NSTX-U Supported by U.S. DEPARTMENT OF ENERGY Office of Science

Boundary Science Group and Particle Control Task Force Prioritizations

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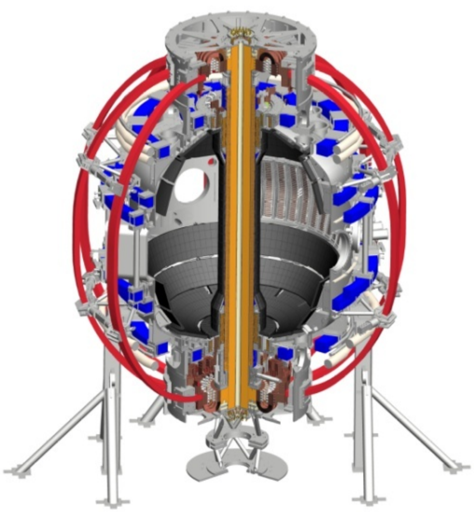
R. Maingi, on behalf of TSG and PC-TF

Leadership Team

NSTX-U Research Forum
MBG Auditorium
February 27, 2015



Culham Sci Ctr
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CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Summary

- Status of TSG prioritizations and underlying logic
  - Pedestal group proposed prioritization
  - SOL/divertor group proposed prioritization
  - Materials & PFC group proposed prioritization
  - Particle Control Task Force proposed prioritization

- Guidance from Maingi to each TSG was to prioritize the top 4-5 days of experiments, and also the next 2-3 days
  - Reason for requesting 4-5 days per group was that some experiments don't pan out or can be combined at later dates
  - Total Priority 1 Run Days was 19.5, while guidance from Jon Menard was for 18 days for Priority 1 & 2

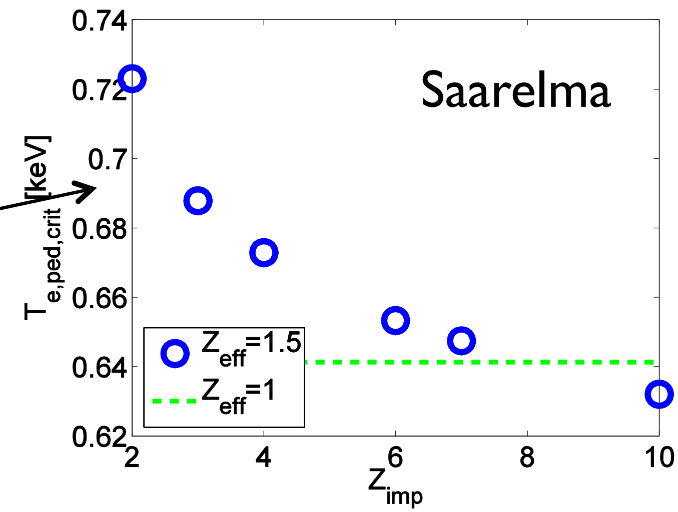
22 Proposal were submitted in the Pedestal TSG

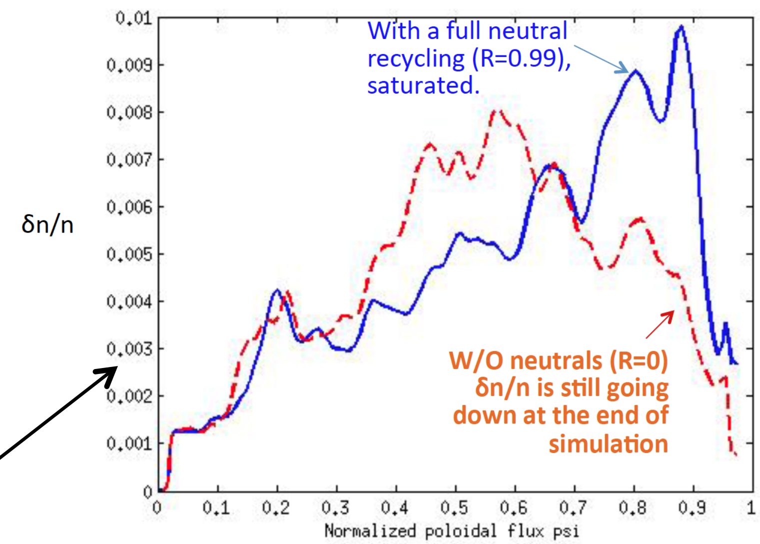
- Proposals were organized into 4 groups
  - Pedestal stability, turbulence, and impurity effects (7 ideas)
  - ELMs and 3D Physics (4 ideas)
  - Pedestal structure and L-H transition (4 ideas)
  - Alternative scenarios and pedestal manipulations (5 ideas)

