Workshop on Transients

by
C.M. Greenfield

Presented to the Fusion Energy Sciences Advisory Committee

March 12, 2015

Transients Workshop: Background

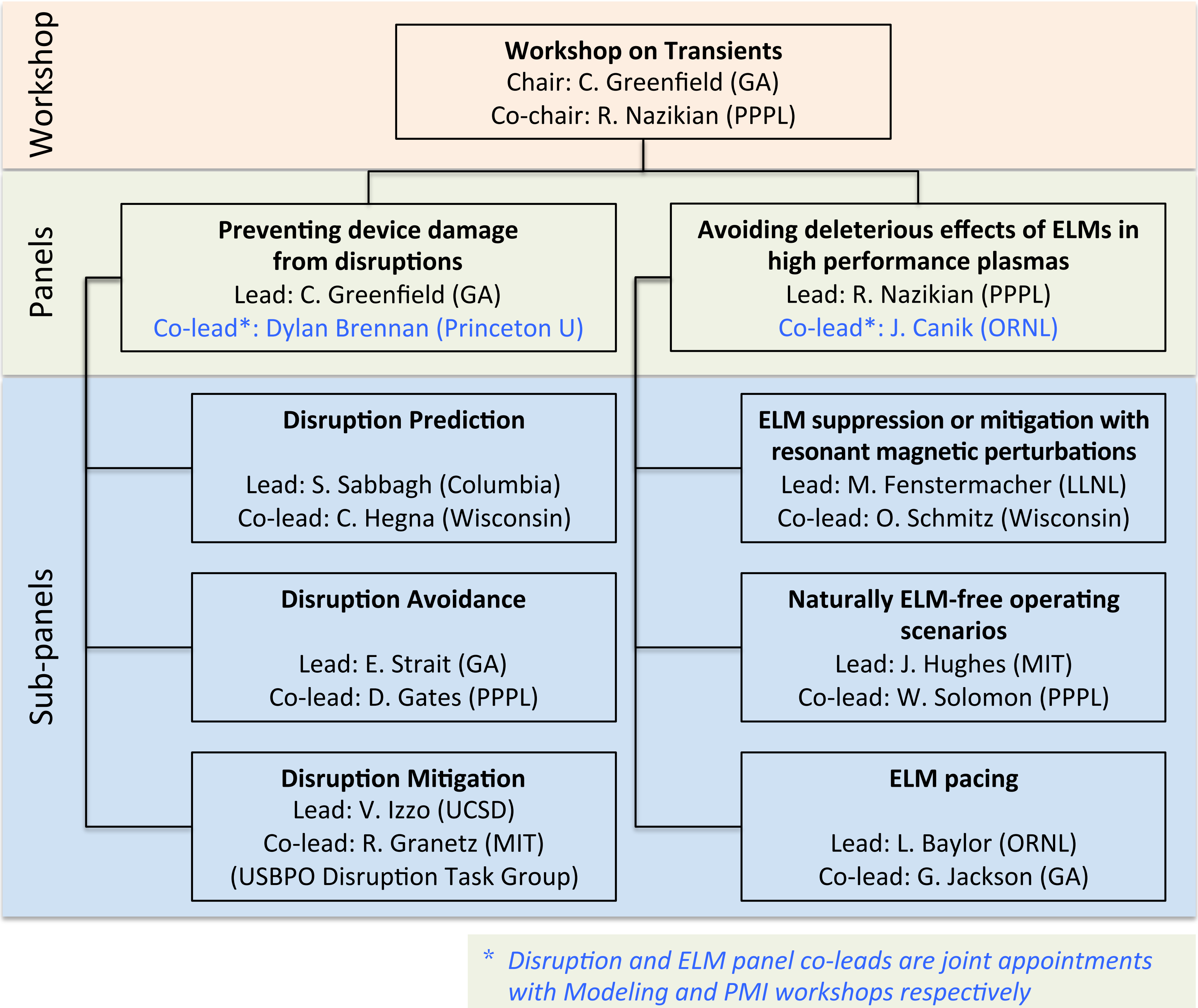
- **Focus on disruptions and ELMs**
  - Can have deleterious effects on tokamak plasmas and have potential to cause damage
  - Generally tolerated in present devices
  - More severe impacts on ITER
  - Even more severe impacts on post-ITER devices (?)
  - "It is critical to develop the means to minimize these events and their consequences when they do occur."
- **Build on previous studies, including**
  - ReNeW (2009) – Thrust 2
    - Same scope, but the present workshop will:
      - Consider five more years of progress
      - Have more depth (this was 1/18 of the output of ReNeW)
  - FESAC Strategic Planning Panel report (2014) – identifies this as high priority initiative
  - USBPO Disruption Task Group

