Integrated Effects of Disruptions and ELMs on Divertor and Nearby Components

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Outline

- HEIGHTS Integrated Package
- Divertor Nearby Fluxes and Assumptions
- Application to ITER Divertor Area
- Simulation Results
- HEIGHTS Upgrade and Current Status
- Summary
Recent Publications

ELMs and Disruptions

1. V. Sizyuk and A. Hassanein, Damage to nearby divertor components of ITER-like devices during giant ELMs and disruptions, *Nucl. Fusion* (2010), Just submitted


Recent Publications (Cont.)

- **Vertical Displacement Events**


- **Runaway Electrons**

Capabilities of Integrated HEIGHTS Analysis

- MHD
- Radiation Transport
- Plasma/material Interaction

Energy Deposition (Ions, Plasma, Laser, Electrons)

Atomic Data

Target Thermal Conduction & Hydraulics
Physical Processes, an Integrated Approach

- Monte Carlo algorithm for SOL plasma impact:
  - Ions, electrons (initial and secondary), photons (secondary);
  - 3D Energy deposition into solid and plasma in magnetic field;
  - All scattering processes including Bremsstrahlung, Compton Absorption, Photoabsorption, and Auger Relaxation

- Thermal conduction:
  - Implicit scheme for heat conduction in plasma;
  - Explicit scheme for the heat conduction in liquid target;
  - Vaporization model for the solid target

- MHD:
  - Total variation diminishing scheme in Lax-Friedrich formulation;
  - Magnetic field divergence correction;
  - Implicit scheme for magnetic diffusion

- Radiation transport:
  - Weighted Monte Carlo algorithms;
  - More than 2500 spectral groups for divertor plasma;
  - Full 3D simulation
Major Results: VDE and Runaway Electrons

HEIGHTS modeling of LOFA and comparison with experimental data*

Modeling of Runaway Electrons Energy Deposition and Structural Response

- W of 0.8-mm thick
- W of 0.1-mm thick

HEIGHTS Integrated Package
Major Results: ELM and Disruptions

Depth of Tungsten Melting under Boron Layer B-W Combination (GA concept)
C.P.C. Wong, "Innovative tokamak DEMO first wall and divertor material concepts",


Tungsten Surface Temperature as a function of ELM Intensity for 1 ms-duration

C.P.C. Wong, "Innovative tokamak DEMO first wall and divertor material concepts",
Research Objective

Radiation to divertor nearby surfaces during ELM and disruption
Predicting heat loads in comparison to the strike-point

- 3D ITER Geometry
- Integrated Model
- Self-consistent Physical Processes
- ITER ELM Parameters:

Predicted:
"In a multi-device comparison it was found that the relative ELM size scales inversely with pedestal collisionality. Given the required high $T_{\text{ped}}$, this scaling predicts an unacceptably large ELM size, $\Delta W_{\text{ELM}} / W_{\text{ped}} > 15\%$, for ITER.**


Desirable:
"A maximum tolerable ELM energy loss limit of $\Delta W_{\text{ELM}} = 1$ MJ, which corresponds to $\sim 1\%$ of the pedestal stored energy $\Delta W_{\text{ped}}$ has recently been set.**

ITER Divertor Coordinate System


Application to ITER Divertor Area
HEIGHTS Computational Domain

Application to ITER Divertor Area
Plasma Impact @ ITER Divertor Surface

Simulation Results

- T = 3.5 keV
- $Q_{\text{ped}} = 126$ MJ
- $R_{\text{div}} = 6.5$ m
- $B = 5.0$ T
- $\alpha = 5.0$ deg
- Exponential distribution in SOL

Giant ELM
- $Q_{\text{ELM}} \approx 10\%$ $Q_{\text{ped}}$

Disruption
- $Q_D \approx Q_{\text{ped}}$
- $t = 0.1 – 1.0$ ms
Spatial Energy Deposition

Simulation Results

Impact power, GW/cm³

- disruption, \( \tau = 1 \text{ ms}, Q = 126 \text{ MJ} \)
- giant ELM, \( \tau = 0.5 \text{ ms}, Q = 12.6 \text{ MJ} \)

Depth, \( \mu \text{m} \)
Divertor Erosion Profiles

Simulation Results

Erosion depth, μm

x distance, cm

giant ELM, τ = 1 ms, Q = 12.6 MJ

disruption, τ = 1 ms, Q = 126 MJ
Divertor Plasma Density Evolution

360.0 μs

1.0 ms giant ELM

Simulation Results
Radiation Fluxes Evolution Nearby Divertor Plate

Simulation Results
**Simulation Results**

**Plasma Impact Dominance**

**Divertor Heat Load and Erosion**

0.1 ms, 12.6 MJ
Divertor Heat Load and Erosion

Simulation Results

Irradiation Dominance

Power, $MW/cm^2$

Temperature, K

X distance, cm

Z distance, $\mu m$

0.1 ms, 126 MJ
Energy deposition at the strike point:

\[ W_t = W_{\text{imp}} + W_{\text{rad}} \]

- \( 182.8 = 143.3 + 39.5 \)
- \( 180.8 = 148.1 + 32.7 \)
- \( 90.7 = 77.9 + 12.8 \)
Radiation Energy Deposition during Disruption

Energy deposition at the strike point:

\[ W_t = W_{\text{imp}} + W_{\text{rad}} \]

\[
\begin{align*}
248.9 &= 161.1 + 87.8 \\
60.8 &= 6.5 + 54.3
\end{align*}
\]

[J/cm²]
ITER Divertor Design Upgrade

Design taken from:
5 Layers Geometry AMR

Mesh construction (RZ plane)

HEIGTHS Upgrade and Current Status
Magnetic Field Reconstruction

HEIGHTS Upgrade and Current Status
Summary and Conclusion

- HEIGHTS models and simulation package are upgraded and applied to plasma evolution in divertor nearby areas during ITER giant ELM and disruptions.
- Heat loads and erosion of carbon vertical target were calculated for ITER-like geometry.
- Simulation confirmed that nearby divertor surfaces may have radiation fluxes comparable with values incident on the vertical target => Damage to nearby components.
- The simulation results prove necessity of future model and code enhancement to the new design and its optimization.

More detail analysis will be available: