IAEA FEC 201

Contribution ID: **4** Type: **Poster**

Plasma Instabilities Represent Serious Threat for a Successful Tokamak Concept

Thursday, 20 October 2016 14:00 (4h 45m)

Plasma-material interaction (PMI) in future Tokamak fusion devices such as ITER is probably the most critical issue in the development of fusion power and a serious obstacle that is difficult to overcome. Plasma instability events such as disruptions, resulting runaway electrons, edge-localized modes (ELM), and vertical displacement events (VDE) are all very serious events and potentially the limiting factor for successful Tokamak concept. The plasma-facing components (PFC), e.g., wall, divertor, and limited surfaces of the Tokamak as well as coolant structure materials are subjected to intense particle and heat loads and must maintain a clean and stable surface environment among them and the core/edge plasma. This is critical to fusion device performance. Comprehensive research efforts are being developed utilizing the HEIGHTS simulation package to study self-consistently various effects of high particle and power transients on material operation/selection. The upgraded full 3D simulation package consists of several modules that fully integrate various stages of PMI response starting from energy release from the bulk to scrape-off-layer and up to the transport of the eroded debris and splashed wall materials as a result of the deposited energy/particle fluxes. The integrated models predict material loss, PFC lifetime from transients, and effects on core plasma performance in real Tokamak/ITER full 3D geometry. The package is extensively benchmarked against various worldwide laboratory and fusion devices as well as for other fields of science including nuclear, high-energy physics, and laser and discharge produced plasma devices for lithography. HEIGHTS is then used to identify safer operating window regimes and upper transient limits that PFC can withstand during various instabilities. Recent simulation, for example, predicted serious damage from plasma disruptions to nearby and hidden locations from secondary radiation resulting from PMI on original disruption area. This couldn't be predicted without comprehensive 3D realistic geometry integrating all processes taking place. Potential melt-layer erosion and splashing is also predicted during plasma transients interaction with liquid layers. In addition, various mitigation methods and their effectiveness are evaluated in more details.

Paper Number

TH/P6-21

Country or International Organization

USA

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Session Classification: Poster 6

Track Classification: THD - Magnetic Confinement Theory and Modelling: Plasma–material interactions; divertors, limiters, SOL