- Run time prioritization was proposed over a broad range of topics
  - Milestone R15-1: Wide I_p, B_t range
  - Effects of neutrals and impurities (IO, ITPA)
  - 3-D field effects (ITPA)
  - L-H threshold (multi-machine collaboration)
  - B-> Li transition, I-mode exploration
    - Strong desire to find some time for EP H-mode, EHO studies

Effect of Impurities and Neutrals on Pedestal – Priority 1

- Effects of different impurities on pedestal structure – Osborne
  - Test He, Li, B, C, N, Ne, Ar effects on pedestal over a range of Ip , BT , Pnbi : Multi machine XP
  - Lower-Z portion of scans tie to ITPA PEP-37: several European colleagues have funding to travel for this
- Understanding (neoclassical?) impurity transport in the pedestal - Loarte
  - Determine the impurities (Ne, Ar, Xe) profiles in th pedestal to test neoclassical predictions for ITER
  - neoclassical transport needs to be confirmed
  - If impurity density profiles are hollow in pedestal ELMs can cause impurity contamination rather than impurity exhaust (modeling result)
  - Need to confirm spectroscopy to measure high-Z
  - If Kr added in, overlap with Reinke's proposal
- Effect of neutral particles on upstream and pedestal turbulence – Chang (XGC1)





Title of proposal	Names	Pri.	P1-day	P2-day	B vs Li	Note
Understanding impurity transport mechanisms in the plasma pedestal	Loarte	1	1		either	IO request. Spectroscopy available?
Effect of neutral particles on upstream and pedestal turbulence	Chang					Basic comparison with XGC
Effects of different impurities on pedestal structure	Osborne				B	ITPA PEP-37: very high priority
Multi-machine studies of the L-H power threshold dependence on aspect ratio	Bongard	1	1		B	Reduce to priority 2?
Effect of beam tangency radius on H-mode access and quality with XGC simulations	Churchill					Makes use of NBI flexibility in NSTX-U
Understanding of ped. anom. transp red/increase L-mode to Type I ELMy H-mode and back	Loarte					IO request
Characterization of the Pedestal Structure as function Ip, BT, and Pnbi	Diallo	1	1		both	Milestone R15-1: Highest priority
Resonant ELM frequency behavior as a function of q95 with 3D fields	Lore	1	1	0.5	P1: B	3-D fields effects on pedestal structure
Impact of 3-D fields on pedestal profiles under varying wall conditions and collisionality	Canik				P2: Li	
ELM suppression with mid-plane coils	Ahn					Only ELM suppression proposal?
Effects of B-> Li transition on the pedestal structure	Maingi	0.5	1		both	With divSOL, M&P, PC TF
Exploration of I-mode regime on NSTX-U	Hubbard	0.5	1		Li	Postpone to full field?
Investigations of nonlinear ELM dynamics	Smith	2		1	B	some overlap with Diallo.
Pedestal peeling-ballooning mode stability along the ballooning boundary	Osborne					req low triangularity
Pedestal rotation shear enhancement with high-n NTV braking and 2nd NBI	Menard	2		1	Li	Only EP H-mode in program Move up to P1?
Generating and Characterizing the EHO via Cnt-Ip Torque Inj.	McKee					EHO initiative? Move to P1?
Effect of poloidal variation of gas fueling on H-mode access and sustainment	Churchill	2		0.5	either	is absolute neutral density required? w/ ASC
Interaction of LGI with 3D fields, RF vs NBI, SOL heating for ped. stability, ELM induced fueling effects	Multiple	pb				

