

# Laser Fusion Chamber Design

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**TOFE**

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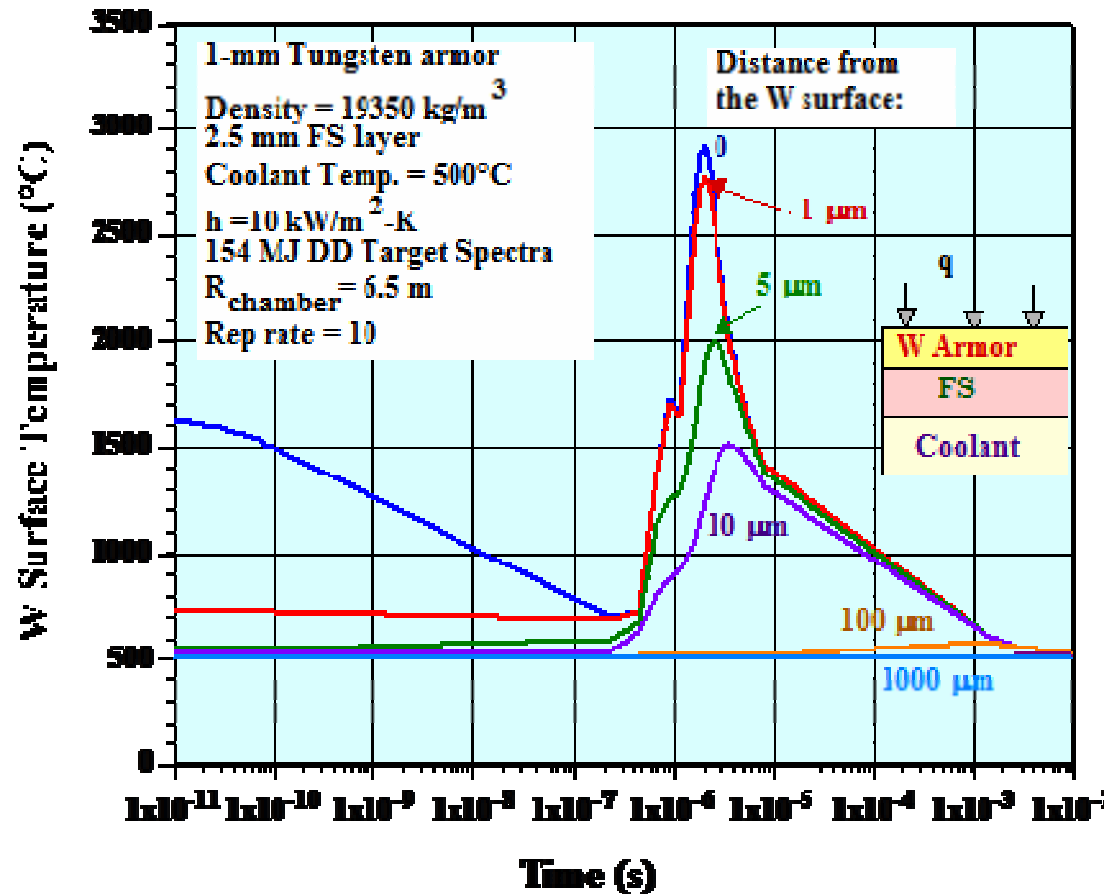
# IFE Chamber Studies in US

- **ARIES-IFE study concluded in 2003**
  - focused on evolving parameter design space
  - laser and heavy ion drivers
  - direct and indirect-drive targets
  - dry wall, wetted wall and thick liquid wall chambers
- **Termination of effort on heavy ion, indirect-drive target, thick liquid wall chamber studies (HYLIFE)**
- **Currently IFE technology is primarily funded through the following two programs:**
  - HAPL study (multi-year, multi-institution effort led by NRL)
  - Z-pinch study (started in 1999 as LDRD, now much broader)



# Chamber Wall Must Accommodate Threat Spectra from Direct Drive Target

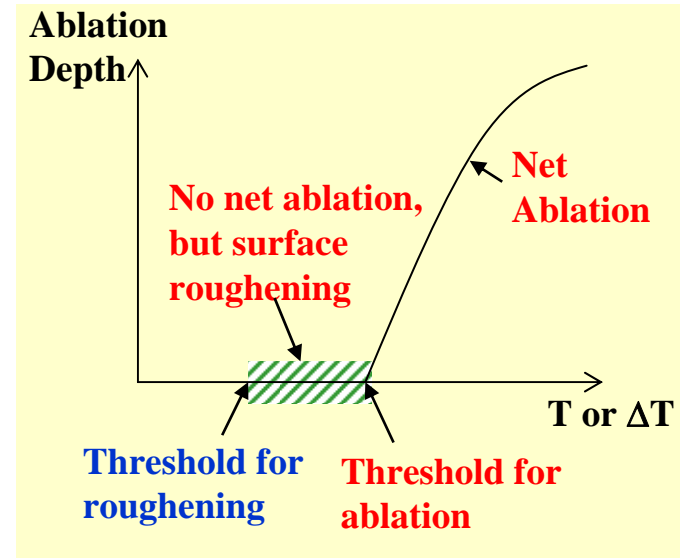
- Threats are:
  - Neutrons (100s ns)
  - Xrays (ns)
  - Ions (microsec)
- Ions and Xrays pose greatest threat to dry chamber wall
- Energy is deposited in near surface (few microns)
- Current design is W layer on steel wall



