DTT Research Plan:
EG3 - Plasma scenarios and associated modelling

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for the DTT RP EG 3

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RP Chapters

Foreword

History, status and prospects of the DTT project

Chapter 1: DTT power exhaust strategy

DTT objectives, programme headlines, research phases

Chapter 2: Plasma scenarios

Reference scenarios in the various research phases

Chapter 3: Divertor and SOL physics

Divertor configurations, heat and particle exhaust

Chapter 4: Transport physics and integrated modelling of plasma scenarios

Plasma profiles and transport properties in the reference scenarios

Chapter 5: MHD, disruptions and control

Stability of reference scenarios, disruption studies

Chapter 6: Physics of heating, current drive and fuelling

Heating, current drive and fuelling scenarios

Chapter 7: Fast particle physics

Fast particle population and MHD in the reference scenarios

Chapter 8: Theory and simulation for preparation of experiments

Contribution of DTT to plasma theory for fusion research development

Chapter 9: Fusion technology developments

Opportunities for testing of fusion relevant components in DTT

RP Appendices

Appendices (synthetic descriptions of machine and subsystems, to be developed by the DTT project team):

Appendix A: DTT parameters
Appendix B: DTT machine description
Appendix C: Plasma facing components
Appendix D: Heating and current drive systems
Appendix E: Diagnostic systems
Appendix F: Control systems
Appendix G: Fuelling and pumping systems
Appendix H: Data system and numerical codes
Appendix I: Project structure, timeline and evolutions

EG3 Terms of Reference

- **EG-3: Plasma scenarios and associated modelling**
- Connecting with the objectives and main scenarios described by EG-1, elaborate simulations of the full plasma discharge scenarios (breakdown, ramp-up, flat-top, ramp-down, discharge termination)
- High-fidelity simulation of selected time slices of the various phases of the discharge
- Define the core plasma parameters for experiments relevant for core-edge integration
- Define a timeline for the core-edge integrated experimental programme
- Write Chapter 2: Plasma scenarios
- Write Chapter 4: Transport physics and integrated modelling of plasma scenarios

Assumed logic in splitting between Ch 2 and Ch 4

- **Chapter 2: Plasma scenarios**

  General overview of achievable plasma scenarios in the different phases

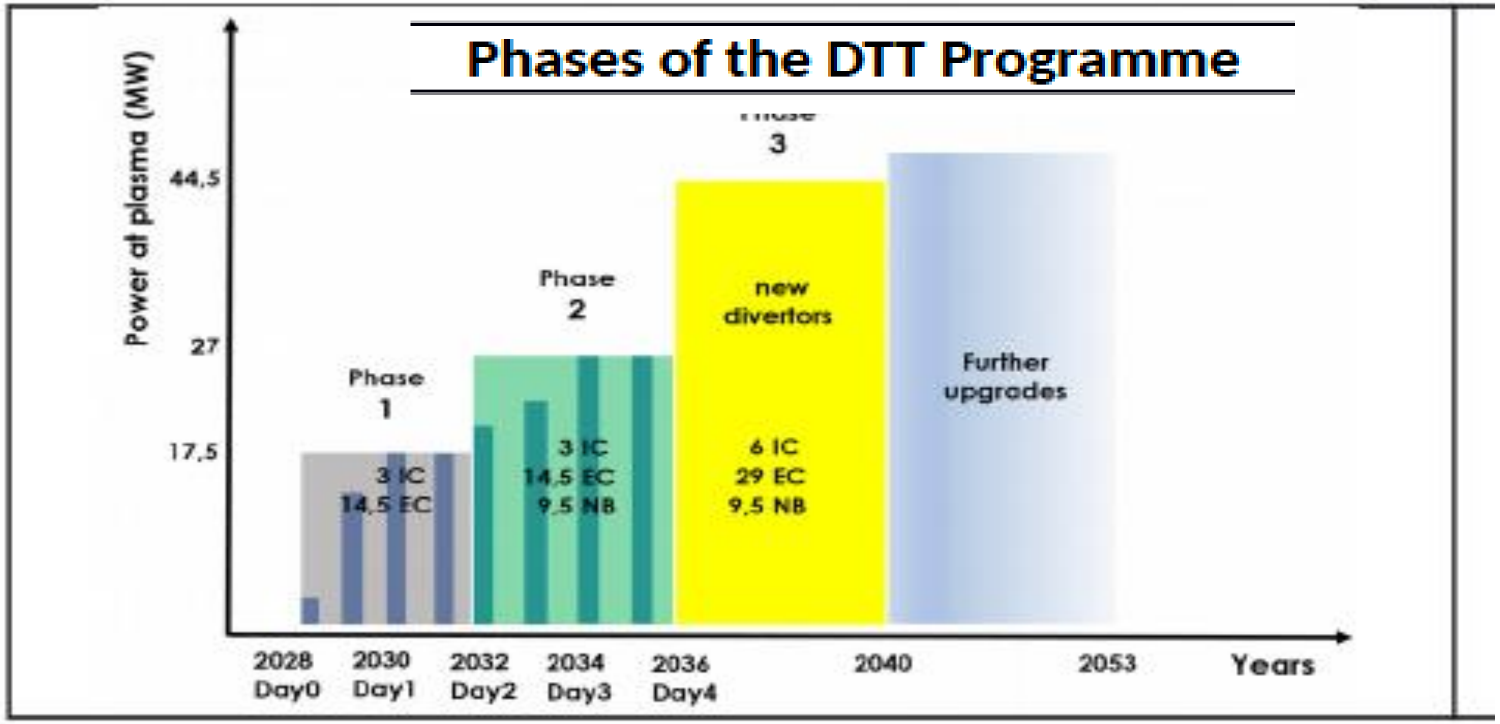
- **Chapter 4: Transport physics and integrated modelling of plasma scenarios**

