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Calculations of the Response of Inertial Fusion Energy Materials to X-ray and Ion Irradiation on Z and RHEPP

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OUTLINE

1. **Z X-ray Experiments: BUCKY Simulations**
2. **RHEPP Ion Experiments: BUCKY Simulations**
3. **Comparison with Experiments**
4. **Summary and Future Work**

BUCKY Melting and Vaporization Models (for Code Jocks only)

•BUCKY has separate 1-D meshes for the gas/vapor/plasma and for the liquid/solid. The gas/vapor/plasma mesh is Lagrangian radiation hydrodynamics. The liquid/solid mesh has no radiation transport or hydro.

•Vaporization and condensation moves cells between the two meshes. This phase change is calculated with thermodynamic and kinetic models. Latent Heat is included.

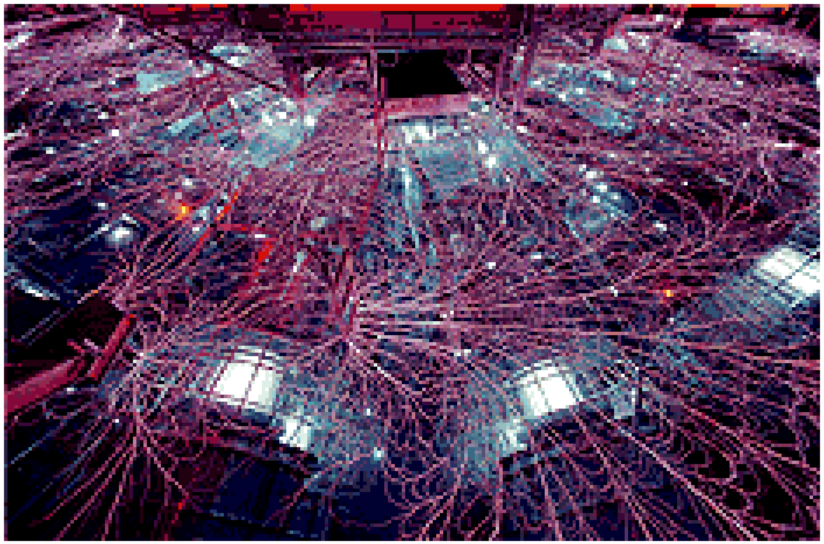
•Melting is calculated within the liquid/solid mesh. Material properties change as the temperature moves through the melting temperature. Latent heat is included through the temperature dependent EOS.

•Thermal conduction (diffusion) is calculated on the liquid/solid mesh using input temperature-dependent conductivities and heat capacities.

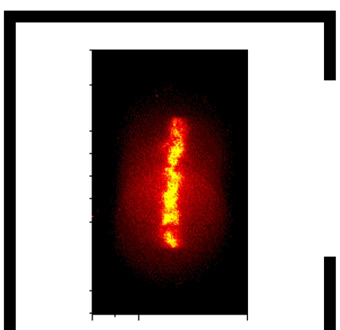
•External electron, ion and x-ray sources deposit volumetrically through out both meshes. Stopping powers are calculated for electrons and ions and are looked up on cold experimental data tables for x-rays. The x-ray deposition is adjusted to included bleaching.

•Radiation transport in the gas/vapor/plasma mesh is calculated with either gray diffusion, mult-group diffusion, Variable Eddington, or multi-angle method of characteristics. Radiation and thermal conduction from the gas/vapor/plasma mesh are surface sources on the liquid/solid mesh.

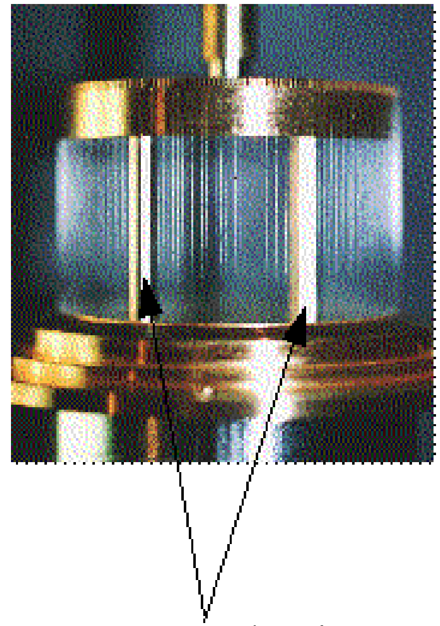
Z-Machine Produces Intense X-rays for Many Uses: Including Study of Inertial Fusion Energy Target Chamber Materials



