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Verification of TOKES simulations against the MGI experiments in JET

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ABSTRACT

The integrated tokamak simulation code TOKES is proposed for estimation of the ITER first wall radiation damage during massive injection of noble gas inside the core for mitigation of the disruptions. Simulations of MGI processes ab initio are almost impossible because of complexity of the problem, but one can get reliable results elaborating the TOKES scenario from JET experiments and applying it for ITER conditions. With this aim the TOKES code is used for simulation of JET shots disrupted with MGI. The TOKES scenario for the thermal quench of MGI at JET and its extrapolation to ITER have been developed basing on analysis of the available JET database and on comparison with the simulations performed.

1. Introduction

Deuterium–tritium (DT) plasma is confined in the ITER reactor core with closed magnetic field surfaces, but the stability of the core plasma may be violated due to intrinsic instabilities or due to strong external influences, so the discharge may run into a disruption.

Unmitigated ITER disruptions will probably damage the first wall of its vacuum vessel with direct plasma impact causing significant melting and vaporization [1]. Fast injection of a noble gas (NG) can mitigate the disruption, transforming the DT plasma energy and the poloidal magnetic field energy into radiation [2]. Radiation redistributes the heat load over the first wall more evenly than the direct plasma impact does. Experiments in existing tokamaks demonstrated effectiveness of Ne, Ar and He gases or their mixtures with D_2 for mitigation of the DT plasma impact on the first wall and simulations [3,4]. Estimation of radiation heat loads during massive gas injection (MGI) of NG in ITER is the one of most important issues for its performance. We intend to use the TOKES code for evaluation of the ITER first wall damage during mitigated disruptions. Despite the lack of reliable scaling for the enhanced cross transport during the MGI, extrapolation of the MGI heat loads from existing tokamaks to ITER is possible.

The TOKES code has been developed in FZK–KIT for integrated two-dimensional simulations of thermonuclear reactors during the last 5 years, see [5] and references there. The simulations include interaction of the DT plasma with the divertor armour and vacuum vessel walls in configurations with diverted magnetic field. Initially the TOKES code model included one-dimensional simulation of the DT plasma inside the core using the magnetic flux coordinates. Recently the TOKES code has been developed for 2D multi-fluid, multi-ion species simulations in the confined region. This upgrade of the code is aimed for simulations of MGI. MGI in ITER is a very fast process lasting few milliseconds only, so generally the plasma and the radiation flux are 3D. The accuracy of 2D approximation for MGI is discussed in Section 2.3. This work is done for development of TOKES model and for verification of the 2D TOKES modeling of the thermal quench (TQ) of MGI against the experimental results from JET.

2. TOKES model for MGI simulations

2.1. TOKES code principles

The TOKES code performs simulations using the triangular grid, covering the interior of the tokamak wall poloidal section and assuming toroidal symmetry for all physical fields. The poloidal magnetic field is calculated solving the Grad-Shafranov equations using the magnetic flux determined in the peaks of the triangular meshes. After determination of the magnetic field the magnetic flux coordinates (MFC) are calculated. Both grids are illustrated in Fig. 1. The plasma parameters are given on the MFC grid. The plasma transport is simulated in fluid approximation and assumed to be two-dimensional: in directions parallel and perpendicular to the magnetic field.

Neutral gas parameters are defined in the centres of triangular meshes. The grid meshes are non-uniform, the mesh sizes are refined at the regions important for neutral gas transport

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[1] See the Appendix of F. Romanelli et al., Proceedings of the 23rd IAEA Fusion Energy Conference 2010, Daejeon, Korea.

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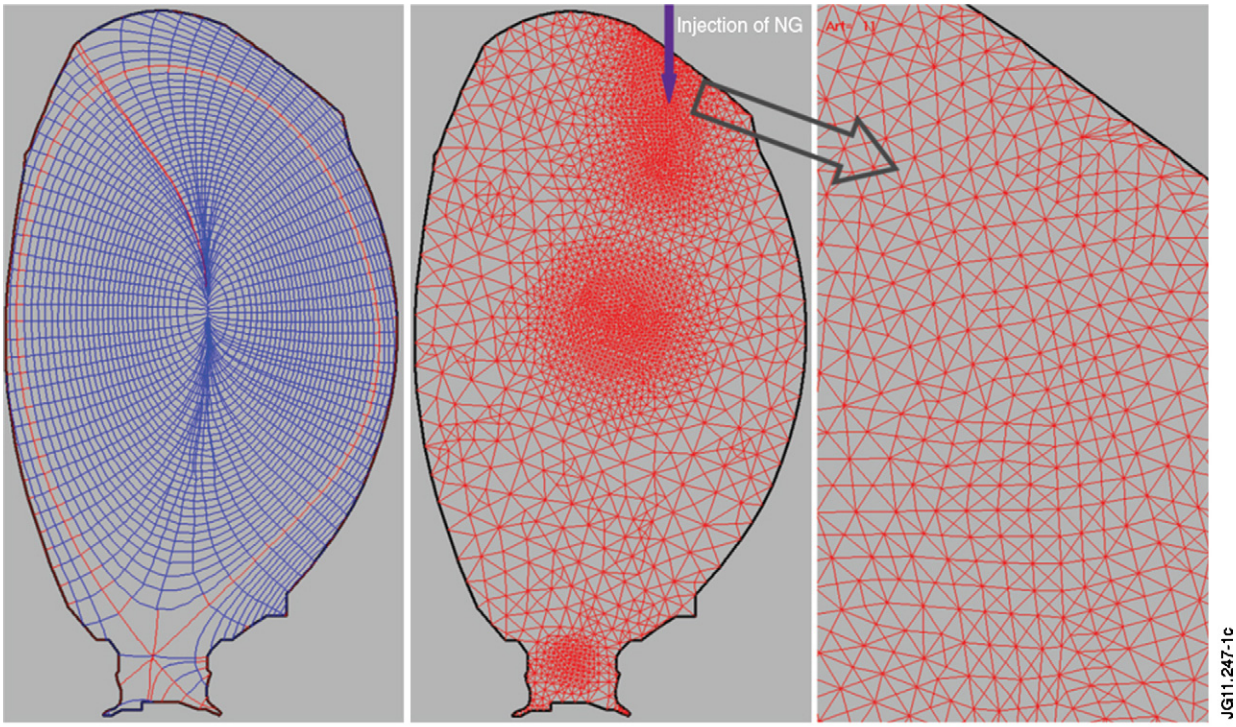

