NSTX-U

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NSTX-U Disruption Prediction, Avoidance, and Mitigation Working Group – Initial Meeting

S. A. Sabbagh and R. Raman

Department of Applied Physics, Columbia University, New York, NY
University of Washington, Seattle, WA

NSTX-U DPAM Working Group Meeting

January 30th, 2015

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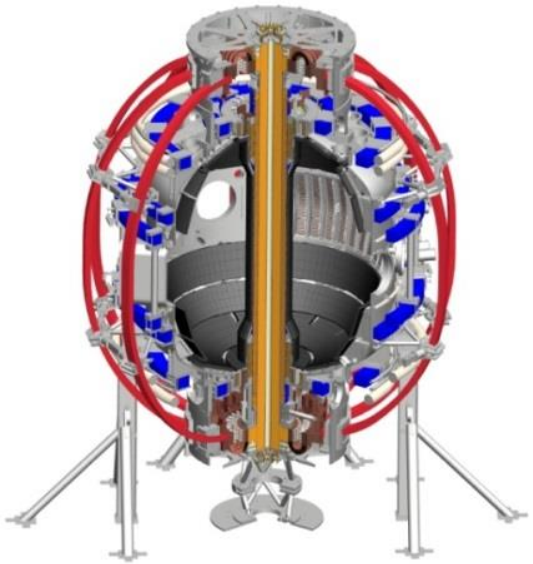

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V1.4

Initial meeting of the Disruption Prediction, Avoidance, and Mitigation (DPAM) Working Group - OUTLINE

- Mission statement and Scope
- Recent History
- Present Charges
- Structure and Organization
- Initial Approach and Summary of Elements
- Open Discussion

DPAM WG – Mission Statement and Scope

- Mission statement
  - Satisfy gaps in understanding prediction, avoidance, and mitigation of disruptions in tokamaks, applying this knowledge to move toward acceptable levels of disruption frequency/severity using quantified metrics

- Scope
  - Location: Initiate and base the study at NSTX-U, expand to a national program and international collaboration
  - Timescale: Multi-year effort, planning/executing experiments of various approaches (leveraging the 5 NSTX-U Year Plan) to reduce plasma disruptivity/severity at high performance
  - Breadth: High-level focus on quantified mission goal, with detailed physics areas expected to expand/evolve within the group, soliciting research input/efforts from new collaborations as needed

Recent history regarding the DPAM Working Group

- DPAM is a top priority research element (one of two) identified by recent FESAC Strategic Planning Panel
  - We championed this effort in July 2014 FESAC talk / white paper (S.A. Sabbagh, et al.)
    - Talk and white paper available at:

      http://nstx.pppl.gov/DragNDrop/Working_Groups/DPAM/Repository
- NSTX-U 5 Year Plan committee recommendation supporting this effort
  - NSTX-U should lead a multi-machine prediction/avoidance effort
- For NSTX-U, we are a “working group” – will also have a wider scope
  - Initial charges for NSTX-U created for the group
  - Roger Raman deputy lead - focus on mitigation

Near 100% disruption avoidance is an urgent need for ITER, FNSF, and future tokamaks

- This is the new "grand challenge" in tokamak stability research
  - Can be done! (JET: < 4% disruptions w/C wall, < 10% w/ITER-like wall)
    - ITER disruption rate: < 1 - 2% (energy load, halo current); << 1% (runaways)
  - Disruption prediction, avoidance, and mitigation (*PAM*) is multi-faceted, best addressed by focused, national effort (multiple devices/institutions)
  - Serves FES strategic planning charge; pervades 3 of 5 ReNeW themes
- Strategic plan summary: Utilize and expand upon successes in stability and control research – synergize elements
  - Add focused, incremental support for US research programs to show near 100% disruption PAM success using quantifiable figures of merit
  - Leverage upgraded facilities with heightened focus on disruption PAM
- Leverage US university expertise, international collaborations
  - e.g. JET high power operation, KSTAR long-pulse operation above ideal MHD stability limits, US university scientists, post-docs, and students

A relatively modest incremental investment will greatly enhance quantifiable progress

DPAM WG - Present NSTX-U Charges

- Physics
  - What are leading causes of disruptions in NSTX & initial NSTX-U ops?
  - How can tokamaks practically minimize disruption frequency and severity? (initial focus on NSTX-U)
  - What prerequisites / tools are needed to prepare NSTX-U to operate a large # of sequential shot-seconds (say 1-5 shot minutes) without a disruption?
- Communication of results
  - How will NSTX-U interface to the upcoming (~June) FES workshops, and address the FESAC/FES Tier 1 issue of “Transients" generally?
    - In which disruption research areas can NSTX-U make leading contributions?
    - What are the associated long-term resource needs from NSTX-U?
  - What are the leading/highest priority NSTX-U contributions to JRT-16?
    - What are the required resources during FY15-16 to support JRT-16?