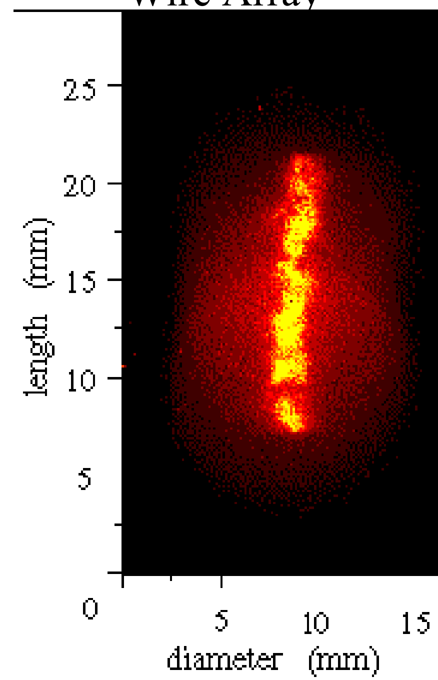
Pinch in Slotted Current Return Can



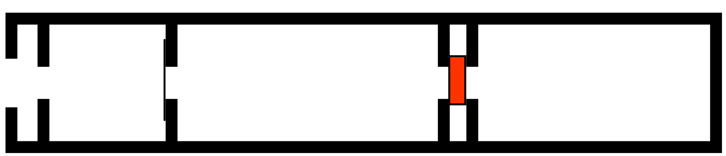
W Wire Array



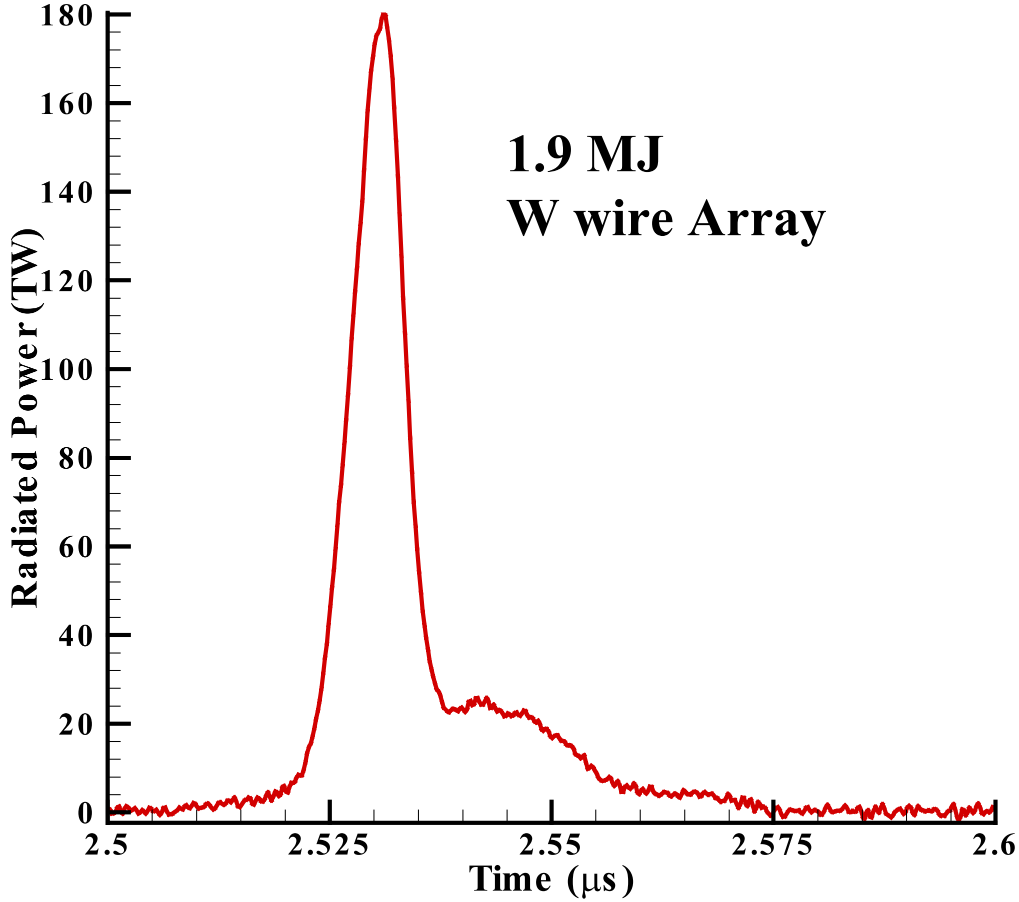
X-ray Pin Hole Image of Imploded Wire Array



Collimators, Filters and Sample Holders



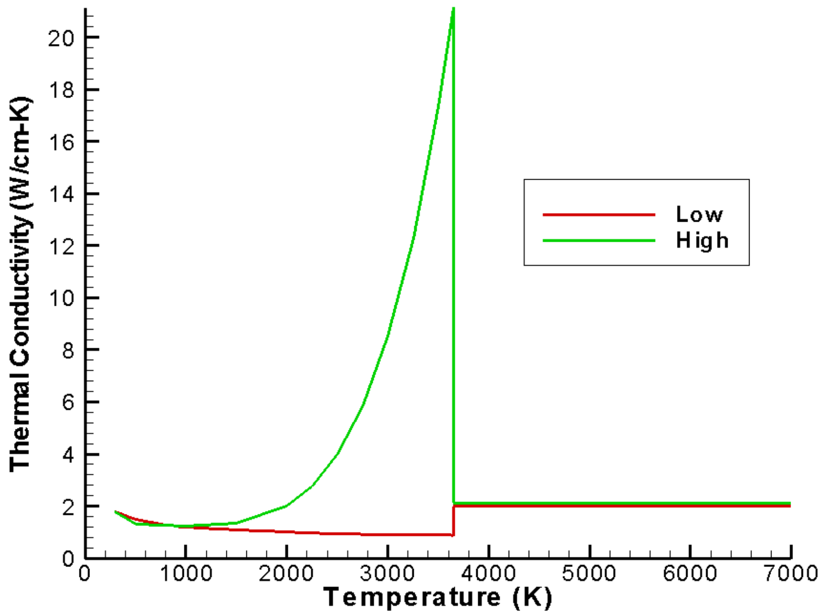
Z Shot 783 Produced Significant X-Rays for IFE Vaporization Experiments

