The impact of low-z powder injection on intrinsic impurities in DIII-D

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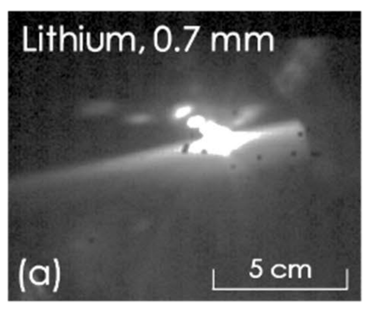
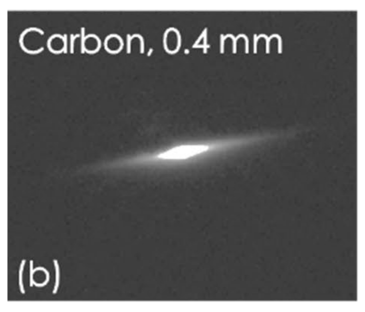
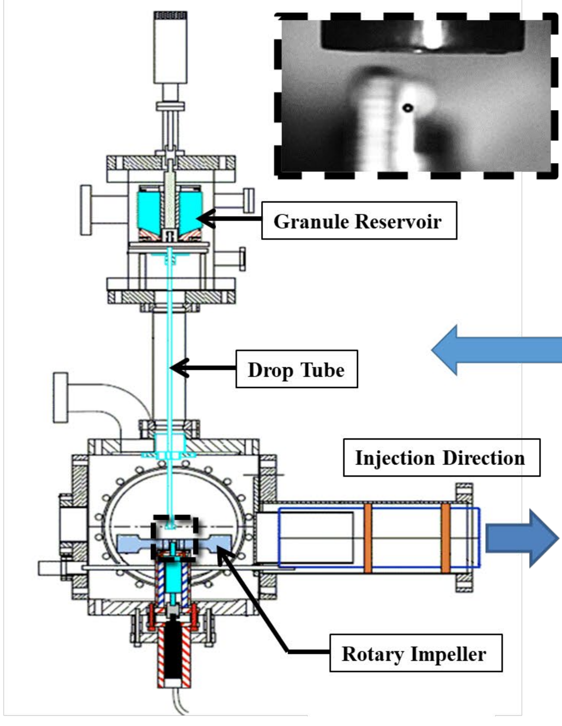
ABSTRACT

- Gravitationally introduced impurity powders and horizontally launched granules are injected into DIII-D ITER baseline discharges to determine impurity interplay.
- Li aerosol reduces core C by up to 4x, but can be counteracted by addition of C granules.
- If C granules are introduced first, Li powder has no effect
- Addition of Li generates periods of suppressed ELM activity proportional to the quantity of Li introduction.
- B powder also flushes core C, but not as strongly as Li.
- Experiments generate benchmarking data for transport codes inform favorable transport conditions in future tokamaks.

BACKGROUND





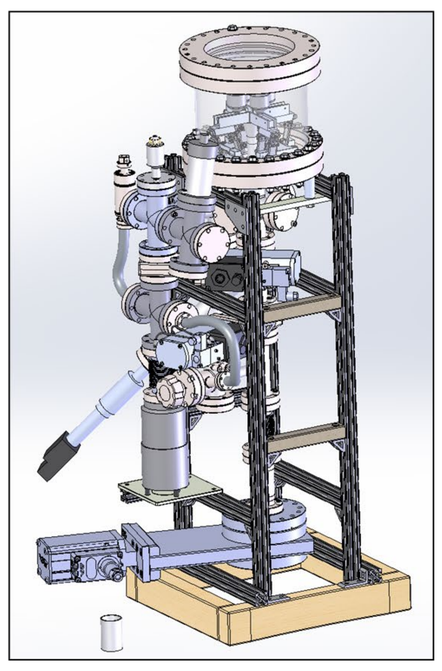


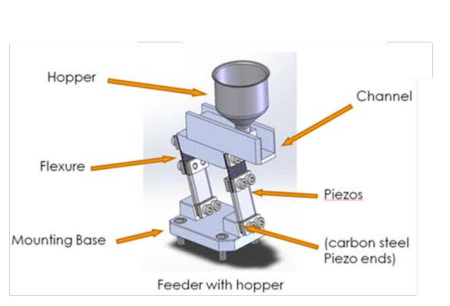
Impurity Powder Dropper (IPD)

