ITER Pre-Fusion Power Operation (PFPO) phase scenarios

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Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

Outline

- Staged approach and available H&CD systems
- First Plasma
- Introduction to PFPO phase
- Key scenarios in PFPO-I phase
- Key scenarios in PFPO-II phase
- Conclusions

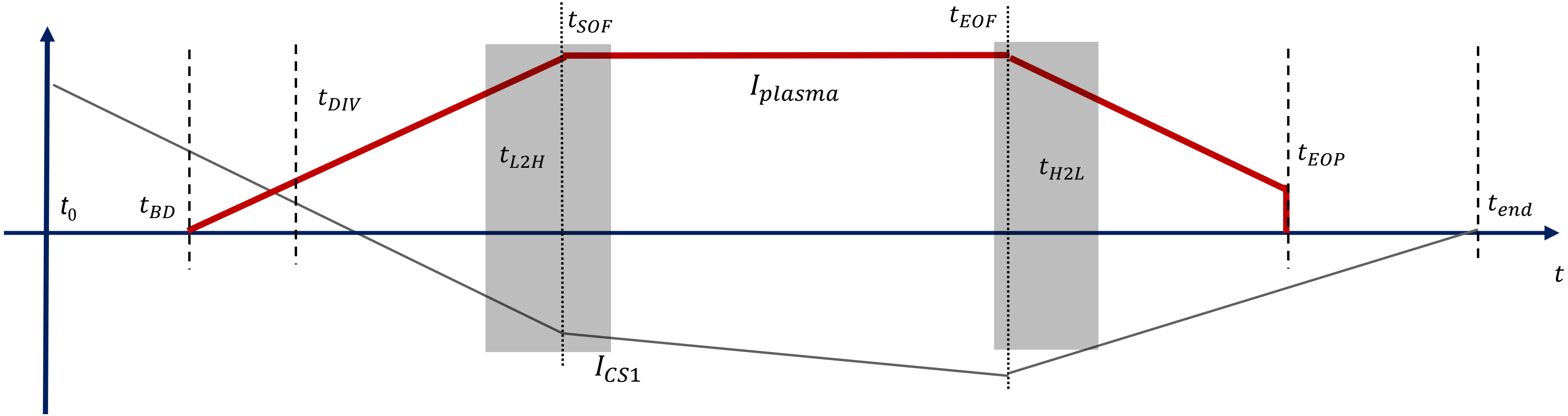
Staged approach and H&CD systems

	1st Plasma	PFPO-1	PFPO-2	FPO	HCD Upg.
EC	5.8MW, 170GHz, UL	20MW + 10MW[1]	→	→	20MW + 20MW[2]
IC			20MW	→	20MW + 20MW[2]
NB			33MW, H-beam	33MW, D-beam	33MW + 16.5MW[2], D-beam
Key Kinetic Scenarios	First plasma	5MA/1.8T H-mode	7.5MA/2.65T H-mode, 15MA/5.3T L-mode	15MA/5.3T DT H-mode (“ITER baseline”)	Hybrid and Steady-State

[1] To be confirmed

[2] HCD upgrade options

Plasma scenario sequences



t_0 – Start of scenario and CS discharge. No plasma yet

t_{BD} – Plasma breakdown. Start of plasma current ramp-up in a limiter configuration

t_{DIV} – Transition from a limiter configuration to a diverted configuration. Transition to a shape controller

t_{L2H} – Confinement transition from L-mode to H-mode along with the auxiliary (and fusion) heating power increase

t_{SOF} – Start of current flat-top. End of current ramp-up

t_{EOF} – End of current flat-top. Start of current ramp-down

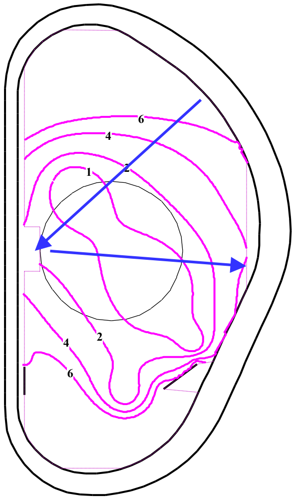
t_{H2L} – Confinement transition from H-mode to L-mode. A large reduction of auxiliary (and fusion) heating power

t_{EOP} – End of plasma. A (non-destructive) disruption is supposed

t_{end} – End of scenario. Zero PF coil currents

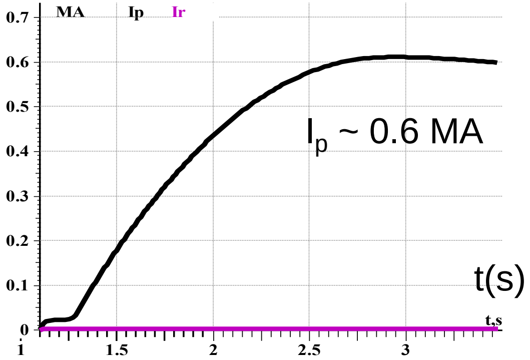
First Plasma milestone

- Achievement of plasma breakdown in hydrogen (or helium) as the first ITER integrated plant system commissioning
- At least 100kA for at least 100ms, possibly up to 1MA for a few seconds
- Feedback control of plasma current, shape and position
- EC assisted pre-ionization up to 5.8MW – 170GHz, X2, upper launcher (UL), reflected by HFS mirror towards LFS beam-dump
- 2.65T, I_{CS}=20kA (~half CS charging)



Surfaces with B_p = 1, 2, 4, 6 mT

ITER criterion B_p<3mT



SCENPLINT modeling with a partial burn-through

PFPO-I phase

- Pre-Fusion Power Operation (PFPO) phases
  - Hydrogen and helium plasmas
  - Trace levels of Deuterium are considered for PFPO-II, whereas the main Deuterium plasmas are considered for initial phase of Fusion Power Operation (FPO)

- PFPO-I
  - Extensive system commissioning activities
  - Establishment of diverted plasma operation will be developed up to 10MA/5.3T
  - Establishment of plasma control, diagnostics, electron cyclotron (EC) heating and current drive (H&CD), and disruption mitigation capabilities
  - An option for early access to high confinement mode (H-mode) through operation at 1.8T with EC heating up to 30MW (to be confirmed)

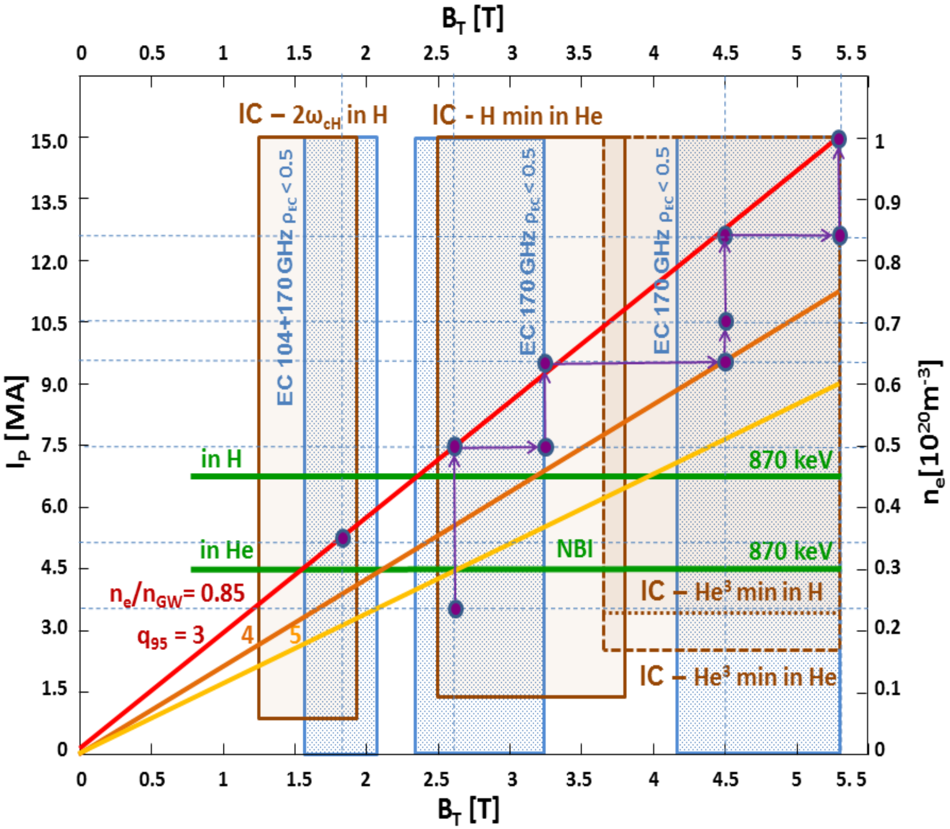
PFPO-II phase

- PFPO-II
  - Heating/diagnostic neutral beams and ion cyclotron H&CD will be commissioned to their full power
  - Advance the capabilities of plasma control, edge localized mode (ELM) and divertor heat load controls, fuelling and disruption mitigation (DMS) systems
  - As a key milestone, high power L-mode operation will be developed up to 15MA/5.3T to demonstrate the full technical capability of the device
  - Various H-mode scenarios at fields above 1.8T by utilizing various mixes of H&CD systems (up to 73MW) to establish the physics and operational basis required for the transition to FPO phase.