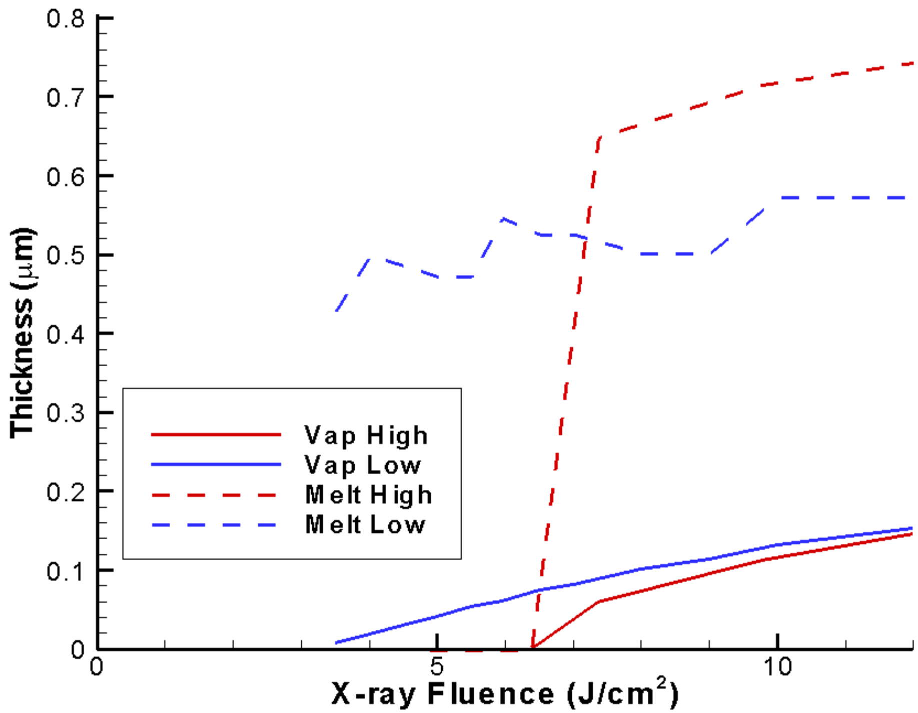


- Z x-rays consist of direct z-pinch x-rays and those from walls (i.e. see work of M. Cuneo and G.A. Rochau of SNL).
- In these simulations, x-ray spectrum is taken as a black-body peaking at about 160 eV.
- A high energy tail has been seen representing a few % of spectrum. This and details of filtering need to be included.

Erosion Threshold for Pure Tungsten Irradiated by X-Rays on Z is Calculated by BUCKY to be 3.5-4 J/cm^2, But Very Sensitive to Thermal Conductivity

- BUCKY Calculations done with Low and High Thermal Conductivity models for solid Tungsten; Conductivity of liquid = 2 W/cm-K.
- After threshold fluence is surpassed, melt depth is insensitive to x-ray fluence because of absorption of x-rays by vapor.
- This effect is reduced by 3-D expansion of vapor (BUCKY is 1-D).
- "Vapor Shielding" has not been tested on Z.





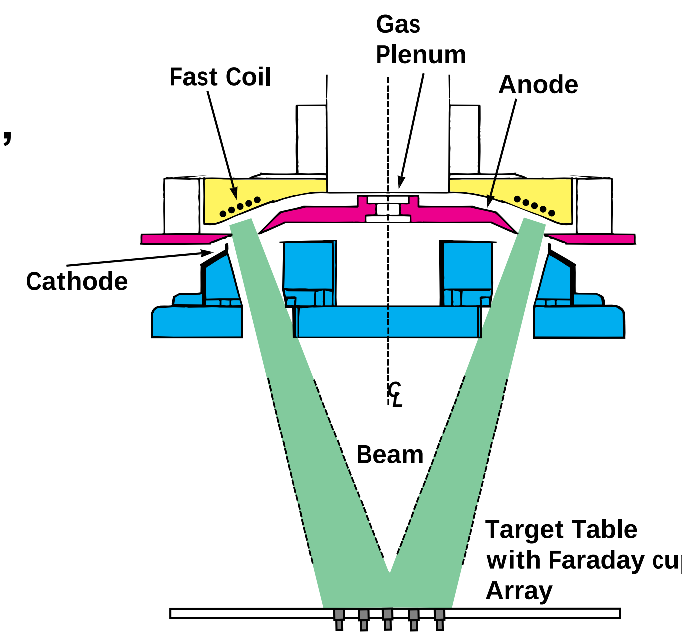
RHEPP Uses a MAP Extraction Diode to Produce Intense Bursts of Ions for Many Uses, Including Study of Inertial Fusion Energy Target Chamber Materials