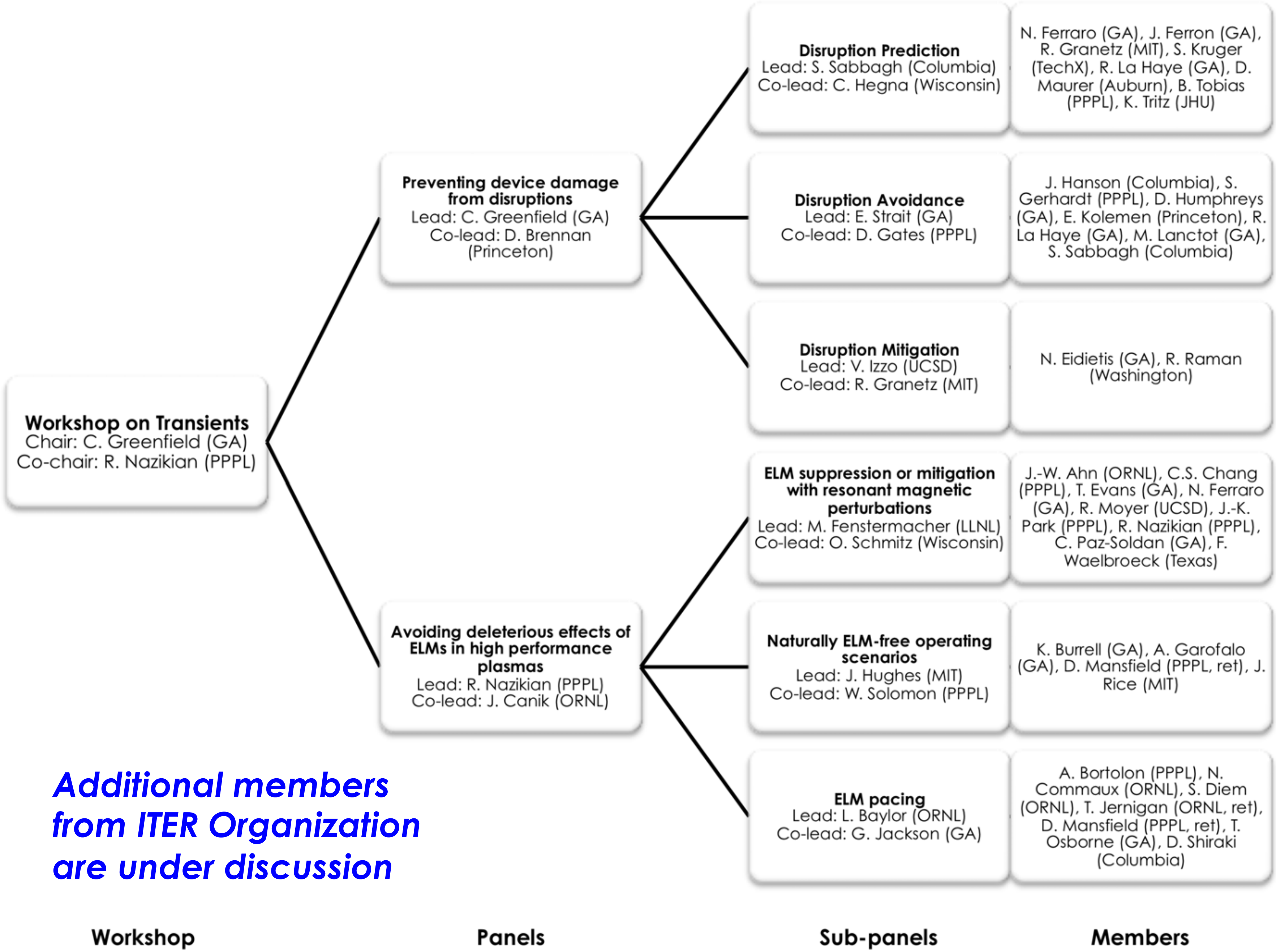
Transients Workshop: Objective

Building on the ReNeW effort, other workshop results, and the ongoing USBPO disruptions task force plans, this workshop will:

