Experimental Plans and Modeling Needs for Disruption Mitigation Studies on NSTX-U

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13-15 July 2015
PPPL, Princeton, NJ

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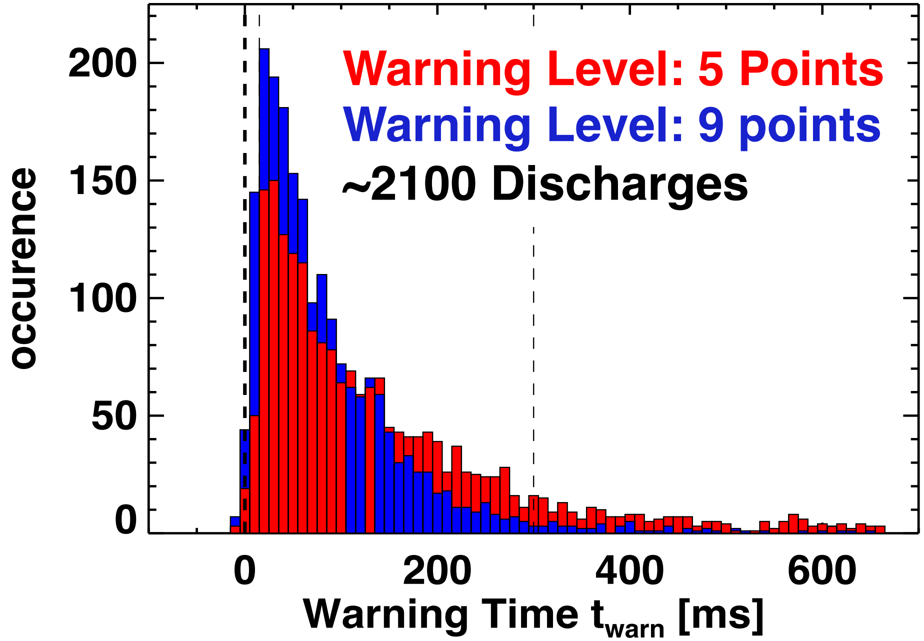
Outline

- Experimental Plans on NSTX-U for the 2016 JRT
  - Disruption Detection and Causes
  - MGI Research

- Modeling Needs to Support Disruption Mitigation Research on NSTX-U

Activities in the Area of Detection
Previous Work

- Analysis of NSTX data yielded a “gray box” algorithm for disruption detection.
- Use tests on single signals, or combinations of signals, to assign “penalty points” when a threshold was exceeded.
- When the sum of the penalty points exceeded an “Aggregate Point Threshold” (APT), then a disruption warning was declared.



Warning at APT=5 Points
<1% late warning
~15% false positive
Sum: 16%

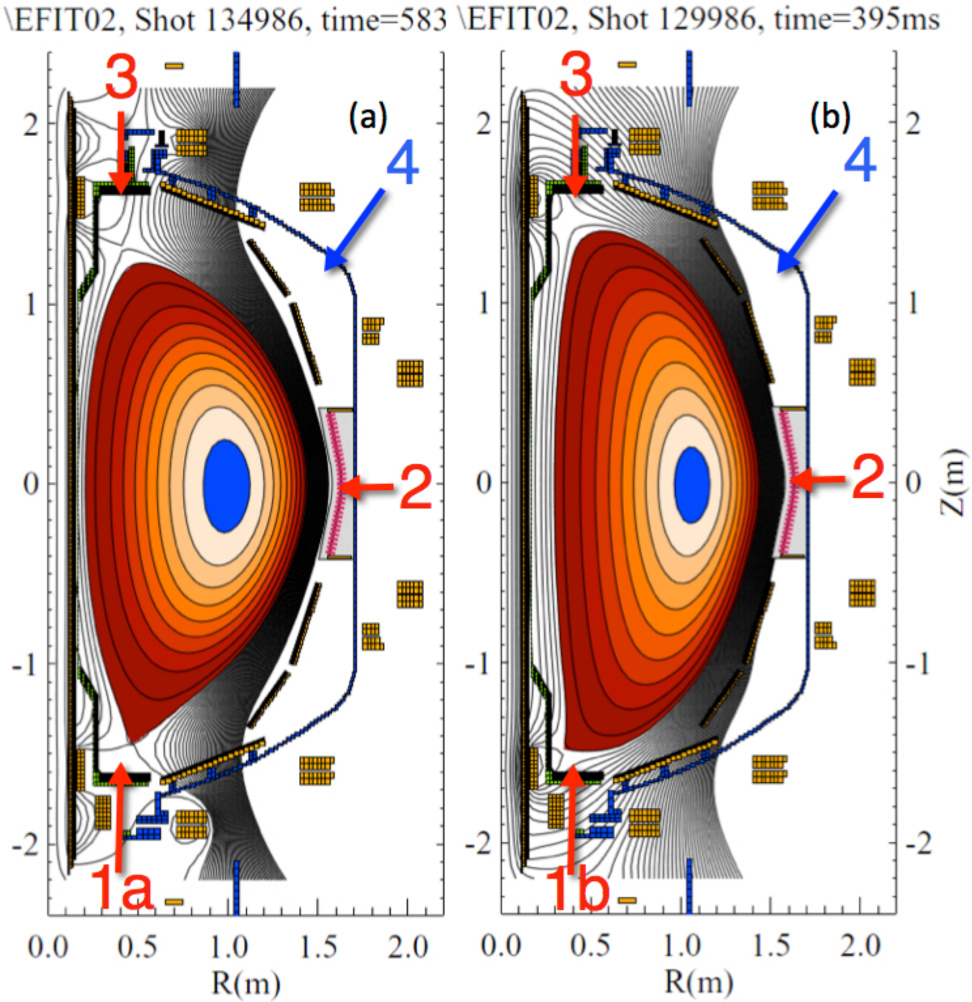
Warning at APT=9 Points
~2% late warning
~4% false positive
Sum: 6%

