Assessment by Physics Working Groups

- Key questions to address in the physics working groups:
  - What can we learn form the proposed BPX?
  - What are the concerns related to each proposal?

- Address what would be learned from two important perspectives:
  - Contribution to the understanding of positive magnetic shear reactor regimes (i.e. ARIES I) which may exhibit NTMs, sawteeth, …
  - Contribution to the science of AT reactor regimes (ARIES-RS, -AT) which will exceed the no-wall beta limit
  - relation to ICCs (need input!)

Overarching Benefit of a Burning Plasma Experiment

A key area of new science accessible to a BPX is the interaction of external control tools with a self organized plasma where alpha heating, stability and transport are all strongly coupled. This science can be addressed to varying degrees on all three devices and is of generic value to all toroidal confinement configurations.

What can we learn from IGNITOR I:

⇒IGNITOR baseline operation can address the science of self heated plasmas in a reactor relevant regime of small ρ^* and with dominant inductive current drive.

⇒Baseline operation with cold edge requires:

L97 H = 1.2 -1.7 & n(0)/<n>= 1.8-1.1

What can we learn from IGNITOR II:

- Transport physics:

⇒ Some aspects of the non-linear coupling between alpha heating, flows, and MHD equilibrium in a self heated regime at small ρ^*
⇒ transient ITB access at low ρ^*, with weak rotation and strong RF heating
⇒ core profile stiffness and global confinement at reactor relevant ρ^*, ν^*, β, n/n_{GW}
⇒ electron thermal transport in the presence of strong alpha heating

Ignitor has heating & fueling tools, but no current drive or rotation control

- MHD physics:

⇒IGNITOR would yield important new MHD physics in reactor relevant regimes not accessible in existing devices

- MHD stability with self-heating p(r)
- Isotropic alpha particle effects on the sawteeth instability

What can we learn from IGNITOR III:

- Wave/plasma physics:

  ⇒The non-linear coupling between ICRH heating, flows, and MHD equilibrium in a self heated regime at small ρ^*

  ⇒Extension of minority ICRH heating physics to plasmas with substantial alpha populations

- Energetic particle physics:

⇒Investigation of AEs in reactor-relevant regime (but only if T_0 can be raised by ≈ 100% over standard operating temperature)

What concerns do we have for IGNITOR?

⇒The simultaneous attainment of limiter radiating edge with enhanced confinement over L-mode and core density peaking

- steady state OH plasmas in C-MOD, FTU show L-mode confinement
- transient current ramp regime needs further validation
- sustainability of density peaking in transition to strong central alpha heating is an issue

⇒Lack of edge particle control and helium ash removal with limiter plasmas

-temperature flexibility limited by absence of edge pumping capability and total power (P_α+P_{aux}) in regime where α-TAEs are predicted unstable

-pumped outboard limiter may be some (small) help (TEXTOR)

⇒Duration of H-mode operation at de-rated current possibly limited by peak power load

⇒Limited diagnostic access for key physics measurements (turbulence, alpha particles, MHD)

=> Inadequate test bed for P(r) control: low J_{BS}, intrinsincally dynamic α heating in proposed scenarios, absence & CD or flow tools

What can we learn from FIRE I:

=> FIRE can address the science of self heated plasmas in reactor relevant regimes of small ρ^* and with a large fraction of non-inductive current sustained for up to several current relaxation times.

What can we learn from FIRE II:

- MHD physics:

=> FIRE, would yield important new MHD physics in reactor relevant regimes not accessible in existing devices

=> global MHD stability	- with self-heating p(r) and self driven current
=> sawtooth stability and CD control	- at large S and isotropic alphas
=> error field penetration and <u>control</u>	- undriven rotation
=> RWM feedback control near ideal wall limit	-…

=> FIRE would address additional issues in H-mode and high β_N

=> NTM threshold beta, pedestal stability	- with small $\rho^*=\rho_i/a$
=> Possible NTM control with LHCD	

What can we learn from FIRE III:

- Energetic particle physics:

⇒ FIRE can study AEs in a reactor-relevant regime (only if T_0 can be raised by ≈ 100% over standard operating temperature)

- Edge physics:

⇒ FIRE will allow the study of core-edge integration and power exhaust in reactor relevant regimes of n/n_{GW} and collisionality

=> Allows the study of SOL and pedestal scaling at reactor relevant collisionality

=> ELM control via strong shaping and particle pumping with double null configuration

=> FIRE has pumping sufficient to address particle control (eg helium pumping) issues

=> Investigate the compatibility of metals in high heat load regions with low core impurity levels

What can we learn from FIRE IV:

- Wave particle physics:

⇒The non-linear coupling between ICRH heating, flows, and MHD equilibrium in a self heated regime at small ρ^*

