Disruption, Thermal, and Surface Analysis of Liquid Layers

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HEIGHTS Capabilities

(SUPERATOM Code)

- The atomic data base of the SUPERATOM code is used in these calculations.

- Some of the data includes:
  - Ionization potentials
  - Energy levels
  - Statistical weights
  - Quantum levels
  - Degeneracy levels
  - Oscillator force
  - Line transition probabilities
  - Ionization cross sections

HEIGHTS Capabilities

(SPLASH Code)

- Liquid-layer splashing and erosion can take various forms:
  - Splashing due to bubble formation and explosion.
  - Formation and growth of hydrodynamic instabilities due to absorption of plasma momentum.
  - Run-off the solid structure.
  - Splashing due to mechanical vibrations of the machine during plasma instabilities.

HEIGHTS Capabilities

(SPLASH Code)

- The liquid metal layer in Tokamak environment will be subjected to all various forces that may exist.

- The SPLASH code models the behavior of such liquid layers under different forces. Among these forces are:

  - Forces from plasma impact momentum
  - External or internal magnetic forces
  - Reaction forces during intense ablation
  - Surface tension and viscous forces
  - Gravitational forces

- In addition the SPLASH code models the explosive erosion behavior of carbon-based materials under intense energy deposition as a result of plasma instabilities.

HEIGHTS Capabilities:

(Response of Liquid Layers)

I. Energy and Momentum Deposition

II. Thermal Response of Liquid-Layers

III. Liquid Mechanical Response

IV. Liquid Hydrodynamic Evolution

HEIGHTS Capabilities

(Liquid Film-Mechanical Response)

- The magnitude of the velocities generated by plasma momentum are calculated by solving momentum conservation equation:

$$\rho \frac{\partial \mathbf{V}}{\partial t} + \rho\, \mathbf{V} \cdot \nabla \mathbf{V} + \nabla \mathbf{P} = \mathbf{F}\ .$$

- The plasma momentum at depth Z, M_Z, is given by:

$$M_Z = m_d V_d = \sqrt{2 m_d E_Z}\ .$$

- The momentum equation can be simplified to:

$$\frac{\partial V_Z}{\partial t} + V_y \frac{\partial V_Z}{\partial y} + V_Z \frac{\partial V_Z}{\partial z} = \frac{\phi_d m_d}{\rho} \frac{dV_d}{dz}\ .$$

HEIGHTS Capabilities

(TRICS/TRAP Codes)