(False positive count dominated by near-disruptive MHD events)

Activities in the Area of Detection
FY-16 Work

- NSTX-U PAM working group will focus on these topics.
  - Intends to develop a database of not only disruptions, but also disruption causes.
  - Look for prominent disruption causes due to plasma physics, facility limitations, or even human factors.
  - Will work to determine unique pre-cursors, for instance, from RFA detection and/or the RWM state space controller.
- MIT collaboration with help in these areas.
  - Will help with setting up the database, as well as testing the previously developed detection algorithms on NSTX-U data.
- Intend to make a "soft shutdown" capability in the NSTX-U PCS.
  - Will likely initially trigger on simple things like the I_P error or the LM amplitude.
    - And will trigger inductive shutdown in the first year.
  - Will grow to include more sophisticated triggering algorithms, as those are developed.
    - And can be coupled to closed-loop trigger MGI in later years.

FY16 Experiments will Enable MGI capability and support the FY16 JRT



1a,b: Private flux region, Lower SOL, Lower Divertor
2: Conventional mid-plane 3: Upper divertor
4: Future installation

NSTX-U MGI experiments will be able to do direct comparison of:

1) Location 1a or 1b with 2
2) Location 2 with short and long connection length pipes
3) Location 3 with 2 (future)
4) Location 4 [TER Upper-Port-Plug 'like'] (future)

Key-Features:

- **Identical valve at each location**
- **Same pipe conductance for poloidal comparison**
- **ITER MGI valve type (double flyer plate design)**

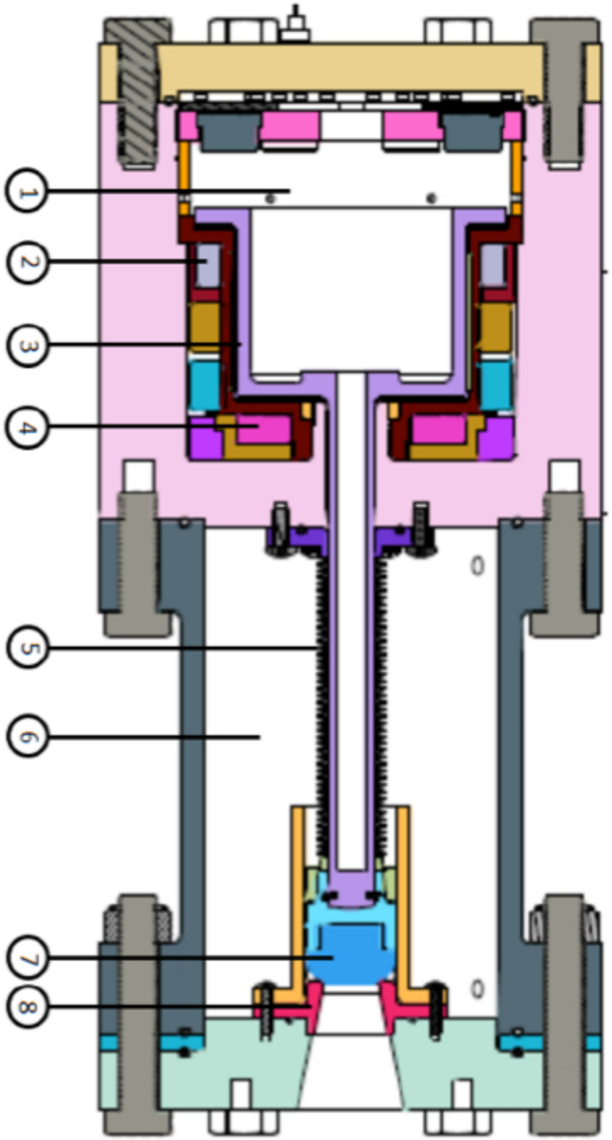
NSTX-U MGI Valve based on TEXTOR and ORNL designs