1. **Review recent progress**
2. **Identify the remaining science and technology challenges that must be addressed to demonstrate that magnetically confined tokamak plasmas with the characteristics desired for a fusion power plant can be robustly produced, sustained, and controlled without deleterious effects on the device's materials and structure**
3. **Based on thorough understanding of the remaining science and technology challenges, the workshop will identify specific research opportunities that can address these challenges in the next decade**
   – These may include both domestic research and international partnerships, and will be informed by the requirements of ITER and future burning plasma devices

Our deliverable is a report to FES due June 30


Workshop
Panels
Sub-panels
Workshop on Transients
Chair: C. Greenfield (GA)
Co-chair: R. Nazikian (PPPL)
Preventing device damage from disruptions
Lead: C. Greenfield (GA)
Co-lead*: Dylan Brennan (Princeton U)
Avoiding deleterious effects of ELMs in high performance plasmas
Lead: R. Nazikian (PPPL)
Co-lead*: J. Canik (ORNL)
Disruption Prediction
Lead: S. Sabbagh (Columbia)
Co-lead: C. Hegna (Wisconsin)
Disruption Avoidance
Lead: E. Strait (GA)
Co-lead: D. Gates (PPPL)
Disruption Mitigation
Lead: V. Izzo (UCSD)
Co-lead: R. Granetz (MIT)
(USBPO Disruption Task Group)
ELM suppression or mitigation with resonant magnetic perturbations
Lead: M. Fenstermacher (LLNL)
Co-lead: O. Schmitz (Wisconsin)
Naturally ELM-free operating scenarios
Lead: J. Hughes (MIT)
Co-lead: W. Solomon (PPPL)
ELM pacing
Lead: L. Baylor (ORNL)
Co-lead: G. Jackson (GA)
* Disruption and ELM panel co-leads are joint appointments with Modeling and PMI workshops respectively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Lead: S. Sabbagh (Columbia)
Co-lead: C. Hegna (Wisconsin)
N. Ferraro (GA), J. Ferron (GA), R. Granetz (MIT), S. Kruger (TechX), R. La Haye (GA), D. Maurer (Auburn), B. Tobias (PPPL), K. Tritz (JHU)
Disruption Avoidance
Lead: E. Strait (GA)
Co-lead: D. Gates (PPPL)
J. Hanson (Columbia), S. Gerhardt (PPPL), D. Humphreys (GA), E. Kolemen (Princeton), R. La Haye (GA), M. Lanctot (GA), S. Sabbagh (Columbia)
Disruption Mitigation
Lead: V. Izzo (UCSD)
Co-lead: R. Granetz (MIT)
N. Eidietis (GA), R. Raman (Washington)
Avoiding deleterious effects of ELMs in high performance plasmas
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ELM suppression or mitigation with resonant magnetic perturbations
Lead: M. Fenstermacher (LLNL)
Co-lead: O. Schmitz (Wisconsin)
J.-W. Ahn (ORNL), C.S. Chang (PPPL), T. Evans (GA), N. Ferraro (GA), R. Moyer (UCSD), J.-K. Park (PPPL), R. Nazikian (PPPL), C. Paz-Soldan (GA), F. Waelbroeck (Texas)
Naturally ELM-free operating scenarios
Lead: J. Hughes (MIT)
Co-lead: W. Solomon (PPPL)
K. Burrell (GA), A. Garofalo (GA), D. Mansfield (PPPL, ret), J. Rice (MIT)
ELM pacing
Lead: L. Baylor (ORNL)
Co-lead: G. Jackson (GA)
A. Bortolon (PPPL), N. Commaux (ORNL), S. Diem (ORNL), T. Jernigan (ORNL, ret), D. Mansfield (PPPL, ret), T. Osborne (GA), D. Shiraki (Columbia)
Additional members from ITER Organization are under discussion
Workshop
Panels
Sub-panels
Members

