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

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2002 American Physical Society Division of Plasma Physics
Annual Meeting
November 11-15, 2002
Orlando, Florida

* Supported by NRL and the NNSA/DP HAPL Program

LA-UR-02-6972

OUTLINE

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

ABSTRACT

The response of candidate Inertial Fusion Energy first wall materials to the intense bursts of x-rays and ions that will emanate from IFE targets is an important issue for power plants and for any facility that would test high yield target performance. In an effort to gain understanding of the behavior of these materials while undergoing rapid phase changes and to validate code that predict such behaviors, a multi-institution group has been conducting experiments on the Z and RHEPP facilities at Sandia. As part of this project, calculations of irradiation with tungsten wire array x-ray on Z and ions on RHEPP have been performed with the BUCKY computer code. When comparing experiments to calculations for graphite and tungsten samples, we have found some behavior that is not predicted by the code. We will show how the greater than 1 keV lines in the Z tungsten wire array x-ray source affect the material response. On the RHEPP ion experiments, we will show how sensitive the results are to the thermal conductivity of the material.

BUCKY Has Been Under Development for About 3 Decades

PHD-IV

- TN burn
- Gray Radiation Diffusion
- 1-D Lagrangian Hydro
- Te ≠ Ti

Target Implosion, Burn, Explosion

FIRE

- Start with PHD-IV
- Remove TN burn
- Multi-group Diffusion
- X-ray and ion energy sources
- Te = Ti

Gas filled target chambers

CONRAD

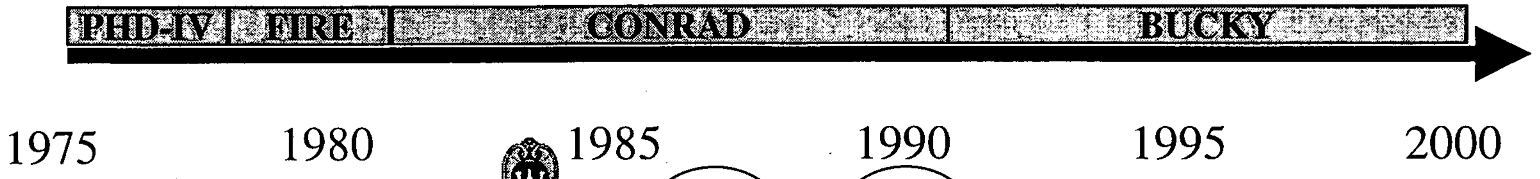
- Start with FIRE
- Vaporization and Condensation by Chamber Wall

- **Vaporizing IFE chamber walls**
- **Tokamak disruption divertor vaporization**

BUCKY

- Combine PHD-IV and CONRAD
- TN burn
- Multi-group Diffusion
- Laser deposition
- Te ≠ Ti
- Time-dependent CRE radiation transport

- **NIF Capsules**
- **NIF chamber wall**
- **Ω experiments**
- **NRL laser targets**
- **Z experiments**
- **ARIES target chamber**



EOS and Opacity Codes for BUCKY have Also been written over a long time

MIXERG

- Gray and Multi-group Opacities for FIRE
- Rosseland and Planck
- Semi-Classical absorption coefficients
- Tabulated ionization energies
- Saha or Coronal Ionization
- Self-consistent ionization for mixtures
- EOS: ideal gas + ionization and excitations

IONMIX

- MIXERG +
- Non-LTE Ionization
- Multi-group
- Rosseland and Planck absorption and emission

EOSOPA

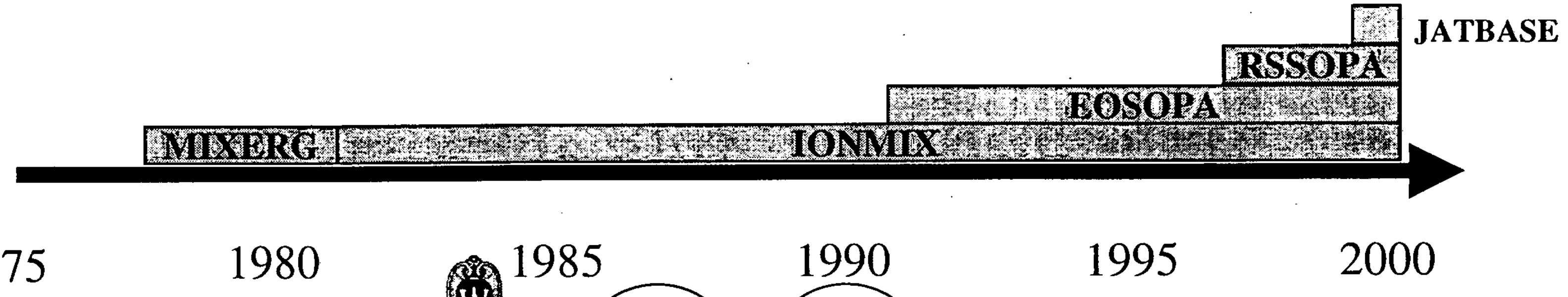
- Hartree-Fock (Cowan) atomic structure
- LS coupling
- UTA or DCA/LTE or CRE for Z (≤ 18)
- UTA/LTE for Z (≥18)
- Creates data for CRE in BUCKY
- Pressure ionization
- Muffin-Tin EOS

