Effect of Re Alloying in W on Surface Morphology Changes After He^+ Bombardment at High Temperatures

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HAPL Meeting-LLNL

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Fusion Technology Institute

University of Wisconsin-Madison

Progress Since the Last Meeting

- Paper will be published in *Journal of Nuclear Materials, 2005*.

  B.B. Cipiti and G.L. Kulcinski, Helium and Deuterium "Implantation in Tungsten at Elevated Temperatures"

- Paper was published in *Fusion Science and Technology*. Vol.47, #4, part 2, May 2005

  R.F. Radel and G.L. Kulcinski, "Implantation of D^+ and He^+ in W-coated Refractory Carbides

- Preliminary work on W-25 Re samples has been performed.

- Evaluation of MWG suggestions for future He irradiation of W coatings has begun.

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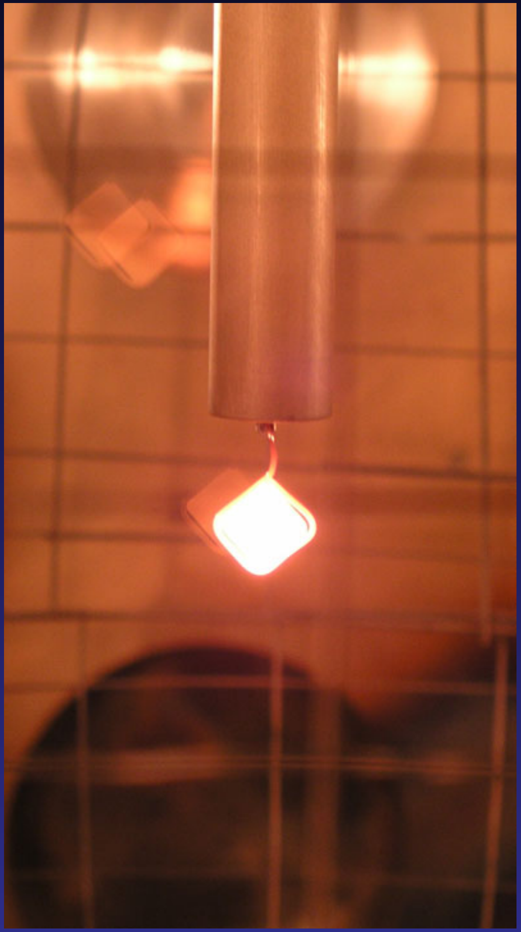
UW IEC Chamber has Capability of High-Temperature Implantation at 10-100 kV



D^+, 20 kV, 5 mA
2 mtorr, 1100 °C

Coatings to Operate In a HAPL Environment He+, D+, 800-1,200 ¡C

- Poly-Crystalline
  - Fluence Effect-He, D
  - Temp Effect
  - Simultaneous He & D
  - Helium Retention
  - W-Re Alloy
- Metallic Foams
  - Large, Medium, & Small Grain W on TaC-He 800 -1,200¡C
  - Large, Medium, & small grain W on TaC-D-800¡C
- Single Crystal
  - He, D Fluence Effect-800¡C
  - Simultaneous He & D
  - Helium Retention

Preliminary Analysis of W-25Re Irradiations

- Samples obtained from Electronic Space Products International.
- 1 cm^2, 1 mm thick samples were electropolished, and then irradiated in the same manner as previous W specimens.
- Constant irradiation conditions for all specimens were He^+ ions, 6 mA/cm^2, 30 kV, 0.5 mtorr background pressure, 800 °C.
- Fluence was varied from 10^{18} to 10^{19} cm^2

