PROSPECTS AND DESIGN REQUIREMENTS FOR ADVANCED TOKAMAK OPERATION OF ITER

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PPPL
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DIII–D
NATIONAL FUSION FACILITY

THE ITER FACILITY

- Overall programmatic goal: “Demonstrate the scientific and technological feasibility of fusion energy for peacefull purposes.”
  - International cost sharing is also a goal.

- Can the ITER facility play a double role? Argue answer is YES
  - Support demonstration of a reliable thermonuclear power source.
  - Investigate steady-state operation of higher β plasmas with ITBs

- Strategy: Identify capabilities which must be built into the design.
  - Assure that design specifics support foreseen ugrades and do not unintentionally preclude Advanced Tokamak operation
  - Defer other expenses for upgrades until opportunity warrants

ITER SCHEDULE

- **Evolution of goals (Inductive □ AT) leads to evolution of facility .**

  -2 yrs. – Construction Agrement, ILE, Host nuclear license

  - Exploit anticipated Design Review to assure AT needs

  - 8 yrs – Construction of the ITER facility

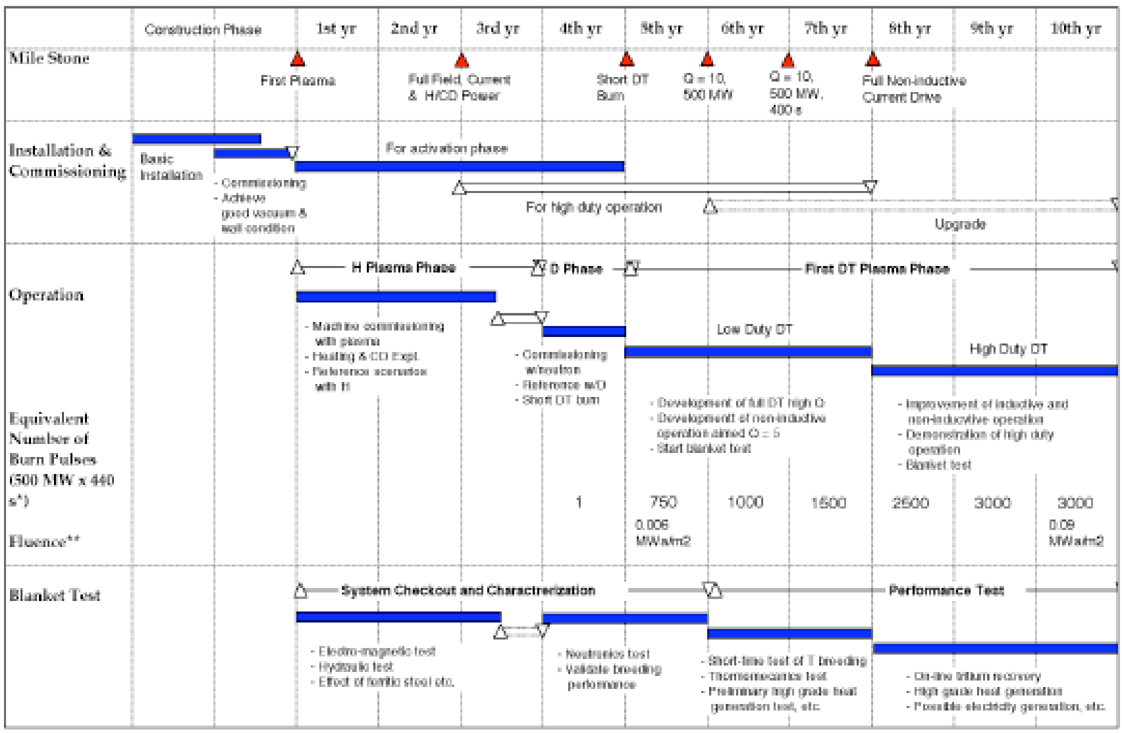
  - 3 yrs – Proton plasmas: no activation, disruptions, divertor,H-mode

  - 1 yr - Deuterium operation and recovery of vessel inventory

  - 2 yrs –Full DT operation, Q=10, □= 400s; Define design upgrade requirements for tokamak optimization investigations

  - 3yrs- Tokamak optimization studies; Full non-inductive current

INITIAL OPERATIONAL PLAN



* The burn time of 440 s includes 400 s flat top and equivalent time which additional flux is counted during ramp-up and ramp-down.
** Average Fluence at First Wall (Neutron wall load is 0.56 MW/m2 in average and 0.77MW/m2 at outboard midplane.)