RSSOPA

- Relativistic (Dirac eqn.)
- JJ coupling
- SOSH UTA's

JATBASE

- JAVA interface for EOSOPA
- User friendly



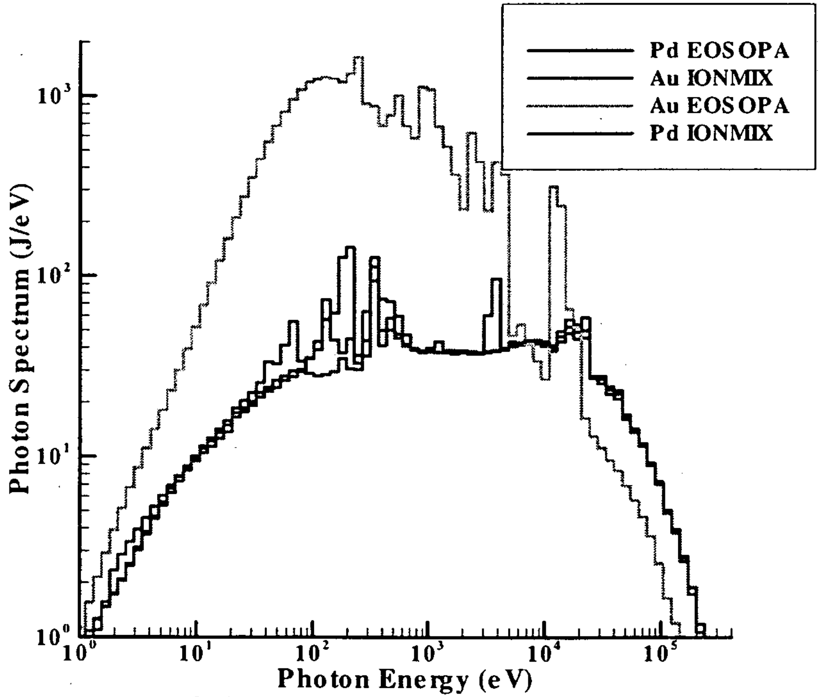
BUCKY Melting and Vaporization Models

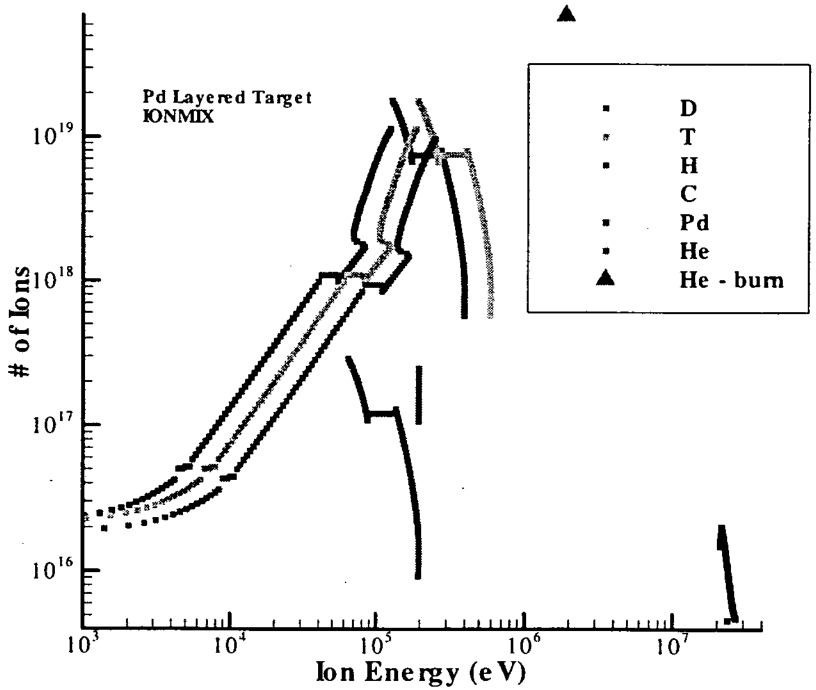
- BUCKY has separate 1-D meshes for the gas/vapor/plasma and for the liquid/solid. The gas/vapor/plasma mesh is Lagrangian radiation hydrodynamics. The liquid/solid mesh has no radiation transport or hydro.
- Vaporization and condensation moves cells between the two meshes. This phase change is calculated 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.

X-ray and Debris Ion Emission for High-Z Coated Direct Drive Laser Targets are Complicated by Physics Issues

- Target Plasma Ionization becomes dominated by radiative processes: LTE is invalid in calculation of opacities.
- Target Plasma is not always thin: fusion product and neutron knock-ons are important.
- Large electric potentials due to target charge-up can effect on spectrum.

BUCKY Target Output Calculations

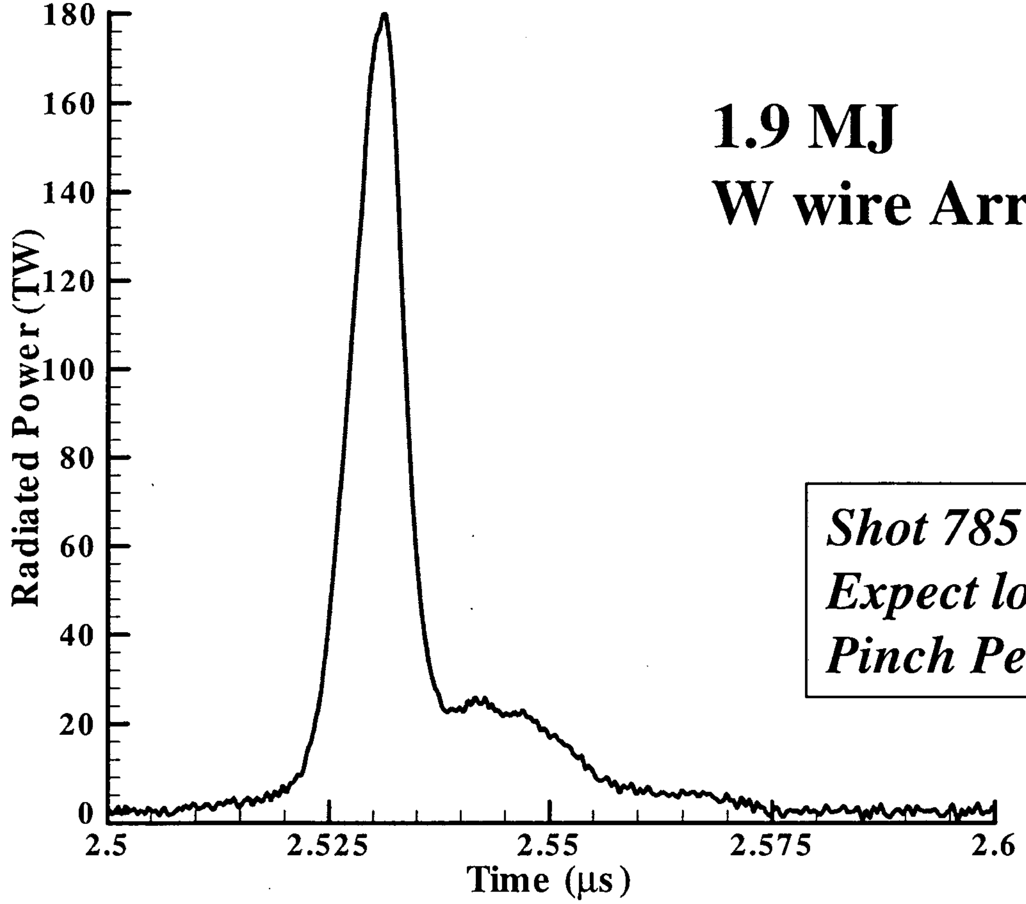




Z-Machine Produces Intense X-rays for Many Uses: Including Study of Inertial Fusion Energy Target Chamber Materials