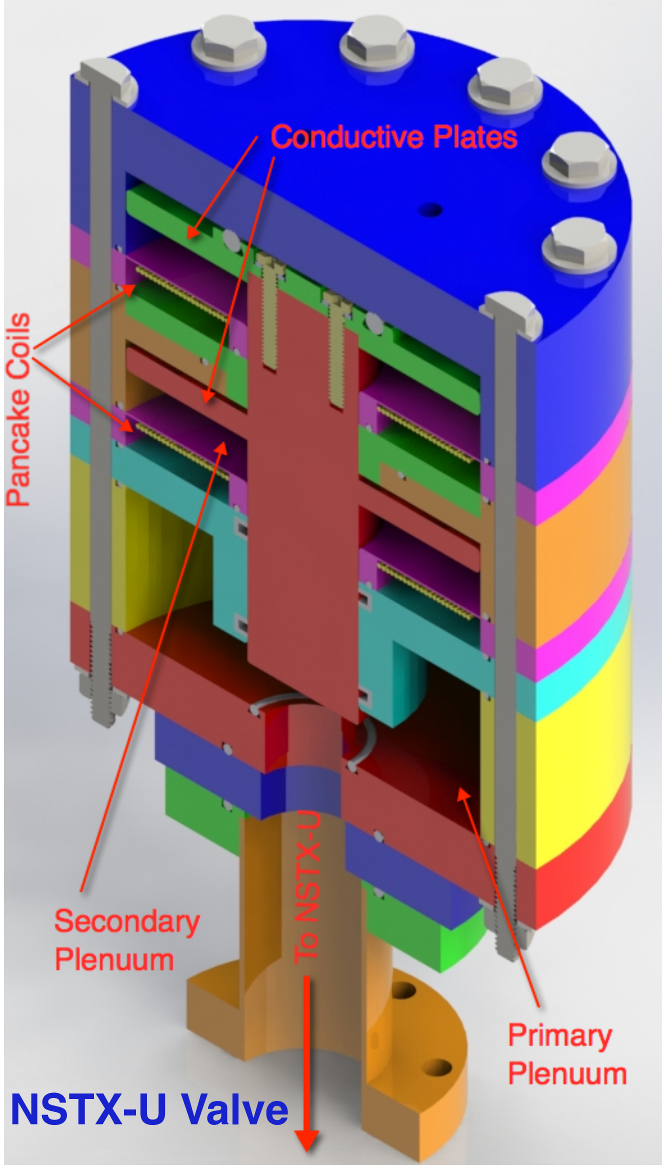
Earlier NSTX-U MGI valve design based on TEXTOR / JET MGI concept (G. Czymek, SOFT 2014)

New double solenoid MGI design – V3 (zero net J x B torque) based on ORNL ITER MGI concept

ORNL Prototype ITER MGI Valve

M. Lyttle, SOFE 2015





General Considerations for this First MGI XP on NSTX-U

- 200 Torr.L of Ne will be used for all experiments (based on FY2013 and 2014 DIII-D experience)
  - Will conduct a scan from 50 to 400 Torr.L to establish Ne injection amounts
- Will conduct experiments after the vessel Li levels are low in NSTX-U
- Will rely on long HeGDC to restore operating conditions
  - Will consider using Li if HeGDC inadequate to restore wall conditions
- Will use NBI heated L-mode discharge (~700 kA) with PFR (private flux region) over injection port
  - Will use H-mode plasmas if possible
- Will conduct a limited set of experiments using a high-current 1 MA H-mode discharge