RHEPP

(Repetitive High-Energy Pulse Power)

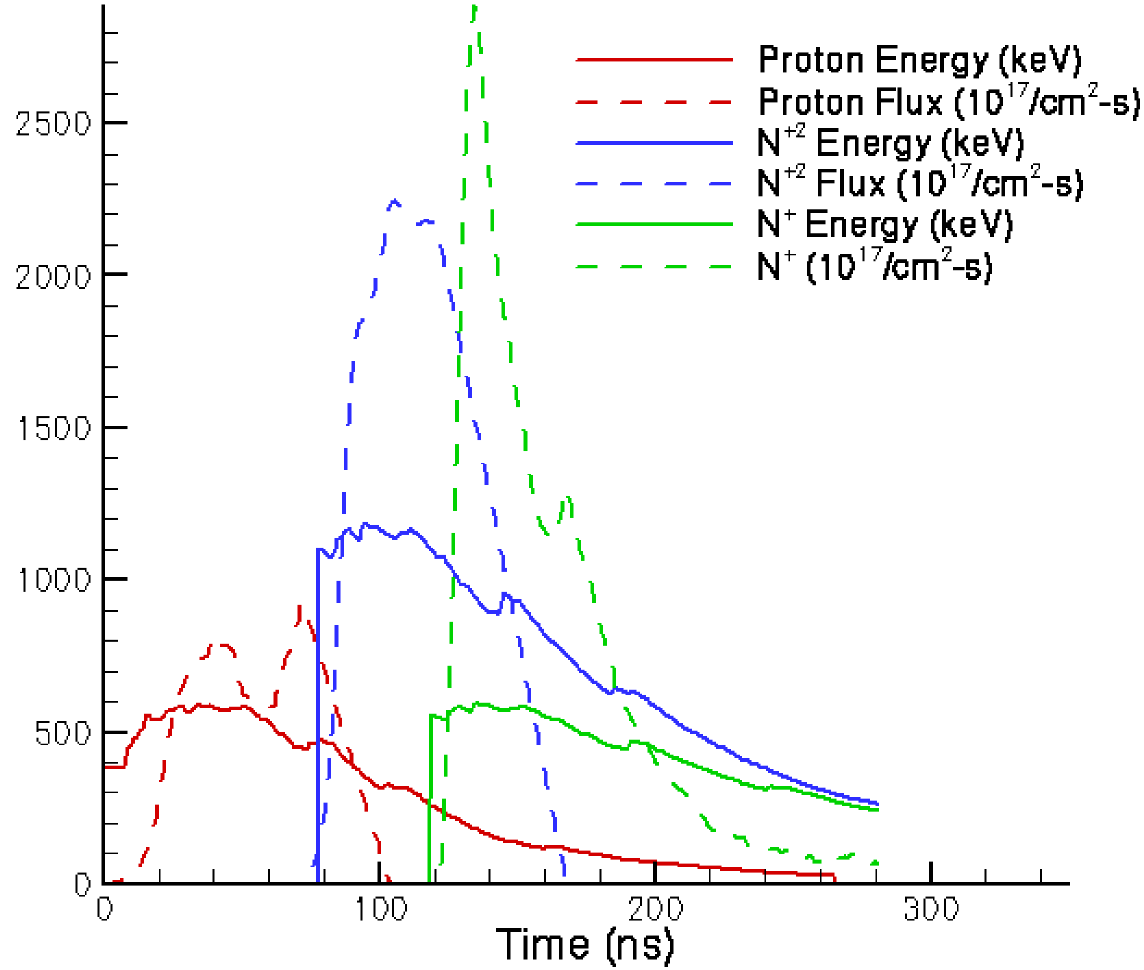
- **500-700 kV**
- **≤ 250 A/cm²**
- **Beams from H, He, N_2, O_2, Ne, Ar, Xe, Kr, CH_4**
- **Overall treatment area**
- **~ 100 cm²**
- **Diode vacuum**
- **~ 10^{-5} Torr**

