1. Completion of Assessment of Dry Chamber Wall Option Without Protective Gas

2. Initial Planning Activity for Assessment of Wetted Wall Option

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Outline of Presentation

Dry Walls (from last ARIES meeting's action items)

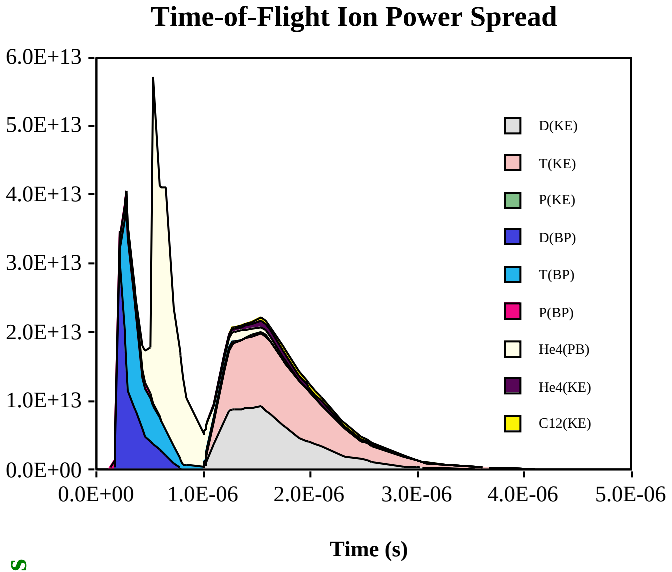
- **Direct-drive target (without protective chamber gas)**
  - Sensitivity study of thermal behavior for different chamber radii (different time of flights and different energy deposition per unit volume)
  - Thermal/erosion effect on chamber wall of reflective light from laser (~10%)
- **Indirect-drive target**
  - Thermal/mass transfer analysis for C and W without protective gas
- **Start documentation**
  - Outline of dry chamber wall report and first draft write-up over next 3 months

Wetted Walls

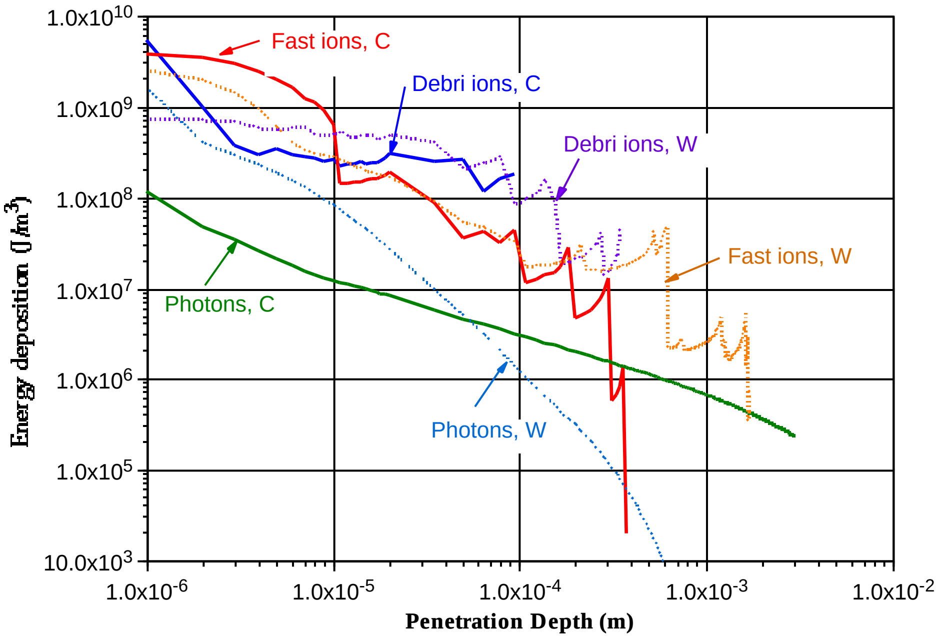
- **Initial Planning for Assessment for Direct-Drive and Indirect-Drive Targets**

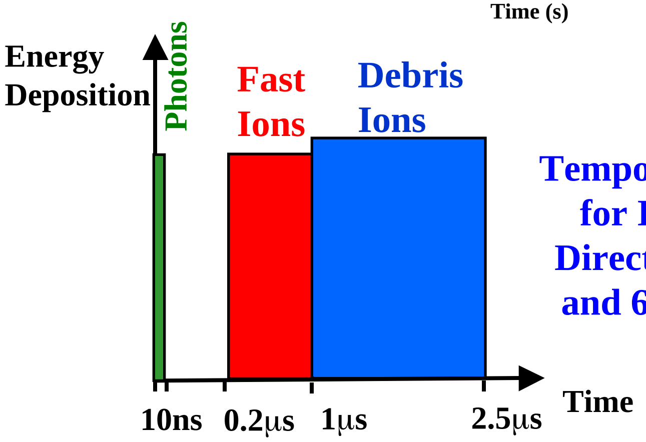
Changing Chamber Radius Affects Photon and Ion Times of Flight and Energy Deposition Density