DivSOL TSG leads and/or contributes to several milestones in 2015 and 2016

- **FY 2015**
  - **R(15-1)**: Assess H-mode energy confinement, pedestal, and scrape off layer characteristics with higher B_T, I_P and NBI heating power
  - **R(15-3)**: Develop the physics and operational tools for obtaining high-performance discharges

- **FY 2016**
  - **R(16-1)**: Assess scaling and mitigation of steady-state and transient heat-fluxes with advanced divertor operation at high power density
  - **R(16-2)**: Assess high-Z divertor PFC performance and impact on operating scenarios

DivSOL groupings (1)

- SOL transport and turbulence
  - Heat flux and SOL width Scaling in NSTX-U, Travis Gray
  - Relaxation of the interchange instability and effect on SOL width with Li wall conditioning, Travis Gray
  - Relationship between lambda_q, S and Connection Length, Travis Gray
  - Initial NSTX-U edge characterization, Vlad Soukhanovskii
  - Relation between the midplane SOL pressure width and the divertor heat flux width, Robert Hager
  - SOL Width Scaling: Goldston's Heuristic Drift Model vs Critical Pressure Gradient Model, Egemen Kolemen
  - Investigation of ELM heat flux footprints with the variation of ELM regime, Kaifu Gan
  - Parallel Correlation of SOL Turbulence, Stewart Zweben

DivSOL groupings (2)

- Radiative divertor
  - Radiative divertor experiments, Vlad Soukhanovskii
  - Toroidal divertor flux deposition asymmetries due to localized gas injection, Jeremy Lore
- Impact of 3D fields on divertor
  - Interaction of applied 3D fields with detachment, Joon-Wook Ahn
  - Role of plasma response in the formation of lobe structures by 3D fields, Joon-Wook Ahn
  - Distinguishing between 3d magnetic field structures and transport, John Canik
  - S parameter under 3D perturbations, Egemen Kolemen
  - Divertor conditions and detachment characteristics in plasmas with 3-D fields, Alberto Loarte

DivSOL groupings (3)

- Snowflake divertor
  - Clarifying Snowflake divertor configuration physics, Vlad Soukhanovskii
  - Assessment of 3D field effects on the properties of the snowflake divertor, Gustavo Canal
  - Performance optimization of divertor detachment, Joon-Wook Ahn
  - Compare alternative advanced divertor configurations: X-divertor*, Snowflake, Egemen Kolemen
  - Detachment comparison study for Snowflake, X-divertor, Standard Divertor and long/short divertor leg*, David Eldon

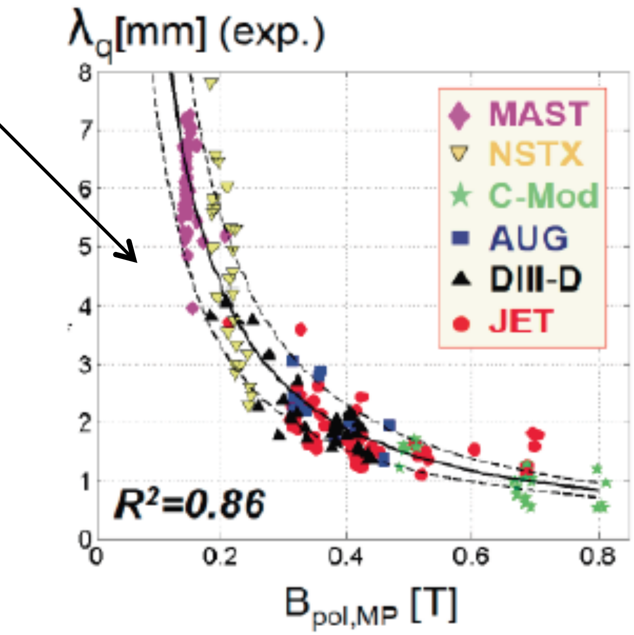
* Also in Advanced divertors (see next slide)