Progressive approach in PFPO

- Heating and Current Drive (H&CD) systems
  - Continuous increase in power along with the staged approach
  - H&CD operational space constrained by B_T and plasma density
  - H^0 870 keV beams in H/He plasmas

- Progressive steps from low to high B_T and I_p at around q_{95}=3~5
  - To minimize risks of disruption and establish techniques of avoidance



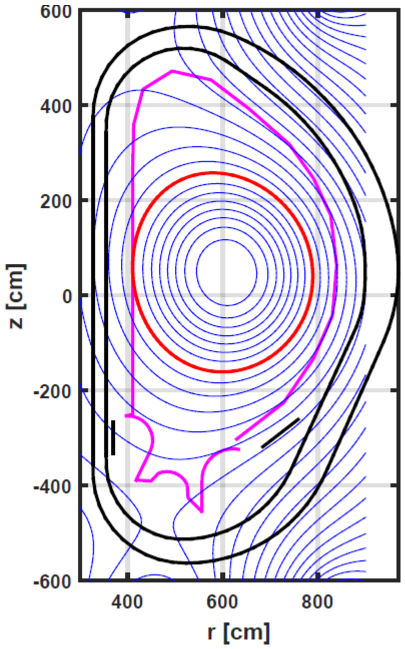
Key Scenarios in PFPO-I phase

- 3.5MA / 2.65T Hyd. L-mode (first divertor plasma)
- 7.5MA / 2.65T Hyd. L-mode (first q_{95}=3 plasma)
- 5.0MA / 1.8T Hyd. or He H-mode (first H-mode with ECH)

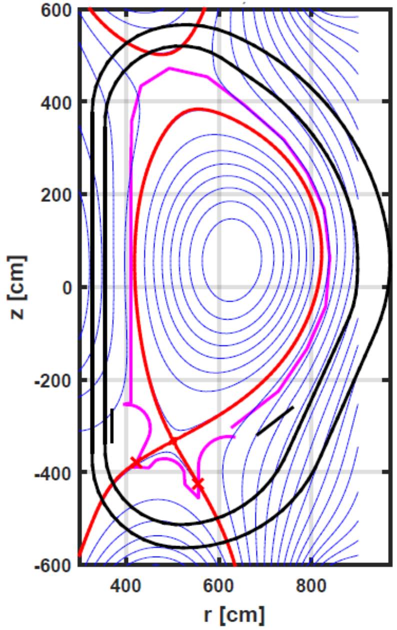
- Low current (<3.5MA) limiter plasmas
- 10MA/5.3T Hyd. L-mode plasmas

First Divertor Plasma

- Establishment of initial divertor configuration at 3.5MA / 2.65T (X-point formation ~3.2MA)
- Initial plasma configuration limited at the inboard side wall
- Commissioning of systems (Plasma control and protection systems, diagnostics and DMS) with flattop ≥10s
- Up to 20-30MW EC, 170GHz with an option for up to 1/3 dual freq. gyrotrons at 170/104GHz
- A wide range of flat-top length for I_{CS}=20kA (~half CS charging)
  - ~115s with Ohmic
  - ~530s with 5MW ECH



Plasma confg. at *t* ≈ 10s (3MA limiter scenario)



Plasma config. at SOF (3.5MA divertor scenario)

Design assumptions and questions

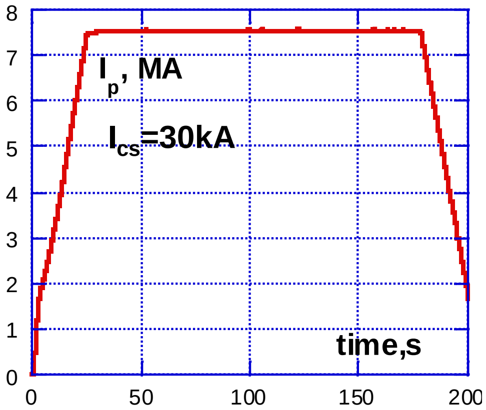
- First diverted plasma is designed to be achieved in the 3.5MA scenario
  - Why the X-point formation is designed at ~3.2 MA during the ramp-up phase, not at lower plasma current or at much high current?

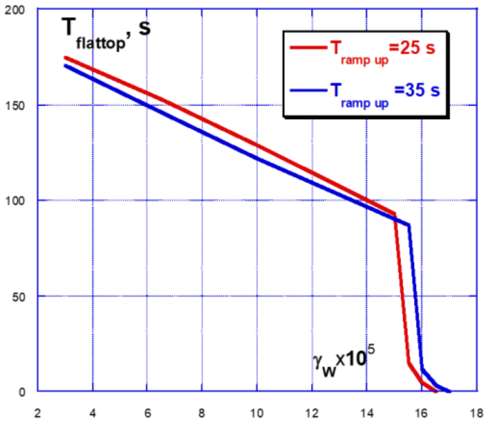
Background and reasons

- First diverted plasma is designed to be achieved in the 3.5MA scenario
  - Why the X-point formation is designed at ~3.2 MA during the ramp-up phase, not at lower plasma current or at much high current?
  - Limiter configuration at higher current can cause issues on the wall, plasma confinement and performance ➔ low possible current
  - 3.2 MA is approximately the minimum current for magnetic control with full bore plasma in divertor configuration (especially for Single Null Lower in ITER)

First q_{95}=3 Plasma

- q_{95}=3, 7.5MA / 2.65T Hyd. plasma is likely to be in L-mode
  - H-mode threshold power (P_{LH}) incl. some margins > P_{aux} (20~30MW) in PFPO-I
  - $P_{LH,Martin} \sim 0.05\ (n_e\ [10^{20} m^{-3}])^{0.72}\ (B_T\ [T])^{0.8}\ (S\ [m^2])^{0.94}\ (2 \times Z/m \times C_{Ion})$, C_{He}~1.4, $C_{H/D/DT}$ ~1.0
- A range of L-mode flat-top duration with 20MW ECH
  - ~65s with I_{CS}=30kA, 5MW ECH, low W content (~10^{-5})
  - ~170s with I_{CS}=30kA, 20MW ECH, low W content (~3×10^{-5})





Flat-top duration vs W content

Design assumptions and questions

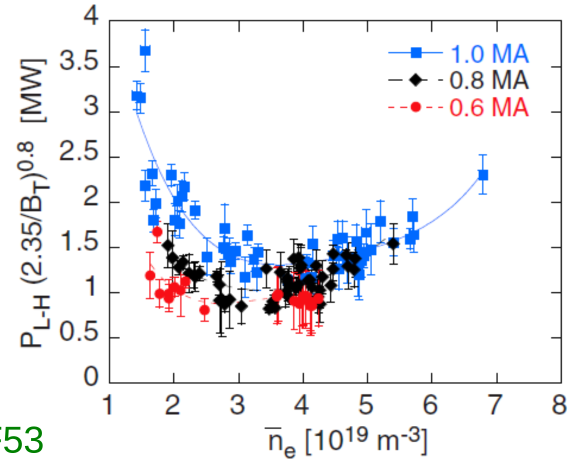
- What would be P_{LH} in q_{95}=3, 7.5MA / 2.65T Hyd. plasma?
  - $P_{LH,Martin} \sim 0.05\ (n_e\ [10^{20}m^{-3}])^{0.72}\ (B_T\ [T])^{0.8}\ (S\ [m^2])^{0.94}\ (2\times Z/m\times C_{Ion})$, C_{He}~1.4, $C_{H/D/DT}$ ~1.0
  - $n_e = 0.26\times10^{20}m^{-3}$ ~43% n_{GW} (= $I_p/(\pi a^2)$ ~$0.6\times10^{20}m^{-3}$)
  - B_T = 2.65T, S = 683m^2, Z=1, m=1

- Why don't we reduce the density to lower P_{LH}?