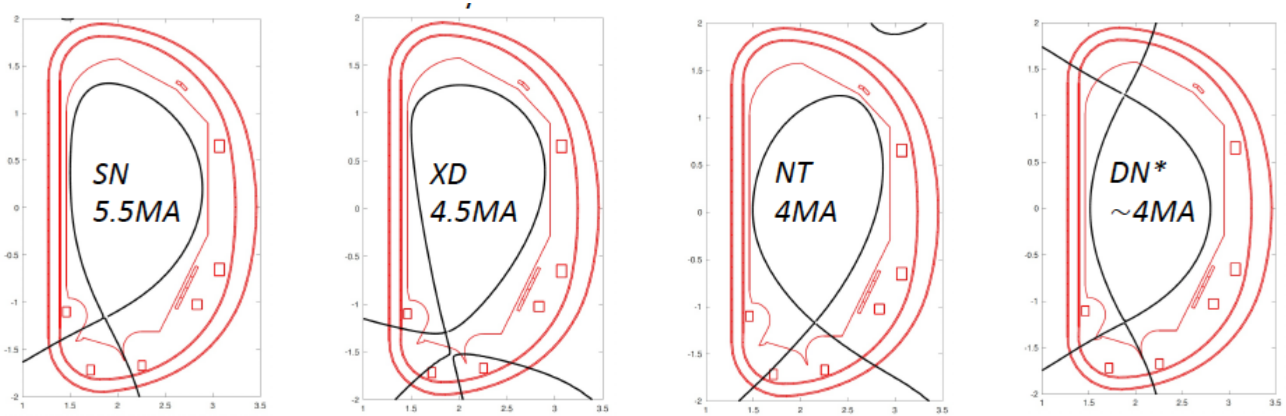
  In depth analysis of transport topics to be investigated, integrated modelling of scenarios

Divertor Tokamak Test facility (DTT)

	DTT	ITER	EU DEMO
R [m] / a [m]	2.19/0.70 = 3.1	6.2/2.0 = 3.1	9.1/2.93=3.1
I_{pl} [MA] / B_{tor} [T]	5.5/5.85	15/5.3	19.6/5.7
P_{sep}/R [MW/m]	15	14	17
P_{tot} [MW]	45	150	460
Pulse length [s]	95	400	7600
β_N [%]	1.5	1.6	2.6
τ_E [s]	0.4	3.6	4.2
H_{98}	~1	~1	~1
ρ^* [10^{-3}]	3.3	2.0	1.5
ν^* at r/a=0.5 [10^{-2}]	1.1	1.1	0.5

