ITER:opportunities of Burning Plasma Studies

Y.Shimomura
ITER Joint Central Team

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Brief Summary of Input to the Specific Questions

ITER/Y.Shimomura

1. How will particle and power exhaust be handled? How well will proposed components withstand the effects of plasma disruptions and other related "off-normal" operational events? (See Janeschitz's view graphs)

1.a Particle Exhaust

Divertor with long legs (> 1m) and large pumps (200 Pam³/s, > 50m³/s for He)

$$F_{core} < N/\tau_E \sim 2.5 \times 10^{22}/s \sim 50 Pam^3/s, \quad F_{divertor} \sim 2 \times 10^{24}/s \sim 4000\ Pam^3/s$$

Detachment is not a necessary condition.

1.b Heat Exhaust

Plasma flow to divertor target < 60 MW/6m²

The present design 20 MW/m2, CFC or W

Very high radiation cooling and detachment are not necessary conditions but will have to be studies for reactor plasmas.

1.c Divertor target material/Disruptions CFC (or W)

Early phase	**CFC**	**because of its compatibility with disruptions**
Later phase	**W**	**because of its longer life time for normal erosion**

High fluence Test : long pulse q_{95} >3.5 operations with small ELMs

2. **What types of heating and current drive are planned and what are the prospects for investigating "steady-state" plasma operation on the relevant plasma time scales?**

Heating and Current Drive System

	Startup	Scenario1	Scenario2	Scenario3	Scenario4
NB (1 MeV,D/H, Variable in.Angle)	33	33	50	50	50
IC (35-62 MHz)	20	40	20	40	20
EC (170 GHz, Steerable mirror)	20	40	40	40	20
LH (~5GHz)	0	20	20	0	40
Total Installed (MW)	73	133	130	130	130

Remarks: The total heating and current drive power ≤ 110 MW

A deep fuelling improves significantly the steady state operation.

Increase boot strap current and reduce the requirement of active current drive in the outer region as well as improve confinement property.

100 s of burn duration is necessary to study inductive burn.

2000 s is necessary to achieve steady state of AT modes from conventional ones.

By optimizing current ramp-up, steady-state of AT can be achieved in 200 s.

3. What is the transport or confinement basis and MHD stability basis for reaching the burning regime and what are the uncertainties in reaching the projected operating regimes? How much margin exists for physics or hardware performance contingencies?

3.a Inductive operation for high Q

ELMy H-mode: Empirical scaling

β_N<2. If NTM, ECCD (20-40 MW)

Margin: Plasma density, High field side pellet injection,

Conservative assumptions (χ_i/χ_e, n(r), P_{LH})

and/or, Higher plasma current

3.b Steady state operation

Q~2 ELMy H-mode with H_H = 1

Q> 5 Advanced tokamak regimes (see 5)

4. What physics program is envisioned and how will the burning plasma scientific issues be addressed? Will planned diagnostic capabilities be commensurate with science program needs? Will the pulse rate and number and lifetime and provisions for the supply of tritium and maintenance, replacement and/or upgrade of activated components be commensurate with the proposed science program?

4.a High Q burning plasma

The flexibility of ITER will allow research in a large operation space.

(P_{fusion}, Q, n, β, pulse length, I_P ---)

(Confirm predictable operation → Explore frontier)

4.b Diagnostics (See Costley's viewgraphs)

Large access ports and remote handling capability

4.c Pulse rate/number, Tritium, Maintenance and Upgrade

≤ 2 pulses/hr. > 30,000 full performance shots

External tritium source (If necessary, tritium production in the later phase)

Maintenance: full remote for in-vessel components

Upgrade: in-vessel components/auxiliaries

5. What operational and/or hardware flexibility is incorporated into the design? What capability exists for studying burning plasma AT ("advanced tokamak") regimes? What are the scientific and technology issues involved in such "advanced" operation and how will they be addressed?

5.a The flexibility of ITER will allow research in a large operation space

(P_{fusion}, Q, n, β, pulse length, I_P ---)

(Confirm predictable operation → Explore frontier)

- **Inductive operations**

  150 → 700 MW, $n/n_G = 0.5 \rightarrow 1$, $\beta_N = 1.2 \rightarrow 2.4$, $Q = 5 \rightarrow 10 \rightarrow 20 \rightarrow \infty$

- **Hybrid operations**

  > 1000 s/500 MW/Q = 5 with reasonable parameters for blanket test (0.77 MW/m^2)

- **Research of fully non-inductive driven operation aiming at Q = 5**

  (higher β/higher confinement, methods included in ITER)

5.b The high repetition rate and the large number of pulses give flexibility in experimental operation

5.c Full remote maintenance of in-vessel components and large size of ports (1.8 m x 2.2 m) give flexibility in hard ware.

5.d Advanced Tokamak Regimes

i) Tools involved

- Relatively close conducting wall (r_P~2m, d_{P-W} ~0.6m)
- Saddle coils for stabilizing RWM
- Current drive and heating (NB/IC/EC/LH, 130/110 MW)
- Large plasma
- High field side pellet injectors

ii) Scientific issues

- General: Transports, mhd etc.-----
- Specific: Stabilization of high β_N and low l_i plasmas, and Deep fuelling

The technical requirements for the new ITER (ITER-FEAT)

1) Demonstrate inductively-driven plasmas at Q _ 10,
2) Aim at demonstrating steady-state at Q _ 5
3) Do not preclude ignition.
4) Demonstrate availability and integration of essential fusion technologies, and
5) Test components for a future reactor including blankets (> 0.5 MW/m^2, > 0.3 $MW \cdot a/m^2$.)

ITER is planned to be the first fusion experimental reactor.

- Flexibility is required to
  1) cope with uncertainties,
  2) study/optimize burning plasma for various objectives, and
  3) introduce advanced features
- Involvement of the world-wide fusion community is essential to
  1) use ITER efficiently and
  2) promote scientific competition among the Parties

Research on Burning Plasma

1. Inductive Operation

    High Q plasma Q~5/10/20/50 ---- Based on standard ELMy H-mode

    Reduction of divertor heat load and erosion

        Radiation cooling, semi-detached, detached divertor operation modes with small ELMs by optimizing plasma, configuration, divertor, fuelling, impurity

    High density, Peaked density profile, Higher beta, Higher fusion power density, Higher fast α pressure etc.

    Pulse reactor?

2. Long Pulse Operation for Blanket Tests

    ≥ 1000 s, > 0.5 MW/m2

    Low divertor erosion for high fluence tests (Small ELM loss, W divertor target)

3.Advanced Tokamak Modes

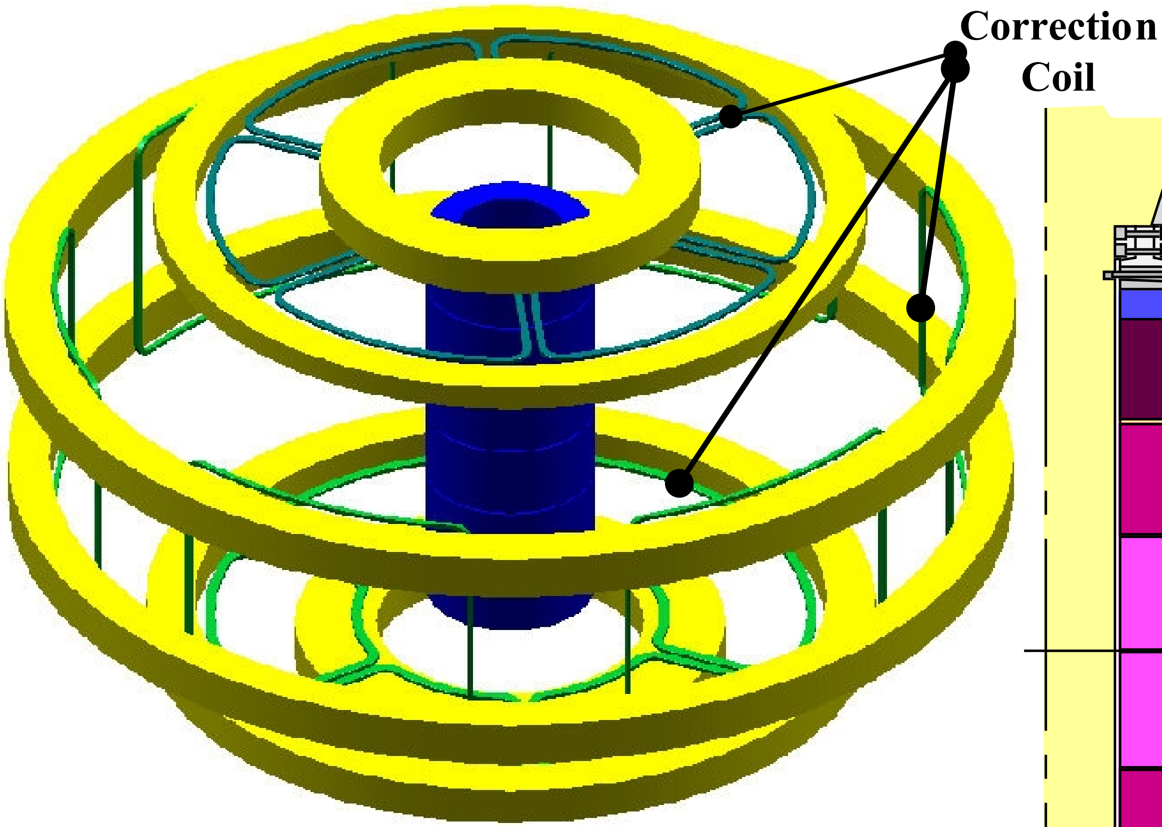
    Steady sate plasma

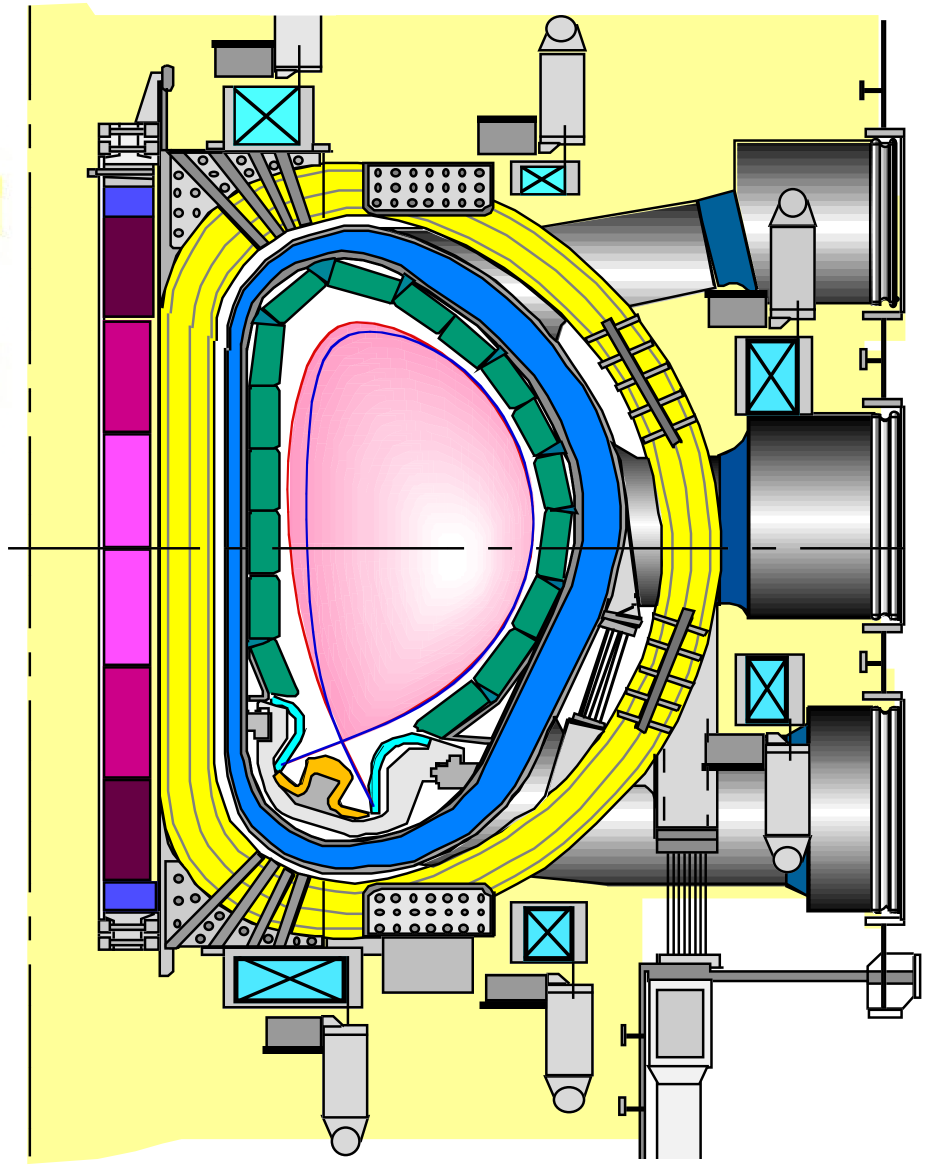
        Higher confinement/beta/density/bootstrap current and peaked density profile

    Interaction among

        burn, external H/CD, fuelling/pumping, impurity, transports etc.

    Steady State reactor?

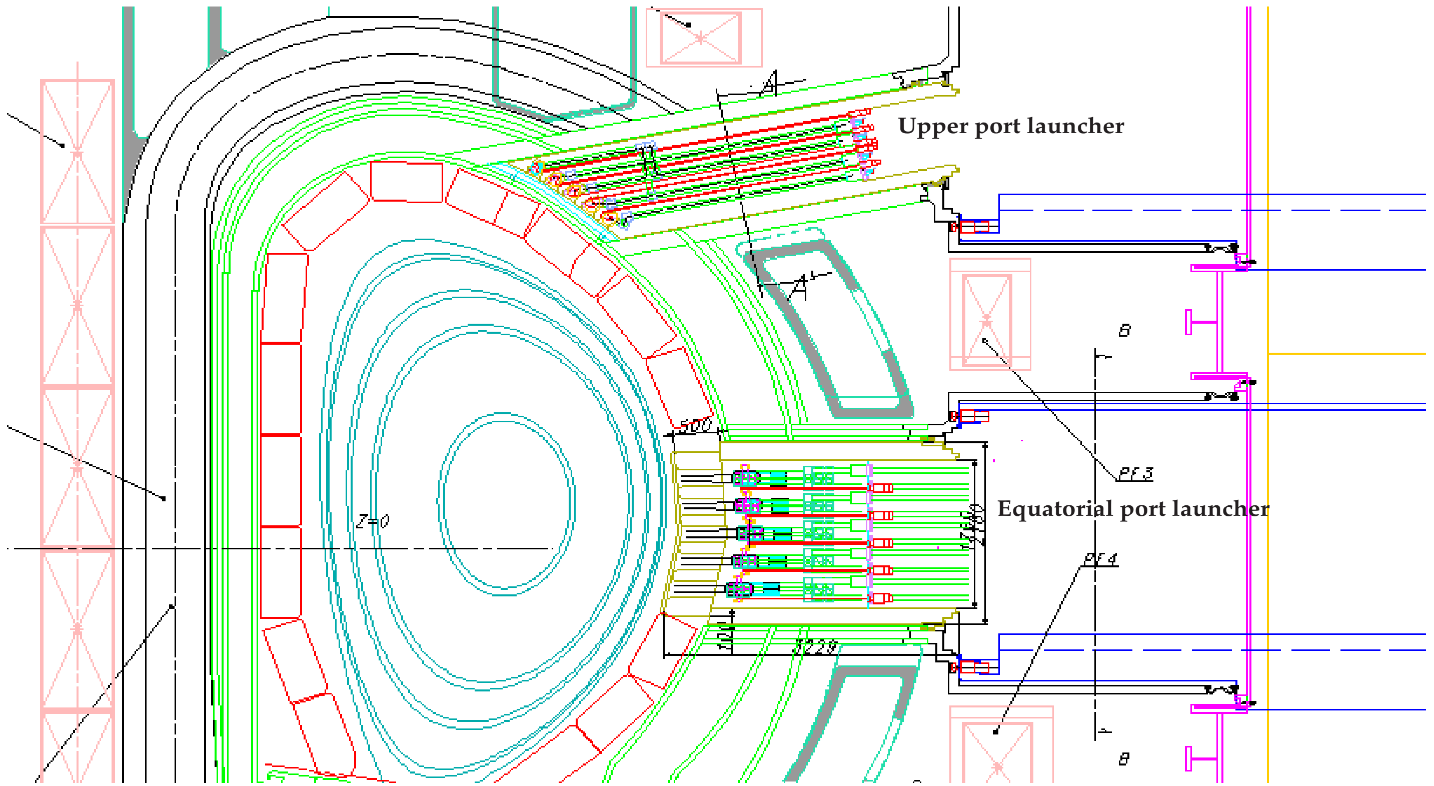




ITER Poloidal Field Coils

<u>Correction Coils</u>
6x3, 100-150kA/coil
For Resistive Wall Mode
~10G/20kA

Electron Cyclotron System



Overview of EC-launcher

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Upper launcher : poloidal steering = - 60 ~ -70°

toroidal angle = 24°

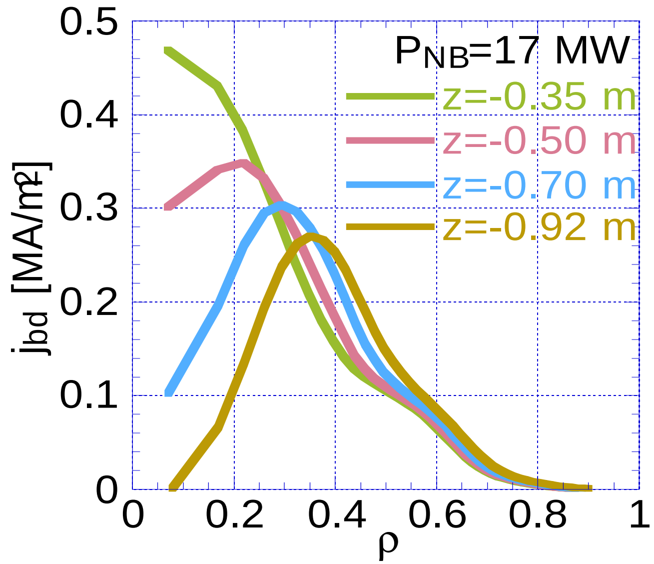
Equatorial launcher: toroidal steering = 20 - 45°