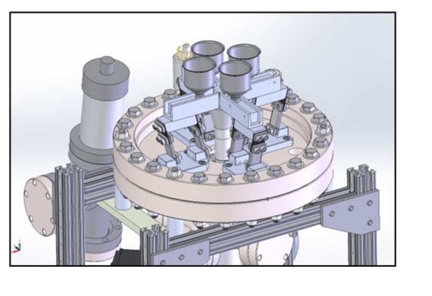
- Injection of stabilized lithium powder (40 μm), boron powder
- Mass injection rate up to 54 mg/sec
- Upper divertor injection

Impurity Granule Injector (IGI)

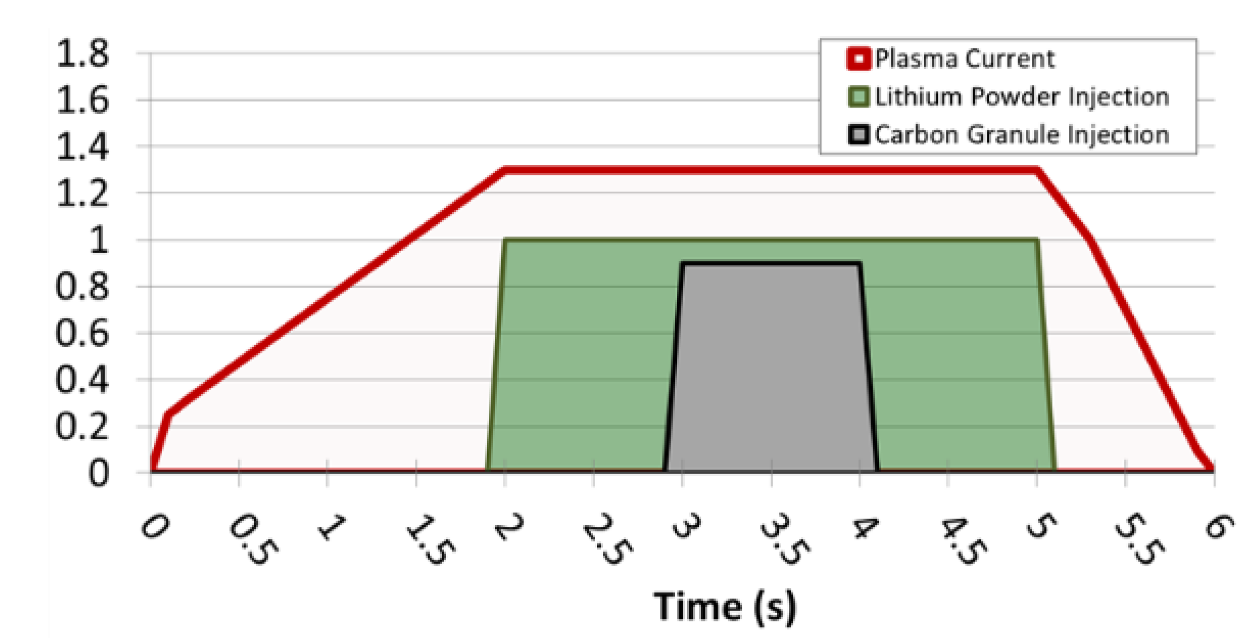
- New feeder allows quasi-periodic injections
- Spherical pellets of C(400 μm), Li (700 μm)
- Up to 150 Hz possible
- 50-120 m/s
- Midplane injection at 285 degrees







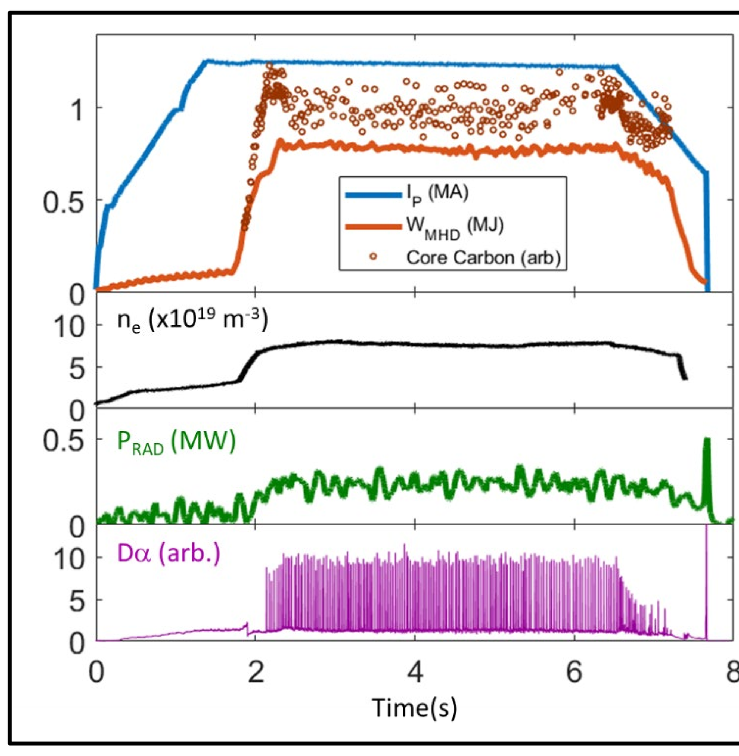
EXPERIMENTAL PROGRAM



Powder Dropper	Granule Injector
	C Granules
Li Powder	
Li Powder	C Granules
B Powder	
B Powder	C Granules
B Powder	Li Granules
	Li Granules