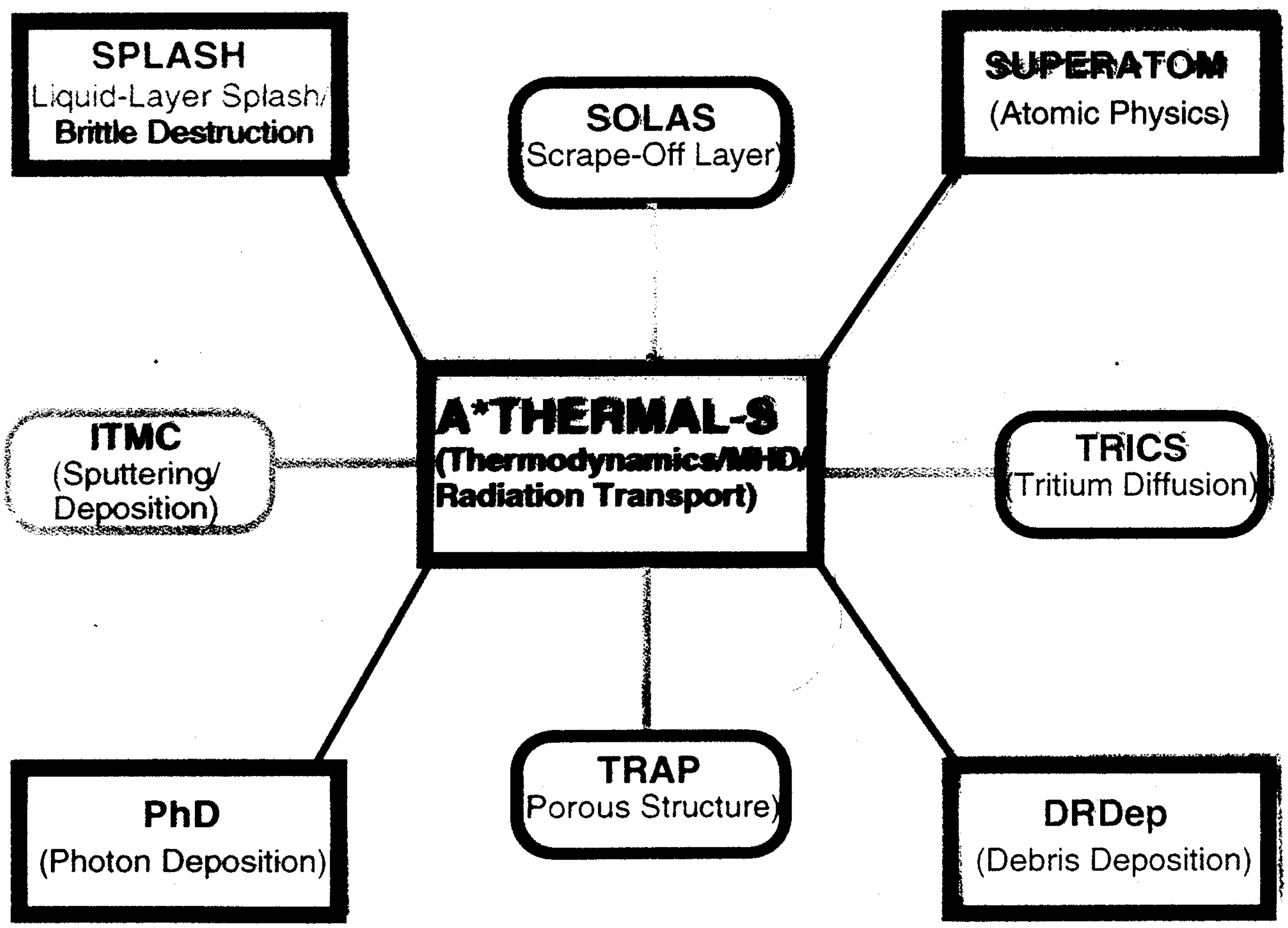
- A General Hydrogen-Isotope Diffusion Code:
  - Multi-layer structure
  - Multi-trap effects
  - Surface recombination models
  - Near-surface particle deposition models
  - Surface erosion effects due to normal/abnormal events
- Diffusion in Porous Structures such as that of Fine and Macroscopic Dust Generated from PFCs and Eroded Materials.
- Hydrogen Release during Intense Pulsed Heat Loads such as from ELMs and VDEs.
- Diffusion and Inventory in Splashed Materials due to Disruption and in the Redeposited Droplets on Nearby Components.

Capabilities of HEIGHTS Package

- Coating and Structure Thermal Analysis
  - Thermal hydraulics
  - Phase change
- Response of PFCs to High Heat Loads
  - Disruptions, ELMS, VDEs, and Runaways
  - Surface erosion mechanisms
  - Explosive erosion of carbon-based-materials
- Sputtering of Materials due to Plasma Bombardments
  - Solids, liquids, and mixtures
- Analysis of SOL Plasma during Normal/Abnormal Events
  - Particle fluxes
  - Sheath potential
- Plasma Radiation and Photon Transport
  - Detail continuum and line radiation
  - Photon deposition on nearby components
- Debris Deposition of the Eroded Materials
- Hydrogen Isotope Behavior in Liquid Materials

Simulation Package for High Energy Interaction with General Heterogeneous Target Systems

HEIGHTS Package



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Concerns Related to Advanced Studies

