Chapter 4
TRANSPORT PHYSICS and INTEGRATED MODELLING

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Rationale of Chapter 4

- Reviews the characteristics of the DTT device from the standpoint of confinement and transport studies
- Discusses DTT experimental possibilities in terms of engineering parameters and of the expected physical plasma parameters, underlying its unprecedented features in addressing core – edge – exhaust integration challenges
- Identifies main T&C aspects which make DTT different from present devices and a new and essential step towards ITER operation and the definition of a DEMO reactor

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- Identifies main T&C aspects which make DTT different from present devices and a new and essential step towards ITER operation and the definition of a DEMO reactor
- Defines the main missions of DTT for confinement and transport studies and describes possible experiments in this topical area
- Experiments are organized in 4 groups and are also outlined in order of time depending on the maximum achievable heating power, magnetic field and current of the different DTT operational phases
- Shows plasma profiles from theory-based transport modelling predictions as examples of reference conditions that can be obtained in DTT experiments

INDEX (Transport)

Experiments organized in operational phases (1 and 3) and heating phases (A-E)

INDEX (Modelling)

4.6 Predictions of plasma profiles during current flat top phases

4.6.1 Description of simulation methodology

4.6.2 Scenario E SN Baseline

4.6.3 Scenario C SN Baseline

4.6.4 Scenario A SN Baseline

4.7 Basic description of diagnostic requirements for transport studies (NEW)

4.8 Headlines of the research programme for transport and confinement physics (NEW)

Complete Table of Diagnostics and preliminary port allocation in Appendix F

Description / Table of modelling tools included in Appendix H

Diagnostics (Section 4.7)

Measured Parameters	Diagnostics, Phase 1	Diagnostics, Phase 2
Electron Density, and density profiles	Interferometers (vertical and tangential), Thomson Scattering (core-edge)	Thomson Scattering (edge-divertor), Reflectometry, He-Beam
Electron Temperature profiles	ECE Radiometer, Thomson Scattering (core-edge)	Thomson Scattering (edge-divertor)
Ion Temperature profiles	CXRS, core - edge – SOL (diagnostic NBI)	
Rotation profiles	CXRS, toroidal and poloidal (diagnostic NBI)	
Safety factor	MSE (diagnostic NBI) and polarimetry	
Impurities	CXRS, Bolometry, SXR Crystal and XUV spectrometry, Visible spectrometry, Visible Z_{eff} Bremsstrahlung, VUV Spectrometry	SXR and Bolometry tomography, Laser Blow Off, Tracer encapsulated Solid Pellet,
Density fluctuations		Phase Contrast Imaging, Beam Emission Spectroscopy, Thermal He Beam, Reflectometry
T_e fluctuations		Correlation ECE
Fast Ions		Fast Ion Loss Detectors, Fast Ion Deuterium Alpha charge exchange

Table 2.1. Summary of DTT heating phases and planned scenarios

Scenario	Ip (MA)	BT (T)	divertor	Power installed (MW)		
				EC	IC	NBI
A	**2**	**3**	**SN/XD**	**8**	**0**	**0**
A NT	1.5	3	NT	8	0	0
B	**2**	**3**	**SN/XD**	**16**	**4.75**	**0**
B NT	1.5	3	NT	16	**4.75**	0
C	**4**	**6**	**SN/XD**	**16**	**4.75**	**0**
C NT	3	6	NT	16	**4.75**	0
D	**5.5**	**6**	**SN**	**16**	**4.75**	**5-10**
D XD	4.5	6	XD	16	**4.75**	5-10
D NT	4	6	NT	16	**4.75**	5-10
D at low BT	2.75	3	SN	16	**4.75**	5-10
E	**5.5**	**6**	**SN**	**32**	**9.5**	**10**
E XD	4.5	6	XD	32	9.5	10
E NT	4	6	NT	32	9.5	10
E at low BT	2.75	3	SN	32	9.5	10

Phase 1 (A – C NT)
2029-2034

Phase 2 (D – D at low BT)