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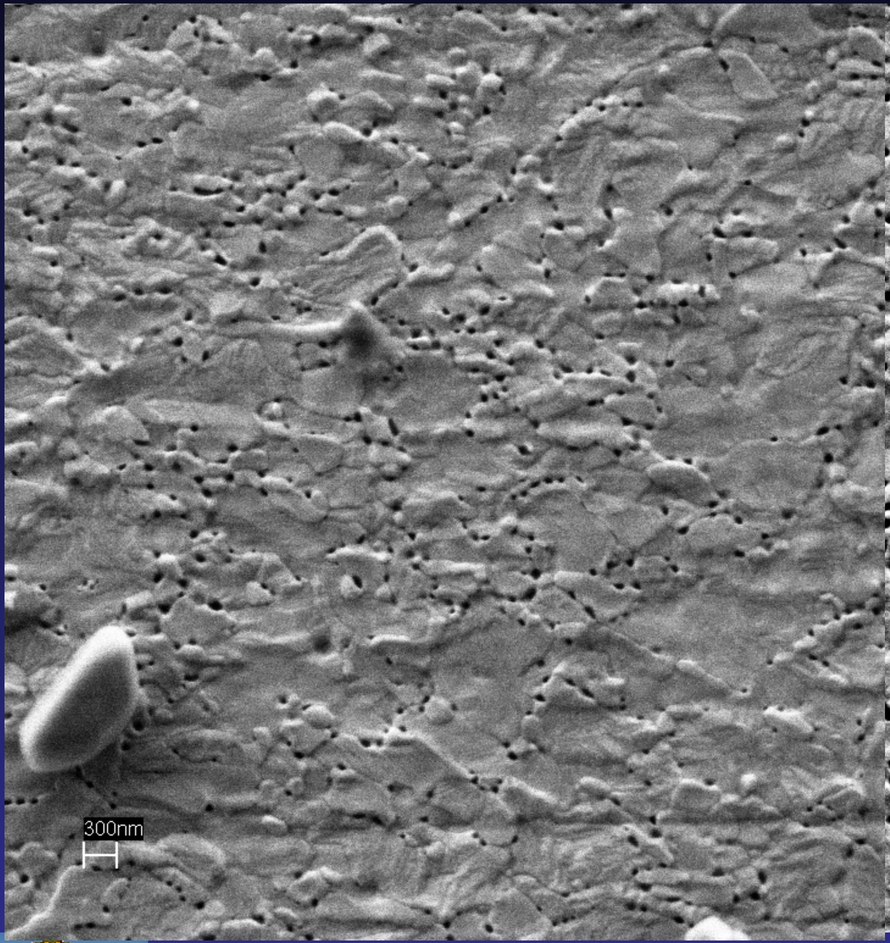
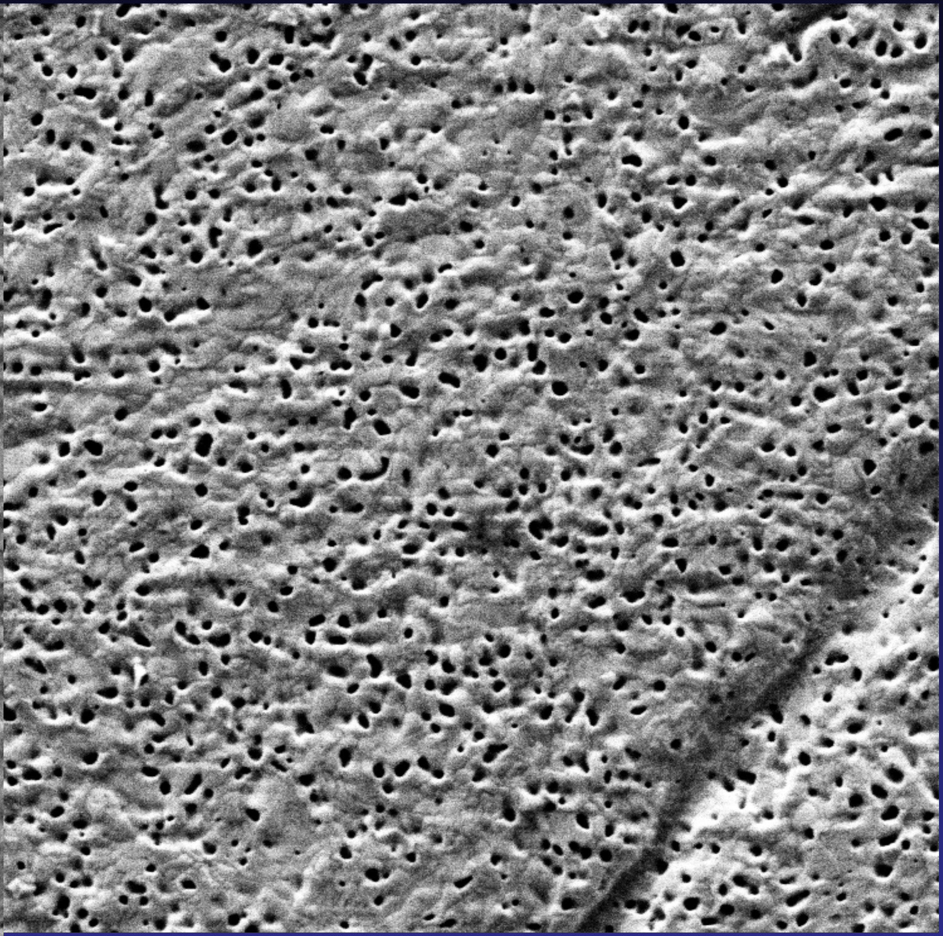
The W-25 Re Samples Show Slightly Larger Pores & a Higher Density Compared to W After $1x10^{18}$ He/cm^2 (800 C)



W



W-25Re

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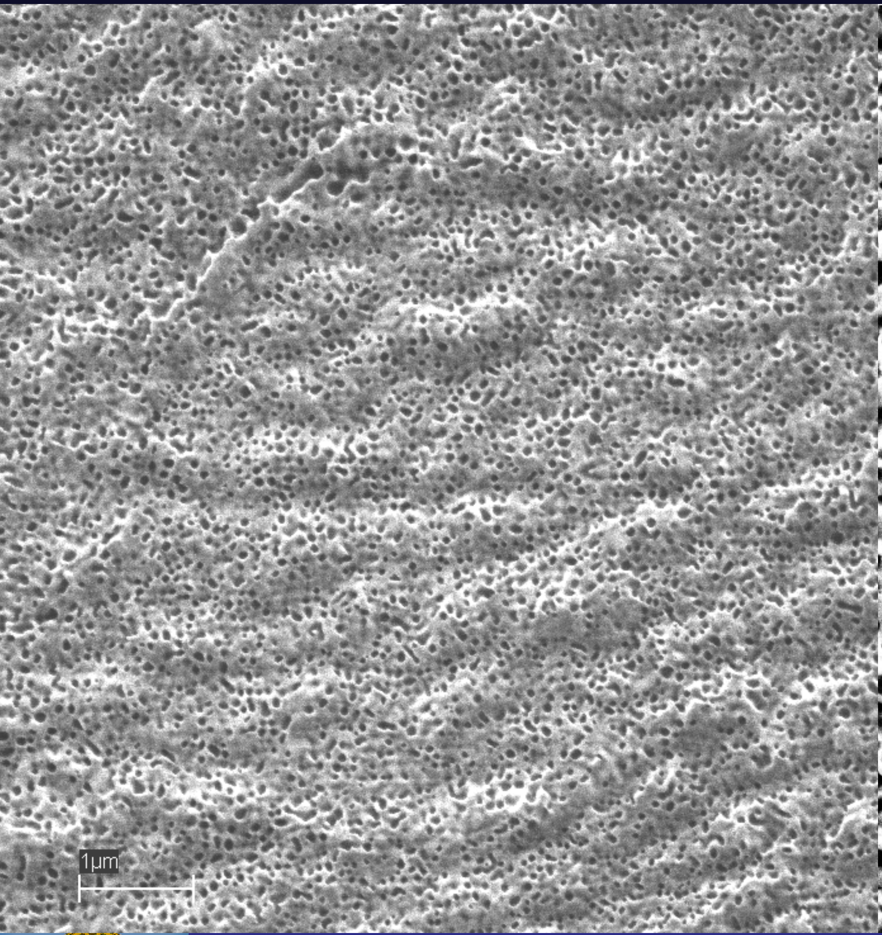
The W-25 Re Samples Show Slightly Larger Pores Compared to W After $3x10^{18}$ He/cm^2 (800 C)



