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Dust in ITER: Diagnostics and removal techniques

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A B S T R A C T

Dust will be present in ITER and will be an issue in terms of safety. The ITER strategy for dust management is based among others on the definition and respect of dust inventory limits. To ensure that the safety limits are fulfilled, dust diagnostics and removal techniques need to be developed considering the Tokamak environment constraints (magnetic field, radiation, vacuum and temperature). This paper presents possible dust inventory build-up monitoring strategies for different periods of the machine operation (during/between pulses and during short or long maintenance periods). The strategies rely on the use of a set of complementary techniques for dust diagnostics and removal.

1. Introduction

In Tokamaks, dust is produced by the interactions between the plasmas (operation and conditioning) and the plasma facing materials [1,2]. Particles with diameters between 100 nm and 100 μm are considered as dust. So far, in existing Tokamaks, dust has not represented a major issue either from operational or safety points of view. Nevertheless, the situation will be different in ITER, in particular because of the activation of the materials, the presence of tritium and beryllium.

In ITER vacuum vessel (VV), various hazards are linked to dust: environmental impact in case of dust spreading, production of hydrogen in case of steam ingress and explosion hazard.

In order to control the dust hazard, the current ITER strategy is based on a defense in depth approach designed to avoid failures, minimise, detect and measure the inventory with respect to safety limits and rely on mitigation systems.

Concerning the safety limits [3], they have been set to 100 kg of W, 100 kg of Be and 200 kg of C mobilizable dust inside the VV and 6 kg of W, 6 kg of Be and 6 kg of C on the hot surfaces of the divertor (temperatures higher than 400 °C for Be or W, and 600 °C for C). These sets of limits could be reviewed with the removal of C tiles from ITER during the DT phase.

The aim of this paper is to review techniques that could be used to control the dust inventories in ITER.

2. Diagnostics for dust monitoring

A review has been performed [4] to list the diagnostics that could be used for dust monitoring, based on the experience gained from various fields (fusion, dusty plasma, electronics, space industry, etc.).

Many of the identified diagnostics can provide basic information on the creation, transport, accumulation areas, etc. Because of the constraints in a Tokamak environment, some techniques appear more attractive and promising. Analysis of the laser scattered light (intensity or light extinction spectroscopy [5]) can be used to assess the size distribution of particles in suspension (diameters smaller than 10 μm). These techniques rely on a proper and difficult modeling of the electromagnetic scattering properties of the dust to take into account their complex characteristics (shape, size and composition). The observation of the plasma edge via visible or infra red cameras, during normal and off-normal plasmas, could also be used to determine the areas where dust is created/mobilized and transported. After a careful calibration (injection of calibrated dust) and the use of superimposed laser sheets, information on dust size and speed could also be obtained. Gravimetric diagnostics [4] such as capacitive diaphragm microbalance or electrostatic grids could be used to obtain data on the local particle concentrations. Finally, dust could be collected through a robotic arm for extensive external analyses (size distribution, quantity, composition, etc.). These techniques, since they are typically (except the robotic arm) operating on a 'shot by shot' basis, could enable a link the plasma operation scenarii with dust transport, mobilization and maybe production. Nevertheless, they do not provide data on the global masses inside the VV or on the hot surfaces of the divertor. They thus have no straightforward application to

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the safety limits but are still valuable in particular if coupled to modeling.

Other techniques thus need to be selected for safety purpose. Concerning the limits inside the VV, since there are many shadowed areas that are difficult to monitor, it is propose to consider the PFC erosion as a potential source of dust creation. The conversion factor between gross erosion, net erosion and mobilizable dust could be determined using the data provided by the diagnostics listed above and/or using the feedback from current Tokamaks and ITER. In particular, significant collection of dust could enable to establish the dust inventory inside the VV and provide more confidence on a realistic conversion factor. In a first estimate, 100% of the net erosion source could be used as an envelope value for the upper limit of the dust creation. Of course, efforts should be put to assess more accurately the conversion factor in order to limit the removal needs and thus the impact on operation time. Techniques such as spectroscopic measurements of the impurities in the edge plasma (plasma facing materials or selected dopants inserted inside the tiles [6]), or Speckle interferometry [7], could be used to determine the net erosion source.

