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Modeling of Plasma Energy Loads and First Wall Material Damage during Disruptions and Vertical Displacement Events on ITER

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Successful operation of ITER depends critically on disruption management for the Pre-Fusion Power Operation (PFPO) phase up through Fusion Power Operations (DT). The power-handling capabilities of the beryllium (Be) first-wall panels (FWP) and other plasma-facing components (PFC) must be preserved in the face of disruptions and vertical displacement events (VDE). This need should account for intentional, low-power events required for electromagnetic load validation in the early operation phases, along with unintentional events that will usually be mitigated by the ITER Disruption Mitigation System (DMS). Multiple characteristics of the disruptions and VDEs influence the time-dependent heat flux and energy deposition onto the PFCs, which then determine the increase in surface temperature, melt formation, and material loss from melt motion and vaporization. Even for relatively low plasma current scenarios during the early operational phases (I_P = 5 MA), initial studies predicted Be melt damage from upward VDE current quenches (CQ) up to ~0.5 mm deep and lateral melt displacements up to ~10 cm for single events [1]. The implication is significant, and extensive damage to Be surfaces due to such events has already been clearly documented on JET [2].

This presentation will detail the extensive studies being performed at ITER to estimate material damage to the Be FWPs during disruptions and VDEs. The simulation efforts described in [1] are significantly expanded to cover a range of VDE and disruption scenarios, allowing for a broad series of parametric studies using a novel simulation workflow developed at ITER. The methodology links together DINA plasma equilibria simulations [3], SMITER 3D field line tracing [4], time-dependent melt formation and dynamics from MEMOS-U [5] with plasma vapor shielding [6], and regeneration algorithms for melt-damaged FWP surfaces. This capability allows for an assessment of heat loads on the damaged panel from either steady-state scenarios or a subsequent VDE/disruption. Preliminary results emphasize the importance of a multi-physics workflow in estimating a realistic lifetime for the ITER blanket. The introduction of Be vapor shielding, for example, significantly reduces the incoming heat flux impacting the FWPs, with vapor shielding efficiencies approaching 70 – 80% in some cases. Such strong shielding substantially slows the surface temperature rise, leading to less-severe melt thickness, melt motion, and surface deformation. The surface deformation, consisting of excavated pits and melt ridges, is shown to influence the local power loading for subsequent events, increasing $q_\perp$ by 15 - 35% for sub-mm deformation. Variations in Be impurity density (1 – 3 x 10^{19} atoms/m^3) in the CQ plasma are shown to significantly modify the disruption timespan, total energy deposition, and first wall limit location. Variations in I_p and the power traversing the last closed flux surface, $P_{sol,}$ will have a direct influence on the time-dependent energy deposition, leading to a factor of 5 impact on $q_\perp$. Work is ongoing to complete these parametric studies, where the most limiting events will be thoroughly explored and presented herein.

References

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