Dry Chamber Wall Configuration

1. **Impact on Power Cycle Performance of Separately Cooling the Chamber Wall (low temperature) and Blanket (high temperature)**
2. **Assessment of Chamber Wall Material Configuration under Energy Loads**

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ARIES Meeting, UCSD

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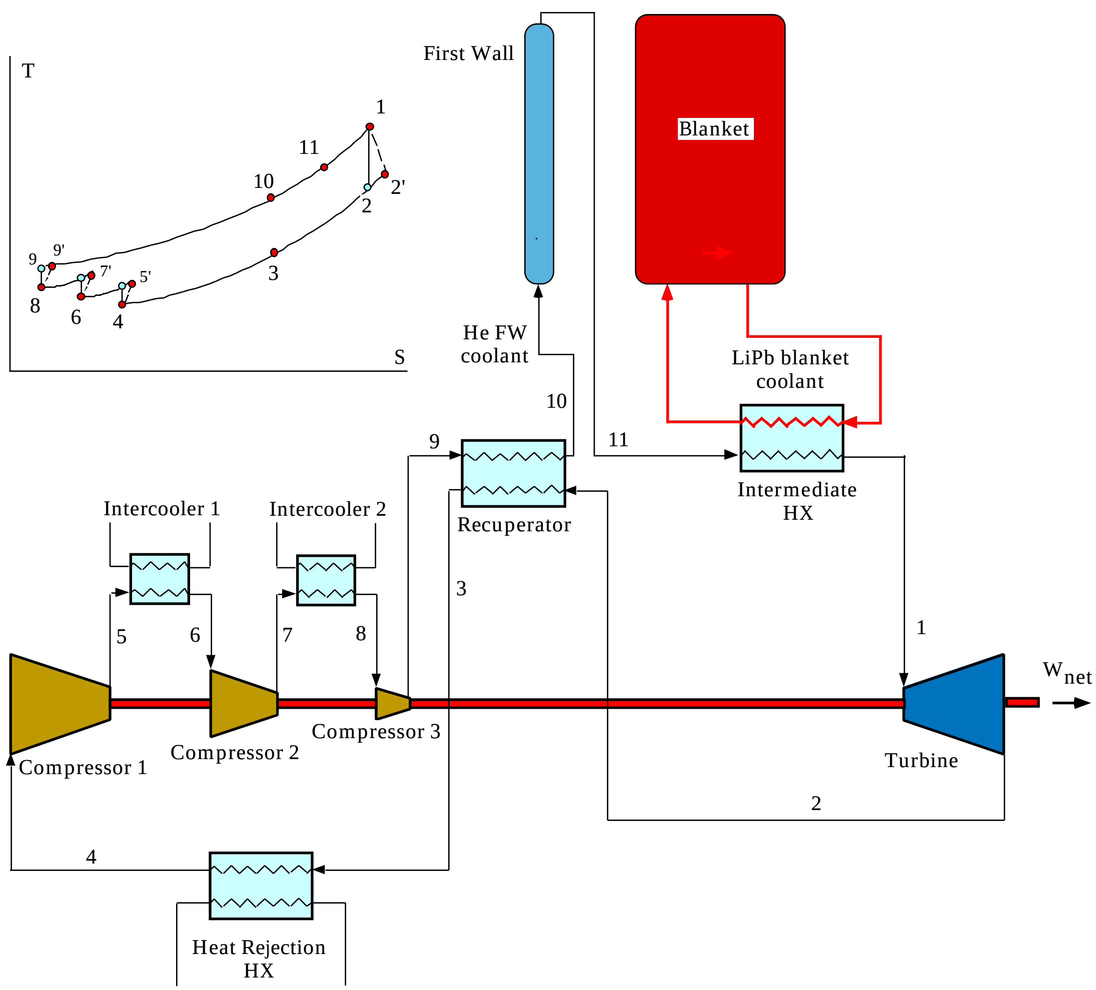
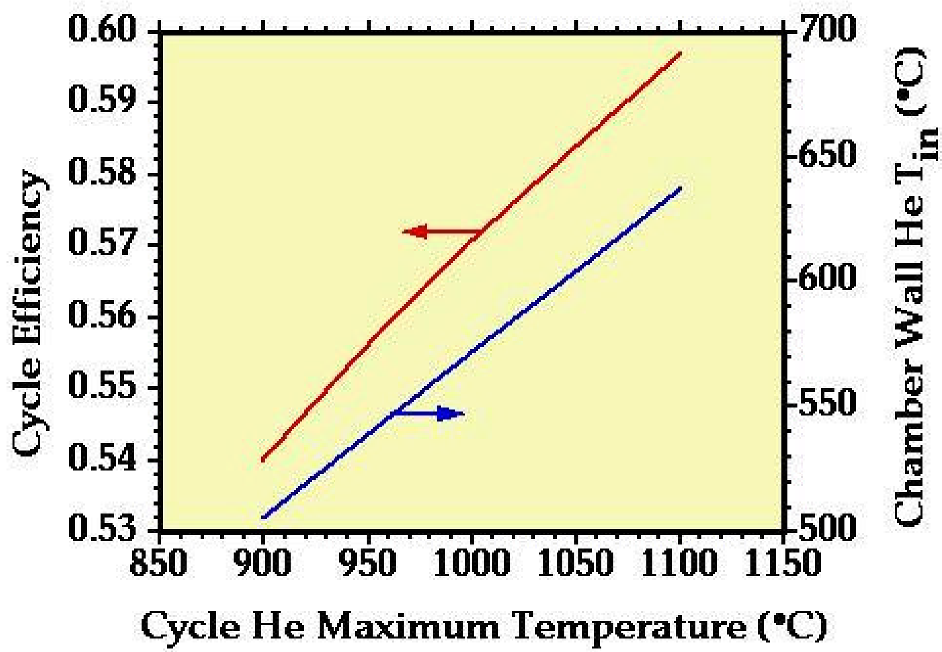
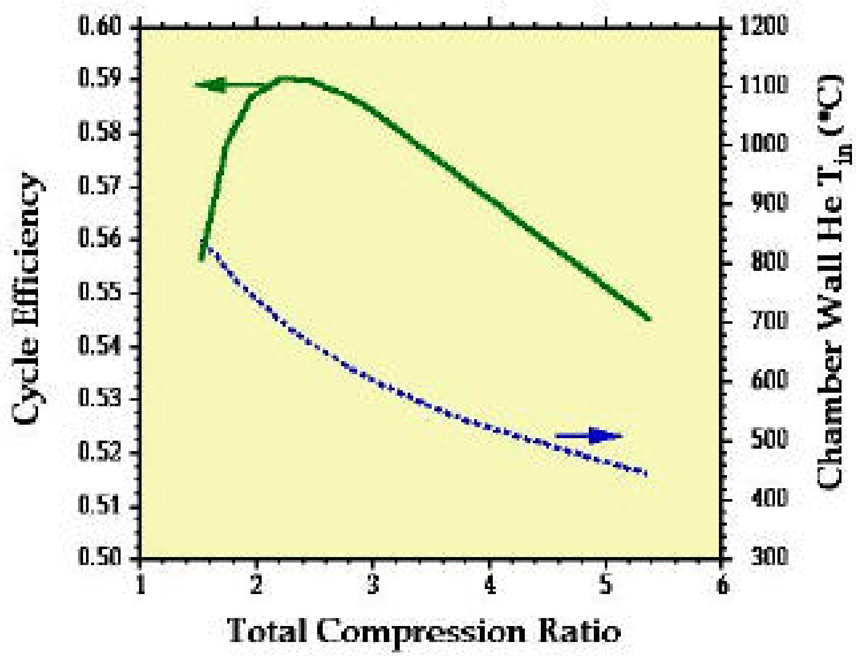
Use ARIES-AT Brayton Cycle as Example to Illustrate Effect on Overall Cycle Efficiency of Running a Low Temperature Chamber Wall and a High Temperature Blanket

- **Min. He Temp. in cycle (heat sink) = 35°C**
- **3-stage compression with 2 inter-coolers**
- **Turbine efficiency = 0.93**
- **Compressor efficiency = 0.88**
- **Recuperator effect. = 0.96**
- **Cycle He fractional ΔP = 0.03**
- **Intermediate Heat Exchanger ΔT(Pb-17Li/He) ~ 50°C**



Chamber Wall He Temperature Dictated by Maximum Cycle He Temperature and Compression Ratio

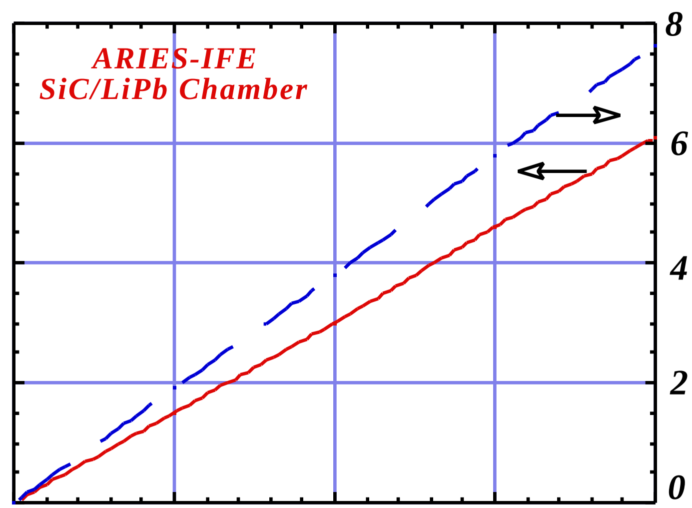




Total Thermal Power in First Wall

- SiC/LiPb chamber
- NRL target: 161 MJ yield, 6 Hz
- 4 m FW radius; Γ ~ 3.4 MW/m^2
- Peak heating is 15 W/cm^3 and varies as $(4/R)^2$ with FW radius
- ~800 MW total nuclear heating in FW/B/S

