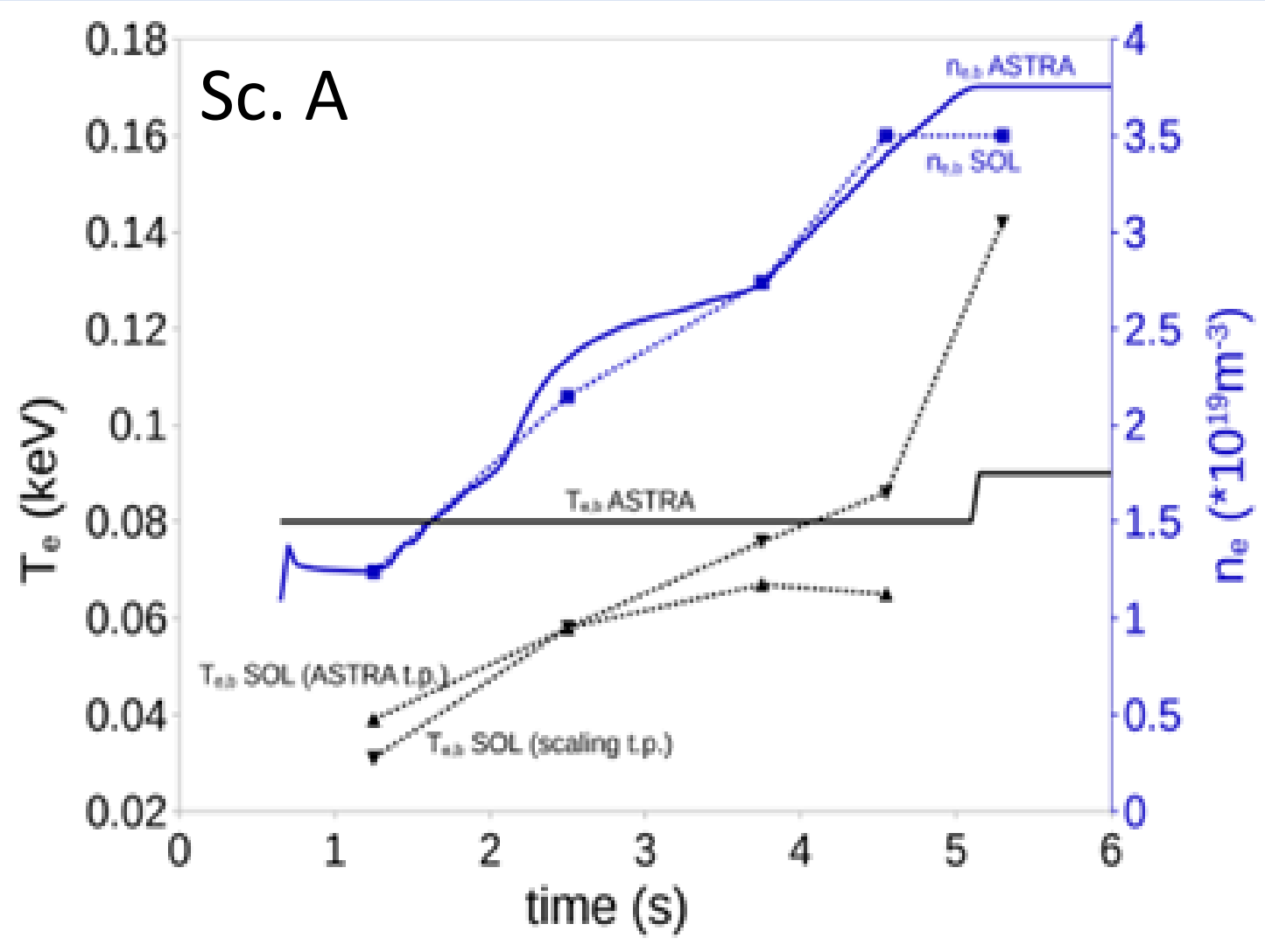
Sc. A T_e peak at the limiter and divertor