Time of Flight α $R_{chamber}$



Energy Deposition per Unit Volume α $1/(R_{chamber})^2$



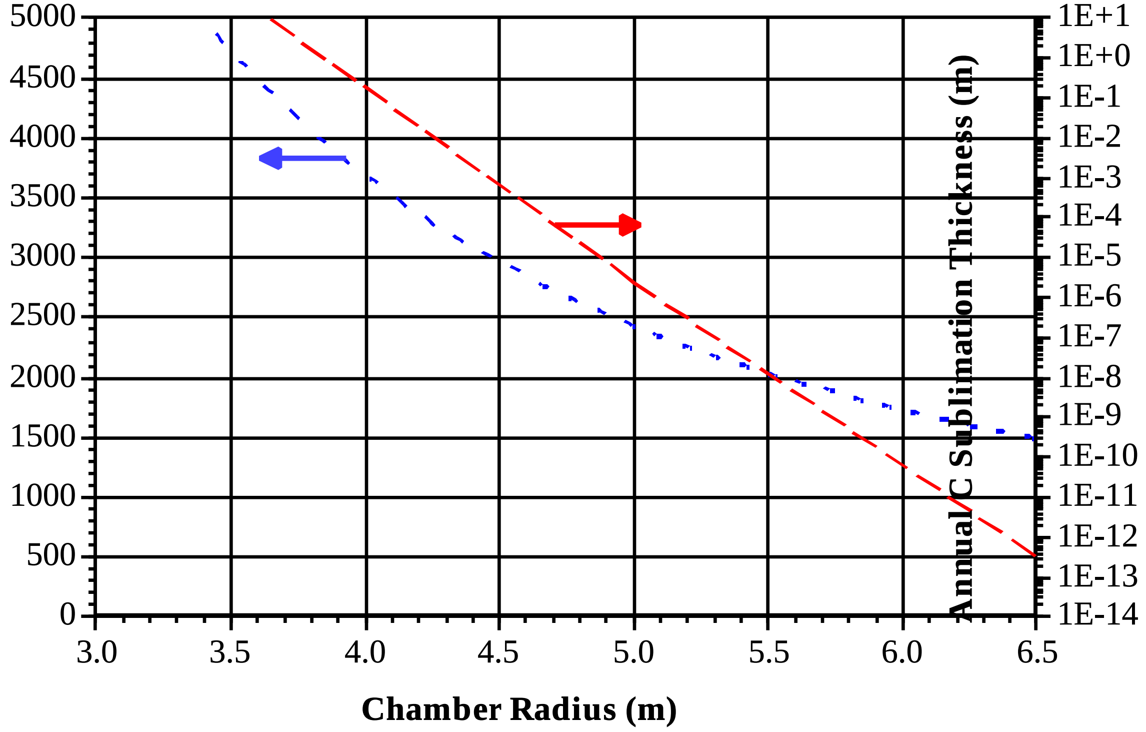


Temporal Distribution for Ions Based on Direct Drive Spectra and 6.5 m Chamber

Energy Deposition for 6.5 m Chamber and Direct Drive Spectra

- **Perform Sensitivity Analysis for for 3 chamber radii: 3.5 m, 5 m and 6.5 m**

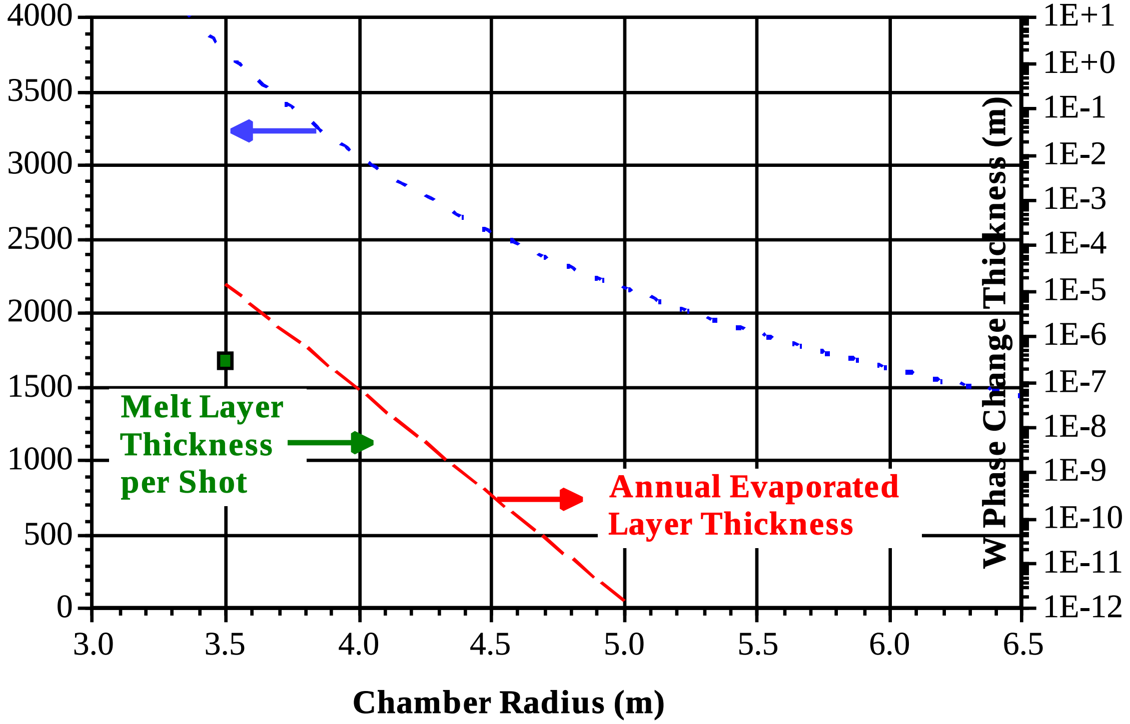
Effect of Changing Chamber Radius on Thermal Behavior of Carbon Flat Wall



- **Initial Temperature = 500°C**
- **k= f(T)**
- **q’’(sublimation) = f(T)**

- **Annual Sublimation Loss > 1-10 μm for Chamber Radius < ~ 5 m**
- **Corresponding Maximum Surface Temperature > ~2500°C**

Effect of Changing Chamber Radius on Thermal Behavior of Tungsten Flat Wall



- **Initial Temperature = 500°C**
- **k= f(T), C = f(T)**
- **q’’(sublimation) = f(T)**
- **Include phase change in ANSYS by increasing enthalpy at melting point to account for latent heat of fusion (= 220 kJ/kg for W)**

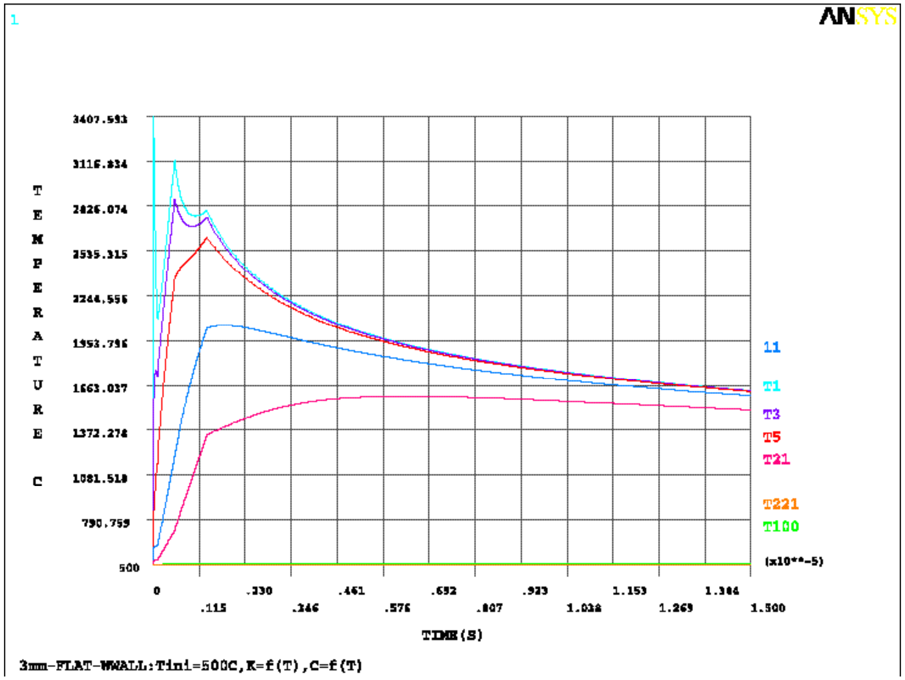
- **Melt Layer Thickness per Shot ~ 0.3 μm for Chamber Radius = 3.5 m**
- **No Melting for Chamber Radius > ~ 4 m**
- **Annual Evaporation Loss > 1-10 μm for Chamber Radius < ~ 3.5 m**
- **Corresponding Maximum Surface Temperature > ~3765°C**

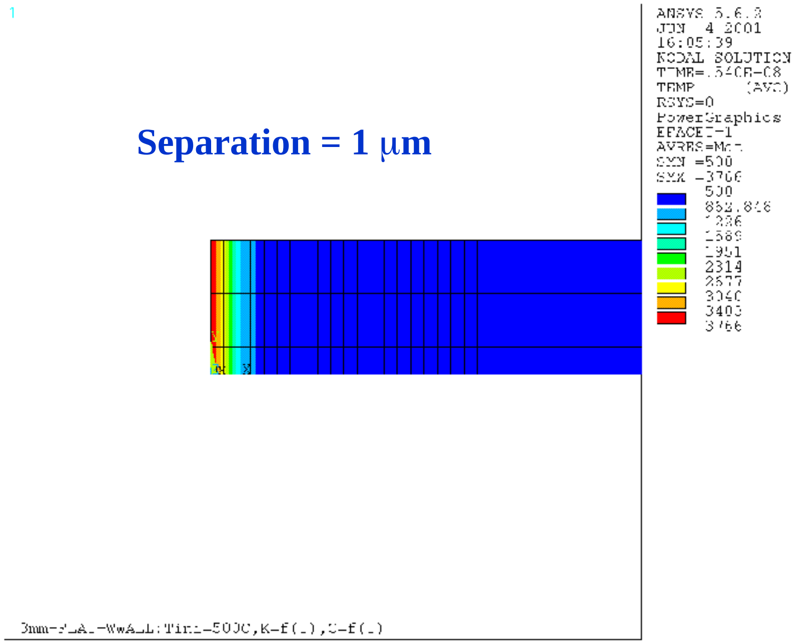
Temperature History and Snap-shot Profile for Tungsten Flat Wall Under Energy Deposition from NRL Direct-Drive Spectra and Chamber Wall Radius of 3.5 m

Temperature profile at the end of X-ray energy deposition:

- **Time = 5.4 ns**
- **W melting point = 3410°C**
- **W max. temp. = 3765°C**
- **Melt layer thickness ~ 0.3 μm**