JRT2016: Asses Benefits of Injection into the Private Flux Region vs. LFS Mid-plane

1. Establish vessel halo currents and divertor heat loading from a reference unstable VDE discharge (PFR over MGI 1a)
2. Inject from Location 2 into stable reference discharge (Config. 1a)
   - Vary gas load from 50 to 400 Torr.L Ne
3. Use MGI to inject from Locations 1a and 2 into a stable reference DN or LSN (H-mode or L-Mode) discharge
   - Use a single gas load (~200 Torr.L)
4. Use MGI to inject from Locations 1a and 2 into an unstable VDE reference discharge
   - Vary MGI injection time at ~200 Torr.L
5. Repeat (2) using Pipe Configuration 3
6. Repeat (5) using 1MA discharge & in Config. 1a)

NOTE: #4 to #6 is based on available Run Time & time required to enable MGI capability on NSTX-U

Planned Analysis

- Compare the following parameters for the three cases:
  - Duration of pre-TQ and TQ
  - Power radiated and profile during pre-TQ and TQ
  - Divertor heat loading
  - Divertor halo currents
  - Gas assimilated by the discharge
- Case 1: PFR vs. Mid-plane injection - (PFR injection, Mid-plane injection, and Un-mitigated VDE)
- Case 2: Mid-plane with Short and Long connection tubes
- Case 3: High-power and Low-Power discharges with short and long connection tubes in the mid-plane tubes

Summary of Simulation Results from Leonov* & Konovalov**

- DINA and ASTRA simulations with ZIMPUR code for impurity neutral transport
  - Model tested with JET discharges
- Pre-TQ determines assimilated impurity amount
  - Duration almost independent of D_2 influx and primarily depended on radiating impurity
  - Closer valve location or higher plenum pressure primarily shortens Pre-TQ phase
  - However, impurity assimilated during Pre-TQ must be sufficient for re-radiating >90% thermal energy during TQ
- For fast response, desirable to place valve inside port plug
  - Advantageous to have D_2 in the gas mix