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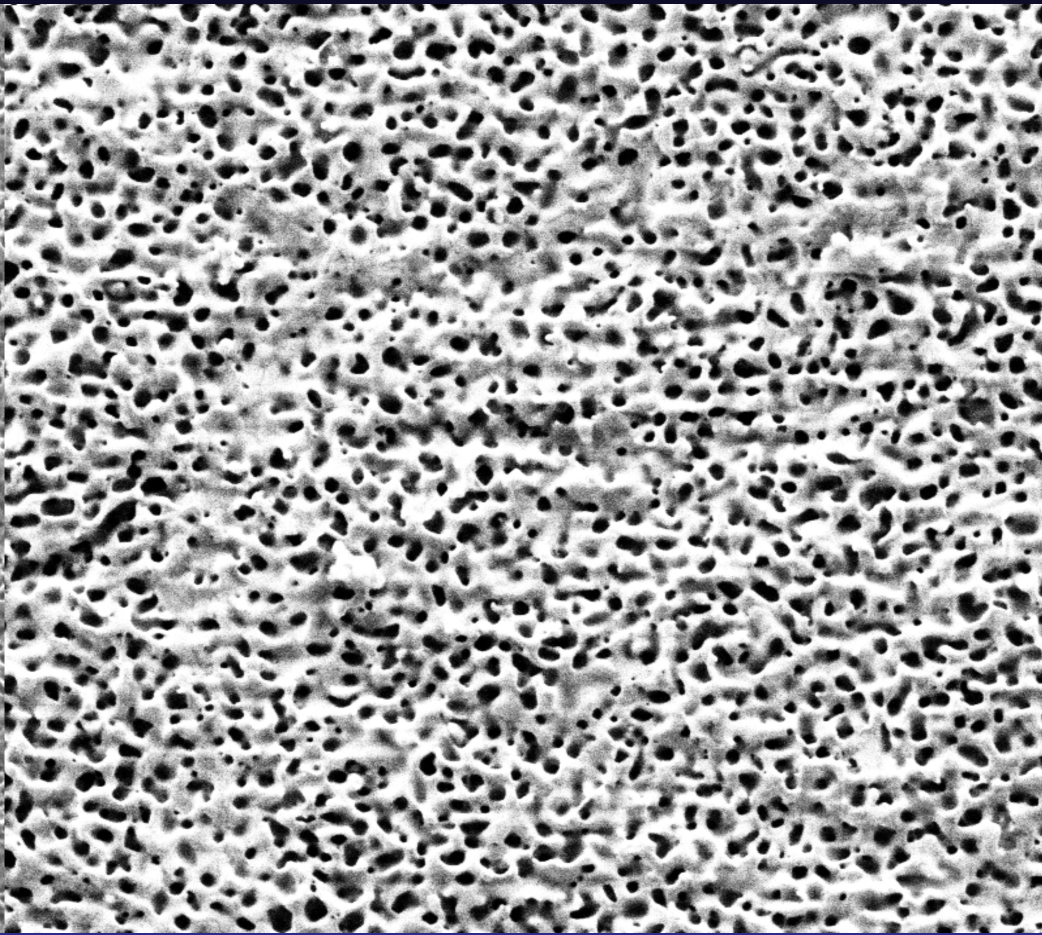
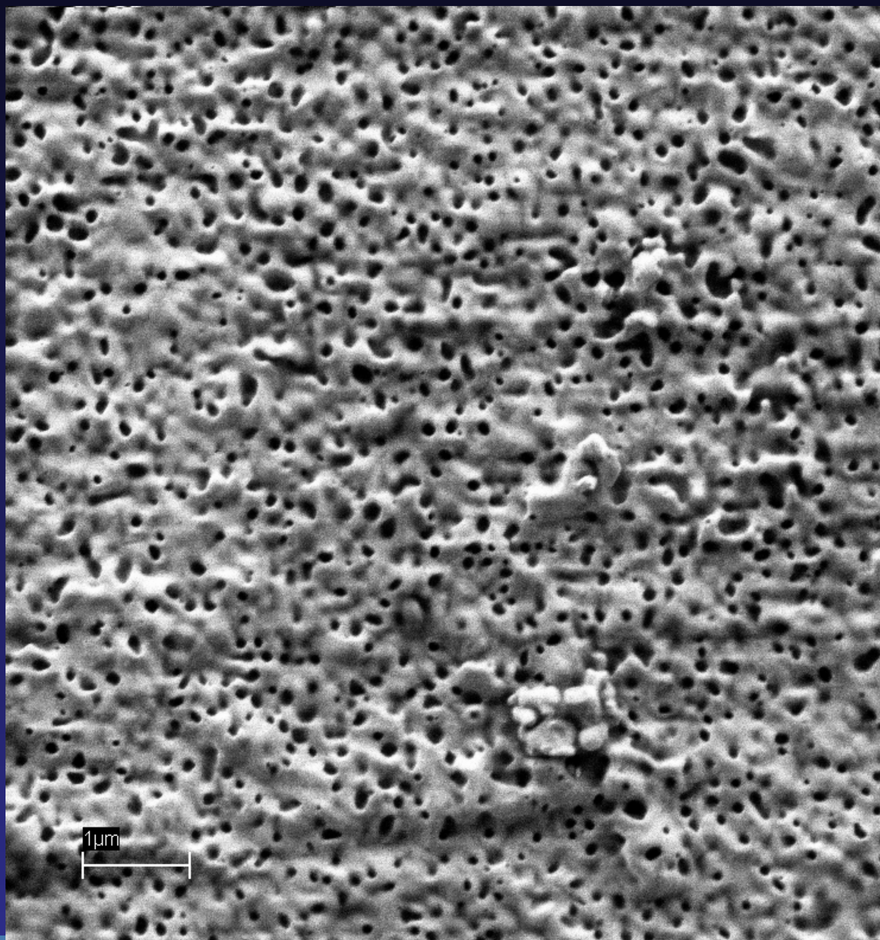
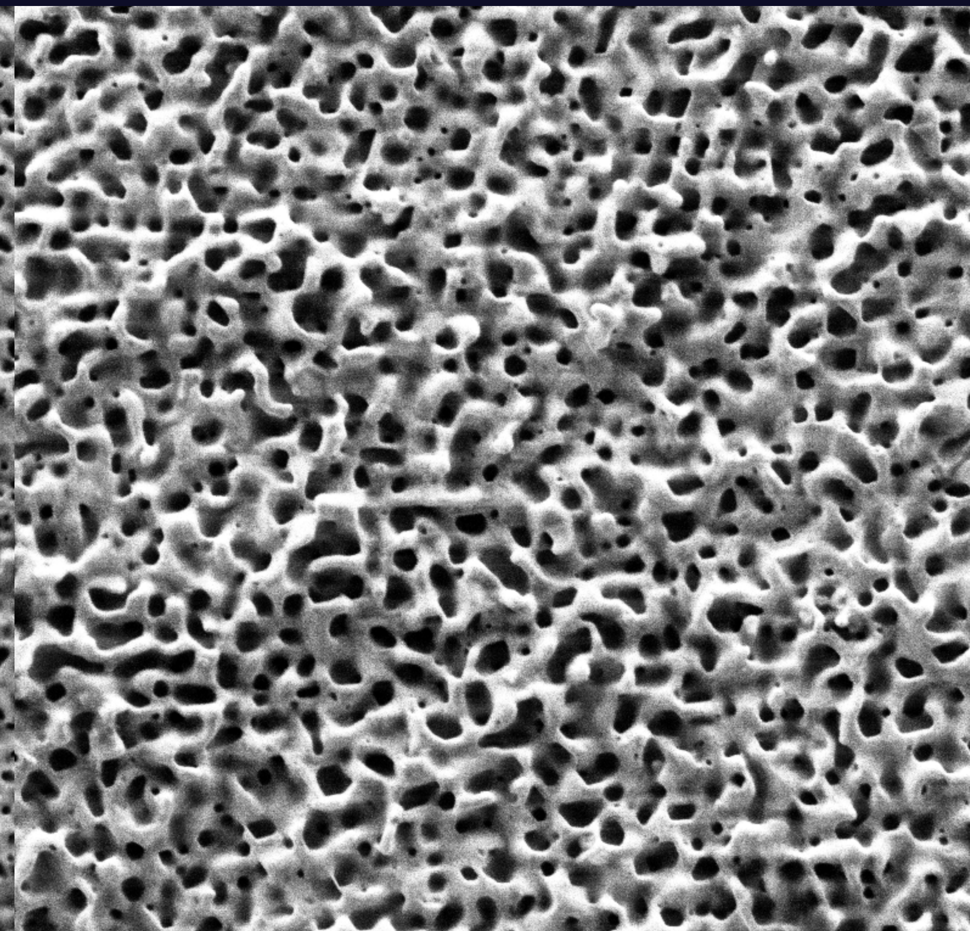


