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Dust Studies in DIII-D and TEXTOR EX-D

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Dust production and accumulation could potentially impose serious safety and operational issues (e.g., radiological, explosion hazards, tritium retention, and fuel dilution) on ITER operation. Dust studies on DIII-D and TEXTOR tokamaks are aimed at developing a detailed physics basis for improved predictive capabilities of dust generation and accumulation by identifying the dominant dust sources, obtaining estimates of the dust generation rates, and understanding the physics of the dust transport. Recent results indicate that disruptions on DIII-D, which provide a similar level of impulsive heat flux to the first wall as a type I ELM on ITER, produce significant amounts of carbon dust. In addition, dedicated dust transport experiments on both DIII-D and TEXTOR indicate significant mobility of dust in the edge plasma.

During normal operation on DIII-D, dust diagnostics, including Mie scattering from ND:YAG lasers, visible imaging and survey spectroscopy, observed a low rate of dust production. The scattering diagnostic can resolve the size of small particles between 50-200 nm in diameter. The observation rates are low, but statistical analysis of the data provides an estimate of the total dust content in the edge and scrape-off layer (SOL) plasmas and allows establishing trends in the dust production rates. It has been shown that during normal plasma operations in DIII-D dust is not a major impurity source, with total carbon content of the dust being less than a few percent of the plasma carbon impurity content. Statistical evidence points to increased dust production in discharges with edge localized modes (ELMs) and disruptions. Generation of dust by disruptions is directly observed by visible imaging using a fast-framing CMOS camera capable of detecting dust particles larger than ~4 microns in diameter. An image of dust produced by a disruption is shown in Fig. 1(a). A single disruption produces up to ~10000 dust particles, corresponding to between 0.01-1 mg of carbon, depending on the dust size which is hard to determine from the camera data. Taking the upper bound estimate, disruptions in DIII-D may produce up to ~1 g of dust over

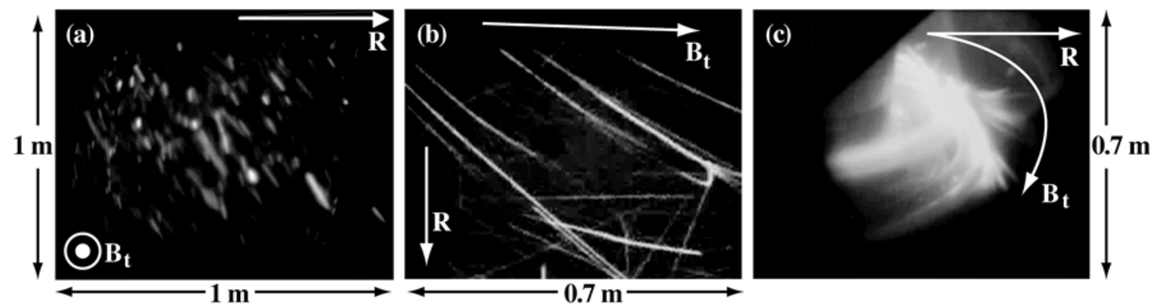

Fig. 1. Dust in DIII-D: (a) dust produced by a disruption (fast camera, tangential view of outboard SOL); (b) dust observed after an entry vent (standard rate camera, looking down in the lower divertor); (c) intentional dust injection into the lower divertor (standard rate camera, tangential view of the lower divertor).

a 15 week experimental campaign. This is two orders of magnitude below the estimated dust inventory in DIII-D as measured by collection techniques during entry vents, so other mechanisms are likely to dominate the dust production. It is possible that a large part of the dust inventory in DIII-D is created by in-vessel activities during vents. In the first 2-3 plasma discharges after an entry vent, cameras detect thousands of dust particles in each discharge. Individual particles moving at velocities of up to a few hundred m/s and breakup of larger particles into pieces are observed. An example of dust tracks observed by a standard rate CMOS camera viewing the lower divertor from above is shown in Fig. 1(b). After about 15 discharges dust is virtually gone during the stationary portion of a discharge, and appears at much reduced levels during the plasma initiation and termination phases. After a few days of plasma operations (about 70 discharges) dust levels are further reduced to just a few observed events per discharge.

Migration of pre-characterized carbon dust was studied in DIII-D by introduction of micron-size (~6 μm median diameter) dust in the lower divertor. A sample holder filled with about 30 mg of dust was exposed to high-power (5 MW of neutral beam injection (NBI) heating) lower single-null ELMing H-mode discharges with strike points swept across the divertor floor. Following a brief exposure (~0.1 s) at the outer strike point, part of the dust was injected into the plasma [Fig 1(c)]. About 1.5%-2% of the total dust carbon content ($2\text{-}3\times10^{19}$ carbon atoms, equivalent to a few million dust particles) penetrated the core plasma, raising the core carbon density by a factor of 2-3 and resulting in a twofold increase of the total radiated power. Individual dust particles were observed moving at velocities of 10–100 m/s, predominantly in the toroidal direction for deuteron flow to the outer divertor target, consistent with the ion drag force. The observed velocities and trajectories of the dust particles are in qualitative agreement with modeling by the DustT code, which solves equations of motion for dust particles in 3D self-consistently using a plasma background from the UEDGE code.

Dedicated experiments with dust have been recently performed in TEXTOR. Pre-characterized carbon dust similar to that used in DIII-D was introduced in amounts ranging from 1 to 45 mg on instrumented dust holders. The holders were mounted on the spherical test-limiter and exposed one by one in the SOL of TEXTOR using the Limiter Lock transport system. The view of the limiter with a dust holder is shown in Fig. 2(a). Three holders with different amounts of dust were exposed during NBI-heated repetitive discharges with line-averaged central density of 2.5×10^{13} cm^{-3} and NBI input power of 1.4 MW at radial distances from 0 to 2 cm from the last closed flux surface. The dust launch occurred either in the beginning of the discharge at t=0 s or at t=1.5 s when NBI injection was activated. Preliminary analyses of the recorded video sequences evidenced the launch of dust in a direction perpendicular to the toroidal magnetic field [Fig. 2(b)], possibly because of **E**×**B** drift due to polarization of the localized ablation cloud.

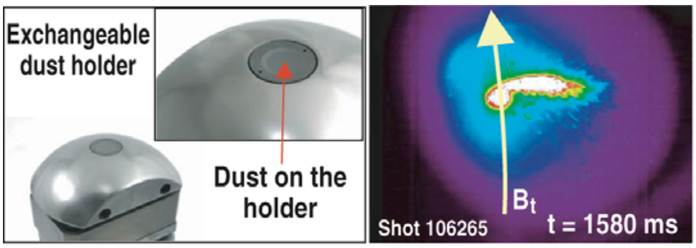

Fig. 2. The dust experiment in TEXTOR: (a) spherical graphite test limiter with exchangeable holder and dust; (b) the launch of dust at the beginning of NBI phase.

In summary, progress has been made in characterization of naturally occurring and artificially introduced carbon dust in DIII-D and TEXTOR. Micron size dust has been shown to be highly mobile, travelling at velocities of up to hundreds of m/s. Dust does not present operational concerns in DIII-D except immediately after entry vents. Disruptions produce notable amounts of dust, but dust production by disruptions alone is insufficient to account for the estimated in-vessel dust inventory in DIII-D. ELMs are also observed to produce dust in DIII-D. These impulsive sources of dust remain a concern for ITER, where wall loads from ELMs and disruptions will be very large compared to those on DIII-D.

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