Planning for Disruption Modeling

led by
Carl Sovinec and Steve Jardin

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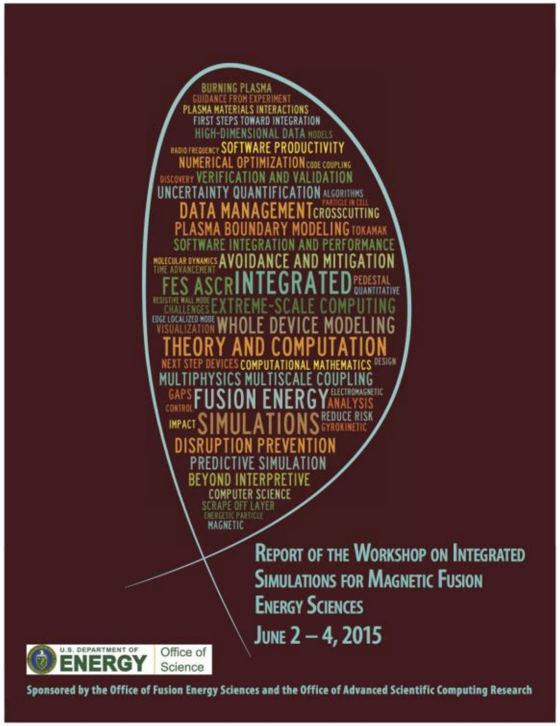
The Workshop for Integrated Simulations for Magnetic Fusion Energy Sciences, June 2-4, 2015 provides a basis.

- The report is available at

http://science.energy.gov/~/media/fes/pdf/workshop-reports/2016/ISFusionWorkshopReport_11-12-2015.pdf



- CEMM contributed to the discussions leading up to the workshop, the workshop, and the report.

- **Disruption Physics**
  - **Panel Chair: Carl Sovinec** (University of Wisconsin-Madison)
  - **Panel Co-Chair: Dylan Brennan** (Princeton University)
  - **Panel Members:**
    Boris Breizman (University of Texas - Austin)
    Luis Chacón[1] (Los Alamos National Laboratory)
    Nathaniel Ferarro (General Atomics)
    Richard Fitzpatrick (University of Texas - Austin)
    Guo-Yong Fu (Princeton Plasma Physics Laboratory)
    Stefan Gerhardt (Princeton Plasma Physics Laboratory)
    Eric Hollman (University of California - San Diego)
    Valerie Izzo (University of California - San Diego)
    Steve Jardin (Princeton Plasma Physics Laboratory)
    Scott Kruger (Tech-X Corporation)
    Ravi Samtaney[1] (King Abdullah University of Science and Technology)
    Hank Strauss (HRS Fusion)
    Alan Turnbull (General Atomics)

We expanded the scope slightly.

- Panel was charged with disruption “prevention, avoidance, and mitigation.”
- We added characterization as an essential physics task for accomplishing PAM.
- Recommendations are captured in 3 “priority research directions.”

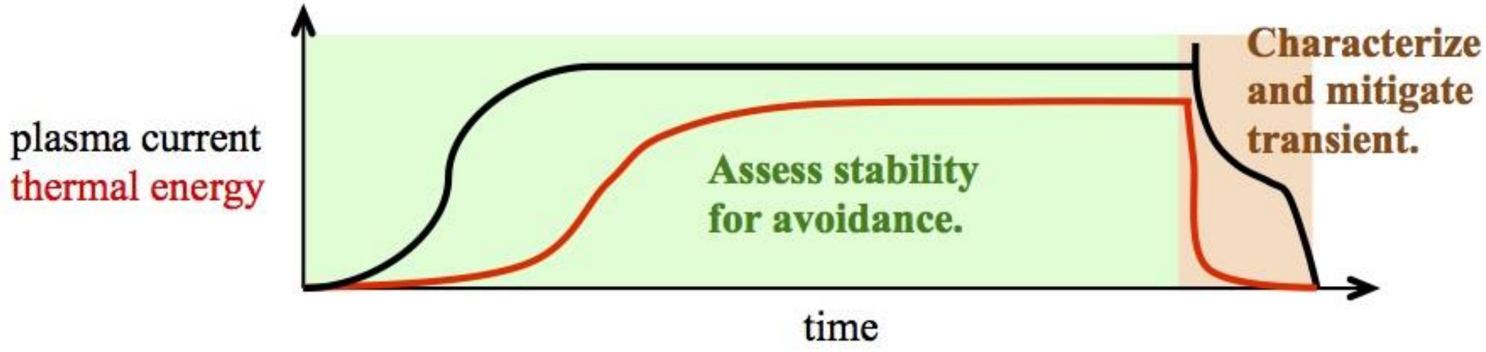
PRD 1: Integrated simulation capability for all stages/forms of tokamak disruption.

instability ➔ thermal quench, current quench ➔ final energy deposition

- Primary goals are characterizing nonlinear evolution and engineering mitigation systems.
- This requires:
  - Macroscopic dynamics
  - Runaway-electron and majority species kinetics
  - Neutral and impurity transport
  - Radiation
  - External electromagnetics (or magnetostatics)
  - Plasma-surface interaction

PRD 2: Develop automated plasma state reconstruction and stability assessment system.

