Global Plasma Simulations for ITER Scenario Development


The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.
The ultimate aim of ITER is to produce 500MW of fusion power from 50MW of input heating power for 500s.

- **PFPO goals:**
  - Commission ITER systems.
  - Exploration of operational space and plasma scenario development to achieve best possible plasma performance in FPO.

- **Main priorities:**
  - Longevity of the divertor
    - Divertor power loads $< 10 \text{MWm}^{-2}$
    - Minimise W sputtering
  - Limit W transport into the core plasma

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**Available actuators:** Heating, fuelling and Ne seeding.
JINTRAC – A state-of-the-art tool for integrated modelling of the whole plasma

- JINTRAC can perform core/edge/SOL/divertor integrated simulations across all phases of a discharge.

- LH power threshold for $f_{GW} > 40%$
  - $P_{LH}^D \propto n_{e20} B_T^{0.8} S^{0.9} M^{-1}$
  - $P_{LH}^H = 2 \times P_{LH}^D$
  - $P_{LH}^{He} = 1.4 \times P_{LH}^D$
  - $P_{LH}^{H+He} = 0.85 \times P_{LH}^H$

Martin Y. R. et al. 2008 Journal of Physics: Conference Series 123 012033,

F. Köchli, IAEA FEC 2018 EX/P7-25
PFPO-1: Initial H-mode plasmas at 5MA/1.8T

- Hydrogen & Helium discharges at 5MA/1.8T
  - 20-30 MW ECRH heating.
- Assess feasibility to sustain robust type-I ELMy H-modes
- Low density - just above the minimum density for H-mode access.

- Problem with divertor power loads?
- Problem with ECRH absorption?
- Problem with core impurity accumulation?
H-mode access in ITER 5MA/1.8T Hydrogen plasma with 30MW ECRH

- Low density: \( n_{\text{el}} = 1.2-1.9 \times 10^{19} \text{m}^{-3} \)
  - Thermal decoupling of electrons and ions
  - \( T_e > 10 \text{keV} \)
  - Full ECRH absorption!
- Ne seeding
  - Keeps maximum power load acceptable
    - 1.5MW core radiation
- \( P \) @256s:
  - Sputtering yield minimal
  - Core \( <n_{W}/n_{H}> \sim 1 \times 10^{-6} \)
  - 1MW core radiation

30MW ECRH allows to sustain a robust type-I ELMy H-mode in 5MA/1.8T Hydrogen plasma

\[ \begin{align*}
\text{Low density:} & \quad n_{\text{el}} = 1.2-1.9 \times 10^{19} \text{m}^{-3} \\
\text{- Thermal decoupling of electrons and ions} & \quad T_e > 10 \text{keV} \\
\text{- Full ECRH absorption!} & \\
\text{Ne seeding} & \quad \text{Keeps maximum power load acceptable} \\
\text{1.5MW core radiation} & \\
\text{\( P \) @256s:} & \quad \text{sputtering yield minimal} \\
\text{\( <n_{W}/n_{H}> \sim 1 \times 10^{-6} \)} & \quad \text{1MW core radiation}
\end{align*} \]
H-mode access in 5MA/1.8T Helium plasma with 30 MW ECRH

- At low density W sputtering a problem
  - Higher He density required.
  - Trade off between between higher $P_{LH}$ and lower W plasma contamination.

- Scan He gas rate:
  - For 30MW ECRH
    - Optimal rate: $>0.3 \times 10^{22}\text{s}^{-1}$
    - Final core $P_{\text{rad,W}} < 1\text{MW}$
    - Divertor fluxes < 1MWm$^{-2}$

30MW ECRH allows to sustain type-I ELMy H-mode in 5MA/1.8T Helium plasma
PFPO-2: H-mode plasmas at 7.5MA/2.65T

- Hydrogen & Helium discharges at 7.5MA/2.65T with
  - 20-30 MW ECRH heating
  - 33MW Hydrogen Neutral Beam (H⁰-NB) Heating

➤ Not enough to get pure H plasma into H-mode! Options:
  1. Low density H plasma
     ➤ Add Ne to get NB absorption up
  2. High density H plasma
     ➤ Add 10% He to lower $P_{LH}$

- Assess feasibility to access robust ELMy H-modes!

