Lecture 1:

Introduction to ITER

AP 4990y Seminar

Columbia University

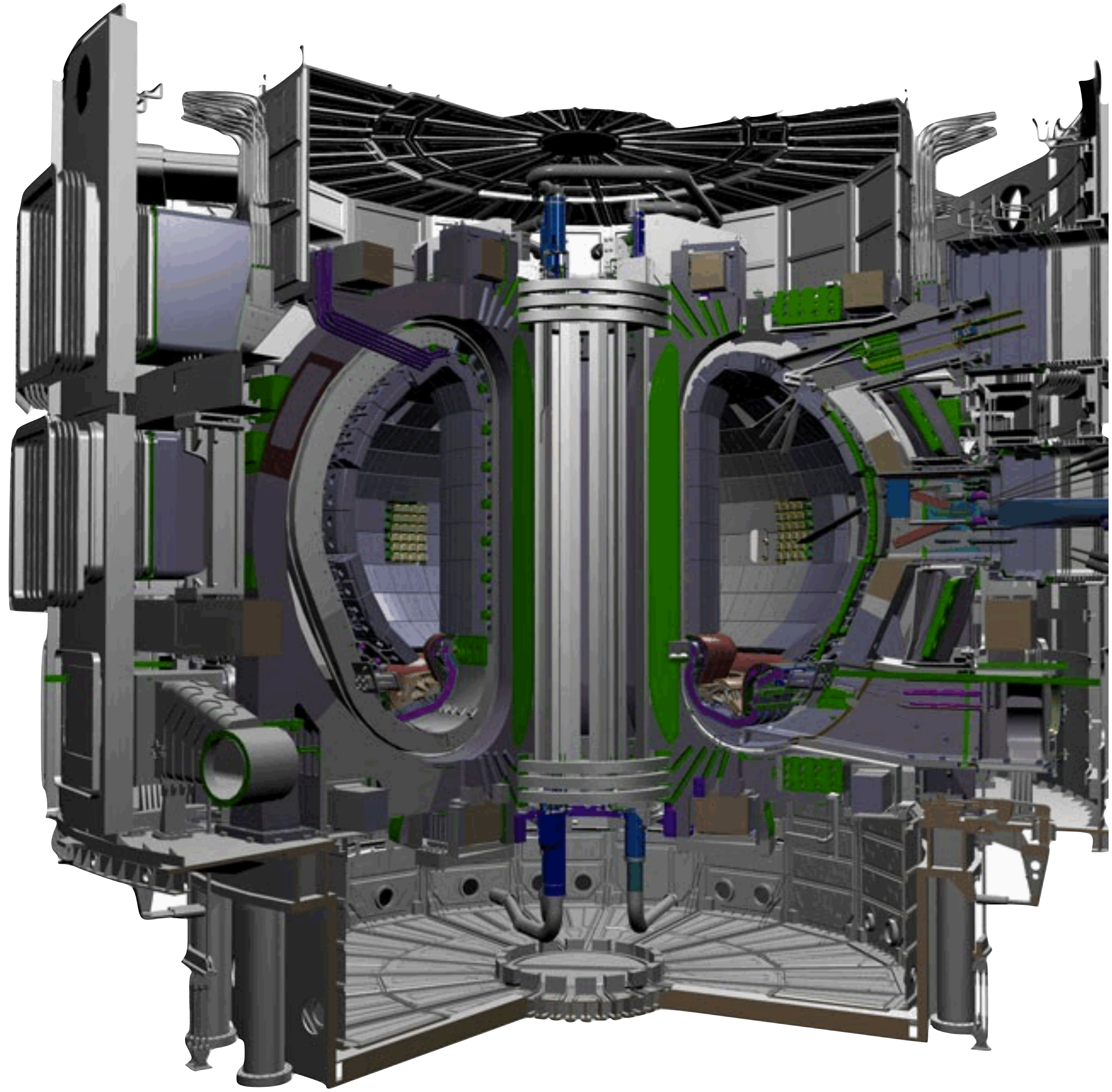
Spring, 2011

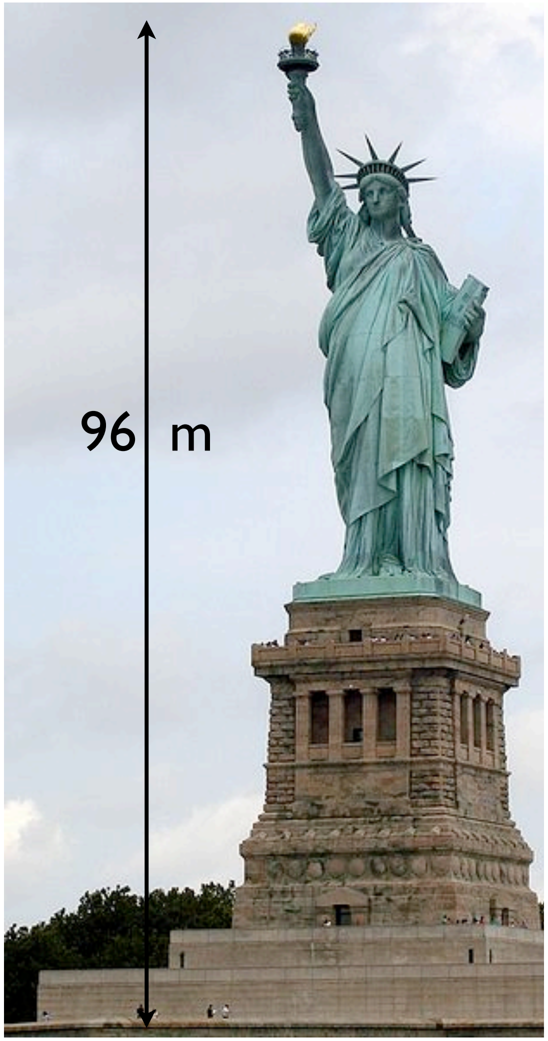
