

# Research thrust to establish predictive simulation capabilities

S. Diem<sup>1</sup>, D. Batchelor<sup>1</sup>, V. Chan<sup>2</sup>,  
A. Garofalo<sup>2</sup>, Y.K. Peng<sup>1</sup>, D. Spong<sup>1</sup>,  
A. Sontag<sup>1</sup>

<sup>1</sup>ORNL, <sup>2</sup>General Atomics



# Advancements in predictive simulation capabilities required for future ST development

- The area of theory and simulation has been identified by the TAP report as a uniquely urgent need for the Alternates
- The highly reliable plasmas required for next step STs require predictive simulation capabilities covering several Tier-1 issues:
  - Start-up and ramp-up
  - First-wall heat flux
  - Electron energy transport
- This thrust also addresses several Tier-2 and 3 issues

# Addressing start-up and ramp-up gap

- **ST goal requires start-up and ramp-up to multi-MA level**
  - RF, NBI, helicity injection, induction all proposed - presently being tested at sub-MA level
  - Extrapolate with validated predictive models to design both startup (0 MA → ~1 MA) & ramp-up (~1 MA → 8-10 MA) phases
- **Time-dependent modeling required to account for confinement and stability during plasma evolution**
- **Improved RF models to predict electron heating and CD**
- **NBI modeling must include fast particle instability effects**
- **Helicity injection requires reconnection models still to be developed**

# Addressing first-wall heat flux gap

- **Small major radius of present STs leads to peak heat fluxes higher than tokamaks, up to  $\sim 40 \text{ MW/m}^2$  for simple divertor**
- **R&D of innovative divertors to lower to  $\sim 10 \text{ MW/m}^2$** 
  - **Need modeling and validation to verify**
- **Simulations of proposed divertor designs using 2-D edge fluid transport codes SOLPS and UEDGE required**
- **Codes will need to incorporate detailed edge models to accurately predict peak first-wall heat flux**

# Addressing electron energy transport gap

- Turbulence and transport occur on a wide range of space ( $10^{-5}$  m to meters) and time ( $10^{-7}$  s to  $10^3$  s) scales
  - Must develop simulations to predict phenomena on microscopic and macroscopic length and time scales
- Effects of magnetic configuration, beta, rotation, etc. on confinement is active area of research
  - Promises a unified means to understand and improve stability and transport -> especially electron heat transport
- Simulation codes will have to treat full plasma geometries

# Predictive simulations can be used to address Tier-2 issues as well

- Tier-2 issues:
  - Integration, disruptions, RF heating and current drive, 3D error fields, ion scale transport, and fast particle instabilities
  - Require development of 3D error field equilibrium, time dependent modeling, and detailed measurements to benchmark codes
- Improved predictive capability needed for integrated scenario, disruption avoidance, ELM avoidance and mitigation, and momentum and fast ion transport
- Data obtained in upgraded and future STs must be combined with predictive simulations to bridge the gap of understanding between present day experiments and DEMO

# Codes under development or improvement

- **3D equilibrium and time dependent modeling**
  - Addresses energetic particle transport and loss to PFCs, 3D modification in B and magnetic island formation near edge
  - VMEC & SIESTA can be used, will need improvement to treat free-boundary equilibria with field ripple, blanket modules, etc.
  
- **Codes that simulate behavior on major time and space scales and account for interactions of multiple processes**
  - SWIM provides a modular approach to this problem, allows existing and new physics codes to function together and interact

# Continuing Code Development and Validation Will Close Gaps

- **Several codes will need modification for treatment of low-A plasmas (HGMC, GYRO, GTC, etc.)**
- **Need to identify improvements in these plasma modeling components to work with SWIM**
- **Time and space resolved measurements from existing and upgraded experiments will be needed to benchmark codes and validate predictive models**
- **Requires active collaboration between code developers, experimentalists and theorists, among institutions**
- **Long term, persistent, collaborative effort will be required**