⇒Physics of minority ICRH heating physics in plasmas with substantial alpha populations, and LHCD in plasmas with significantly larger T_e

⇒FIRE has a significant degree of flexibility (ICRH, LHCD) to address issues of access and control of conventional and advanced modes of operation

- Transport physics:

⇒ FIRE can address the non-linear coupling between alpha heating, flows, and MHD equilibrium in the self heated regime

⇒ ITB access and control at low ρ^*, with weak rotation

⇒sustainability of ITB with strong electron heating and CD

⇒ pedestal characteristics, core profile stiffness and global confinement at reactor relevant ρ^*, ν^*, β, n/n_{GW}

⇒electron thermal transport with strong alpha heating

FIRE has some flexible tools for heating, current drive, fueling, and particle control, but not rotation control

What concerns do we have for FIRE:

⇒Predicted ELM power loads on FIRE near the upper boundary of acceptable energy deposition. ELM control and amelioration is needed.

⇒Compatibility of high average power load on W divertor with low core impurity levels.

- ⇒Limited temperature flexibility due to high power loads (Ulrickson)
- ⇒Further research required

⇒Absence of direct momentum input from beams (AT access and control: ExB shear control tool)

- ⇒Possible solution is to employ edge NBI (Budny) or RF induced rotation

⇒NTM control with LHCD not sufficiently understood or validated.

⇒Scenarios for transition from RF to self heating are not well developed (common to all devices)

ITER I:
What is the new science that can be learned?

=> ITER can address the science of self heated plasmas in a reactor relevant regime of small ρ^* and with the capability of full non-inductive current drive for many current relaxation times.

ITER II:
What is the new science that can be learned?

• Transport physics:

=>Non-linear coupling between alpha heating, flows, and MHD equilibrium with equilibrated profiles in the self heated regime

⇒ITB access and control at low ρ^* with controllable rotation (NNBI) and current profile control under condition of dominant alpha self heating

=> Investigation of pedestal characteristics and global confinement at reactor relevant ρ^*, ν^*, β_N, n/n_{GW}

- Profile and pedestal stiffness tests in new regime

=> electron thermal transport and global confinement in alpha-dominated regime

ITER has a large suite of tools for heating, current drive, fueling, particle control, and rotation control

What can we learn from ITER III:

- MHD physics:

- ITER can yield important new MHD physics in reactor relevant regimes not accessible in existing devices

=> MHD stability at high β_N	- with self-heating p(r) and large self driven current
=> sawtooth stability and CD control	- at large S with isotropic alphas
=> NTM seeding and control with ECCD	- at small ρ^*
=> error field penetration driven and control with correction coils	- undriven & RF & NNBI induced rotation

What can we learn from ITER IV:

- Energetic particle physics:

=> ITER can effectively explore high-n AE stability boundaries with a modest increase in temperature (+20%) in a reactor relevant range of temperatures (> 20 keV)

- i.e., ITER is unstable at 24 keV, 20 keV is marginally stable.

- Wave particle physics:

⇒The non-linear coupling between ICRH heating, flows, and MHD equilibrium in a self heated regime at small ρ^*

⇒Physics of minority ICRH heating in plasmas with substantial alpha populations, and LHCD in plasmas with significantly larger T_e

=> ITER has a significant degree of flexibility (ICRH, LHCD, ECH, NNBI) for profile control and to address issues of access and control of conventional and advanced modes of operation

What can we learn from ITER V:

- Boundary physics:

⇒ ITER will allow the study of core-edge integration and power exhaust in reactor relevant regimes

⇒operates at higher n/n_{GW} for the same collisionality making detached edge operation more compatible with core confinement

⇒Allows the study of SOL and pedestal scaling at reactor relevant parameters

⇒ITER has substantial exhaust pumping capability for addressing ash removal, particle and temperature control

What concerns do we have for ITER?

⇒ Electromagnetic shielding of control coils limits active RWM control
- may need additional edge rotation for greater stability margin
- Improvements possible

⇒ Beam ion loss or alpha loss is a possibility above 25 keV
- 1MeV NNBI and alphas are destabilizing
- mitigation methods exist: low energy edge NBI

⇒Present location of the above-midplane EC antenna may not provide robust stabilization of the neoclassical tearing mode

LHCD efficiency assumed by ITER seems too high
- steady state operation at 9.0 MA with 52% bootstrap current may require more LH power than planned.

What concerns do we have for ITER II:

⇒Predicted type I ELM power loads on ITER near the upper boundary of acceptable energy deposition. ELM control and amelioration is needed.

⇒Tritium retention is a major concern for the proposed ITER carbon divertor. No validated solution for tritium recovery is available at this time, however proposed solutions are being investigated.

- high-Z divertor is also a possible option

⇒Status and role of turbulence & alpha physics diagnostics unclear (generic issue)