Nuclear Heating in First Wall



From Laila El-Guebaly

Fusion Technology Institute
University of Wisconsin - Madison

- Fraction of output energy:
  - X-rays + ions + gamma = 29%
  - Neutrons = 71%
- Assume:
  - multiplication factor of 1.1
  - ~ 4% nuclear heating in FW

30% of total power in FW

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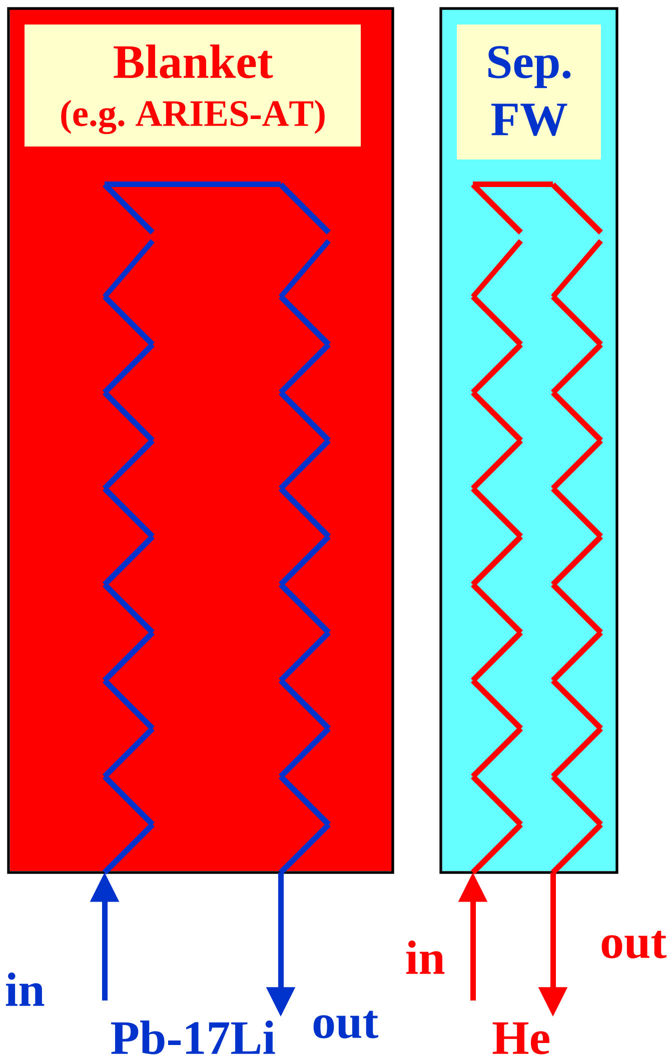
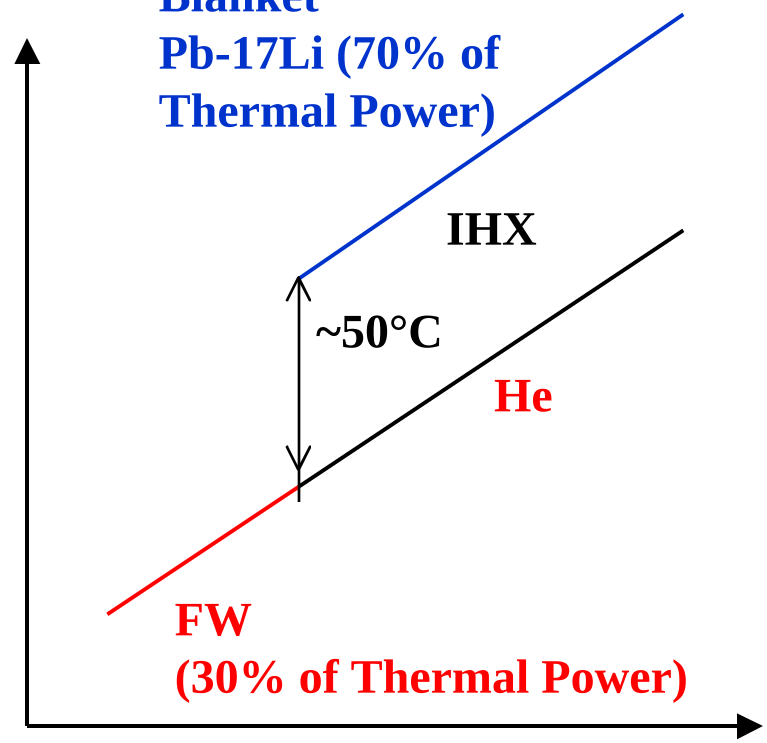
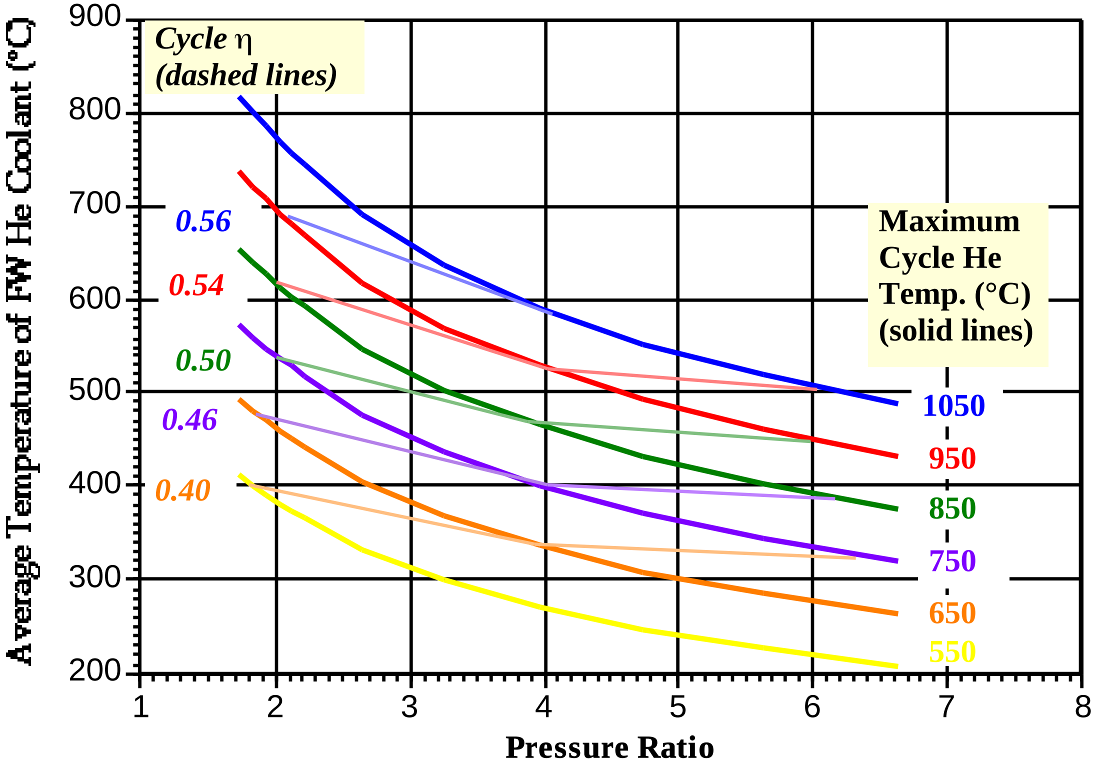
ARIES-ST Power Parameters





The Chamber Wall Temperature can be Maintained <900 K to Reduce Radiation to the Target while Maintaining an Acceptable Cycle Efficiency



Example Case:

- For a ΔT_{FW} of ~100-150°C and compression ratio of 4.5, the avg. surface T_{wall} at target injection can be lowered to ~600°C while maintaining a cycle efficiency of 50%

