Current Issues in Modeling Disruption Effects on Plasma Facing Components

Ahmed Hassanein
(Presented by Rich Mattas)
Argonne National Laboratory

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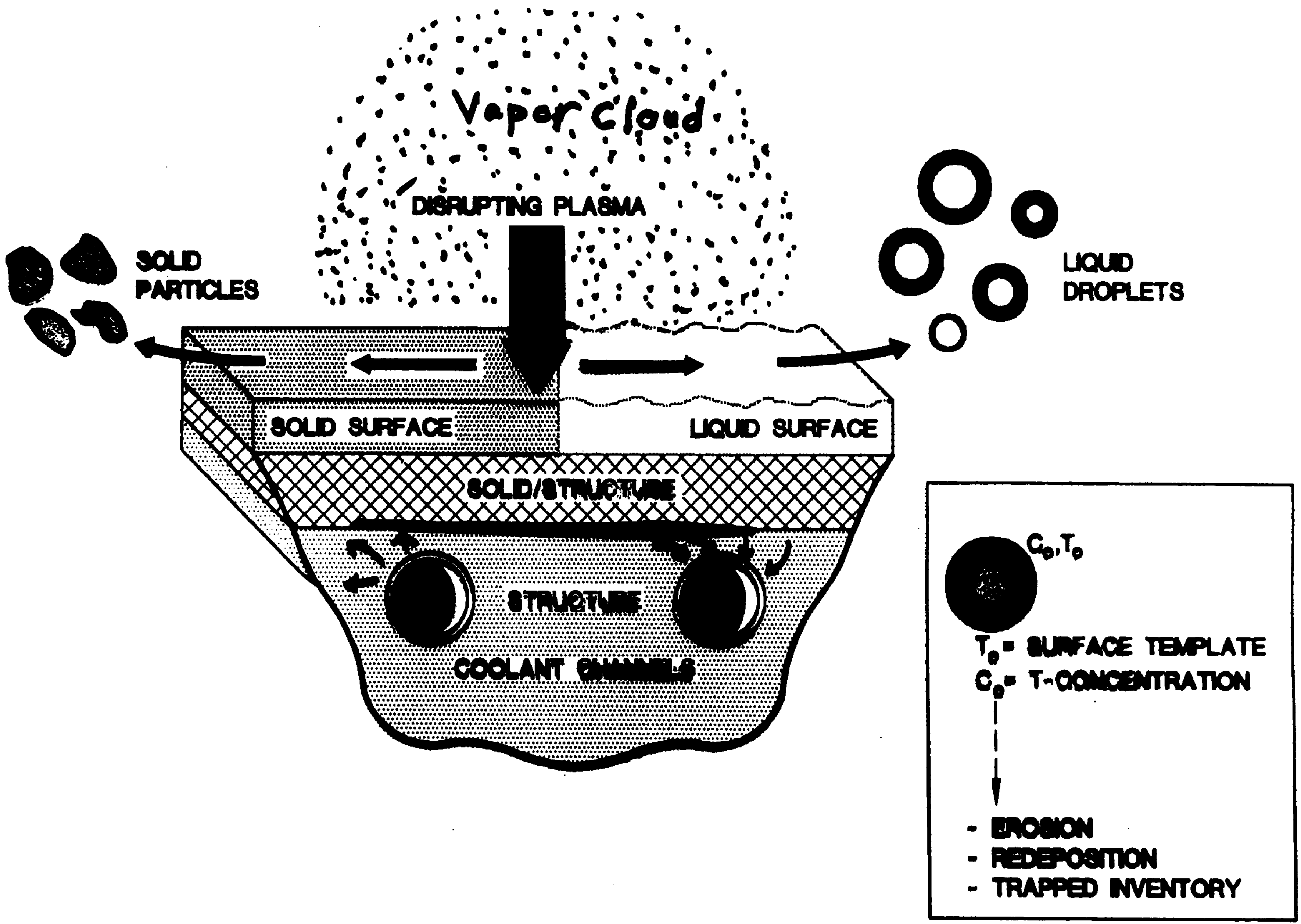
Current Concerns and Studies

- **Vapor-Cloud Effects**
  - Vapor turbulence and MHD instabilities
  - Expansion and damage to nearby components
  - Impurities effect on energy radiation