Picture of Z

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



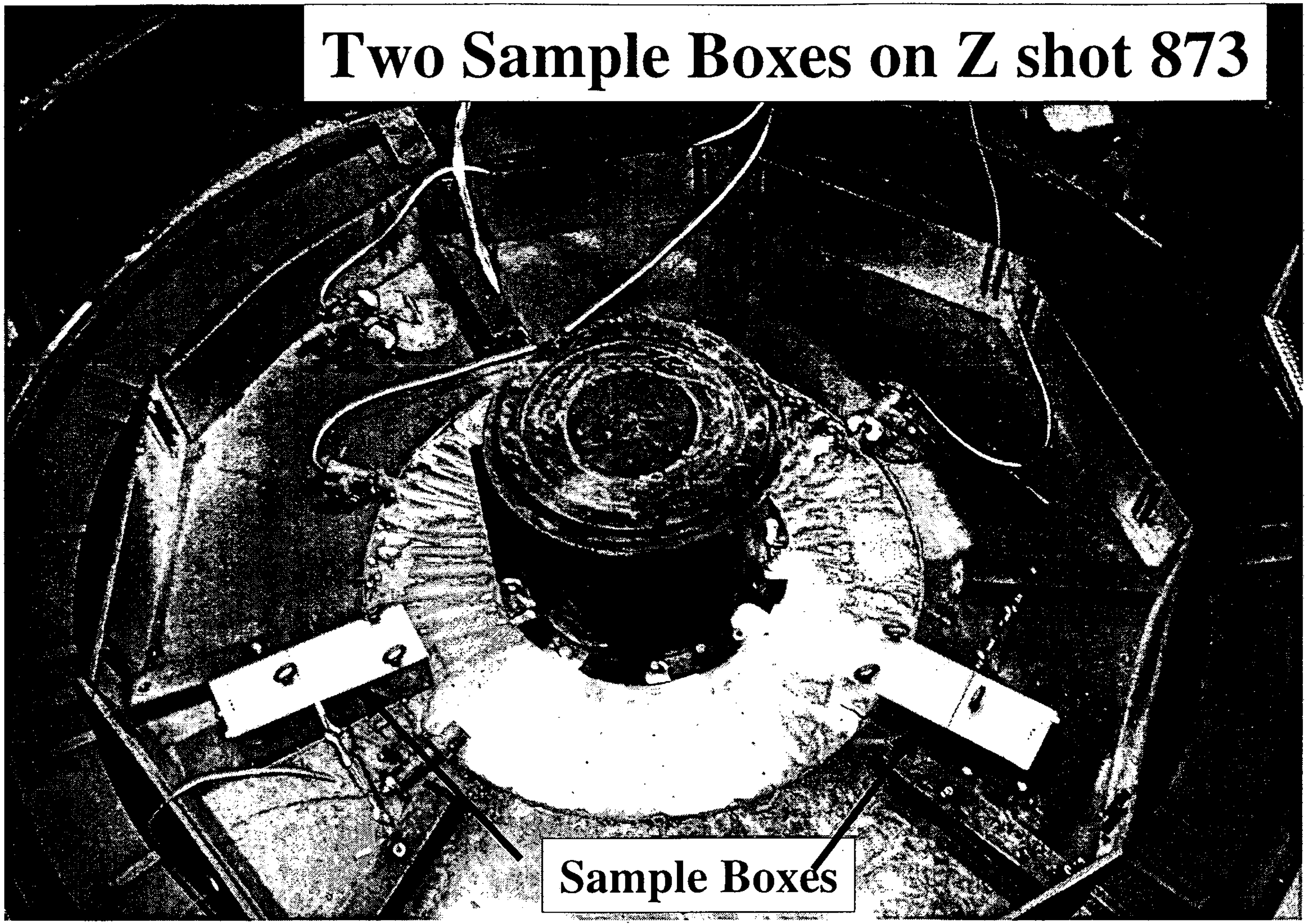
1.9 MJ
W wire Array

Shot 785 was a Ti Wire Array
Expect lower Yield and Harder Spectrum
Pinch Performance is Still being Analyzed

