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Erosion of dome armour after multiple disruptions and ELMs in ITER

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1. Introduction

In the future tokamak ITER a part of confined plasma is dumped onto the divertor armour during intense transient events (TE) such as disruptions and bursts of the Edge Localized Mode (ELM). This may result in surface melting and evaporation. During one ITER discharge about 10^3 ELMs are expected, and during ITER operation several hundred disruptions interspaced by ELMs may occur [1]. The heat load of a single giant ELM or a disruption causes a plasma shield being formed from evaporated material in front of the target [2]. This shielding layer is a source of intense radiation with durations up to 1 ms for ELMs and up to 15 ms for the disruptions. The intense radiation exposes the surface of the dome elements nearby, which may cause their melting, evaporation, and formation of own plasma shield [3,4]. Radiation power is also deposited on the surface of dome gaps and in the gaps between divertor cassettes thus yielding additional damage.

The walls of the cassettes are designed as so called 'sandwiches' to be made of copper plates covered with either pure sintered W or tungsten lamellae [1].

The energy range of TE, which causes the dome damage, should be estimated as well as tolerable number of the multiple TE.

In this study the results of numerical simulations of the melt motion erosion for a tungsten dome armour faced to the divertor plate, W-Cu sandwich inside the dome gaps, and the gaps between the cassettes after repetitive radiation heat loads caused by multiple disruptions with the energy deposition Q of 10-30 MJ/m^2 and the duration t of 1-10 ms are presented. It is to note that corresponding simulations for ELMs have revealed that the heat loads in the range of Q= 1-4 MJ/m^2 and t = 0.2-0.5 ms do not cause any erosion of the dome elements. The target melt motion erosion is calculated with the fluid dynamics code MEMOS-1.5D described in [3]. Radiation fluxes at the dome surface and the divertor plate are calculated with the magneto-hydrodynamic code FOREV-2D [5].

2. Main implications

It is assumed that the heat flux profiles have a pronounced peak near the separatrix strike position (SSP); SSP stochastically changes along the divertor plate from one TE to another TE having the Gaussian distribution with the dispersion ranging from 0.05 and 0.1 m.

Two scenarios are presented: 1) short-time disruption with the SSP heat load Q=12 MJ/m^2 and t =1 ms and 2) long-time disruption with Q=30 MJ/m^2 and t =10 ms. Typical geometry of FOREV-2D calculations is shown in Fig.1 (A - divertor plate, B - dome lateral surface, C – edge surface of W-Cu sandwich). Fig. 2 demonstrates the calculated radiation at the lateral walls of the dome.

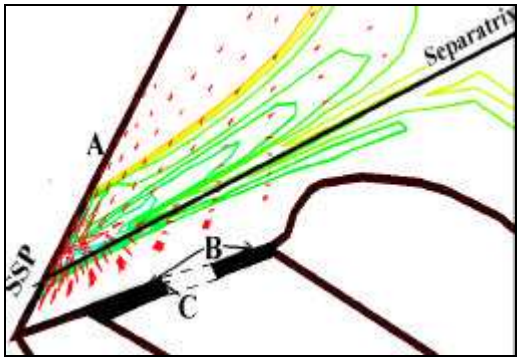

Fig. 1. Sketch of divertor geometry. The contours of plasma density and the arrows of radiation fluxes are plotted

The radiation transport in the plasma shield near the divertor surface is calculated using 45 groups of non-LTE Rosseland opacities for tungsten [6]. The absorption of the radiation heat load in the material vaporized from the dome surface is roughly taken into account, using the Bouguer low and the Rosseland opacities. For multiple TE the total erosion is composed the erosions of sequential TE with the stochastically varied SSP.

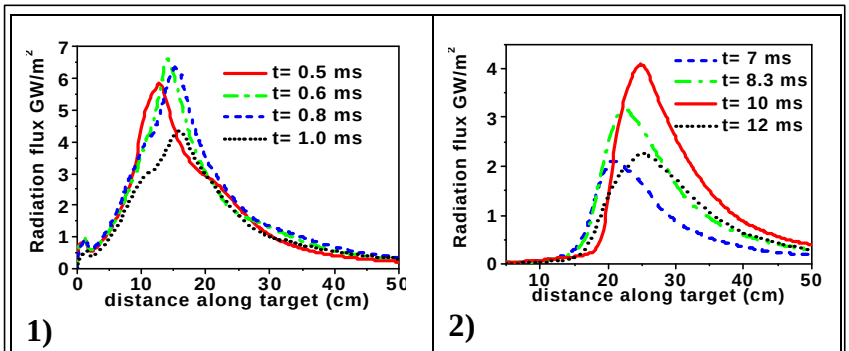

Fig. 1. FOREV-2D profiles of heat load at the dome surface for both disruption scenarios

The melt motion is described in the 'shallow water' approximation, with account of the surface tension and viscosity of molten metal. The plasma pressure gradient along the divertor plate, as well as the gradient of surface tension produce the melt acceleration. A two-dimensional heat transport equation with two boundary conditions at the moving vapor-liquid- and liquid-solid interfaces describes the temperature inside the target. Two variants of the thickness of W armour of the sandwich are simulated: h=0.5 cm and h=1 cm.

It is worthwhile notify that the calculated load gives a lower estimation for the expected damage. The Rosseland opacities underestimate the radiation flux and comprehensive calculations (using for example Lebesgue approach [6]) can result in a factor up to 2 and in decreasing the energy threshold for dome damage.

3. Simulation results

Simulations for the dome armour damage under radiation heat loads caused by single ELMs with W =4 MJ/m^2 and t = 0.2÷ 0.5 ms demonstrated that the temperature of W armour remains always below the melting point, which is due to a rather short irradiation time. The temperature of the edge surface inside the dome gaps is also below the melting points of W and Cu. In case of giant ELM with W=6 MJ/m^2 and t=0.5 ms the tungsten armour melts without noticeable evaporation: the melt pool depth reaches 70 µm. Only in case of disruptions the dome damage may get significant.