Background and reasons

- What would be P_{LH} in q_{95}=3, 7.5MA / 2.65T Hyd. plasma?
  - $P_{LH,Martin} \sim 0.05\,(n_e\,[10^{20}m^{-3}])^{0.72}\,(B_T\,[T])^{0.8}\,(S\,[m^2])^{0.94}\,(2\times Z/m\times C_{Ion})$, C_{He}~1.4, $C_{H/D/DT}$ ~1.0
  - $n_e = 0.26\times10^{20}m^{-3}$ ~43% n_{GW} (= $I_p/(\pi a^2)$ ~$0.6\times10^{20}m^{-3}$)
  - B_T = 2.65T, S = 683m^2, Z=1, m=1
  - ➢ $P_{LH,Martin}$ (H) ~ 38MW + uncertainties

- Why don't we reduce the density to lower P_{LH}?
  - ➢ H-mode threshold power roll-over at low density
  - ➢ The density for minimum P_{LH} ~ 40% n_{GW}

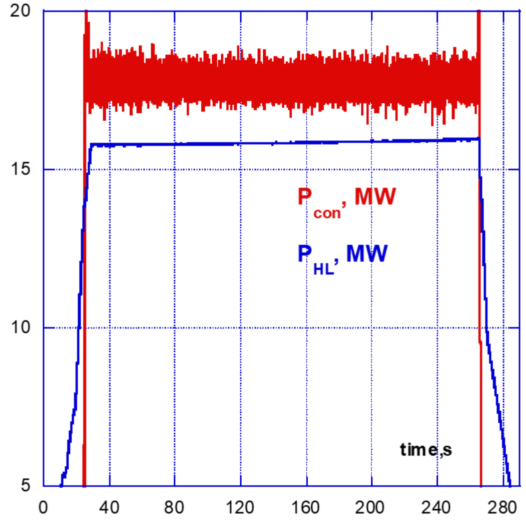


Ryter, NF53

First H-mode with EC H&CD

- q_{95}=3, 5MA / 1.8T Hyd. or He plasma in H-mode
  - $P_{LH,Martin}$~ [10-27 MW in He and ~20-35MW in Hyd.] ≤ P_{aux} (20~30MW) in PFPO-I
- He H-mode flat-top duration with 20MW ECH, 50% n_{GW}
  - ~245s with I_{CS}=20kA, low W content (~2×10^{-5})
- 2 options for 20MW ECH
  - ~1/3 gyrotrons at 104 GHz (2X – pre-heating), the rest at 170 GHz (3X – main heating)
  - 24 gyrotrons 170 GHz (3X)

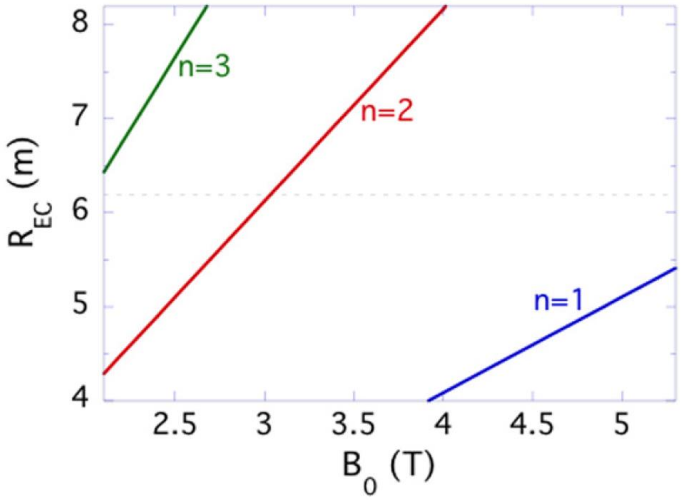
DINA, I_{CS}=20kA



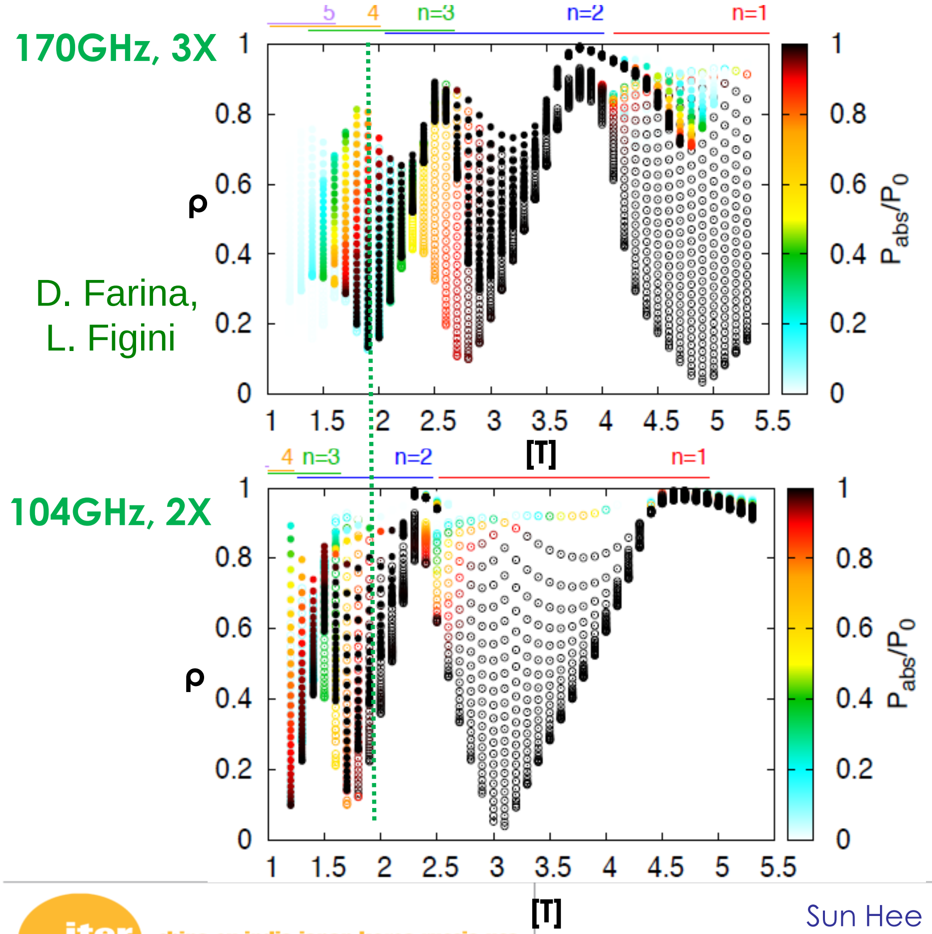
EC resonance layer

- Where electron cyclotron frequency (ω_{ce}) = applied EC frequency/harmonic number (ω_{EC}/n)
  - [$\omega_{ce} = eB/m_e$] = ω_{EC}/n ➔ $R_{res}=B_0R_0/B$ = ~ 173*(B_0[T]/f_{EC} [GHz])*n [m]
  - Examples
    1. f_{EC}=170 GHz, n=1, B_0 = 5.3 T → R_{res} ~ 5.3 m
    2. f_{EC}=170 GHz, n=3, B_0 = 1.8 T → R_{res} ~ 5.3 m
    3. f_{EC}=104 GHz, n=2, B_0 = 1.8 T → R_{res} ~ 6.0 m