Heating phases and achievable configurations





Reference scenarios (Chapter 2)

fase	q95	I	BT	config divertore		EC (installata)	IC	NBI
A1	4.3	2	3	SN		8	0	
A2	4.3	2	3	XD		8	0	
A3	4.3	1.5	3	NT		8	0	
B1	4.3	2	3	SN		16	4	
B2	4.3	2	3	XD		16	4	
B3	4.3	1.5	3	NT		16	4	
C1	4.3	4	6	SN		16	4	
C2	4.3	4	6	XD		16	4	
C3	4.3	3	6	NT		16	4	
D1	3	5.5	6	SN		16	4	10
D2	3	4.5	6	XD		16	4	10
D3	3	4	6	NT		16	4	10
E1	3	5.5	6	SN		32	8	10
E2	3	4.5	6	XD		32	8	10
E3	3	4	6	NT		32	8	10

Phase 1
2028-2032

Phase 2
2032-2036

Phase 3
2036-2040

Phase 1

No NBI
Up to half max RF power

Power	BT/Ip	Achievable scenario	
	3/2	H-mode baseline SN , XD	
8 MW ECH	3/1.5	NT L-mode	A
	3/2	Hybrid?	
	3/2	H-mode baseline SN , XD	
16 MW ECH +4 MW ICH	3/1.5	NT L-mode	B
	3/2	Hybrid	
	3/2	High β AT scenario	
	6/4	H-mode baseline SN , XD	
16 MW ECH +4 MW ICH	6/3	NT L-mode	
	6/4	Hybrid (?)	C
	6/4	I-mode	
	6/4	EDA, QCE, QH (?)	

Phase 2

NBI + Up to half max RF power

Power	BT/Ip	Achievable scenario
	6/5.5-4.5	H-mode baseline SN , XD
16 MW ECH +4 MW ICH + 10 MW NBI	6/4.5	NT L-mode
	6/5.5	Hybrid (?)
	6/5.5	I-mode
	6/4	EDA, QCE, QH

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Phase 3

NBI + Full RF power

Power	BT/Ip	Achievable scenario
	6/5.5-4.5	H-mode baseline SN , XD
32 MW ECH +8 MW ICH + 10 MW NBI	6/4.5	NT L-mode
	6/5.5	Hybrid (?)
	6/5.5	I-mode
	6/4	EDA, QCE, QH (?)

E

Some specific limiting parameters

- Up to 5.85 T / 5.(5) MA, q_{95} < 3, $k_{95} \leq 1.65$, $\delta_{95} \leq 0.35, \delta_{sep} \leq 0.48, \delta_{95up} \geq -0.31$

- Some important parameters for scenario and transport studies

- n_{GW} = $I_p[MA] * 6.5 \ \left[10^{19}\ m^{-3}\right] \Longrightarrow$ 35.7 at 5.5 MA and 13.0 at 2 MA $\left[10^{19}\ m^{-3}\right]$

- ECRH cut-off: $n_{ECRH} \leq 35.8$ (O1 at 5.85 T) & ≤ 17.9 (X2 at 3.0 T) $\left[10^{19}\ m^{-3}\right]$

- P_{LH} (at $10^{20}\ m^{-3}$) $\simeq$ 8 MW (3T) and 14 MW (5.8 T) (from Martin's 2008)
- P_{LH} (at 0.5 n_{GW}) $\simeq$ 6 MW (3T) and 20 MW (5.8 T) (from Martin's 2008)

- Maximum heating powers and minimum densities compatible with walls protection?
- Pulse lengths? (at 5.5 MA: 14s ramp-up + 20s ramp-down, flat top from 20s to 50s depending on adopted transformer and actual Vloop, modelling required …)

Chapter 4

I. Integrated modelling of the scenarios

II. DTT Transport physics

- Integrated modelling of scenarios started (Casiraghi PPCF subm. + Bonanomi ASTRA)
- Progressive validation and understanding of experiments in early phase required (limited possibilities of scaling down scenarios in early phase, due to limited availability of heating power)