W-25Re

The W-25 Re Samples Show Slightly Larger Pores Compared to W After 1×10^{19} He/cm^2 (800 C)



W



W-25Re

Tentative Conclusions from the W-25Re Irradiations

- Alloying W with 25% Re does not improve its resistance to pore formation after high temperature He^+ bombardment at 800°C.
- Alloying W with 25% Re may even lower the threshold for pore formation and increase the average size of the pores.

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MWG Recommendations for Future Helium Studies of W Coatings in the UW-IEC Device-June 05

1) Report the energy spread of impinging ions (D & He).
2) Improve temperature reading accuracy.
3) Report D to He ion ratios and ion energies for simultaneous implantations.
4) Perform experiments on single crystal and polycrystalline tungsten samples only, until processes are better characterized/modeled; no need to go to other materials.
5) Provide SEMs and/or TEMs of implanted region cross-sections.
6) Measure material loss or lack of it.
7) Account for the difference in volumetric helium deposition between IEC and the HAPL reference chamber.

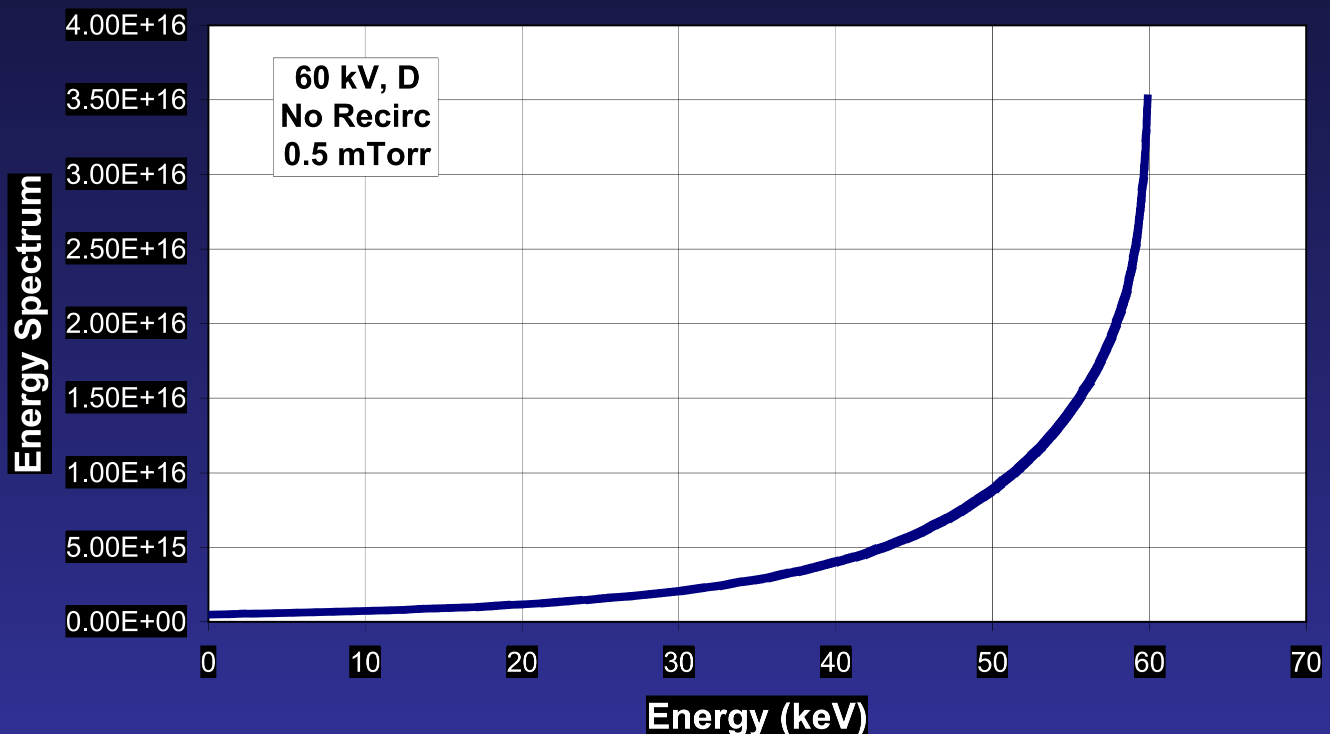
UW Has Begun Modeling Inertial-Electrostatic Confinement (IEC) Experimental Energy Spectra

- Model includes
  - Spherical geometry
  - Only deuterium at present
  - Background neutral gas
  - Collisionless 1-D motion
  - Prescribed radial electrostatic potential (Child-Langmuir)
  - Charge exchange
  - Ionization
- Modifications required to simulate HAPL first-wall:
  - Include helium atomic physics in computer code
  - Operate IEC experiments at lower pressure to reduce ion energy spread
    - Requires separate ion source
    - Must scan voltage to fit HAPL helium ion energy spectrum

