Mitigation of ELM peak heat loads on NSTX-U through impurity granule injection

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ABSTRACT

Controlling the peak heat load associated with large wall-exposed tokamaks is equally crucial to enable operation at high plasma density and power. Cold wall tokamaks, such as NSTX-U, are able to reach high plasma density and power, but experience high heat loads due to their relatively thin wall. Mitigation of these heat loads is critical for the operation of high density and power experiments. Particle influxes, particularly of high-Z impurities, can naturally reduce the ELM frequency. The injection of impurity granules (Li, B, C) is a method to simulate the high-Z influxes. Recent experiments have shown that the injection of impurities can reduce the ELM frequency by orders of magnitude.

The principle of particle injection experiments is to create an additional density influx into the plasma surrounding the edge plasma. This is accomplished by the injection of low velocity (~5m/s) granules into the edge plasma. Granules of low Z impurity species (Li, B, C) are radially paced at a rate 10+ times higher than the natural ELM frequency by injection of impurity granules. While some portion of the Granule species ablates rapidly at the plasma edge, the remaining species transport further out. This allows for experiments with injection of impurity granules. The ablation intensity is greater in time, which allows particle injection into the NSTX-U scrape-off layer where it can be tracked with a high-speed camera.

Looking beyond the NSTX-U experiments, global fast camera imaging in the scrape-off-layer has shown proliferation of microgranules and pace location of ELMs. While the compact nature of the ST geometry, global fast camera imaging of the plasma edge, and access to the NSTX-U first wall make the conditions for particle injection experiments unique, the benefits of these experiments extend beyond these conditions. The future of particle injection experiments will be highly dependent on the developments of advanced diagnostics and experimental techniques.

Stimulating ELMs through granule injection

1. Injected granules create an asymmetric high density gradient
2. Dense supersonic jets of cold plasma leads to perpendicular pressure gradients
3. Flux lobes become ballooning unstable resulting in an edge localized mode (ELM)

Pacing ELMs reduces peak heat flux

Granule Ablation Imaging Diagnostics

The granule injector has 2 dedicated cameras, one which monitors the granule position, and another which observes the edge plasma to determine the local edge plasma density along the injection flightline.

Goal: Comparison of Boron Carbide and Carbon injection into low frequency ELMs to emulate for 3D field application for main ion control

Planned Granule Injector Experiments

DIII-D Lithium Granule Injection Experiment

While some portion of the granule does penetrate deeply, the primary mass deposition is located further out

NSTX-U Granule Ablation and Penetration Projections

Electron inventory calculation for multi-species particle injection

Triggering ELMs with lithium granule injection and 3D fields in lithiated discharges

Goal: Locate maximum heat load per granule injection to induce ELMs in a naturally ELM-free discharge.

Experimental Plan

1. Injection of low velocity (~5m/s) granules to determine mass density limit
2. Injection of impurity granules to create an asymmetric high density gradient
3. Injection of low Z impurity species (Li, B, C) to determine lower mass density limit
4. Injection of lithium granules (700 mm, 500 mm, 300 mm) to determine lower mass density limit
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Additional camera will be added on NSTX-U during all experiments through diagnostic collaboration with LLNL.

This allows direct measurement of injection velocity and penetration depth.

NSTX Legacy Profile Data used for Granule Injection Simulation (t = 300 - 500 macc)