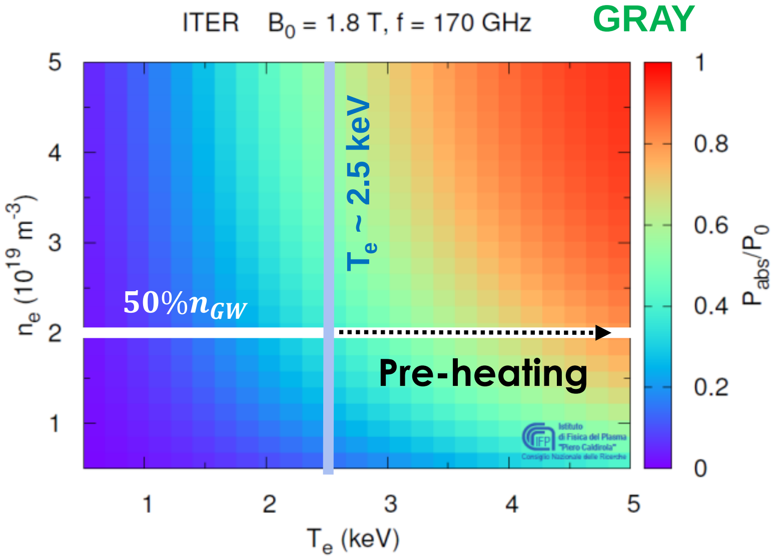
170GHz, Farina, NF52



2X/3X EC power absorption at 1.8T

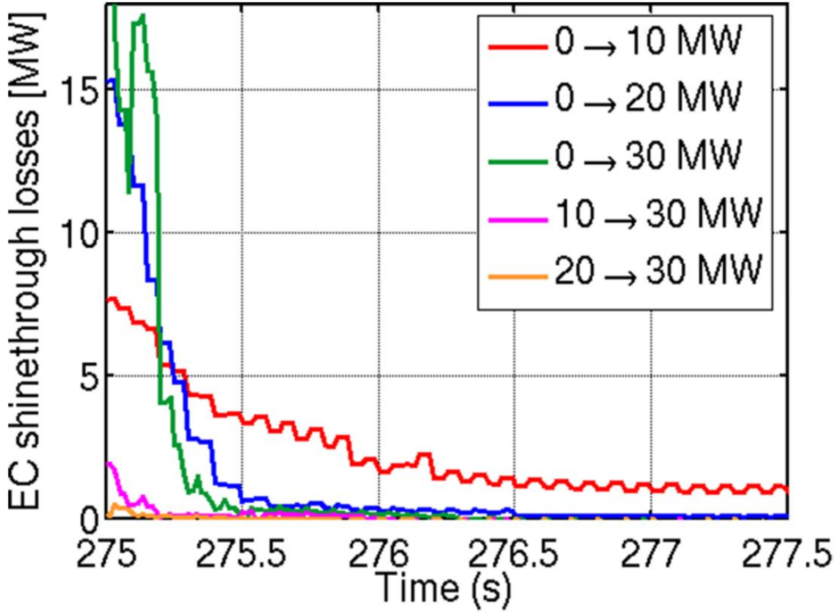


- Good EC absorption (black colour) for both 3X and 2X at 1.8T
- But, 3X EC may need pre-heating, since T_e ~2-3keV at the early phase of 1.8T plasma
- Or ?



Third harmonic EC H&CD

NF59, M. Schneider

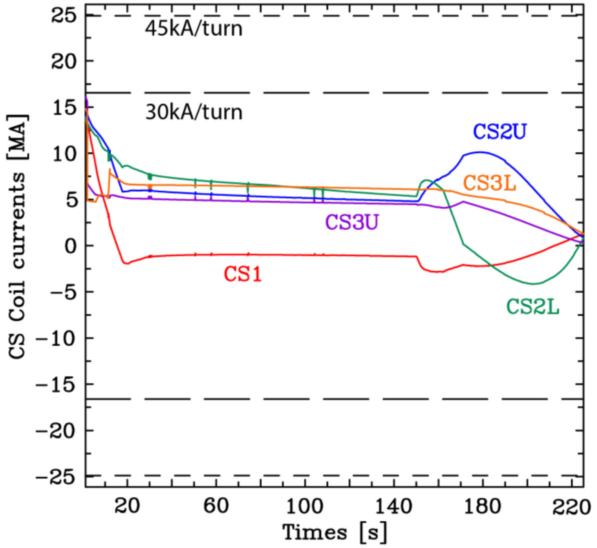


EC power shine-through losses for various EC power transitions, JINTRAC+GRAY, 170GHz EC, Hyd. Plasma at 1.8T

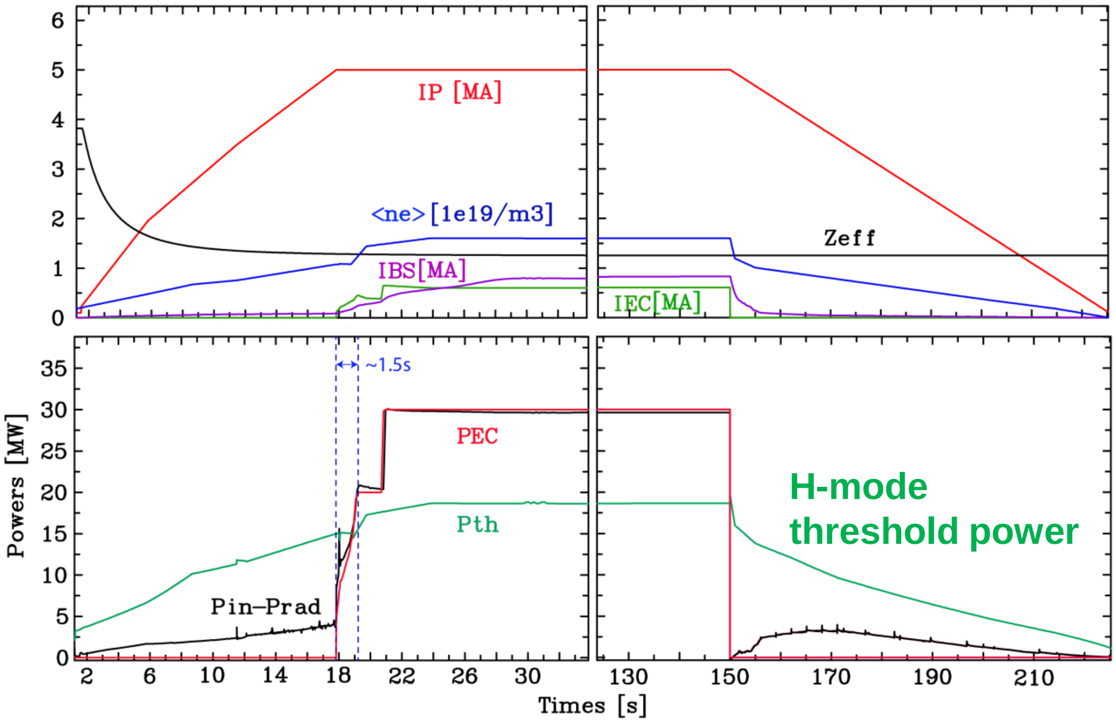
- Time-dependent transport process allows to use only 3X 170GHz,
  - EC power shine-through losses can be large but transient (~1s << ~5s limit for ITER first wall)
  - Plasma temperature can rise high enough for good EC absorption at relatively short time

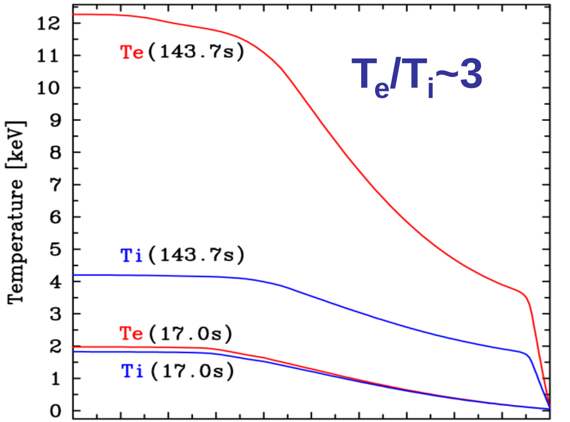
5MA/1.8T Hyd. H-mode Scenario

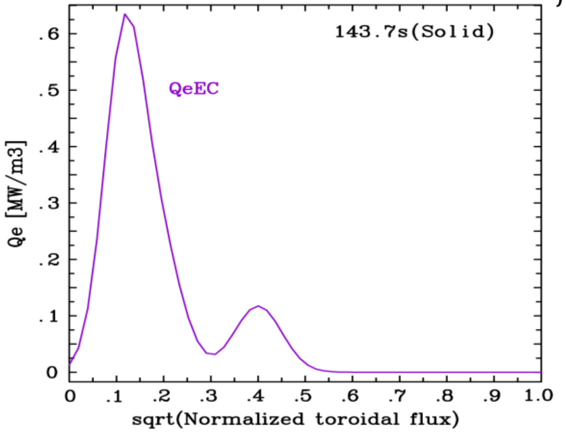
- Findings from JINTRAC/GRAY and DINA studies are integrated into CORSICA scenario simulation
  - 30MW EC (only 170GHz, 3X at 1.8T, 20MW EL, 10MW UL) for Hyd. plasma
  - EC power absorption and CD efficiency based on JINTRAC/GRAY results
  - f_{GW} ~ 40%, n_{Be}/n_e ~ 2% and $n_W/n_e \sim 2 \times 10^{-6}$
  - 30kA CS charging
  - H_{98}~1.0
  - Continuous Sawtooth model