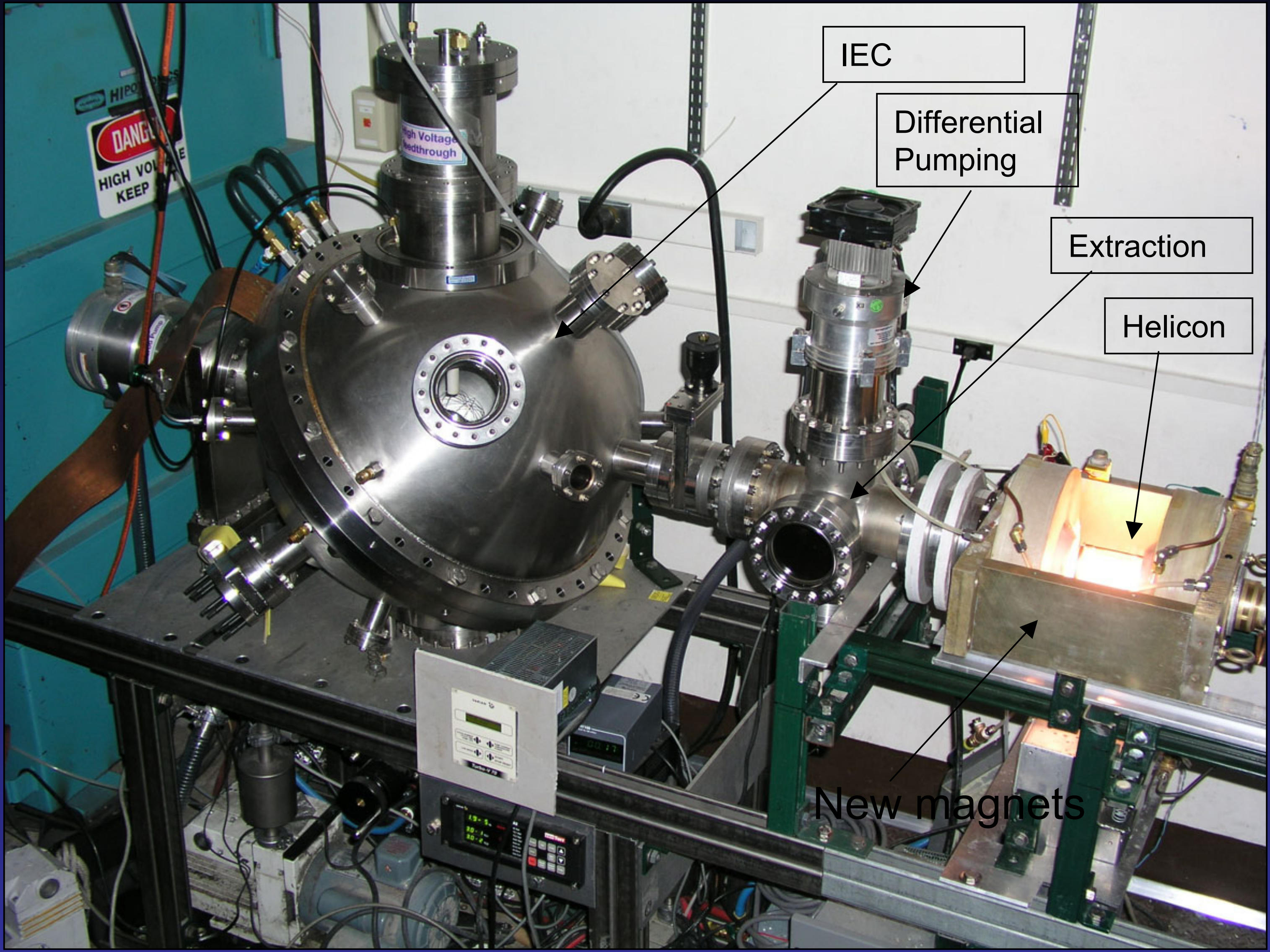
Typical IEC Deuterium Ion Energy Spectrum is Calculated with Charge-Exchange and Ionization Included

- Helium ion energy spectrum would be similar (at 0.5 mtorr), but probably peaked at an even higher energy due to smaller atomic physics cross-sections.

Approximately 50% of the D+ ions incident on the Target Have Energies within 5 keV of the Cathode Voltage



IEC Chamber to be Used for Low Background Gas Pressure Implantations



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Improved Temperature Readings

1) Calculations are in progress to predict temperature differences across the 1 cm^2 sample as a function of ion flux gradients across the sample.