Phase 3 (E – E at low BT)
2038-onward

Headlines Section 4.8

Headline number	Headline contents	Priority (+, ++, +++)	ITER	DEMO
Construction Phase 2022-2029				
C.4.1	Diagnostics for plasma operation, essential profiles measurements (temperatures, densities, rotation), bolometry, SXR spectroscopy	+++		
Phase 1 2029-2034				
1.4.1	Ohmic and L-mode transport properties at half field and half current (Scen. A,B), and full field full current (C)	+++	*	*
1.4.2	H-mode access at half (A,B) and full field (C) with P_{ext}<20 MW and dominant electron heating	+++		
1.4.3	First studies of effects of impurity seeding on confinement for edge-core integrated scenarios (B, C)	+++	*	*
1.4.4	Characterize transport in edge and core in different scenarios, compare full and half field	+++	*	*
1.4.5	Transport properties in presence of 3D ELM control, in no ELM regimes and in negative triangularity plasmas	+++	*	*

Modelling activities missing

A 8MW
B-C 20 MW

A-B 2 MA/3T
C 4 MA/6T

Headlines Section 4.8

Phase 2 – D : 5.5 MA / 6 T, 25-30 MW

Phase 2 2034-2038				
2.4.1	Extend all studies of Phase 1 to higher power	+++	*	*
2.4.2	Characterize transport in high beta hybrid / advanced scenarios at high power and half field and current	+++	*	*
Phase 3 2038-... Phase 3 – E : 5.5 MA / 6 T, 50 MW				
3.4.1	Extend all studies of Phase 1 and 2 to full experimental capabilities	+++	*	*

Additional proposals for discussion

Phase 2 => More clearly mention confinement studies in scenarios / regimes characterized by complete core-edge integration

Phase 2/3 => Include keywords on Energetic Particles and Burning Plasma physics

Chapter contents in next version(s)

1. Parameter domains achievable in DTT experiments: now from 0D global confinement scaling laws => Future supported and more determined by 1D modelling
2. Increased detail in the correspondence of experiments wrt operation and heating phases ⇒ more detailed definition of transport experiments (and scenarios) in concomitance with increased definition of DTT operational capabilities and achievable parameter domains

3. Increased integration and consistency among different chapters (core – edge – SOL integration, e.g. exhaust requirements increasingly reflected in core / pedestal experimental possibilities, closer experiment – theory connection)
4. Augmented detail in corresponding diagnostic capabilities and diagnostic coverage
5. Increased and updated 1D modelling activity reflected in the new version of the RP (closer connection between 1D modelling and theoretical activities)

More general aspects

1. Perspectives after the EUROfusion Facility Review ⇒ which impact on the DTT progress and the EU participation ?

2. Possibility of definition of Tasks with corresponding Calls (e.g. for diagnostics, heating, modelling, …) ?

3. Closer interaction between team of DTT-RP “writers” and the DTT team

4. Control, Data Acquisition / Access and Communication (CODAC in general) (IMAS-sification) as an additional separate chapter of the new research plan ?