Z X-Rays Consist of Direct Z-Pinch X-rays and Those from Walls

Picture of Z X-ray Spectrum

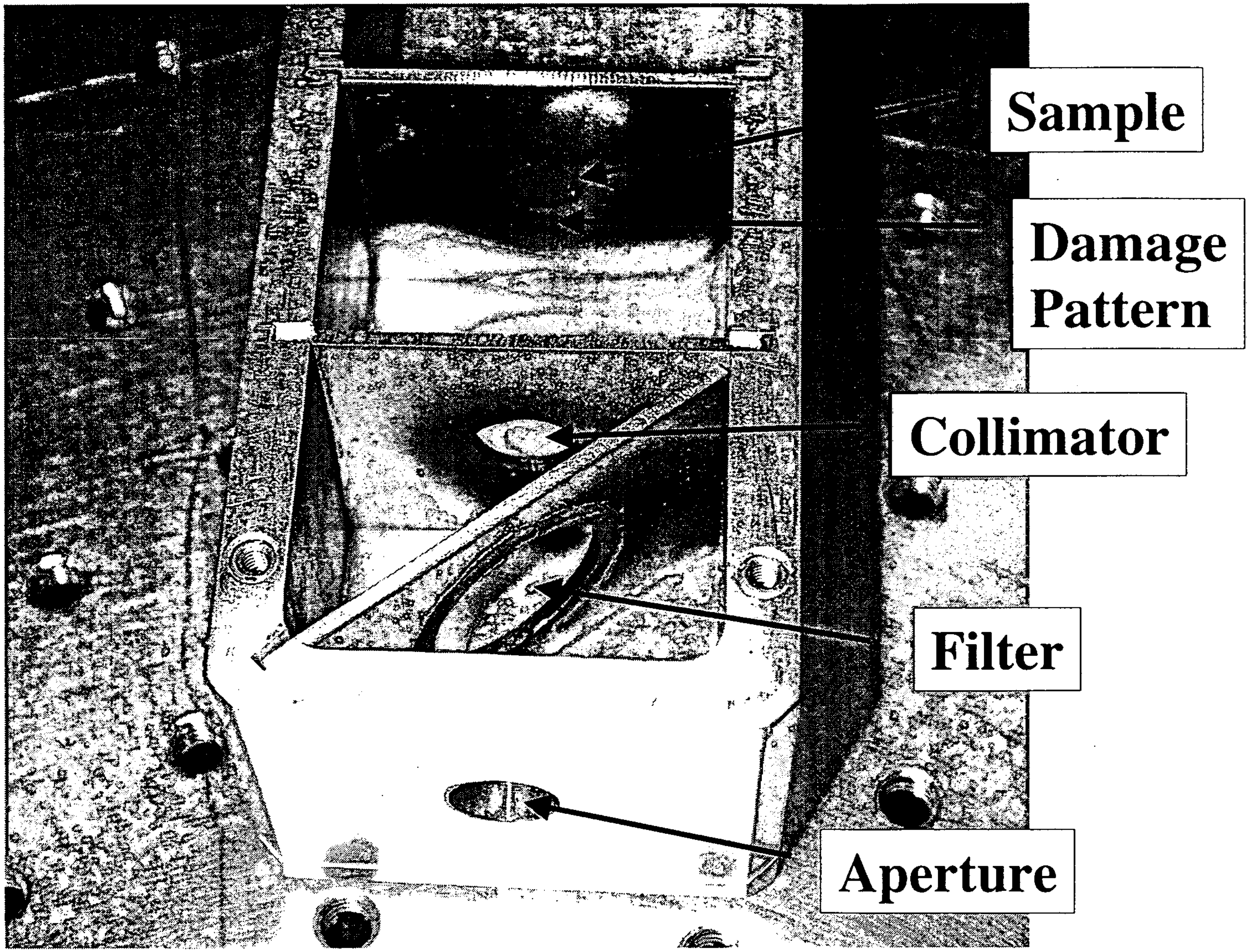
Validation of BUCKY Vaporization on Z-Machine



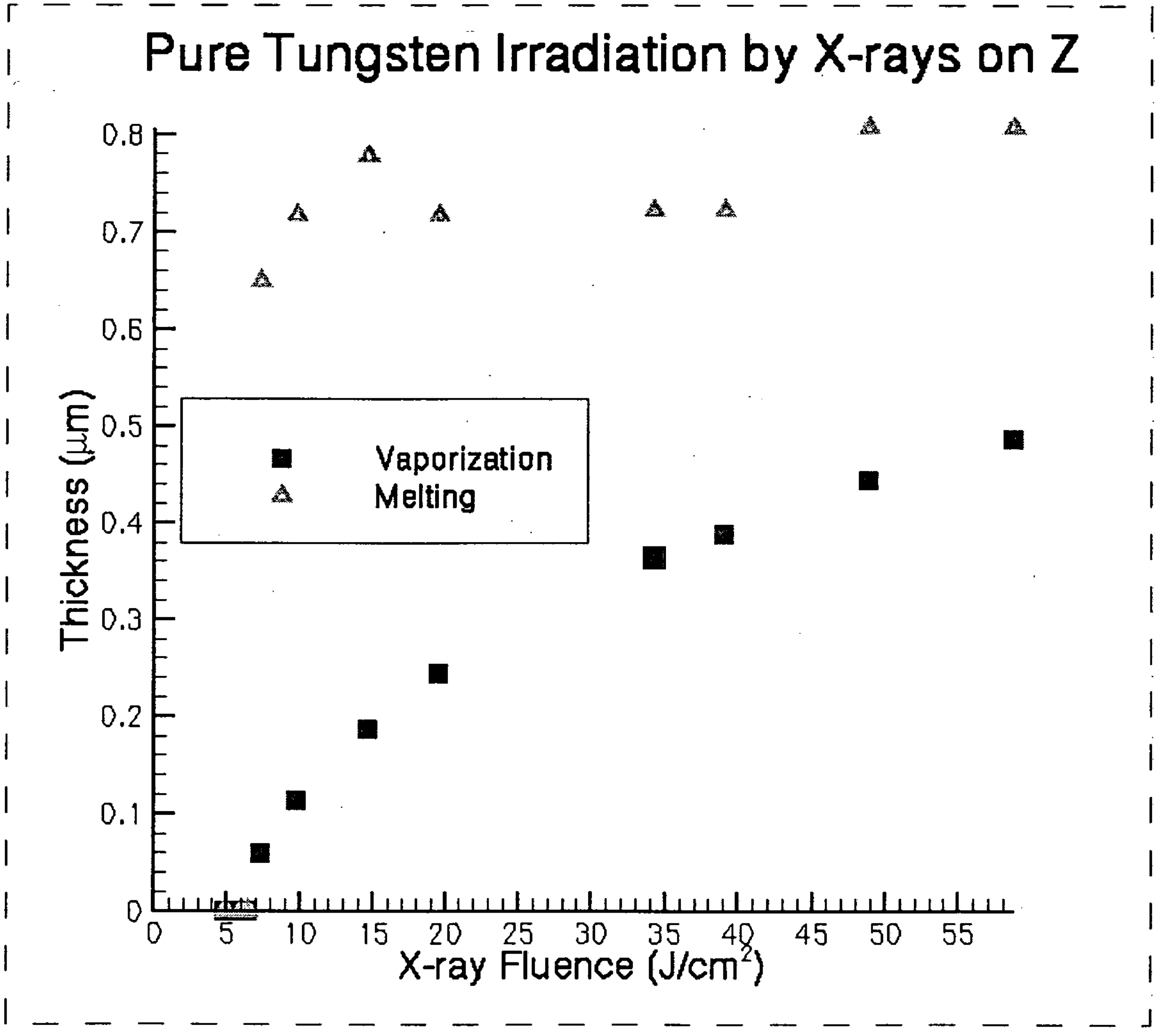
Two Sample Boxes on Z shot 873

Sample Boxes

Post-Shot Damage Pattern Inside Sample Box on Z-Machine



Erosion Threshold for Pure Tungsten Irradiated by X-Rays on Z is Calculated by BUCKY to be 7 J/cm²