- Full scenario (E1) $P_{aux} \simeq 45$ MW, $P_{rad} \simeq 15$ MW

- Max available power in early phase is $P_{aux} \leq 18$ MW (B1 – C1)
- Note: ECRH X2 at 2.9 T / 2.5 MA and ECRH O1 at 5.8 T / 5 MA allows unprecedented one to one comparison of high field (low beta) and low field (high beta) operation in the same device

Scenario Modelling / transport studies must profit of full hierarchy of models

- Very valuable and broad expertize in the members of the EG 3
- Essential element is close interaction with other Expert Groups

- METIS (full discharge scenarios modelling)
- JINTRAC (HFPS) : JETTO+SANCO coupled to EDGE2D/ EIRENE
- Edge codes $\Longrightarrow$ interaction with EG 2
- ASTRA (includes STRAHL) and IMEP
- TGLF and QuaLiKiz (+ NN versions)
- Heating modules ECRH / ICRH : GRAY, TORBEAM, PION (TORIC) …
- NBI: PENCIL, RABBIT, NUBEAM, ASCOT, ORBIT … $\Longrightarrow$ interaction with EG 4
- Gyrokinetic codes (GENE, GKW) $\Longrightarrow$ interaction with Theory EG 5
- …

Chapter 4, DTT Transport Physics

- **Main characteristics of DTT**

1. Dominant electron heating (⇒ assessment of ion heating fraction in different conditions)
2. Relatively small L-mode operational window at 3 T ($\mathrm{P_{LH}} \simeq 6$ MW)
3. Large L-mode operational window at 5.8 T ($\mathrm{P_{LH}} \simeq 20$ MW)
4. Low torque input, low core particle source, opaque edge, modest CD capabilities (high, low density ?)

- **Main mission from the confined plasma standpoint**

- Compatibility of ELM-free regimes (e.g. I-mode, EDA H-mode, XPR, QH) and small ELMs regimes (QCE) with divertor configurations, detachment, impurity control
- From the standpoint of the confined plasma critical questions are:
- Is confinement good enough in conditions which are compatible with exhaust?
- If not, what can be done to improve it (from pedestal to core)
- Can we control core profiles of radiated power and how do these affect confinement ?
- ITER Baseline scenario (at ~2.5 MA / 3 T, required 10-20 MW, possible from B1 on)

DTT Transport Physics, general research goals

- There is really a wealth of transport physics questions that DTT can investigate

1. OH and L-mode properties of confinement (including positive and negative δ, scaling of confinement / transport vs Ip, BT, ne in electron heated conditions, ρ^* scaling, isotope studies)

2. L-H transition physics, impact of divertor configurations and exhaust requirements (high separatrix density, opaque edge, seeding, isotope studies)

3. Properties of H-mode confinement (note DTT should be able to access H-mode with ECRH(+ICRH) only) (BT vs q_{95}, and BT vs R (low vs high BT), opaque edge and fueling, pellets, isotope studies)

4. Confirm & further assess ITG / TEM / ETG (high density) paradigm ($\mathrm{n}/\mathrm{n}_{\mathrm{GW}}$ vs ν)

5. Impurity transport (note that DTT should almost be accumulation free … (examples from C-Mod))

6. Properties of intrinsic rotation / residual stress (profile shearing, ρ^* scaling, …) in L- & H-mode

7. … (general note, DTT naturally allows parameter decorrelation in comparison to low field devices)

DTT Transport Physics, diagnostic requirements

- Diagnostics requirements can be organized in three main blocks

1. Diagnostics required for (first and high power) operation
2. Diagnostics required for achievement of main scientific goals
3. Diagnostics required for general physics research

- These are not fully separated boxes, since some diagnostics of 2 and 3 can move to 1 in a later stage (e.g. to enable real-time control of various parameters)

DTT Transport Physics, diagnostic requirements

- For "conventional" transport studies, essential are $\mathbf{n}_e$, $\mathbf{n}_Z$, $\mathrm{T}_{\mathrm{e,i}}$, $\mathrm{v}_{\varphi,(\theta)}$ profiles measurements, as well as bolometry and spectroscopy for radiation and (2D) impurity density
- Possibly measurements of E_r profile

- Availability of diagnostics in time will determine the scientific program that can become meaningful to perform
- Goal: coherence between machine exp possibilities and diagnostic capabilities

