Multi-species particle injection using the NSTX-U Granule Injector

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Princeton NJ
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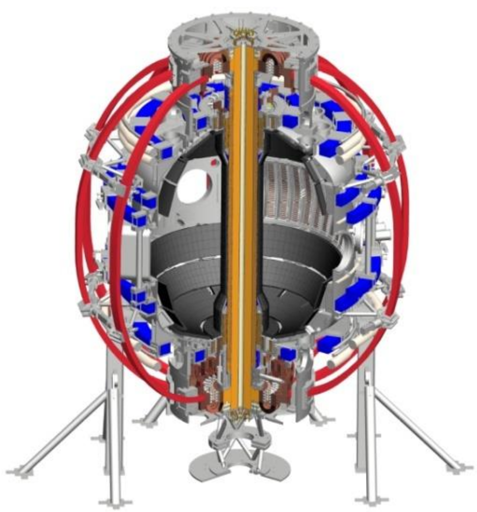

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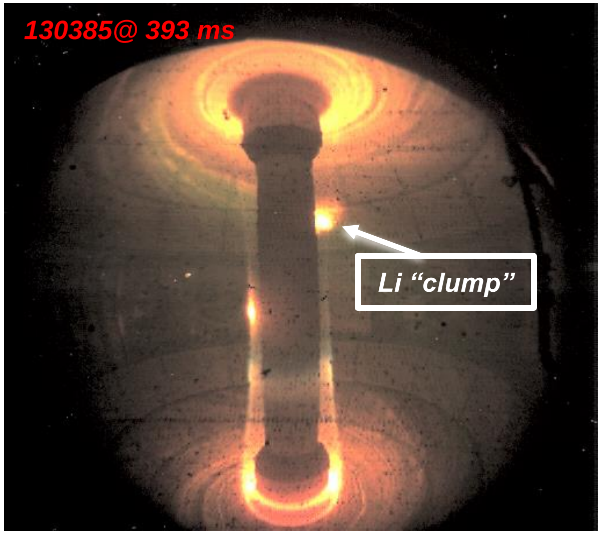
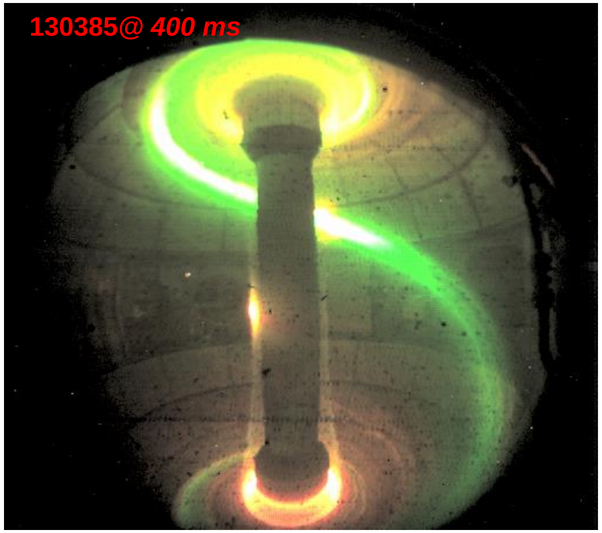
Stimulating ELMs through granule injection

- Granules injected into the plasma create a localized perturbation which generates an asymmetric high density filament
- Sonic expansion of cold plasma along helical flux tubes leads to perpendicular pressure gradients
- Flux tubes become ballooning unstable resulting in an edge localized mode





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

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ITPA PEP #30 : ELM control by pellet pacing in ITER-like plasma conditions and consequences for plasma confinement

Pacing ELMs at an increased frequency should lead to a reduction in ELM heat load