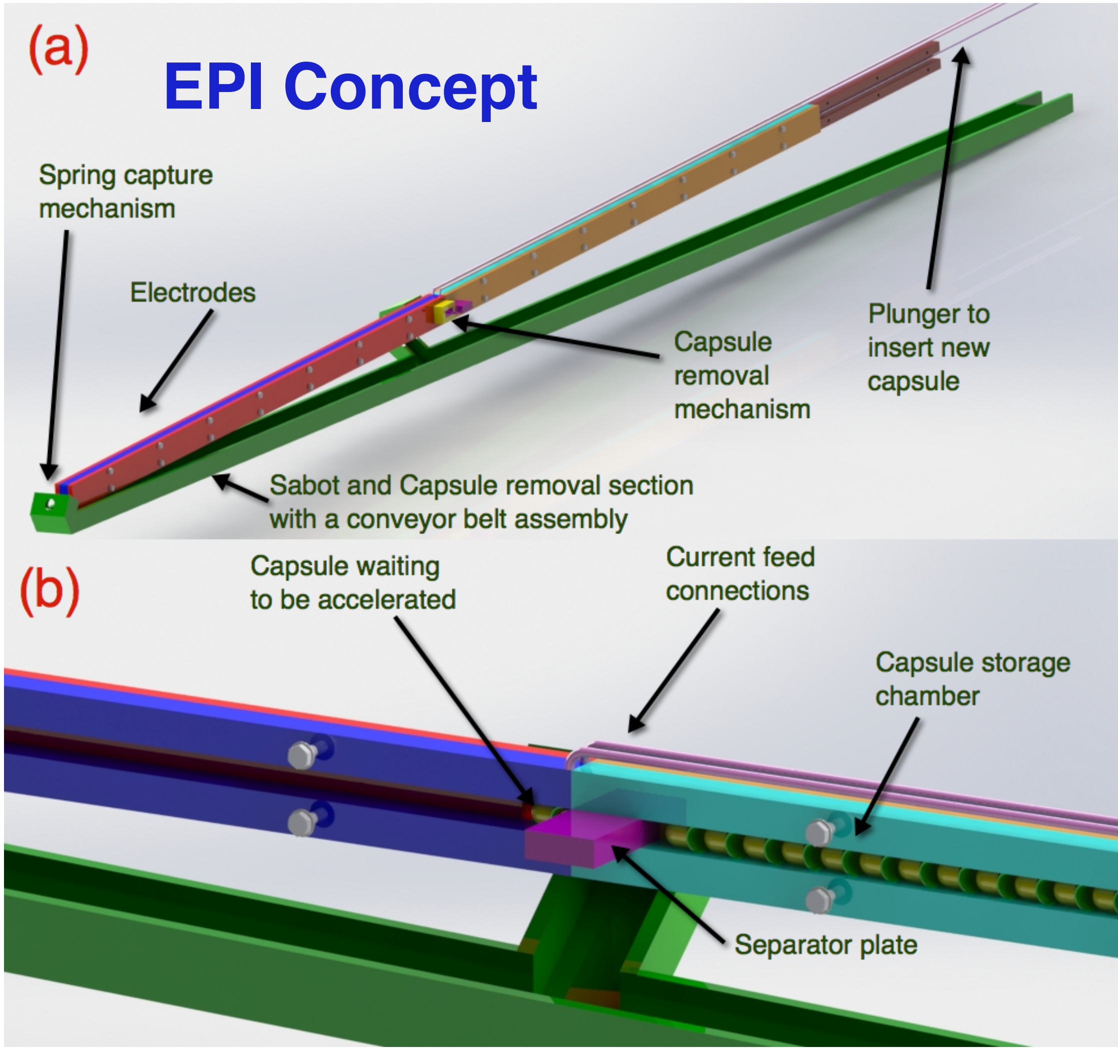
*** IAEA FEC 2014 THP3-35 & **THP3-31**

Modeling Needs for MGI Impurity Penetration

- Because of the much larger size and significantly more energetic conditions of the ITER plasma edge, reliable simulations are the only way to know if a critical fraction of impurities can be assimilated by the ITER discharge, and on an acceptable time-scale.
- DIII-D & NSTX-U can have nearly identical poloidal cross-section, but with very different aspect ratios, so may be good test beds for the modeling effort
  - Then also validate on other machines including JET
- Begin with simple 1 or 2D models (TSC based ?) to calculate impurity penetration fractions
  - Then extend to 3-D
  - Provide realistic impurity assimilation results as input to NIMROD for impurity mixing and radiated power studies

Other DM Concepts

- ITER DM system is based on MGI & SPI
- Advanced concepts that deposit impurities in the core, are also being developed
  - Shell Pellet (DIII-D)
  - Electromagnetic Particle Injector Concept (NSTX-U)



Modeling Needs for Solid Particle Penetration

- Shattered Pellet: Penetration and ablation of frozen Ne and Ar pellets of different size, shape, and velocity, in a range of plasma conditions
  - Can rely to some extent on database from pellet injection work
- Shell Pellet and EPI: Penetration and ablation of B, BN, Be composed of small spheres
- Electron temperature and density variations from NSTX-like to ITER-like in:
  - SOL conditions
  - H-mode pedestal conditions
  - L-mode edge conditions

Summary

- NSTX-U MGI research will improve the knowledge base by studying the importance of the poloidal gas injection location, especially from the private flux region

- Will begin to develop and test disruption prediction and avoidance algorithms

- PPPL theory group has the potential to make important contributions to developing capability for reliable gas and solid particle penetration and assimilation in high-temperature plasma

Backup Slides

Integration of Diagnostics and Resulting data

Thomson scattering, EFIT

Physics of gas penetration (fraction that penetrates separatrix)

H-alpha array, Spectroscopic detectors

System response time (gas trigger time to first detection of injected gas interacting with the plasma edge)

Multi-color Soft X-ray, H-alpha, Ip, EFIT, Thomson scattering, Mirnov coils

Delay in current quench after the gas contacts plasma edge

Rate of current quench and vertical dynamics of the plasma

3-D MHD response to the whole equilibrium and MHD activity

Thermal quench evolution & pedestal collapse

Bolometer array- Core radiated power dynamics

Halo current sensors- Dependence on halo current amplitude on gas assimilation (Mitigated vs. a VDE disruption)

Two color divertor fast infrared camera and Eroding thermocouples

Spatial distribution of Thermal loads & fast heat flux measurements