- **Secondary Radiation**
  - Transport and damage to nearby components
  - Less "secondary" vapor-shielding effect

- **Macroscopic Erosion**
  - Splashing and transport to other components
  - MHD instabilities in liquid layer
  - Brittle destruction of carbon-based materials


Vapor Cloud
DISRUPTING PLASMA
SOLID PARTICLES
LIQUID DROPLETS
SOLID SURFACE
LIQUID SURFACE
SOLID/STRUCTURE
STRUCTURE
COOLANT CHANNELS
C_o, T_o
T_o = SURFACE TEMPLATE
C_o = T-CONCENTRATION
- EROSION
- REDEPOSITION
- TRAPPED INVENTORY

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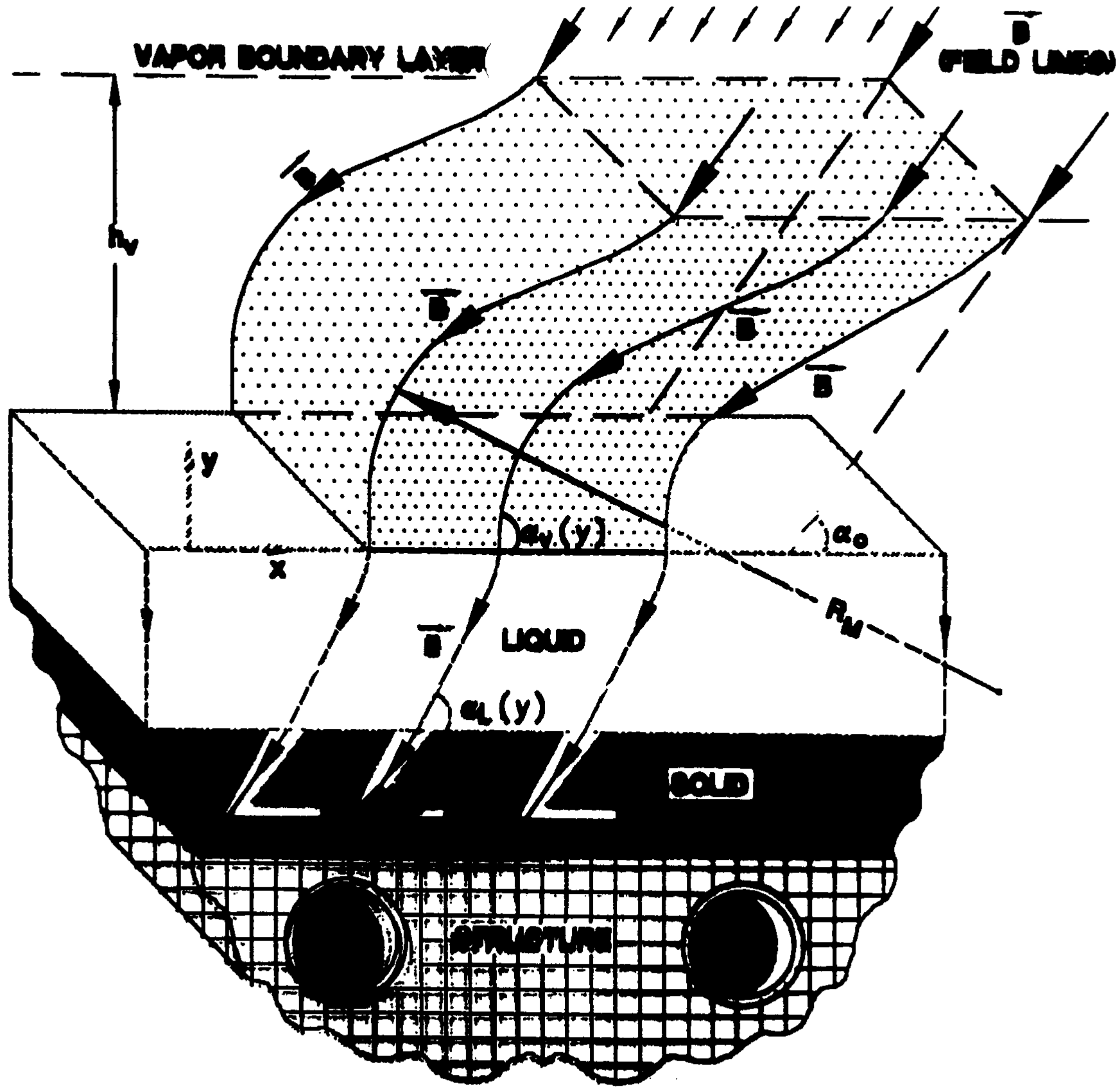
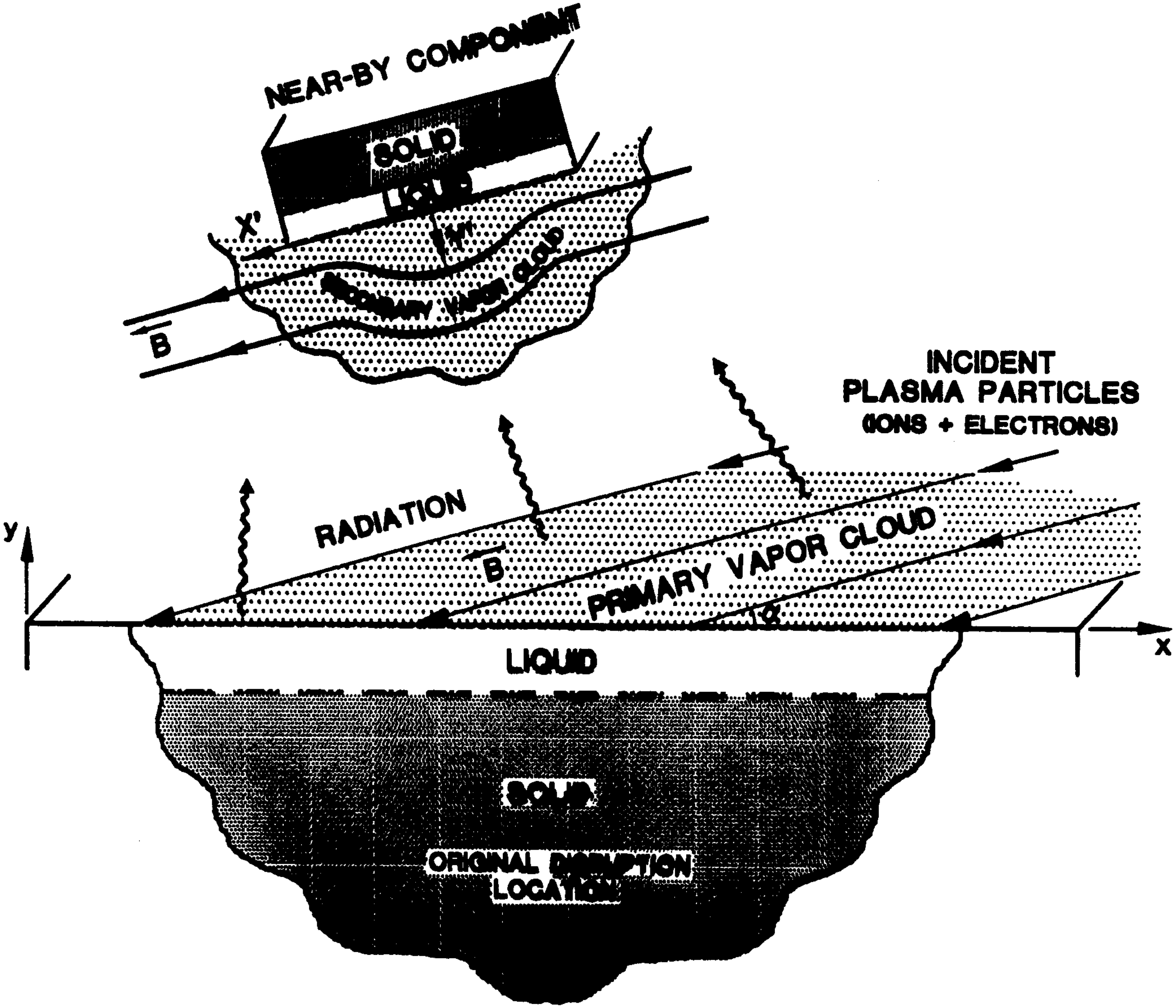