Equatorial port : standardized port plug for IC/EC/LH

Neutral Beam Injection for ITER

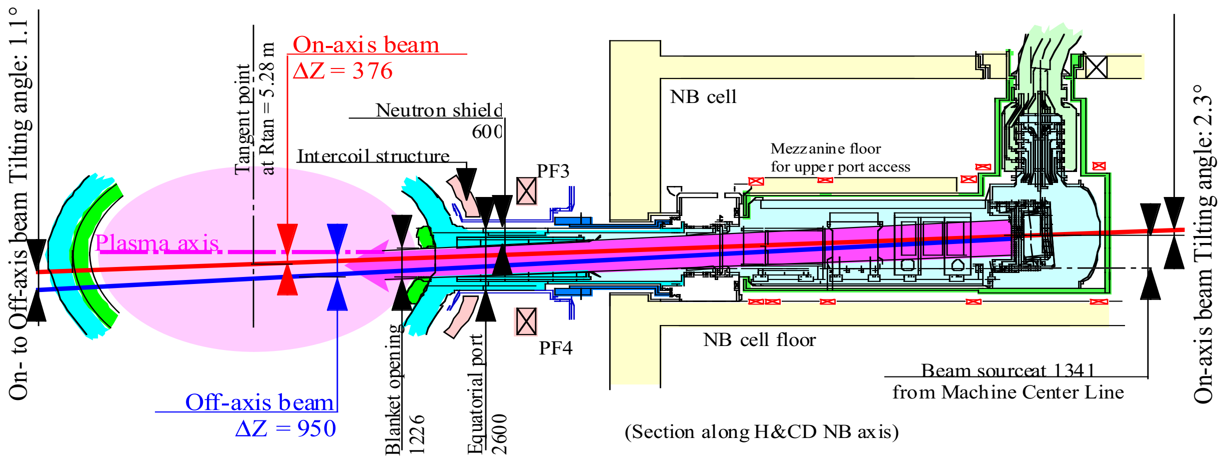
(1 MeV, 16.5 MW/Port)
Initial Installation 33 MW, Upgrade 50 MW

Beam Driven Current Profile



$\gamma \approx 0.4 \times 10^{20}$ A/Wm^2

NB Elevation Layout



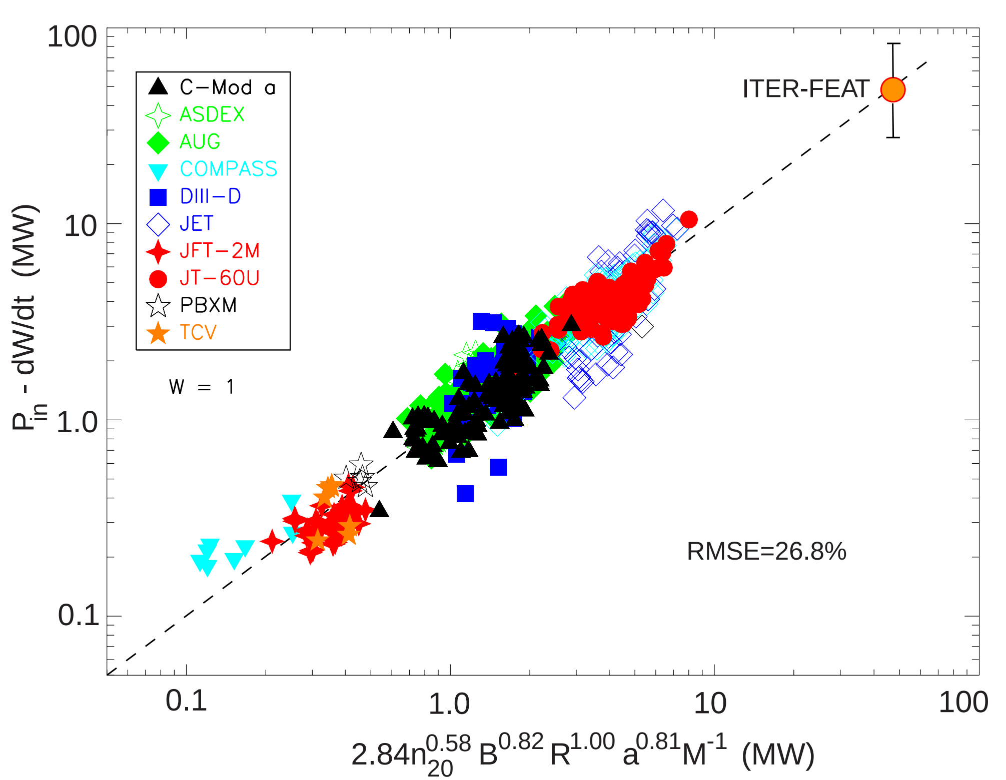
ITER Machine Capability

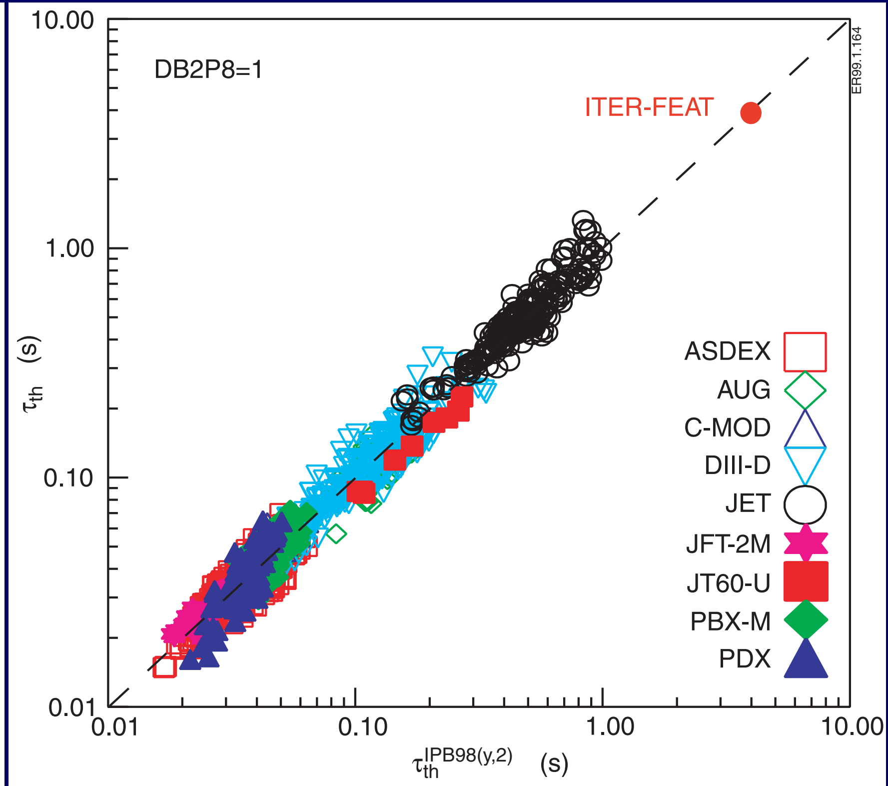
	Reference Performance	Flexibility
I_P (MA)	15 (flat top 400-500 s)	17 (flat top 100-200 s)
Fusion Power (MW)	500 (~2000s)	700 (100-200s)
κ_x/δ_x	1.85/0.49	2.0/0.55(a=1.85m)
Pumping	200 Pam^3/s	higher in shorter pulse

	Initial	Possible Upgrade	
NB (MW)	33	50	33
RF (MW)	40	80	100
ECCD for NT (MW)	(20)	(40)	
Saddle coils for RWM	20KA/10G/2Hz	~50KA	

Divertor/Blanket	Exchangeable concept
Large common ports	14 for blanket tests, RH, Diagnostics, H/CD

Standard Operations: ELMy H-mode

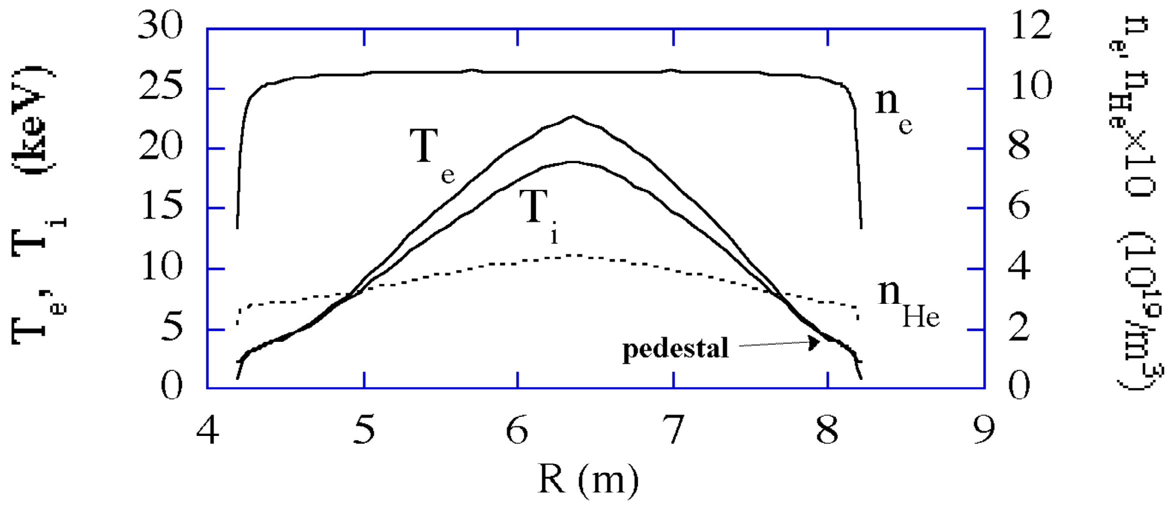




$$P_{LH} = 2.84 M^{-1} B_T^{0.82} \overline{n}_e^{0.58} R^{1.00} a^{0.81}$$

$$\tau_{E,th}^{IPB98(y,2)} = 0.144 I_p^{0.93} B_T^{0.15} P^{-0.69} n_e^{0.41} M^{0.19} R^{1.97} \varepsilon^{0.58} \kappa_a^{0.78}, \quad \tau_E = H_H \tau_{E,th}^{IPB98(y,2)}$$

(s, MA, T, MW, $10^{20}m^{-3}$, AMU, m and $\kappa_a = S_x / \pi a^2$)



Profiles of Electron Temperature (T_e), Ion Temperature (T_i), Electron Density (n_e), Helium Density (n_{He})

Conservative Assumptions in Standard Analysis

Ç P Flat Density Profile

Ç Q $P = P\alpha + P_{oh} + P_{aux} - (P_{brem} + P_{cycl} + P_{line}/3)$

Radiation Loss ~ 30 %

The confinement Data Base does not include this effect.

τ_E is under estimated.

P_{LH} is estimated 30% higher.

3Å $\chi_i/\chi_e = 2$

Example:

Fusion PowerÅ 500MW **Q: 20-10**

Alpha HeatingÅ 100MW **Additional HeatingÅ 25-50MW**

Total Heating PowerÅ 125-150MW

Å Power required for L-H transoitionÅ 50MW Å j Å

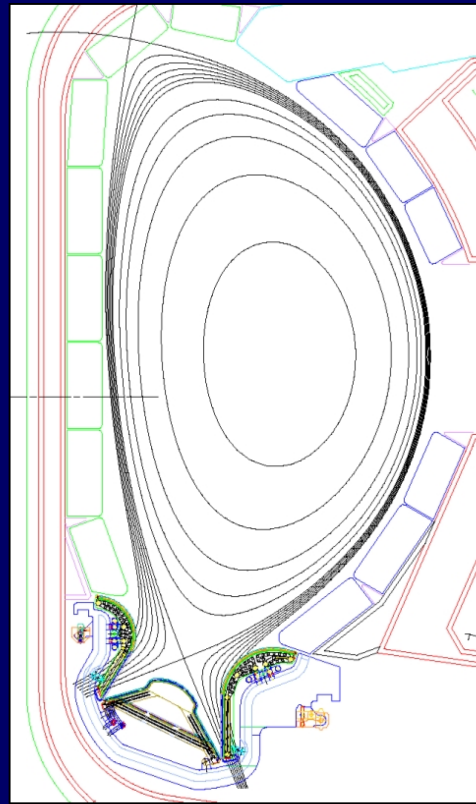
Radiation lossÅ 50MW

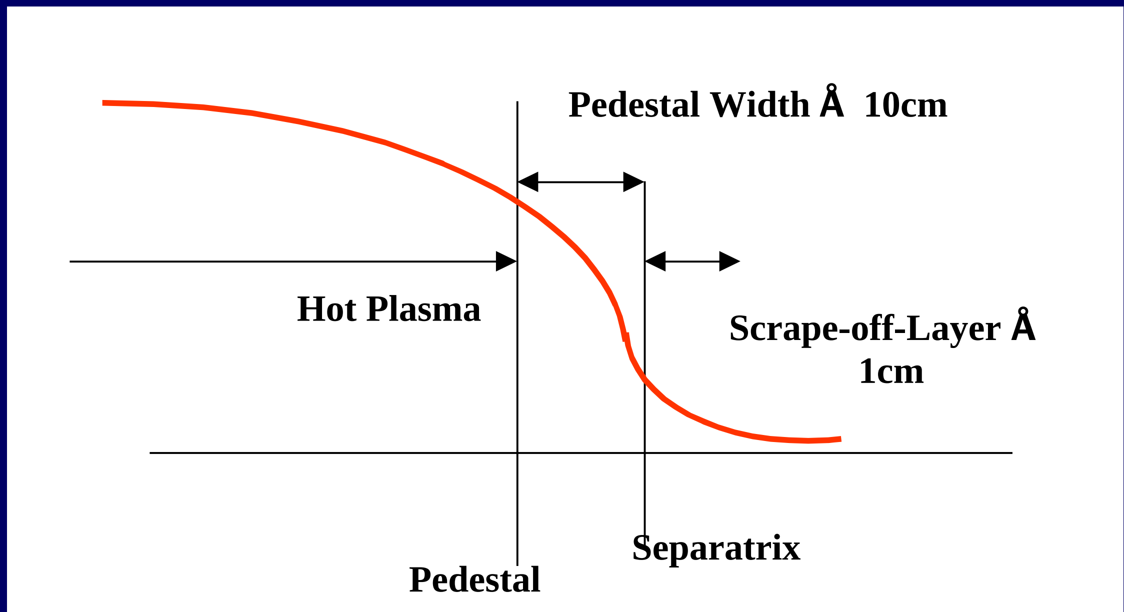
Power in to Scrape-off-LayerÅ 75-100MW

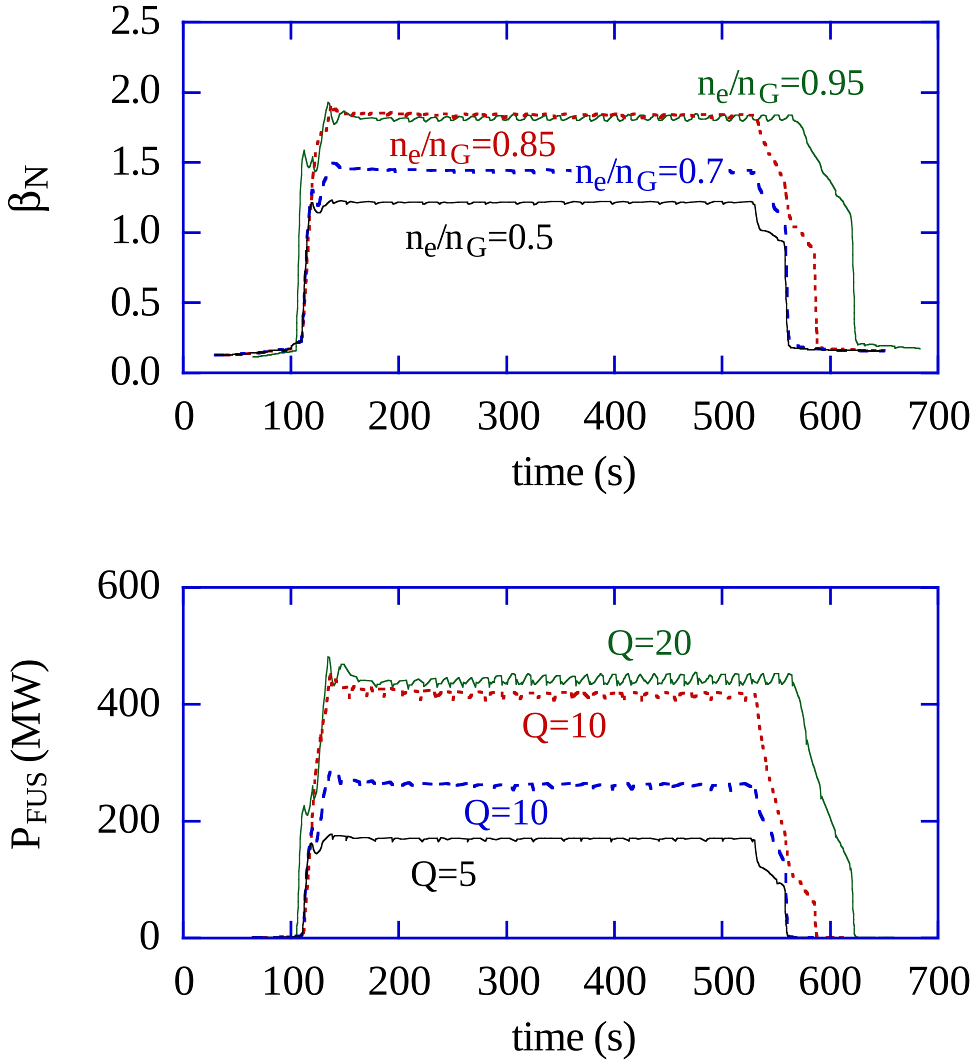
Power to Divertor TargetÅ 30-60MWÅ < 60MW or Å 10MWÅ m^2Å

Å Maximum allowable heat load : 20MWÅ m^2 Å

Detached plasma is not a necessary condition.

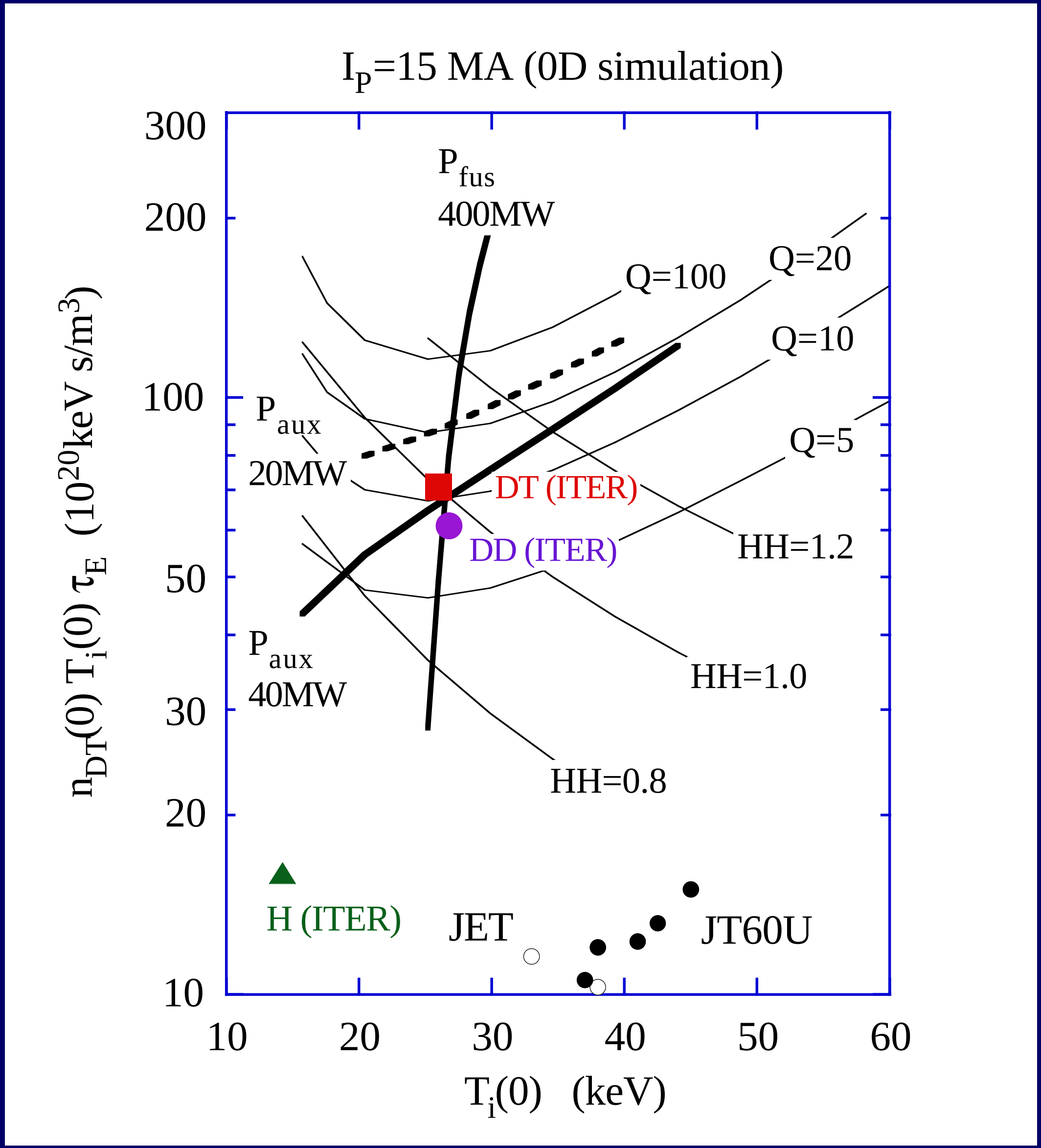






I_P = 15 MA, H_H = 1.0, τ_{He}^*/τ_E = 5, Divertor heat flux Å 10 MW/m^2

n_G (10^{20}/m^3) = I_P (MA) / πa^2, β_N = β (%) / [I_P/aB_T]

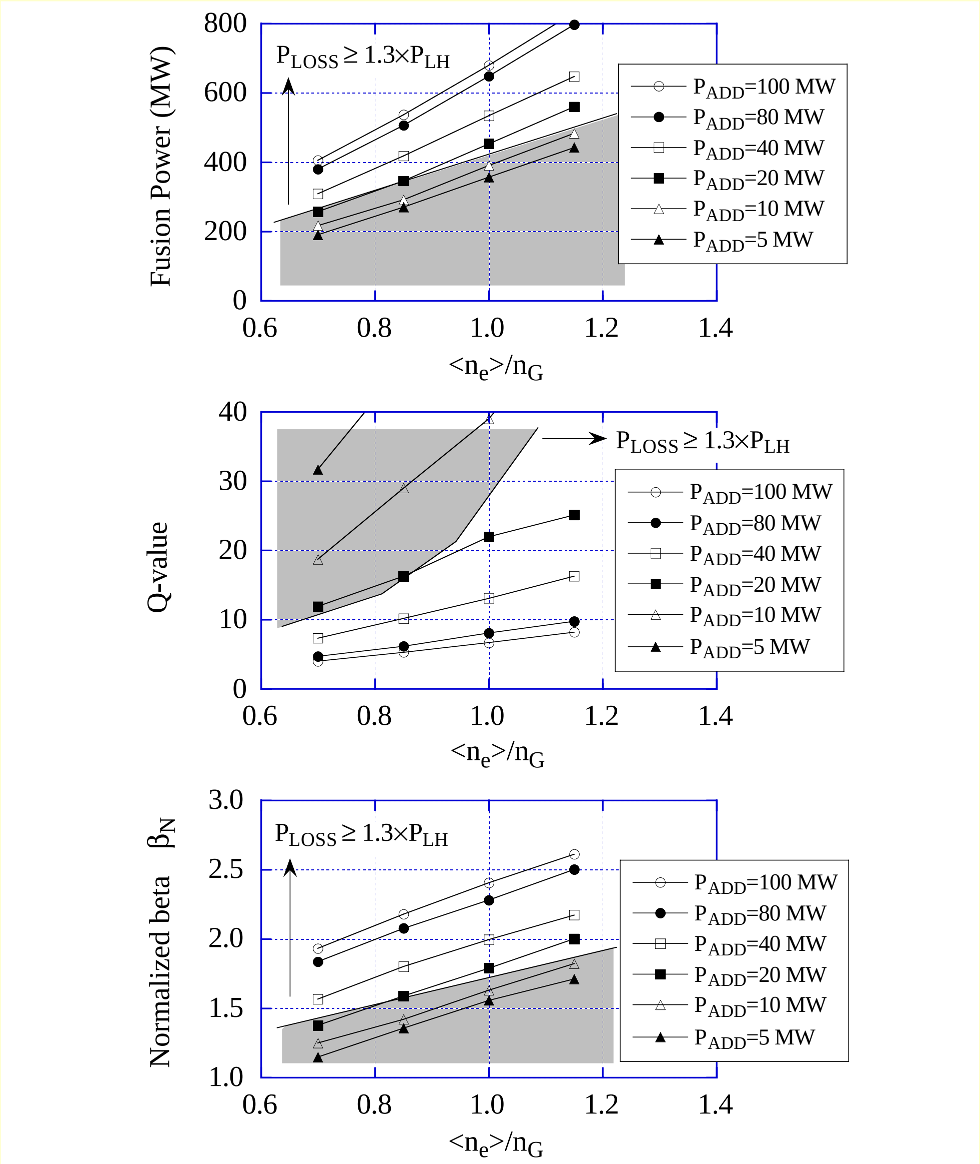


Lawson diagram of ITER with n/nG = 0.85.

Hydrogen plasma is operated at 7.5 MA and 2.7 T because of difficulty of L-H transition.

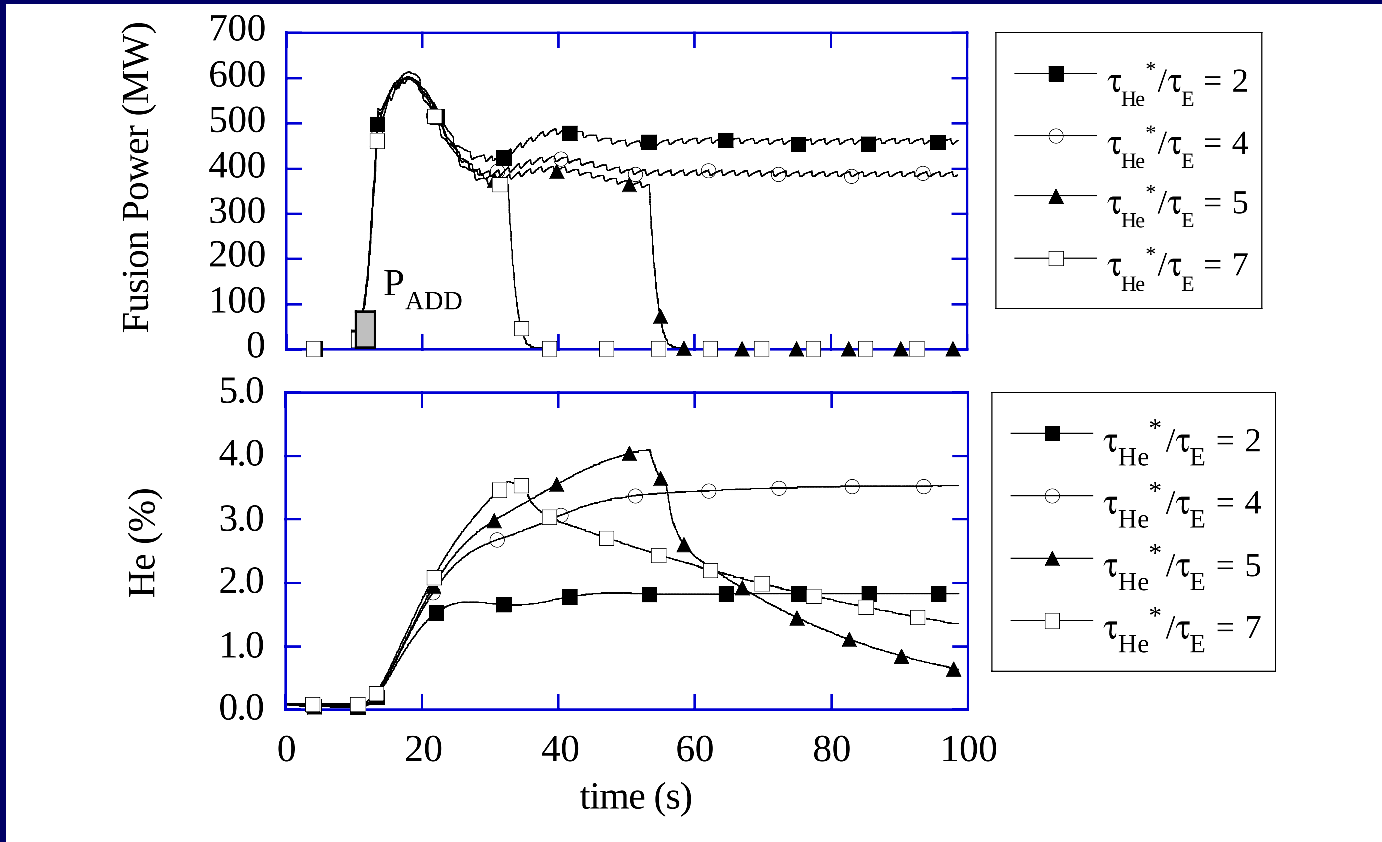
Data of the present machines are not ELMy H-mode.