Time traces in 5MA/1.8T Hyd. H-mode



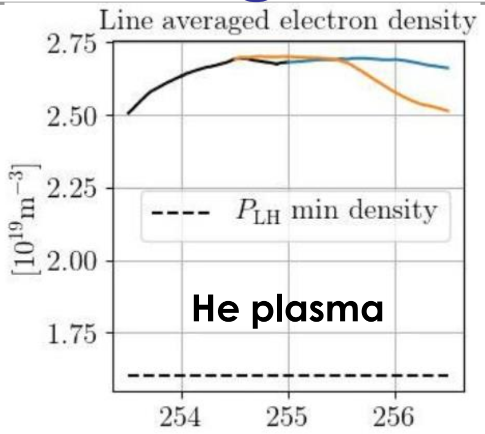


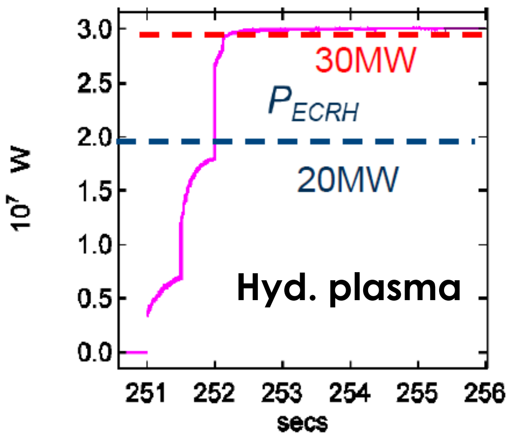


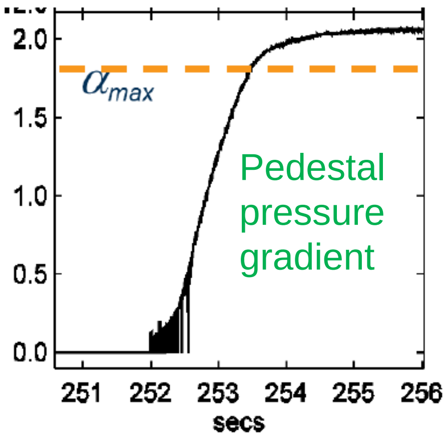
- 3rd Harmonic EC power absorption quickly increased (~1.5s for 20MW, similar to JINTRAC/GRAY cases)

5MA/1.8T core-edge-SOL modelling

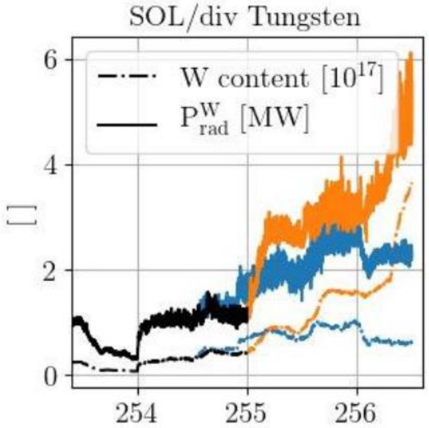
- Core-edge-SOL coupled JINTRAC simulations additionally showed
  - 30MW ECRH allows to sustain type-I ELMy H-mode in He and Hyd. Plasmas
  - However, He plasma needs high plasma density to avoid W sputtering issue at low density







Asp, IAEA 2021



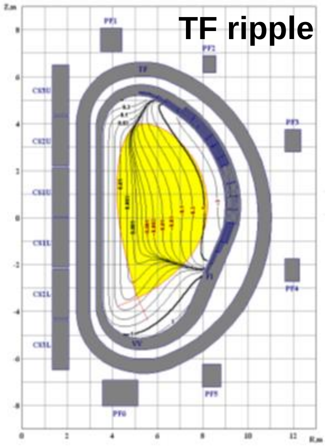
Design assumptions and questions

- Why H-mode in Hydrogen plasma is a preferred option in 1.8T despite of its higher H-mode threshold power?

- Previously, an option to make 10MW ICRH available in PFPO-I was considered. What could be potential issues of using ICRH in 1.8T operation?

Background and reasons

- Why H-mode in Hydrogen plasma is a preferred option in 1.8T despite of its higher H-mode threshold power?
  - As previously shown, W sputtering issues with He
  - Extrapolation of physics (e.g. divertor operation) and established techniques (e.g. ELM controls) to hydrogen isotopes, D, T and DT, would be better understood
- Previously, an option to make 10MW ICRH available in PFPO-I was considered. What could be potential issues of using ICRH in 1.8T operation?
  - TF ripple is optimized for half (2.65T) / full (5.3T) field operation. If the fast ion losses are high (still to be confirmed), this may require larger plasma-wall gaps to recover reasonable ripple losses at 1.8T. Larger plasma-wall gaps can reduce the power coupling between ICRH antenna and plasma.



δ_{max}=-1.28% in 1.8T

Key Scenarios in PFPO-II phase

- 5.0MA / 1.8T Hyd. H-mode (H-mode with increased P_{aux})
- 7.5MA / 2.65T He H-mode (half-current / half-field H-mode)
- Progressive steps in Hyd.
  ([7.5→9.5 MA] / 3.3T ➔ [9.5→10.5→12.5 MA] / 4.5T ➔ 12.5MA / 5.3T)
- 15MA/5.3T Hyd. L-mode (first full-current/full-field plasma)

- 7.5MA / 2.65T Hyd. H-mode access
- q_{95}=4 and 5 long pulse operation scenarios

High Power 5MA/1.8T H-mode Scenarios

- H or He plasmas
- Large H&CD power margin over P_{LH} (NF59, M. Schneider):
  - 73MW (PFPO-2) including 20MW ECRH, 20MW ICRH, 33MW NBI
  - Good ICRH power absorption : n=2 Hyd. heating in Hyd. plasma / n=2 Hyd. minority heating in He plasma
  - Need to reduce NB energy (power) due to large NB shine-through losses at low density (~$2\times10^{19}m^{-3}$)
    - PNB ~ $(ENB)^{2.5}$
    - 500keV (8.3MW) ~ 530keV (9.4MW) in Hyd. plasmas
    - 580keV (12MW) ~ 660keV (16.7MW) in He plasmas

Half-current / Half-field H-mode

- 7.5MA/2.65T He H-mode
- He plasmas are good candidate for H-mode access than Hyd. plasmas
  - Density (~ $3.0 \times 10^{19} m^{-3}$) required to avoid NBI shine-through limit is lower in He
  - H-mode threshold power is also lower, good ICH scheme exists (Fundamental H minority)

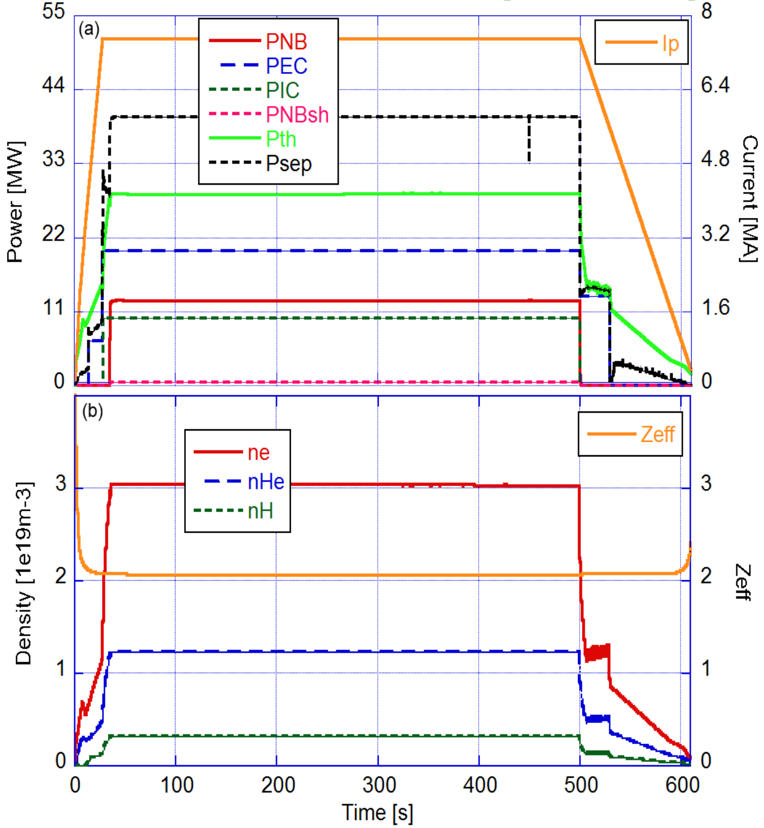
- Potential He H-mode access and operation issues
  - $P_{LH,Martin}$ (He) may be not sufficiently low
  - Density for minimum P_{LH}, ~ 40% f_{GW} (~ $2.4 \times 10^{19} m^{-3}$), is lower than the density required to avoid NBI shine-through power (> $3.0 \times 10^{19} m^{-3}$) for 870keV
  - Limited density rise by gas fueling only – Low particle penetration through the pedestal
  - Hyd. beams and pellets into He – Fuel dilution (affects P_{LH} and ICRH scheme)
  - Low ion pedestal pressure (~ 50%) – Lower confinement (H_{98} ~ 0.7-0.8)