Edge modelling Sc. E



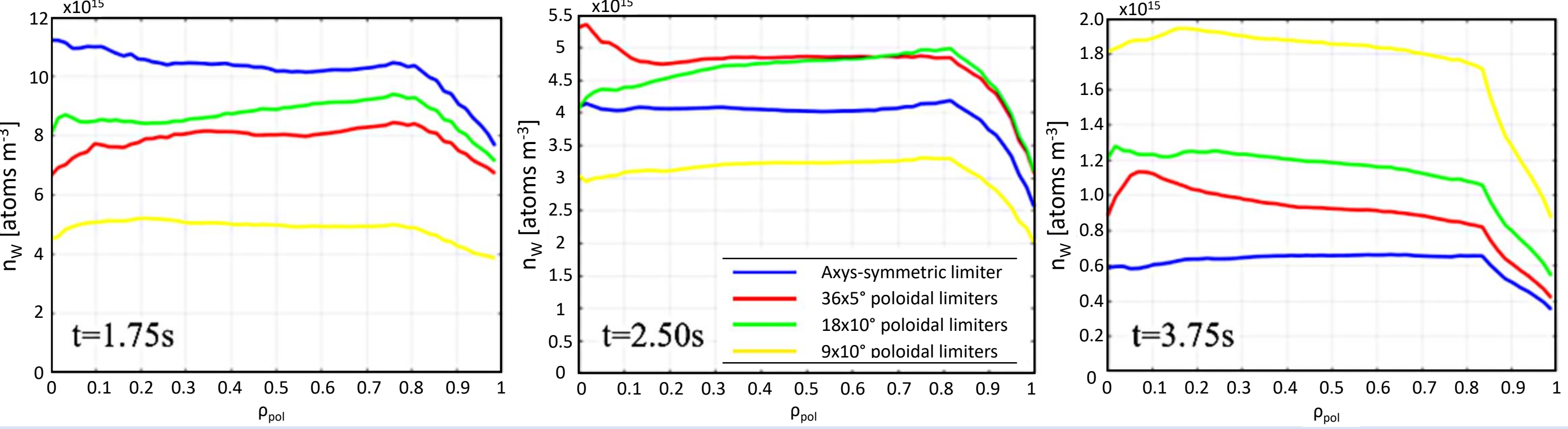
Sc. A T_e peak at the limiter and divertor

- Edge plasma profiles predicted by SOLEDGE2D-EIRENE were consistent with ASTRA outputs; discrepancies remained within expected uncertainties of scalings.
- Sc. A:** Peak heat loads <1 MW/m² and T_e < 100 eV ensure safe operation. N seeding during ramp-up effectively reduced wall temperatures but increased resistivity and sputtering; intrinsic impurities are preferable for early control.
- Sc. E:** Peak heat loads <1 MW/m² at limiter, T_e > 100 eV are concerning for plasma contamination
- Integrated core-profiles (n_e, T_e, Z_{eff}, fluxes) during the ramp up and flat top phase
- PWI modelling ensured that a fast ramp-up scheme limits impurity concentration in Sc. E within acceptable limits (c_w~10⁻⁵). It is negligible during flat top phase (even considering ELMs) thanks to DTT closed divertor geometry



ASTRA and SOLEDGE Sc. A and Sc. E ramp-up and BFT profiles

PWI modelling



W density radial profile during the ramp-up with different limiter geometries.

W density in the core and separatrix during the ramp-up and flat top of scenario E

Sc. E condition	Mod. Set-up	Net erosion rate	C _{w,sep} (part/m ³)	C _{w,core} (part/m ³)
t = 1.25 s	D only	2.0 nm/s	3.9 × 10 ¹⁵	4.2 × 10 ¹⁵
t = 2.5 s	D only	1.0 nm/s	2.0 × 10 ¹⁵	2.9 × 10 ¹⁵
t = 3.75 s	D only	0.4 nm/s	0.9 × 10 ¹⁵	1.3 × 10 ¹⁵
Attached (D)	2% O, w/ ELMs	Up to 0.5 nm/s	≤ 10 ¹²	≤ 10 ¹²
Detached (D+Ne)	2% O, w/ ELMs	Up to 0.5 nm/s	≤ 10 ¹²	≤ 10 ¹²
Extreme case	D+ burst over OT	~0.5 nm/s	≤ 10 ¹⁴	≤ 10 ¹⁴

CONCLUSION

- Integrated modelling achieved: core (ASTRA/METIS), edge (SOLEDGE), and PWI (ERO2.0) integrated modelling performed for DTT scenarios development.
- Operational windows identified: modelling confirms feasible trajectories from ramp-up to H-mode, with acceptable heat fluxes and impurity sources in a metallic environment.
- Day 0 scenario: ramp-up and flat-top show manageable wall loads (<5 MW/m²) and stable impurity levels; nitrogen seeding is useful but should be minimized in ramp-up.
- Full power scenario: fast ramp-up scheme ensures that tungsten concentration remains within tolerable limits; flat-top achievable with controlled auxiliary heating; outer divertor detachment obtained with neon seeding, maintaining core purity >80%.
- PWI robustness: erosion rates in flat-top remain low, even with ELMs and oxygen impurities; redeposition due to divertor closure ensures limited net W source.