Ions are generated by the magnetically-confined anode plasma (MAP) source

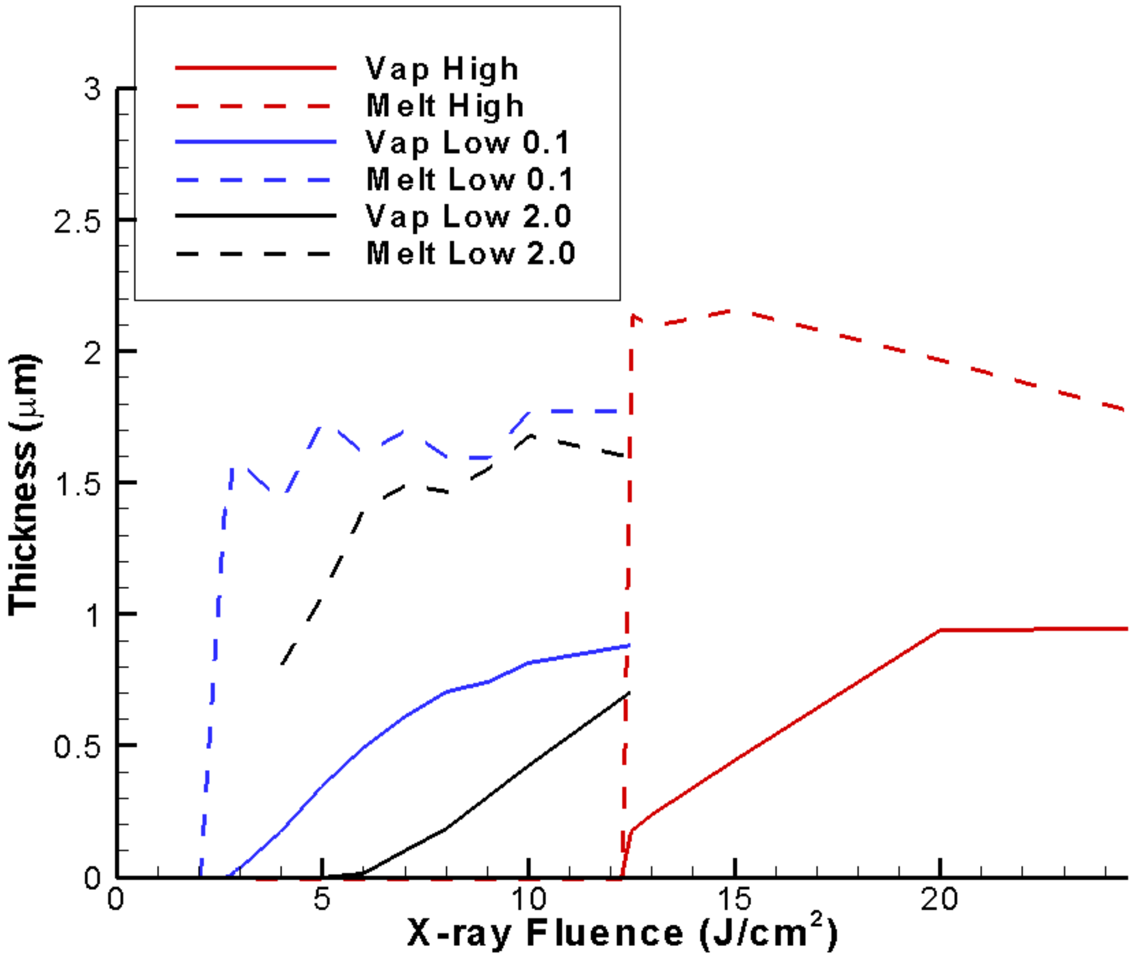


In the Most Recent Series of Experiments, RHEPP Nitrogen Beams are Used to Study Target Chamber Materials

- N^{+2} peaks at about 1.2 MeV in a pulse about 60 ns wide (FWHM).
- N^{+} peaks at about 0.6 MeV in a pulse about 60 ns wide (FWHM).
- H^{+} peaks at about 0.6 MeV in a pulse about 80 ns wide (FWHM).
- All are included in the BUCKY simulations.