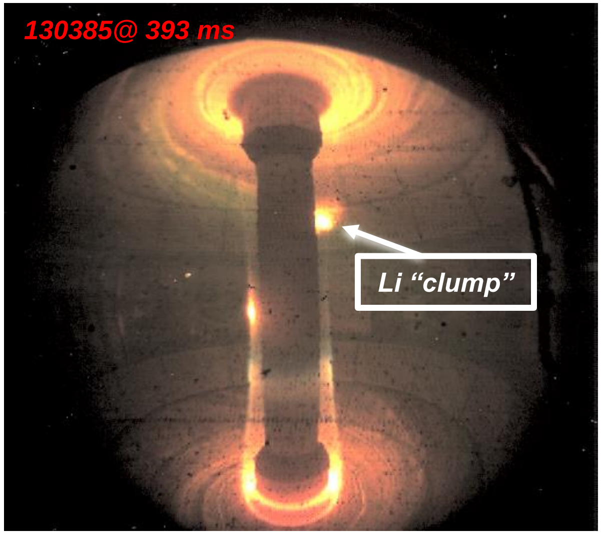
$\Delta W_{ELM} \times f_{ELM} \sim const$ ***(Herrmann PPCF 44 (2002))***

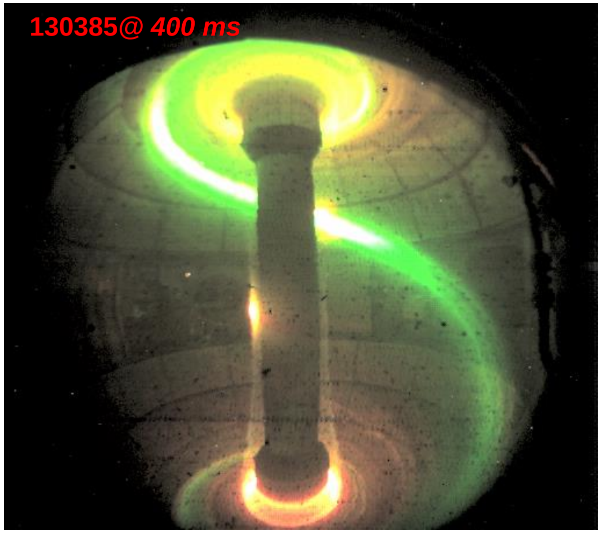
Testing ELM triggering with different materials will provide a better understanding of ablation physics and material deposition within the plasma

$$\frac{Dr_p}{Dt} = -\frac{C n_e^{1/3} T_e^{5/3}}{4\pi n_g r_g^{2/3}}$$

C : ablation constant,
n_g : granule density
r_g : granule radius

P. Parks, NGS Model





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

Granule Injector XP1: Multi-species particle injection for ELM pacing and impurity transport

Goal : **Comparison of Boron Carbide, Carbon, and Lithium injection into low frequency ELM-y H-modes for ELM pacing (pre-Lithium).**

- Examine ablation rates and penetration depths of multiple granule species. Determine effect of mass deposition location on ELM efficiency
- Compare characteristics of stimulated ELMs to both spontaneous ELMs and the non-linear MHD code JOREK*.
- High speed camera measurements of granule ablation and plasmoid formation to locate mass seeding within pedestal. Compare to pellet ablation models.
- Are ELMs paced at 3-5 times the spontaneous natural frequency sufficient for divertor heat flux mitigation and to what extent?
- This effort could be combined with the controlled introduction of Lithium by the PCTF (200 μg Li per 900 μm pellet, 35 μg per 500 μm pellet)

	Lithium	Beryllium	**Boron Carbide**	**Carbon (Vitreous)**	Tungsten
Sublimation Energy	**1.6 eV**	3.3 eV	**5.3 eV (B)**	**7.5 eV**	8.68 eV
Density	**.534 g/cm ^{3}**	1.85 g/cm ^{3}	**2.52 g/cm ^{3}**	**2.09 – 2.23 g/cm ^{3}**	19.25 g/cm ^{3}

B_4C

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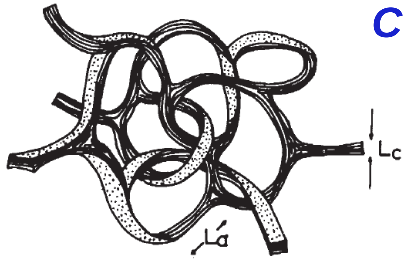


Fig. 3 Structural model for the network of ribbon stacks in glassy carbon.