5. …

Figures in the Chapter

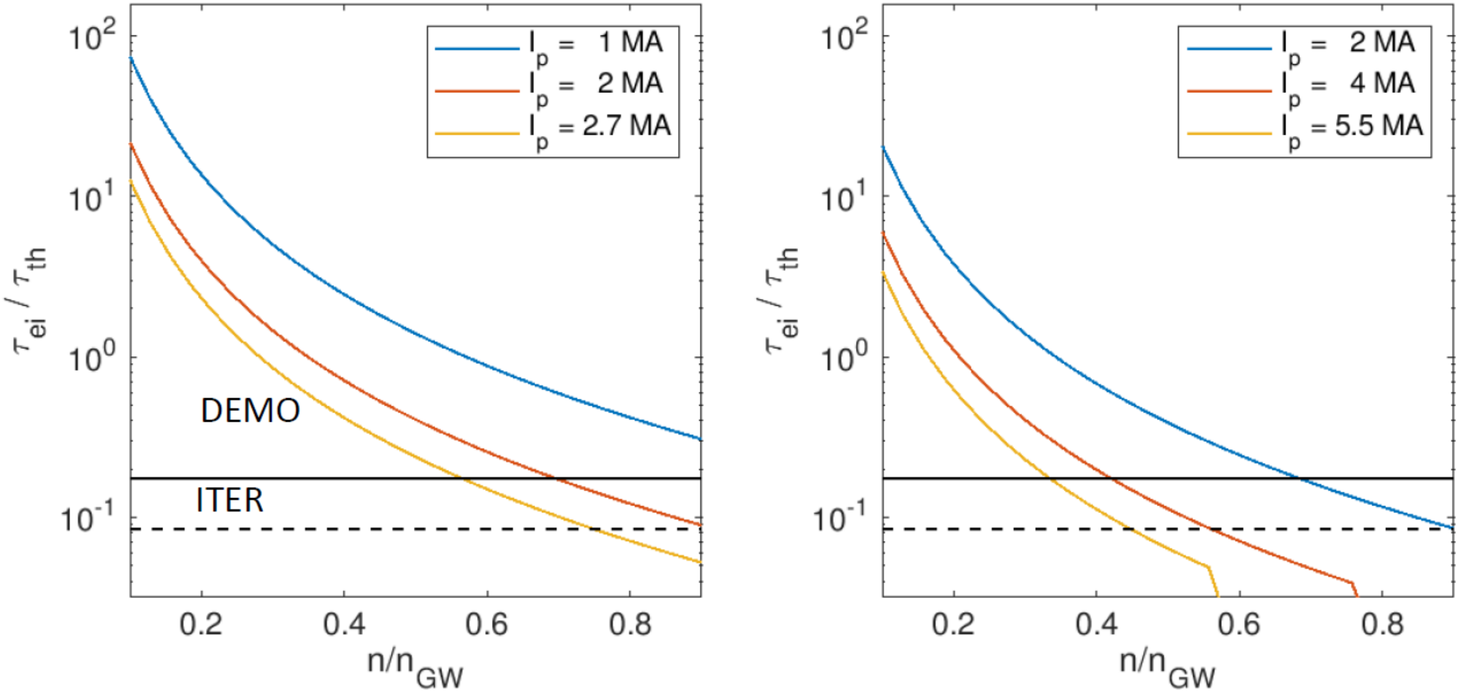


Fig. 4.1: Volume-averaged values of the electron to ion energy exchange time divided by the confinement time at 2.9 T, 30 MW (left) and at 5.8T, 40 MW (right), as a function of the Greenwald fraction for three values of the plasma current. Horizontal lines identify the ITER (dashed) and DEMO (solid) reference values at full current and full power, as well as at foreseen high Greenwald fraction (0.9).