Transients Workshop: Schedule

Date	Activity	Participants
Immediate	Organize panels	Workshop and sub-panel leads
February 20	Sub-panel kickoff videoconference	Workshop and sub-panel leads and co-leads
February, March	Sub-panel organization and conference calls as needed	Sub-panel leaders and members
March 30-April 2	Virtual workshop to gather community input	Community (submits 2-page white papers and give short presentations)
April 15	Deadline for submitting white papers	
April, May	Sub-panel conference calls as needed	Sub-panel leaders and members
June 8-10	Workshop on Transients *at General Atomics*	Leaders and sub-panel members invited. Others may attend on a first-come, first-serve basis (limits due to room size and lab attendee administrative limit)
June 11	Report writing *at General Atomics*	Leaders and writing committee
June 30	Submit completed report to FES	Leaders

My intention is to welcome community input and participation

- **There are trade-offs**
  - I will do everything I can to make sure everybody has an opportunity to affect our report
  - But… we actually need to produce a report – broad participation may not be practical at every step
- **Sub-panels are being kept small to preserve working character**
  - Mostly populated by invitation
  - Members are expected to contribute to written report
- **<u>Two-page</u> white papers and <u>short</u> presentations: Virtual workshop week of March 30**
  - **Announcement and call for white papers will come today or tomorrow**
- **Transients Workshop: June 8-10 at General Atomics**
  - Attendance may be limited (due to factors I can't control)
    - 100 person capacity of conference room
    - Legal/bureaucratic limit (DOE \$100K/workshop limit ➔ lab/ government employee attendance ≤ ~35)
  - Limited remote participation should be possible (need to preserve working character of meeting)

For more information

- **All four community planning workshops will have website either hosted by the US Burning Plasma Organization or linked from the USBPO website**

  http://burningplasma.org
- **Direct link: https://www.burningplasma.org/activities/?article=Transient**

Backup slides follow…

Frequently asked questions (1)

- **Will the Transients Workshop establish priorities for research in the next N years?**
  – No. Due to the laws governing how DOE receives advice from the community, advice on prioritization can only come through a FACA* committee like FESAC**. The tradeoff is that nobody is recused from participating in these workshops.
  – Although we can't prioritize, I'm sure we will say something about sequencing (you have to do A before you do B)
- **What is N?**
  – Nominally 10 years, but for Transients, I see two time scales
    1. What do we have to do to make ITER successful, and what is the deadline?
    2. What do we have to do beyond ITER to make FNSF/DEMO/ Power plant/etc. successful?
- **Isn't the answer just "build a stellarator?"**
  – Our marching orders are to plan solutions specific to the tokamak
  – FES may revisit stellarators in a future workshop (not this year)

* Federal Advisory Committee Act
** Fusion Energy Science Advisory Committee

Frequently asked questions (2)

- **Can I join a sub-panel?**
  - You would need to contact the leader of the sub-panel you're interested in. Please understand that the subpanel may already be full.
- **Do I want to join a sub-panel?**
  - Do you want to spend hours in conference calls?
  - Do you want to write sections of the report?
- **If asked, should I join a sub-panel?**
  - Yes!
- **If I can't join a sub-panel can I still make my voice heard?**
  - Yes! Write a white paper, give a presentation at the pre-workshop, and/or participate in discussions at the main workshop.
- **How can I ensure that I will like everything in the final report?**
  - You probably won't like everything. I probably won't like everything. We will do the best job we can, but you can't – and shouldn't try to - make everybody happy.
- **How will FES use the report we produce?**
  - This is not entirely clear, but it seems reasonable to assume it will be used in planning future research

Transients Workshop Organization and Goals

- The Transients workshop will be organized in two panels, each with three sub-panels. Each sub-panel will consider a complete research program in their area, which in most cases will include elements of experiment, theory, and modeling. Since there are obvious overlaps with the Workshop on Integrated Simulations, where appropriate one member of each panel or sub-panel can be designated to serve jointly on an Integrated Modeling panel.
- Our task is largely that of revisiting Thrust 2 in the 2009 ReNeW report, taking into account the ensuing six years of progress – and discovery of new issues. The research plan we will develop may go into more detail than ReNeW, but we are once again being asked to develop a spanning set of research activities rather than prioritizing them.
- All sub-panels should consider two time scales for research. The most rapid progress is needed to ad-dress areas that will impact safe operation of ITER. In some cases, additional progress will be needed beyond ITER in order to be able to safely address transients in more demanding future devices such as an FNSF or DEMO.