- Adequate edge coverage should be considered a priority for core-edge-SOL studies (critical are also SOL diagnostics to constrain and validate edge modelling $\Rightarrow$ EG 2)

- Most appropriate fluctuation measurements (in connection with planned turbulence codes applications, core / edge) (to be determined …).
- …

Main questions related to transport/scenarios of relevance for ITER and DEMO that DTT could answer

Key issue towards fusion reactors

Compatibility of heat exhaust solutions with good plasma confinement

Actions to mitigate exhaust in general have a negative effect on core performance:

- Increase ne_sep for detachment → approach Grw limit → confinement deterioration
- Impurity seeding → fuel dilution
- ELM mitigation → degraded pedestal

ITER, low field devices
DEMO large minor radius
low nGrw

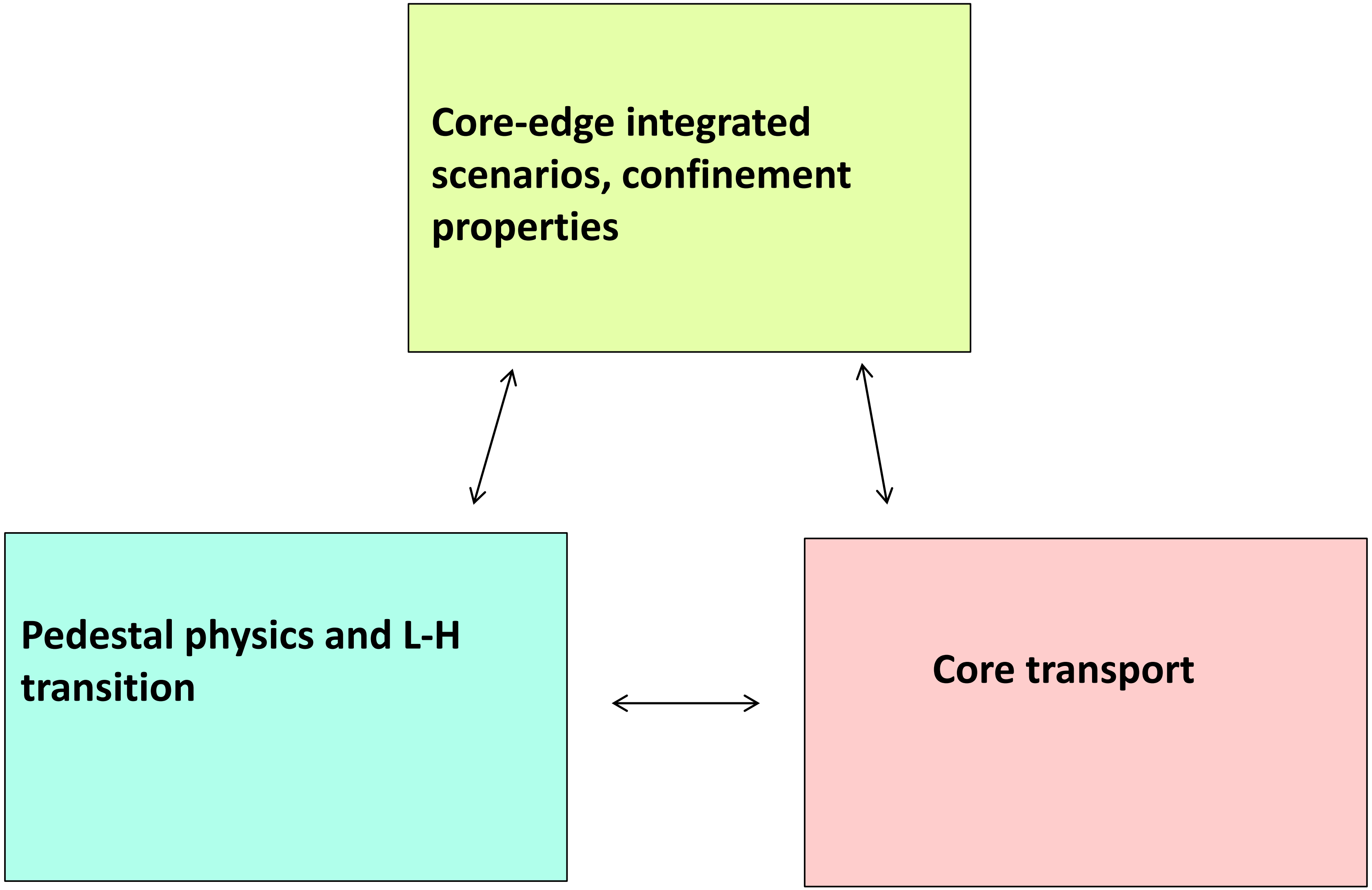
→ They operate always near Grw limit

DTT high field device
small minor radius, high nGrw

→ Large flexibility of operating at various Grw fractions to study effect of edge on core

→ At B_T=3T/Ip=2 MA DTT becomes a low B_T device like ITER and DEMO, and we can compare the two configurations in the same device

Main questions related to transport/scenarios of relevance for ITER and DEMO that DTT could answer



main questions related to transport/scenarios of relevance for ITER and DEMO that DTT could answer

Core-edge integrated scenarios, confinement properties

- Regimes with no ELMs or small ELMs, EDA, QCE, QH (?)

  I-mode, negative δ
- Impurity seeded detached scenarios at ITER- and DEMO-relevant values of ν^*, ρ^* and β with ITER- and DEMO-like plasma shape (δ~0.5?)
- Effects of Grw fractions on edge and core transport
- Plasmas with high density but low collisionality
- Impurity control
- Study of Advanced Tokamak and Hybrid regimes and of their compatibility with power exhaust solutions. Comparison high/low BT.

P

transition

main questions related to transport/scenarios of relevance for ITER and DEMO that DTT could answer

Core-edge integrated scenarios, confinement properties

Pedestal physics and L-H transition

- Pedestal physics beyond MHD peeling-ballooning
- H-mode threshold in different gas, effects of divertor and impurity seeding on threshold and pedestal
- Physics of fuelling by gas puff and pellet injection (impact on L-H transition, pedestal and confinement)
- High density and low collisionality
