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Advances in predictive thermo-mechanical modelling for the JET divertor experimental interpretation, improved protection, and reliable operation

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The JET targets are the in-vessel components which receive the largest sustained thermal load. Operating instructions limit the energy and maximum surface temperature allowed for each shot, while IR cameras are used for protection during each discharge.

Surface delamination and radial cracks have been observed in the outboard tungsten-coated CFC tiles, while bulk tungsten special lamellas were intentionally melted in dedicated experiments. These different types of damage were not reproducible using existing models and tools. Several analysis and development activities have been performed during the last campaigns for their improvement, covering from the prediction of the plasma parallel heat flux density to the transient thermo-mechanical behaviour of the tiles.

The parallel heat flux density is reconstructed from the surface temperature measurements—acquired by the experimental IR cameras—using inverse analysis techniques. New inverse algorithms have been developed for a realistic representation of the tile geometry and coating thickness. A set of geometrical and loading projection corrections have been introduced which explain a reduction of the measured parallel heat flux density of up to 1/3 when compared to previous estimations.

Once the corrected parallel heat flux has been characterized, predictive analysis can be run for ensuring that the maximum temperature and stress remain within the allowable limits. The integrity assessment of the tiles uses a profile of the heat load defined by an engineering footprint, which has been correlated to several plasma parameters. The engineering footprint averages the inter-ELM, ELM transients, and associated strike point movements, leading to a wider footprint compared to that obtained using typical inter-ELM scaling laws. This has turned out to be critical for replicating the deformation effects of the tiles. The observed failure modes can now be reproduced—and therefore avoided—by means of coupled-field 3D thermo-mechanical models.

All these improvements have been implemented in integrated analysis tools which can predict the behaviour of the divertor tiles in a power consistent manner. This development carried out at JET supports the experimental understanding, enhances the real-time protection systems, improves the evaluation of the operating instructions, and is also transferable to ITER.

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