Management of dust in fusion devices.

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Abstract:

Dust generation in next-step fusion devices will inexorably increase with the longer plasma duration, higher stored energy and more intense plasma-wall interaction. This poses issues for (i) public safety, (ii) vacuum vessel integrity in accident situations, (iii) plasma contamination and (iv) diagnostic first mirrors. The dust inventory will be regulated, however methods to measure dust inventories or remove dust when it approaches safety limits are in their infancy. Management of dust inventories will be a *requirement* for the operation of next-step fusion devices and the science and technology to do this needs to be developed.

Dust Production.

Dust is produced in tokamaks by plasma-wall interactions. While dust is not an operational issue in contemporary tokamaks, the increase in duty cycle and erosion levels in next step machines will cause a large scale-up in the amount of dust particles produced. The impact of energetic ELMs and disruptions on plasma facing components has been studied in plasma simulators[1]. Carbon plasma facing components can break up by brittle destruction producing dust particles. Co-deposited layers are particularly susceptible to disintegration because of their poor thermal conductivity and weak mechanical strength. Metals can melt and produce aerosols of metallic particles. Even under steady state conditions sputtered C_n clusters can chemically agglomerate to produce dust particles.

Dust Hazards

1. Dust particles may be radioactive from tritium or activated metals, toxic and /or chemically reactive with steam or air. Tritiated dust is respirable[2,3] and remarkably mobilisable due to its beta decay induced static charge[4]. A release of radioactive dust in an accident would have major consequences. To maintain public safety the mobilisable dust inventory of ITER will be maintained below 670 kg[5].
2. A more stringent constraint is that small quantities of dust on hot surfaces can undergo chemical reactions and lead to overpressure events that could rupture the vacuum vessel.

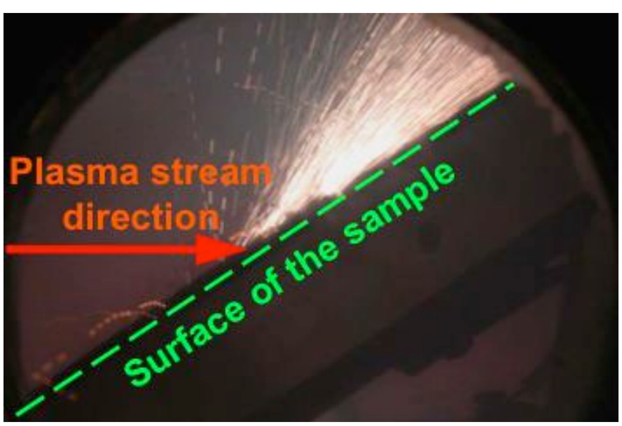

FIGURE 1. Tungsten droplet tracks in QSPA ELM simulator at Troitsk, 1.6 MJ/m2 first pulse. Ref. 1

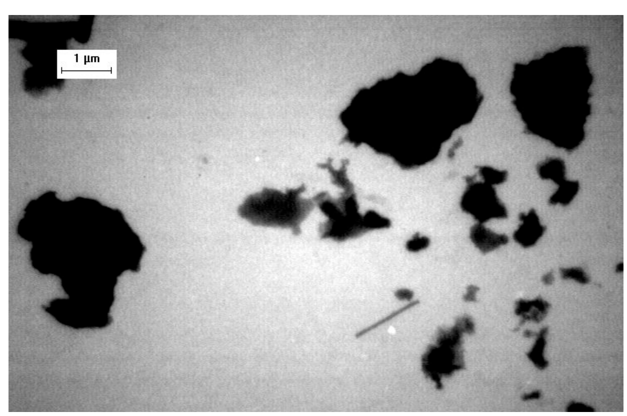

FIGURE 2. TEM microphotograph of tritiated dust particles from TFTR. The scale bar is 1 µm. The count mean diameter is 1.23 µm. Ref. 2

Significant quantities of hot dust for ITER are 6 kg of Be, C, and W dust, or, if carbon is not present, 11 kg of Be and 77 kg of W dust.

3. A third limit on dust is related to potential transport of tungsten dust to the plasma core. Tungsten is a very efficient radiator and the core tungsten concentration needs to be in the 10^{-5} range or below to sustain a burning plasma. However the relation between core tungsten and surface tungsten dust is not known at present.
4. Dust accumulation can 'blind' the first mirrors of diagnostics necessary for machine operation.

Dust Monitoring

The ITER strategy for dust measurement is based on erosion measurement, dust monitors and sampling. At present the erosion method conservatively assumes that 100% of eroded material is transformed into dust (limited experience in Tore Supra and JT60 suggests a number closer to 10%). This method does not appear sensitive enough to assure compliance with the hot dust constraint #2 above. Electrostatic and gravimetric dust monitors of surface have been demonstrated in the laboratory but paucity of funding has impeded the necessary demonstrations in tokamaks. Dust in plasmas has been observed by fast cameras and Thompson scattering and comparison to plasma transport models has begun.

Dust Removal

The ITER strategy is to rely on vacuum cleaning for dust removal. This will entail a major interruption in plasma operations, however for ITER the 670 kg dust limit is expected to be reached at about the same time as the planned shutdown for divertor replacement. This will not be the case in power reactors aiming at high availability. A electrostatic dust removal method that would not need a dedicated intervention was demonstrated by the Japanese in the ITER EDA, but has not been demonstrated in tokamaks. Vacuum cleaning of dust in tile gaps has not been proven.

Needed R&D

The scientific and engineering of practical methods to monitor and remove dust from tokamaks needs to become a higher priority for next-step fusion devices to be licensable by regulatory authorities. This R&D should be done in laboratories, tokamak and plasma simulator facilities and coordinated through the ITPA with related ITER R&D. Validated methods to monitor and remove dust from next step fusion devices will be required. In particular work is needed on:

1. Validation of surface dust measurement techniques in tokamaks including the measurement of small quantities of dust on hot surfaces.
2. Quantification of dust production rates.
3. Validation of dust plasma transport models to quantify plasma contamination.
4. Quantification of dust mobilization under accident conditions
5. Development and tokamak demonstration of fast and efficient methods to remove dust with minimal or no impact on availability for plasma operations.
6. Quantification of the impact of dust on diagnostic mirrors and development of countermeasures.

A next-step long-pulse, flexible, high power, hot wall machine with relevant first-wall materials and appropriate access and flexibility would be ideal to validate the most promising candidates for dust monitoring and removal. Previous reviews of dust in fusion devices may be found in refs. [6,7,8,9,10,11,12,13,14].

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