Modeling Capabilities for APEX Study

1) Stability of a free liquid-metal surface

   - MHD effects
   - Plasma Wind
   - Disruption forces

2) Plasma liquid-metal interaction

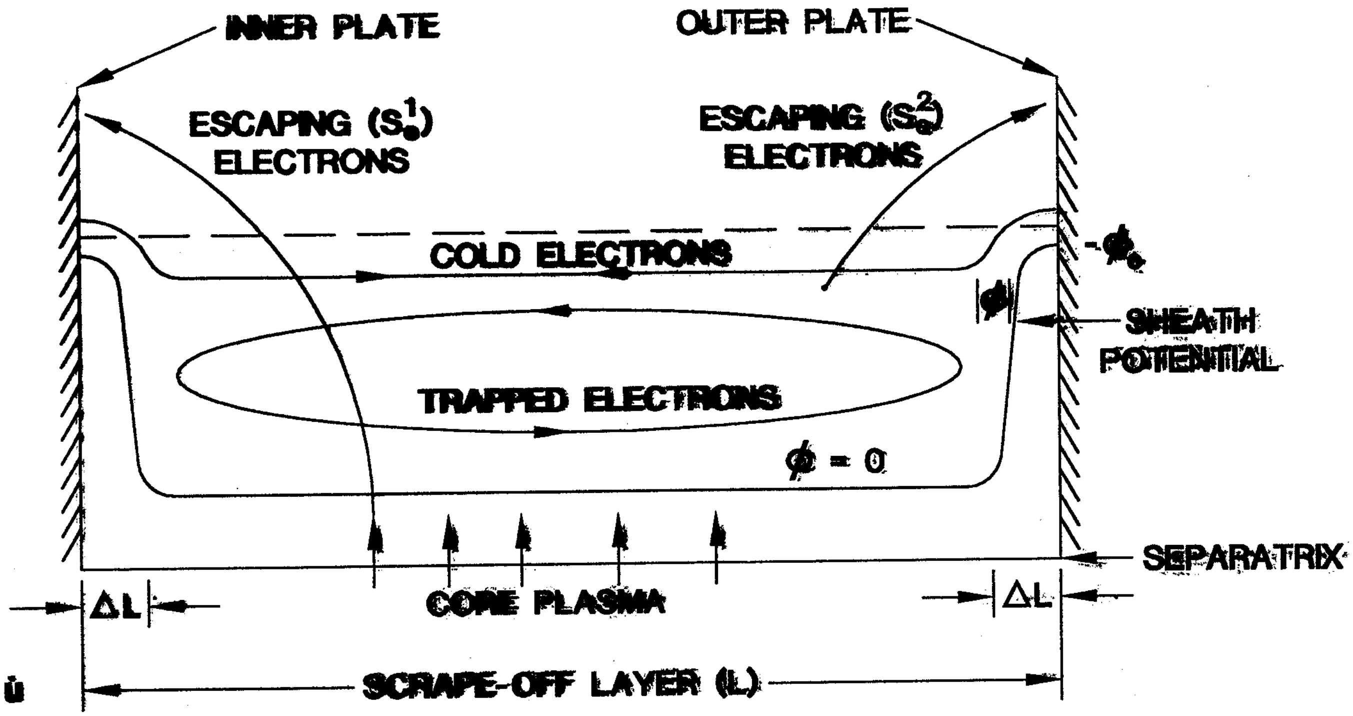
   - macroscopic erosion/splashing
   - droplets transport in SOL plasma
   - Helium pumping

3) Effects of eroded material on SOL plasma

   - Self-consistent model is needed
   - Heat transfer, erosion, and radiation transport should be coupled

4) SOL parameters in low-recycling plasma

   - low-density high-temperature edge plasma
   - collisionless behavior
   - Sheath potential effects


INNER PLATE
OUTER PLATE
ESCAPING (S_e^1) ELECTRONS
ESCAPING (S_e^2) ELECTRONS
COLD ELECTRONS
$-\phi_e$
$|\phi|$
SHEATH POTENTIAL
TRAPPED ELECTRONS
$\phi = 0$
SEPARATRIX
ΔL
CORE PLASMA
ΔL
SCRAPE-OFF LAYER (L)