- Effects of high shaping δ~0.5?

port

main questions related to transport/scenarios of relevance for ITER and DEMO that DTT could answer

Core-edge integrated scenarios, confinement properties

Pedestal physics and L-H transition

Core transport

- Transport in plasmas with dominant electron heating and low torque
- Density peaking at negligible core NBI particle sources
- Ion stiffness mitigation strategies
- Turbulence diagnostics, model validation

main questions related to transport/scenarios of relevance for ITER and DEMO that DTT could answer

Core-edge integrated scenarios, confinement properties

- Regimes with no ELMs or small ELMs, EDA, QCE, QH(?), I-mode, negative δ
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Core transport

- Transport in plasmas with dominant electron heating and low torque
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- Ion stiffness mitigation strategies
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Possible items related to transport/scenarios in the DTT Research Plan

Plasma scenarios & integrated modelling: Research plan index proposal

1. Introduction

2. Core-edge integrated scenarios, confinement properties

- Regimes with no ELMs or small ELMs, EDA, QCE, QH(?), I-mode, negative δ
- Impurity seeded detached scenarios at ITER- and DEMO-relevant values of ν^*, ρ^* and β (?) with ITER- and DEMO-like plasma shape (δ~0.5?) (Te/Ti ?)
- Effects of Grw fractions on edge and core transport
- Plasmas with high density but low collisionality
- Impurity control
- Study of Advanced Tokamak and Hybrid regimes and of their compatibility with power exhaust solutions. Comparison high/low BT.

Possible items related to transport/scenarios in the DTT Research Plan

3. **Pedestal physics and L-H transition**
   - Pedestal physics beyond MHD peeling-ballooning
   - H-mode threshold in different gas, effects of divertor and impurity seeding on threshold and pedestal
   - Physics of fuelling by gas puff and pellet injection (impact on L-H transition, pedestal and confinement)
   - High density and low collisionality
   - Effects of high shaping δ~0.5?
4. **Core transport**
   - Transport in plasmas with dominant electron heating and low torque
   - Density peaking at negligible core NBI particle sources
   - Ion stiffness mitigation strategies
   - Turbulence diagnostics, model validation
5. **Conclusions**