Figures in the Chapter

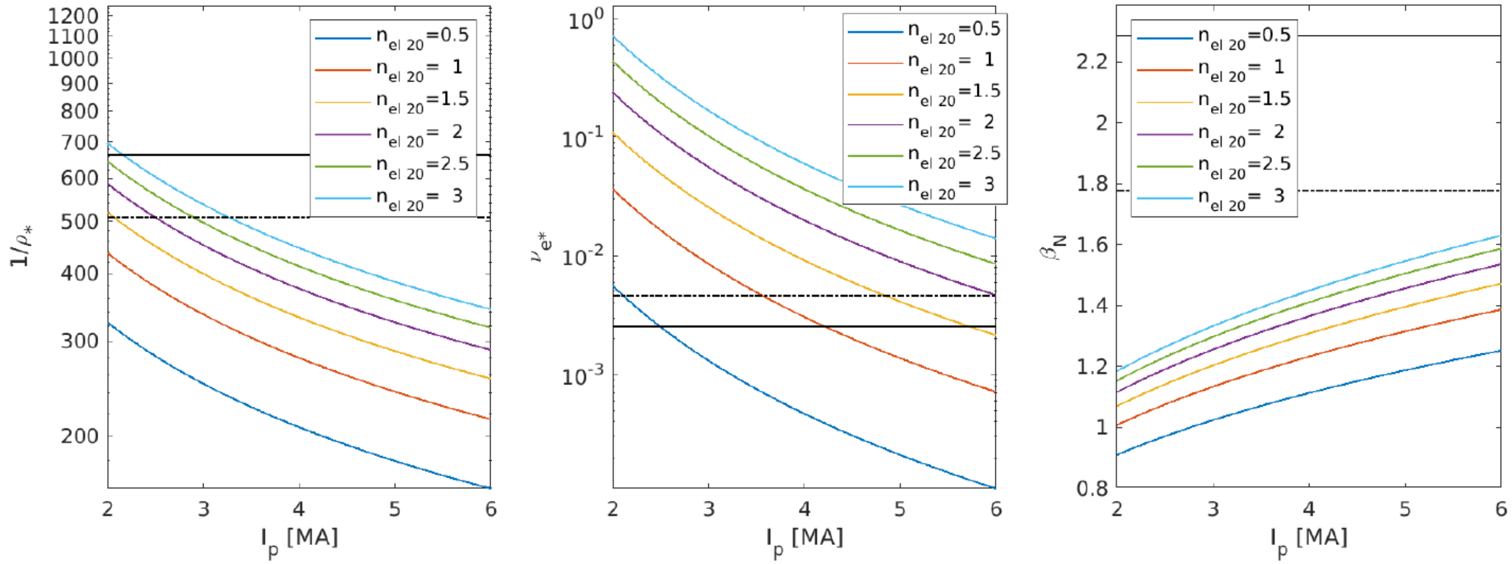


Fig. 4.2: Dimensionless plasma parameters (from left to right: volume-averaged values of $1/\rho_*$, ν_{e*} and β_N) as a function of the plasma current in MA, for different values of the line-averaged density at 5.8 T, with 40MW of auxiliary heating. We recall that at 5 MA, a line-averaged density of 1.5 10^{20} m^{-3} corresponds to a Greenwald fraction of 0.42. Horizontal lines give DEMO (solid) and ITER (dashed) reference values. From the application of the scaling laws, the thermal stored energy is computed and then used to compute the dimensionless parameters. This is also used for the calculation of β_N. The expression of ν_{e*} used in these plots is $\nu_{e*} = 5\ 10^{-5}\ \ln\Lambda\ Z_{eff}\ R\ q\ n_e /(T_e^2\ (r/R)^{1.5})$, with lengths in meters, density in 10^{19} m^{-3} and temperature in keV.