Panel 1: Preventing Device Damage from Disruptions

Sudden terminations of a fusion grade plasma can be triggered by either MHD instabilities or hardware failure. Developing an approach to preventing damage related to the sudden release of the plasma's thermal and magnetic energy content will require progress in three broad areas. When a disruption is imminent and unavoidable, a mitigation system will be deployed to safely shut down the discharge. This should be a last resort, with preference to efforts to completely avoid the disruption via plasma control. The decision making – steps to take for avoidance, when to engage the mitigation system, etc. – will require advances in predictive capabilities.

Panel 1: Preventing Device Damage from Disruptions *Sub-panels*

1. **Disruption Prediction**
   - There has been significant progress in disruption prediction in individual devices. Examples include the system devised for NSTX experiments that predicts most disruptions with few false positives. Another system has been deployed on JET that is routinely used to trigger its mitigation system. Advances are needed to improve the accuracy and reduce the incidence of false positives, and to produce a "portable" predictor that can be deployed on new devices such as ITER with some acceptable minimum training set.
2. **Disruption Avoidance**
   - Most disruptions occur when the plasma approaches known stability limits. A challenge for plasma control is to be able to operate near these limits without crossing them. In some cases, active suppression of instabilities can be done under plasma control (e.g. ECCD used to "search and suppress" NTMs in DIII-D).
3. **Disruption Mitigation**
   - As a last resort, the plasma must be safely terminated. Mitigation systems deployed on present-day tokamaks rely on injection of massive quantities of materials to radiate away the plasma's energy content via gas injection or shattered pellet injection. Other methods have been proposed but studied in much less detail. Several issues remain under study, such as radiation asymmetries and the generation of a "runaway" electron population that can cause severe, local, damage to in-vessel components. This area is time critical as the ITER Disruption Mitigation System (DMS) is scheduled to undergo a final design review in 2017.

Panel 2: Avoiding deleterious effects of ELMs in high performance plasmas

Edge Localized Modes, or ELMs, are repetitive instabilities that are effective in flushing impurities from the core of H-mode plasmas but are also capable of depositing large amounts of heat and particles in concentrated target areas in the divertor. Several techniques are currently under study for use in ITER and subsequent devices for the suppression or mitigation of these instabilities, and for the development of alternate operational scenarios that are free of ELMs and meet impurity control requirements. Since these areas are also related to the physics of the H-mode pedestal and boundary physics, there may be connections (and joint members) with panels within the Workshop on Plasma-Materials Interactions.

Panel 2: Avoiding deleterious effects of ELMs in high performance plasmas
Sub-panels

4. **ELM Suppression or Mitigation with Resonant Magnetic Perturbations**
   – ELM suppression and/or mitigation with magnetic perturbations generated by externally powered coils has been demonstrated in DIII-D, and subsequently explored on several de-vices in the US and elsewhere. The promise of this approach led to it's becoming the leading method for ELM control in ITER, with the planned addition of an internal coil set to the ITER baseline design. While the current progress in experiments is encouraging, the under-standing of the suppression or mitigation mechanisms in a range of existing devices is still insufficient for robust extrapolation to ITER, FNSF or beyond. This panel will address the outstanding issues and research needs in experiment, modeling and theory in this area.
5. **Naturally ELM-free Operating Scenarios**
   – Alternate operational scenarios, such as the QH-mode and I-mode, have been identified which combine the favorable confinement properties of ELMing H-mode plasmas with an edge region that is naturally free from ELMs. This panel will address research needs and identify paths for applying these or similar scenarios to ITER and subsequent devices.
6. **ELM Pacing**
   – Rapid, repetitive injection of pellets of deuterium or lithium have been shown to trigger ELMs, thereby increasing the ELM frequency and decreasing the impulsive fluxes produced by each individual ELM to a potentially tolerable level. Further research will explore the parameter space where this technique is capable of ameliorating the negative consequences of ELMs in high performance scenarios and to continue to build a scientific basis for extrapolation to future devices.