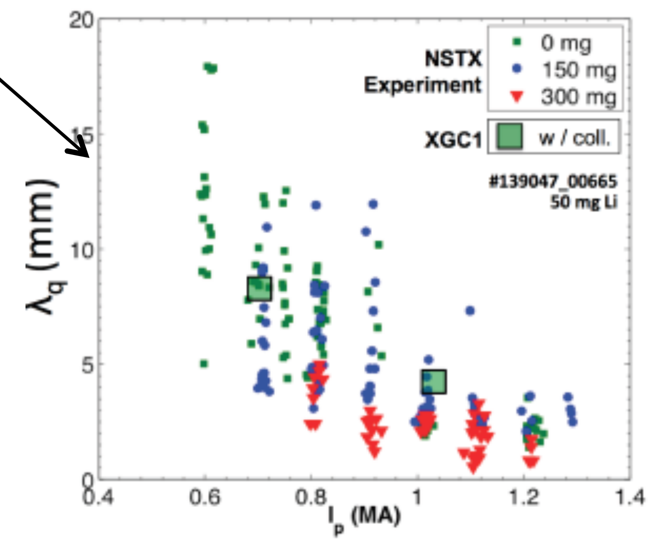
DivSOL groupings (4)

- Advanced divertors
  - Transport and radiation in the high flux expansion divertor configuration with cusp-like fields, Vlad Soukhanovskii
  - Testing advanced divertors on NSTX, Mike Kotschenreuther
- Miscellaneous
  - Boundary diagnostic-optimized configuration (BDOC) for model comparisons, Vlad Soukhanovskii
  - ENDD Midplane Neutral Density Profiles in NSTX-U, Daren Stotler
  - Obtain 2D divertor density image using lithium emission, Oliver Schmitz
  - Effect of Lithium on SOL Power Balance, Travis Gray
  - Transport and radiation in the high flux expansion divertor configuration with cusp-like fields, Vlad Soukhanovskii
  - Studies of low- and high-Z dust transport in NSTX-U, Roman Smirnov

Understanding the SOL heat flux width and role of turbulence – Priority 1 Experiment

- Heat flux and SOL width Scaling in NSTX-U, Gray
- Relaxation of the interchange instability and effect on SOL width with Li wall conditioning, Gray
- Relationship between lambda_q, S and Connection Length, Gray
- Initial NSTX-U edge characterization, Soukhanovskii
- Relation between the midplane SOL pressure width and the divertor heat flux width, Hager
- SOL Width Scaling: Goldston's Heuristic Drift Model vs Critical Pressure Gradient Model, Kolemen
- Investigation of ELM heat flux footprints with the variation of ELM regime, Gan
- Parallel Correlation of SOL Turbulence, Zweben





Proposed run-time allocation
Guidance: 5 Tier I run days and 2-3 Tier II run days