Fig. 1. Orthogonal magnetic flux coordinates for simulation of plasma dynamics and the triangular grid for propagation of neutral gas and for solution of the Grad-Shafranov equation. The triangular grid is densified along the NG injection line, near the magnetic axis and the *x*-point for better accuracy of the calculations.

simulations – along the direction of NG injection – and in sites important for the magnetic field calculation that is at magnetic axis and around the *x*-point. The neutrals interact with the plasma defined on MFC grid via thermal energy and momentum exchange, ionization, recombination and the charge-exchange.

The plasma transport is calculated in the confined region with closed magnetic surfaces as well as in the SOL and in the private region, where they intersect the wall. For facilitation of the MGI simulations we assume that the initial equilibrium configuration of the magnetic field does not change during pre-TQ and TQ, so the plasma transport proceed in the same MFC grid. This approximation is reasonable for pre-TQ and TQ and violates at current quench (CQ) stage. Here we restrict ourselves with MGI simulation from start to the end of TQ only. Simulation of CQ stage of MGI is a more challenging task, it needs simulation of the magnetic configuration evolution and modelling of runaway electrons generation and transport to the vessel wall. This is the aim of future activity for our group.

2.2. TOKES scenario

The TOKES scenario describes phenomenologically the enhanced cross-transport for different MGI stages. It defines the effective transport coefficients and the time moments for switching off and on the enhanced transport. It does not describe the physics of enhanced cross-transport and does not allow simulation of the MGI caused disruption ab initio. It is based mainly on energy conservation arguments, on the effective thermoconductivity value $\chi_{\perp eff}$ and on the timings observed from experiments.

Two JET pulses have been chosen for simulation of MGI. Most informative JET discharge disrupted with massive gas injection is JPN76314. For this pulse time dependencies for the edge temperature, T_{edge} for the temperature at the magnetic axis, T_c the total radiation power P_{rad} and the power at outer and inner divertor plates are available, see Fig. 2. Besides, during this pulse the radial and time dependence for temperature has been measured at the edge of the confined region in the midplane for approximately 30 cm from the separatrix as is seen in Fig. 3. But the pulse has

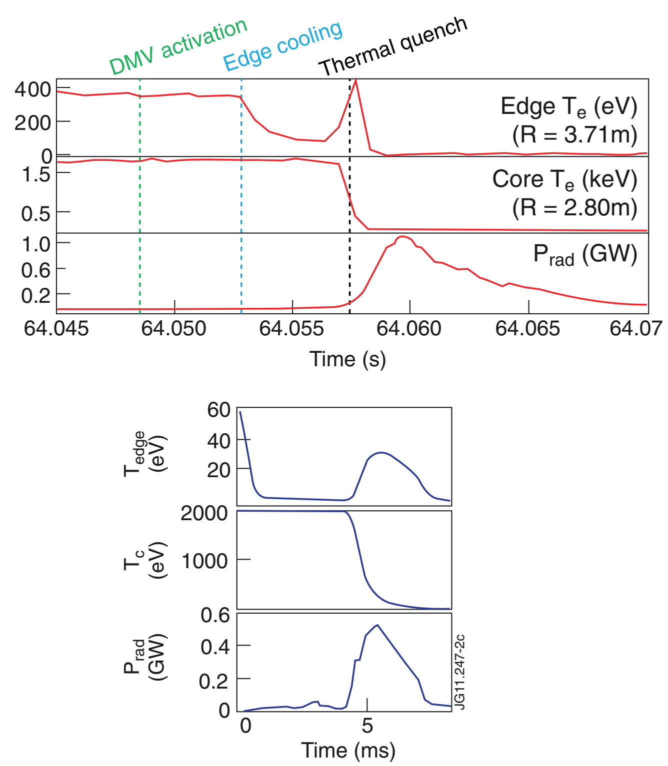

Fig. 2. Comparison of time dependences for T_{edge}, T_c and P_{rad} measured in JET pulse JPN76314 (upper panel) with the result of TOKES simulation for this pulse (lower panel).