- I_P=15MA, τ_{He}^*/τ_E~5, $H_{H98(y,2)}$ = 1.0, flat density profile
- Argon impurity is seeded to limit the power to divertor region



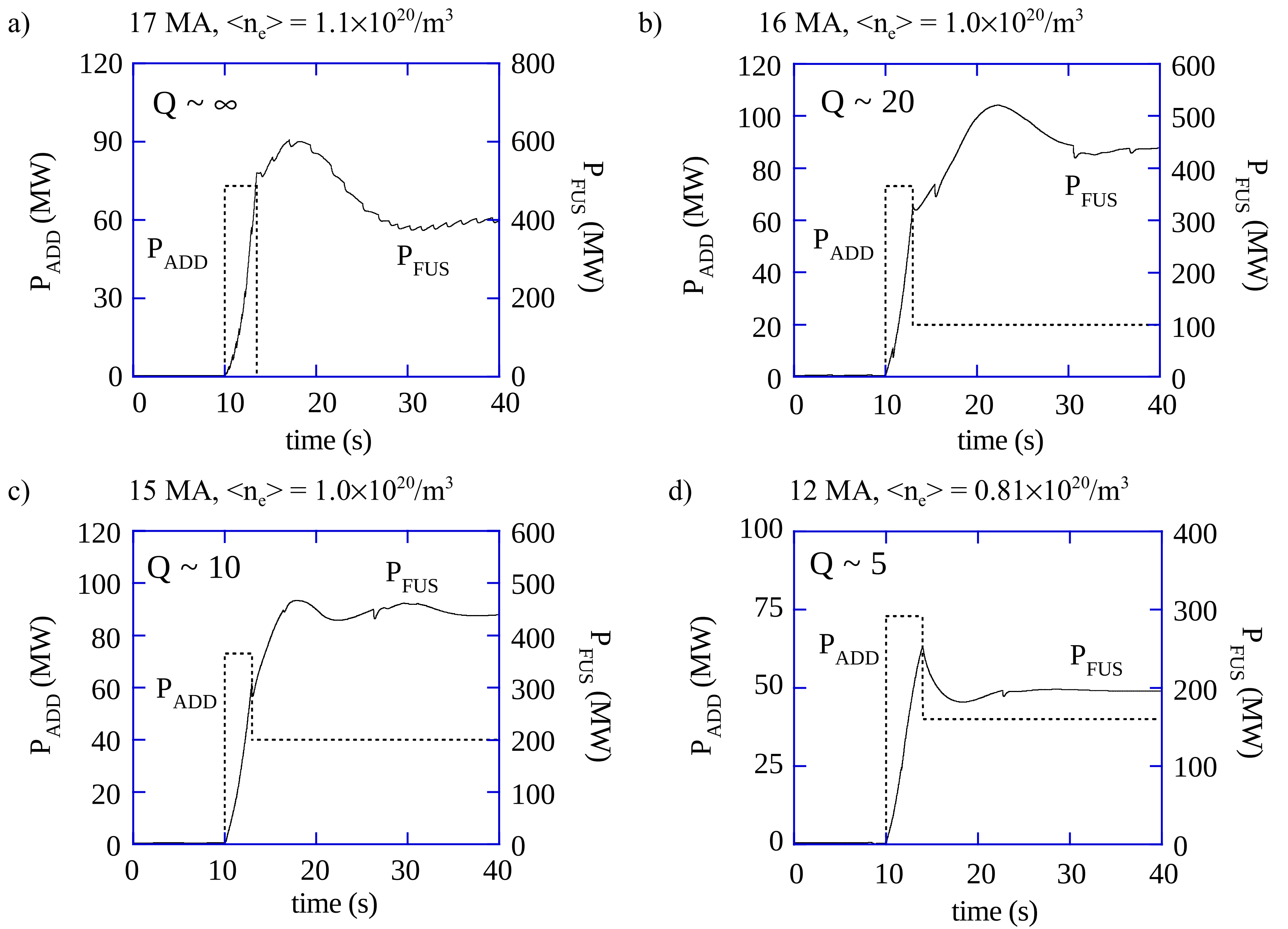
Density is one of the most important parameters

A burn length of ~60 s is the minimum to study inductiviely driven plasma

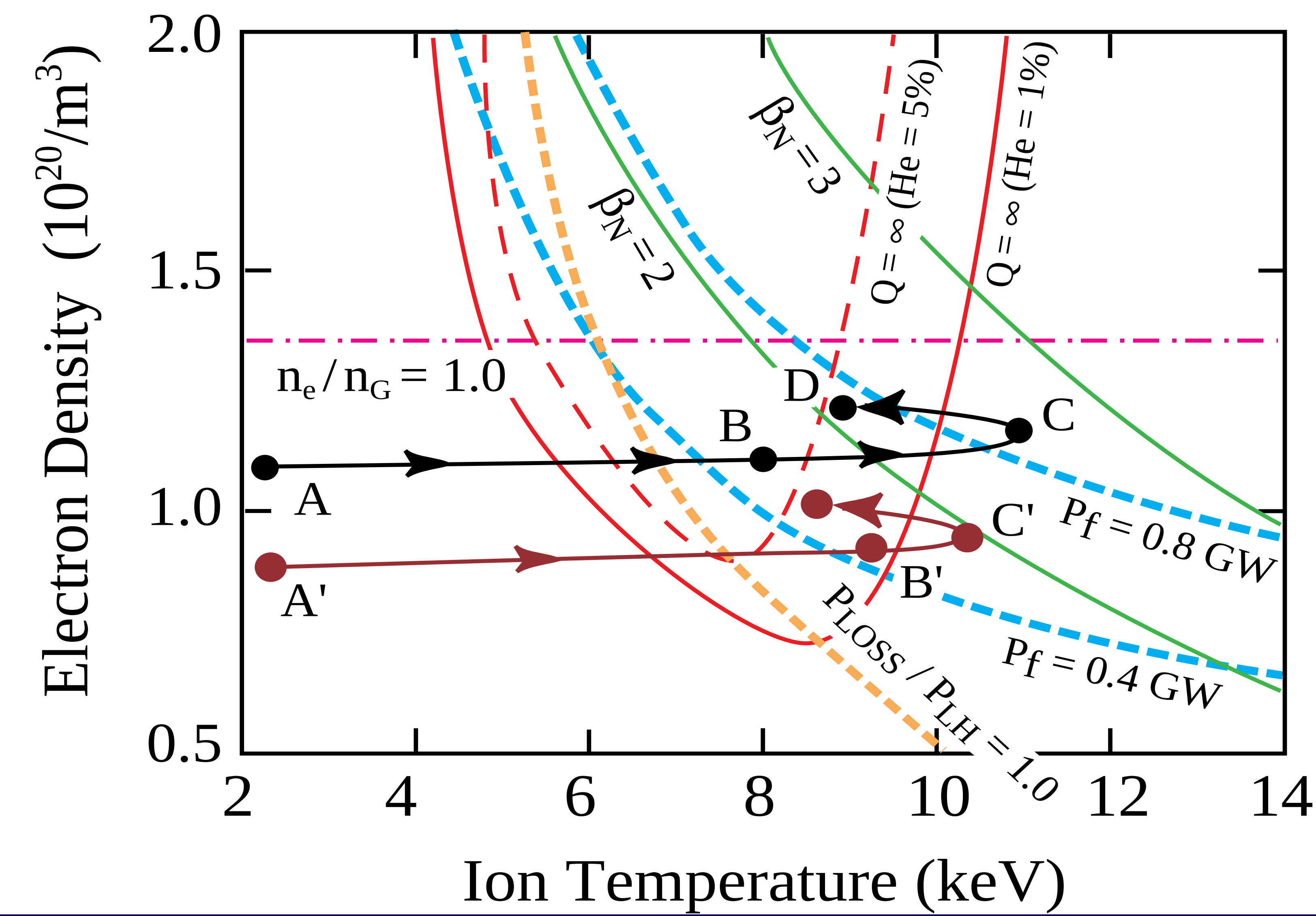


I_P = 17 MA, $<n_e>$ = 1.1∞$10^{20}/m^3$ (n_e/n_G = 0.81) and P_{ADD} = 73 MW (t = 10-13.5 s)

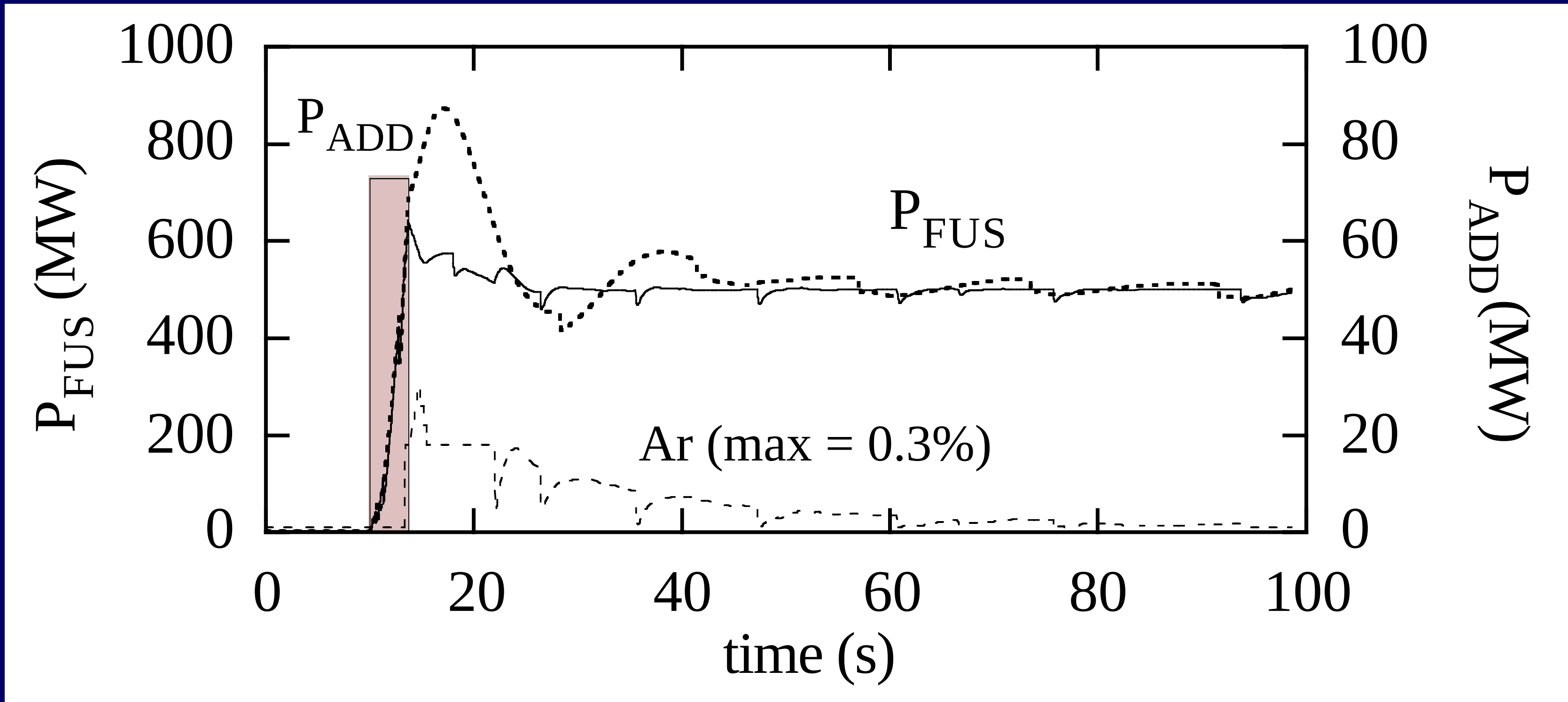
1.5D Simulation of Thermal Stability ($\tau_{He}^*/\tau_E = 5$, $H_{H98(y,2)} \sim 1.0$ after H-mode transition)



Thermal Instability with 17 MA



Control of power excursion by impurity injection



I_P = 17 MA, τ_{He}^{*}/τ_E = 3, $H_H(y,2)$ = 1.0 and 73 MW of heating power (P_{ADD}) is added from 10s to 13.7s: solid line - with argon (Ar) impurity seeding, dotted line - without impurity seeding

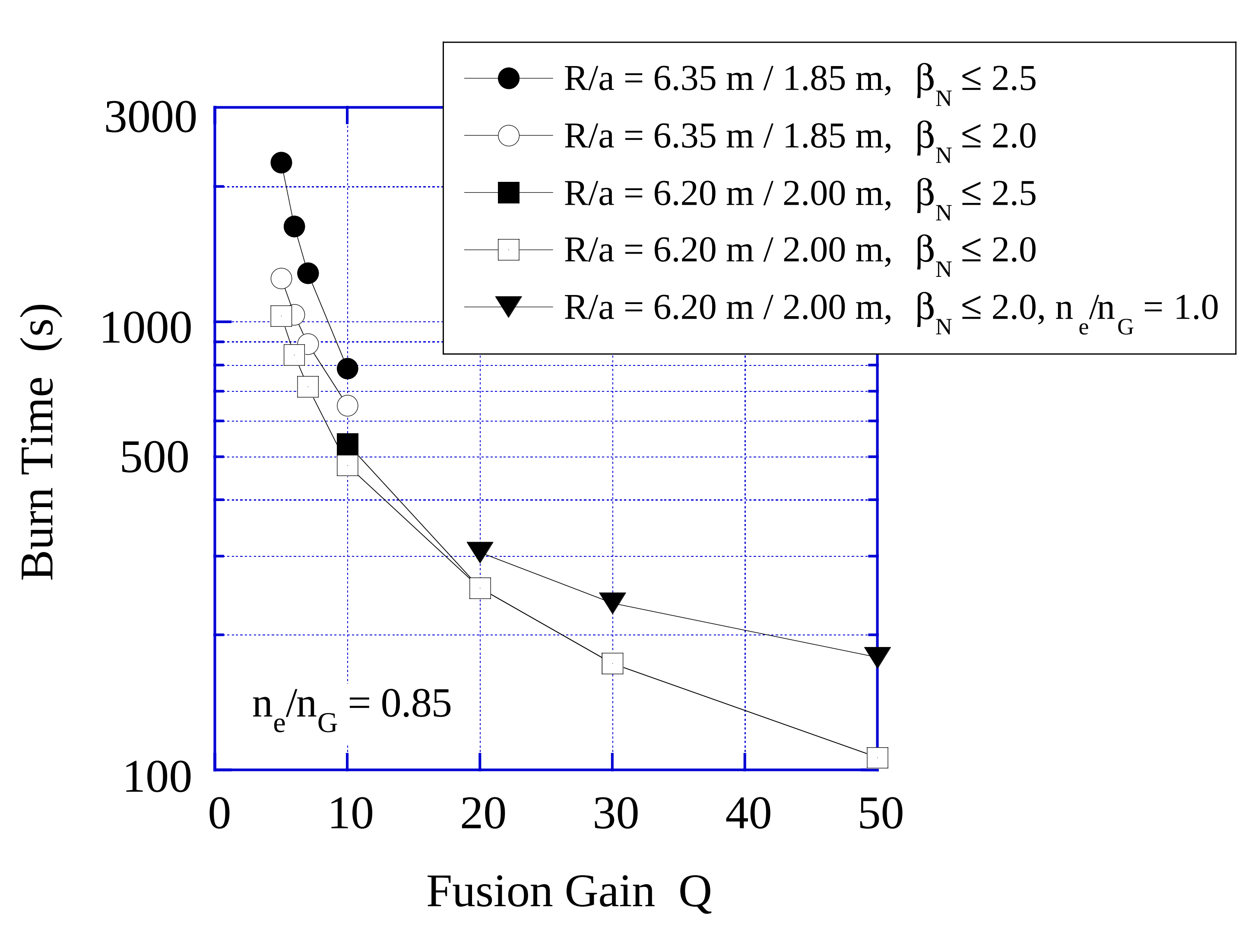
Examples of ITER-like Discharges

(Example)

JET	Pellets	Ar seeded	q_{95}~3.4	q_{95}~3	ITER 15 MA Q =10/20	ITER 16/17 MA Q =20/50
H_H	1.0-0.8	1.0	0.98	1.0	1.0	1.0
β_N	1.8	1.78	2.17	1.8	1.7/1.75	1.7/1.8
n_e/n_G	1.2-1.0	0.9	0.92	0.95	0.85/0.95	0.8/0.85
Z_{eff}	1.7	1.8	1.4	1.7	1.7/1.6	1.6/1.6
δ_X	0.39	0.23	0.34	0.43	0.5	0.5
q_{95}	2.8	2.8	3.4	3.1	3	2.85/2.69

Q = 10-20/400MW, Q = 50/500MW,
Ar seeded: ~0.1%,
Divertor heat load < 10 MW/m^2

Å H_H = 1Å



Blanket Test :>1000s, 500 MW Å Test areaÅ 0.77 MW/m² Å

Long Pulse Operation

	Hybrid #7	Hybrid #2
I_P (MA)	13.3	14.4
q_{95}	3.5	3.2
$\langle n_e \rangle$ ($10^{20} m^{-3}$)	0.90	1.0
n_e / n_G	0.85	0.85
β_N	1.9	2.2
P_{FUS} (MW)	350	500
P_{NB}, P_{RF} (MW)	73	60
$Q = P_{FUS} / (P_{NB}+P_{RF})$	4.8	5.0
τ_E (s)	2.62	2.40
$f_{He,\ axis\ /\ ave}$ (%)	2.9 / 2.2	3.9 / 2.7
$Z_{eff,\ ave}$	1.73	2.03
$P_{Separatrix}$ (MW)	100	129
I_{CD} / I_P (%)	28	32
I_{BS} / I_P (%)	18	20
Burn time (s)	1280	1220
Shot # for 0.2 MWa/m^2	12800	9400

* Neutron fluence at test area = 0.28 MWa/m^2
* Neutron flux at test area = 0.55 MW/m^2 at 350 MW, 0.78 MW/m^2 at 500 MW

R (m) / a (m) = 6.2 / 2.0, $\kappa_{95} / \delta_{95}$ = 1.7 / 0.33, τ_{He}^* / τ_E = 5, HH(y,2) = 1.0

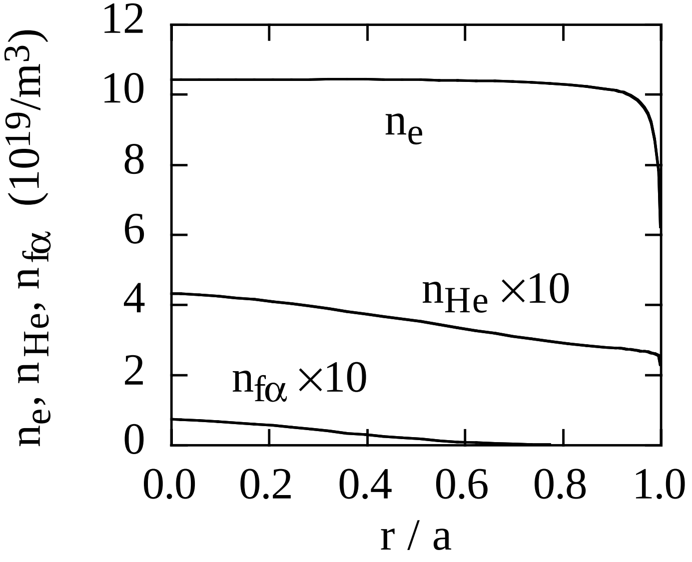
** High triangularity gives q_{95} = 3.7 instead of 3.5.