Li

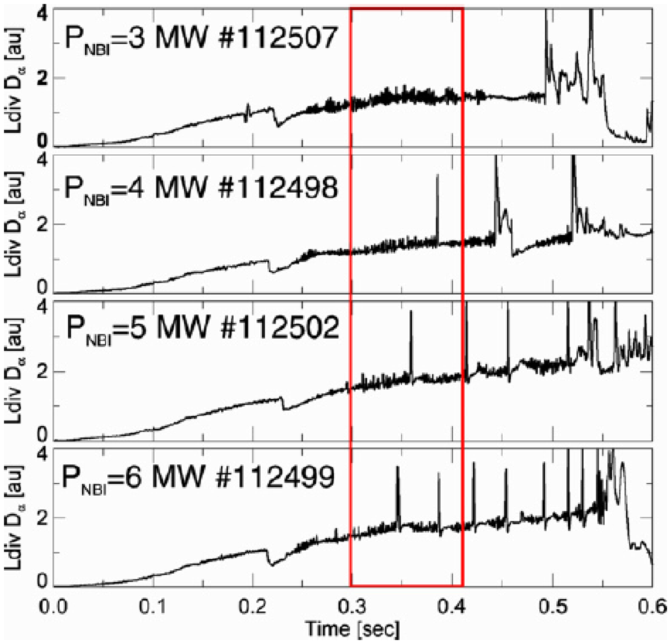
*Mansfield NF **53** (2013)*

** S. Futatani, G. Huijsmans et al. NF **54** (2014)*

Granule Injector XP1: Multi-species particle injection for ELM pacing and impurity transport

Experimental Plan

- Achieve NSTX-U discharges with low natural ELM frequency, based on NSTX results.
- Inject 500 μm and 900 μm pellets to observe ablation physics, determine pacing efficacy and monitor impurity transport
- Compare characteristics of spontaneous and stimulated ELMs.
  - Examples : ELM duration, magnetic signature, PFC wetted area, divertor heat load and energy deposition profile
- CHERS monitored impurity transport, material migration study with MAPP, examine QDM's and coupons for long term movement
- **1.5 days requested (3 - 0.5 day runs)**
  - B_4C, C, Li granules into boronized discharge
- **1 day minimum**
  - B_4C -or- C, Li granules into boronized discharge