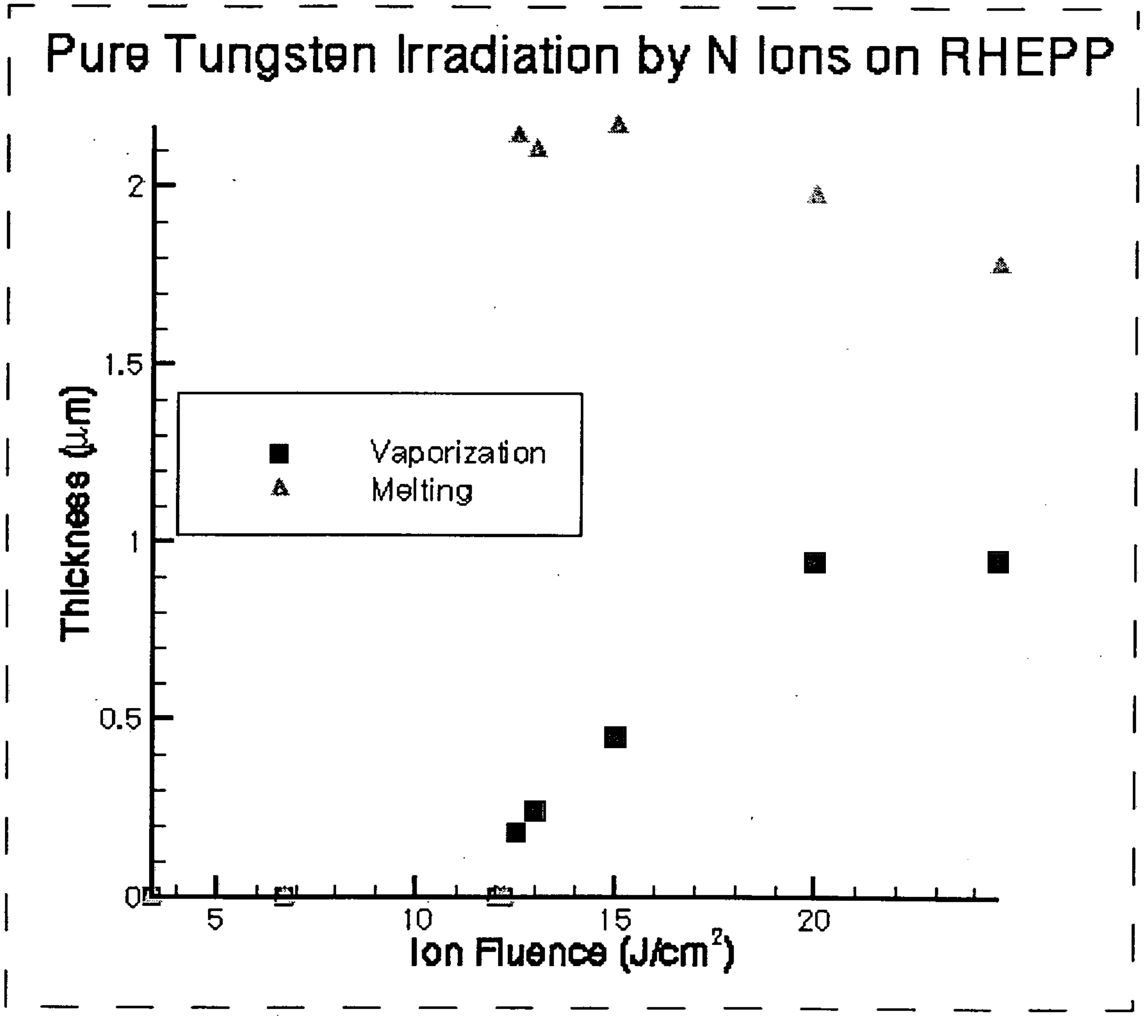
RHEPP Uses a MAP Extraction Diode to Produce Intense Bursts of Ions for Many Uses, Including Study of Inertial Fusion Energy Target Chamber Materials

Schematic Picture of RHEPP

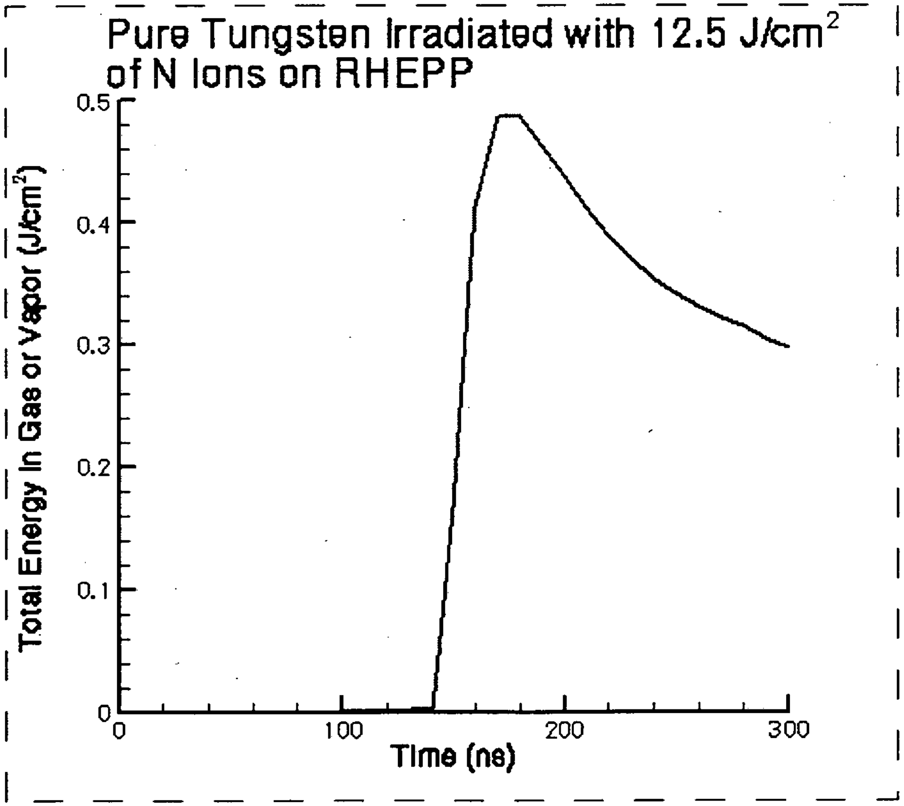
RHEPP Nitrogen Beams are Used to Study Target Chamber Materials