Operation Parameters of ITER

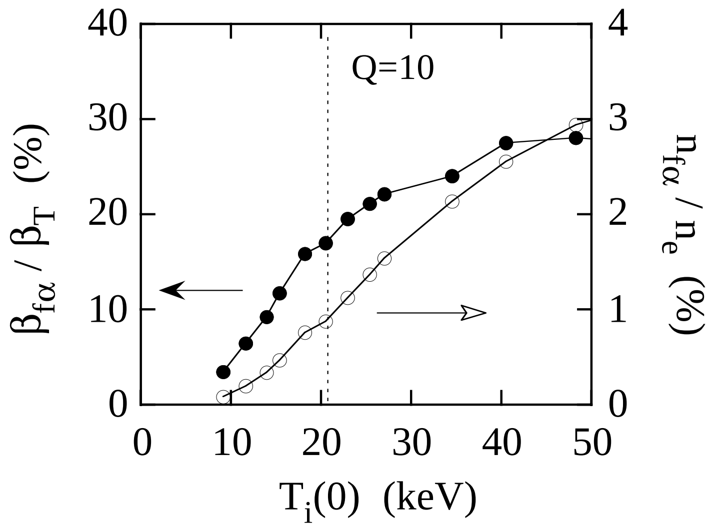
15 MA, $H_{H98(y,2)}$=1.0

		Q = 20	Q = 10
$\langle T_i \rangle$	keV	7.1	8.0
$\langle T_e \rangle$	keV	7.7	8.8
$\langle n_e \rangle$	$10^{19}/m^3$	11.3	10.1
$\langle n_e \rangle / n_G$		0.95	0.85
f_{He} (axis)	%	4.6	4.4
P_{FUS}	MW	400	400
β_N		1.7	1.8
$\langle \beta_T \rangle$	%	2.4	2.5
$\langle \beta_{f\alpha} \rangle$	%	0.13	0.17
$\beta_{f\alpha}$ (axis)	%	0.9	1.2
$n_{f\alpha}/n_e$ (axis)	%	0.5	0.8
$\tau_{S,f\alpha}$ (axis)	s	0.7	1.0
$\tau_{e,i}$ (axis)	s	0.8	1.1
τ_E	s	4.5	3.7
W_{thr}	MJ	310	320
$W_{f\alpha}$	MJ	18	24

* Typical Density Profile (Q=10)

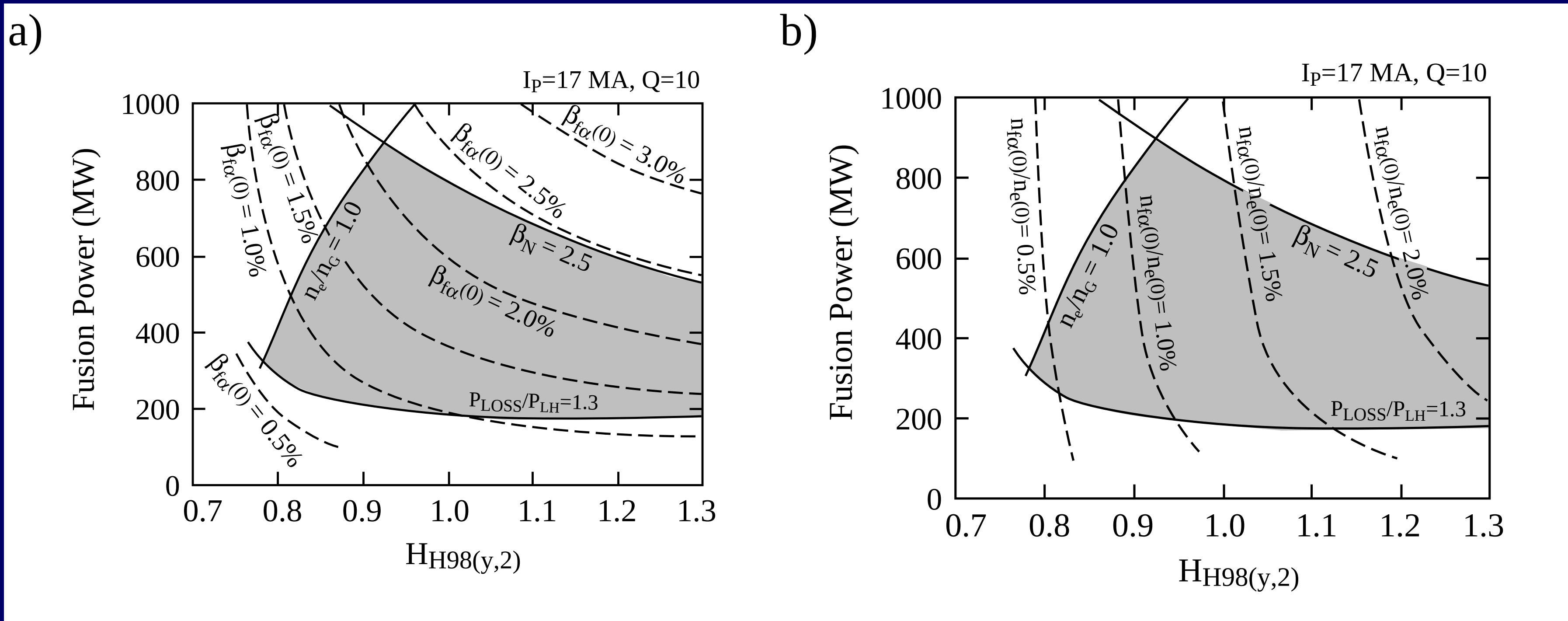


* Fast Alpha Beta & Density

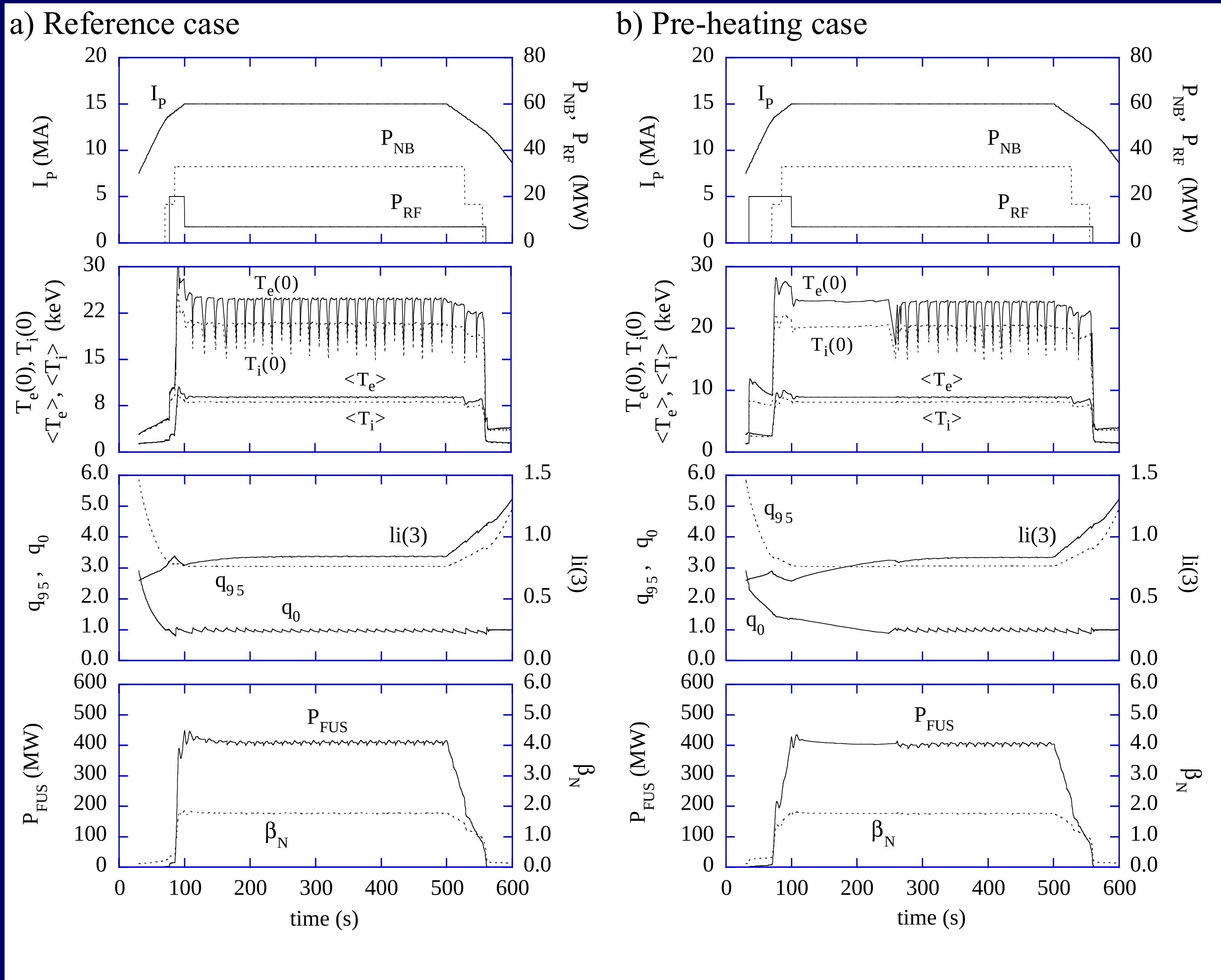


* $n_{f\alpha} \sim n_D n_T \langle \sigma v \rangle_{DT} \times \tau_{s,f\alpha}$ ($n_{f\alpha}/n_e$ has a weak dependence on n_e)

Fast Alpha Particle Parameter in ITER (17MA)



High fast alpha particle pressure can be accessed only with better confinement

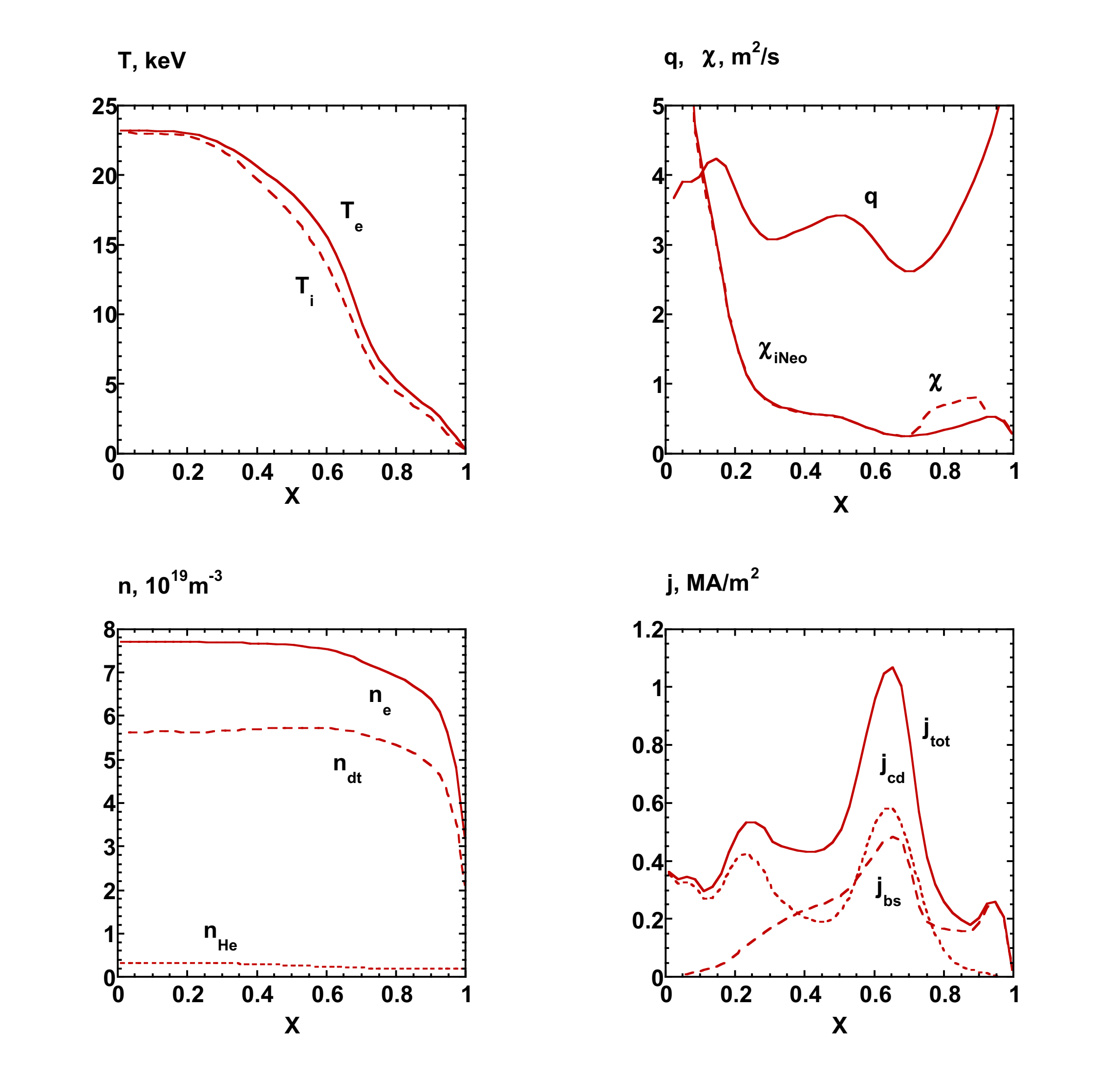


Onset of the first sawtooth crash

(a) 20 MW of RF heating power is added at t = 77s

(b) 20 MW of RF power is added at t = 34s to reduce current penetration.

QÅ 5.4, I_P= 9.5 MA Steady State Operation

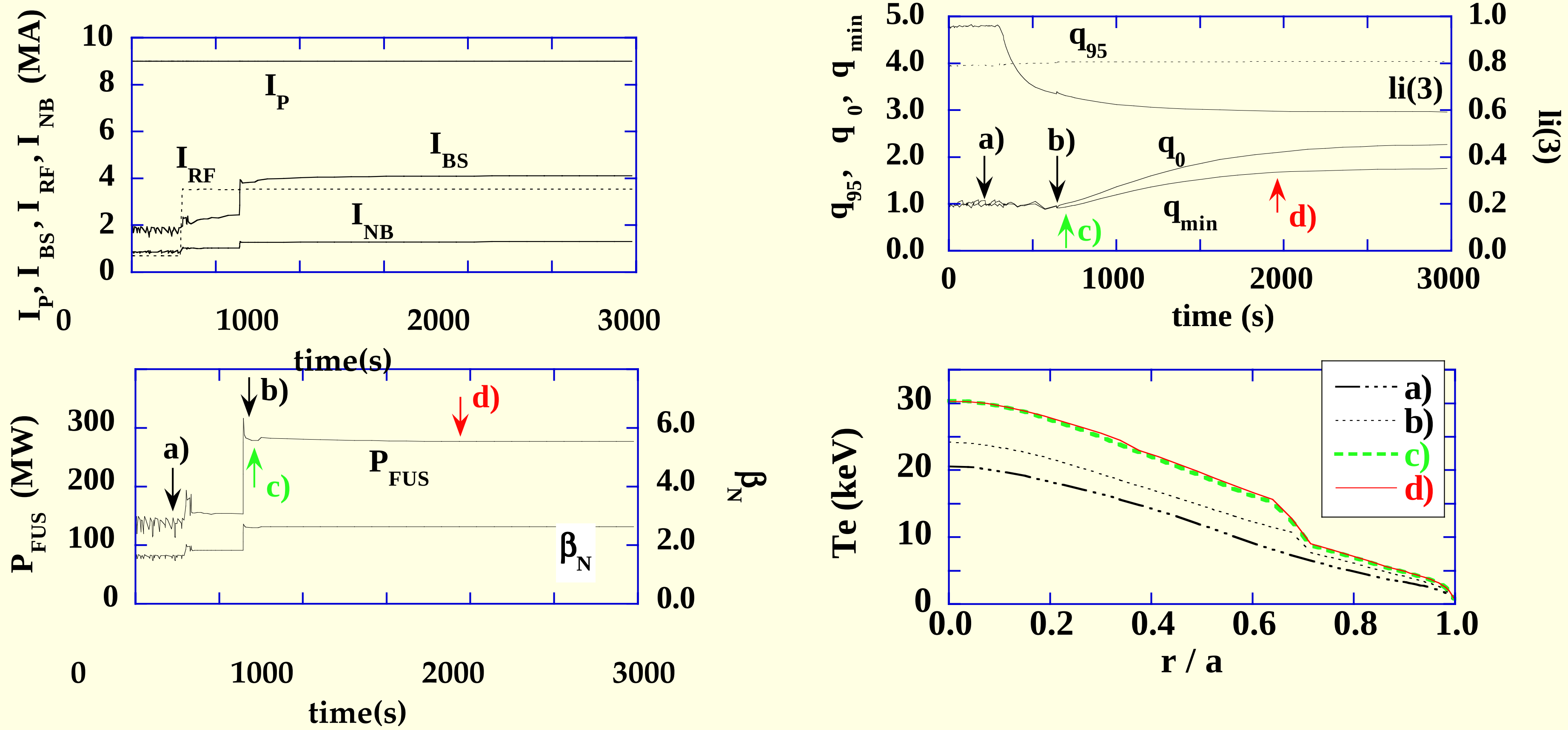


P_{FUS} / P_{CD} = 340 MW / 63 MW,

Z_{eff} ~ 1.9 (He / Be / Ar = 4% / 2% / 0.16%) , $P_{sep.}$ =100 MW, H_H = 1.45, β_N = 2.7

r = 0-0.5 (NB:28 MW), r = 0.5-0.8 (EC and LH : 35MW)