Figures in the Chapter

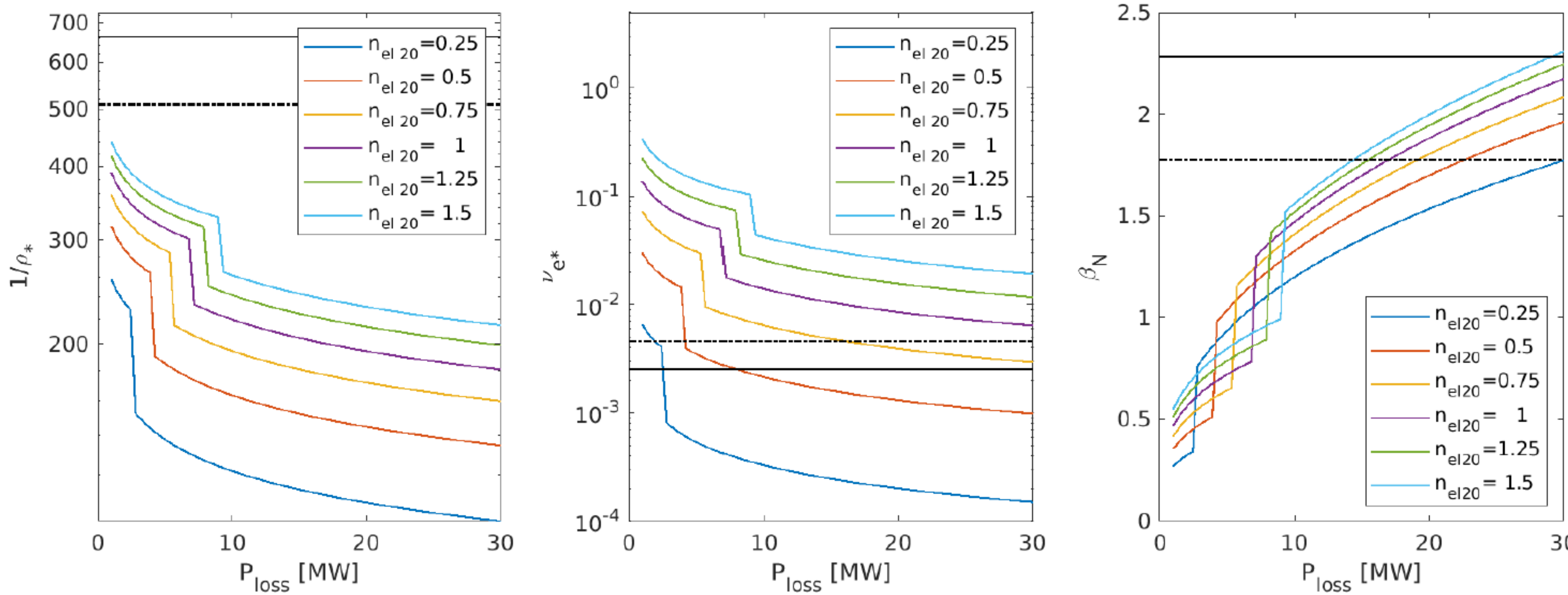


Fig. 4.3: Dimensionless plasma parameters (from left to right volume averaged values of $1/\rho_*$, ν_{e*} and β_N) as a function of the heating power in MW, for different values of the line averaged density at 2.9 T and 2.7 MA. We recall that at 2.7 MA, a line-averaged density of 10^{20} m^{-3} corresponds to a Greenwald fraction of 0.57. Horizontal lines give DEMO (solid) and ITER (dashed) reference values.