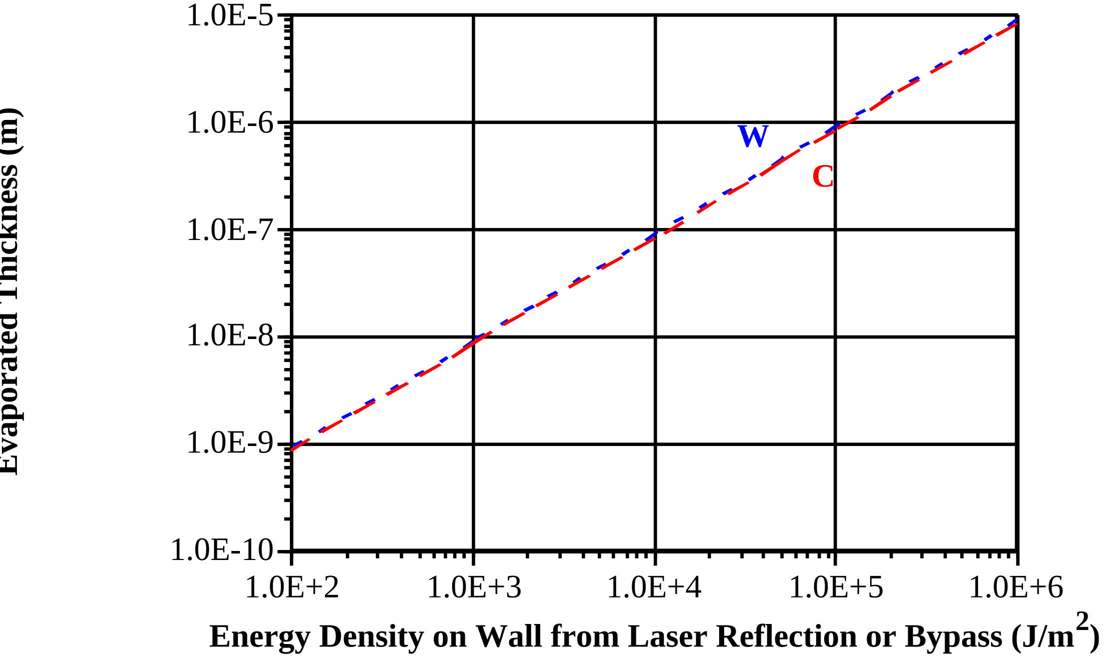
Temperature History





Separation = 1 μm

Evaporated Thickness of C and W as a Function of Laser Energy Density on the Chamber Wall (from reflection or target by-pass?)



Conservative estimate assuming all laser energy used for temperature increase from 500°C to sublimation/evaporation point and phase change(s):

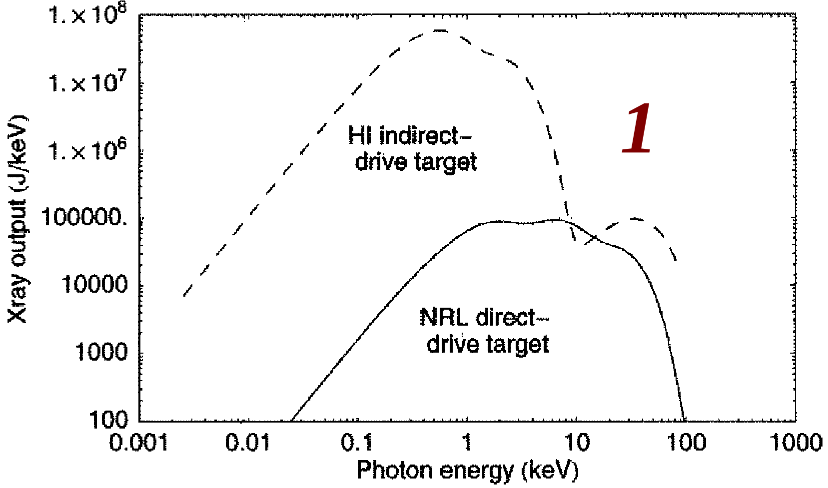
- 0.1 μm loss per shot corresponds to ~ 16 m of annual evaporated loss
- For a laser energy of 1.6 MJ with 100 beams of area ~ 0.01 m^2 each at the chamber wall, the corresponding laser energy density 1.6 x 10^5 J/m^2 for a 10% loss on the chamber wall
- Key issue:
  - Must avoid or minimize shots with laser reflection or target by-pass on the chamber wall
  - Must find in-situ repair measure for threatened region