Concerning the limits on the hot surfaces of the divertor, it is proposed to monitor the deposition quantities (including layers and dust). This is justified by the fact that the stability of the deposited layers in this area is difficult to determine. Moreover this set of limits is driven by the impact of the material specific surface area (SSA) on the H_2 production. From the current feedback in existing Tokamaks, deposits and dust have SSAs of the same order of magnitude. Infra red thermography [8] coupled with laser induced breakdown spectroscopy [9] for the deposit thickness calibration, or Speckle interferometry, could be used to obtain a mapping of the deposited areas in the divertor region (including the tile castellations). Because of the specific geometry of the divertor, the observation of the lower vertical targets, leading to glancing incidence for the optical measurements, will have to be carefully addressed. However the management of the dust on the hot surfaces of the divertor (as well as in the VV) could also rely on removal techniques.

3. Removal techniques

Once the dust inventory limits (within the uncertainties) are reached, it will be necessary to remove the dust from the VV. Dust is expected to accumulate on the horizontal surfaces of the ports and in the divertor region (see Fig. 1). The removal of dust, flakes and deposited films from the vessel is a three stage process comprising material mobilization (unsticking materials from the surfaces including gaps/castellations), collection of the mobilized materials and transport within/outside the vessel. Depending on the objectives of the removal, various techniques could be foreseen.

Regular removal could be envisaged to avoid an increase of the inventory during operation periods. This concerns the hot surfaces of the divertor that could be cleaned by laser [10]. After mobilization, the dust could be transported to areas not in direct interaction with the plasma where the safety constraints would be reduced. This regular removal can also be foreseen for the global inventory inside the VV. Lasers could be used for mobilization, while collection could be done by charged electrodes or cold fingers. The transport outside the VV still needs to be addressed in this case. Other techniques, relying on a permanent system (electrostatic [11,12] or vibrating [6] conveyors) installed between the divertor cassettes and the vacuum vessel, have also be foreseen. Even if they can be efficient, the space required and the maintenance of such systems are still an issue.

Removal can also be performed at a larger scale once dust inventory is close to the limits. Dust could be mobilized via laser or flash lamps [6] and collected with a vacuum cleaner. This would require shutdown time to deploy a dedicated articulated arm and to break down the vacuum (for better efficiency of the vacuum cleaner).

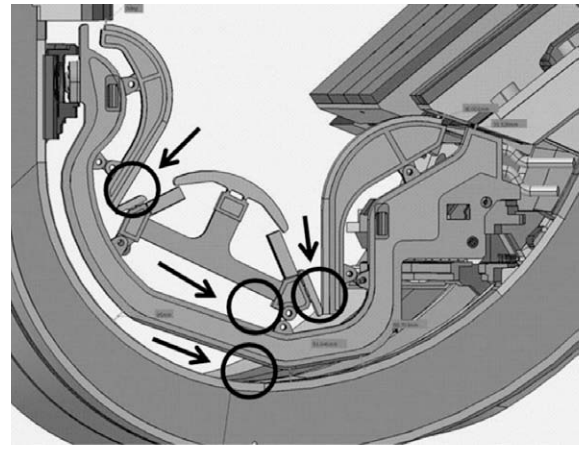

Fig. 1. ITER divertor with expectable accumulation areas (circle and arrows).

Finally, extensive removal (even behind tiles and under the divertor cassettes) must be anticipated. This would be required at least when the material configuration is changed but could be needed earlier if the dust inventory under the divertor cassettes is identified as an issue. Liquid [8] or gas blasting could be used to mobilize and collect the dust that could then be evacuated in drains present in two ITER lower ports. In the latter case, the impact on the machine conditioning and the fluid processing need to be addressed.

4. Conclusion

Various potential techniques have been identified for the control of dust inventory. There is no 'ideal solution' yet and further efforts are needed to check the technical feasibility of these solutions in the current ITER design. Moreover the strategy has also to include the dust management outside the vacuum vessel, i.e., from the hot cells to the final disposal.

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