Outline

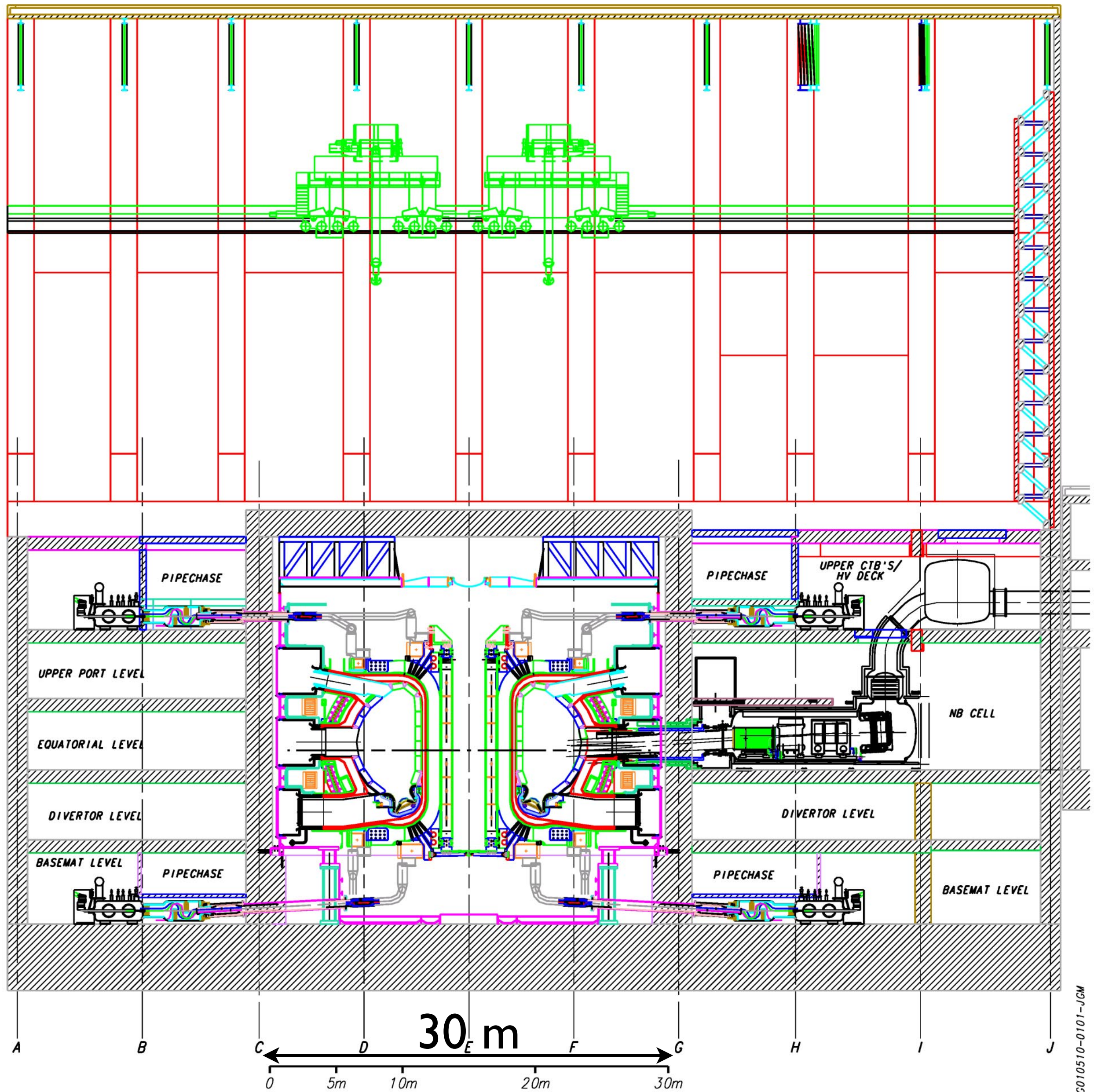
- What is ITER?
- ITER's history
- Plan for semester
- ITER's status: Talk by outgoing director

