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1. Research Goals and Plans for Plasma sustainment: Advanced Scenarios and Control

1.1. Overview of goals and plans (Gerhardt)

1.1.1. Develop the basis for steady state operations and axisymmetric plasma control for next-step STs while helping resolve key scenario and control issues for ITER

1.1.2. Thrusts and goals by topical area

1.1.2.1. Scenario development
1.1.2.2. Axisymmetric control development
1.1.2.3. Event handling
1.1.2.4. Scenario optimization for next step devices

1.2. Research Plans

1.2.1. **Thrust 1 – Scenario Development (Gerhardt, Raman)**
1.2.1.1. Pursue 100% Non-Inductive Current at Progressively Higher I_P and B_T
1.2.1.1.1. Year 1: 075T, 600-800kA, few tau-E
1.2.1.1.2. Year 2: 075-1T, 600-800kA, few tau-R
1.2.1.1.3. Years 3-5: 1T, 800-1300kA, up to 4-5s
1.2.1.2. Develop Long-Pulse Partial Inductive Operation Up to 2 MA, High Power
1.2.1.2.1. Two types of partial inductive operation:
1.2.1.2.1.1. High-IP operation supports collisionality scaling and divertor heat flux studies
1.2.1.2.1.2. Long pulse operation for particle retention and disruptivity reduction studies
1.2.1.2.2. Years 1 & 2: Re-optimize startup for reduced fuelling at IP=1200-1500 kA
1.2.1.2.2.1. Goal: Enhance utility of Li pumping by reducing the early gas load
1.2.1.2.3. Years 3-5: Performance Extension (Gerhardt)
1.2.1.2.3.1. Discharges up to 2 MA for 5 seconds
1.2.1.2.3.2. Long pulse at ~1 MA for up to 10 seconds
1.2.1.2.3.3. Connection to heat flux mitigation
1.2.1.3. Use of RF heating for improved NSTX-U scenarios (Gerhardt, Taylor)
1.2.1.3.1. Assess HHFW heating for improved non-inductive fraction in high performance plasmas
1.2.1.3.2. Assess EBWCD heating and CD for optimization of the current and pressure profiles in steady state plasmas.
1.2.1.4. Couple to non-inductive ramp-up (w/ SFSU) (Gerhardt, Raman)

1.2.2. **Thrust 2 – Axisymmetric Control Development**

- 1.2.2.1 n=0 Boundary and VDE Control (Kolemen, Gerhardt)
  - 1.2.2.1.1: Assess and improve n=0 vertical stability (observer, n=0 RWM)
  - 1.2.2.1.2: Incorporate bipolar PF-2 coils into shape and n=0 control loop.
  - 1.2.2.1.3: Develop MIMO shape control for improved inner and bottom gap regulation.
- 1.2.2.2 Axisymmetric Divertor Control
  - 1.2.2.2.1 Years 1 & 2: (Kolemen, Soukanovskii, Gerhardt)
    - 1.2.2.2.1.1 Develop upper/lower snowflake control at higher current
    - 1.2.2.2.1.2 Assess schemes for dual X-point control w/ new divertor coils
    - 1.2.2.2.1.3 Assess magnetic balance control in the presence of 4 X-points
    - 1.2.2.2.1.4 Document heat flux reductions compared to standard DN
    - 1.2.2.2.1.5 Assess impact of limited Mo coverage on scenarios
  - 1.2.2.2.2 Years 3-5: (Gerhardt, Soukhanovskii)
    - 1.2.2.2.2.1 Utilize cryopump and divertor upgrades to control density in long pulse scenarios
    - 1.2.2.2.2.2 Years 3-5: Pending progress in BP TSG, begin implementation of closed loop radiative divertor control
    - 1.2.2.2.2.3 Utilize PF-1B coil to improve control of the SFD through the full flux swing.
- 1.2.2.3 Current and Rotation Profile Control (Gerhardt, Kolemen, Yuh, Park, Sabbagh)
  - 1.2.2.3.1 Years 1 & 2: realtime diagnostics and testing.
    - 1.2.2.3.1.1 Feed forward test ability of different beam combinations to modify the q-profile. (Gerhardt)
    - 1.2.2.3.1.2 Install and commission rtMSE and implement as constraint in rtEFIT (Kolemen, Yuh)
  - 1.2.2.3.2 Years 2-4: Current and Rotation Profile Control Tests
    - 1.2.2.3.2.1: Complete controllers for β_N+q_{min} and β_N+$F_{T,0}$ control (Kolemen)
    - 1.2.2.3.2.2: Develop first β_N+F_T profile control algorithm (Kolemen)
  - 1.2.2.3.3 Years 4-5:
    - 1.2.2.3.3.1 Utilize NCC coil for better NTV control (Kolemen, Park, Sabbagh)
    - 1.2.2.3.3.2 Study feasibility of combined control (for instance, β_N, q_{min}, F_T profile) (Kolemen, Gerhardt)