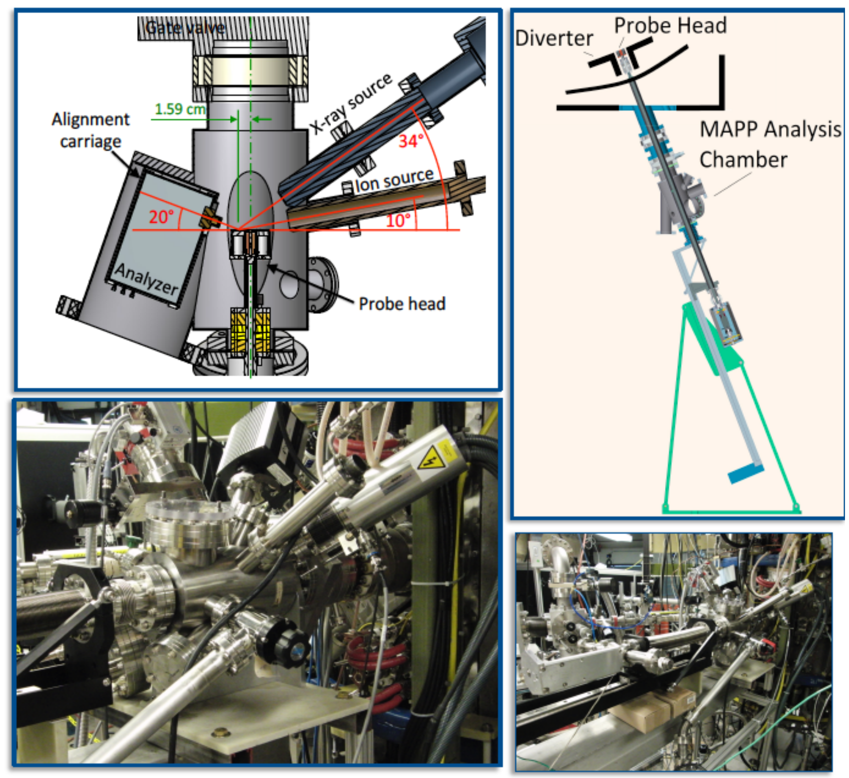
- DivSOL TSG Leaders propose Tier I run time
  - SOL transport and turbulence – 1.5 days (R15-1), T. Gray and S. Zweben
  - Radiative divertor – 1 day (R16-1), J. Lore and V. A. Soukhanovskii
  - 3D fields – 1 day (ITER/ITPA), J.-W. Ahn and E. Kolemen
  - Snowflake divertor physics – 1 day (R16-1), G. Canal and V. A. Soukhanovskii
  - B2Li transition studies – 0.5 day, TBD

- Tier II run time and Piggyback
  - * Advanced divertors (Eldon, Kolemen, Kotschenreuther, Soukhanovskii): 2 days
  - ENDD Midplane Neutral Density Profiles in NSTX-U, Daren Stotler
  - Boundary diagnostic-optimized configuration (BDOC) for model comparisons, Vlad Soukhanovskii
  - Effect of Lithium on SOL Power Balance, Travis Gray
  - Obtain 2D divertor density image using lithium emission, Oliver Schmitz
  - Studies of low- and high-Z dust transport in NSTX-U, Roman Smirnov

FY2016 milestone R16-2 needs baseline data before high-Z upgrade

- Tile installation between FY15 and FY16 runs to support FY16 milestone
  - Having machine shops evaluate differences in cost for W vs. Mo
  - Targeting row-2 of NSTX-U with minimal divertor height changes
- Development of reference, high-Z discharge proposed at previous meeting alongside reference parameter scans
  - Only opportunity to get baseline data before upgrade this coming outage
- Reference shape will also provide closer strike-point to MAPP location for material transport and evolution studies

New capability:
Material Analysis Particle Probe (MAPP)