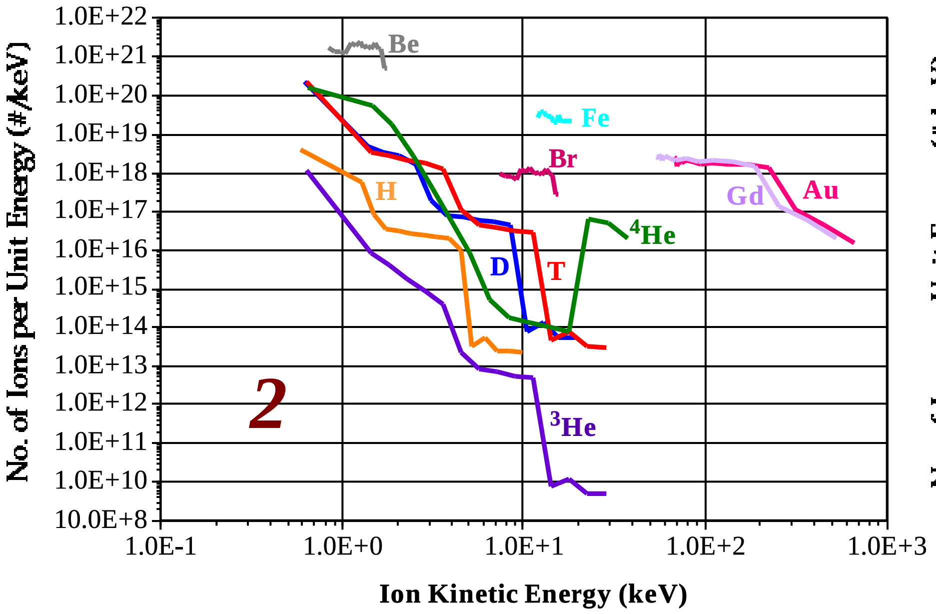
X-ray and Charged Particles Spectra

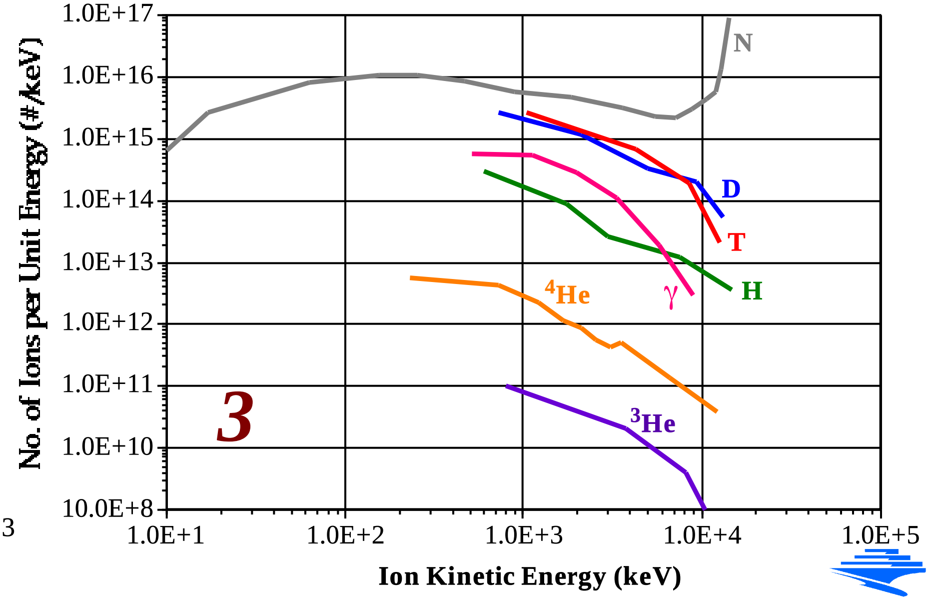
HI Indirect-Drive Target

1. X-ray (115 MJ)
2. Debris ions (18.1 MJ)
3. Fast burn ions (8.43 MJ)

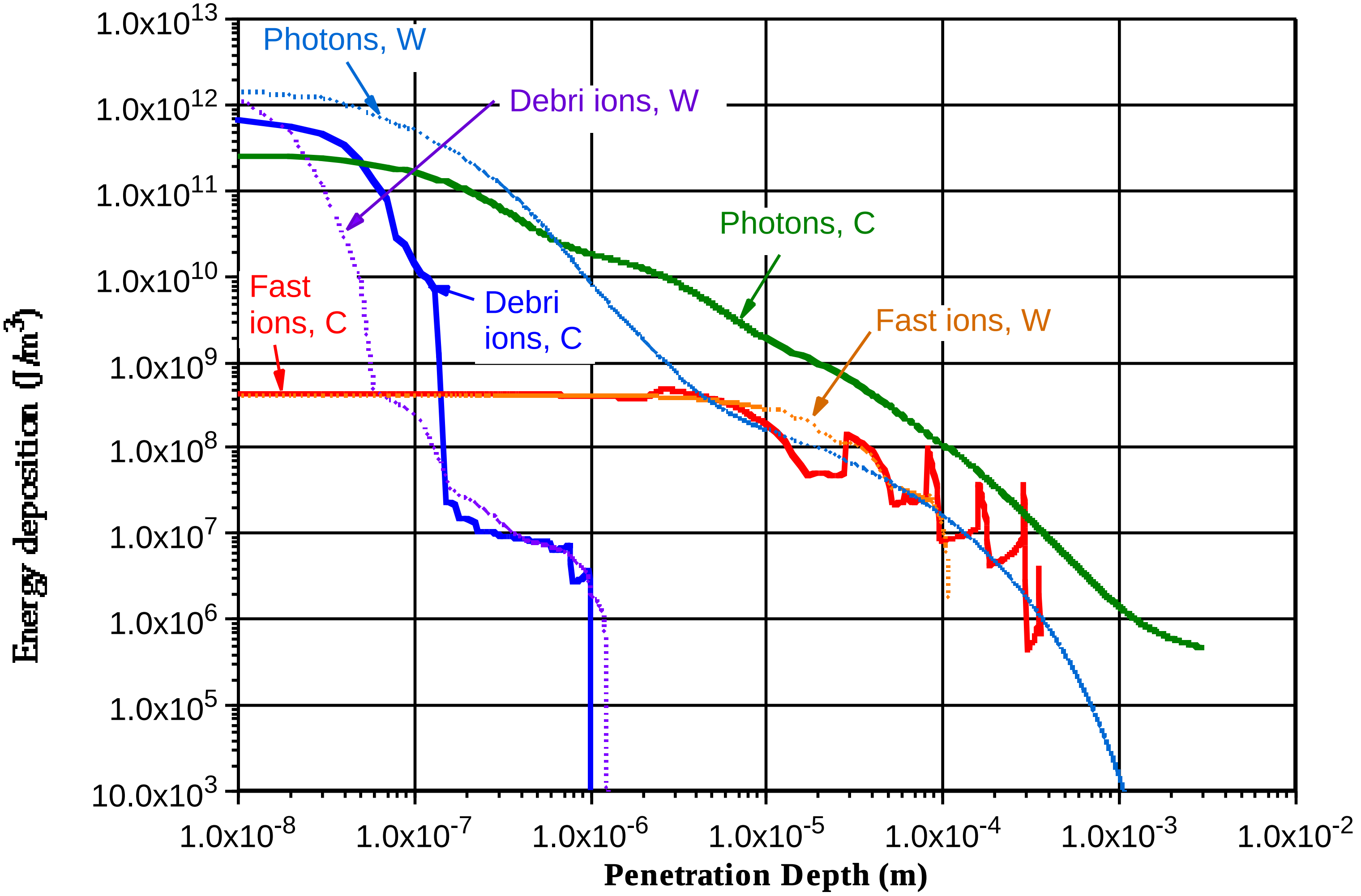
(from J. Perkins, LLNL)







Photon and Ion Attenuation in Carbon and Tungsten for Indirect Drive Target Spectra Without a Protective Chamber Gas



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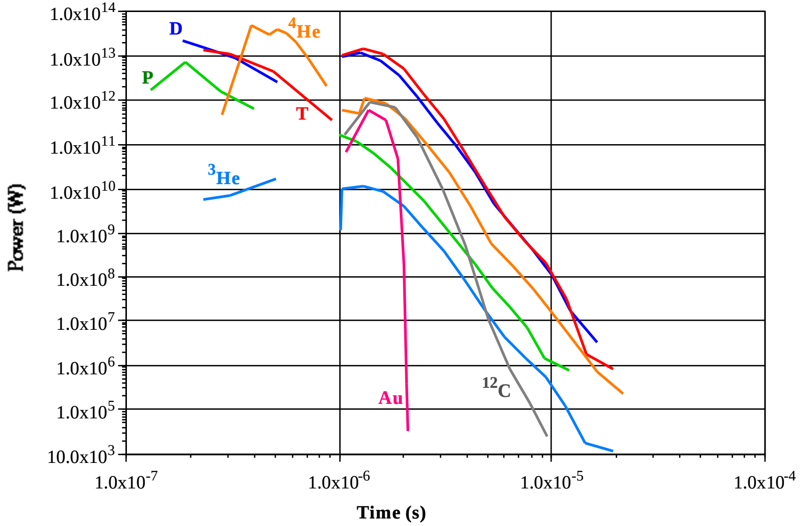
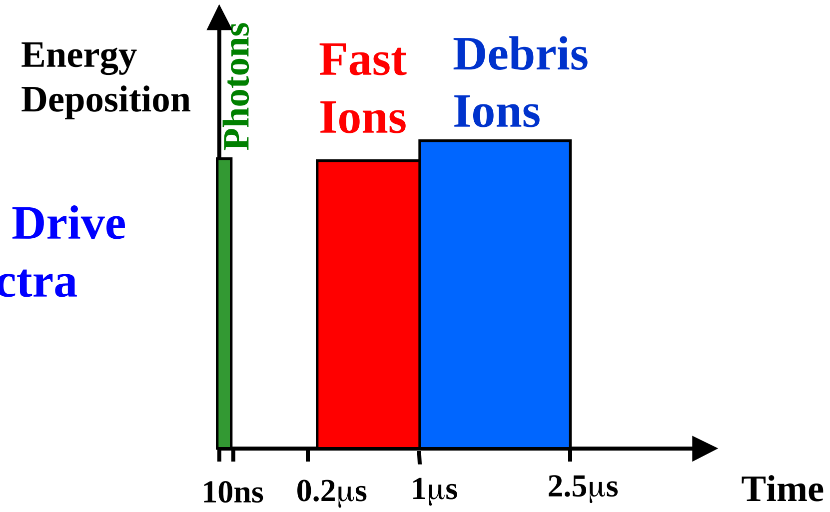
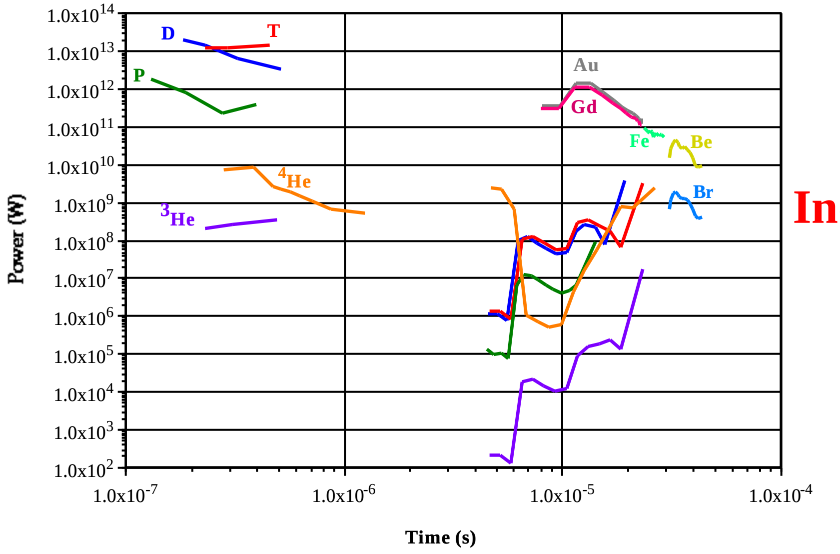
Temporal Distribution of Energy Depositions from Photons and Ions for Direct Drive and Indirect Drive Spectra and Chamber Radius of 6.5 m