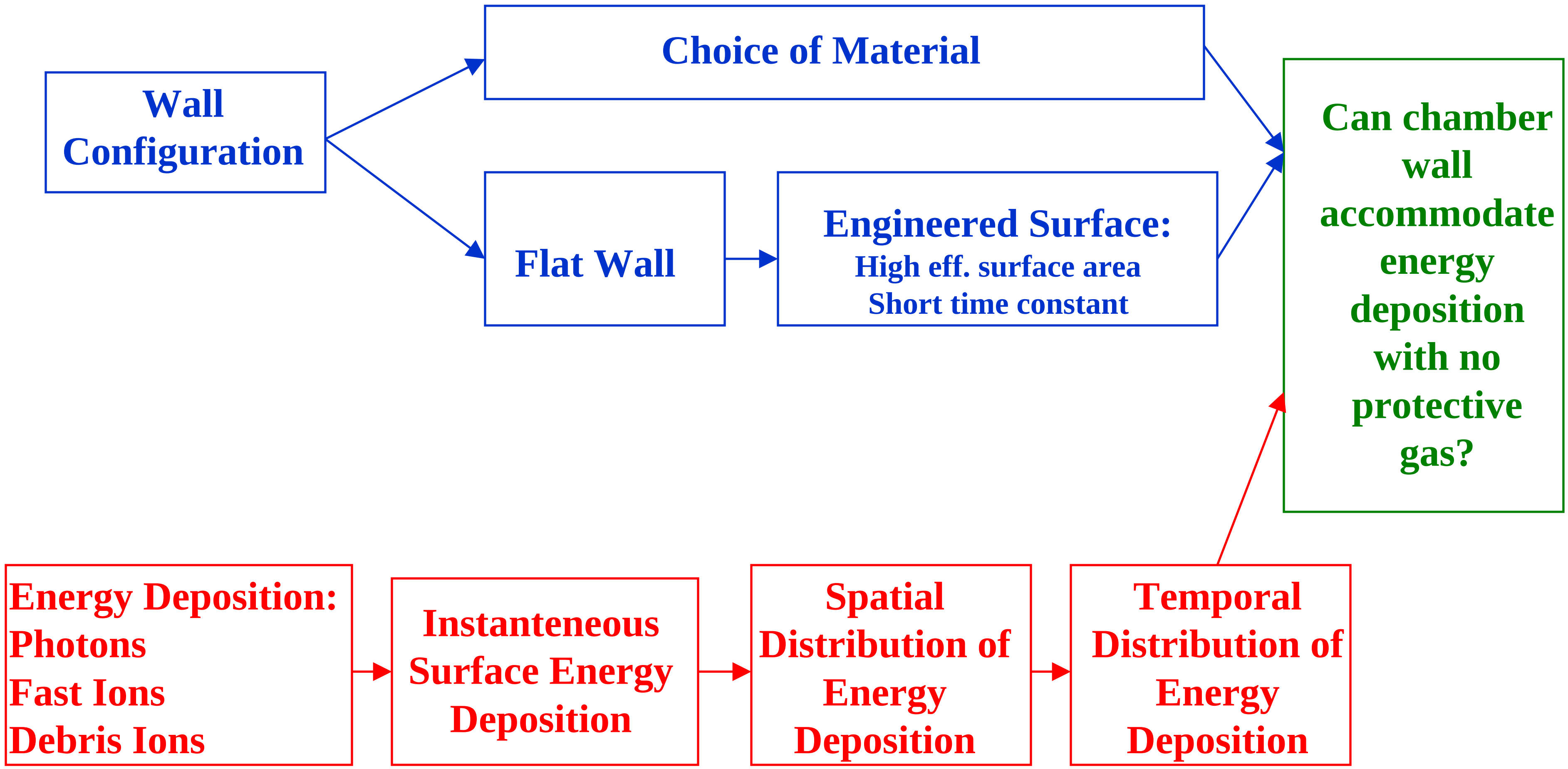
Dry Chamber Wall Engineering Assessment

- **Material Option (C, SiC, W...) (M. Billone)**
- **Material Configuration to Help Accommodate Energy Deposition**
- **Protective Chamber Gas**
  - **e.g. Xe**
  - **Effect on target injection**
  - **Effect on laser**
  - **UW has performed detailed comparative studies for different material and gas pressure (R. Peterson/D. Haynes)**

- **Ideal Solution**
  - **Dry wall material configuration which can accommodate energy deposition without any protective gas in chamber**

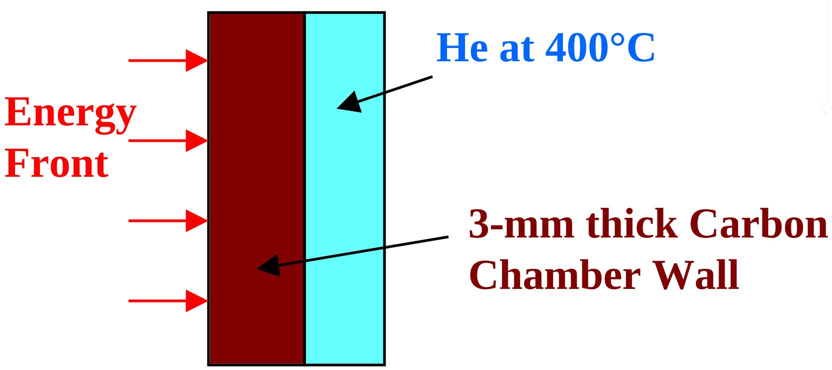
- **Initial assessment of this possibility**

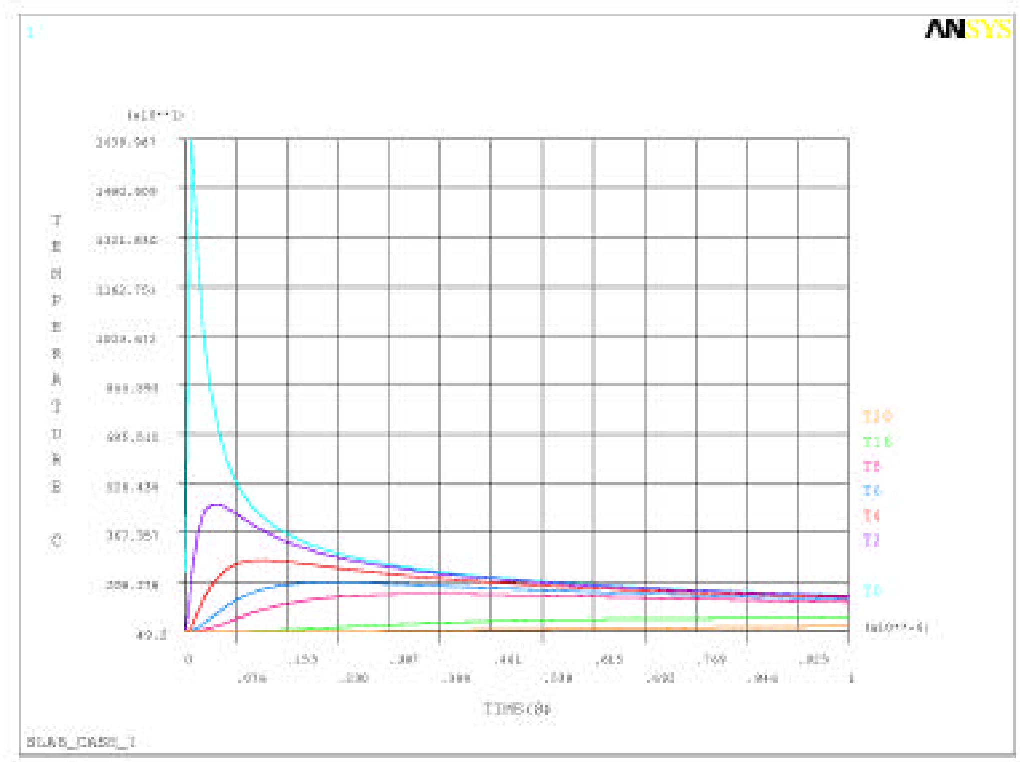
Approach Relies on More Precise Energy Deposition Analysis and Engineered Surface



Consider Total Energy Deposited Instantaneously on Flat Wall Surface As Upper Bound Initial Case

- Energy Accounting from NRL Direct-Drive Target Calculations:
  - X-rays = 2.14 MJ
  - Fast Ions = 18.1 MJ
  - Debris Ions = 24.9 MJ
- Assume chamber radius = 6.5 m
- Apply resulting energy density on chamber wall over smallest computational time increment

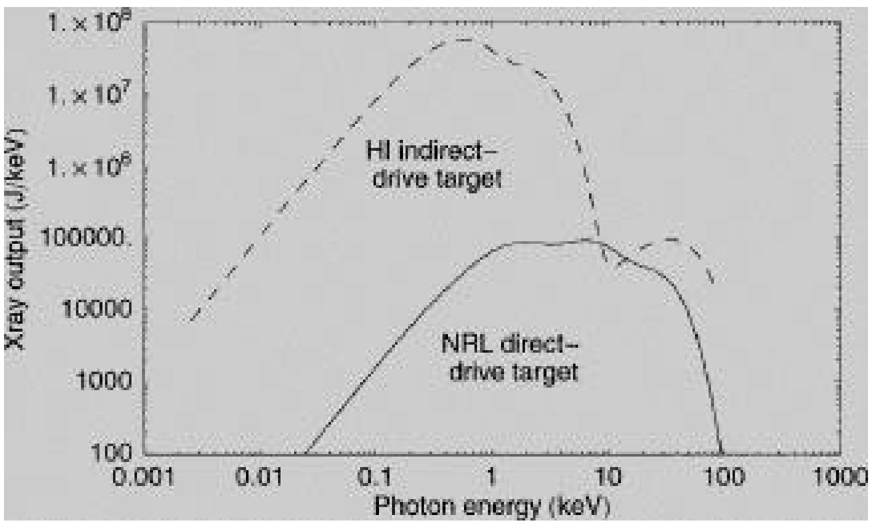




- Temperature subscript refers to distance from surface (microns)
- k_{Carbon} = 400W/m-K

Photon Spectrum and Attenuation in Chamber Wall

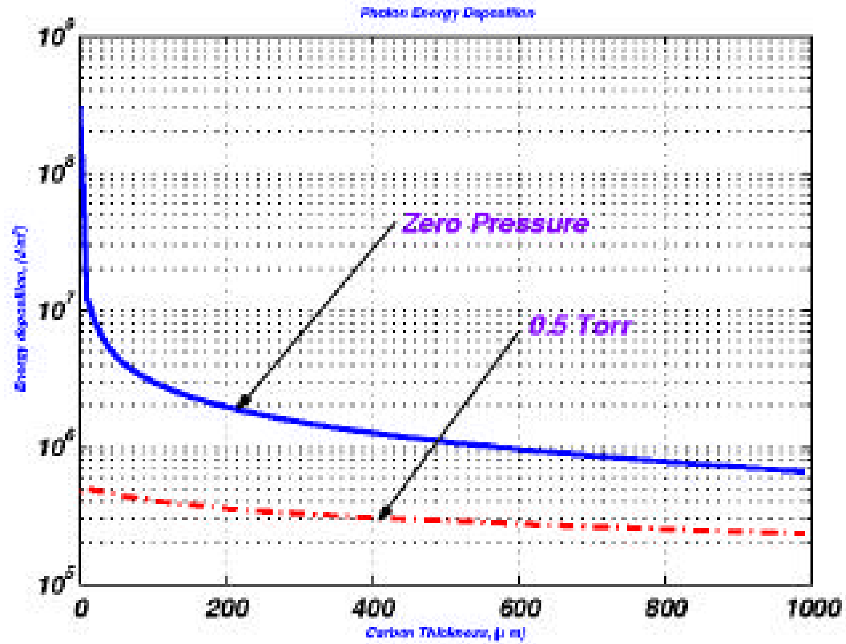
X-ray Spectrum for NRL Direct-Drive Target