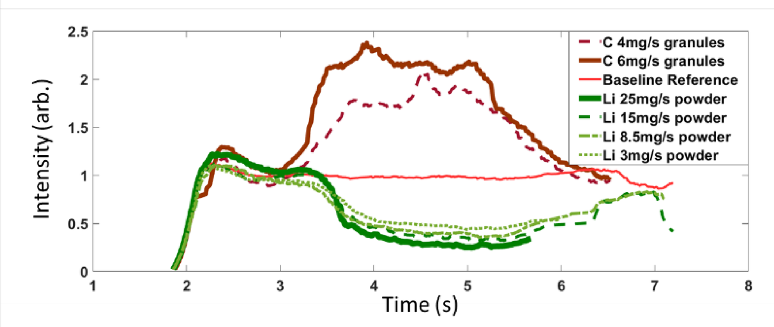
Injection program for impurity transport discharges

- Injections into 9 MW NBI heated ITER baseline discharges
- I_p = 1.3 MA, B_T = -1.73T, q_{95} = 4.4, $1.9<\beta_N<2.3$
- Series of single impurity and mixed impurity injections plasmas
- Powder Dropper and Granule Injector timings can be swapped
- Baseline reference discharge shown at right.
- The core carbon concentration is provided by charge exchange normalized to provide a unitary baseline for future comparisons.



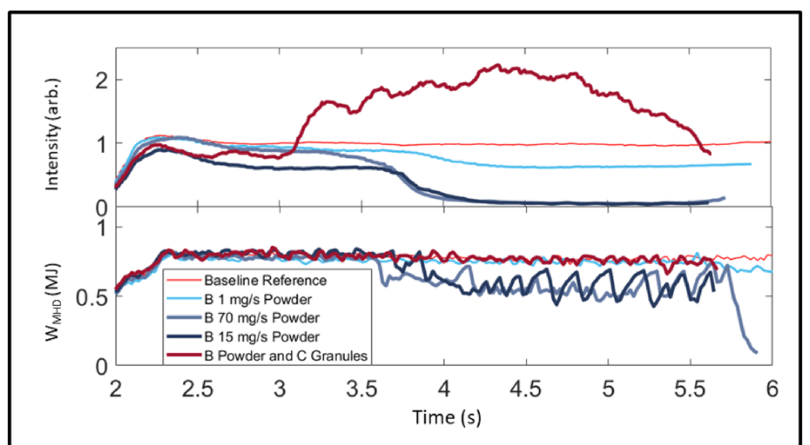
Results of Li and C single species impurity injection on core carbon signals

- Central line is normalized core carbon signal level
  - Average of open circles in above time history, all signals normalized to this level
- Green lines are C concentration after Li injection
  - Signal level decreases slightly with higher Li injection amounts
- Red lines are C concentration after C granule injection



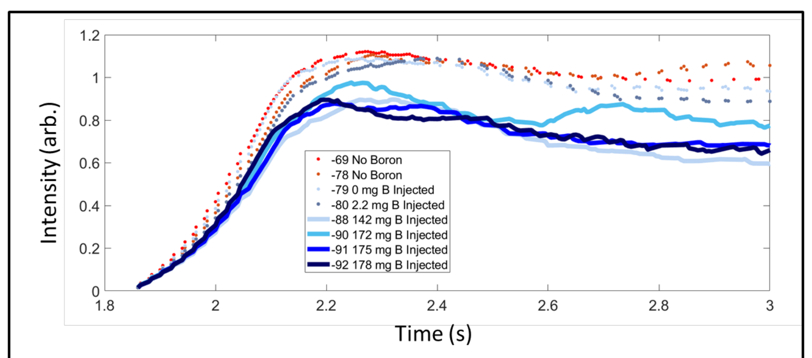
Injection of B powder also reduces core C, but not as efficiently as Li

- Plasma more sensitive to B powder injections, in addition boron powder injection levels are also harder to regulate.
- Levels above 15 mg/s lead to a transition out of H-mode and a substantial loss of stored energy.
- Like Li, when C granules are injected B powder injection is unable to moderate the increased level of core carbon.