- Problem with divertor power loads?
- Problem with NB absorption?
- Problem with core impurity accumulation?
H-mode operation in 7.5MA/2.65T Ne rich Hydrogen plasma

- Low plasma density
  - \( n_{el} \sim 2.5 - 3 \times 10^{19} \text{m}^{-3} / f_{GW} \sim 45\% \)
- L-mode: Max 2\% Ne to avoid full divertor detachment
- H-mode: 6\% of Ne give low NB shine-through
- 20MW ECRH + 33MW NB
  - Type-III ELMy H-mode

30MW ECRH + 33 MW NB allows to sustain a stable type-I ELMy H-mode in 7.5MA/2.65T Ne rich H plasma
H-mode access in 7.5MA/2.65T Hydrogen plasma with ~11% Helium

- 20MW ECRH + 33 MW NB
- $n_{\text{He}}/n_e \sim 11\%$
- $n_{\text{Ne}}/n_H \sim 10\%$
  - NB shine-through: $1\text{MW} < 1.8\text{MW}$
- Divertor loads too high
- 6.4 MW core radiation:
  - Ne: 5.8MW
  - W: 0.8MW

20MW ECRH + 33 MW NB allows to sustain type-I ELMy H-mode in 7.5MA/2.65T H plasma with ~11% He and 10% Ne.
H-mode access in 7.5MA/2.65T Helium plasma

- **20MW ECRH + 33 MW NB**
- High initial NB shine-through rapidly decreased by increasing density.
  - Max He gas rate $2 \times 10^{22} \, \text{el/s}$
  - Any higher leads to full detachment.
- **W core:**
  - Concentration $\sim 1 \times 10^{-4}\%$ of He
  - Radiation $\sim 0.25\text{MW}$
- Divertor power fluxes $< 1\text{MWm}^{-2}$
  - No Ne in these simulations!

20MW RF + 33 MW NB allows to enter a stable type-I ELMy H-mode in 7.5MA/2.65T He plasma.
PFPO-2: First plasma at 15MA/5.3T - Hydrogen L-mode

First plasma at current, field and NB power required for DT Q=10!

- Important proof-of-concept!
- $P_{LH} \propto B^{0.8} Z^{3/2} M^{-1} > 100$MW for 15MA/5.3T Hydrogen plasma!
  - Only up to 73MW available auxiliary heating
    - H-mode operation not possible
    - ELM control not needed!
    - Possibility of commissioning the hydrogen neutral beams at full energy (1MeV):
      - H plasma need very high density $> 4.3 \times 10^{19}$m$^{-3}$ for permissible neutral beam shine-through.
      - ECRH heating to sustain plasma
First plasma at 15MA/5.3T: Hydrogen L-mode

- Final average density > $5.0 \times 10^{19} \text{m}^{-3}$
  - Pellet fuelling essential
- Full NB power (33MW) injected.
- Divertor power loads < 5MWm$^{-2}$
- Levels of Ne, Be & W very low
  - W sputtering increases when NB applied
    - W sputtering yield < $1.2 \times 10^{-5}$
  - Be Sputtering yield < $2.5 \times 10^{-5}$
  - Final W core radiation: 7kW

Commissioning of Hydrogen Neutral Beam Heating at full power possible in 15MA/5.3T Hydrogen L-mode.
Summary and conclusions

- With state-of-the-art integrated modelling tool JINTRAC we have developed integrated core/pedestal/SOL/divertor scenarios for ITER PFPO respecting operational and technical constraints.

- The ITER Research Plan: initial power of 20MW ECRH in PFPO-1.
  - Upgrade by 10MW to 30MW ECRH for PFPO-1 under discussion.

Our study support this upgrade and suggest that robust type-I ELM/H-mode operation for 5MA/1.8T H, He and H-He minority plasmas requires 30MW ECRH in PFPO-1.

- PFPO-2: Type-I ELM/H-mode operation at 7.5MA/2.65T requires:
  - 20MW RF & 33MW NB in He plasma
  - 20MW ECRH & 33MW NB in H plasma with a He/Ne minority mix
    - More robust H-mode with 30MW ECRH
    - Caveat: Benefits from a 15% lower $P_{LH}$ as observed on JET.
  - 30MW ECRH & 33MW NB in H with Ne minority
    - 20MW ECRH & 33MW NB not yet ruled out but will likely be more marginal.

PFPO-2 key milestone for DT Q=10: fully developed 15MA/5.3T integrated H L-mode scenario allowing for 33MW/1MeV NB.
Thank you for your attention!