http://www.iter.org/

- Culmination of 50 years of magnetic fusion research
- 500 MW fusion power for 7 min pulses
- EU, Japan, Russia, China, S Korea, India, USA
- At 22B US$ (14B US$ official), the most ambitious international science project ever
- 23,000 tons (tokamak only), or $1M/ton




96 m


PIPECHASE
UPPER CTB'S/ HV DECK
UPPER PORT LEVEL
EQUATORIAL LEVEL
NB CELL
DIVERTOR LEVEL
BASEMAT LEVEL
A
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G010510-0101-JGM

History

- CDA: Conceptual Design Activity (1998-1990/2)
- EDA: Engineering Design Activity (1992-1998)
- ITER-FEAT: 1.3 times smaller at "half price"
- ITER project agreement signed in Nov, 2006
- ITER Physics/Design Review: Sept, 2007
- ITER Cost & Schedule Baselined: July 2010
- Bulldozers start clearing ground: Aug 2010

ITER-EDA Goals

- Achieve controlled ignition (1.5 GW for 1000 s) with finite but limited margins on most likely projections from current fusion experiments;
- Ensure 1 MW/m2 of 14 Mev neutrons in driven burn;
- Providing flexibility to explore a range of possible operating scenarios including recently established advanced Tokamak discharges.
- Reliable containment and control of burning plasma;
- Very large superconducting magnet and structures;
- In-vessel structures (blanket and divertor) able to withstand high heat and neutron fluxes and electromechanical forces;
- Remote handling systems for maintenance/intervention of an activated tokamak structure;
- D/T fueling and fuel processing systems;
- Tritium breeding capability (for ITER's second, Enhanced Performance Phase).