Figures in the Chapter

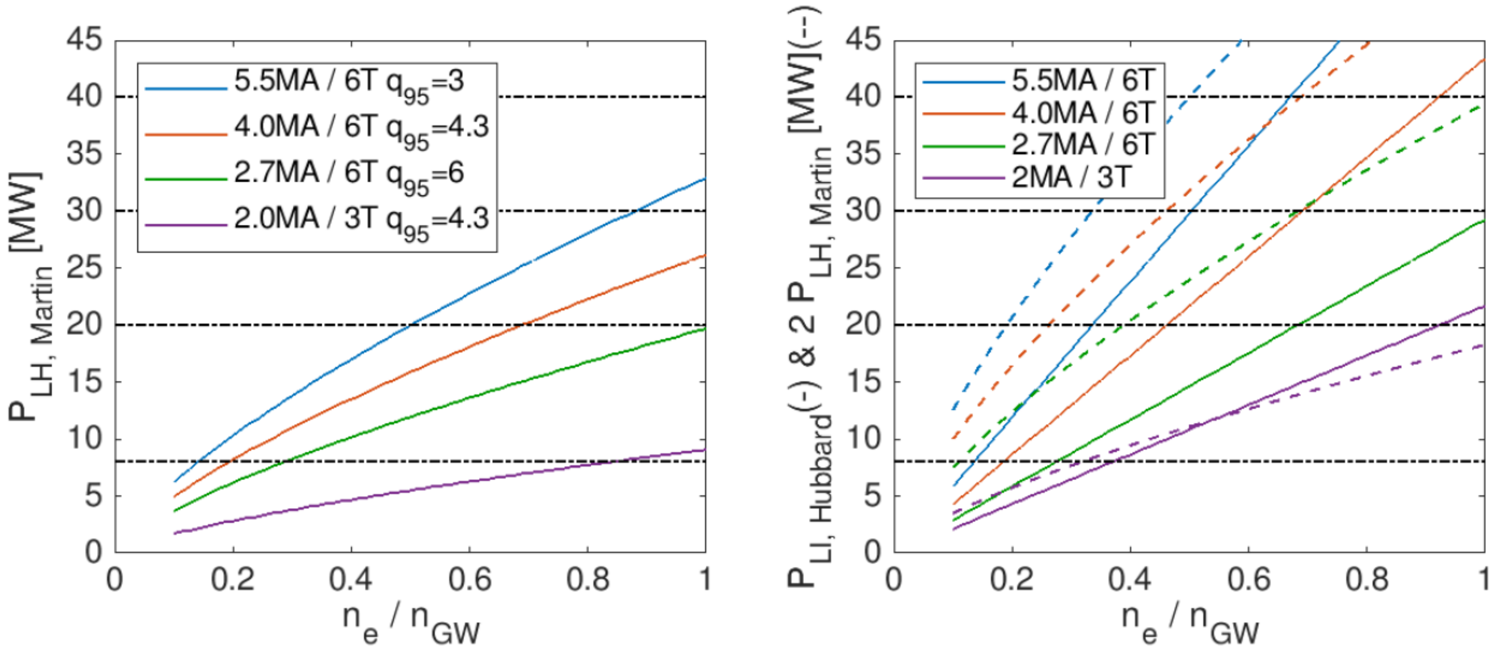


Fig. 4.4: Heating power for H-mode access (left) and for I-mode access (right) for different combinations of current and magnetic fields, foreseen in the different DTT phases, as a function of the corresponding Greenwald fraction. Horizontal dashed lines identify maximum heating power in the different DTT heating phases (8 MW for phase A, 20 MW for phases B and C, 30 MW for phase D, 40 MW for phase E. In phase A (8 MW), access to H-mode is only possible at low Greenwald fraction and with limited power window above the threshold. The same situation is present in phase C (20 MW, 6T and 4 MA). A large operational window for the I-mode regime should be particularly possible at 6T with reduced current.

Figures in the Chapter

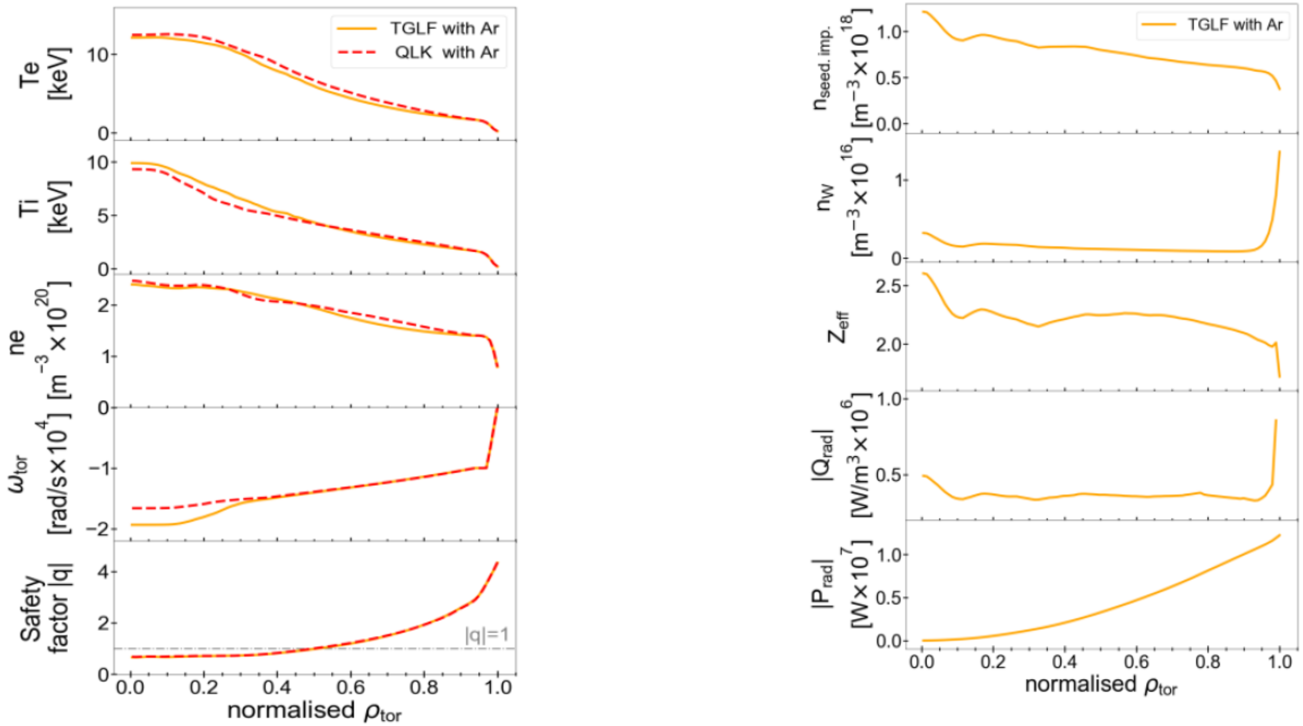
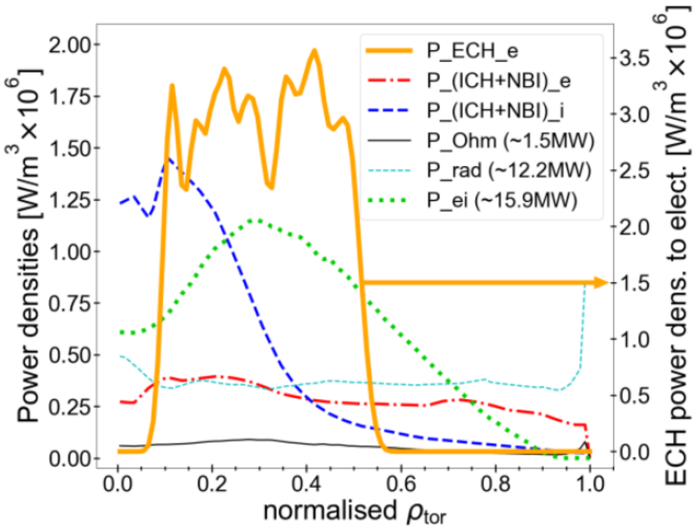