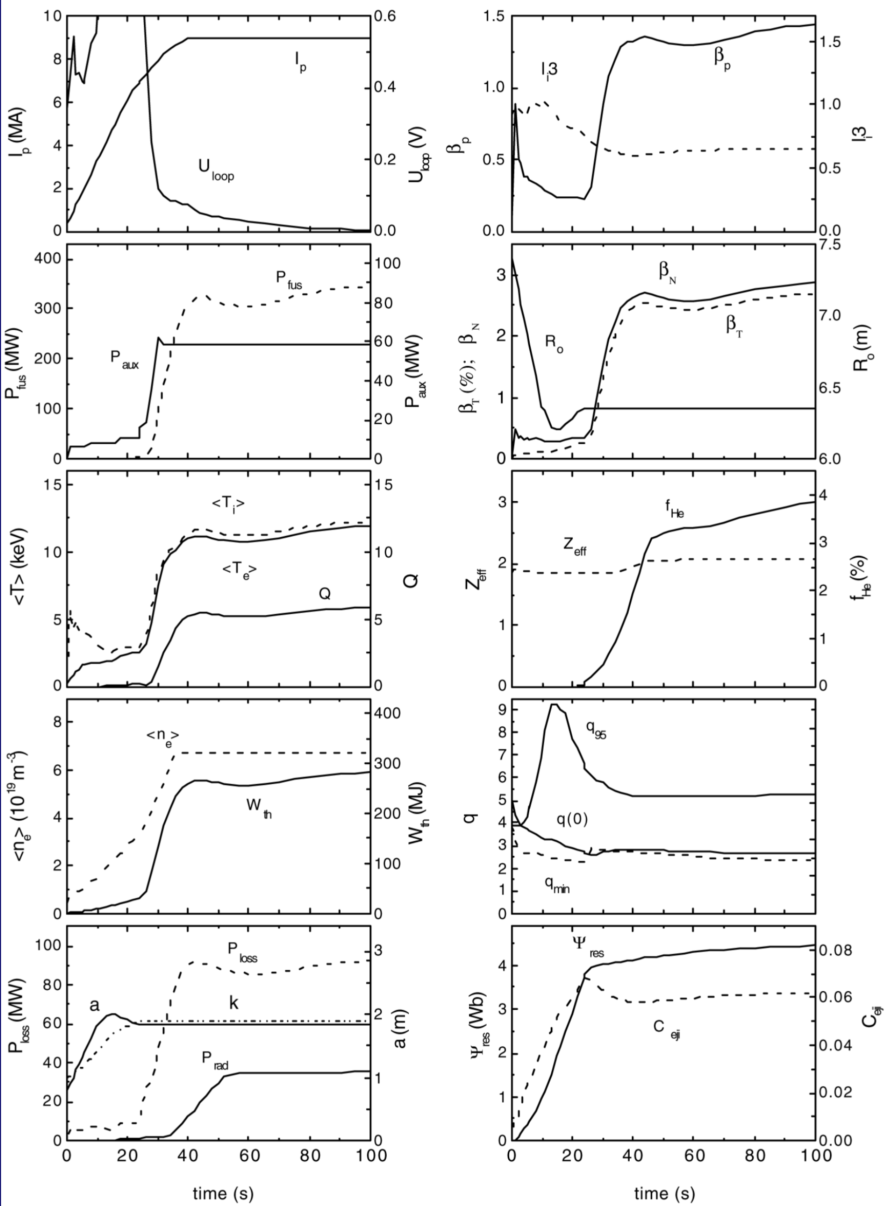
Non-inductive Operation with Internal Transport Barrier from a Conventional Operation



$\langle n_e \rangle = 0.67 \times 10^{20}/m^3$ ($\langle n_e \rangle / n_G = 0.8$), HH = 1→ 1.4, P_{FUS} / P_{CD} = 280 MW / 80 MW (Q=3.5)

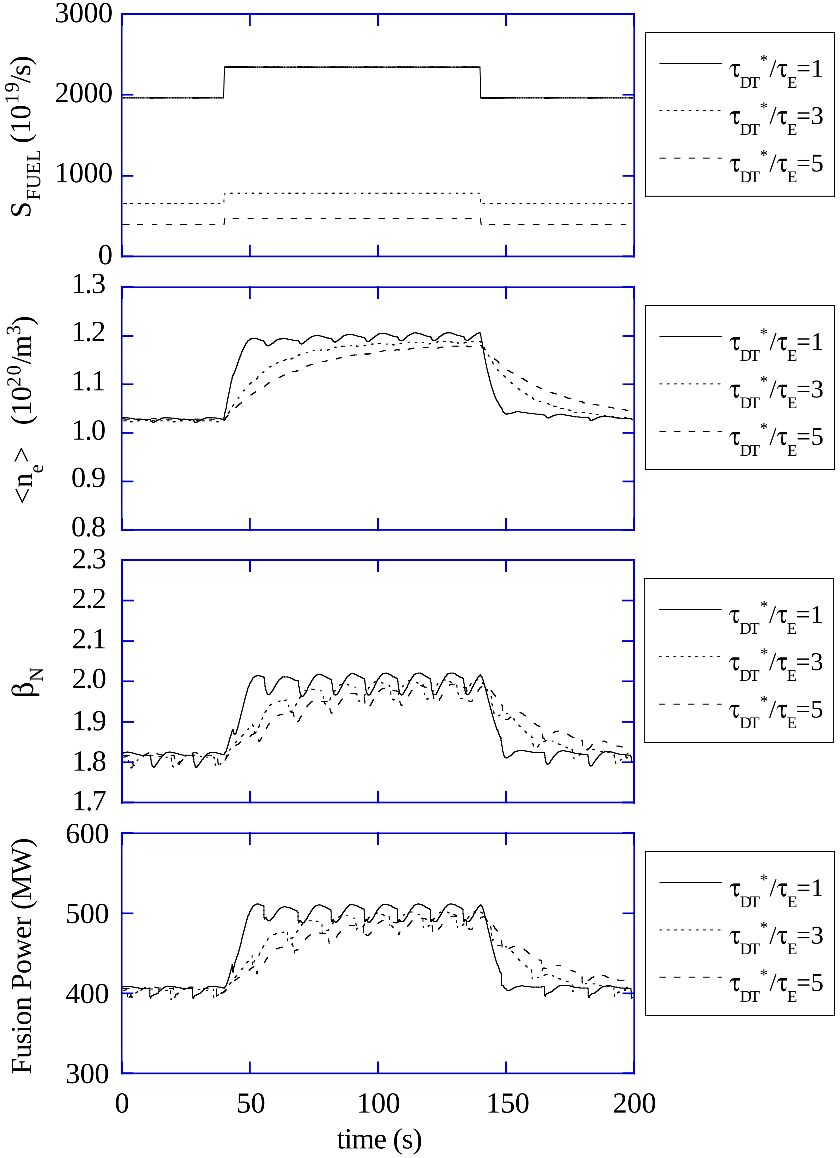
On axis (EC)	: 20 MW,	γ_{20}(EC) = 0.15,
Off axis (NB)	: 20 MW,	γ_{20}(NB) = 0.18→ 0.28
Far off axis (LH)	: 40 MW,	γ_{20}(LH) = 0.3

Fast Formation of Steady State Plasma



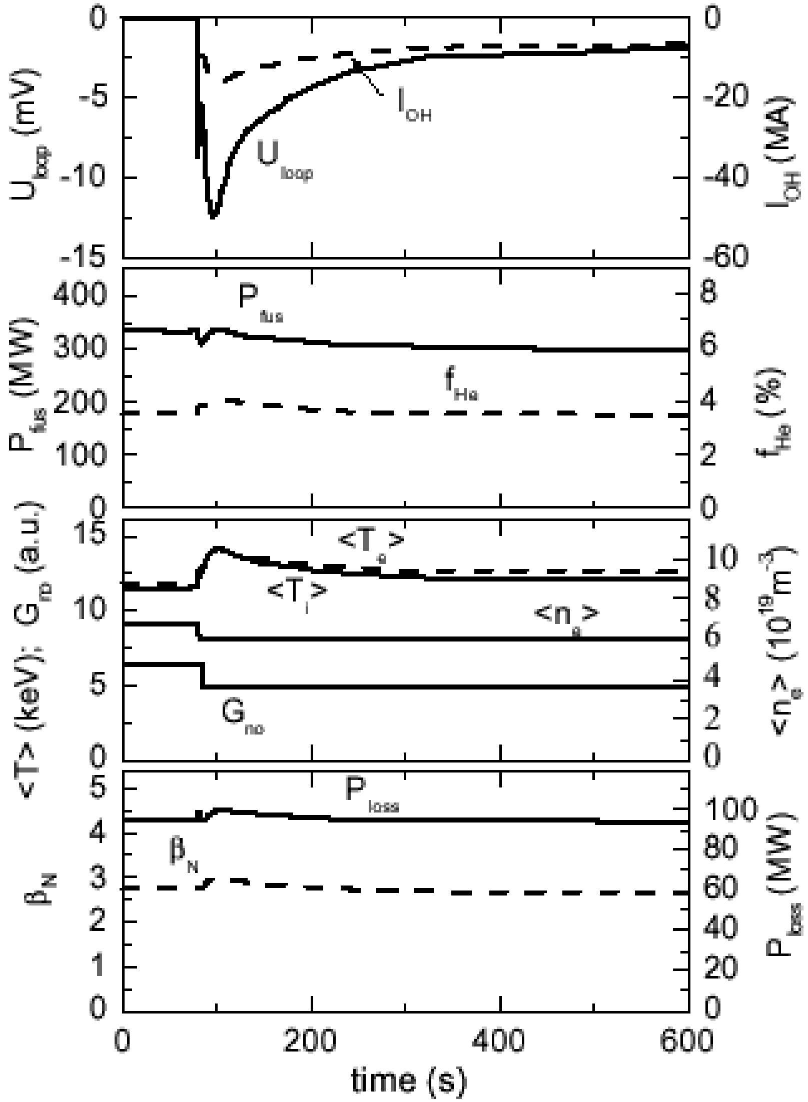
Evolution of plasma parameters for the WNS steady-state operational scenario. X-point formation corresponds to t=15.7 s, start of flat-top corresponds to t = 40 s, start of burn corresponds to t = 40 s.

Inductive

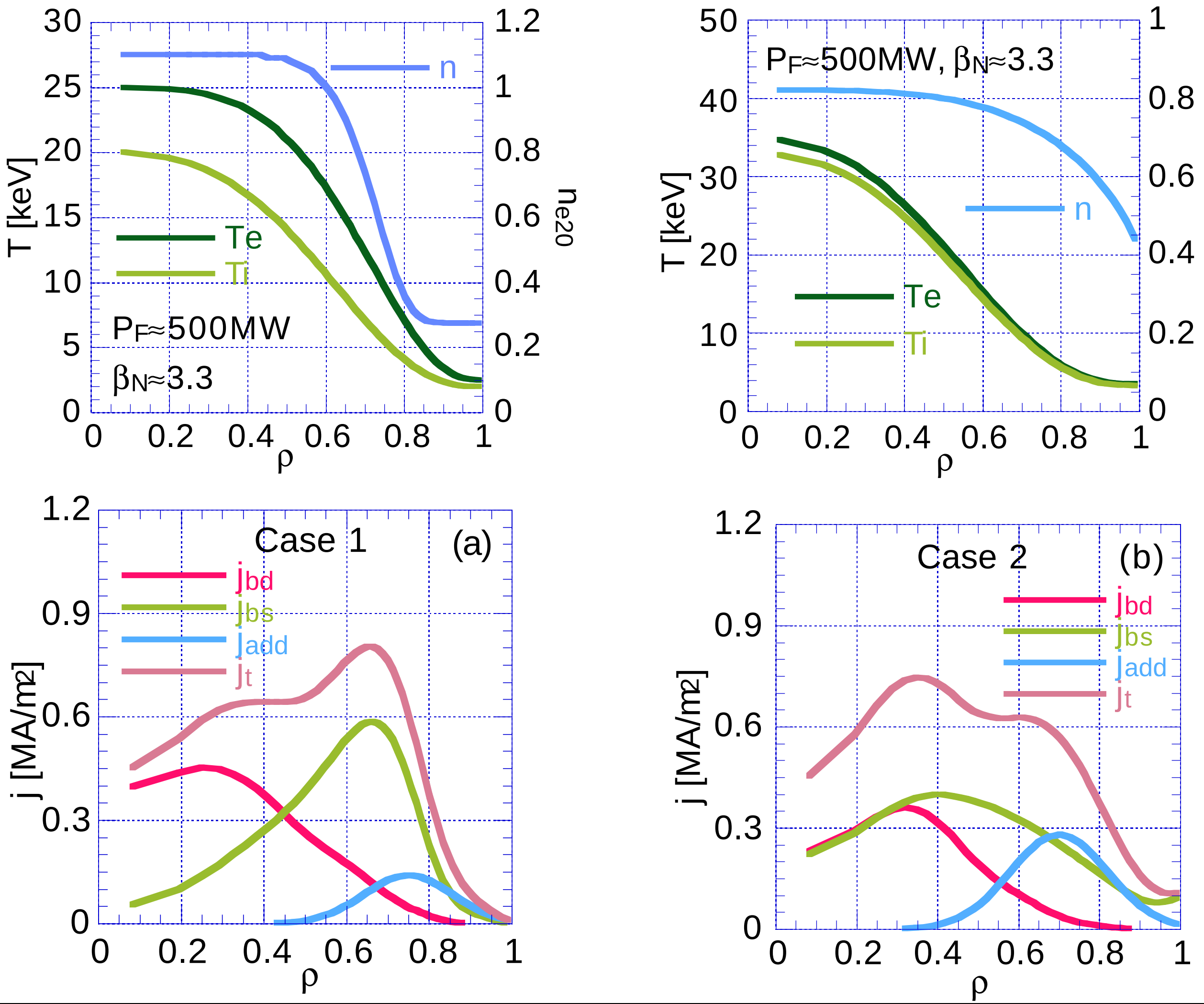


Time response of fusion power to increase of fuelling rate (S_{FUEL}) for various τ_{DT}^*/τ_E values. Here, $H_{H98(y,2)}$ = 1.0, P_{NB} = 33 MW, P_{RF} = 7 MW and τ_{He}^*/τ_E = 5.

Non-inductive



Evolution of plasma parameters as a reaction on the 25% testing decrease in the plasma gas-puff fuelling (G_{n0}) for the WNS steady-state scenario.

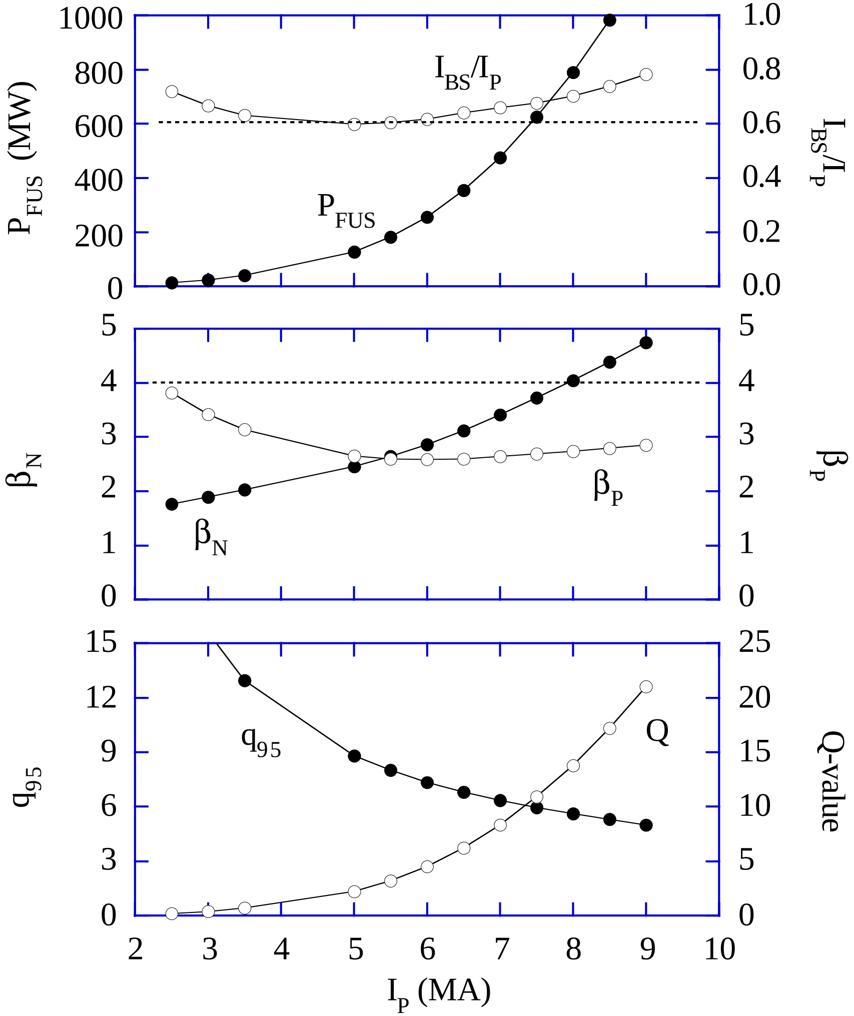


	Bootstrap-C	NB-C	LH/EC-C
Case 1 (Negative shear, q > 2)	5.8	3.0 (50 MW)	1.2 (LH 15 MW)
Case 2 (Negative shear, q > 2)	5.2	2.2 (30 MW)	2.6 (LH 40 MW)
Flat density (Weak shear, q > 1.5)	3.0	3.9 (36 MW)	3.1(LH 50 MW)

I_P = 10 MA, <n> ~ 7 x 10^{19} m^{-3} (0.8n_G), β_N ~3.2, P_{fusion} = 400-500 MW, a = 2m

If P = 100 MW, H_H ~1.6,

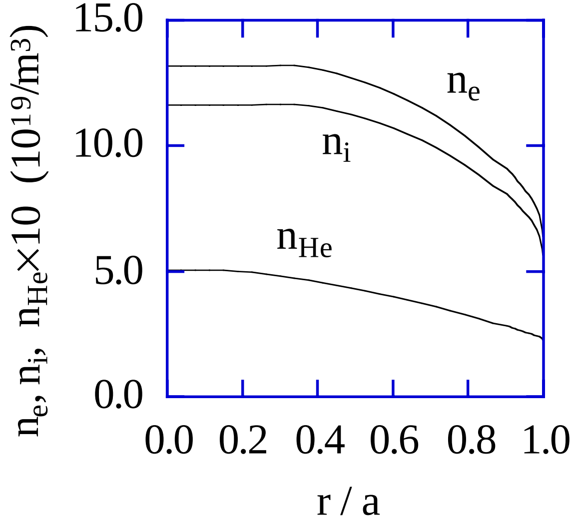
Bootstrap Current Fraction in ITER (PRETOR simulation)

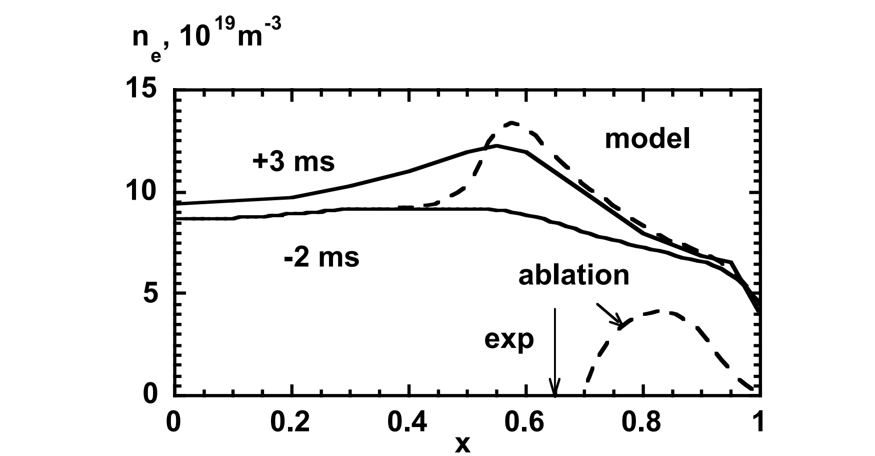


/a = 6.35m / 1.85m, P_{NB} / P_{RF} = 17 MW / 40 MW

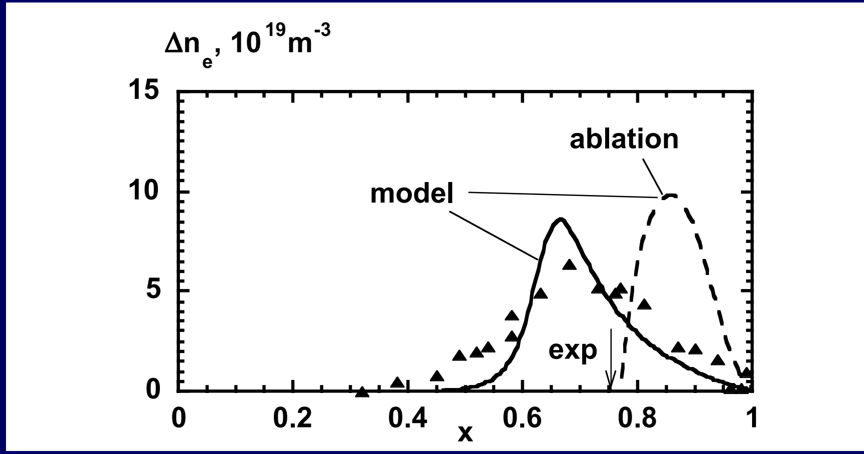
n_e>/n_G = 1.5, $H_{H98(y,2)}$ = 1.6, f_{Be} = 2%, f_{Ar} = 0.12%

* Typical Density Profile

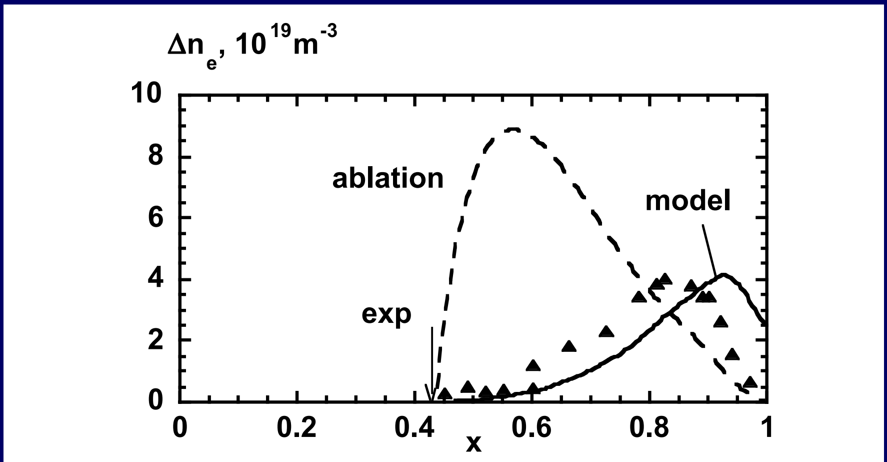




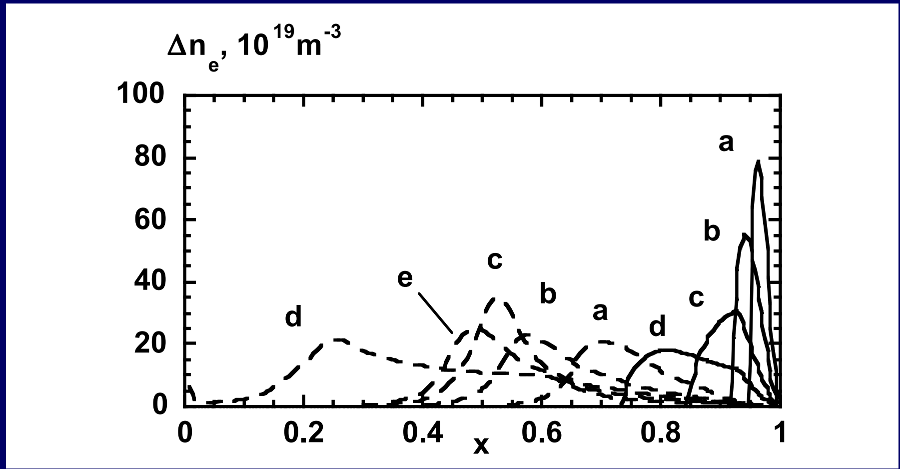
AUG/H



D-III-D/H



D-III-D/L



ITER/H

a : 100m/s , b:300m/s,c:1000m/s, d: 3000m/s

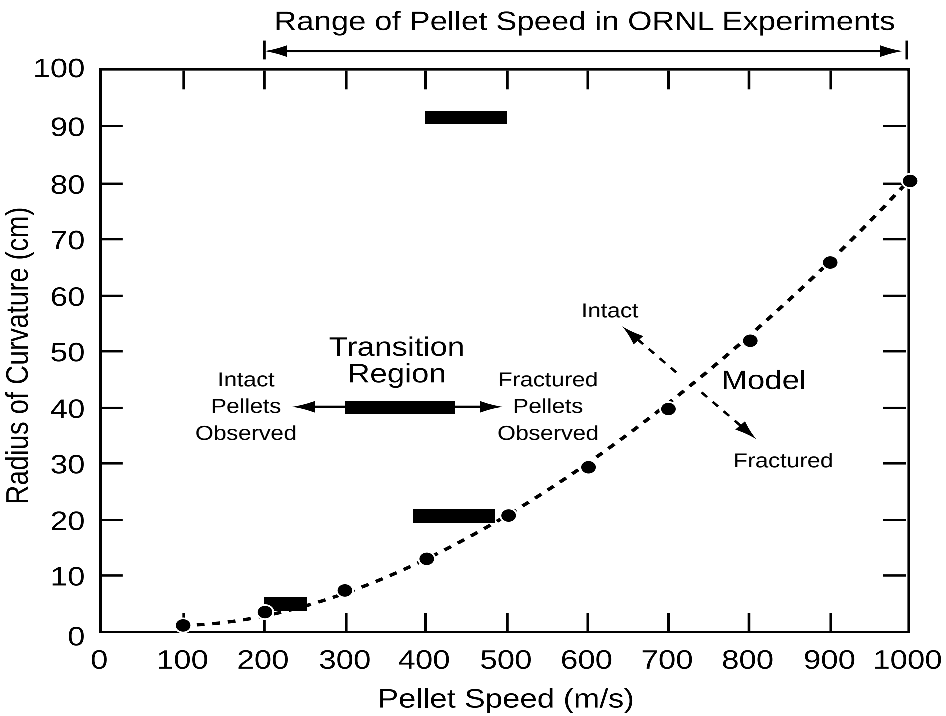
D = h = 1 cm

By A. Polevoi (Kuteav/Parks/Strauss, ablation/cloud size/mass relocation)

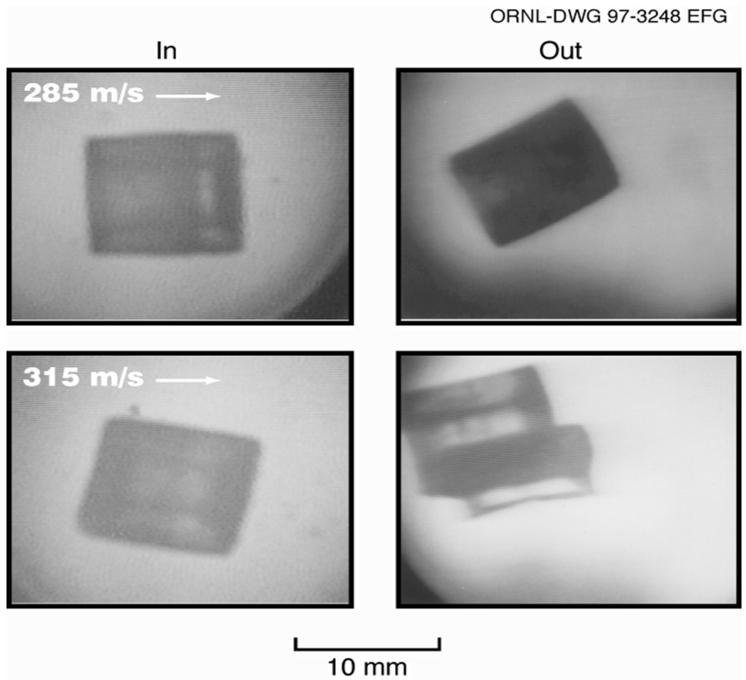
Pellet Fuelling

Assumption: Teb = 1 KeV, $n_e = 10^{20} m^{-3}$, 10 mm pellet
Low field side: 0.2 a at 1 km/s
High field side: (0.2a) at 0.3 km/s
(Simple extraporation from ASDEX-U)
Model will have to be developed for high field side injection

100 Pam^3/s, 1 cm^3/s, 0.27 g/s or $5.5 \times 10^{22}/s$ of tritium extraction has been achieved (n_{DT} VP = 6.3 X 10^{22} IN ITER-FEAT). A total of 36 g T_2 and 28 g D-T runs.



Test data summary for 2.7-mm pellets shot through curved guide tubes of different radii

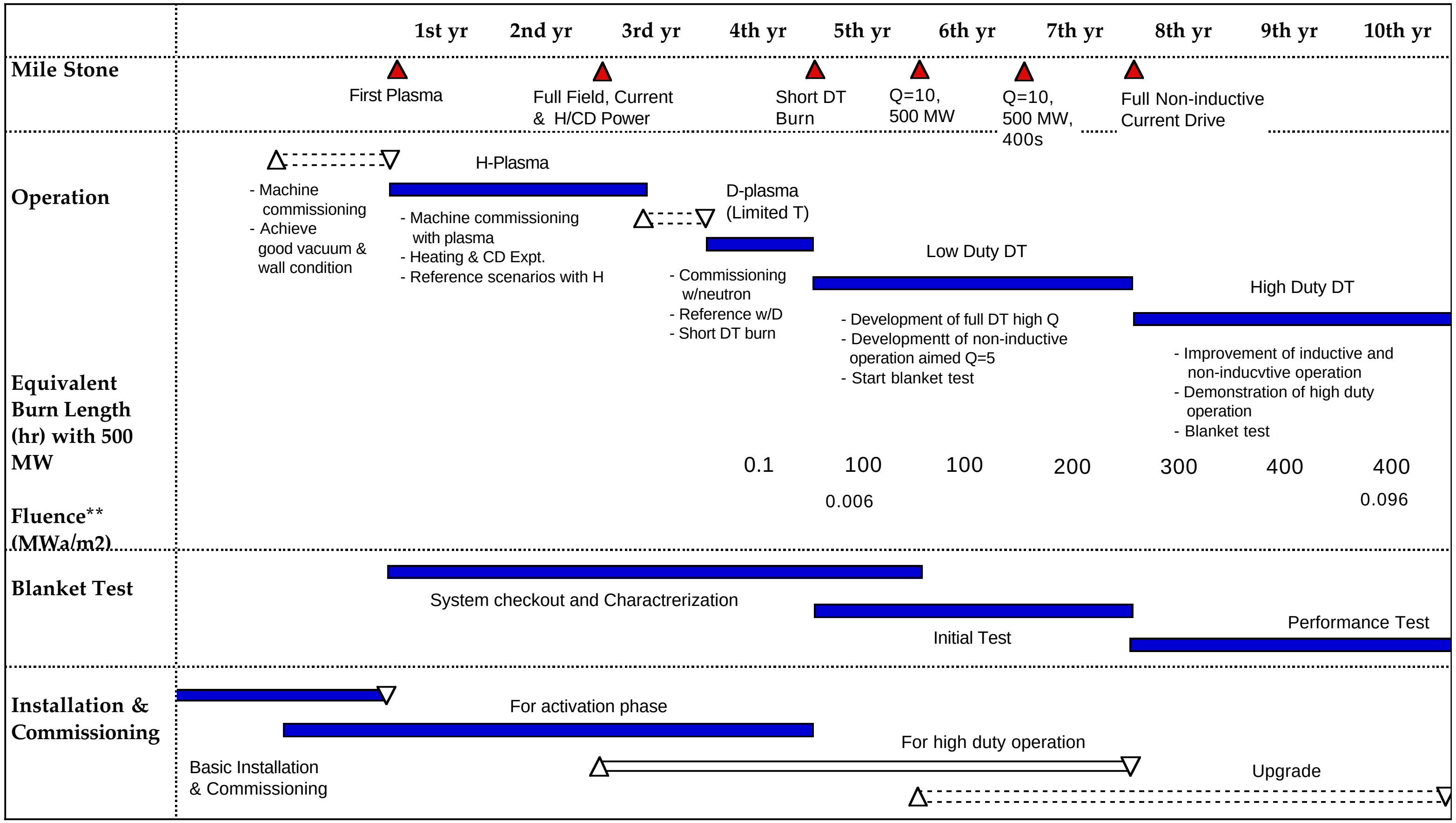


Photograph sets for 10-mm pellets shot through 80-cm-radius curved guide tube. (Upper 285 m/s, Lower 315 m/s)

Preliminary Analysis with High Field Side Pellet Injection

	ITER E Mode1 1/2
Major radius (m)	6.35
Minor radius (m)	1.85
Elongation (95% flux)	1.85
Plasma current (MA)	12.5
Toroidal field on axis (T)	5.18
Safety factor, q95	3.77
Normalised beta βN,max/li3	3.56
Bootstrap fraction fbs	0.46
Confinement coefficient, HH	1.25
Plasma density, <n> ($10^{20} m^{-3}$)	0.92
n_{line}/n_{GW}	0.77
n_o/n_{ped} max	1.65
Av. Electron temperature (keV) <nT>/<n>	16.4
Aux. Heating power (MW) (NBI)	100
Fusion power (MW)	780
Q	7.85

ITER: High field side pellet injection: 2Hz, 2r=h=0.7 cm, vp = 0.5 km/s. χi = χe = D with parabolic profile



*Average Fluence at First Wall (Neutron wall load is 0.56 MW/m2 in average and 0.77MW/m2 at outboard midplane.)