ITER-FEAT Goals

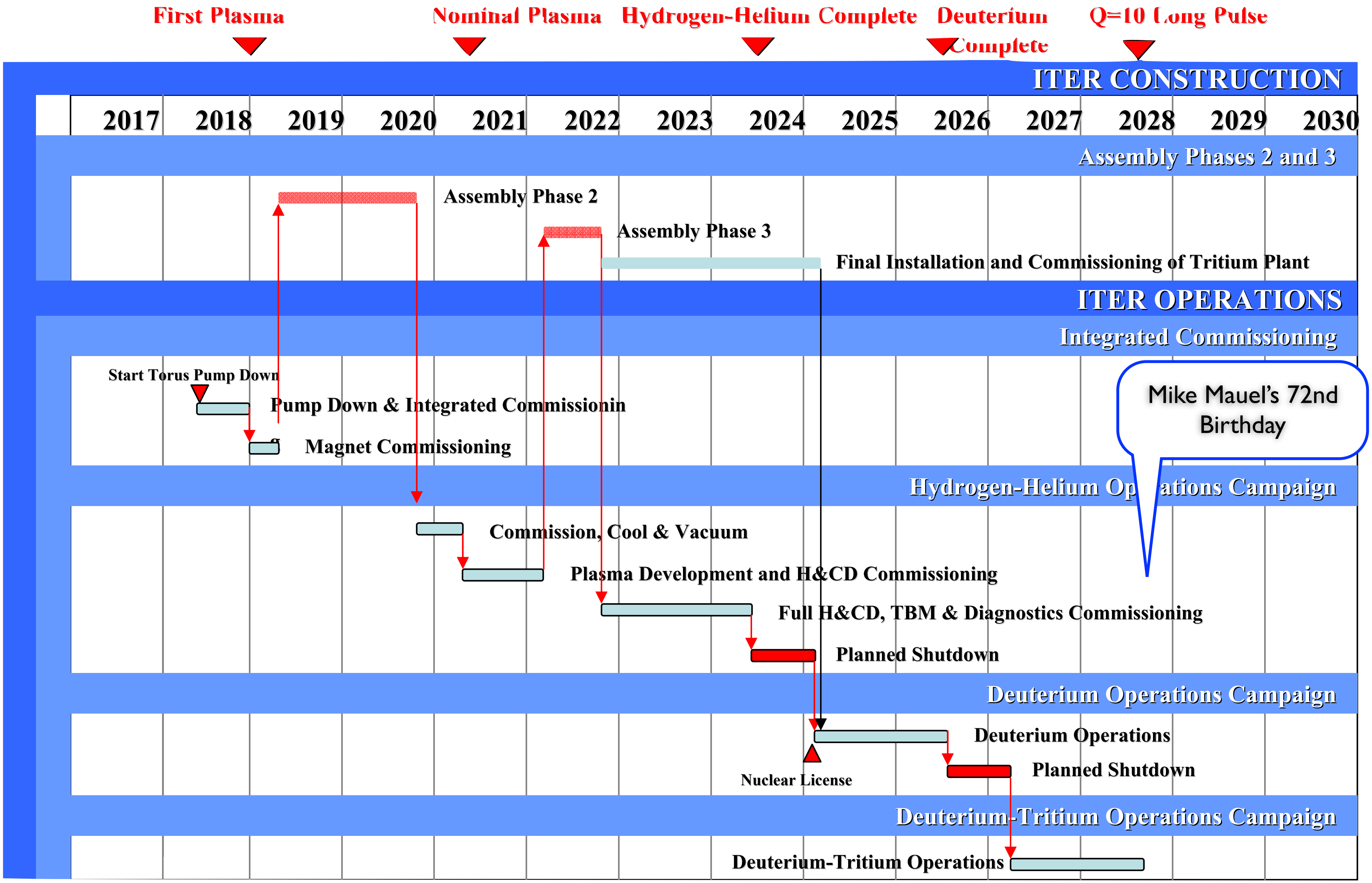
- To achieve extended burn in inductively driven plasmas at Q > 10 for a range of scenarios, whilst not precluding the possibility of controlled ignition;
- To aim at demonstrating steady state operation through current drive at Q > 5.
- Demonstrate availability and integration of essential fusion technologies;
- Test components for a future reactor;
- Test tritium breeding module concepts, with a 14 MeV average neutron power load on the first wall >0.5 MW/m2 and an average neutron fluence >0.3 MW a/m2.

Today

2019(?)

Approach to DT Operation

-First D-T Plasma foreseen at the end of 2026



ITER Parameters

ITER-EDA

Table 1
ITER main parameters and dimensions

Total fusion power	1.5 GW
Neutron wall loading	1 MW/m^2
Plasma inductive burn time	1000 s
Plasma major radius	8.1 m
Plasma minor radius	2.8 m
I_p	21 MA
k_{95} (ellipticity @ 95% flux surface)	1.6
q_{95} (safety factor @ 95% flux surface)	3
b_0 @ 8.1 m radius	5.7 T
b_{max} @ TF coil	12.5 T
TF ripple at separatrix	<1%
Auxiliary heating power	100 MW

ITER-FEAT

Table 2. ITER parameters and operational capabilities.

Parameter	Attributes
Fusion power	500 MW (700 MW)[a]
Fusion power gain (Q)	$\geqslant$10 (for 400 s inductively driven burn), $\geqslant$5 (steady-state objective)
Plasma major radius (R)	6.2 m
Plasma minor radius (a)	2.0 m
Plasma vertical elongation (95% flux surface/separatrix)	1.70/1.85
Plasma triangularity (95% flux surface/separatrix)	0.33/0.48
Plasma current (I_p)	15 MA (17 MA)[a]
Safety factor at 95% flux surface	3 (at I_p of 15 MA)
Toroidal field at 6.2 m radius	5.3 T
Installed auxiliary heating/ current-drive power	73 MW (110 MW)[b]
Plasma volume	830 m^3
Plasma surface area	680 m^2
Plasma cross section area	22 m^2

[a] Increase possible with limitation on burn duration.
[b] A total plasma heating power of 110 MW may be installed in subsequent operation phases.

Equivalent discharges on DIII-D… $G = \beta_N H_{89}/q_{95}^2$

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Table 1. Parameters at full performance for the four operating scenarios.