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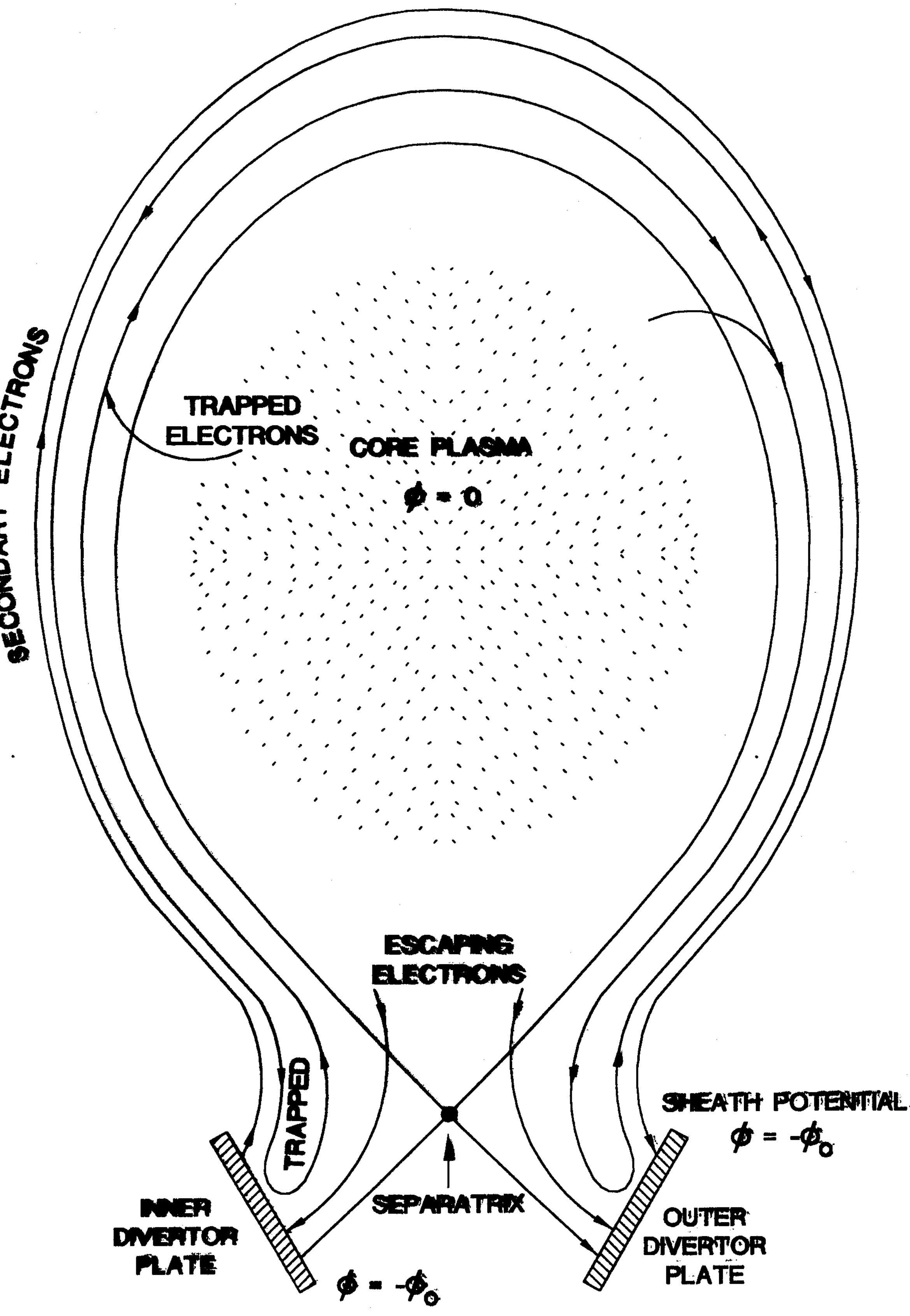
SECONDARY ELECTRONS
TRAPPED
ELECTRONS
CORE PLASMA
$\phi = 0$
ESCAPING
ELECTRONS
TRAPPED
SHEATH POTENTIAL
$\phi = -\phi_o$
INNER
DIVERTOR
PLATE
SEPARATRIX
OUTER
DIVERTOR
PLATE
$\phi = -\phi_o$

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HEIGHTS Capabilities

(A*THERMAL-S MHD-Code)

- **Influence of a strong magnetic field on debris-cloud expansion dynamics:**
  - 2-D vapor-cloud expansion model
  - Magnetic and frictional forces
  - Magnetic-field diffusion
  - Vapor-plasma electrical conductivity
  - Induced electric field
  - Joule heating of vapor-plasma
  - Oblique incidence

- **Numerical Methods**
  - Lagrangian for 1-D model
  - Particle-in-Clouds (PIC) for 2-D model

HEIGHTS Capabilities

(Self-Consistent Radiation-Kinetic Model)

- Optical properties are calculated for real plasma conditions.

- At each time step, quantities such as density, temperature, and spectral radiation flux are used to calculate absorption and emission coefficients.

- This is achieved by solving the kinetic equations for ion concentration and for level populations of each charge state.

- Calculation of the emission and absorption coefficients includes the three kinds of radiation:
  - bremsstrahlung radiation
  - recombination radiation
  - line radiation

HEIGHTS Capabilities

(Radiation Transport Model)

- Non-LTE Radiation Transport Model
- Both Continuum and Line Radiation are Included
- Up to 4000 Photon Energy Groups for the Continuum Spectrum
- Up to 100 Separate Lines can be used for the Low-Z Materials
- Each Single Line is Treated as a Continuum Spectrum (mini-multigroup)
- Doppler and Stark Broadening of Line Radiation
- Numerical Methods
  - Forward/Reverse method for 1-D model
  - Ray Tracing Techniques for 2-D model