INTEGRATED SCENARIOS

- Charge to E2 subgroup: Examine operational scenarios for each BPX.
  - These devices present new challenges to integrated modeling since the complex interaction of multiple physical processes will govern a BPX's behavior and fusion performance.
    - New features: Strong α-heating and (for AT regimes) current profile $\Longleftrightarrow$ transport.
  - *Properly diagnosed BPX experiments will provide a valuable set of data to improve our understanding of fusion science as we continue to study these interactions.*
- Evaluation is done using:
  - 0D calculations.
  - 1.5D modeling.
  - Evaluation of access to advanced regimes.

METHODOLOGY: 0D

- Start with reference operating points defined by advocates.
- Calculate *Q* over parameter space to produce POPCON diagrams.
  - Parameters ($n(0)/\langle n\rangle$, $T(0)/\langle T\rangle$, χ_{HE}^*/χ_E, n/n_{Gr}, Z_{eff}, $H_{98(y,2)}$) varied around operating point.
  - Operating space defined by $Q > 5$, $\beta_N < 2$, $P_{aux} < P_{aux}^{max}$, $n/n_{Gr} < 1$, $P_{loss}/P_{thr} > 1$.
- Use H98(y,2) scaling relation derived from database containing over 2000 ELMy H–mode discharges.
  - Trends not always consistent with single-tokamak databases:
    - Dependences on triangularity, proximity to Greenwald density limit and density peaking not present in H98(y,2).
    - Beta degradation in H98(y,2) not consistent with data.
    - Scalings with additional parameters, separate core-pedestal dependencies and pure Gyro-Bohm examined in less detail.
    - *This remains an active area of research.*

METHODOLOGY: 1.5D TRANSPORT SIMULATIONS

- Start with reference operating scenarios defined by advocates.
- Integrated modeling using transport models for core and edge:
  - Core:
    - Multi-Mode Model.
    - GLF23 (stiffer).
    - Coppi-Tang (for L–mode).
  - H–mode pedestal:
    - Scans of assumed pedestal value to determine required T_{PED} for given Q.
    - Theory-based model fit to experimental data.
- Codes: Baldur, TSC, XPTOR, ONETWO, GTWHIST, CORSICA.
- Uncertainties in all of these motivate future efforts in developing models.

"THE NEXT STEP BURNING PLASMA EXPERIMENT SHOULD BE CAPABLE OF ADVANCED TOKAMAK RESEARCH"

(1999 Fusion Summer Study, Development Path Issues Subgroup Report)

- **Key requirements for AT capabilities are evaluated in each device:**
  - **Strong plasma shaping**
  - **Current profile control capability**
  - **Active MHD control**
    - **Resistive wall modes**
    - **Neoclassical tearing modes**
  - **Long-pulse capability: $\tau_{DUR}/\tau_{CR} \geq 2 - 3$**
  - **Sufficiently resolved measurements of current, density, temperature, rotation, α-particles, etc.**
  - **Transport (pressure profile) control capability**

$\Rightarrow$ Flexibility to pursue alternate operational scenarios

ASSESSMENT OF ITER

- Burning plasma operating space for baseline operating scenarios with $Q \approx 10$ is robust (most robust of three considered).
  - 0D calculations indicate $H_{98(y,2)} > 0.9$ required.
  - 1.5D calculations indicate $T_{PED} = 2.9 – 5.0$ keV required for $Q = 5 – 16$.
    - Pedestal model predictions are at low end of temperature range.
- Advanced tokamak regimes with 100% noninductive current drive are accessible.
  - Supported by on and off-axis heating and current drive tools.
  - MHD control via ECCD (NTM) and error field correction coil (RWM).
  - Near steady-state accessible (up to 700 MW for 3000 s?).
    - Pulse length at highest fusion power may be limited by blanket module cooling.
    - Remaining issue: Some question about exactly what the limits are.

ASSESSMENT OF FIRE

- Burning plasma operating space for baseline operating scenarios with $Q \approx 10$ is robust.
  - 0D calculations indicate $H_{98(y,2)} > 1.0$ required.
    - Reasonable based on JET data selected from the IPB98(y,2) database for high triangularity and modest n/n_{Gr}.
    - With moderate density peaking ($n(0)/\langle n \rangle \geq 1.5$), $Q = 10$ is available even with $H_{98(y,2)} = 1.0$
  - 1.5D calculations indicate $T_{PED} = 2.5 - 5.5$ keV required for $Q = 4 - 15$.
    - Pedestal model predictions at low end of this range.
- Advanced tokamak regimes with 100% noninductive current drive are accessible.
  - Supported by on and off-axis heating and current drive tools.
  - MHD control via LHCD (NTM) and internal coil (RWM).
    - ECCD under consideration for use at low field.
  - Pulse length of $\tau_{DUR}/\tau_{CR} = 1 - 3$ may limit studies of steady-state regimes.

ASSESSMENT OF IGNITOR

- Burning plasma operating space for baseline operating scenarios with $Q = 10$ is available with enhancements over L–mode confinement:
  - $H_{97L} = 1.0 – 1.2$ with $n(0)/\langle n \rangle \approx 2$.
    - Transient density peaking plausible with early pellet injection. Sustainment of density peaking not demonstrated.
  - $H_{97L} = 1.3 – 1.6$ with broad density profiles.
  - $H_{97L} = 1.7 – 2.0$ with both broad density and temperature profiles.
- H–mode operation may improve the high fusion gain potential.
  - Single- or double-null configurations available at slightly reduced current.
  - Full current limiter H–mode may be a possibility, but there is no basis to predict performance quality.
  - *Characteristics of H–mode in Ignitor are highly uncertain due to factors that have not been evaluated (e.g. divertor heat load).*
- Lack of provisions for current profile control and particle removal prevents stationary AT operation.
- Advanced performance scenarios may transiently improve Q.
  - Techniques using current ramp and intense heating to form internal transport barriers well known and reliable in present-day machines.