From J. Perkins, LLNL

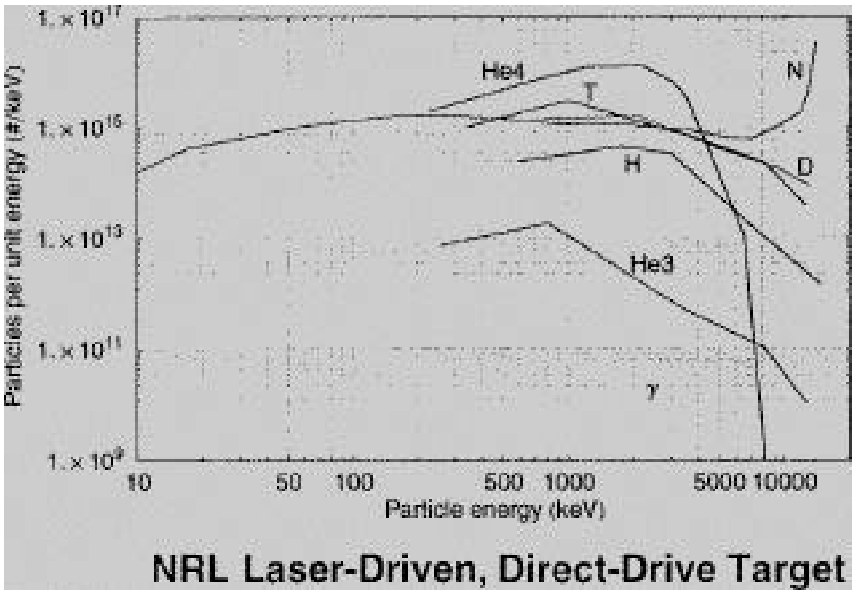
Energy Deposition from Photon Interaction in C for Given Spectrum with:

- No gas
- 0.5 Torr Xe



Fast Ions Spectrum and Attenuation in Chamber Wall

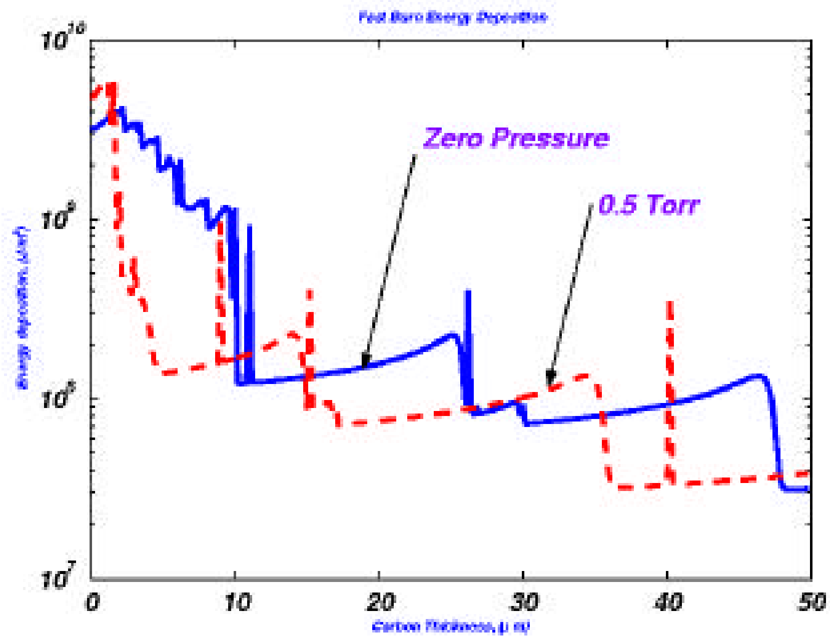
Fast Ions Spectrum for NRL Direct-Drive Target



From J. Perkins, LLNL

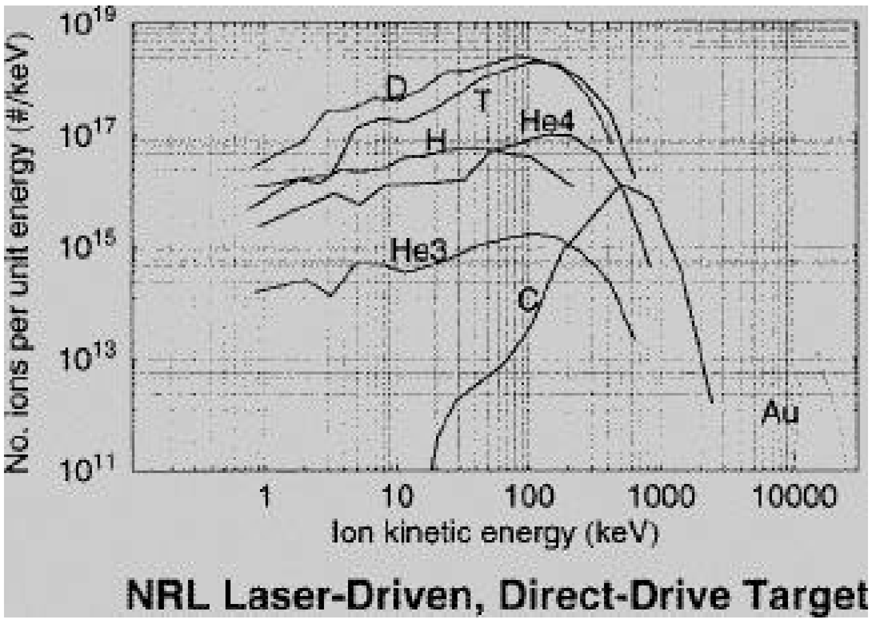
Fast Ion Energy Deposition in C (Bethe Formula) for Given Spectrum with:

- No gas
- 0.5 Torr Xe



Debris Ions Spectrum and Attenuation in Chamber Wall

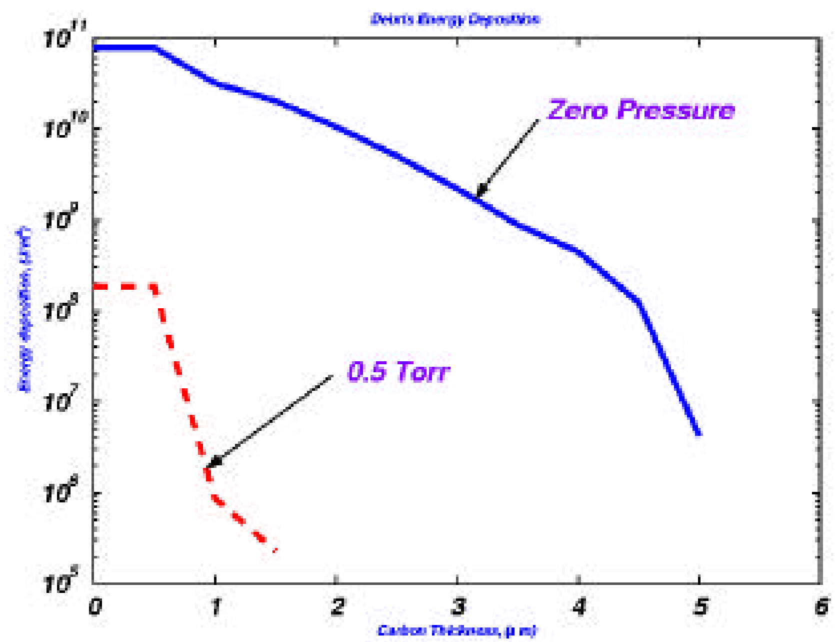
Debris Ions Spectrum for NRL Direct-Drive Target



From J. Perkins, LLNL

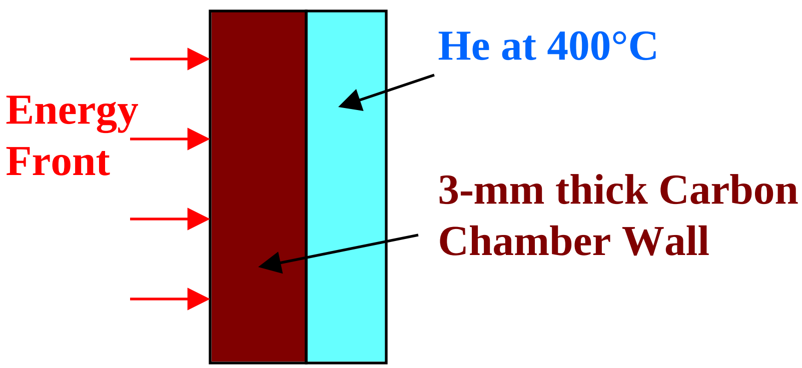
Example Debris Ions Energy Deposition in C for Given Spectrum with:

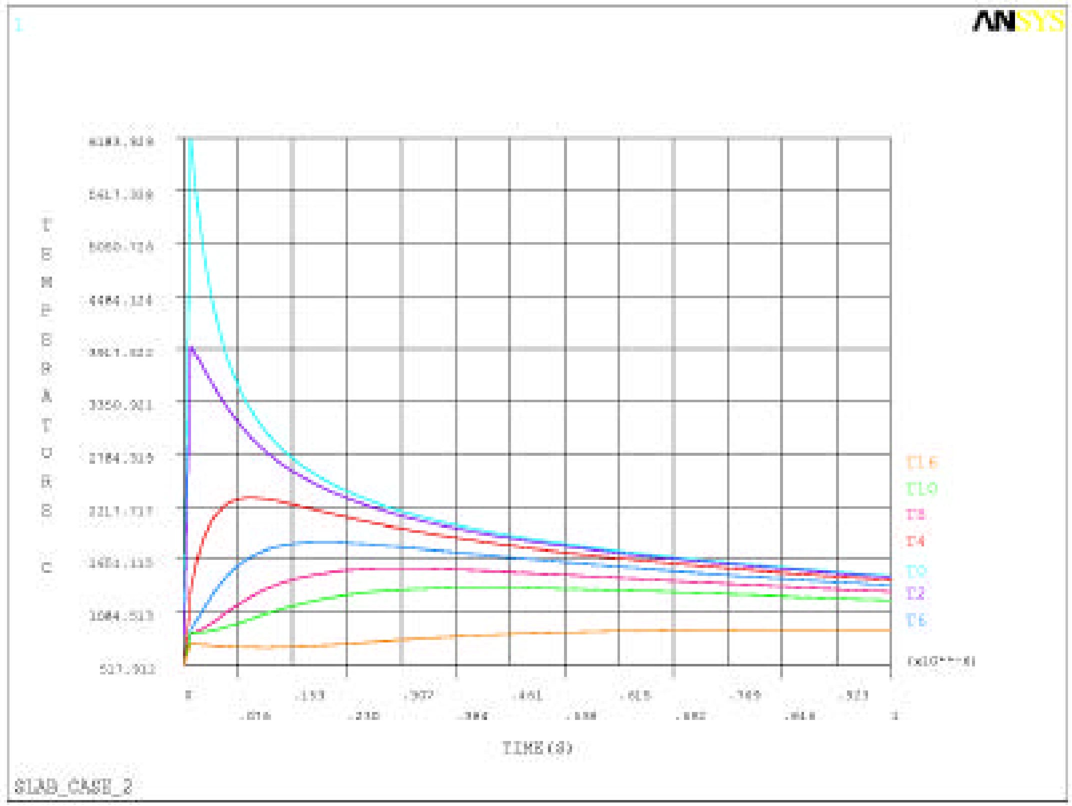
- No gas
- 0.5 Torr Xe



Consider Total Energy Spatially Deposited Instantaneously in Flat Wall

- Energy Deposition Estimated from NRL Direct-Drive Target Spectra for
  - X-rays
  - Fast Ions
  - Debris Ions
- Assume chamber radius = 6.5 m
- Apply resulting spatial energy deposition per unit volume in chamber wall over smallest computational time increment

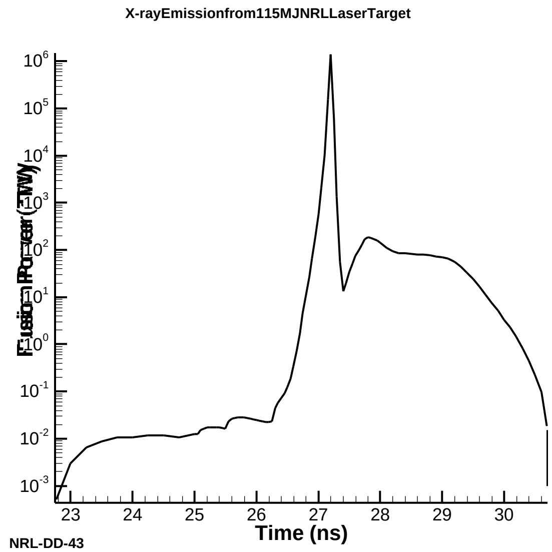




- Temperature subscript refers to distance from surface (microns)
- k_{Carbon} = 400 W/m-K

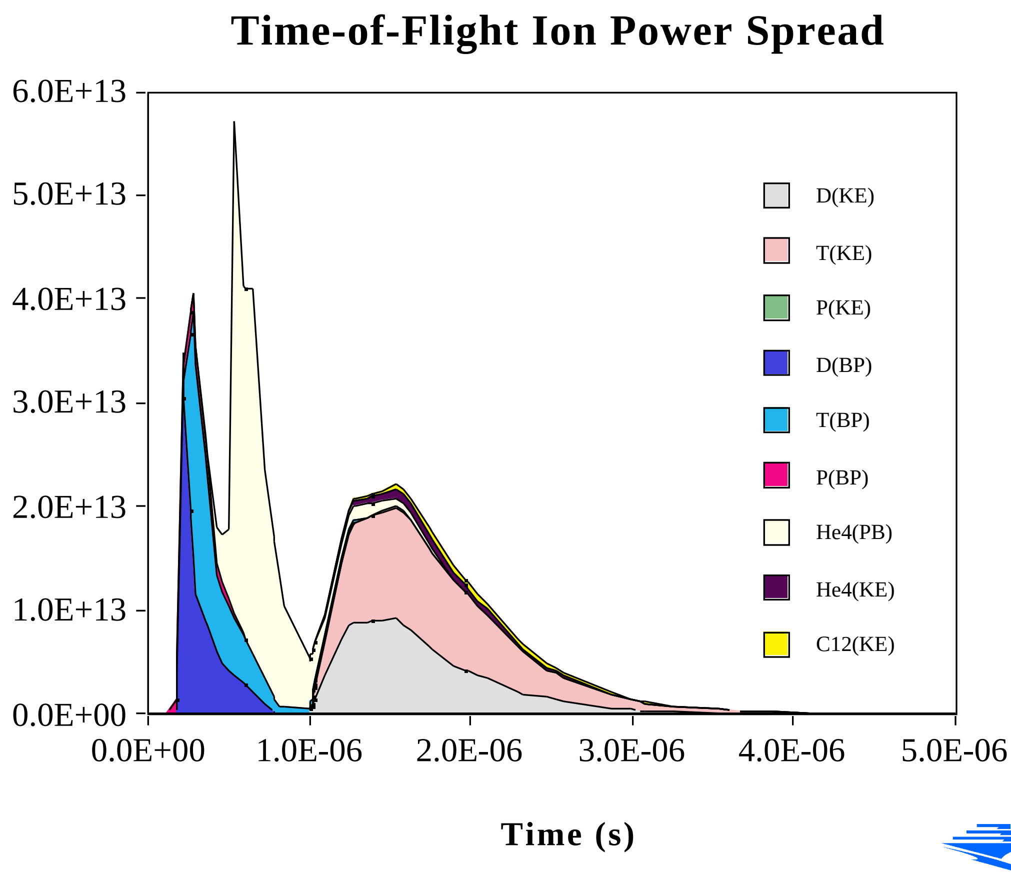
Photons and Ions Also Have a Temporal Distribution