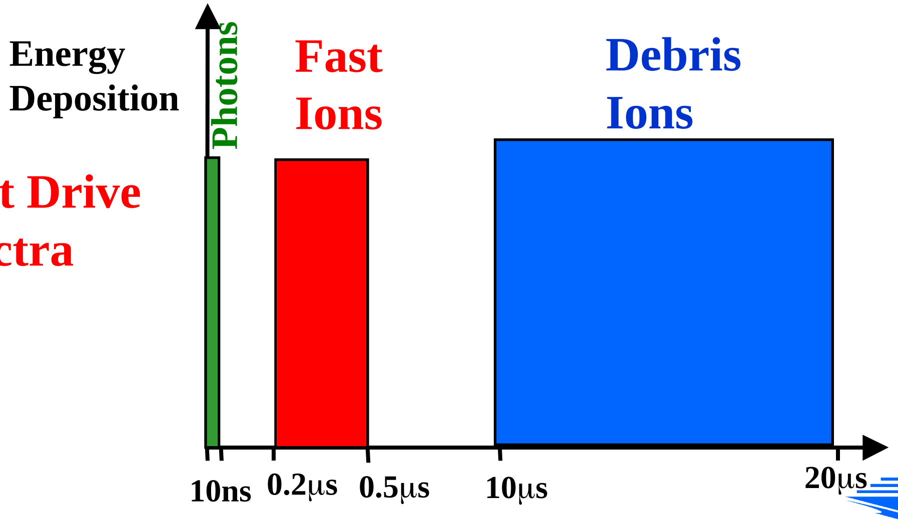




Direct Drive Spectra



Indirect Drive Spectra



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Sublimation/Vaporization is Included in the Analysis as a Heat Flux Boundary Condition at the Surface Dependent on Temperature

Carbon

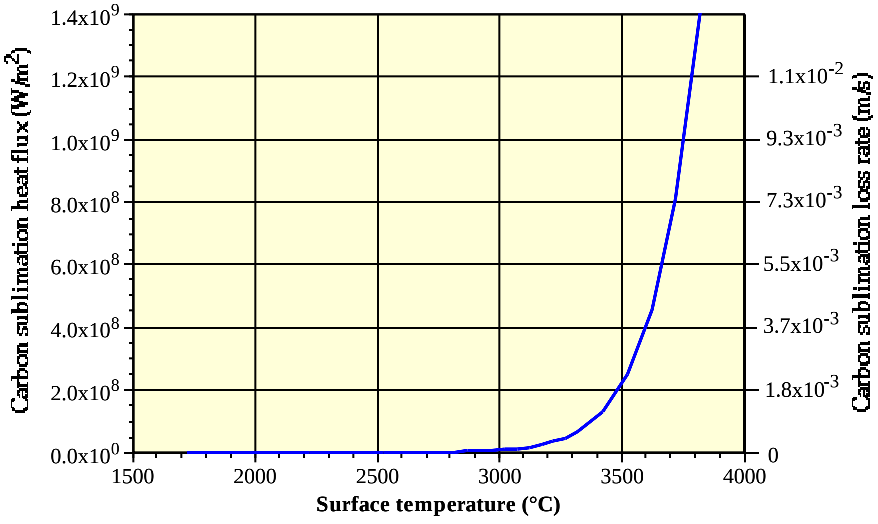
Latent heat of evaporation = 5.99 x10^{7} J/kg

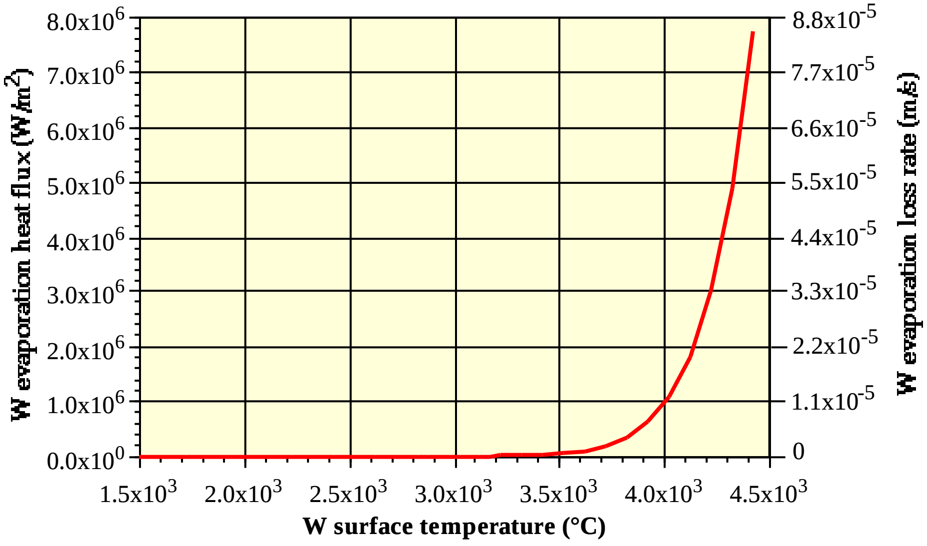
Sublimation point ~ 3367 °C

Tungsten

Latent heat of evaporation = 4.8 x10^{6} J/kg

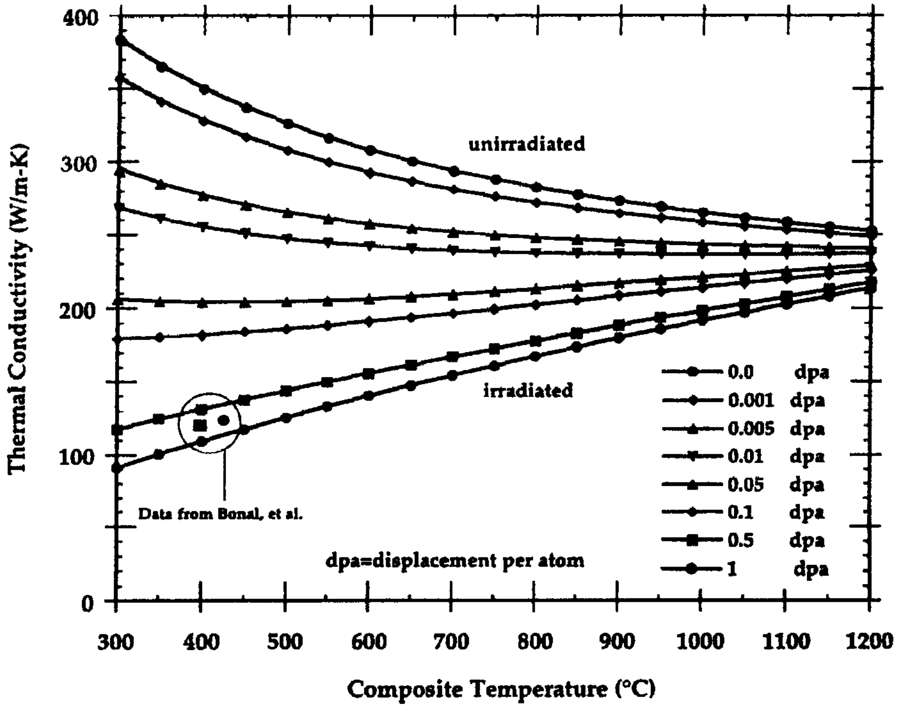
Melting point ~ 3410 °C





Temperature-Dependent Properties are Used for Carbon and Tungsten

- C thermal conductivity as a function of temperature for 1 dpa case (see figure)
- C specific heat = 1900 J/kg-K
- W thermal conductivity and specific heat as a function of temperature from ITER material handbook (see ARIES web site)

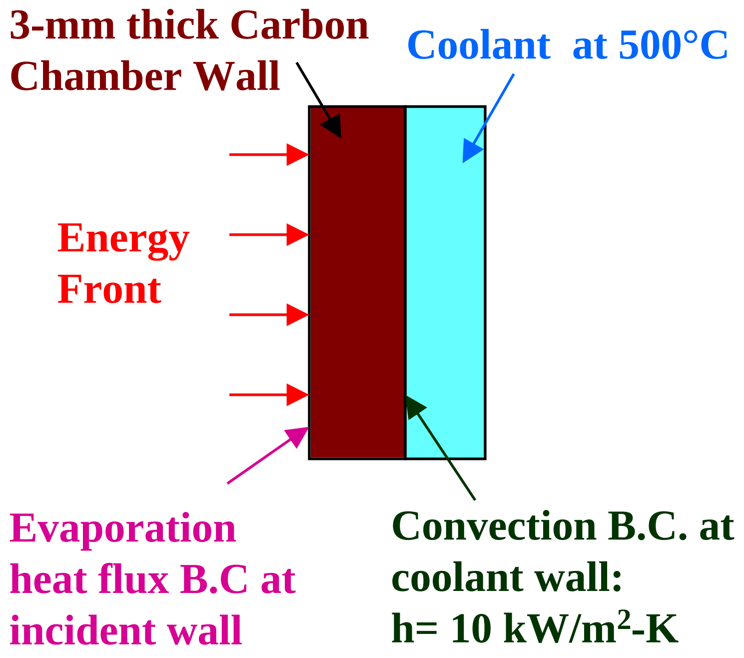


Calculated thermal conductivity of neutron irradiated MKC-1PH CFC

(L. L. Snead, T. D. Burchell, Carbon Extended Abstracts, 774-775, 1995)