2) It is not clear that ± 10°C differences (current pyrometer capability) will have significant effects on surface morphology

D/He Ratios During Simultaneous Irradiations

1) The ratios of D^+ to He^+ in the IEC can be found by utilizing a Langmuir probe in the source region of the IEC outside the anode grid.

2) This method assumes that the fractions of D^+ and He^+ are relatively independent of background neutral gas pressure.

SEM and TEM Analysis

1) Cross sectional analysis of bombarded samples is planned for the Fall/Winter of 2005

2) Techniques for cross sections are being developed

3) Analysis will be correlated with RBS measurements

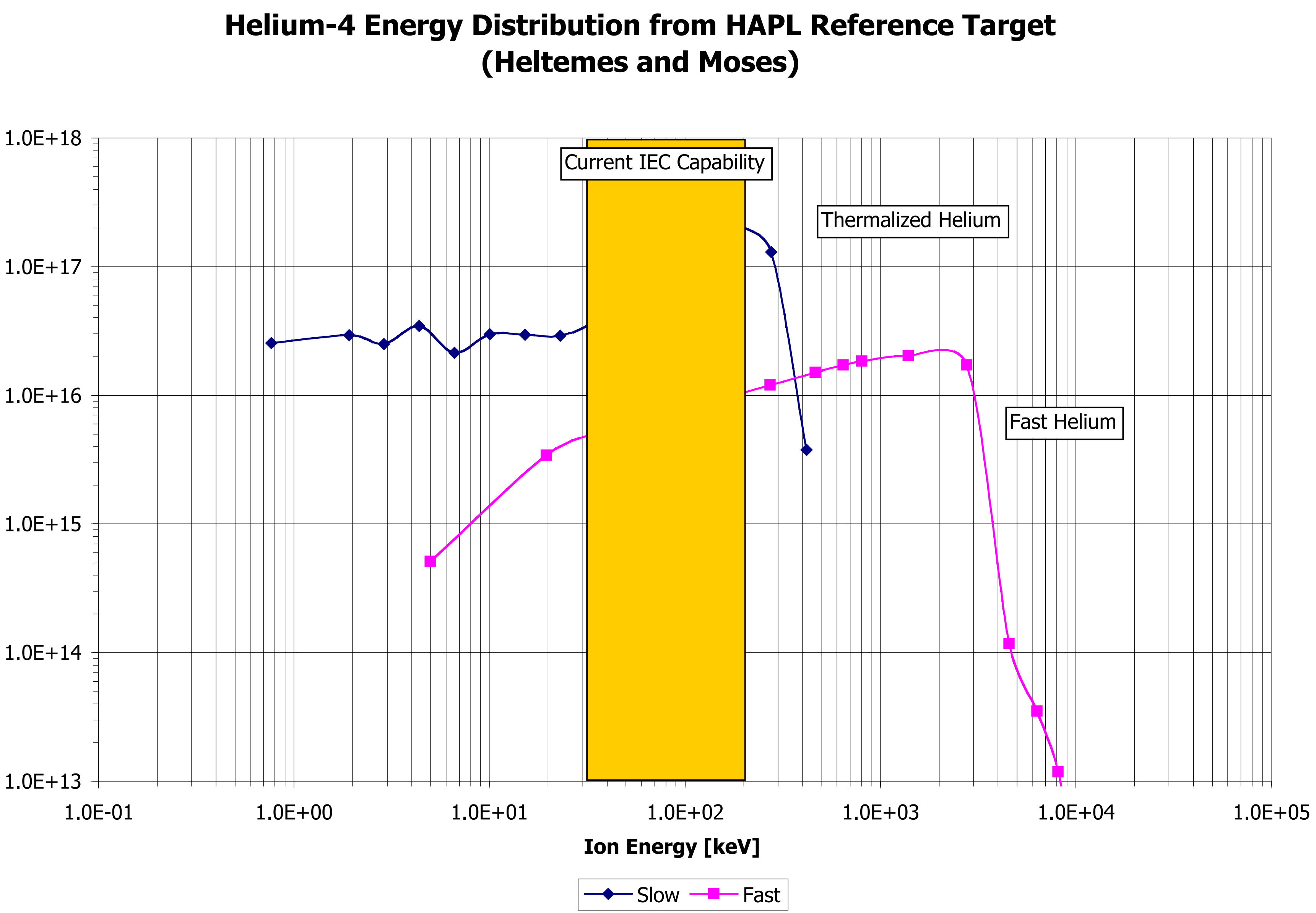
Measure Loss of Material From Irradiated Specimens