Picture of RHEPP Nitrogen Spectrum

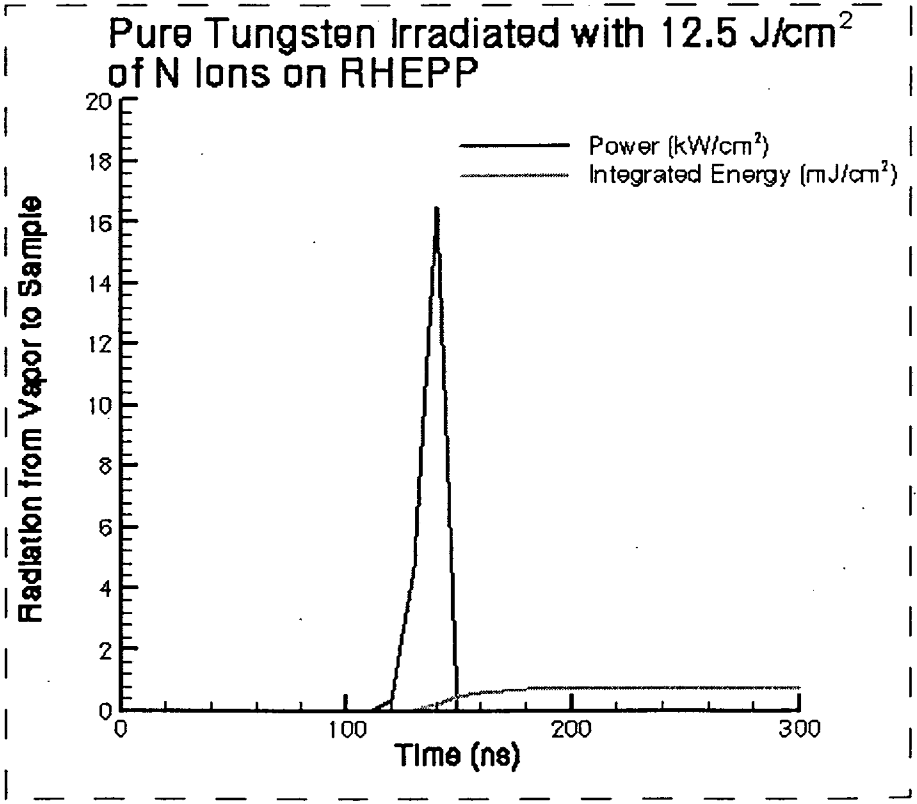
Erosion Threshold for Pure Tungsten Irradiated by Nitrogen Ions on RHEPP is Calculated by BUCKY to be 12.25 J/cm^2



The Vapor Produced in RHEPP Experiments Protects the Sample from Later Ions, Through the is Some Re-Radiation to the Sample