NSTX-U DPAM WG – Structure and Organization

- Working Group
  - Focused physics research, cross-cutting NSTX-U TSGs or SGs
  - Does not allocate run time – rather, advises SGs and TSGs regarding XP priority and needs related to the group's mission
- Communication of results / group discussion
  - Specific DPAM WG meetings will be held with appropriate frequency
  - To reduce the number of meetings, DPAM WG discussions on specific science elements will often be conducted in coordination with NSTX-U Macroscopic Stability TSG (or other TSGs)
  - Interface to USBPO through established channels
  - Interface to ITPA through MHD Stability Group, et al., and established joint experiment / analysis groups (e.g. MDC-19, 21, 22, etc.)
- Aid research efficiency and collaboration
  - Communicate researcher points of contact to avoid duplication of effort

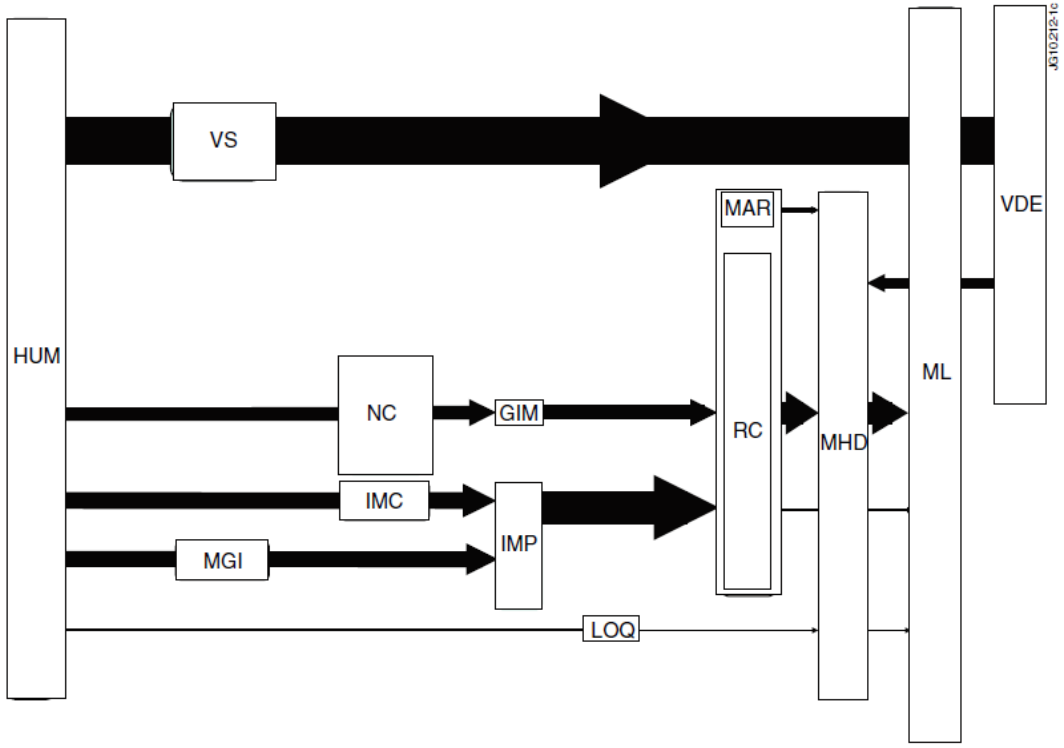
DPAM WG Initial Approach to Disruption Prediction and Avoidance – related physics Elements

- Initial Approach
  - Define disruption criteria, characterization, severity
  - Define a characterization for disruption causes, with related quantitative evaluations
    - Start by adopting a formalization similar to JET, altered as appropriate for NSTX-U, which includes connections between categorized elements
- Elements
  - Significant research efforts presently exist (and/or are part of the NSTX-U 5 Year Plan) that cover these elements
    - Engage, utilize, communicate these efforts related to DPAM mission
  - As progress is made, identify important research elements not being covered and solicit additional effort in these areas (from within group, and/or from new collaborations), including potential hardware needs

Example of disruption physics elements interconnected to describe paths toward disruption

- Elements
  - Provide a logical and quantifiable set of components in the disruption chain, with underlying physics
- Connections
  - Shows interrelations of the elements, arrow thickness showing relative probability of path
  - Can have multiple inputs / outputs

Example: Disruption Elements and Connections Diagram (JET)



P.C. de Vries *et al.*, Nucl. Fusion **51**, 053018 (2011)

(Incomplete) List of physics elements tied to disruption prediction, avoidance (highlighting individual involvement)