1) Samples will be weighed before and after irradiation.

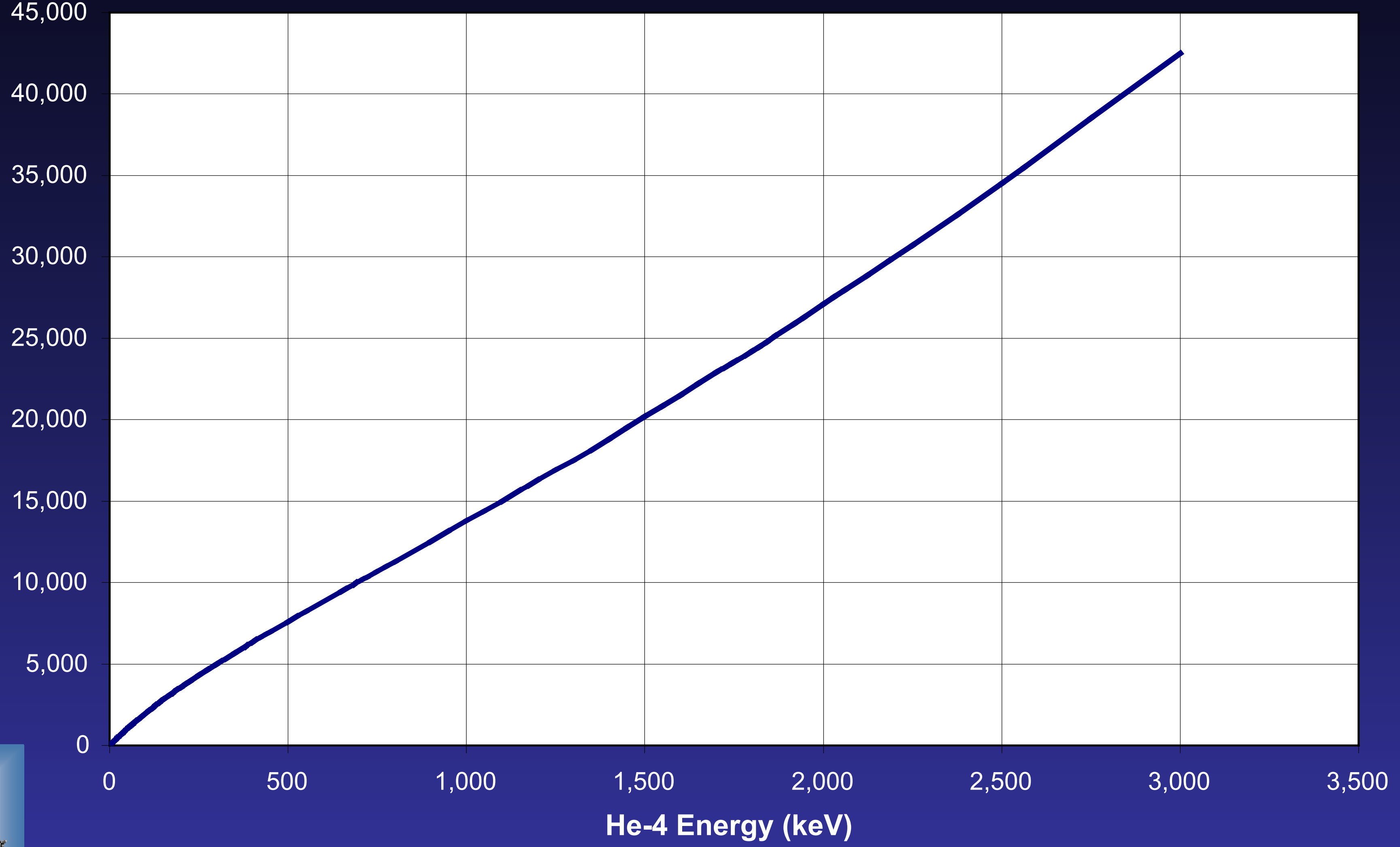
1) Accuracy will be ±0.1 micron (@ ±10 micrograms)

"Account for the difference in volumetric helium deposition between IEC and a HAPL system"

- The concern is associated with the fact that @ 10^{18} cm^{-2} and 60 keV, the injected He concentration in the first 1,000 Å is ≈10^{23} cm^{-3}.
- This injected density will be achieved in the first 4-5 microns of W in 1 day of operation in the HAPL chamber.