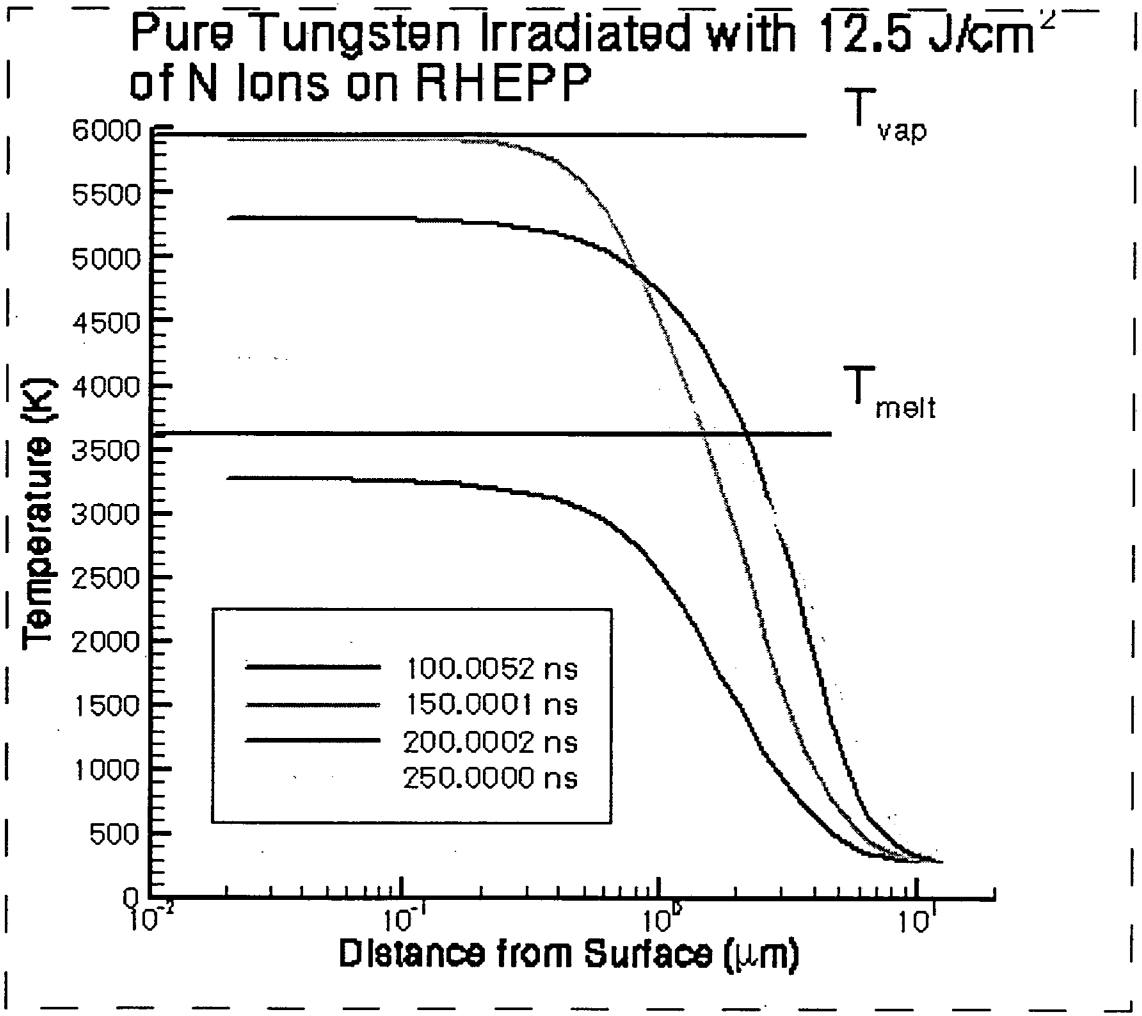


Pure Tungsten Irradiated with 12.5 J/cm^2 of N Ions on RHEPP

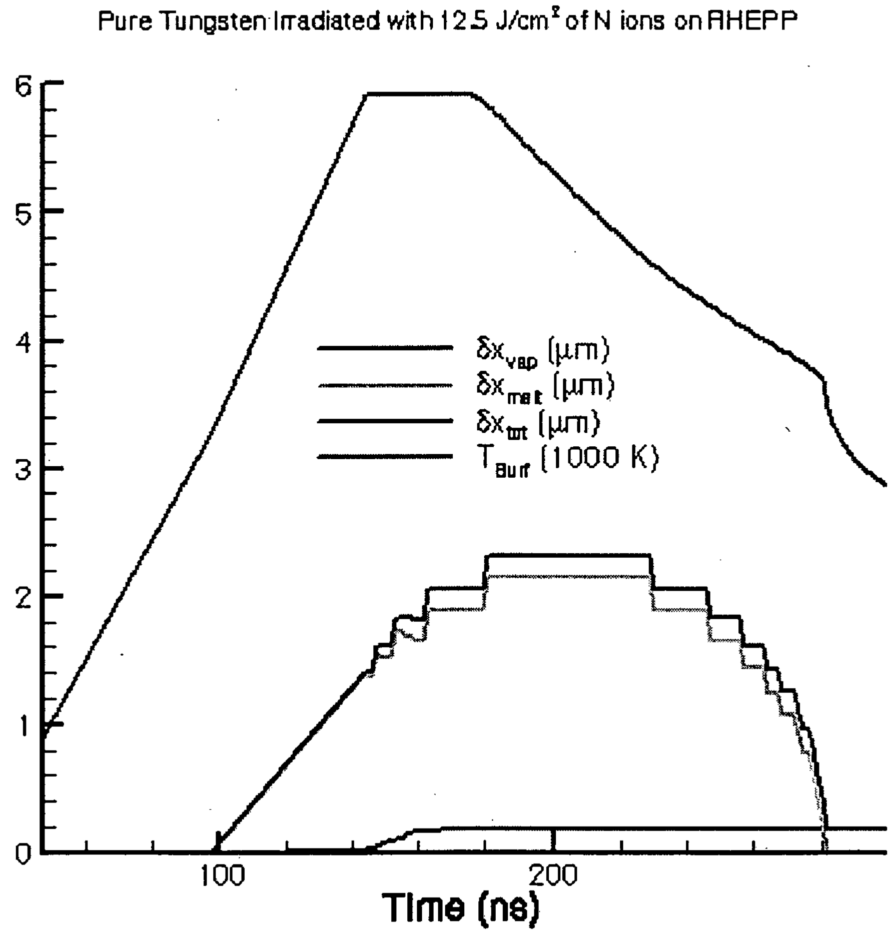


Pure Tungsten Irradiated with 12.5 J/cm^2 of N Ions on RHEPP

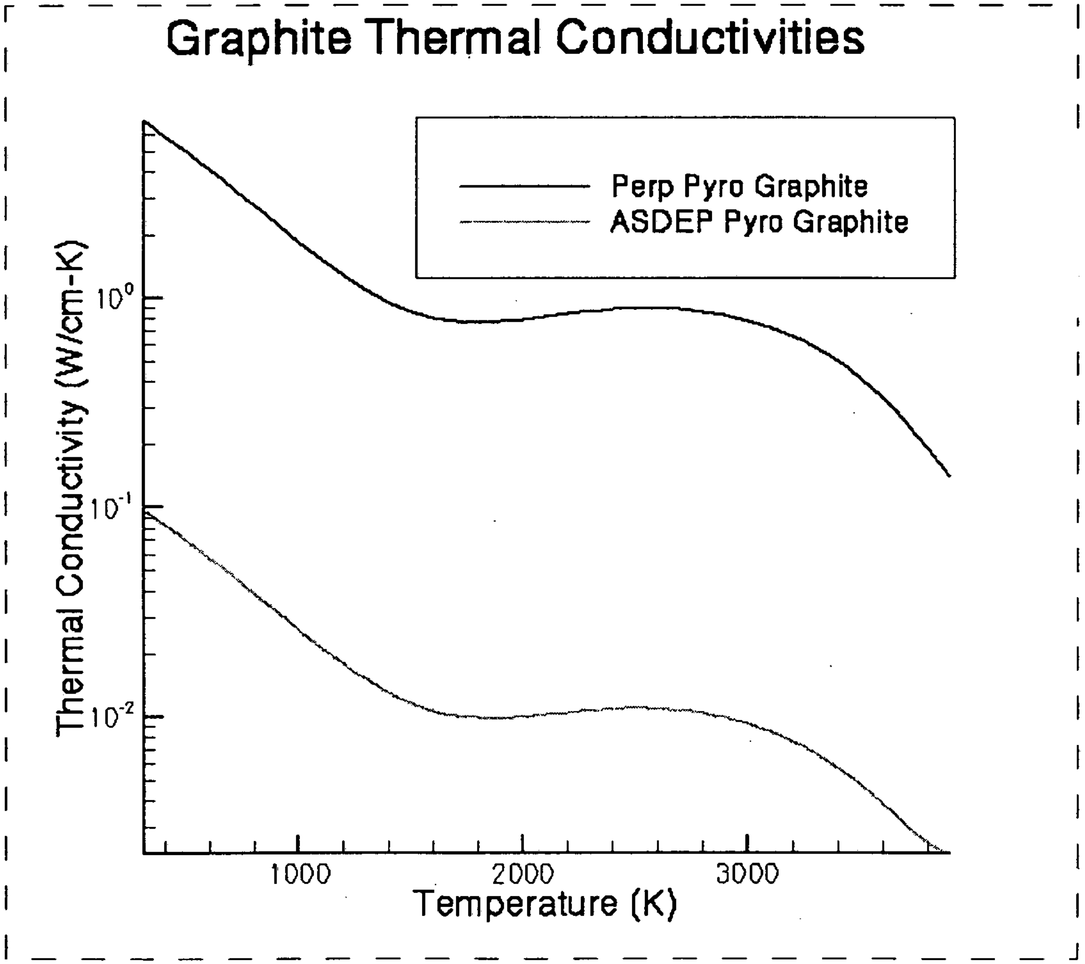
Material First Melts and Then Vaporizes Due to Volumetric Ion Deposition: Deposition Length about 1 Micron