Example Photon Temporal Distribution

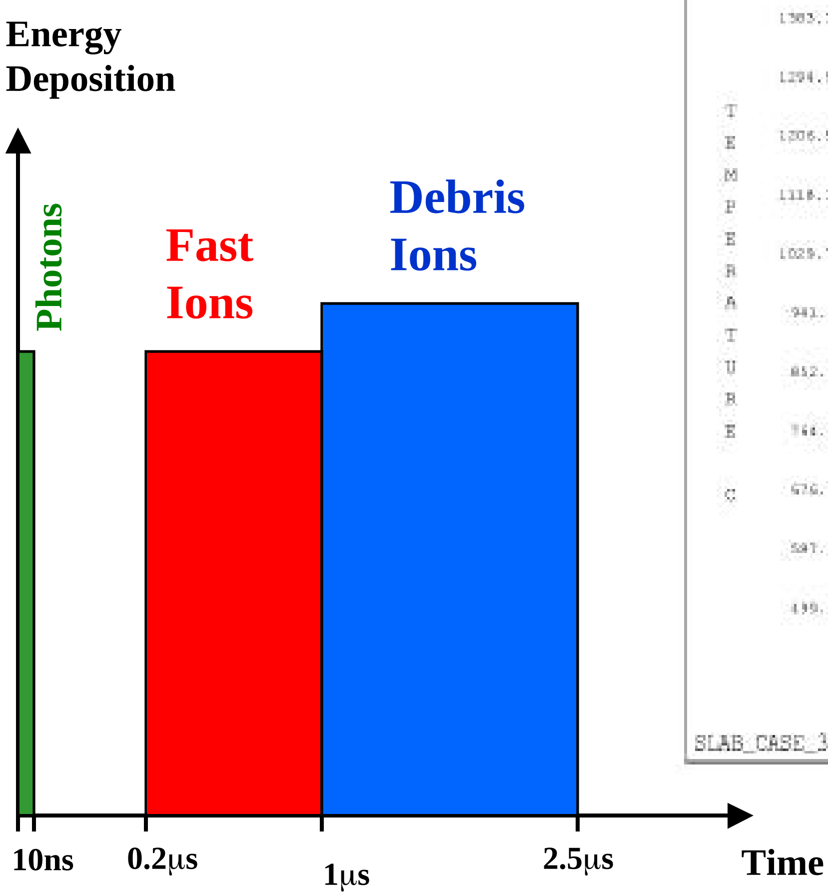


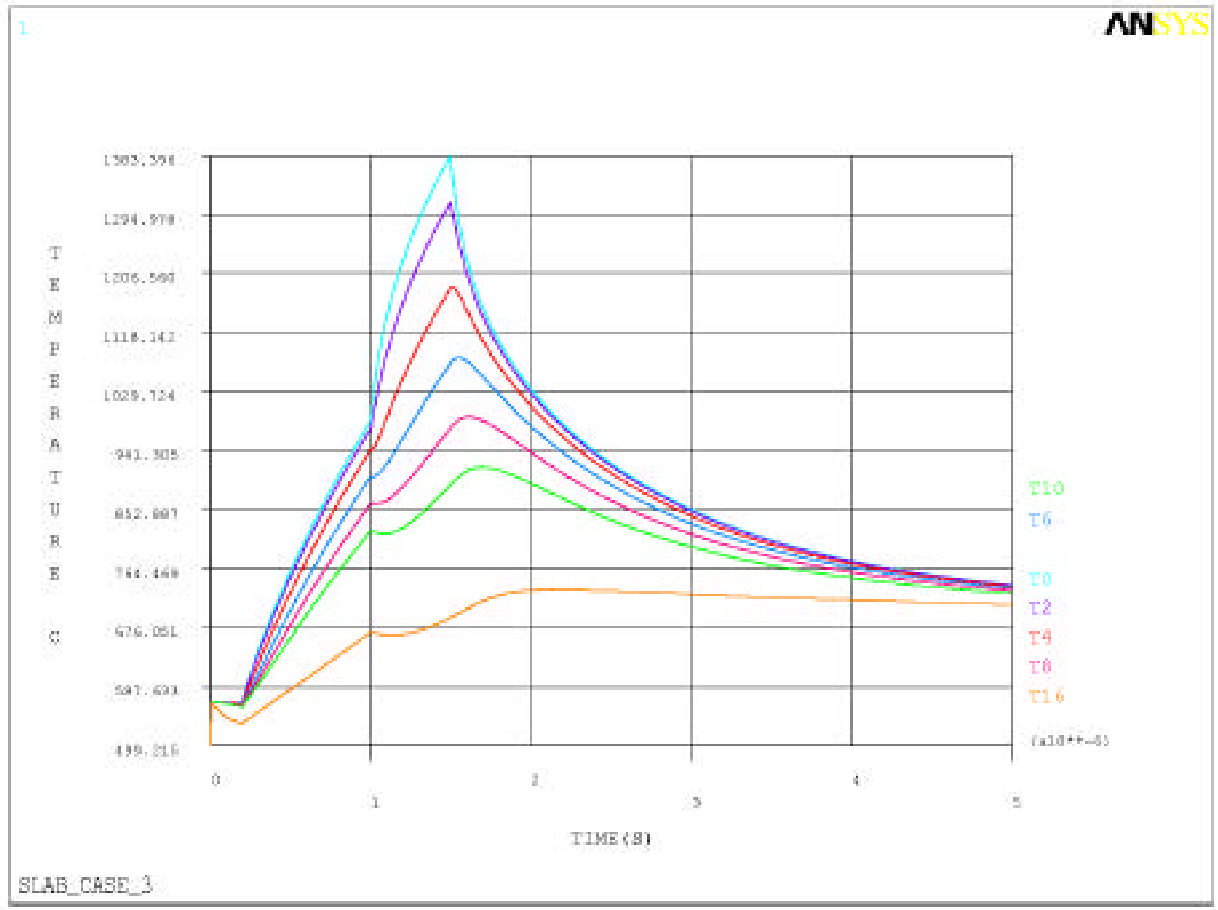
From R. Peterson and D. Haynes's presentation
At ARIES meeting last September

Temporal Distribution for Ions Based on Given Spectrum and 6.5 m Chamber



Consider Total Energy Spatially Deposited over Time in Flat Wall

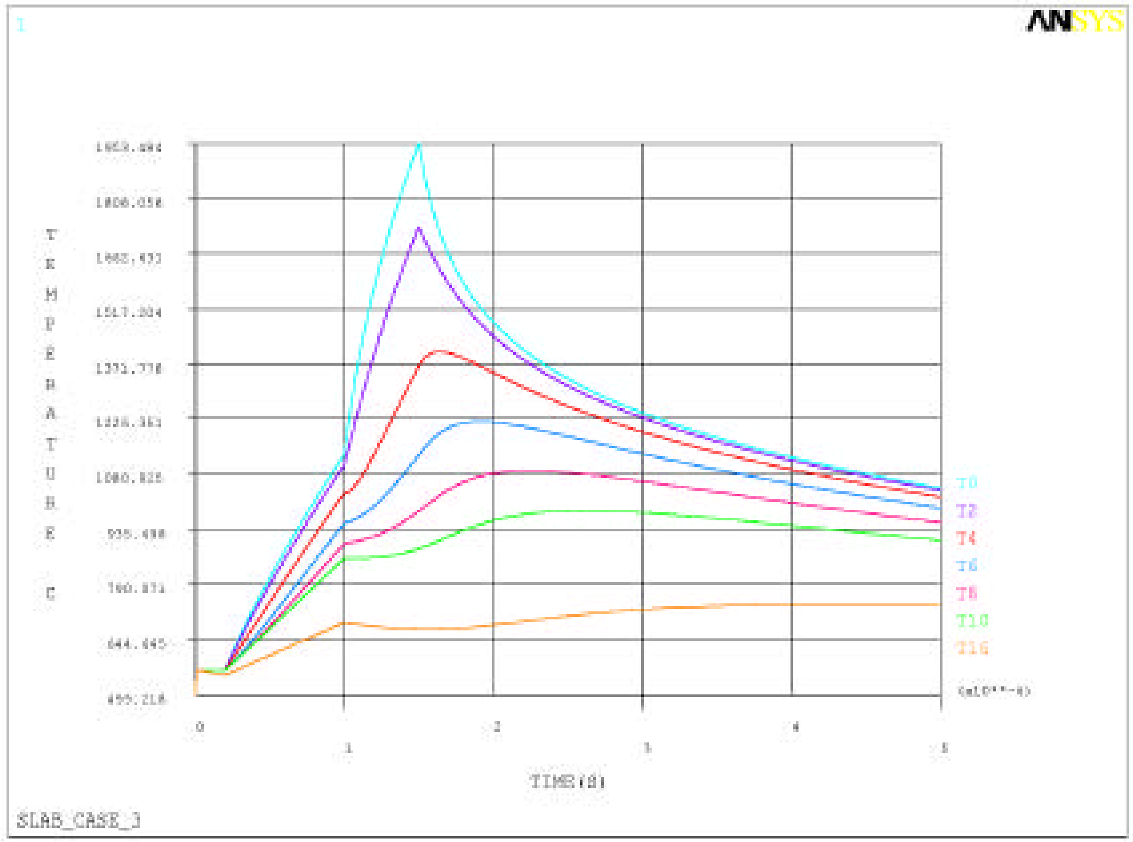




- Temperature subscript refers to distance from surface (microns)
- k_{Carbon} = 400 W/m-K

Case with Total Energy Spatially Deposited over Time in Flat Wall with Different k_{Carbon}

- **Maximum Surface Temperature = 1383 °C for k_{Carbon}= 400 W/m-K**
- **Maximum Surface Temperature = 1953 °C for k_{Carbon}= 100 W/m-K**

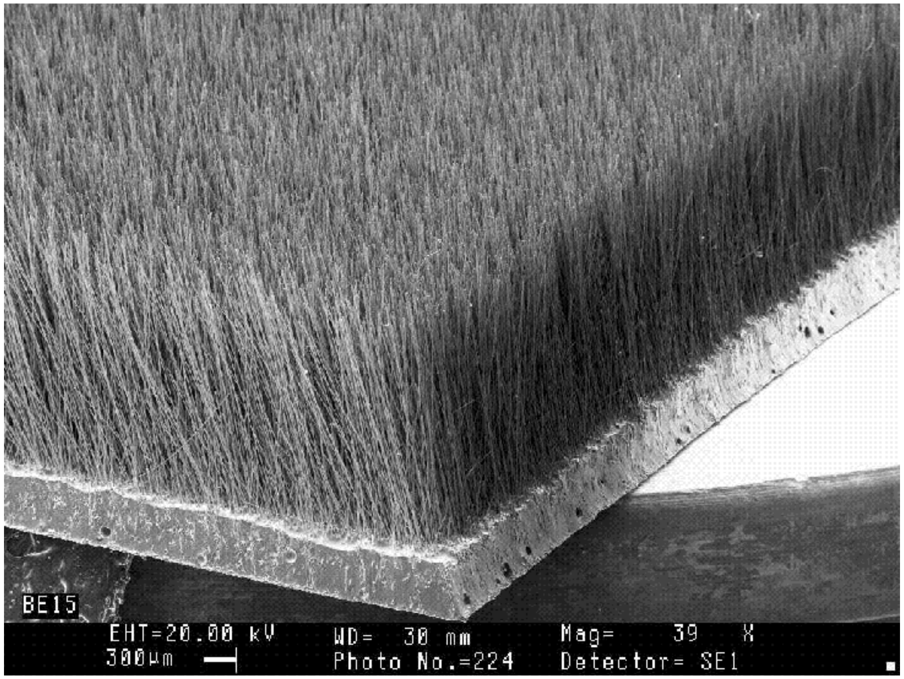


- **Temperature subscript refers to distance from surface (microns)**
- **k_{Carbon} = 100 W/m-K**