VAPOR BOUNDARY LAYER
B (FIELD LINES)
h_v
B
B
B
y
$\alpha_v(y)$
α_o
x
R_M
B LIQUID
$\alpha_L(y)$
SOLID
STRUCTURE

HASSANEIN


NEAR-BY COMPONENT
SOLID
LIQUID
X'
Y'
SECONDARY VAPOR CLOUD
B
INCIDENT
PLASMA PARTICLES
(IONS + ELECTRONS)
RADIATION
B
PRIMARY VAPOR CLOUD
α
y
x
LIQUID
SOLID
ORIGINAL DISRUPTION
LOCATION

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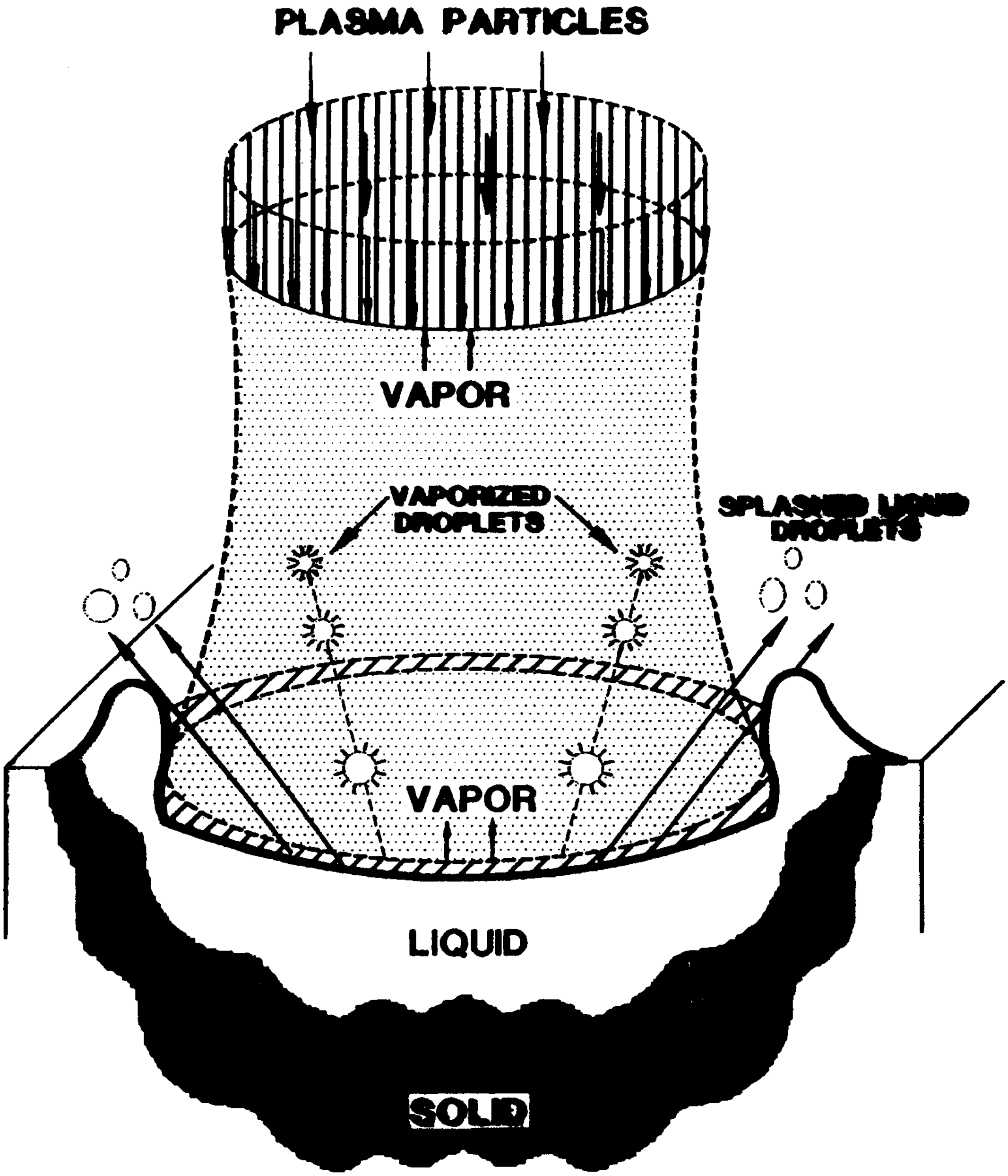