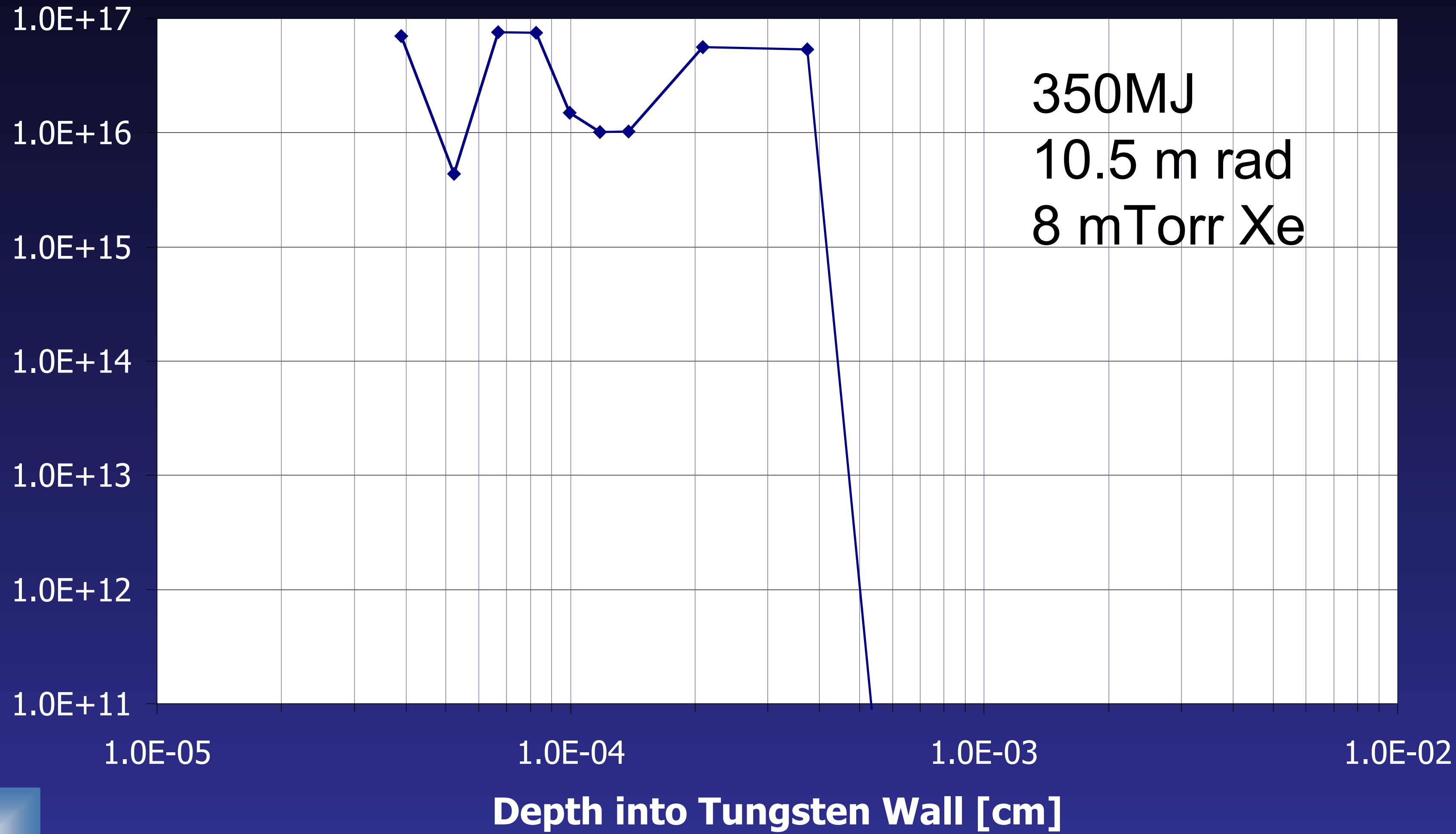

Helium-4 Energy Distribution from HAPL Reference Target
(Heltemes and Moses)
Current IEC Capability
Thermalized Helium
Fast Helium
1.0E+18
1.0E+17
1.0E+16
1.0E+15
1.0E+14
1.0E+13
1.0E-01
1.0E+00
1.0E+01
1.0E+02
1.0E+03
1.0E+04
1.0E+05
Ion Energy [keV]
Slow
Fast

The Maximum Range of He-4 From HAPL Ref Target in W is 4-5 Microns



Each Shot in the HAPL Chamber Injects 10^{18} to 10^{19} He/cc

Injected Helium Density in Tungsten Wall per Shot
Heltemes and Moses



Questions To Consider On Simulation Studies for He Implantation

1) How much of the He is retained at high temperatures? (what is the effect of annealing?)
2) What is the effect of dose rate on pore formation?
3) What is the effect of the depth distribution of Helium on pore formation?