The effect of runaway electrons on plasma facing components in ITER device – A serious threat to its success!

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Outline

- HEIGHTS Upgrade
- Modeling of Runaway Electrons
- ITER device Geometry and Main Values
- Simulation Results
- Summary
HEIG drds Simulation Package

- MHD
- Radiation Transport
- Plasma/material Interaction

Energy Deposition (Ions, Plasma, Laser, Electrons)
Atomic Data
Electrode Thermal Conduction & Hydraulics
**Plasma Transient / Instabilities:**

**Plasma Material Interaction Key Concerns**

- **HEIGHTS** major modeling events for surface and structural response to plasma transients:
  - Edge Localized Modes (ELM’s)
  - Disruptions
  - Vertical Displacement Events (VDE’s)
  - Runaway electrons

- **Key concerns:**
  - PFC erosion lifetime
  - PFC structural integrity
  - Plasma contamination
Runaway Electrons

- Normal electrons collide with plasma ions/electrons-limiting their energy
- Runaway electrons-are accelerated by toroidal electric field, collisions decrease as $E^{-1.5}$; runaway process
- Existing work: crude model; angle of incidence = magnetic field angle.
  Our work: rigorous computation of angle, penetration depth, 3-D effects
Detailed Analysis is Needed of Runaway Electrons Energy Deposition and Structural Response ➔ Very Serious!

\[ E_t = 50 \text{ MeV} \]
\[ B = 5-8 \text{ T} \]
\[ \text{Time} = 10-100 \text{ ms} \]
\[ \text{Energy Density} 50 \text{ MJ/m}^2 \]
Runaway Electrons Impact Angle
Runaway Electrons Incident Angle Distribution

E = 50 MeV
B = 8 T
$\alpha_B = 1$ deg
Runaway Electron Monte Carlo Energy Deposition Model

This includes:

- Electron-Electron Scattering
- Electron-Nuclear Scattering
- Bremsstrahlung
- Compton Absorption
- Photoabsorption
- Auger Relaxation
Model Benchmarking

--Very good agreement seen


[38] Lockwood G.J., Ruggles L.E., Miller G.H., Halbleib J.A. 1980 Calorimetric measurement of electron energy deposition in extended media – theory vs experiment Report SAND79-0414 (Sandia Laboratories)


HEIGHTS Benchmarking

HEIGHTS Calculation

Previous Numerical Simulations


E = 10 MeV   B = 8 T   \( \alpha = 1 \) deg

P = 50 MJ/m2   t = 0.1 s
Influence of Energy Ratio

$E_{\perp}=0$
$\varphi = \alpha$

$E_t = 50$ MeV
$B = 8$ T
Time = 10 ms
Energy Density 50 MJ/m$^2$

$E_{\perp}=0.1E_t$
$\varphi \neq \alpha$
Idea: Tungsten Layer as Additional Absorber

W of 0.1-mm thick

- $E_t = 50$ MeV
- $E_\perp = 0.1 E_t$
- $B = 8$ T
- Time = 10 ms
- Energy Density 50 MJ/m$^2$

W of 0.8-mm thick
Influence of Tungsten Layer Location on Be and Cu Temperature
Influence of Tungsten Layer Location on Cu Temperature

The graph shows the temperature of Cu as a function of depth for W layers of different thicknesses. The blue line represents a W layer of 0.8-mm thickness, while the red line represents a W layer of 0.1-mm thickness. The temperature at the melt point (T_melt) is indicated by a dashed line.

- W of 0.8-mm thick
- W of 0.1-mm thick
Summary and Conclusion

- Runaway electron analysis - major model development and HEIGHTS package effort completed
- Excellent HEIGHTS/data comparison
- Tangential part of particle energy increases angle of incidence
- Increased incident angle leads to overheating of deep layers
- Serious problem for ITER - melting, danger of interlayer destruction, and damage to coolant channels
- A dual (Be/W) structure may be one solution
- Design optimization of damage mitigation may be possible
- More analysis just accepted for publication in NF (2009)