Net consumption of tritium

The first ten years	~ 5kg
Average 0.3/Blanket test area 0.4 MWa/m^2	~ 15 kg (Minimum requirement)
Average 0.5/ Blanket test area 0.7 MWa/m^2	~ 25 kg (Design value)

~30kg of tritium could be supplied with external sources

Phased Operations

Hydrogen Phase

Confirmation of the machine performance and increase of reliability of the operation

Full commissioning of the ITER system in a non-nuclear environment

Development of operation scenarios with semi-detached divertor and ~70 MW

Better control/mitigation of disruptions/VDEs/ELMs/runaway electrons

Characterization of dusts

Build-up of experimental groups in the world wide fusion community

Deuterium Phase

Nuclear commissioning and confirmation of the basic plasma characteristics

No human access into the vessel

Deuterium Tritium Phase

Research of long burning plasmas

Optimization of operations for various objectives

Engineering tests including blanket tests for the next step

Participations

1. The maximum numbers of the ILE staff from the different Parties will be set in consideration to the contributions of the Parties. The complement of the directly employed ILE staff should be kept to a minimum necessitated in the project implementation.

2. The ILE staff arrangements should encourage mobility between the project and the Parties' domestic programmes.

3. To ensure wide scientific participation in the Project, the short-term (less than a year) participation of qualified personnel from universities and other institutions ("Guest Researcher") will be encouraged.

4. The operation of ITER will be conducted by the ILE staff only. The scientific exploitation of ITER will, beside the ILE staff, also involve the participation of researchers from fusion laboratories, universities or other research institutes of the Parties, which will be only part-time on site.

Physics Issues of Burning Plasmas in Inductive Mode

1. Thermal instability/Burn control
   - Normal operation: Stable
   - Q_10: Thermal instability could be triggered.
2. Collective fast alpha particle effects
   - Normal operation : β_{axis} _ 1 %
   - Higher beta (_2 %): $H_H > 1$ $P_{ad} > 100$ MW, $I_P > 15$ MA
3. Thermal beta effects
   - Normal operation : β_N _ 2
   - Higher beta : $n > n_G$, $H_H > 1$, $P_{ad} > 100$ MW
4. Sawtooth effect
   - Normal operation : with sawtooth
   - No sawtooth : $q_0 > 1$, ~ 100 s
5. Pedestal/Edge Plasma/Divertor

Additional Issues of Burning Plasmas in Non-inductive Mode

6. Interaction among burn, I_b/I_{ad}, fuelling/pumping, impurity, transport, etc.

How can appropriate plasmas (high Q, β_N and I_b/I_p) be obtained?

Requirements are clear but predictions are not reliable.

Stabilization :	high β_N with low l_i
High n, peaked n:	deep fuelling
High H_H:	ITB, deep fuelling

Conclusions

The flexibility of ITER will allow research in a large operation space.

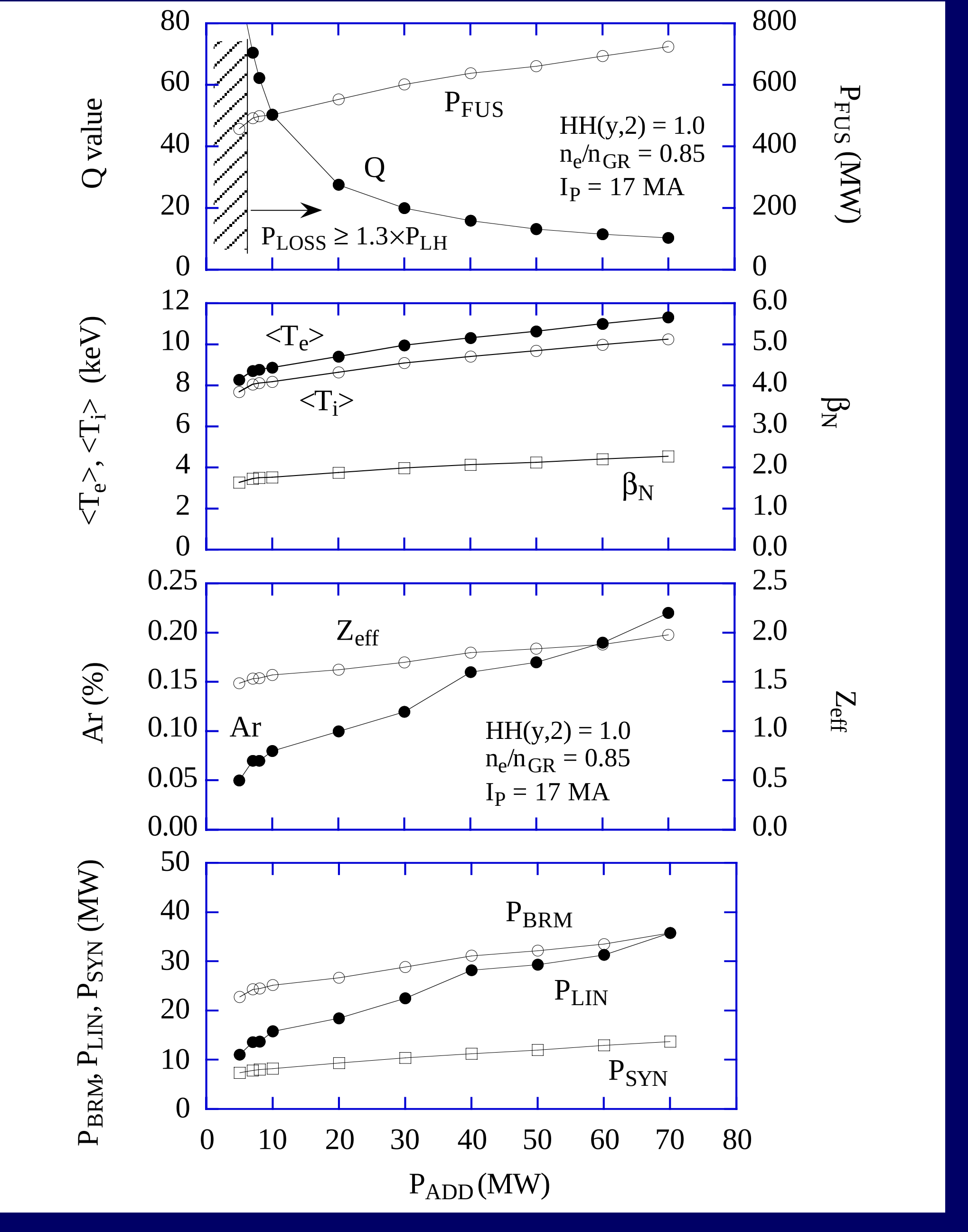
(P_{fusion}, Q, n, β, pulse length, I_P -----)

(Confirm predictable operation ⇒ Explore frontier)

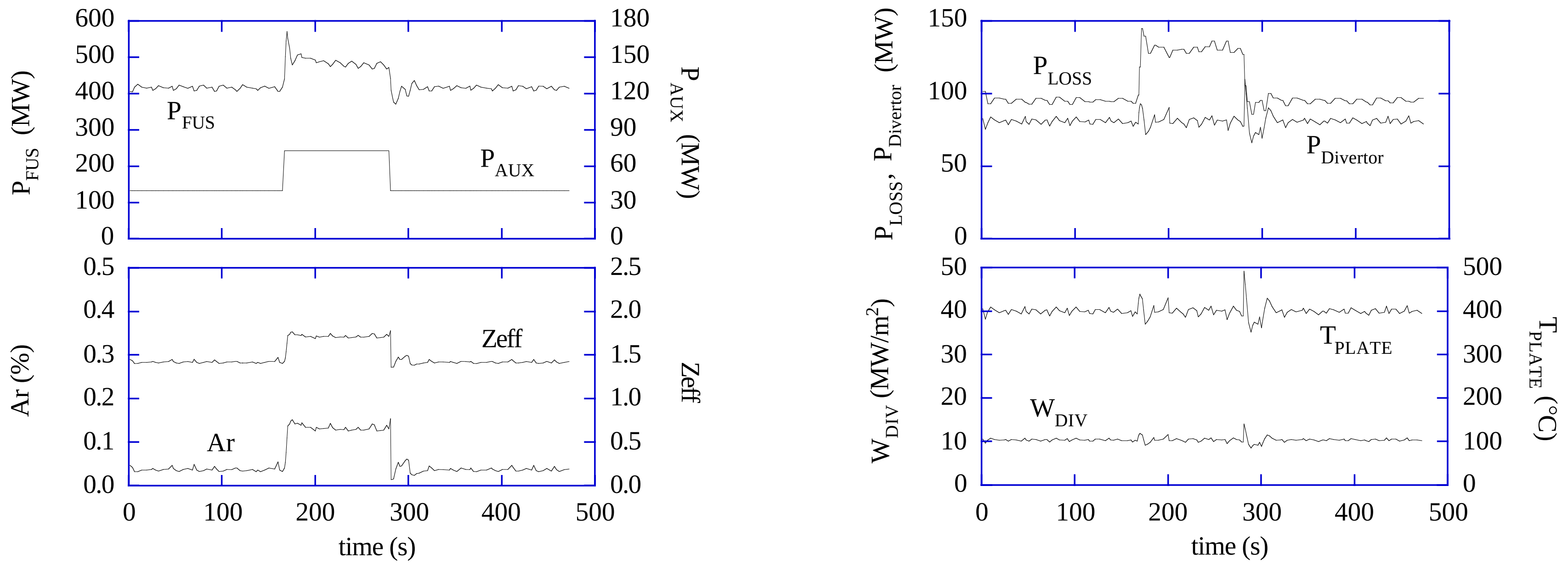
- **Predictable operations and extended operations with inductive current drive**
  - **150 → 700MW, n/n_G=0.5 → 1 , β_N =1.2 → 2.4, Q = 5 → 10 → 20 → ∞**
  - **~ 100 s burn is necessary to study plasma behavior.**
- **Hybrid operations**
  - **> 1000 s / 500 MW/Q=5 with reasonable parameters for blanket test (0.77 MW/m^2)**
  - **If necessary, q95 > 3.5 scenarios is available.**
- **Research of fully non-inductive driven operations aiming at Q=5**
  - **(higher β/higher confinement, methods included in ITER)**
  - **~ 2000 s is necessary to achieve steady state of AT mode from conventional one.**
  - **By optimizing current ramp-up, steady state of AT can be achieved within 200 s.**

The experimental concept will increase efficiency, involve the worldwide fusion community and promote scientific competition.

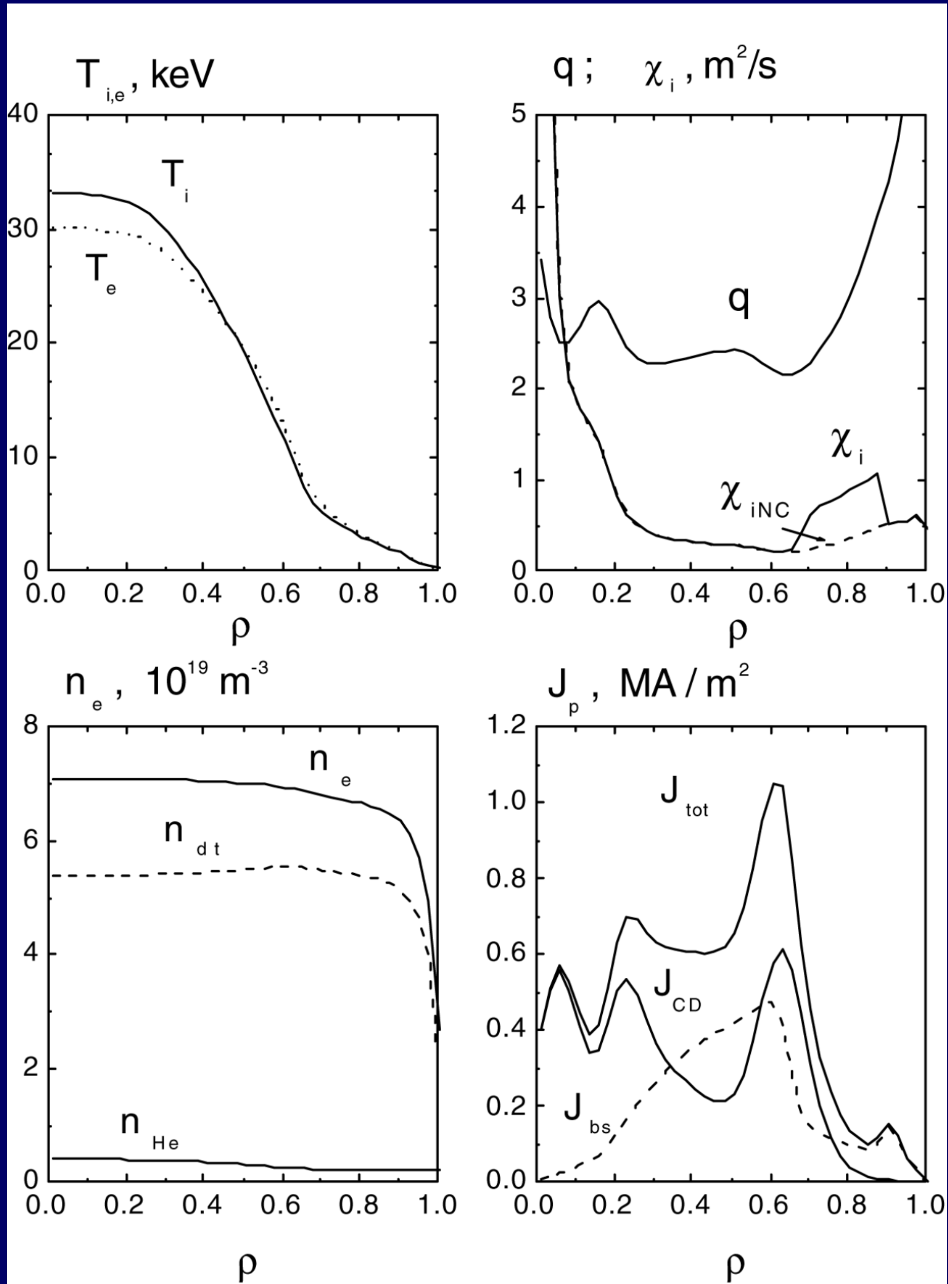
PRETOR Simulation for Various Heating Powers



Ip=17 MA, $\langle n_e \rangle = 1.15∞10^{20}/m^3$ ($\langle n_e \rangle / n_G=0.85$), τ_{He}/τ_E~5 and argon is seeded to limit the power to the divertor region to 30 MW



Simulation for feedback control of target plate temperature by impurity seeding in case of sudden increase of fusion power P_{FUS}.



Plasma parameter profiles at the current flat-top (t > 1000 s) for the steady-state WNS operational scenario.
H_H = 1.57, Q = 6, βN = 2.95, $P_{NB} + P_{LH}$ = 30 + 30 MW, R/a = 6.35 /1.85