Melt Duration is about 200 ns: Rapid Re-Solidification

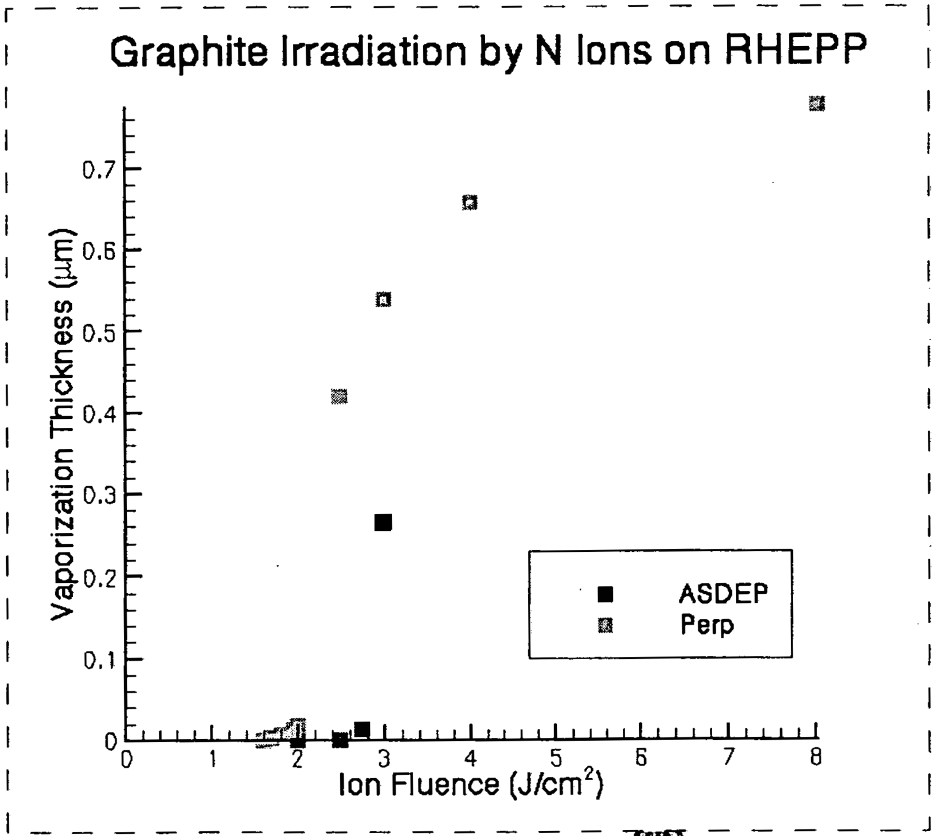


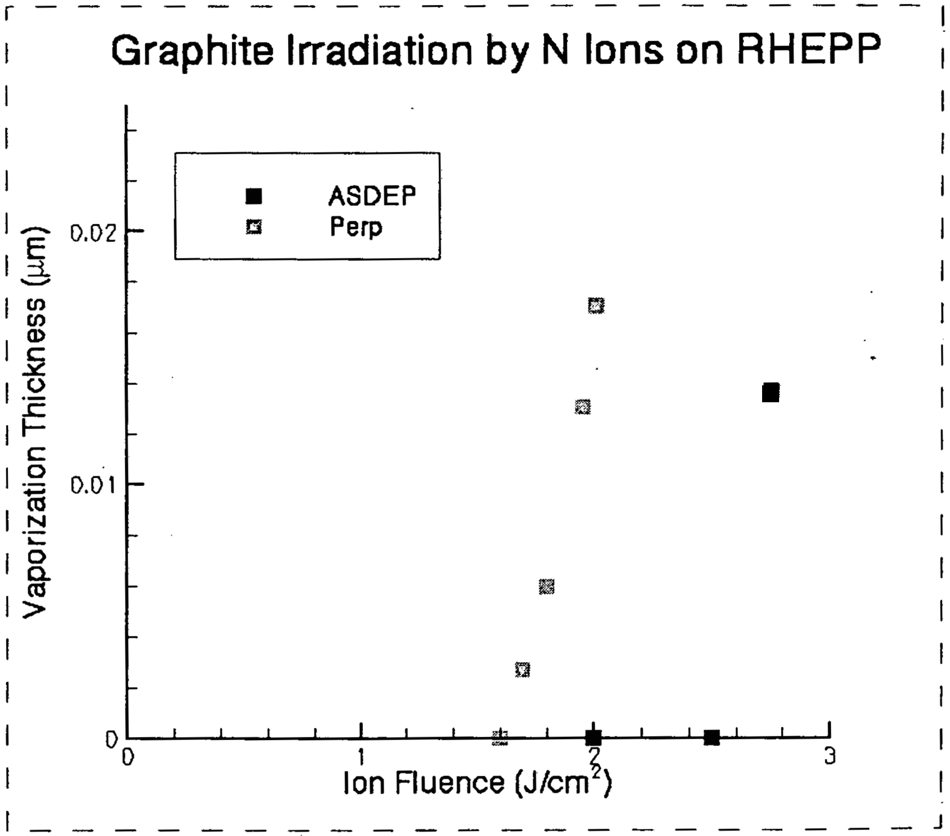
Two Types of Pyroletic Graphite are Considered, PERP and ASDEP, With Quite Different Thermal Conductivity Models



Erosion Threshold for Pyroletic Graphite Irradiated by Nitrogen Ions on RHEPP is Calculated by BUCKY For Two Thermal Conductivity Models

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





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