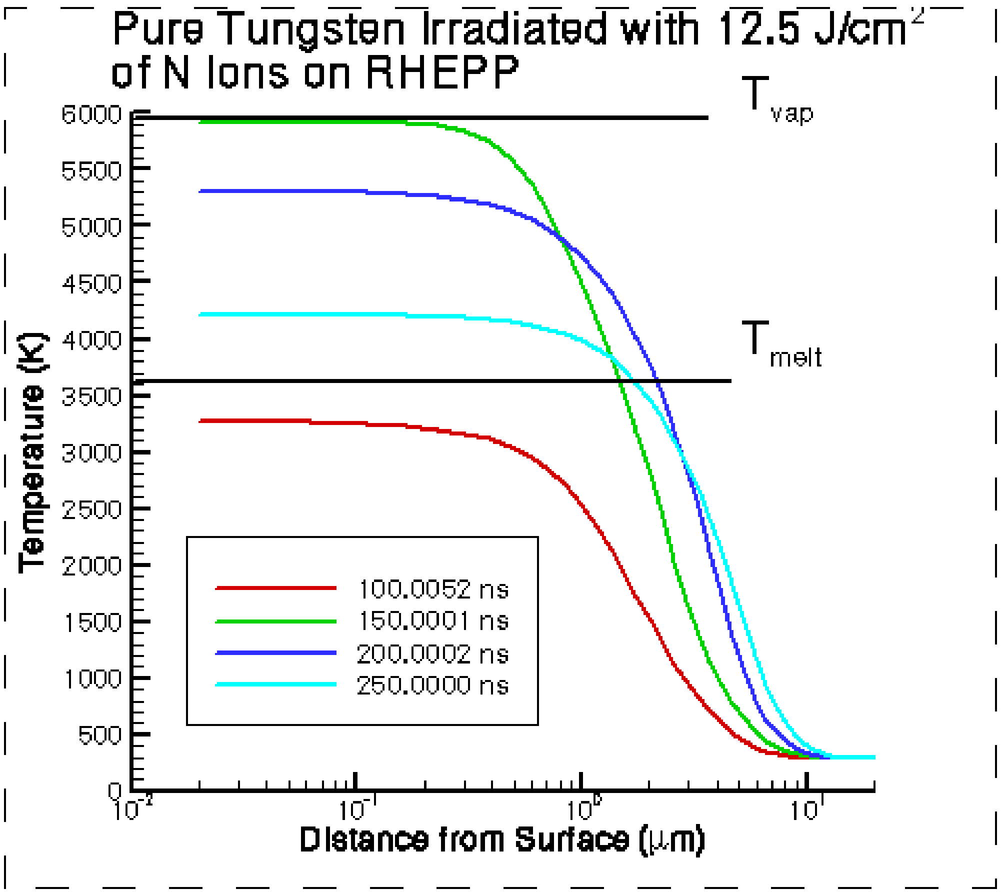


Erosion Threshold for Pure Tungsten Irradiated by Nitrogen Ions on RHEPP is Calculated by BUCKY to be ~6 J/cm^2



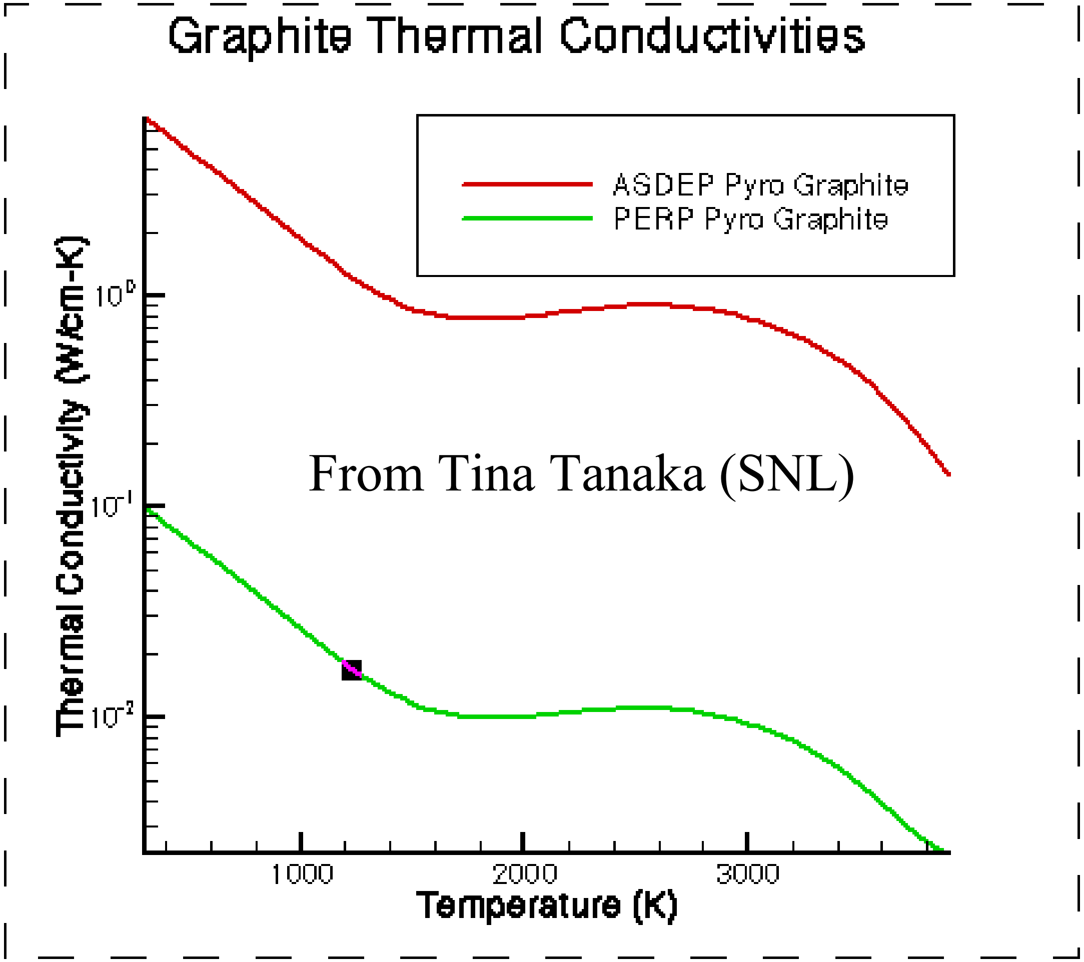
- BUCKY simulations done for High and Low solid thermal conductivities and melt conductivities of 0.1 and 2.0 W/cm-K.
- Threshold is very sensitive to thermal conductivity of solid and melt.
- After threshold fluence is surpassed, melt depth is insensitive to ion fluence because of absorption of ions by vapor.
- This effect is reduced by 3-D expansion of vapor (BUCKY is 1-D).