PLASMA PARTICLES
VAPOR
VAPORIZED DROPLETS
SPLASHED LIQUID DROPLETS
VAPOR
LIQUID
SOLID

Droplet Shielding Effect

- **Heating of target surface by radiation power W_s emits macroscopic particles with density n_d, and radius R_{d0} leaving the surface with velocity U**

$$n_{do} = \frac{W_s}{q_d V_{do} U} \quad ; \quad V_{do} = \frac{4}{3}\pi R_{do}^3$$

- **Because of radiation absorption by macroscopic particles radiation power to surface decreases**

$$\frac{dW}{dx} = -\frac{W}{l_v}; \; l_v = \frac{1}{n_d \sigma}; \; \sigma = \zeta \pi R_d^2$$

- **Absorbed radiation is spent in vaporization of macroscopic particles reducing their volume V_d and therefore radiation power decreases**

$$U\frac{dV_d}{dx} = -\frac{W}{q_v}\zeta \pi R_d^2$$

- **Net radiation power reaching target surface depends only on ratio ξ between vaporization energy q_v and destruction energy q_d**

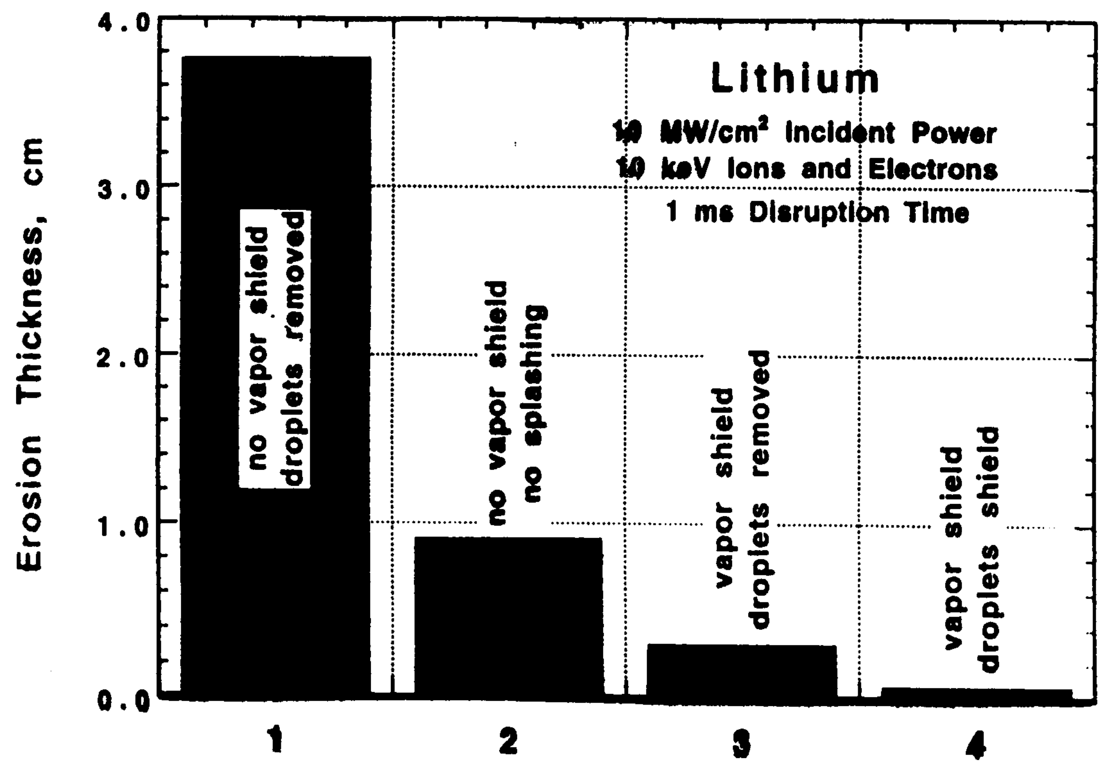
$$\xi = \frac{W_s}{W_0} = \frac{1}{1+\lambda} \;, \; \lambda = \frac{q_v}{q_d}$$