	Baseline (131498)	Hybrid DIII-D startup (131711)	Hybrid ITER startup (131265)	Advanced inductive (133137)	Steady state (131198)
β_N, β_p	1.8, 0.65	2.2, 1.1	2.8, 1.3	2.8, 1.05	3.0, 1.6
Equivalent ITER I_p (MA)	15.0	11.4	11.2	14.8	10.7
q_{95}	3.1	4.3	4.1	3.3	4.7
H_{89}, H_{98}	2.0, 1.1	2.6, 1.5	2.5, 1.45	2.4, 1.5	2.2, 1.46
G	0.37	0.31	0.4	0.6	0.3
B (T), I_p (MA)	1.92, 1.47	1.92, 1.13	2.11, 1.28	1.93, 1.49	1.92, 1.05
n (10^{19} m^{-3}), n/n_G	8–10, 0.5–0.65	6.6, 0.55	5.3, 0.41	5.3, 0.35	4.7, 0.4
P_{aux} (MW)	3.5	3.47	8.0	7.7	9.38
τ_E (s)	0.22	0.24	0.17	0.18	0.115
$v_\phi(0)$ (km s^{-1}), M_ϕ	140, 0.26	220, 0.4	290, 0.36	220, 0.3	190, 0.4
$\langle p\rangle\tau_E$ (kPa s)	8.1	8.4	9.7	10.4	5.3
Z_{eff}	3.0	2.9	1.9	1.8	1.9
Averaging time (s)	2.6–3.6	2.85–3.45	2.8–3.3	2.8–3.8	3.4–3.9
P_{fus} (MW) (89P, 98y2, DS03)	443, 427, 404	382, 371, 329	532, 477, 432	818, 723, 723	532, 502, 452
Q (Projected to ITER) (89P, 98y2, DS03)	10.3, 22.4, ∞	6.3, 10.2, ∞	5.8, 23.3, ∞	13.5, ∞, ∞	2.7, 5.8, 19.8
Auxiliary heating	NBI	NBI	NBI	NBI	NBI + off-axis ECCD
Internal MHD	Sawteeth, $n = 2$ tearing	Sawteeth, $n = 2$ tearing	Fishbones, $n = 3$ tearing	Sawteeth, $n = 3$ tearing	$n = 3$ tearing

Key Physics: H-Mode Fusion

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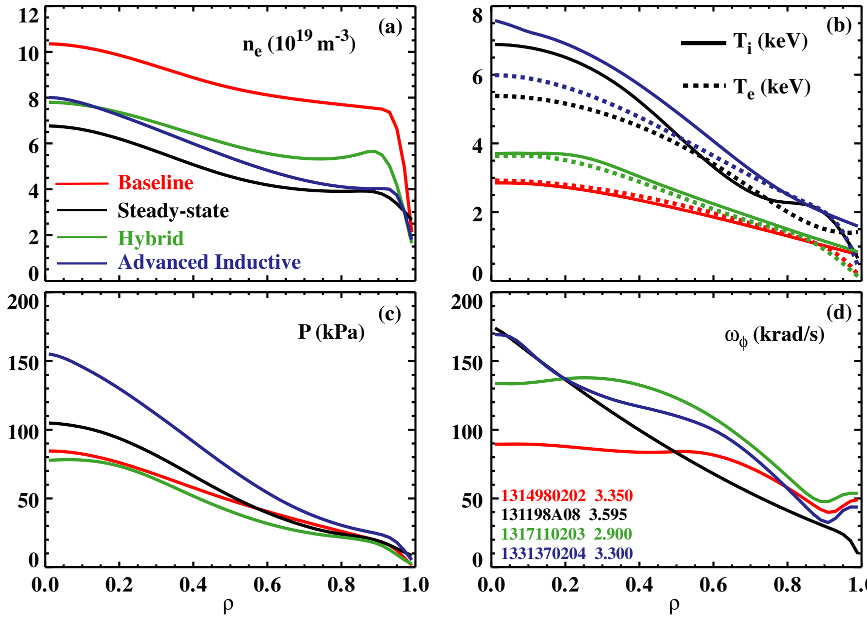

Figure 3. Profiles as a function of normalized radius ρ for (a) electron density n_e, (b) ion and electron temperatures T_i and T_e, (c) plasma pressure P and (d) plasma rotation ω_φ, for baseline (131498, in red), steady-state (131198, in black), hybrid (131711, in green) and AI (133137, in blue) scenario plasmas. Note that all four discharges shown were operated at a common field of 1.9 T, such that the plasma pressures can be directly compared. The advanced scenarios have the same pressure as the baseline scenario at lower I_p or higher pressure at equal I_p.