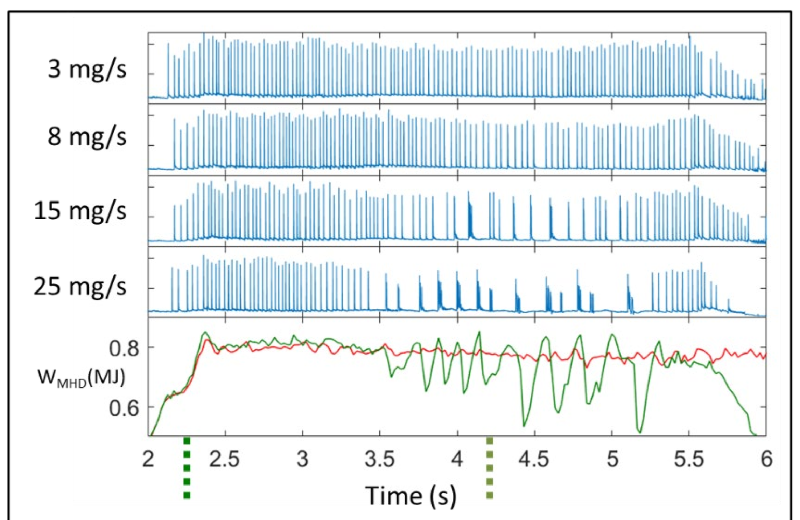
Mild conditioning indicators after large boron injections

- Injection into discharge 176780 was larger than anticipated depositing 140 mg of Boron powder.
- Several subsequent attempts were required to return to standard operational conditions
- Once discharges were running again a lowered overall Carbon baseline level was observed.
- The numbers in the key at right indicate the amount of B injected at the time of the measurement.



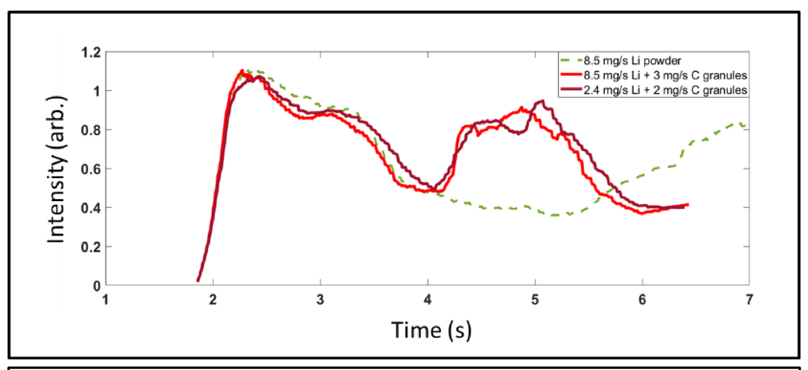
Increasing levels of Li injection lead to extended periods of ELM free activity

- Dα signals show the effect of increasing lithium introduction on the ELM cycle
- Vertical scales for the Dα panels are arbitrary
- Bottom panel shows evolution of plasma W_{MHD} for the baseline (red) and 25mg/s (green) injections
- Terminating these ELM free sections are very large ELMs that can contain up to 30% of the total stored energy.