Example: High Thermal Conductivity



- T_{vap} is the vaporization temperature, and is assumed to be constant in these simulations.
- For 12.5 J/cm^2 on RHEPP N ions deposited on Pure Tungsten, there is only a small amount of vaporization (0.177 μm).
- When there is a large amount of vaporization or vaporization in the middle of a solid, the vapor density and suppress vaporization, increasing T_{vap} (model in BUCKY)

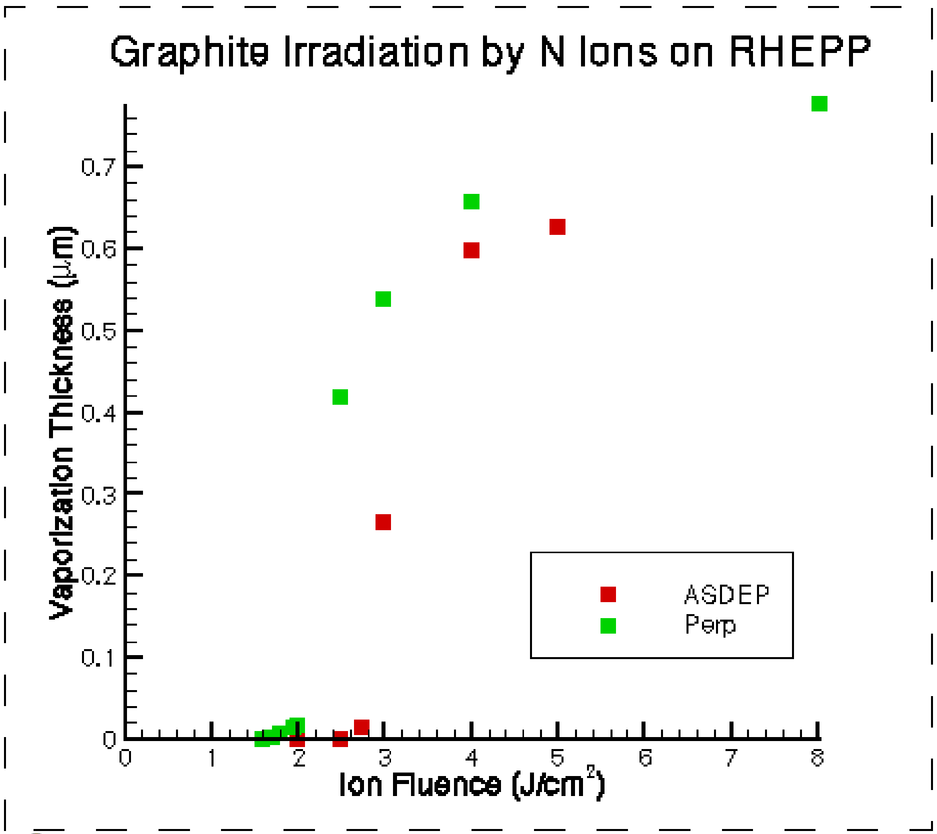
Two Orientations for Pyrolytic Graphite are Considered, Perpendicular (PERP) and Parallel (ASDEP), With Quite Different Thermal Conductivity Models

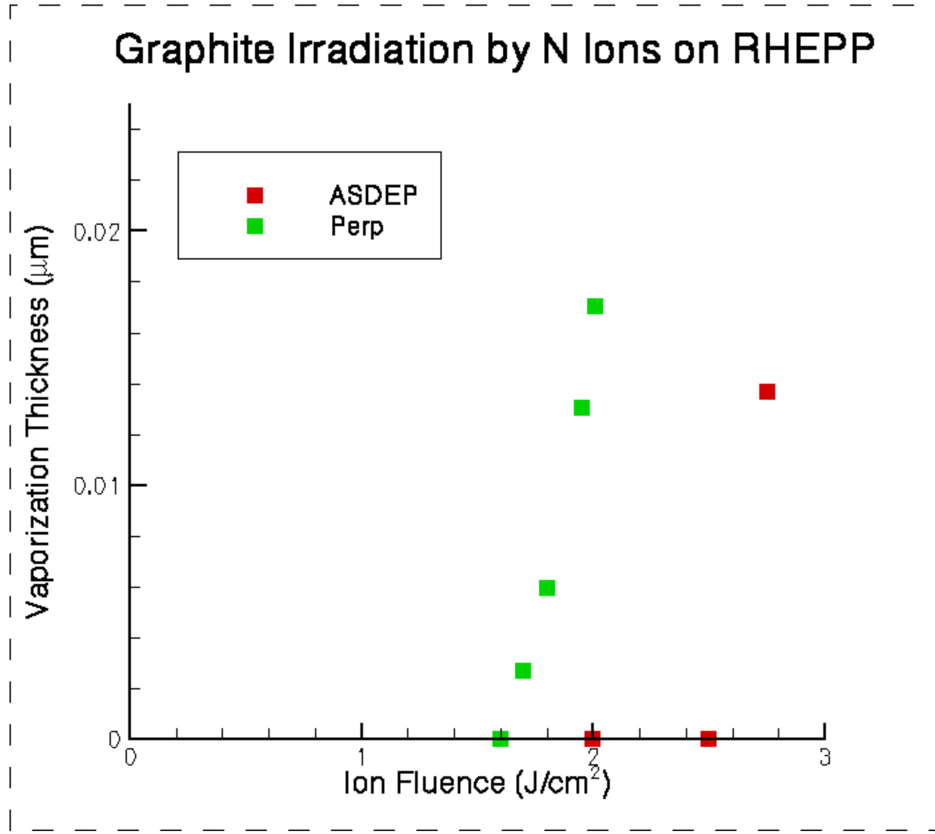


- The thermal conductivity of Pyrolytic Graphite is very an-isotropic.
- Conductivity in the direction parallel to the fibers (ASDEP) is 60 times that in the direction perpendicular to the fibers (PERP).
- Experiments on RHEPP and BUCKY simulations have been carried out for both orientations.