M&P parallel session summary

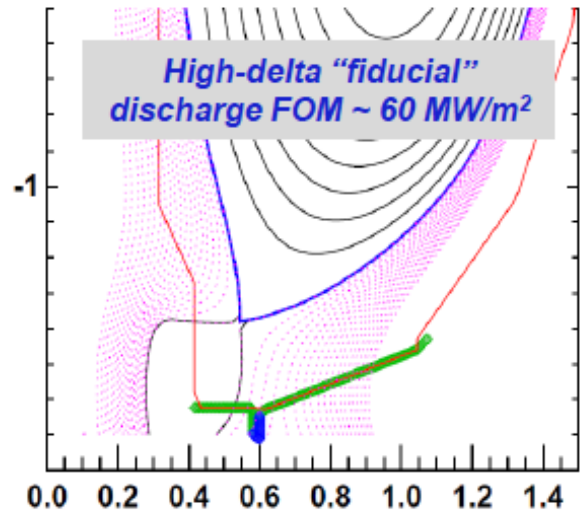
- 15 presentations provided to the group
  - Initial request for time was 14.5d, 8.5d with "minimums"
  - 1 hour open discussion held at the end to provide priorities and distribution

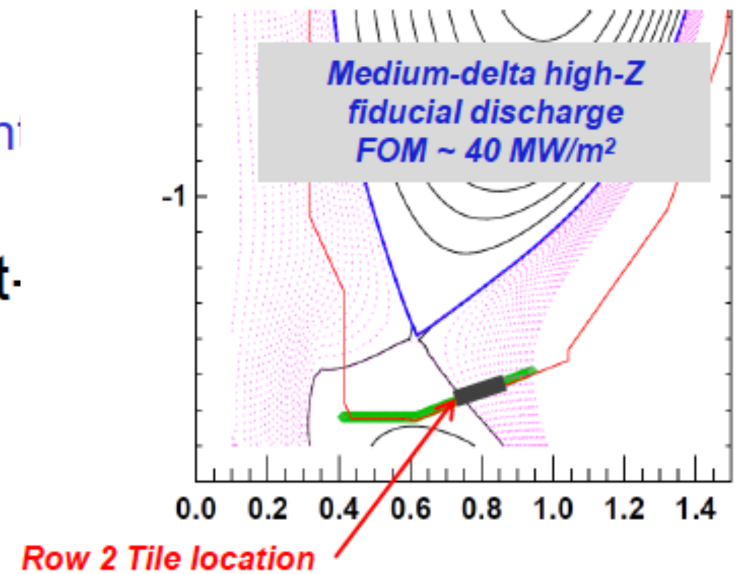
- Nearly all initial XPs were paired up resulting in multiple authors on each

- Final allocation provides split between R16-2 and M&P thrusts
  - Allocation provides 1.5d for R16-2, 2.5d for M&P thrusts 1&2
  - Implicit is +0.5 day for B->Li transition (Allain, Scotti, Soukhanovskii)
  - Allocation assumes XMP requests fulfilled with cross-cutting time

Characterizing heat flux profiles and divertor heat transport in preparation for high-Z tile installation – Priority 1 Expt

- Peak heat flux in discharges with strike point where high-Z tiles will go, Jaworski
  - R16-2: assessment of high-Z PFCs
    - Eventual upgrade of inboard divertor requires assessment of high-Z design
    - Large operational experience will be created by operation in “standard high-delta shape”
    - Need to create similar heat-fluxes and plasma-conditions to make assessment of future upgrades
  - This XP will establish range of heat-fluxes available for FY16 tests





- Leading edge effects, Gray

M&P Summary Table

#	Experimental Title	Author(s)	Priority	Topical area	Run time	Shape	B/Li	Scan	Comments
1	Heat transmission pathways and leading edge effects	Jaworski/ Gray	1	R16-2	1.5d	High-Z	B + Li	Pinj & div. puff	XMP req. for shape
2	Boronization Optimization	Skinner	1	M&P T-1	0.5d	High-Z prefer.	B	MAPP + few shots	cross-cutting time assumed
3	BDOC, mixed material migration and IBA targets	Vlad/ Nichols/ Wright	1	M&P T-1,2	1d	High-Z	B + Li	none	throughout run
4	Understanding Li longevity	Scotti/Allain/ Bedoya	1	M&P T-1,2	1d	High-Z	Li	Li dep, Pinj, div puff	MAPP
5	Textured Mo (high-Z metal) surface study	Skinner	2	M&P T-1	0d	High-Z	Li	none	piggy-back
6	ELM effects on mixed material migration	Nichols	2	M&P T-2	0d	High-Z	Li	none	piggy-back ELMy
7	Behaviour of high-Z impurities…	Reinke	2	R16-2	0d	High-Z		Kr/Xe gas puff, HHFW	Consider in PCTF
8	Supporting Surface Science	Koel	-	M&P T-1,2	0d				Surface science

