SPARC presents divertor heat exhaust challenge

- SPARC is a DT-burning tokamak experiment designed to demonstrate net fusion energy production
- Based on newly developed high temperature superconductor magnet technology
- Under design by Commonwealth Fusion Systems (CFS), MIT, and collaborators
- Challenge of heat exhaust in SPARC:
  - $q_{\parallel}$ order of magnitude higher than in any tokamak to date
  - Moderate pulses (~10 s)
  - Limited diagnostics (mission-driven project)
  - Limited access due to tritium
- Project Goal: Use UEDGE tool to understand SPARC edge plasma and PFC survivability
Project overview

• Successfully completed the revised goals of the original INFUSE proposal.
  • Developed simulation solutions of standard divertor geometry and performed sensitivity scans to input parameters (power, impurity species, fraction, wall B.C., transport coefficients).
  • Developed simulation solutions of the X-point target (XPT) divertor geometry.

• 2 Publications (3rd in progress)

• Impacts on SPARC device design and operations
  • Improved confidence in design assumptions used.
  • Provided additional justification for the inclusion of the X-point target into SPARC design.
  • Started the creation of a simulation database that will inform an accelerated early phase of operations.
Project status at INFUSE 2020

- Focus on setting up the UEDGE simulations:
  - Grid generation
  - Tuning of transport coefficients
  - Selection of boundary conditions

- Sensitivity scans of the base case improved confidence in the baseline simulation.
Extensive scans of SPARC standard divertor geometry

- Generated >100 converged solutions at different impurity fractions and input power levels.
- Used the data set to organize and identify key metrics for divertor detachment based on solution grouping.
  - Low target $T_e$ is a necessary but insufficient metric for divertor detachment in these regimes.
- Performed sensitivity scans in wall B.C. and target plate tilt angle.
  - Device design currently takes credit for a 50% dissipative radiation fraction in the scrape-off layer.
  - Obtaining detached divertor conditions in simulation at moderate impurity fraction suggest these assumptions are likely achievable.
XPT equilibrium simulations highlight potential but also key considerations

• Peak parallel heat flux of >7 GW/m² entering the other divertor.
  • Reduced to 40 MW/m² surface peak on the outer target with only 0.3% Ne impurities.

• In single null though, power sharing to the inner divertor increases and results in much higher heat fluxes than with standard divertor.

• Increased power to the inner divertor found to be insensitive to transport coefficients.
Highlights key issues for the incorporation of an X-point target into SPARC

• Provided justification to include capabilities for XPT into SPARC
  • Wide ‘foot’ entrance needed to encompass secondary X-point.
  • Swept standard divertor can transiently place strike point at the bottom of the foot where incident field line angles are high.

• Results suggest that in lower single null XPT inner divertor should be carefully monitored
  • Pushes for the need to develop equilibrium control capabilities for a balanced double null with XPT.

Project Impacts

• For SPARC:
  • Design assumptions – bolstered confidence in the radiative dissipation fraction assumed in design.
  • Device capabilities – made a case for including the XPT divertor geometry into SPARC despite the added design challenges.

• For ARC:
  • Early operations – developed the start of a simulation database that can be used to inform and guide early SPARC operations. Crucial for accelerating ‘learning’, which will be needed as ARC is being designed in parallel 2025 onwards.

• For the broader edge plasma community:
  • Advanced understanding of reactor relevant divertor scenarios – SPARC pushed the code beyond typical parameter space.
  • Code development – a wide range of python interface utilities have been developed and shared with the broader community.
INFUSE Programs on the SPARC Timeline

- Divertor Component Testing
  - Oak Ridge National Laboratory
  - Divertor CDR
  - Materials Downselect

- Divertor Plasma Simulations
  - Lawrence Livermore National Laboratory
  - Plasma Facing Components PDR

- SPARC 3D Field Physics
  - Lawrence Livermore National Laboratory
  - Error Field Correction Coil PDR

- Toroidal Field CDR
- Central Solenoid CDR
- Limiter CDR
- Central Solenoid Model Coil PDR
- Central Solenoid PDR
- Superconducting Cable AC Loss and Quench Detection
- Alpha Particle Diagnostics

SPARC commissioned