1.2.3 Thrust 3 - Disruption Avoidance and Off-Normal Event Handling

- 1.2.3.3 Years 1 & 2: (Gerhardt)
  - 1.2.3.3.1 Implement basic detector in PCS, and design architecture of control response
  - 1.2.3.3.2 Incorporate data from new "Digital Coil Protection System"
  - 1.2.3.3.3 Assess accuracy of predictor for NSTX-U disruptions, and refine as necessary
  - 1.2.3.3.4 Do initial tests of automated rampdowns
- 1.2.3.4 Years 3-5 (Gerhardt)
  - 1.2.3.4.1 Add additional realtime diagnostics for improved detection fidelity
  - 1.2.3.4.2 Optimize rampdowns for different types of alarms
  - 1.2.3.4.3 Incorporate closed loop MGI if it appears promising

1.2.4 Thrust 4 - Explore Optimal Scenarios for Next Step STs

- 1.2.4.1 Study optimal profiles for high confinement and good stability (Gerhardt)
  - 1.2.4.1.1 Years 3-4: Optimization of the current profile for best confinement and core n=1 stability
  - 1.2.4.1.2 Years 3-5: Explore alternative optimal scenarios – EPH or w/ ITBs (Gerhardt, Canik, Yuh)
- 1.2.4.2 Study the conditions for classical beam current drive (Gerhardt)
  - 1.2.4.2.1 Years 1-2: Study what parameters determine when *AE modes lead to anomalies in the fast ion diffusion and NBCD
  - 1.2.4.2.2 Years 3-5: Determine if anomalous diffusion be used for scenario optimization
- 1.2.4.3 Integration of pedestal control tools (Gerhardt, Soukhanovskii, …)
  - 1.2.4.3.1 3D field integration
- 1.2.4.4 Explore & validate integrated models for projections to FNSF
  - 1.2.4.4.1 Years 1-2: Compare NBCD & q-profile predictions from integrated codes to NSTX-U (Gerhardt)
  - 1.2.4.4.2 Years 3-4: Test reduced transport models against profiles from most attractive scenario targets. (Gerhardt, Guttenfelder)
  - 1.2.4.4.3 Years 4-5: Use knowledge to project scenarios to ST FNSF devices (Gerhardt)

1.3 Summary timeline for tool development to achieve research goals (Gerhardt)

1.3.4 Theory and simulation capabilities (Gerhardt)

1.3.2.1 TRANSP/pTRANSP/NCLASS w/ free boundary and passive conductors (Gerhardt)

1.3.2.2 GTC-Neo (Gerhardt, Kaye)

1.3.2.3 Reduced models for thermal and fast ion transport (Gerhardt, Guttenfelder)

1.3.3 Diagnostics (Gerhardt)

1.3.3.1 Real-time rotation

1.3.3.2 Real-time MSE

1.3.3.3 Real-time Thomson Scattering

1.3.3.4 Real-time neutron rate

1.3.3.5 Real-time divertor heat flux measurements

1.3.4 Other facility capabilities including plasma control

1.3.4.1 2nd NBI for current and rotation profile actuator (Gerhardt)

1.3.4.2 2nd SPA for NTV rotation braking control (Gerhardt)

1.3.4.3 Divertor cryopumps for density control (Gerhardt, Canik)

1.3.4.4 NCC for NTV rotation braking control (Park, Sabbagh, Gerhardt)

1.3.4.5 Coil and power supply upgrades (Gerhardt)

1.3.4.6 EBW heating and current drive for J-profile control in advanced scenarios (Taylor, Gerhardt)