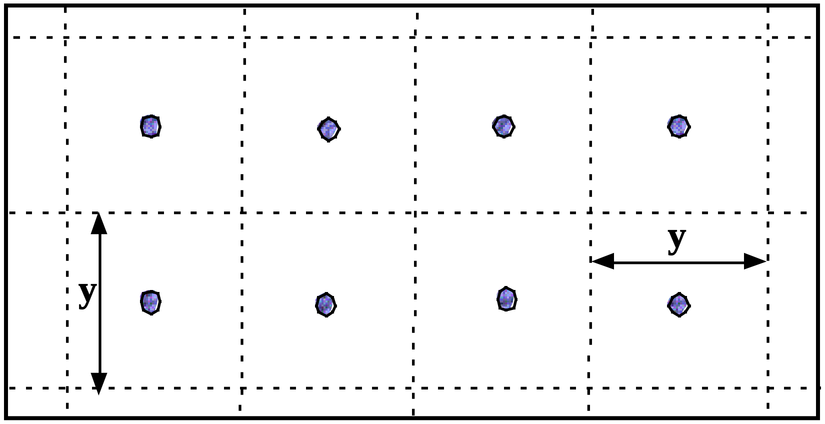
Introduce Engineered Surface Configuration

- **Porous Media**
  - Fiber diameter ~ diffusion characteristic length for 1 μs
  - Increase incident surface area per unit cell seeing energy deposition

e.g. ESLI Fiber-Infiltrated Substrate



Modeling Porous Fiber Configuration



Probability for energy front to contact fiber:

over first unit cell, $P_1 = d/y$

over second unit cell, $P_2 = (1-P_1)\, d/(y-d)$

over third unit cell, $P_3 = (1-P_1-P_2)\, d/(y-2d)$, etc...

up to $P_n=(1-P_1-P_2-...P_{n-1})\, d/(y-(n-1)d)$

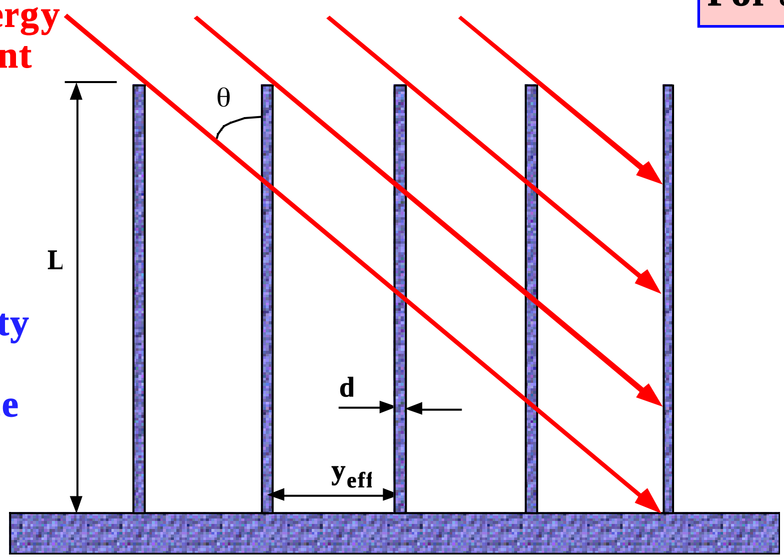
where $n=y/d$

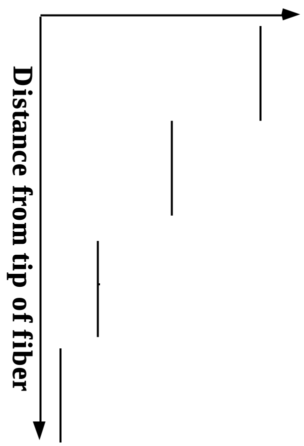
$y_{eff} = yP_1+2yP_2+3yP_3...+nyP_n$

Fiber Density, $(1-\varepsilon) = \pi d^2/4y^2$

For ε=0.9 and d=10μm, y=28μm, y_{eff} = 54μm

For ε=0.8 and d=10μm, y=19.8μm, y_{eff} = 29.6μm





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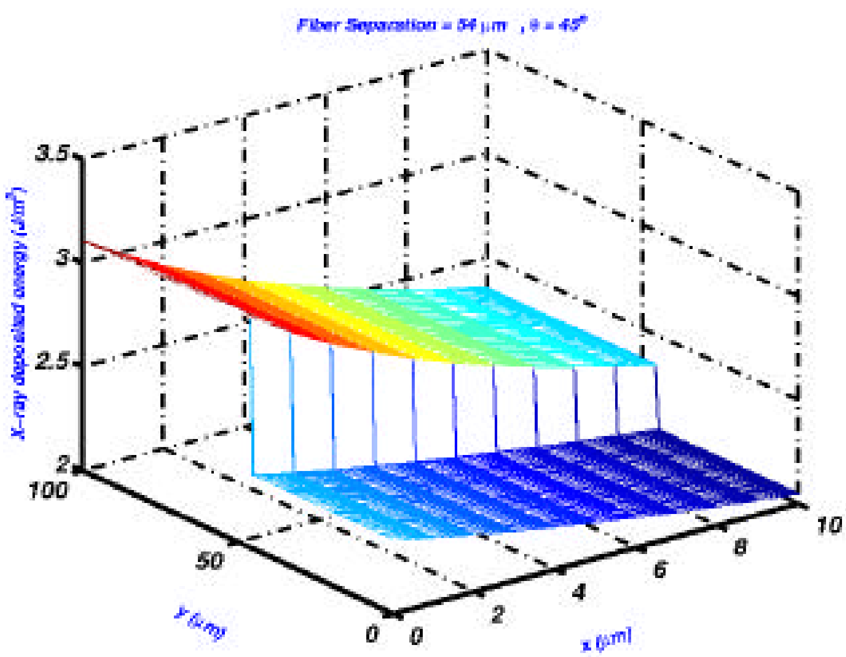
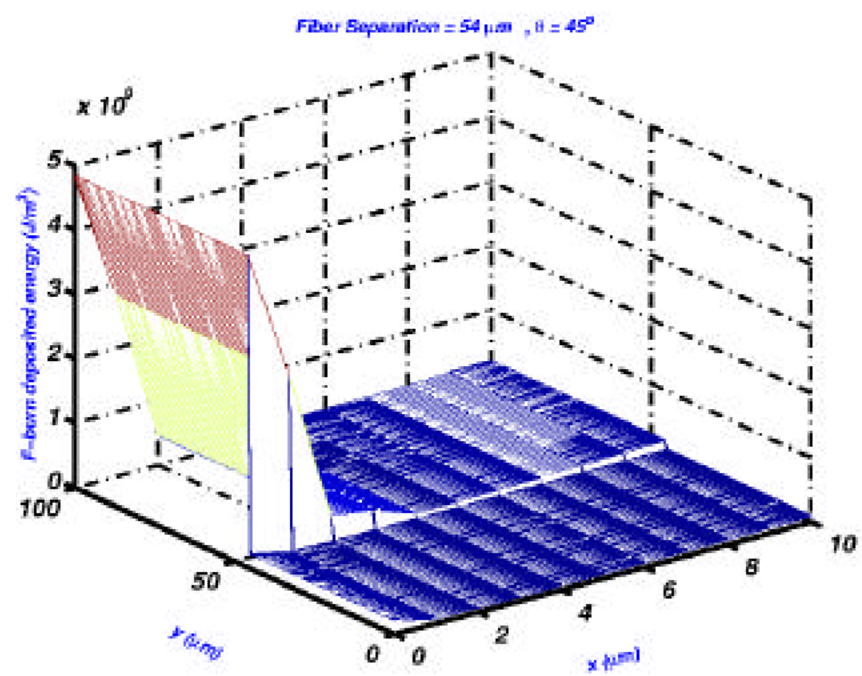
Example Spatial Energy Deposition in Fiber Based on Photon and Fast Ions Attenuation