Fig. 4.5: Radial profiles for the E SN scenario flat-top phase: (a) of the electron and ion temperatures, electron density, toroidal rotation, and safety factor absolute value, with turbulent transport calculated by TGLF SAT2 (solid orange lines) or by QLK (dashed red lines) with argon; (b) profiles of the seeding impurity and tungsten densities, effective charge, radiative power density, and radiative power, calculated by TGLF and FACIT.

Figures in the Chapter



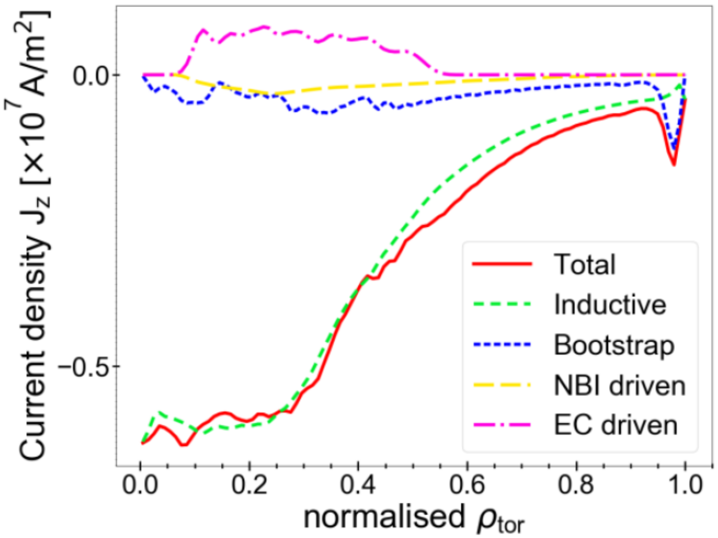


Fig. 4.6: Radial profiles of power densities for the E SN scenario: ECRH power deposited to electrons P_{ECRHe}, NBI and ICRH power deposited to electrons $P_{(ICRH+NBI)e}$, NBI and ICRH power deposited to ions $P_{(ICRH+NBI)i}$, Ohmic power P_{Ohm}, radiative power Prad, and thermal exchange power between electrons and ions P_{ei} (from the TGLF-SAT2 simulation).

Fig. 4.7: Radial profiles of current densities in the SN E scenario: total current J, inductive current J_{ind}, bootstrap current J_{BS}, NBI drive current J_{NB}, and EC drive current J_{EC}.

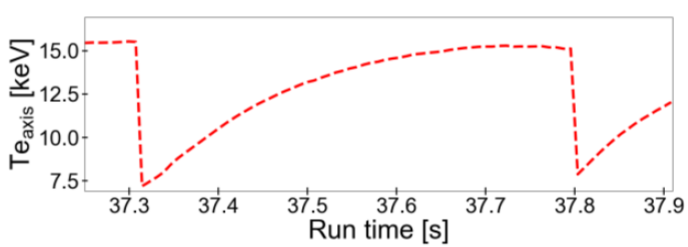


Fig. 4.8: Time evolution (a) of the electron temperature at the plasma centre Te_0 during a sawtooth and (b) of the |q| profile after a sawtooth crash.