Figure 6.2.3-1 Initial Operation Plan

QUESTIONS/ISSUES FOR ITER OPERATIONS

- **Experiments on existing devices motivate AT operation of ITER**

  - **Conceptual pictures (intellectual building blocks) established**

- **Questions for investigation on DIII-D and C-MOD bearing on ITER**

  - **Role of H-mode pedestal in confinement**
  - **$\beta > \beta_{\text{no-wall}}$ in steady-state**
  - **Role of rotation in confinement and MHD stability**
  - **Control of thermonuclear burn**
  - **Recovery of tritium from co-deposited layers**
  - **Principles and Practice of exploiting Internal Transport Barriers**
  - **SN vs DN divertors and accomodation of power and particle fluxes**

UPGRADES FOR TOKAMAK OPERATION ITER-1

ITER UPGRADE	PLASMA	AT PHYSICS	DESIGN IMPACT
More gyrotrons (up to 70 MW)	AT	ECCD supress NTMs Heating &burn control ECCD for non-inductive	Minimal
Pancake Solenoid	Inductive, AT, ^{1}H	Controls shape Optimizes confinement, □ Controls ELMs	Major Key element of base design
Positive ion neutral beams	Inductive, AT, ^{1}H	Angular momentun source Plasma rotation stabilizes resistive wall mode; improves confinement	Major, Not in base design Multiplex with negative ion neutral beam
Negative ion beam	Inductive, AT, ^{1}H	Heating near center	Already in design
Fast Wave Heating	Inductive, AT, ^{1}H	FWCD Heating localization ITB Trigger TAE simulation High bootstrap	Minimal; FW Antennas in ports are readily exchanged; Antenna engineering needed

UPGRADES FOR TOKAMAK OPERATION ITER-2

ITER UPGRADE	PLASMA	AT PHYSICS	DESIGN IMPACT
Lower Hybrid	AT	Efficient edge CD	Modest: Depends on SOL plasma which is TBD
Pellet launch from transformer core	^{1}H, HiQ, AT	Maximize pellet velocity and fuelling efficiency	Modest but crucial hole through TF magnet; Trial with ^{1}H plasmas
N=1 error field and feedback coils	AT	Control resistive wall kink mode, Required for $\beta > \beta_{no\text{-}wall}$	Large, actuator coils must be near plasma, Perhaps between VV shells
Internal TAE mode antenna	^{1}H, HiQ, AT	TAE frequency and decrements indicate MHD state of core; disruption indicator	Moderate; antennas inside VV but low power
Long divertor legs	^{1}H, HiQ, AT	Flexibility in divertor operation, strike points; Attached vs detached plasmas	Already in existing design

UPGRADES FOR TOKAMAK OPERATION ITER-3

ITER UPGRADE	PLASMA	AT PHYSICS	DESIGN IMPACT
Cold trap divertor	HiQ, AT	Recovers unburned tritium from walls; Demonstrates control of tritium inventory	Modest rework of present divertor cassette; installation of laser,etc to heat codeposition layer
Double Null divertor configuration	^{1}H, HiQ, AT	Increases shaping ability Localizes heat flux to outside strike points	Major revision of VV, blanket, diveror cassette Plans
Divertor sweeping	^{1}H, HiQ, AT	Spreads divertor heat load, ameiliorating hot spots due to surface roughness caused by disruptions	Requires investigation of a/c losses in superconducting magnets.
Heat flux margin for first wall	HiQ, AT	Supports exploitation of success, increasing β_N to β_N=2.7 and P=1000MW	1000 MW operation is close to limit for present design.

CONCLUSIONS

• The ITER facility can support all the modifications and upgrades presently forseen as requirements for AT operation.

- Cost-capability tradeoffs remain to be carried out.

• Inductive operation at $\beta=\beta_{\text{no-wall}}$ = 2.7 will produce 1000 MW for 400s

• Research on steady-state, noninductive discharges with upgrades will suffice to determine viability of steady-state operation for a First Fusion Reactor