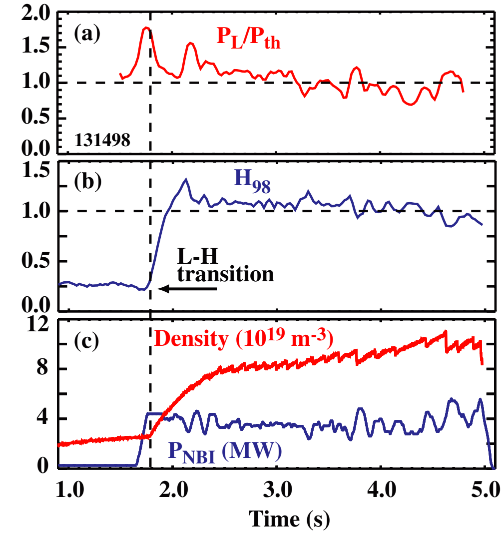

Figure 4. Time evolution of (a) ratio of loss power to calculated L–H transition power, (b) confinement factor H_{98} and (c) line density and injected neutral beam power for baseline scenario discharge 131498. A shorter time average is used for the line density data here as compared with the same data in figure 2(d), such that the effect of individual ELMs on the density can be more clearly distinguished. (Colour online.)

Nucl. Fusion **49** (2009) 085035 P.B. Snyder *et al*

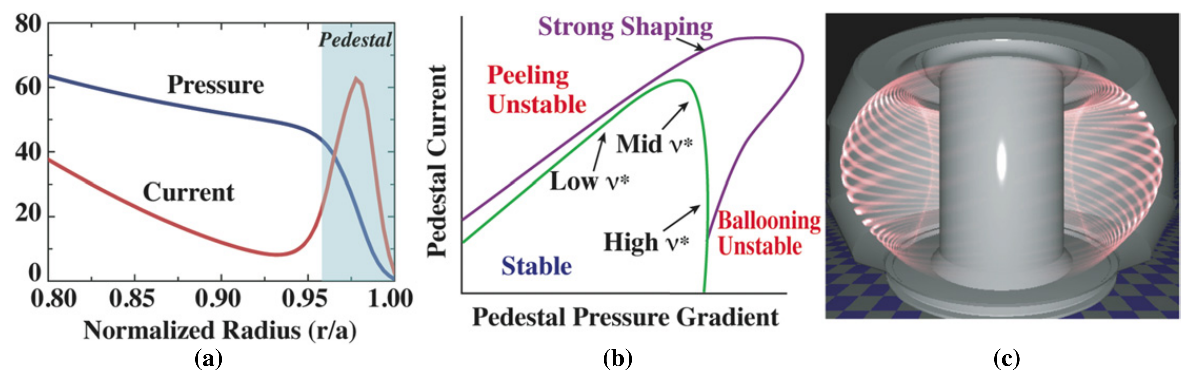

Figure 1. (a) Typical profiles in the edge barrier or 'pedestal' (shaded) region. (b) Schematic diagram of pedestal stability, including impact of shaping and collisionality. (c) Typical peeling–ballooning mode structure in 3D ($n = 18$).

Plan for Semester

- One page project proposal, due February 17
- Midterm progress presentation (10 minutes), due March 10
- Schedule your project presentation, where students will submit "chits", comments, and questions, (first-come-first-serve!)
- Submission of your final written project report by the end of the semester.

Norbert Holtkamp appointed ITER Project Construction Leader (April, 2006)

Dr. Norbert Holtkamp was born in Fuerstenau/Germany in 1961. He studied physics at the University of Berlin, where he also began to develop a special interest in accelerator physics.

Since then Dr. Holtkamp has worked at several accelerator laboratories around the world: he got his PhD at the University of Darmstadt, moved on the Deutsches Elektronen-Synchrotron (DESY) in Hamburg, and in 1998 he moved on to the United States to work at the Fermi National Accelerator Laboratory in Chicago.

In 2000 Dr. Holtkamp was offered to lead the construction of the Spallation Neutron Source (SNS) Accelerator, where he started work in January of 2001.

Today*: Professor, PPA (Particle Physics and Astrophysics) and Photon Science, 2010-present; Director, Accelerator Directorate, SLAC, 2010-present.*