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Dust mobilization experiments in the context of the fusion plants—STARDUST facility

M.T. Porfiri [a,*], N. Forgione [b], S. Paci [b], A. Rufoloni [a]

[a] *Associazione Euratom-ENEA sulla Fusione, via E. Fermi, 45-00044 Frascati, Italy*
[b] *Pisa University, Via Diotisalvi 2, 56100 Pisa, Italy*

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Abstract

This paper deals with the dust mobilization in fusion facilities, in which the plasma disruptions induce an erosion of small particles causing external releases if accidents occur. In the ITER safety guidelines the administrative limits of 200 kg carbon, 100 kg beryllium and 100 kg tungsten inside the VV have been fixed to avoid the population evacuation in case of accident. The conservative assumption to mobilize all these dusts is adopted in the accident analyses. To support a less conservative hypothesis some experiments have been performed inside the STARDUST facility (ENEA Frascati laboratories, Italy). The ECART code has been used for blind simulations to validate the dust transport model implemented. The results match satisfactorily the experiments. The dusts used were carbon, stainless steel, tungsten and a mixed dust (C, SS, W). The experiments represent a LOVA due to a small or a large air leak through two different VV ports. The measured mobilization rate ranges from 0.03% to 100% of the total amount of dust. That means the mobilization is strongly dependent on the relative position between air inlet and dust location and that the dust mobilization assumptions in the accident analyses shall be reduced, in some cases of several factors.

Keywords: ITER; Dust mobilization; STARDUST; ECART; LOVA

1. Introduction

For a fusion experimental device like ITER the dust mobilization is one of the main safety concerns.

In fact the plasma disruptions and the bumps of the plasma against the first wall or the divertor structures cause significant erosions of mobilizable materials. In ITER the administrative limits for dust inside the VV have been established as 200 kg of carbon, 100 kg of beryllium and 100 kg of tungsten, on the base of the estimated dust radioactivity. These limits have been developed to avoid, also in the case of severe accident, the evacuation of the population from the area surrounding the plant.

In the past, several experiments have been performed to characterize the aerosol particles behavior in

* Corresponding author. Tel.: +39 06 94005624;
fax: +39 06 94005314.
E-mail address: porfiri@frascati.enea.it (M.T. Porfiri).

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dry and wet conditions in a nuclear fission power plant. On the contrary, the literature relative to the fusion plants is poorest, due to the limited number of fusion facilities. The extrapolation of the results obtained for fission is not possible, because of the different mechanism of dust production, having a strong influence on granulometries and topologies of the dusts, and of the different thermal hydraulic conditions in the facilities. The scope of the STARDUST experiments is to build a base of knowledge about the dust behavior in a fusion plant, in which pressure vacuum conditions and relatively high temperatures are present, when a loss of vacuum accident occurs.

2. The STARDUST facility

The STARDUST facility is a stainless steel cylindrical tank heated up by electrical resistances. The scheme of the main components of the apparatus is shown in Fig. 1. A data acquisition system allows to control the pressure, the wall temperature and the air inlet flow rate in order to perform the experiments in the desired conditions and to collect the main data. The dust is placed in a tray sited in the bottom part of the tank, at the divertor level. The vacuum pump evacuates the air until a pressure of few Pascals is reached. Then the air inlet through the flow meter is calibrated before introducing the gas according to the desired pressurization rate: 27 l/m for 300 Pa/s and 149 l/m for a pressurization rate of 3000 Pa/s, given the shaft of the valves A and B. When the tank pressure equalizes the atmospheric pressure, the tank can be opened, the dust tray extracted and weighed to verify the dust amount moved from the tray in the experiment.

3. Dust characterization

The type of dust utilised (tungsten, carbon and stainless steel) is similar to that existing inside the vacuum chamber of a fusion device, when the plasma facing materials vaporize for the high energy deposition. Analyses by means of a SEM were necessary to characterize in a more accurate way the commercial dust used in the experiments. The mean diameter measured for carbon was 4–5 μm, for tungsten 0.3–0.5 μm and for stainless steel 20–30 μm.

Four types of experiments have been performed, changing the dust material: with only carbon, with only stainless steel, with only tungsten and with a mixing of the three types (one-third each of the three materials).

The amount of dust in the experiments was 5 g for tungsten and stainless steel, 2 g for carbon and 3 g when a mixed dust was used. It has been deposited on a tray (with a surface of 25 cm^2) to reproduce a surface density, in terms of g/cm^2, representative of that expected in the ITER VV.

4. Matrix of the experiments and results

The matrix of the experiments is reported in Table 1, together with the results in terms of percentage of dust mass resuspended. The label of each experiment follows the criteria reported below:

- first part is the type of dust (W, SS, C or M for mixed dust);
- second part is the position of the air inlet (A for the equatorial port level, B for the divertor port level);
- third part is the pressurization rate (300 Pa/s for slow pressurization rate, 3000 Pa/s for the fast one).

For each type of experiment several trials have been carried out [1,2], to collect reliable resuspension data, unless the results were congruent and clearly evident after a couple of tests.

For the experiment M_B_300 same dust samples (related to the 17 stubs as shown in Fig. 2) have been collected and analyzed by EDX (energy dispersive X-ray) to check the composition distribution of the redeposited dusts in different positions inside the tank by means of the microanalysis.

The results for the stubs 2, 14 and 17 are shown in Fig. 3. It must be taken into account as the high contribution of carbon is due to carbon dust presence, but above all, to the material of the adhesive tape in the stubs, made essentially of carbon, that was necessary to collect the dust for the SEM. In the microanalysis it was impossible to remove this contribution.

Due to the light weight and the relative small size of the carbon dust, its presence in the stubs has to be considered as a constant in all the samples collected. The differences to be highlighted is the relative amount of tungsten in all the samples, significant in the lower stub 2 and the absence of stainless steel (Cr and Fe are