- **Macroscopic particles are entirely vaporized at distance L depending on initial size of MP R_{do}, velocity U, radiation power from vapor cloud toward to the surface W_o, and ratio ξ,**

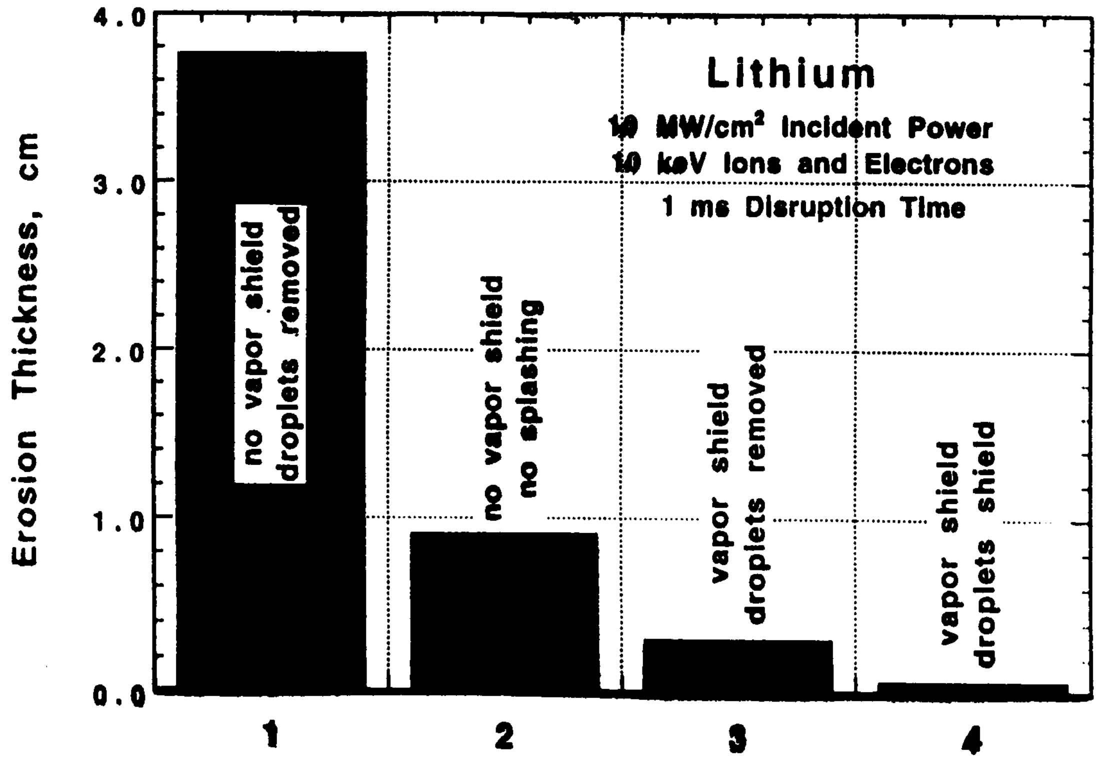
$$\frac{L}{R_{do}} = \frac{q_v U}{W_o}\frac{4}{\zeta}F \;, \quad F = \frac{v_0}{u_0},$$

$$v_o = \frac{1}{3}\ln\frac{\sqrt{1+u_0+u_0^2}}{1-u_0} + \frac{1}{\sqrt{3}}\, arctg\frac{u_0\sqrt{3}}{2+u_0} \;, \; u_o = \sqrt[3]{\frac{\lambda}{1+\lambda}}$$