- This PRD primarily contributes to avoidance and plasma control.
- Development of such a system would be useful for all macroscopic modeling efforts.



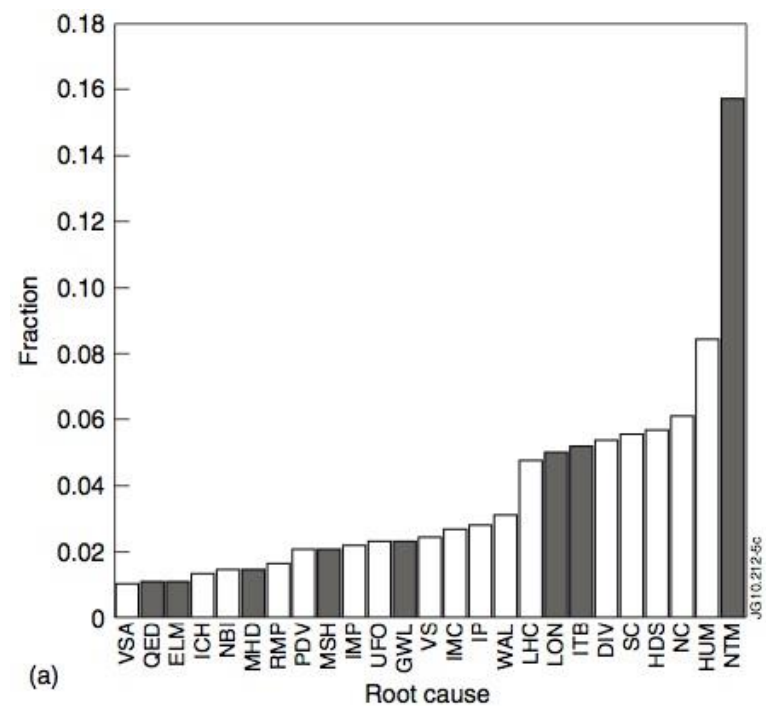
PRD 3: Verification and Validation

- The proposed initiative includes the nonlinear modeling (as would be expected).
- VV methodology is also expected to weigh-in on whether linear MHD stability is relevant for prediction or forecasting.
  - This connection is rather generally assumed but has not been proven.

Background Information

- There are many causes for disruptions.
- The transients panel outlined different disruption sequences.

- Note that NTM (meaning locking) is the most frequent root cause.



Root causes of JET disruptions from DeVries, et al., NF 51, 053018.

Challenges and Opportunities Section

- Avoidance and onset prediction
  - Sensitivity to profiles is also an important consideration for nonlinear modeling.
- Magnetic islands, rotation, and locking
  - Bifurcation, rotation physics, NTV, turbulence-induced viscosity
  - Timescale challenges
- Thermal quench
  - Loss of confinement not well understood
  - Parallel kinetics, impurity influx, and radiation all contribute
- Current quench
  - TQ changes resitivity, its profile, and affects position control to start CQ
  - Coupling to external EM is needed
- Runaway electrons
  - Large **E** from TQ
  - Generation mechanisms remain topics of analytic study
  - Loss mechanism involves coupling with macroscopic dynamics
- Disruption mitigation
  - Requires radiation, ionization/recombination, neutral transport
  - Shattered pellet injection is relatively unexplored computationally

Crosscutting with Applied Math/CS

- Implicit methods for multi-physics, multi-scale simulation
- Scalable solvers
- Physics integration & moving beyond interpretive simulation
- Emerging computer architectures
- Large data sets, especially from scans of profiles for stability mapping (also UQ)

Planning - physics

1. Runaway electrons
   – Basic idea: Extend NIMROD's continuum kinetic formulation to model RE population
   – Start with axisymmetric plasmas
   – Can we model the formation of runaways during the thermal quench?
   – Relative merits of PIC vs continuum models
2. Long time scale disruptions

   Basic idea: Most disruptions are caused by NTMs/RWM, so we need to study feedback stabilization of NTMs
3. Neutral Dynamics
4. Model for shattered pellets

Planning – AM/CS

- CS issues: 5D scaling and optimization
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- AM issues: CFL condition and implicit methods for energetic particle population
- AM issues: (Perhaps not useful for a good pitch): Creating good equilibrium (correct delta-prime stability: zero plus or minus epsilon) requires understanding the linear stability properties and being able to build a linear code out of the extended MHD codes would be useful, but MHD operator is hard