Energy deposition and melt deformation for ITER vertical displacement event scenarios

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Successful operation of ITER depends critically on disruption management for the Pre-Fusion Power Operation 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), including intentional events required in the early operation phases for disruption load validation. Multiple factors 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 ITER’s early operational phases ($I_P = 5$ MA), initial studies predict Be melt damage from upward VDE current quenches (CQ) up to ~0.5 mm deep for single events [1]. The implication is significant given the ~10mm Be armor thickness on the majority of the ITER FWPs. Extensive damage to Be surfaces due to such events has already been clearly documented on JET.

This paper continues the efforts in [1], reporting on an extensive series of parametric studies of VDE scenarios for ITER. A similar methodology is utilized: 2D magnetic flux profiles from the DINA code provide input to the SMITER 3D Field line tracing software, producing 3D maps of $q_\perp$ and $\vec{B}$ on the FW panels. These maps then yield the time-dependent melt formation and dynamics via the MEMOS-U code. The DINA simulations provide heat fluxes and current densities in the halo region from a full power balance, including radial transport, ohmic heating, radiation and losses along field lines. Additionally, a new library of vapor shielding efficiencies is incorporated into the MEMOS-U simulations. The vapor shielding is characterized using the 1-D PIXY code [2] taking into account plasma parameters from DINA, allowing for a time-dependent heat flux modified by the shielding effect based on heat flux magnitude and Be vaporization rate. The shield is shown to equilibrate rapidly, in ~1-2 ms, relative to the ~200 ms VDE energy deposition. The parametric variables of interest with regard to Be erosion include uncertainties in power into the halo region, variation in the CQ plasma position, variation in deposited magnetic energy (based on $I_P$) uncertainties in Be material properties, and Be impurity density (affecting the CQ time), for upward and downward VDE scenarios at low $I_P$. Finally, the lifetime consequences of exposing a damaged FW panel geometry to both steady-state heat fluxes and multiple VDEs will be explored and presented.