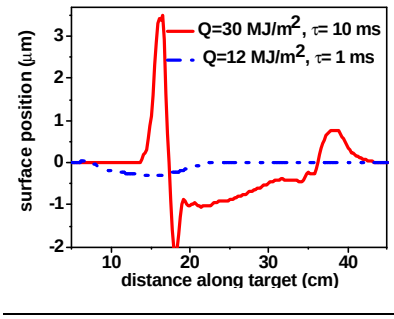

Fig. 3. Surface roughness of dome surface after single disruption

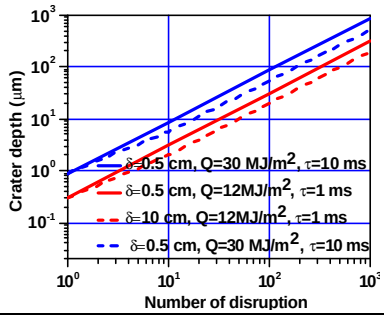

Fig. 4. Crater's maximum depth versus disruption number for d=0.5 and d=10

Erosion of dome armour (the surface B of Fig. 1**).** For both simulated scenarios the radiation fluxes at the dome surface reach 2-7 Gw/m^2 with the width of most irradiated area of 0.3-0.5 m, during several ms for the first scenario and more than 10 ms for the second one. The melt depth reaches 170-200 µm and the power at the dome surface is high enough to evaporate W atoms amount sufficient for formation of a rather thick "secondary" shielding layer near the dome surface, with the plasma pressure of 1-2 bars. For both scenarios about 0.2-0.3 µm of W armour is evaporated after each disruption. The pressure gradient generates violent melt motion with the velocities below 0.6 m/s in both directions from the position of radiation flux maximum. After resolidification, the total magnitude of surface roughness is about 3 µm for the long-time disruption scenario (Fig. 3), and in case of short-time disruption the melt motion only weakly influences the total erosion profile the after material loss about 0.3 µm caused mainly by the evaporation.

The simulation for the consequences of multiple disruptions implies the erosion additivity for multiple events as it was assumed for sequential ELMs in [7]. The plasma shield location and thus the position of radiation flux maximum changes in the same way as the SSP does. Fig. 4 demonstrates the maximum crater depth versus the number of disruptions for the Gaussian distribution of SSP with $\delta = 0.1$ m and 0.005 m. For both scenarios the total erosion of the dome surface is below 1 mm after 10^3 disruptions. In

assumption of stochastic motion of SSP the crater depth decreases by factor 1.5-2.

Erosion of edge surface of W-Cu sandwich (the surface C on Fig.1). Due to a geometric factor, the radiation fluxes impacting on the edge surfaces of the W-Cu sandwich inside the dome gaps are slightly less than the fluxes shown in Fig. 2. Nevertheless, the radiation causes melting of W armour up to the depth of 100 µm and the melting of unprotected Cu plate up to the depth of 200-300 µm (Fig.5).

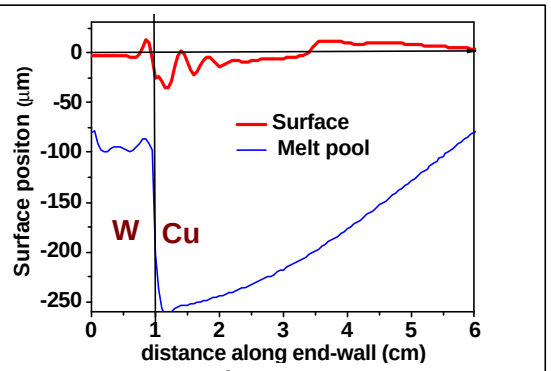

Fig. 5. Final surface roughness and the depth of melt pool at the dome edge. Q=30 MJ/m^2 and t =10 ms

The power at the edge surface is high enough to evaporate significant amount of Cu atoms and form a rather thick secondary shielding layer near the edge surface, with the plasma pressure of several bars. This leads to violent melt motion along the gap surfaces with the velocities exceeding 1 m/s and thus to significant melt motion erosion of copper surface up to 30 µm (per one disruption), and the melt motion erosion of the edge nearby W is about 4 µm.

In case of ELMs, the numerical simulations of erosion in the deep gaps between the divertor cassettes resulted in not damaged copper surface deeper than 0.5 cm. For the disruptions, this safety depth increases up to 1.2-1.3 cm.

3. Conclusion

Numerical simulations demonstrated that in case of disruptions a significant erosion of dome armour can be expected.

To prevent possible damage, all dome surfaces opened for the radiative heat load from the shielding layer in front of the divertor surface should be protected by tungsten armour.

More detailed numerical simulation of the dome surface erosion under the intense transient events is necessary using the Lebesgue opacities for tungsten plasma.

References

[1] ITER Physics Basis, Nucl. Fus., 39 (1999) 2137. [2] H.Wuerz et al., J.Nucl.Mater., 290-293 (2001) 1138. [3] B.N. Bazylev, H.Wuerz, J. Nucl. Mater., 307-311 (2002) 69. [4] H.Wuerz et al., J. Nucl. Mater., 307-311 (2002) 60. [5] S.E. Pestchanyi, B.N. Bazylev and I.S. Landman., 31st EPS Conference on Plasma Physics, http://eps2004.clf.rl.ac.uk/pdf/P1_135.pdf. [6] H.Wuerz et al., Fusion Science&Technology, v. 40 (2001) 191. [7] B. Bazylev et al., Europhysics Conference Abstracts, Vol. **27A**, P-2.44.