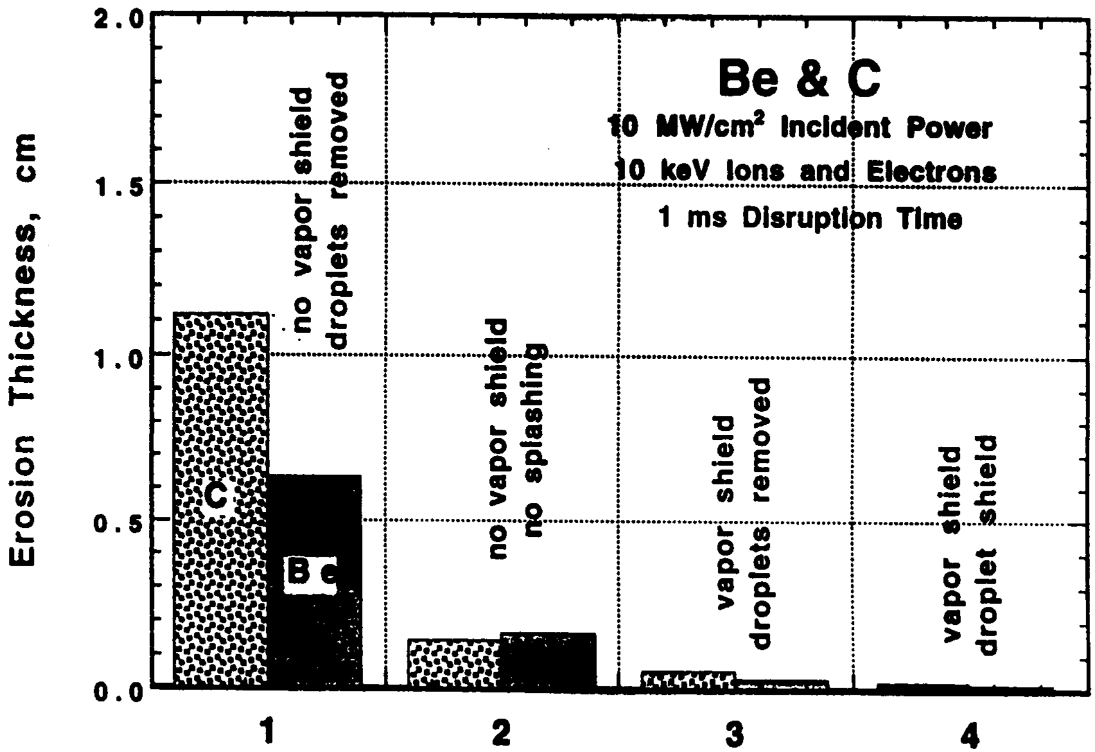
HEIGHTS Analysis of Total Erosion Thickness of Divertor Plate Materials



HEIGHTS Analysis of Total Erosion Thickness of Divertor Plate Materials



HEIGHTS Analysis of Total Erosion Thickness of Divertor Plate Materials



APEX LIQUID WALLS RESPONSE DURING TOKAMAK PLASMA DISRUPTIONS

- **Main mass loss mechanisms:**

  Vaporization

  Ablation – macroscopic particles (droplets)

- **Processes that decrease net mass loss of liquid walls:**

  1) Vapor shield

  - Vapor cloud absorbs incoming energy flux W_0
  - Conversion to back radiation (secondary radiation)
  - Decrease heat load on liquid surface to < 10% W_0

  2) droplet shield

  - Due to ablation (splashing) the surface emits droplets therefore cloud of vapor and macroscopic particles exists nearby the exposed surface
  - droplets (macroscopic particles) absorb radiation power and decrease heat load onto surface
  - droplets vaporization path length depends on vapor dynamics in oblique magnetic field

PROPOSED APEX WORK

A. HASSANEIN (ANL)

(1) Disruption effects on liquid metal surfaces.

-- Vporization
-- Splashing
-- Effects on design and other nearby components.
-- Condensation on diagnostic windows (important issue)

(2) Disruption effects on FLIBE surfaces.

-- All similar issues as above.

(3) Disruption effects on NSTX device.

-- Calculations for actual design parameters of NSTX.

(4) Particle pumping of liquid metal and FLIBE surfaces.

-- Develop kinetic models to study particle behaviour and recycling for moving liquid surfaces. (important issue)

-- This include both D/T and He particles (self-pumping?)

-- This issue significantly affect SOL and plasma interface behavior

(5) MHD effects on free liquid-metal surfaces

-- We have the capabilities to study the various effects of strong B-field on free moving liquid jets and surfaces. This work will be complementary to work done at UCLA and others if needed. We are doing this for the High-Energy Physics program.