Example Temperature History for Carbon Flat Wall Under Energy Deposition from Indirect-Drive Spectra

- **No protective gas**
- **Coolant temperature = 500°C**
- **Chamber radius = 6.5 m**
- **Maximum temperature = 17,650 °C**
- **Sublimation loss per shot = 3×10^{-3} m (6×10^{5} m per year)**



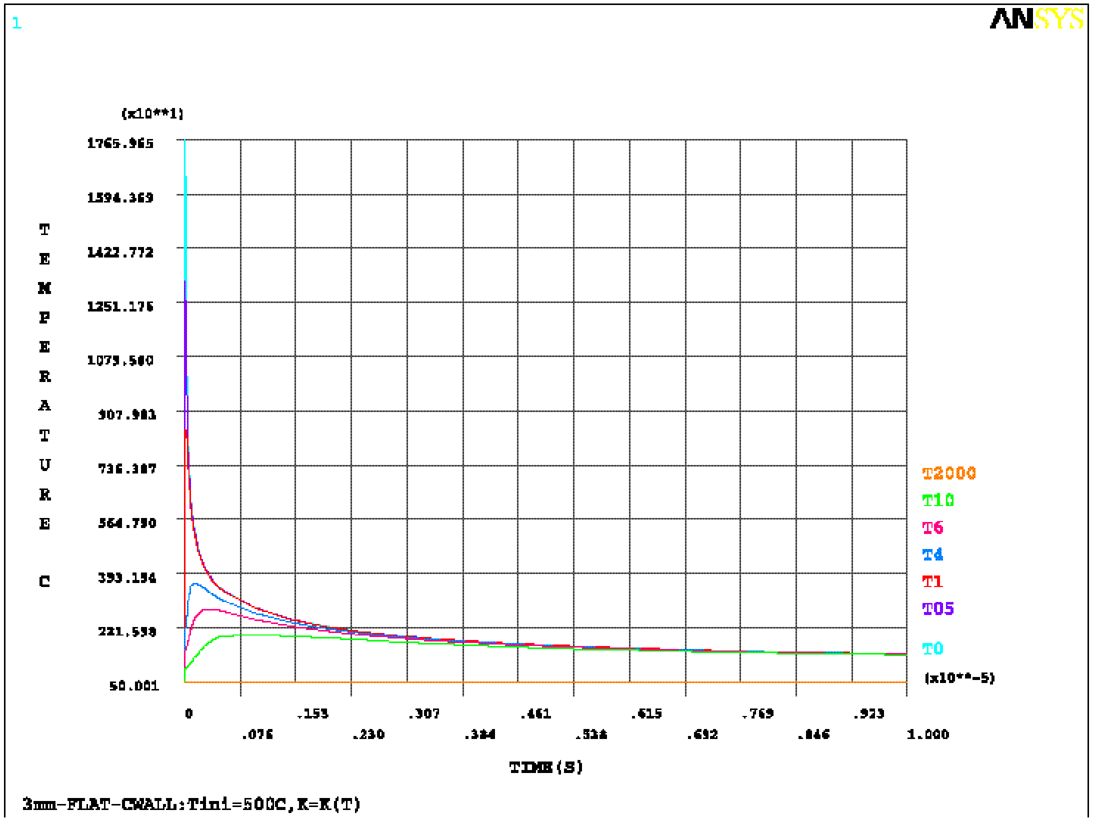
3-mm thick Carbon Chamber Wall

Coolant at 500°C

Energy Front

Evaporation heat flux B.C at incident wall

Convection B.C. at coolant wall: h= 10 kW/m^2-K

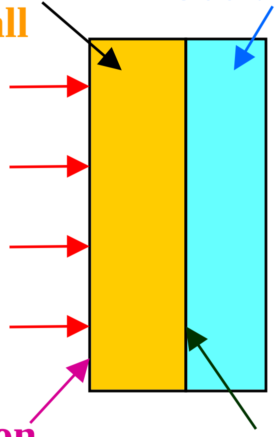


3mm-FLAT-CWALL:Tini=500C,K=K(T)

Clearly, the Presence of a Protective Gas is a Must for Indirect-Drive Target Spectra

Example Temperature History for Tungsten Flat Wall Under Energy Deposition from Indirect-Drive Spectra

- No protective gas
- Coolant temperature = 500°C
- Chamber radius = 6.5 m
- Maximum temperature = 86,300 °C
- Sublimation loss per shot = 0.63x10^{-3} m (10^5 m per year)