7.5MA/2.65T He H-mode

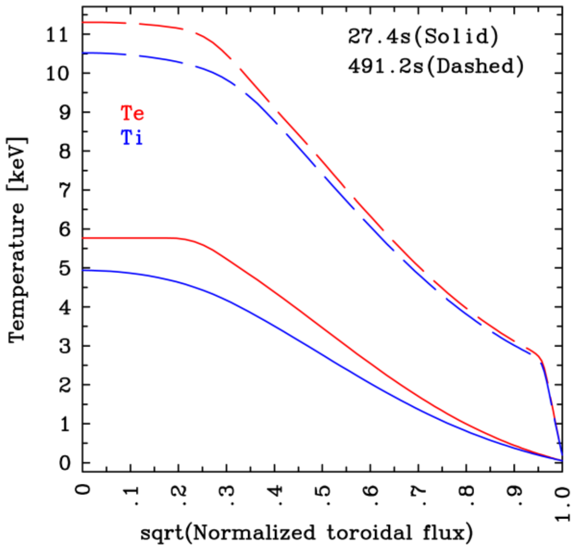
- **Conservative assumptions applied**
  - 20MW EC, 10MW IC at t_{SOF}
  - 13MW NBI (600keV) at t_{SOF}+7s
    – delayed NBI injection with low energy to reduce the shine-through power
  - 60% of EPED1+SOLPS for pedestal
  - $n_H/(n_H+n_{He})$ ~ 20%
  - n_e (flat-top) ~ 3.0 × $19m^{-3}$ (~ 50% f_{GW})

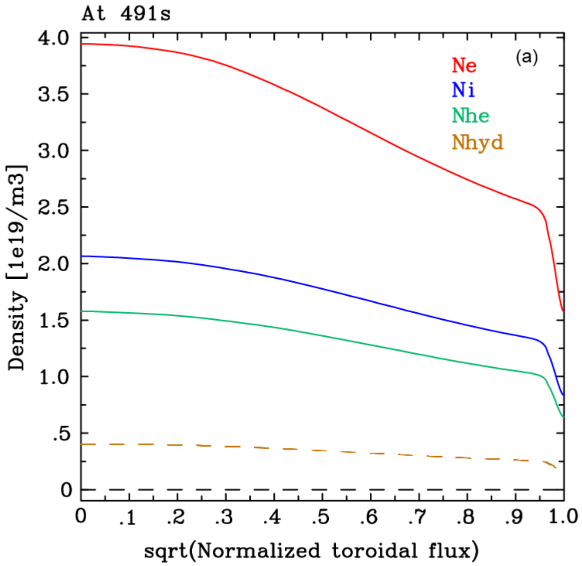
- **H-mode operation can be achieved**
  - H_{98} ~ 0.68, β_N ~ 1.2
  - Power margin over P_{LH} ~ 1.5

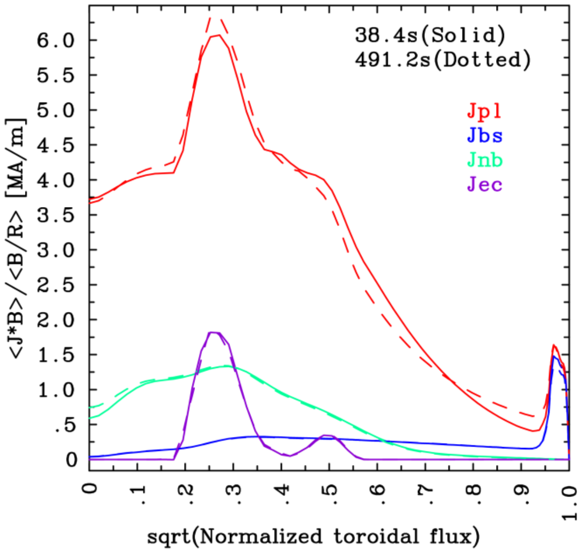
CORSICA (NF57, Kim)



Profiles in 7.5MA/2.65T He H-mode







- Access to He 7.5MA/2.65T H-mode was also studied by using TRANSP and JINTRAC, assuming different density peaking, HCD mix and waveforms, and source models.

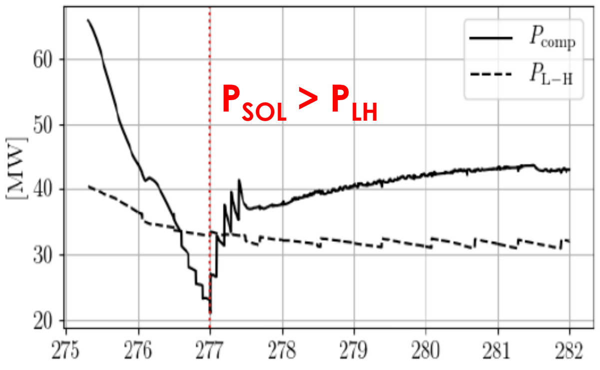
Design assumptions and questions

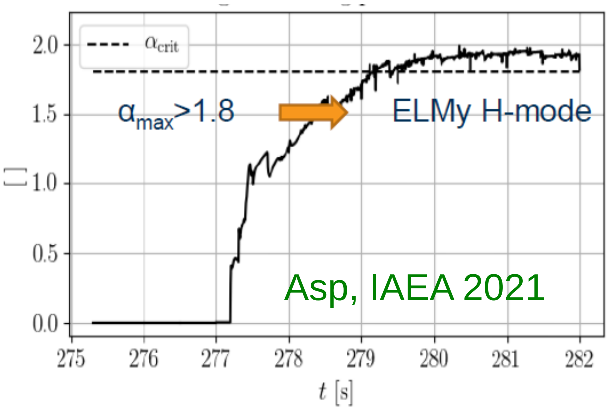
- In 7.5MA/2.65T Hyd. plasmas, the density required for NBI shine-through ~$0.45 \times 10^{20} m^{-3}$, and $P_{LH} \sim (n_e)^{0.72}$, and there is no good ICRH schemes. What would be possible ways of achieving H-mode in Hyd. plasma at 7.5MA/2.65T in PFPO-II?

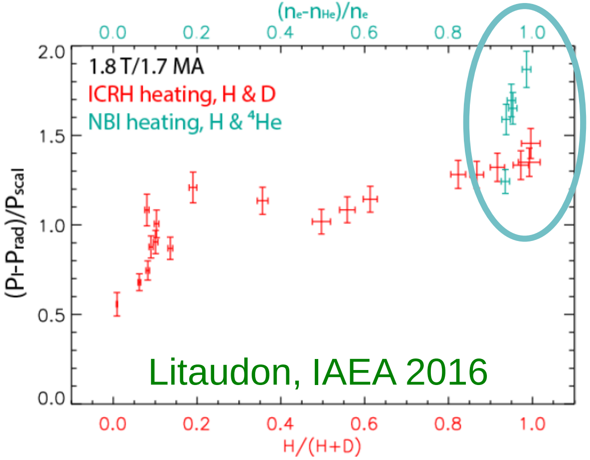
Background and reasons

- In 7.5MA/2.65T Hyd. plasmas, the density required for NBI shine-through ~0.45 × $10^{20}m^{-3}$, and P_{LH} ~ $(n_e)^{0.72}$, and there is no good ICRH schemes. What would be possible ways of achieving H-mode in Hyd. plasma at 7.5MA/2.65T in PFPO-II?
  - Use Ne to reduce NB shine-through at low density (required for lower P_{LH}) – NB shine-through decreases along with Z_{eff}
  - Use He to reduce P_{LH} – Injecting ~15% of He in H plasmas is likely to decrease P_{LH} if JET observation is applied.