Erosion Threshold for Pyrolytic Graphite Irradiated by Nitrogen Ions on RHEPP is Calculated by BUCKY For Parallel (ASDEP) and Perpendicular (PERP) Thermal Conductivity Models

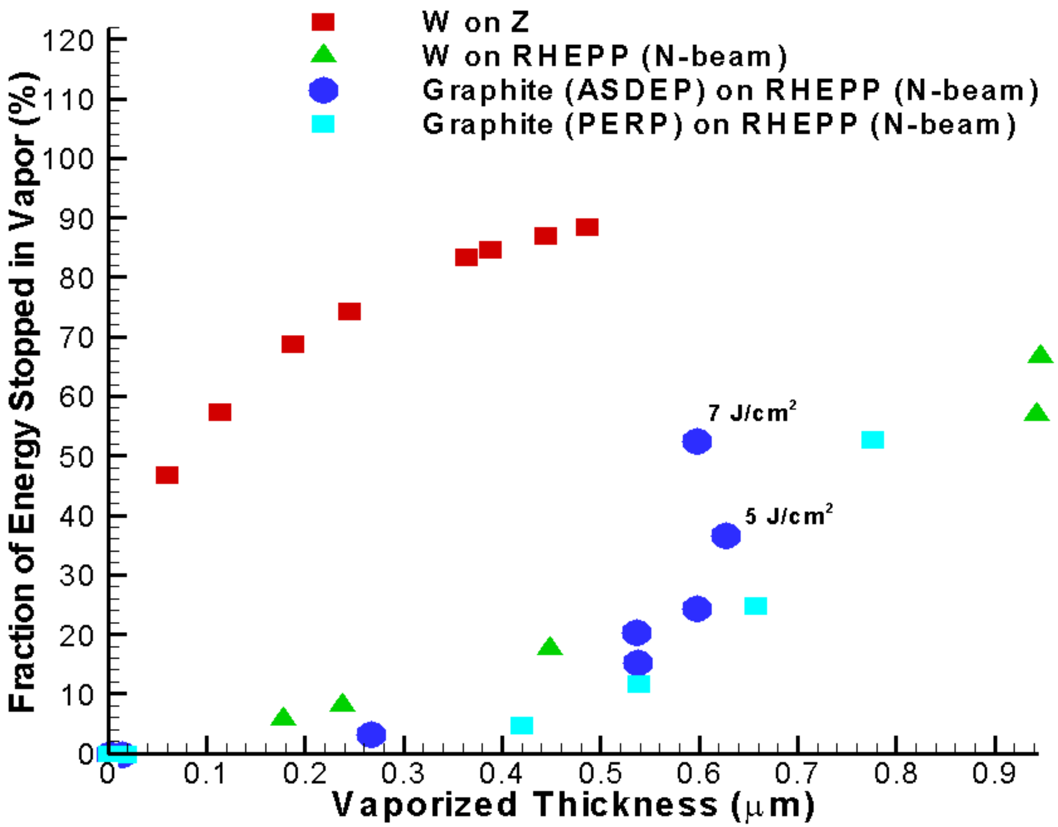
Threshold for Vaporization of PERP Pyrolytic Graphite is 1.6 J/cm^2.
Threshold for Vaporization of ASDEP Pyrolytic Graphite is 2.5 J/cm^2.





Self-shielding of Vaporizing Samples from X-rays and Ions is Important in BUCKY Simulations

Tungsten results for high Conductivity



- Fraction (%) of ion or x-ray energy that is stopped in the gas and vapor is plotted against the width of material vaporized.
- W is very successful at stopping Z x-rays.
- W and Graphite are about equally able to stop RHEPP N-beams.
- The points outside of the trend were high fluence (5 and 7 J/cm^2) where 8-10 % of the energy was re-radiated to the sample over a long time.

Comparison BUCKY Predicted Thresholds And Measured Data: BUCKY Slightly Over-Predicts Damage in Experiments

	BUCKY	Experiments
Tungsten with Ions	6 J/cm^2	> 7 J/cm^2
Tungsten with X-rays	3.5-4 J/cm^2	2-3.5 J/cm^2
PERP Graphite with Ions	1.6 J/cm^2 (~2 for dx > .01 μm)	<3.0 J/cm^2
ASDEP Graphite with Ions	2.5 J/cm^2 (~2.75 for dx > .01 μm)	3.5-4.0 J/cm^2

Summary and Future Work

•BUCKY Simulations have been performed for Graphite and Tungsten samples shot on RHEPP and Z.

•Initial Comparisons have been performed. Simulations and Experiments are consistent but there are still uncertainties in x-ray drive spectrum and material properties.

•Effects of variations in Z x-ray spectrum and RHEPP ion species should be studied.

•Other materials (Tungsten alloys, liquids) should be studied.