Figures in the Chapter

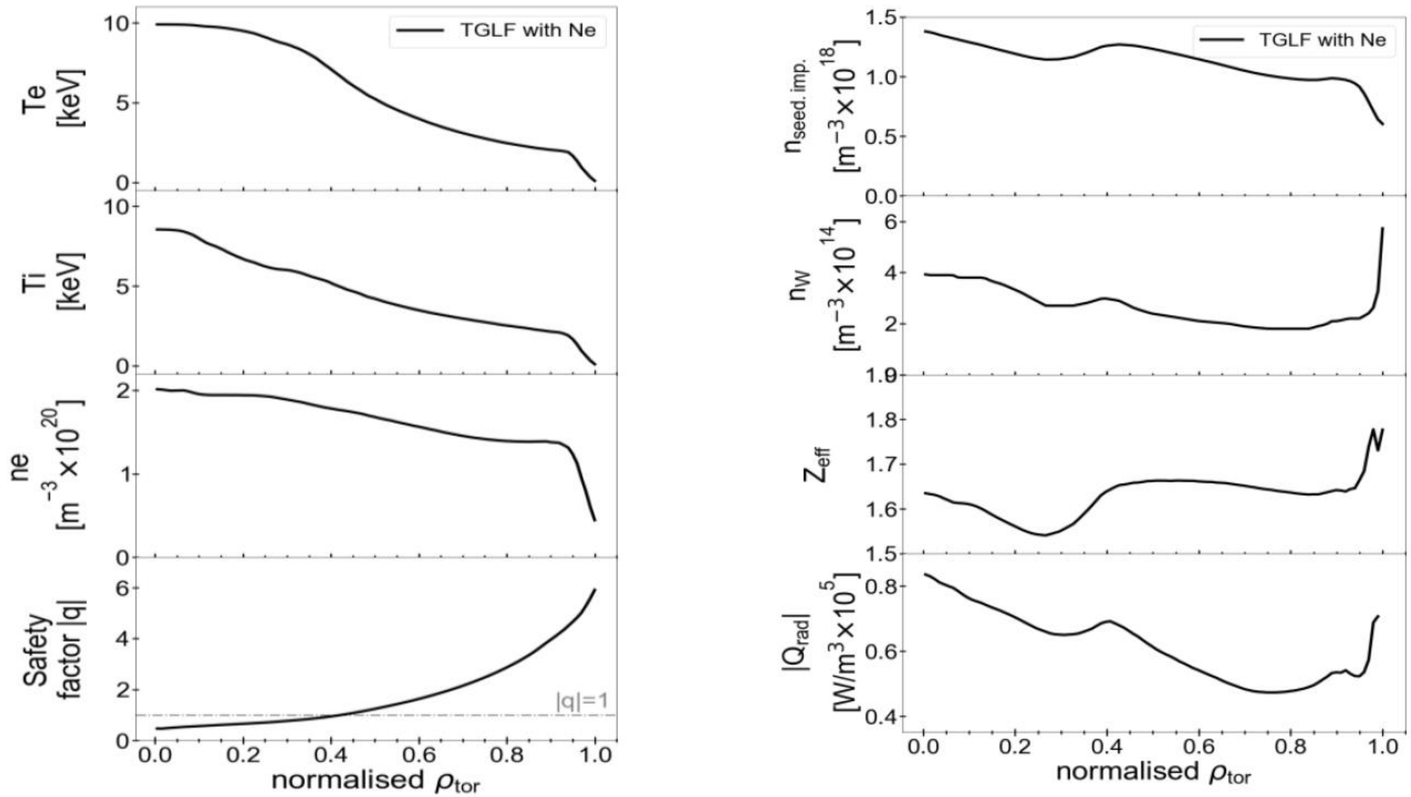


Fig. 4.9: Radial profiles for the C SN scenario flat-top phase (a) of the electron and ion temperatures, electron density and safety factor absolute value and (b) of the seeding impurity (Neon) and tungsten densities, effective charge and radiative power density, with turbulent transport calculated by TGLF and neoclassical by FACIT.