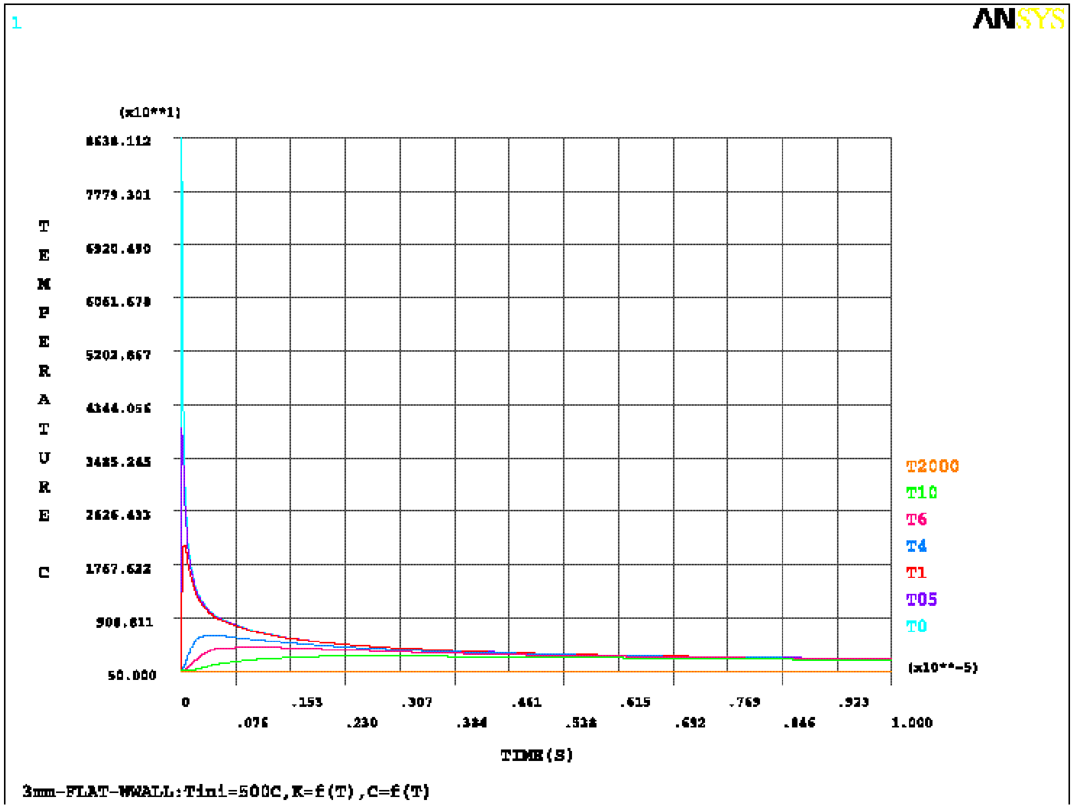
3-mm thick W Chamber Wall

Coolant at 500°C

Energy Front

Evaporation heat flux B.C at incident wall

Convection B.C. at coolant wall:
h= 10 kW/m^2-K

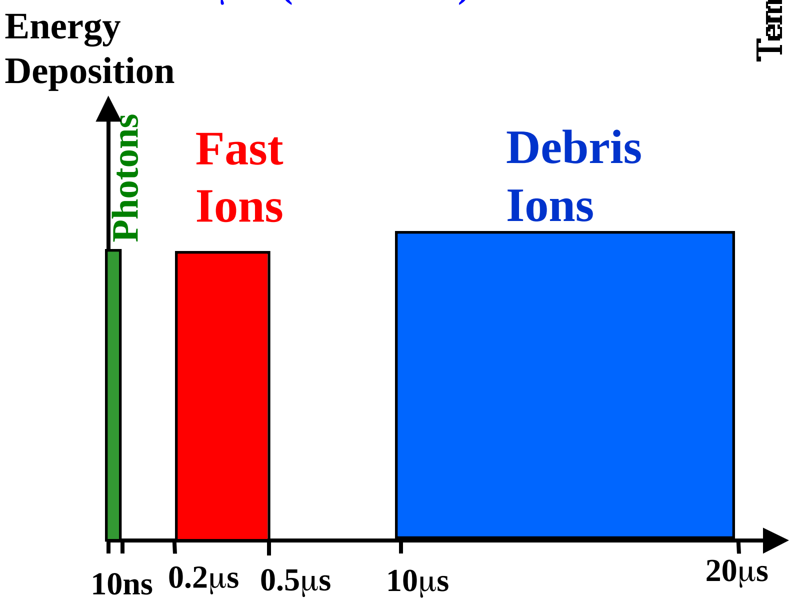


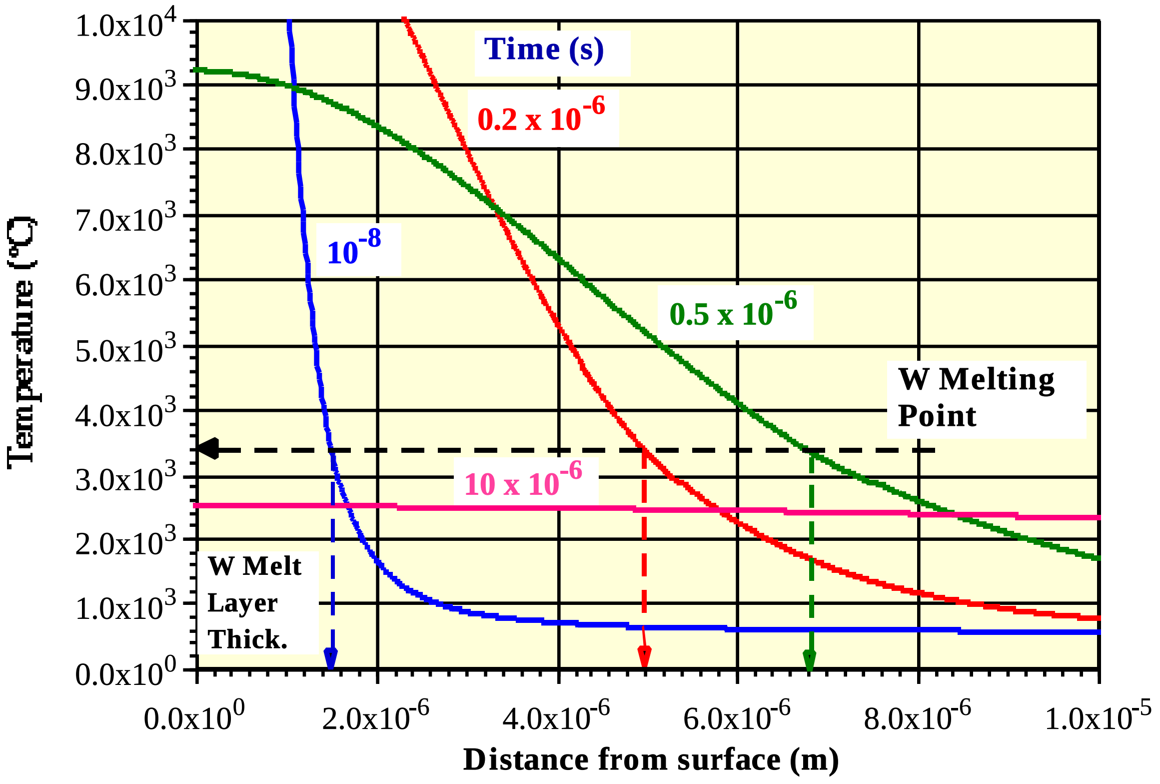
3mm-FLAT-WWALL:Tini=500C,K=f(T),C=f(T)

Again, the Presence of a Protective Gas is a Must for Indirect-Drive Target Spectra

Corresponding Melt Layer for Tungsten Flat Wall Under Energy Deposition from Indirect-Drive Spectra

- No protective gas
- Coolant temperature = 500°C
- Chamber radius = 6.5 m
- Substantial melt layer thickness per shot at different time:
  - 1.5 μm (10^{-8} s)
  - 5 μm (0.2 x 10^{-6} s)
  - 6.8 μm (0.5 x 10^{-6} s)





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Proposed Outline of Dry Chamber Wall Report (I)
(First draft of report to be written over next 3-4 months)

1. Introduction (Raffray/ Najmabadi)
   - Erosion is a key lifetime issue for dry chamber wall design
   - Separate thin armor region from structural backbone
     - Most issues linked with armor itself
     - Possibility of repairing armor (in-situ)
   - Gas protection helps but adversely affect target injection
   - Overall topic probably make or break issue for dry walls
   - Importance of spectra and energy partitioning between x-rays and ions
   - Precise analysis required– correct energy deposition calculations from x-ray and ion spectrum and detailed calculations of resulting spatial and temporal distributions of heat fluxes
   - Possible use of engineered surface to increase frontal area

2. Spectra from target calculations (direct drive and indirect drive)
   - Describe spectra for NRL direct-drive and HI indirect-drive targets
     - Comparison with past target assumptions (Peterson/Haynes)
   - Temporal distribution of x-rays (Peterson/Haynes)
   - Time of flight of ions (Tillack/Zaghloul)

Outline of Dry Chamber Wall Report (II)

3. Calculations of spatial distribution of energy deposition with (Peterson/Haynes) and without (Zaghloul/Raffray) protective gas

3.1 Direct drive NRL target
- x-rays
- fast ions
- slow ions
- Importance of fine grids
  - Calculations of temporal variation of energy deposition
  - As a function of protective gas pressure
  - Sensitivity analysis for model assumption (e.g. for lower energy ions)

3.2 Indirect drive target
- Same as for direct drive

4. Material properties at temperature and under irradiation (Billone)
- Carbon
- W

Outline of Dry Chamber Wall Report (III)

5. Thermal analysis for direct drive NRL target
    - Flat case for C with (Peterson/Haynes) and without (Raffray/Wang) protective gas
        - Including sublimation effect
        - Effect of temporal energy deposition distribution
        - Effect of k(T) vs. constant k for carbon
        - Effect of scaling up energy deposition for same spectra
        - Effect of scaling up stopping power in model for low energy ions
    - Fibrous surface without protective gas (Raffray/Wang)
        - Model for energy deposition calculations
        - Model for thermal analysis
        - Parametric studies of geometry
    - Flat case for W with (Peterson/Haynes) and without (Raffray/Wang) protective gas
        - Including melting + sublimation effect
        - Effect of scaling up energy deposition for same spectra
        - Effect of scaling up stopping power in model for low energy ions

Outline of Dry Chamber Wall Report (IV)

6. Thermal analysis for indirect drive target with (Peterson/Haynes) and without (Raffray/Wang) protective gas
   - Carbon
   - W
   - Effect of debris accumulation on chamber wall

7. Other erosion mechanisms (Raffray/Hassanein/Federici)
   - Physical sputtering
   - Chemical sputtering
   - RES
   - Macroscopic erosion
   - Splashing and melt layer loss

8. Safety Issues (Petti/El-Guebaly)
   - Including C fiber configuration vs flat C surface
   - Activation
   - Disposal/recycling and activation of debris in particular for indirect-drive

Outline of Dry Chamber Wall Report (V)

9. Tritium inventory and recovery (Federici/Hassanein)

10. How to understand and apply properties and parameters derived for equilibrium conditions for highly-pulsed, irradiated IFE conditions (Raffray/others)

11. Conclusions (Raffray/all)
    - Combination of precise analysis and engineered material = Strong ray of hope for dry wall chambers!!
    - Design window seems to exist
    - Protective gas is a must for indirect-drive spectra
    - Outstanding issues

- **Comments are welcome**
- **Gentle notice to all co-authors:**
  - **I will send a schedule for the report write-up and would appreciate receiving your contribution(s) in time for the first draft of the report to be ready within the next 3-4 months**