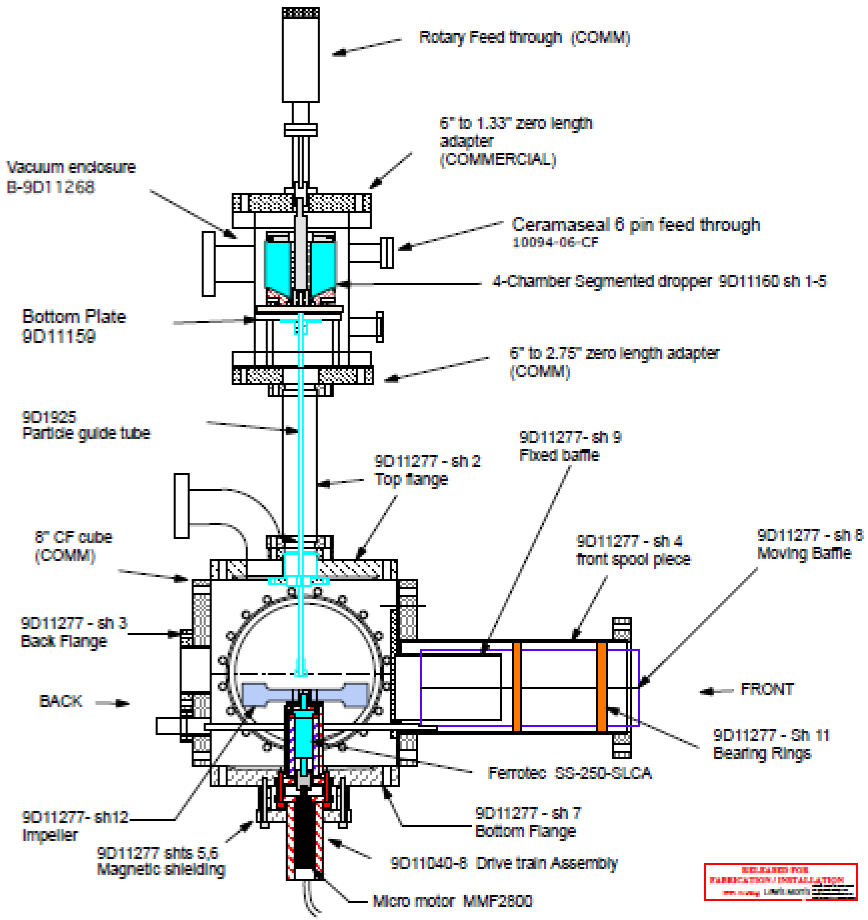


R. Maingi et al. / Journal of Nuclear Materials 363–365 (2007) 196–200

Incremental Physics : These pellet injections could be repeated under lithiated wall conditions with identical discharge settings thus comparing edge plasma behaviors due to lithium conditioning through direct material probe.

Backup

NSTX-U Granule Injector



Target granules are housed within the 4-chamber segmented dropper.

Particle drop rates are controlled by voltage applied to a piezoelectric disk.

The granules travel down a guide tube where they are impacted by a pneumatic rotary impeller and driven into the plasma.

Available sizes and weights (approximate)
900μm, 700μm, 500μm, 300μm

Proposed Granule Composition
Lithium, Boron Carbide, Vitreous Carbon

Injection Velocity
50 – 150 m/sec

Granule to Granule Injection Frequency
50 – 500 Hz

Granule Injector XMP : Pre-Experiment Requirements

Granule Injector Subsystem	Required Actions
Air Operated Impeller	Check air pressure, calibrate impeller speeds, and confirm photodiode operation.
Timing and Triggers	Confirm pulsed dropper operation and time of flight calculations
Injector Alignment	Confirm species specific particle alignment.*
Particle Selectability	Test ability to inject various size particles
Full Systems Check	Confirm Operational Readiness

* Will need to be reconfirmed when switching particle species

While the final four items require an active plasma, there are minimal restrictions on discharge characteristics.

Thus piggybacking with other XMPs is possible if they are not adversely impacted by the granule injection.

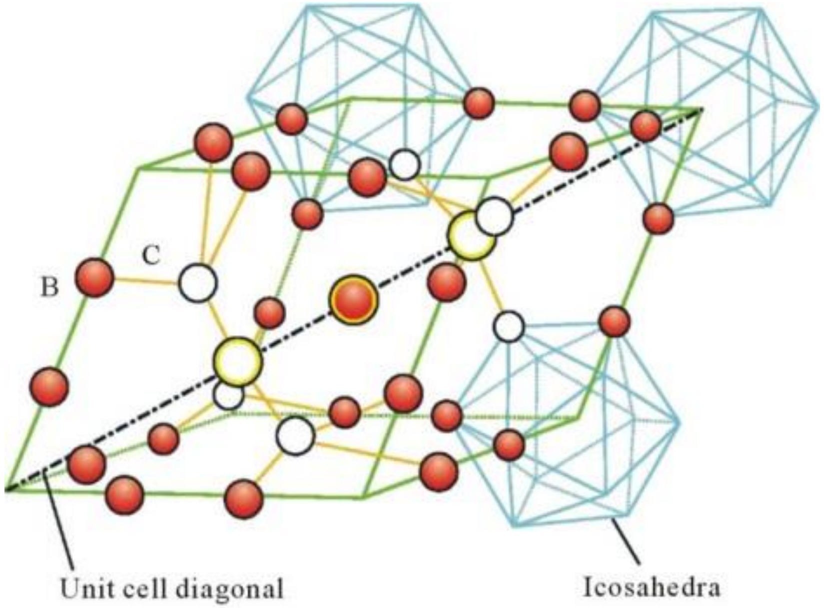
XMP Request : 0.5 Day

Boron Carbide (B_4C) composition

	Lithium	Boron Carbide	Carbon (Vitreous)
Sublimation Energy	1.6 eV	5.3 eV (B)	7.5 eV
Density	.534 g/cm ^{3}	2.52 g/cm ^{3}	2.09 – 2.23 g/cm ^{3}

Boron Carbide Pellets (300, 500, 850 μm sizes)	B_4C
Grade	CG (Ceramic) (% values)
B + C min.	99
B (Boron) min.	77
C (Carbon) max.	22.5
B2O3	0.10
Fe (Iron) max.	0.10
Si (Silicon)	0.01
N (Nitrogen)	0.01
B + C min.	99

Technical Specifications : Industrial Supply Inc. (2015)



Z.C. Kovziridze et al, J of Electronics Cooling and Thermal Control Vol 3 (2013)

Boron Carbide is an extremely light ceramic with a hardness approaching diamond.