- Impurity control (NC)
  - bolometry-triggered shutdown (SPG); "tailoring" radiation-induced TM onset (LD, DG)
  - change plasma operational state / excite ELMs, etc. (TBD – perhaps JC)
- Greenwald limit (GWL)
  - density/power feedback, etc. (DB)
- Locked TM (LTM)
  - TM onset and stabilization conditions, locking thresholds (JKP,RLH,ZW)
  - TM entrainment (YSP)
- Error Field Correction (EFC)
  - NSTX-U EF assessment and correction optimization (CM,SPG)
  - NSTX-U EF multi-mode correction (SAS, YSP, EK)
- Current ramp-up (IPR)
  - Active aux. power / CD alteration to change q (MDB, SPG)
- Shape control issues (SC)
  - Active alteration of squareness, triangularity, elongation – RFA sensor (SPG,MDB)
- Transport barrier formation (ITB)
  - Active global parameter, V_ϕ, etc. alteration techniques (SAS,JWB,EK)
- H-L mode back-transition (HLB)
  - Active global parameter, V_ϕ, etc. alteration techniques (SAS,JWB,EK)
- Approaching vertical instability (VSC)
  - Plasma shape change, etc. (SPG, MDB)
- Resistive wall mode (RWM)
  - Active global parameter, V_ϕ, etc. alteration techniques (SAS,JWB)
  - Active multi-mode control (SAS,YSP,KT)
- Ideal wall mode (IWM)
  - Active global parameter, V_ϕ, etc. alteration techniques (JEM)
- Internal kink/Ballooning mode (IKB)
  - Active global parameter, V_ϕ, etc. alteration techniques (SAS,JWB)
  - Active multi-mode control (SAS, YSP, KT)

Abbreviations:
JWB: Jack Berkery
AB: Amitava Bhattacharjee
DB: Devon Battaglia
MDB: Dan Boyer
JC: John Canik
LD: Luis Delgado-Aparicio
DG: Dave Gates
SPG: Stefan Gerhardt
MJ: Mike Jaworski
EK: Egemen Kolemen
RLH: Rob La Haye
JEM: Jon Menard
CM: Clayton Myers
JKP: Jong-Kyu Park
YSP: Young-Seok Park
RR: Roger Raman
SAS: Steve Sabbagh
KT: Kevin Tritz
ZW: Zhirui Wang
TBD: (To be decided)

- Interest from Theory
  - Amitava Bhattacharjee, Allen Boozer, Dylan Brennan, Bill Tang have requested involvement

Disruption mitigation research can also be used to quantify disruption severity reduction

- Power handling and shutdown **(red text: individuals involved)**
  - Heat / radiation / plasma parameter variation criteria for handoff from normal operation to disruption mitigation (SPG)
  - Heat / radiation load characteristics (including asymmetry) in NSTX-U (RR, ORNL (JC?))
  - MGI characteristics in NSTX-U, incl. acceleration of gas penetration to core plasma (RR)
  - Innovative techniques for mass deposition, incl. electromagnetic particle injection (RR)
  - MGI effectiveness as a function of poloidal position of injection (RR)
  - Influence of wall conditions on disruptions and their mitigation (SPG)
  - Innovative first wall applications, including sacrificial limiters and liquid metal PFC (SPG,MJ?)
- Halo currents
  - Halo current characteristics during NSTX-U disruptions (SPG,CM,AB)
  - Active control of disrupting plasma and halo currents (SPG,CM,SAS)
- Runaways
  - Criteria for runaway electron generation (SPG)

Joint Research Target for FY16 (JRT16) focused on disruption mitigation (with prediction/avoidance elements)

DPAM is a grand challenge problem – help make the solution a reality

- Status
  - NSTX-U DPAM research efforts have already started among individuals and small groups on the NSTX-U Team
- Action Items
  - Please contact Steve and Roger (sabbagh@pppl.gov; rraman@pppl.gov) to join and contribute to the group
  - Open discussion (now) regarding the DPAM WG as summarized in this talk
    - Please send further constructive comments to Steve and Roger by email as desired
- Next Step
  - Meeting to discuss DPAM physics elements related to NSTX and initial NSTX-U operation (focus on 5 Year Plan) (to be announced)

Important Links for NSTX-U DPAM Working Group

- General
  - DPAM Working Group - meetings folder area
    - http://nstx.pppl.gov/DragNDrop/Working_Groups/DPAM/2015
  - General repository file area
    - http://nstx.pppl.gov/DragNDrop/Working_Groups/DPAM/Repository
- NSTX-U specific
  - NSTX-U 5 Year Plan
    - http://nstx-u.pppl.gov/five-year-plan/five-year-plan-2014-18
  - NSTX-U diagnostics
    - http://nstx-u.pppl.gov/diagnostics
  - NSTX-U DPAM group - summary page
    - http://nstx-u.pppl.gov/program/working-groups/disruption-pam

Supporting slides follow

ITER Disruptivity Requirements (Lehnen 2013)

Disruption Mitigation System *requirements*

DT phase (requirements gradually increasing from H/He phase)

	Energy load on divertor target	Energy load on first wall (VDEs)	EM load due to halo currents (VDEs)	Runaway electrons
Disruption rate (Avoidance)	≤ 5 %	≤ 1-2 %	≤ 1-2 %	<< 1 %
Prediction success	≥ 95 %	≥ 98 %	≥ 98 %	~ 100 %
Mitigation performance	≤ 1/10	≤ 1/10	≤ 1/2	≤ 2 MA

Compatible with "response time" of ≤ 20ms?

minimum requirement
substantial melting still likely