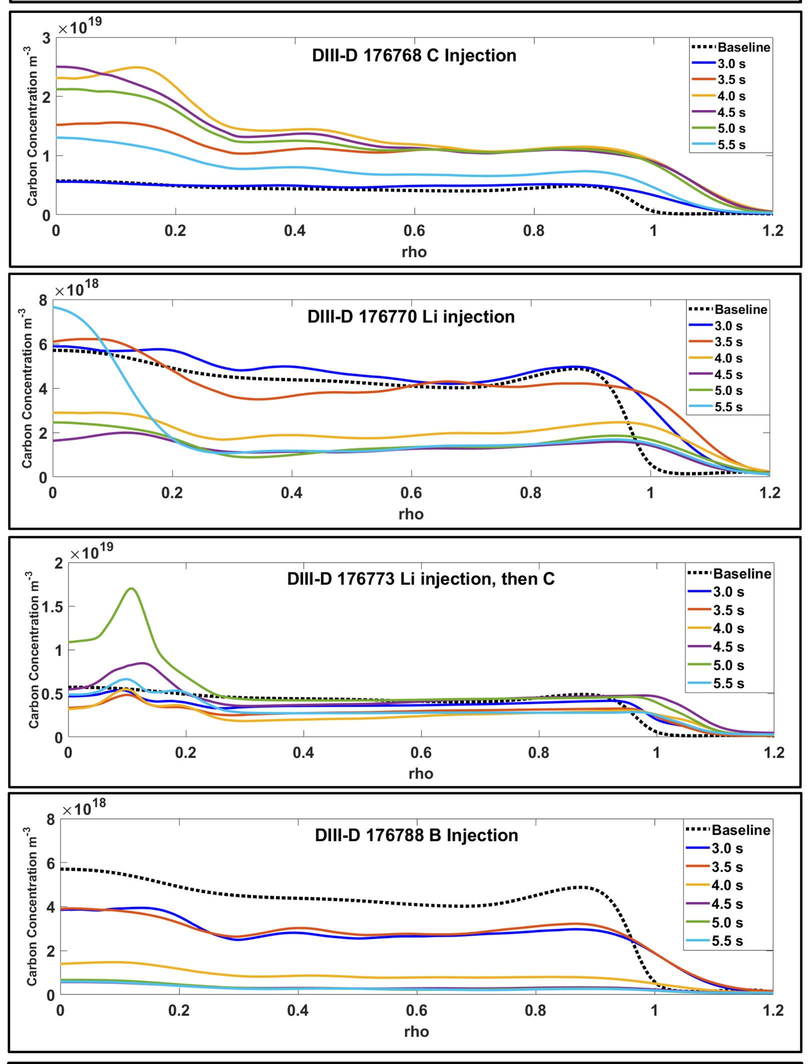
Modification of core carbon through utilization of multiple impurity species

- Green line is C concentration after Li injection at midrange level
- Red lines show that reintroduction of C returns the signal to baseline levels
- C injection stopped at t = 5s, Li continues and returns core levels to previous suppressed quantities
- Mid-shot C level is not strongly reliant on Li or C quantities



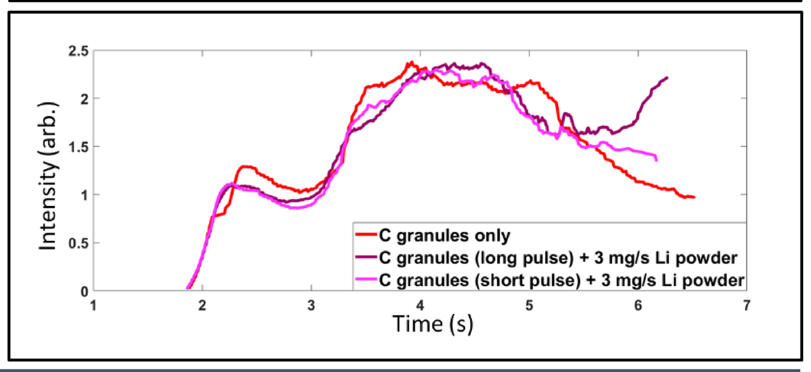
Radial profiles of impurity flushing effects show species specific effects

- Black dotted line in each trace is the reference discharge carbon concentration profile.
- Extended C granule injection leads to full profile elevation followed by core peaking of C signal as seen in progression from 3.5s to 4.0s.
- Li injection leads to depression of carbon concentration over the full profile by nearly 3x. Recovery occurs from inside out
- Third panel shows the depression of C with the Li injection as seen in single impurity injection discharges.
- Once C granules are injected, profile peaks towards the discharge core but rho > 0.3 is largely unaffected.
- B profiles show evidence of conditioning prior to injection and flushing during injection



Reversal of species introduction order leads to persistent elevated core carbon

- Carbon granules introduced during the early time
- C and Li combined pulses included 1- 3.5s long C injection and 1 -2.5s long C injection. Stopping the carbon earlier did not appear to modify the pumpout rate.
- Li injection was unsuccessful at flushing the elevated core carbon concentration



CONCLUSIONS

- These experiments extend previous mass injection programs to high power ITER baseline discharges and are able to confirm prior observations of ELM free periods (Li injection) and inter-shot conditioning effects (B Injection)
- While Li and B powder are able to reduce core C concentrations below baseline level they cannot compensate for the continued introduction of C from the granule injector. Whether this is a result of the injection method or a threshold effect which shields core C is still under investigation.
- A carbon threshold level beyond which the Li is not able to affect the core could explain differences in core impurity penetration seen in similar discharges in NSTX and DIII-D
- Analysis ongoing with these measurements providing benchmarking data for neoclassical transport codes such as NEO and XGC to help determine if the corresponding variations in impurity transport can be explained by simulation and will inform favorable transport conditions in future tokamaks.

ACKNOWLEDGEMENTS / REFERENCES

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