It is also highly neutron absorbent and very stable under ionizing radiation bombardment.

Its uses include body armor, high pressure nozzles, sandblasting grit, and reactor shielding

Molecular formula	B_4C
Molar mass	55.255 g/mol
Appearance	dark gray or black powder, odorless
Density	2.52 g/cm^3, solid.
Melting point	2,763 °C (5,005 °F; 3,036 K)
Boiling point	3,500 °C (6,330 °F; 3,770 K)
Solubility in water	insoluble
Acidity (pK_a)	6–7 (20 °C)

D2 pellet pacing experiments and divertor heat flux mitigation

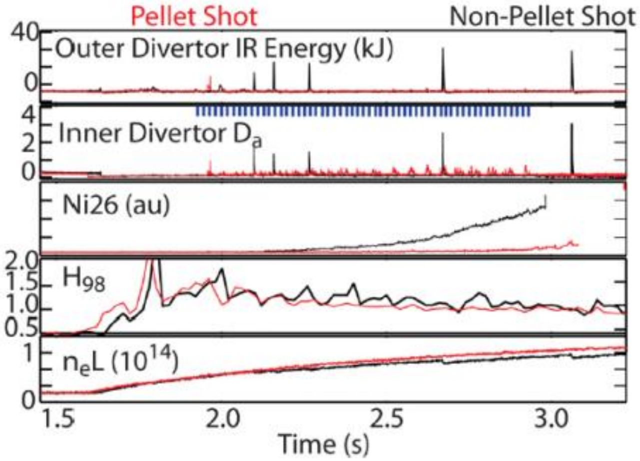


FIG. 4. Comparison of 60 Hz 1.3 mm pellet case (red 147691) and no-pellet plasma with 5 Hz ELMs (black 147690). Divertor deposited energy and divertor particle flux are shown with nominal pellet request times by blue tick marks. Central Ni emission, normalized energy confinement H_{98}, and electron density are shown.

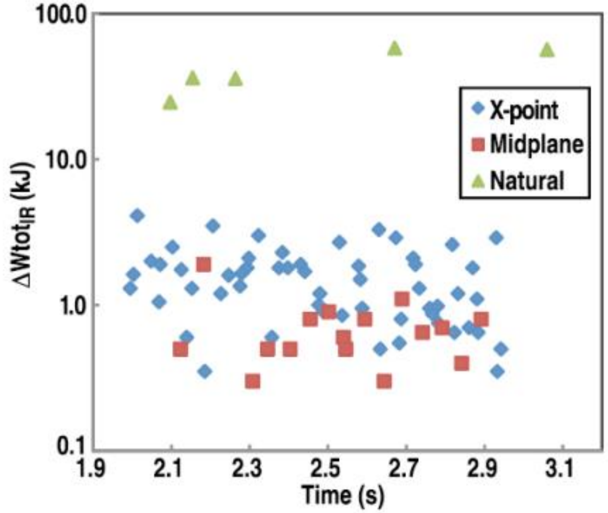


FIG. 6. Energy deposited (log scale) in the divertor from the IR camera data for each ELM in the discharges shown in Fig. 4. The natural ELMs are from the non-pellet comparison discharge.

082513-4 Baylor *et al.* Phys. Plasmas **20**, 082513 (2013)

ITPA PEP #30 Motivating Quote : "Experiments have shown that it is possible to reduce the ELM energy loss by high frequency pellet injection, and a demonstration at the ITER ELM size decrease range and for ITER like plasma conditions remains has now been performed on DII-D. The consequences for plasma performance and pellet ELM triggering requirements in these ITER relevant conditions however remain uncertain and need further investigation on other devices."