Initial Planning Activity for Assessment of Wetted Wall Option

Wetted Wall Chamber Issues

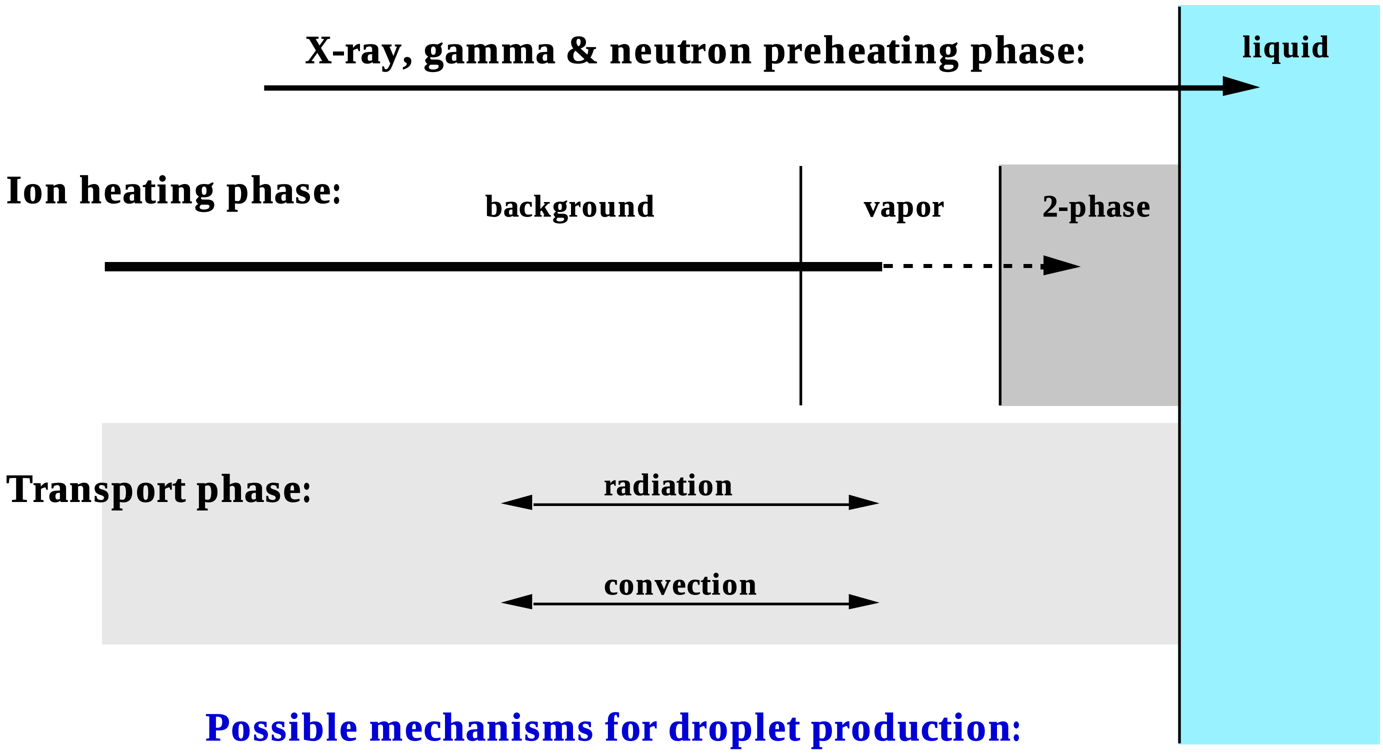
Film Flow

- Assure full coverage, adequate uniformity
- Avoid dripping
- Avoid droplet ejection from blast

Clearing

- Return chamber environment to a condition which allows successful target and driver propagation
  1. Help determine criteria (target injection and beam propagation)
  2. Model energy deposition and aerosol creation processes
  3. Scope time scales for recondensation (in flight and on wall)
  4. Model "late-stage" thermal and fluid dynamic behavior (DP task)

Liquid Wall Interaction



X-ray, gamma & neutron preheating phase:

liquid

Ion heating phase:

background

vapor

2-phase

Transport phase:

radiation

convection

Possible mechanisms for droplet production:

surface vapor explosion
bulk boiling
isochoric heating
convective flow & shocks
in-flight recondensation

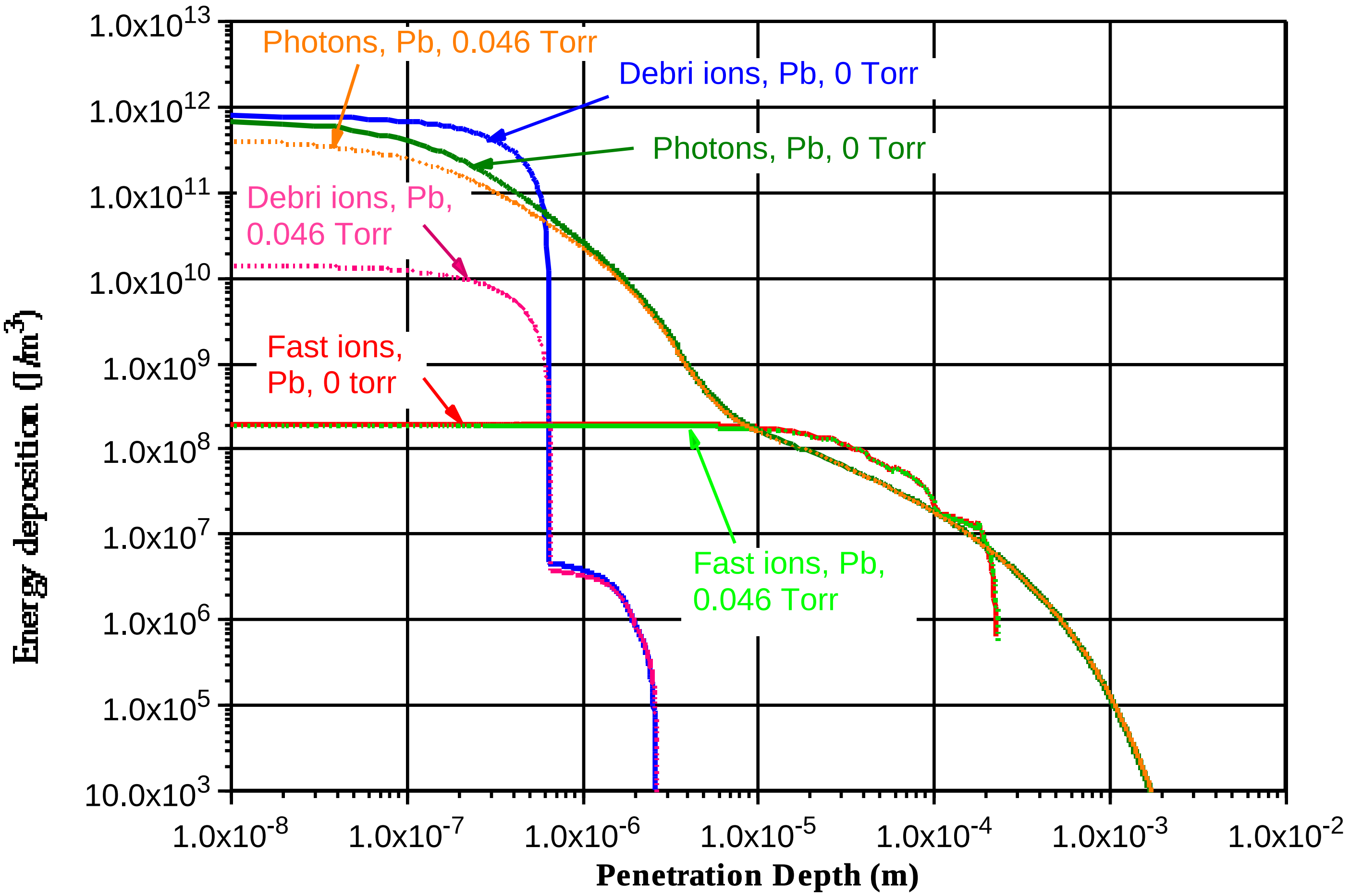
Concern about creating quiescent atmosphere in time for next shot:

- **Time scale of recovery mechanisms, e.g:**
    - **Condensation**
    - **Clearing**
    - **Aerosol evacuation**

- **Initial effort to determine extent of ablation and limiting conditions for aerosol formation**

- **Future effort will address key issues linked with recovery process time scales**

Photon and Ion Attenuation in Lead Wall for Pb Chamber Pressure of 0 and 0.046 Torr (Pb Partial Pressure at 800°C)



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