JINTRAC core-edge-SOL simulation with **~10% Ne** and ~**11% He**



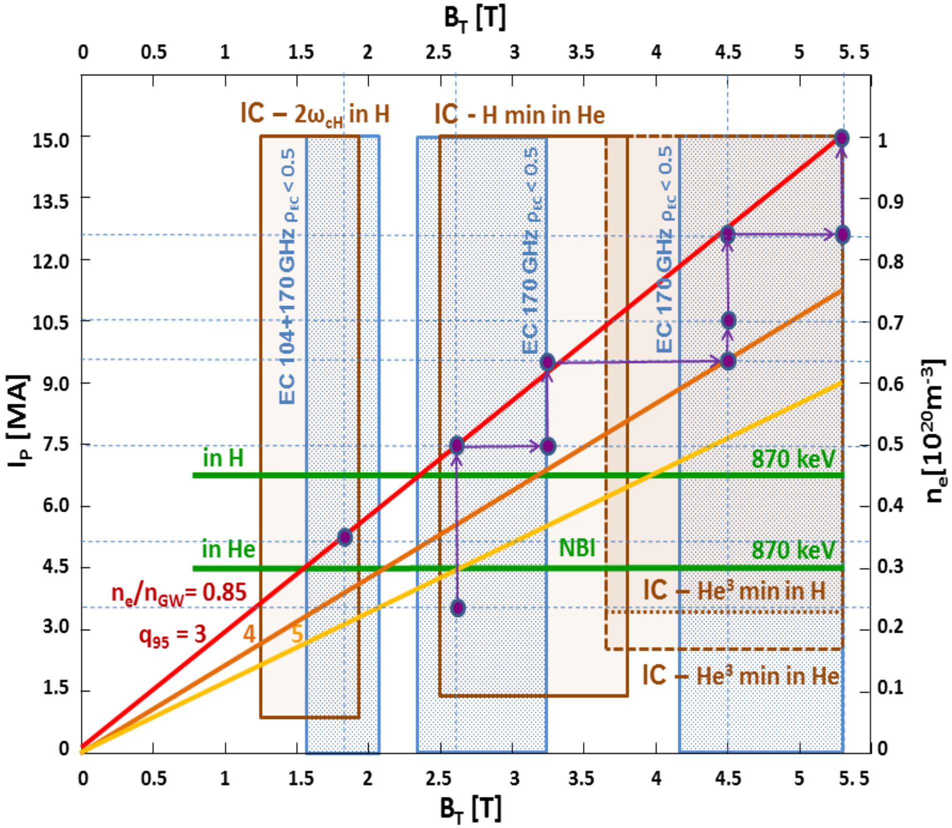




Progress steps towards 15MA/5.3T operation

- Progressive steps towards 15MA/5.3T L-mode Hyd. operation
  - Plasma operation at full technical performance in PFPO-2
  - Multiple steps in B_T and I_P in current proposal
  - Detailed path will be adapted as issues arise during the development

- Tentatively, starting from 7.5MA / 2.65T
  ➔ [7.5→9.5 MA] / 3.3T
  ➔ [9.5→10.5→12.5 MA] / 4.5T
  ➔ [12.5 →15 MA] / 5.3T



Progress steps studied using CORISCA

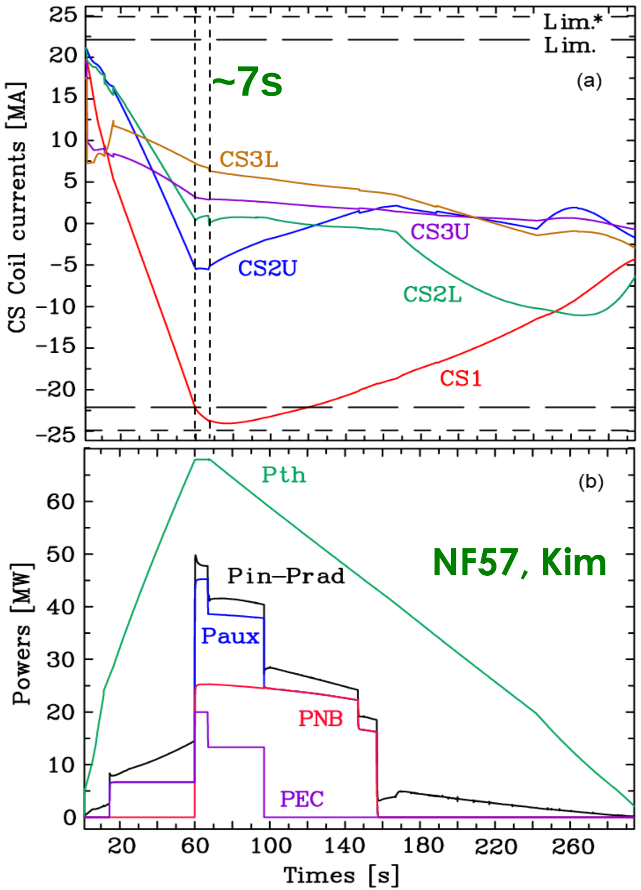
- H&CD applied very conservatively, up to 33MW NB, 20MW EC and 10MW IC **NF57, Kim**

Ion	I_p/B_t [MA/T]	L/H-mode	H_{98}	n_e/n_{GW}	P_{aux} [MW]	$(P_{in}-P_{rad})/P_{th}$	$\Delta t_{flat-top}$ [s]
H	7.5/2.65	Dithering	0.52	~ 0.67	37.8	1.00	438
H	7.5/2.65	L	0.48	0.58	44.2	-	428
H	9.6/3.25	L	0.35	0.46	34.5	-	185
H	12.7/4.70	L	0.35	0.38	45.0	-	81
H	15.0/5.30	L	0.33	0.35	45.2	-	7

He(H%)	I_p/B_t [MA/T]	L/H-mode	H_{98}	n_e/n_{GW}	P_{aux} [MW]	$(P_{in}-P_{rad})/P_{th}$	$\Delta t_{flat-top}$ [s]
He(0.2)	7.5/2.65	L	0.36	0.28	27.3	-	~500
He(0.1)	7.5/2.65	H	0.76	0.46	42.0	1.50	>500
He(0.1)	9.6/3.25	H	0.77	0.46	48.0	1.17	>500
He(0.1)	11.3/4.00	Dithering	0.53	0.39	48.5	1.00	~500
He(0.1)	12.7/4.70	L	0.34	0.33	50.8	-	144
He(0.1)	12.7/4.70	Dithering	0.43	0.38	59.3	1.00	335
He(0.1)	15.0/5.30	L	0.32	0.32	62.0	-	6

Full-current / Full-field operation

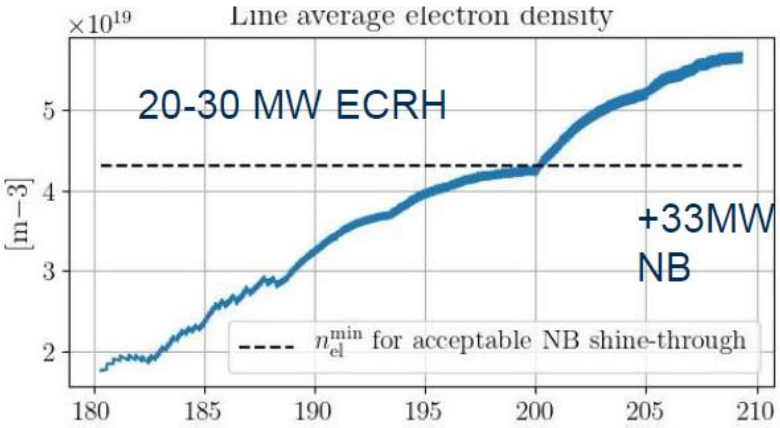
- 15MA/5.3T Hyd. L-mode
- CORSICA simulation (Kim, NF57)
  - 60s ramp-up & fully CS charging (I_{CS}=45kA)
  - H_{98}~0.33
  - $\Delta t_{flat\text{-}top}$[s] ~7s with P_{aux}=45MW
  - Similar flat-top length (5-6s) for 15MA/5.3T He L-mode



- DINA simulation (IDM:GNREJL)
  - Fastest I_p ramp-up (~50s) & full CS charging
  - $\Delta t_{flat\text{-}top}$[s] ~10s with P_{aux}=0 MW (fully inductive)
  - $\Delta t_{flat\text{-}top}$[s] ~100s with P_{aux}=73 MW

15MA/5.3T core-edge-SOL modelling

- JINTRAC 15MA/5.3T Hyd. L-mode
  - Density increased over $0.45 \times 10^{20} m^{-3}$ by adding pellets, and then full NB power (33MW) injected
  - Low level of impurities and divertor power loads ($<5 MWm^{-2}$) achieved
  - Commissioning of Hyd. NBI at its full power is possible



Asp, IAEA 2021

List of ITER PFPO phase scenarios

Also METIS, ASTRA, etc.