Particle Control Task Force: Priorities as discussed in pre-forum meetings

- Task Force Goals (Duration: 2015-2018):
  - Confirm physics design calculations of the cryopump plenum geometry
  - Deploy a number of long pulse particle control techniques
  - Coordinate effort for density feedback implementation with cryo

Particle Control Task Force – Cryo physics design

- Task Force Goals:
  - Confirm physics design calculations of the cryopump plenum geometry
    - Semi-analytic model and 2-D calculations used for physics design
    - Need divertor thermography, Langmuir probe data, D_α profiles, which should be available relatively early in run
    - Desire to do this with boronized conditions (early) and lithiated conditions, with follow up experiments in 2016 after installation of high-Z row (joint with M&P)

Particle Control Task Force – Techniques (1)

- Task Force Goals:
  - Deploy long pulse particle control techniques
    - Naturally occurring ELM regimes: easy to obtain in NSTX with boronization (early), but can also achieve with lithiumization with 'low' amounts of inter-shot deposition (50-100 mg)
    - Lithium Granule Injector (LGI) for ELM triggering in discharges with low natural ELM frequency (some LSN with boronization early, 'high' lithium doses for ELM-free)
      - Consider using LGI as tool to controlled B -> Li transition
    - LiTERs to reduce impurity sources
      - Downward facing evaporator available 'early', upward facing one in 2016

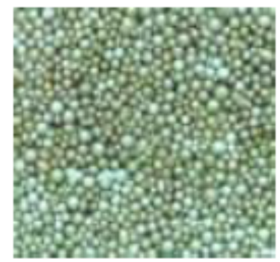
Particle Control Task Force – Techniques (2)

- Task Force Goals:
  - Deploy long pulse particle control techniques
    - Snowflake divertor and/or gas puffing to reduce divertor T_e and sources (joint with Boundary Science group)
      - Timing of the snowflake likely paced by PCS optimization
      - Can probably do the source study (piggyback early, including e.g. 3-D asymmetries and tile edges) and dedicated gas puffing first with boronized walls
      - Recycling and particle balance can support these
      - Comprehensive suite of diagnostics to support these
    - 3-D fields for ELM destabilization (mostly with Li)
    - Li dropper for destabilization of micro-edge instabilities (2016+)
    - Cryopump + density feedback (2017+)

Granule Injector capable of injecting Li and other impurities to trigger and pace ELMs – Priority 1

- ELM triggering via granules (Lunsford) & with 3-D fields (Lore, Canik) – plan to share same discharges to maximize run time
- Granule injector using Li successfully in EAST, DIII-D to trigger and pace ELMs
- Broad interest in other low-Z granules for ELM triggering
- Bonus: ELM destabilization physics and granule ablation physics to be tested in codes, e.g. JOREK

B_4C



Li

Mansfield NF 53 (2013)