Photon Energy deposition

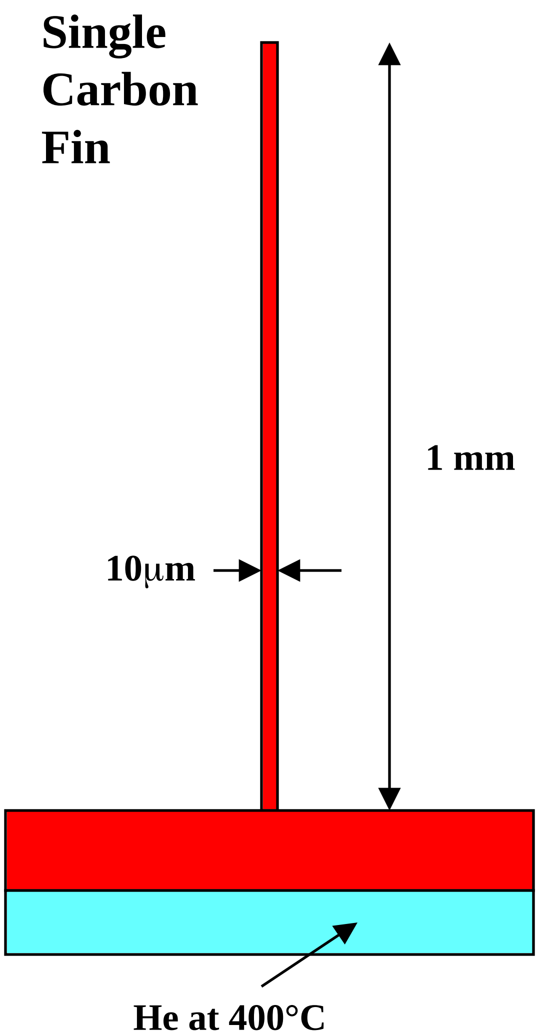


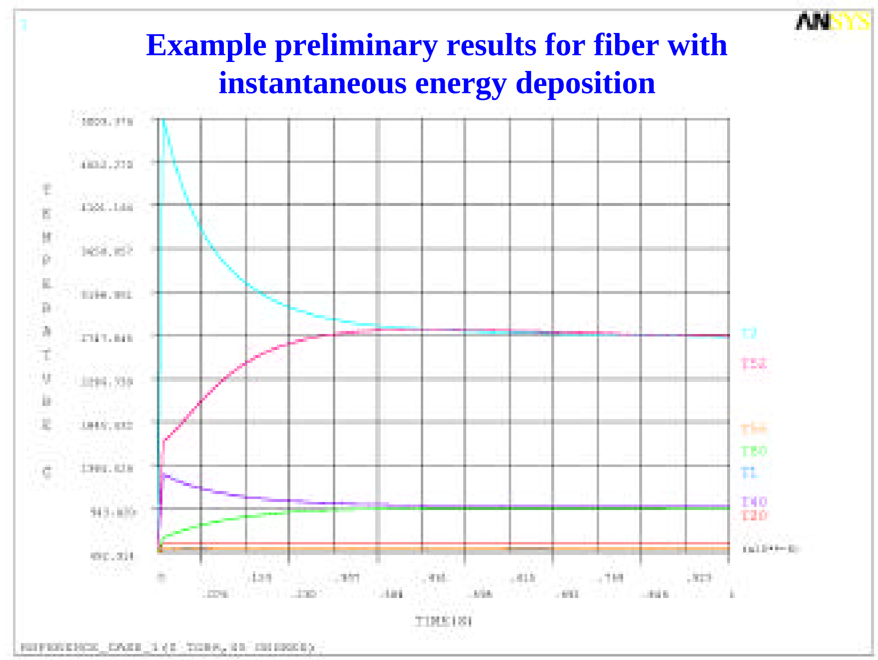
Fast Ions Energy deposition



x = distance from side of fiber; y= distance from base of fiber

Work in Progress



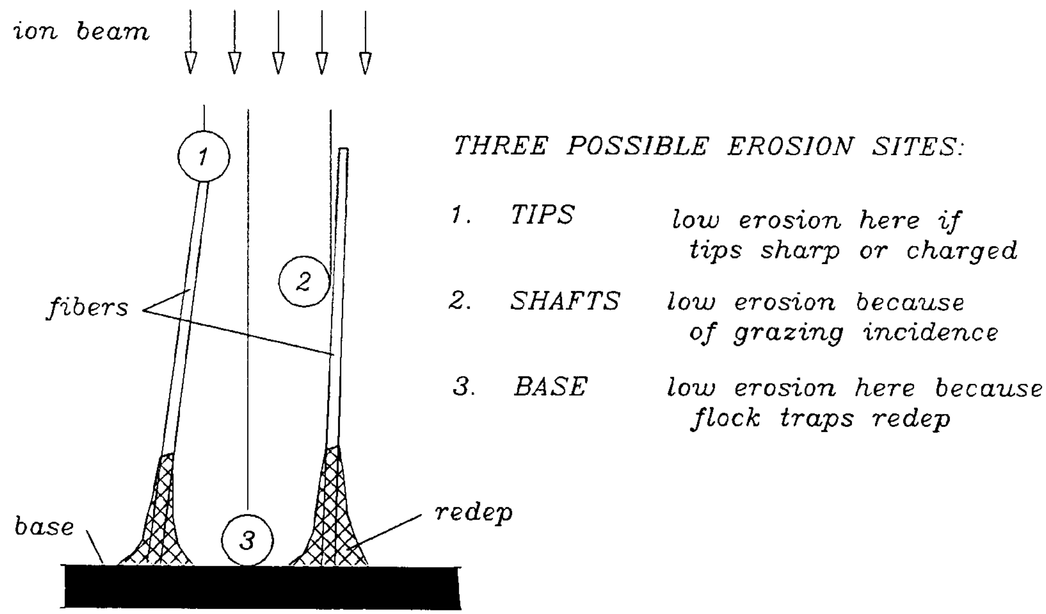


Future Work:

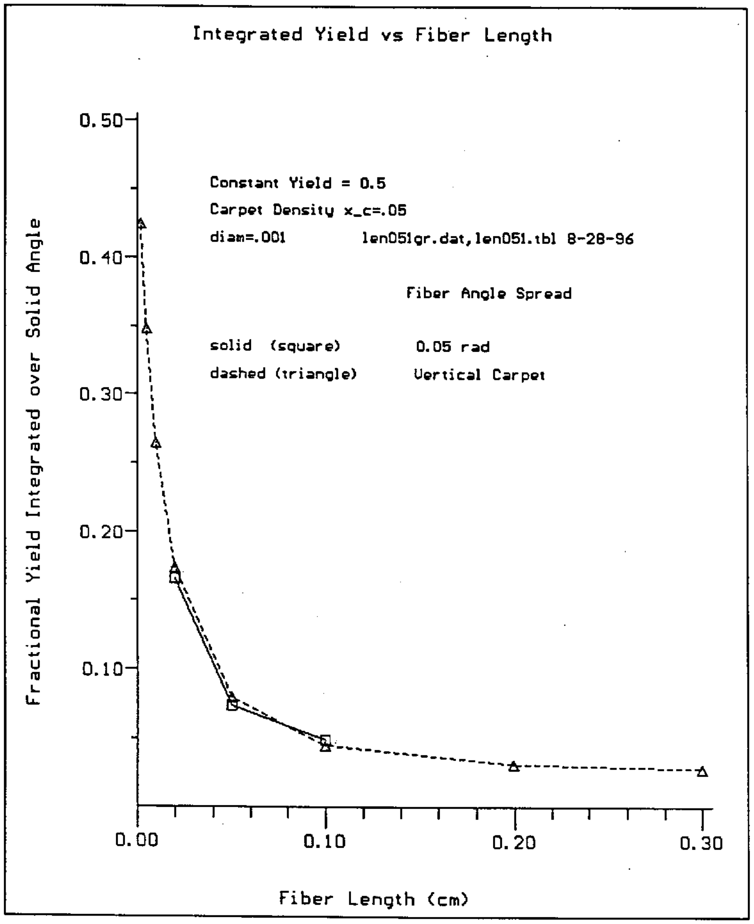
- Ascertain effect of spatial+temporal energy deposition distributions
- Optimize configuration
- Determine if fiber wall configuration provides better performance than flat surface

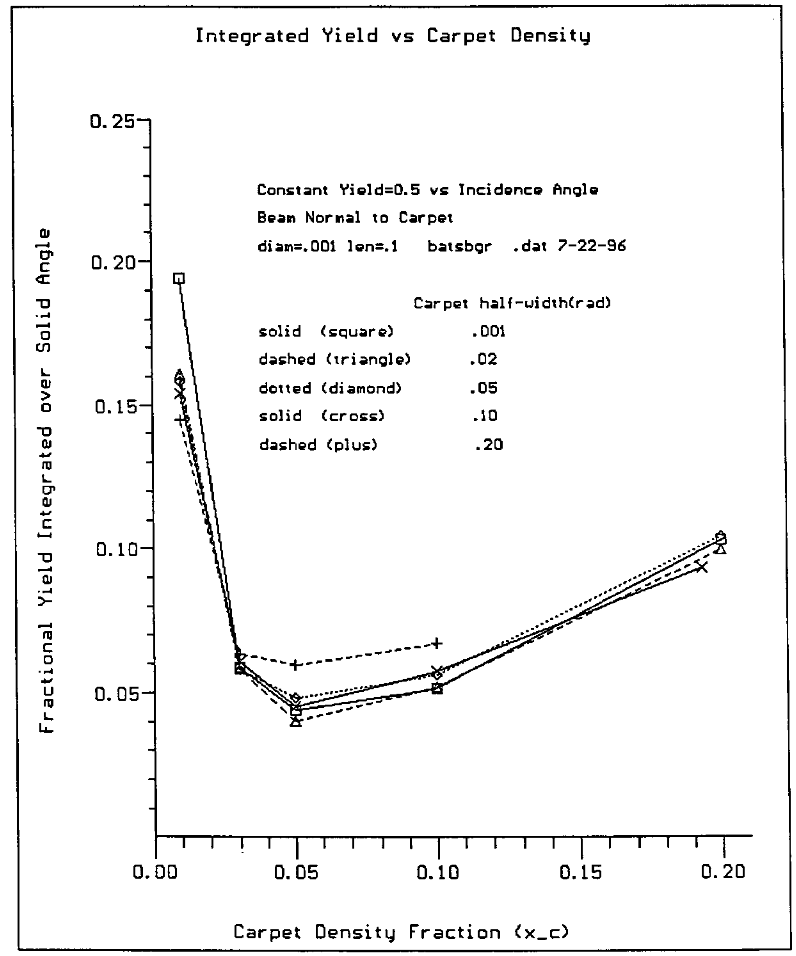
Sputtering in Fiber Configuration

- **Simple mono-energetic analysis has been performed by Marvin Douglas for ESLI fibers (Xe, 1.4 keV)**
- **Initial meeting and exchange of information**
- **Future effort based on need and schedule**



M. Douglas' Analysis Indicates that Sputtering Yield Decreases as Fiber Length Increases and Shows a Minima with Carpet Density Fraction





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Summary

- **The Chamber Wall Temperature can be Maintained < 900 K to Reduce Radiation to the Target while Maintaining an Acceptable Brayton Cycle Efficiency**

- **Possibility of Accommodating Energy Deposition with No Gas**
  - **More precise accounting of spatial and temporal distributions of energy deposition from photons and ions**
    - E.g. Max. temperature in C slab decreases from 16,000°C (equivalent instantaneous surface heat flux) to 6000°C (spatial distribution) to 1400°C (spatial + temporal distributions)
  - **Engineered porous surface**
    - Need detailed analysis to assess attractiveness and to optimize geometry