DINA

Pulse	Run	Database	Reference	Ip[MA]	B0[T]	Fuelling	Confinement	Workflow
105001	4	ITER	15MA H-DINA2017-01	-14.97	-5.3	H	Ohmic	DINA
105002	4	ITER	15MA H-DINA2018-04	-14.97	-5.3	H	Ohmic	DINA
105003	4	ITER	10MA H-DINA2018-03	-10.08	-5.3	H	Ohmic	DINA
105004	4	ITER	7.5MA H-DINA2016-01	-7.52	-2.65	H	L-mode	DINA
105005	4	ITER	7.5MA H-DINA2016-02	-7.52	-2.65	H	L-mode	DINA
105006	5							
105007	10							
105008	6							
105009	6							
105010	6							
105011	10							
105012	5							
105013	1							
105014	1							
105015	1							
105016	1							
105017	1							
105018	1							
105019	1							
105020	1							
105021	1							
105022	1							
105023	1							
105024	1							
105025	1							
105026	1							
114100	51							
114101	41							
115001	4							
115002	4							

JINTRAC

Pulse	Run	Database	Reference	Ip[MA]	B0[T]	Fuelling	Confinement	Workflow
104001	1	ITER	Elina IAEA-FEC 2016 TH/P2-23 Figure1 15MA 5.16T pe	-15.0	-5.16	H	L-mode	JINTRAC mkimas
104001	2	ITER	Elina IAEA-FEC 2016 TH/P2-23 Figure1 15MA 5.30T pe	-15.0	-5.3	H	L-mode	JINTRAC mkimas
104102	12	ITER	Elina IAEA-FEC2021 figure1, Vasilli Hyd. 5MA 1.8T	-5.0	-1.8	H	L-mode	JINTRAC mkimas + spider-inverse
104102	22	ITER	Elina IAEA-FEC2021 figure1, Vasilli Hyd. 5MA 1.8T	-5.0	-1.8	H	L-H	JINTRAC mkimas + spider-inverse
104102	32	ITER	Elina IAEA-FEC2021 figure1, Vasilli Hyd. 5MA 1.8T	-5.0	-1.8	H	L-H	JINTRAC mkimas + spider-inverse
104102	42	ITER	Elina IAEA-FEC2021 figure1, Vasilli Hyd. 5MA 1.8T	-5.0	-1.8	H	H-mode	JINTRAC mkimas + spider-inverse
104103	12	ITER	Elina IAEA-FEC2021 figure4, Luca Hyd. Ne rich 7.5M	-7.5	-2.58	H	L-mode	JINTRAC mkimas + spider-inverse
104103	22	ITER	Elina IAEA-FEC2021 figure4, Luca Hyd. Ne rich 7.5M	-7.5	-2.58	H	L-H transition	JINTRAC mkimas + spider-inverse
104103	32	ITER	Elina					
104103	42	ITER	Elina					
104104	12	ITER	Elina					
104104	22	ITER	Elina					
104104	32	ITER	Elina					
104105	12	ITER	Elina					
114102	12	ITER	Elina					
114102	22	ITER	Elina					
114102	32	ITER	Elina					
114103	12	ITER	Elina					
114103	22	ITER	Elina					
114103	32	ITER	Elina					
114103	42	ITER	Elina					

CORSICA

Pulse	Run	Database	Reference	Ip[MA]	B0[T]	Fuelling	Confinement	Workflow
100501	3	ITER	Nonactive-H, 7.5MA 2.65T L-H-L, 46.8MW Paux	-7.5	-2.65	H	L-H-L	CORSICA
100502	3	ITER	Nonactive-H, 7.5MA 2.65T L-H dithering, 39.2MW Pau	-7.5	-2.65	H	L-H dithering	CORSICA
100503	3	ITER	Nonactive-H, 7.5MA 2.65T L-mode, 46.8MW Paux	-7.5	-2.65	H	L	CORSICA
100504	3	ITER	Nonactive-H, 9.6MA 3.25T L-mode, 42.8MW Paux	-9.6	-3.25	H	L	CORSICA
100505	3	ITER	Nonactive-H, 12.7MA 4.70T L-mode, 46.8MW Paux	-12.7	-4.7	H	L	CORSICA
100506	3	ITER	Nonactive-H, 15MA 5.3T L-mode, 46.8MW Paux	-15.0	-5.3	H	L	CORSICA
100507	3	ITER	Nonactive-H, 5MA 1.8T L-H-L, 30MW Paux	-5.0	-1.77	H	L-H-L	CORSICA
110501	3	ITER	Nonactive-He, 7.5MA 2.65T L-H-L, 43.0MW Paux	-7.5	-2.65	He4	L-H-L	CORSICA
110502	3	ITER	Nonactive-He, 9.6MA 3.25T L-H-L, 49.2MW Paux	-9.6	-3.25	He4	L-H-L	CORSICA
110503	3	ITER	Nonactive-He, 11.3MA 4.00T L-H dithering, 56.8MW P	-11.3	-4.0	He4	L-H dithering	CORSICA
110504	3	ITER	Nonactive-He, 12.7MA 4.70T L-H dithering, 53.0MW P	-12.7	-4.7	He4	L-H dithering	CORSICA
110505	3	ITER	Nonactive-He, 12.7MA 4.70T L-H dithering, 63.0MW P	-12.7	-4.7	He4	L-H dithering	CORSICA
110506	3	ITER	Nonactive-He, 15MA 5.3T L-mode, 53.0MW Paux	-15.0	-5.3	He4	L	CORSICA
110507	3	ITER	Nonactive-He, 15MA 5.3T L-H dithering, 63.0MW Paux	-15.0	-5.3	He4	L-H dithering	CORSICA
110508	3	ITER	Nonactive-He, 7.5MA 2.65T L-mode, 28.3MW Paux	-7.5	-2.65	He4	L	CORSICA
110509	3	ITER	Nonactive-He, 7.5MA 2.65T L-H-L, 43.0MW Paux	-7.5	-2.65	He4	L-H-L	CORSICA

Conclusions

- ITER PFPO phase (and FP) scenarios have been developed within the staged approach and updated along with the identification of engineering and physics issues
- Various types of scenarios have been applied to study specific area of interests
  - Engineering oriented tokamak operation (e.g. DINA)
  - Plasma performance and operation oriented (e.g. CORSICA)
  - Core-edge-SOL transport integrated (e.g. JINTRAC)
  - Target plasma performance and physics (e.g. ASTRA, METIS, SOLPS-ITER)
- Candidate components for an IMAS High Fidelity Plasma Simulator (HFPS) have been selected and are being refined (DINA + JINTRAC) and will be used to further improve ITER scenarios
- ITER IMAS paradigm will support co-simulation between HFPS and ITER plasma control system simulation platform (PCSSP), to facilitate the development/validation/verification of various control functions

Back-up slides

Fusion power production and beyond in ITER

- **Fusion Power Operation (D/DT): up to several 100s of seconds (Q ≥10)**
  - Commissioning of systems for routine 15MA/73MW operation
  - Development of reliable technics for various control and operational challenges
  - Approach to Q=10 DT operation with conventional confinement (H_{98}~1.0)

- **Hybrid Mode (or inductive long-pulse) Operation (DT): up to 1000s of seconds (Q ≥5)**
  - HCD power upgrade excluding LHCD system
  - Tailoring of plasma current to achieve hybrid regime confinement (H_{98}~1.2-1.4)

- **Steady-State Operation (DT): up to 3000s of seconds (Q~5)**
  - Approach to fully non-inductive operation with high confinement (H_{98}~1.6)
  - Studies on long-pulse operation issues

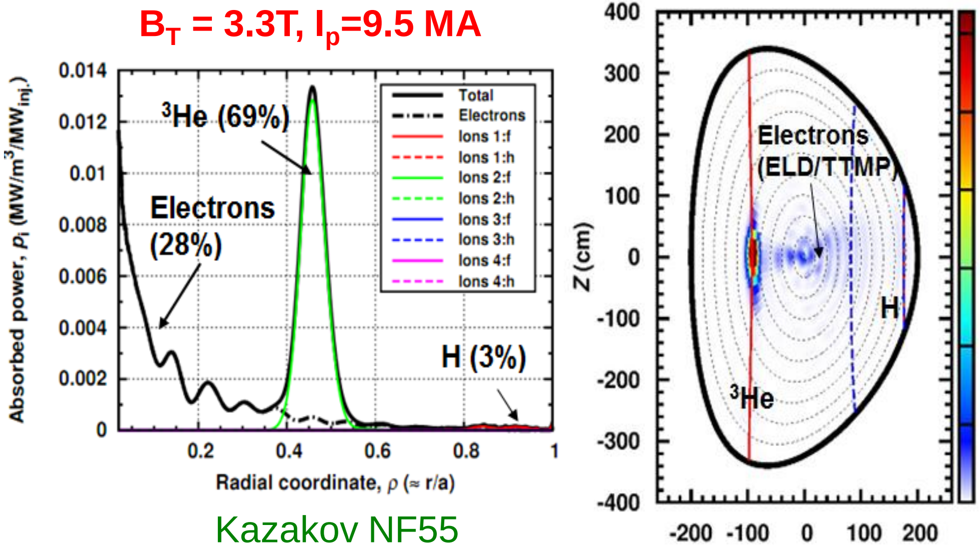
3-ion heating scheme

- New ICRH heating scheme for Hyd. Plasma and at intermediate **B_T (3.0~3.3T)**

  : 3-ion heating scheme1 in Hyd. plasma with 15% He4 , 0.05% He3

  - At 3.0T: ~83% SPA
  - At 3.3T: ~90% SPA

B_T = 3.3T, I_p=9.5 MA



Kazakov NF55

[1]Utilizing the enhanced E_+ in the vicinity of the ion-ion hybrid cut-off layer, located close to the minority cyclotron resonance of a third ion.