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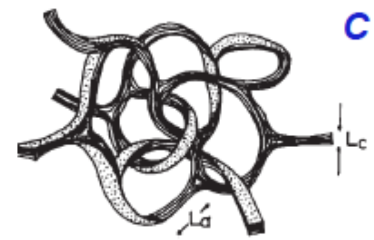
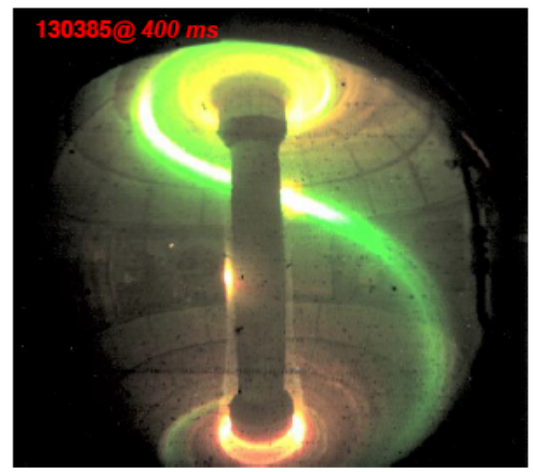


Fig. 3 Structural model for the network of ribbon stacks in glassy carbon.



Injection of low velocity (~5m/s) lithium clumps (~2mm) into NSTX (2008)

Title of proposal	Name	P1 days	P2 days	B/Li?	Comments	
Characterize plasma near planned plenum entrance	Canik	0.5		B		
Multi-species particle injection for ELM pacing and ir	Lunsford	0.5	0.5	B	combine	
ELM pacing with 3D fields in boronization operationa	Lore				combine	
Lithium granule injection into ELM free H-modes wit	Lunsford	1		Li	combine	
Re-establish ELM pacing via 3-D fields in NSTXU	Canik				combine	
Divertor gas puff effect on impurity reduction	Soukhanovskii	0.5		Li		
EHO Scoping Study	Goldston	0.5	0.5	Li	combine	w/ PED? (
EHO 3D coil interaction (possible control)	Kolemen				combine	
Coupling to Plasma Fluctuations Using Amplitude Mc	Golfinopoulos				combine	
Combining ELM pacing with divertor gas injection for	Lore	1		Li	combine	Placehold
Combination of 3D fields with snowflake for impurity con	Ahn				combine	
Optimize gas fueling for low density startup and H-m	Battaglia	0.5	0.5		combine	w/ ASC?
Establish minimum SOF density vs Ip ramp rate	Battaglia				combine	
Controlled introduction of Lithium into NSTX-U	Maingi	0.5		both	combine	
Recycling and pumping with lithium coatings	Soukhanovskii				combine	
Study of the chemical evolution during transition from B	Allain				combine	
Characterization of carbon and lithium sources follov	Scotti				combine	
Optimization of helium-dispersed lithium evaporati	Scotti		0.5	Li		
Development of Small ELM regimes	Gray		0.5	both		w/ ASC?
Assess high-Z granule injection	Soukhanovskii		pb?			which grou
Boundary diagnostic-optimized configuration (BDOC	Soukhanovskii					
High-Z impurity injection	Reinke		0.5			w/ M&P, T
I-mode	Hubbard					
	TOTAL	5	3			

Overall run day prioritization across groups

- Milestone R15-1: Wide I_p, B_t range – 1 day
- Effects of neutrals and impurities (IO, ITPA) - 1 day
- 3-D field effects (ITPA) – 1 day
- L-H threshold (multi-machine collaboration) – 1 day
- I-mode exploration – 0.5 day
- SOL transport and turbulence, heat flux – 1.5 days (R15-1)
- Radiative divertor – 1 day (R16-1)
- 3D fields, likely emphasizing detachment – 1 day (ITER/ITPA)
- Snowflake divertor physics – 1 day (R16-1)
- Power exhaust and heat flux with large strike point radius - 1.5 days
- Boundary diagnostic optimized plasmas; material migration – 1 day
- Understanding Li pumping longevity – 1 day
- Boronization optimization – 0.5 day
- Cryopump assumption validation, H-mode development – 0.5 day each
- LGI + 3-D fields – 1.5 days
- Divertor gas puff for impurity reduction, EHO scoping – 0.5 day each
- Combination of ELM/impurity control – 1 day
- B -> Li transition studies – 2 days (0.5 day across each of 4 groups)

Ped

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