# W Armor Lifetime

- **Several possible mechanisms could lead to premature armor failure:**

- ablation
- melting (is it allowable?)
- surface roughening & fatigue
- accumulation of implanted helium
- fatigue failure of the armor/substrate bond (experiments at UCLA and ORNL)

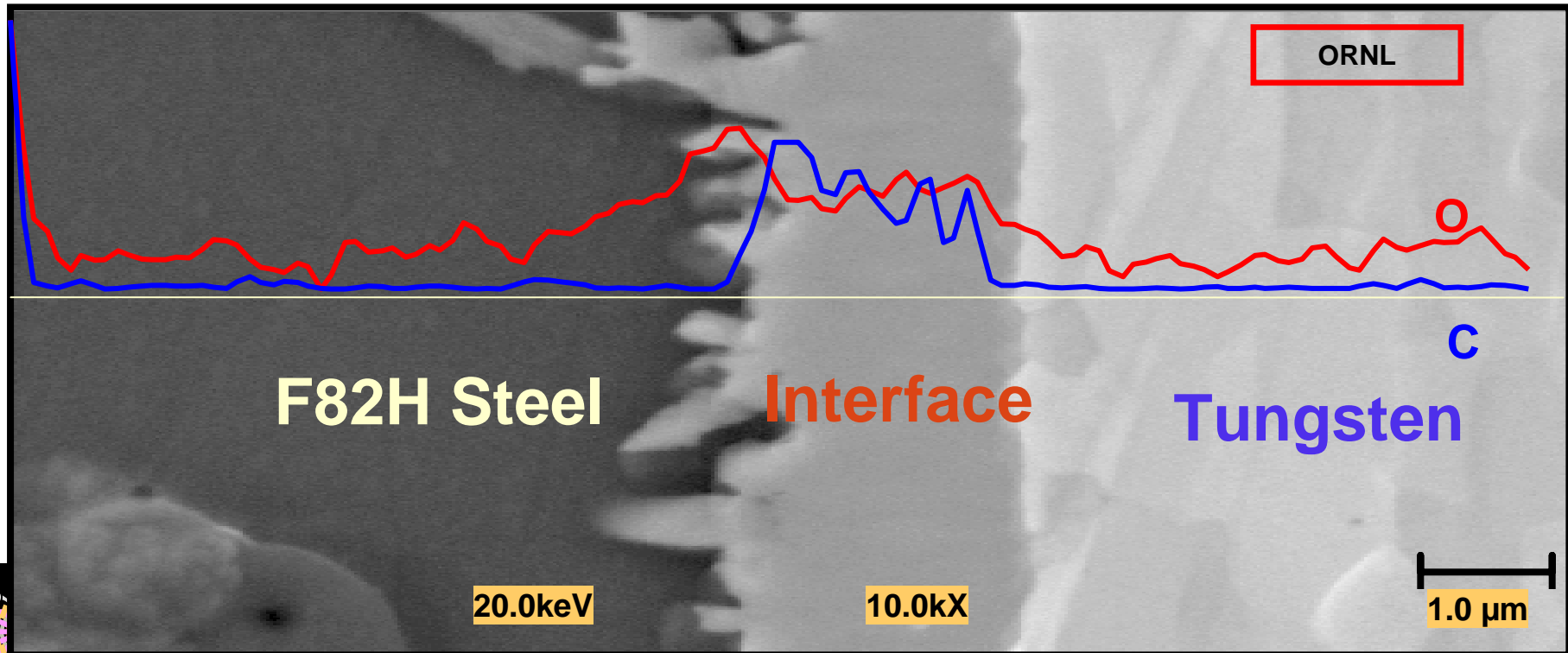
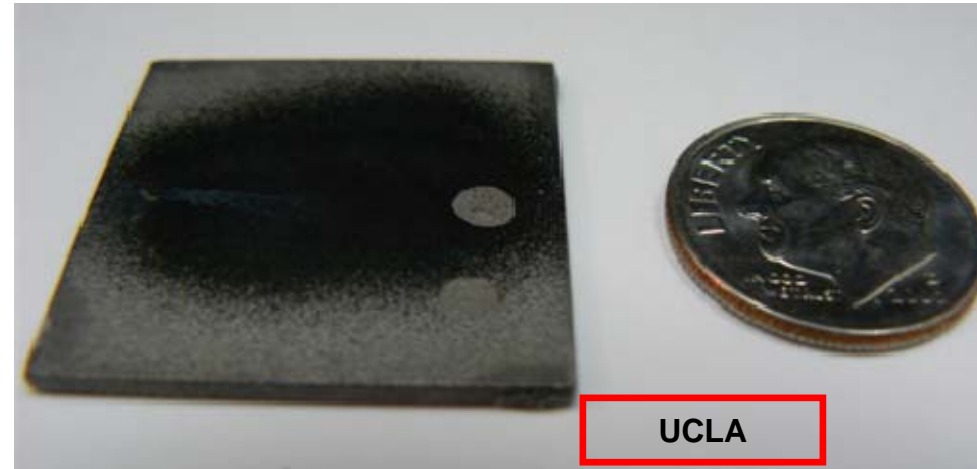


- **Because the exact IFE ion and X-ray threat spectra on the armor cannot be duplicated at present, experiments are performed in simulation facilities:**

- Ions (RHEPP - Sandia)
- Laser (Dragonfire - UCSD)
- IEC (UW)
- Fatigue testing of the W/FS bond in ORNL infrared facility
- He management is addressed by conducting implantation experiments (UNC) along with modeling of He behavior in tungsten (UCLA).

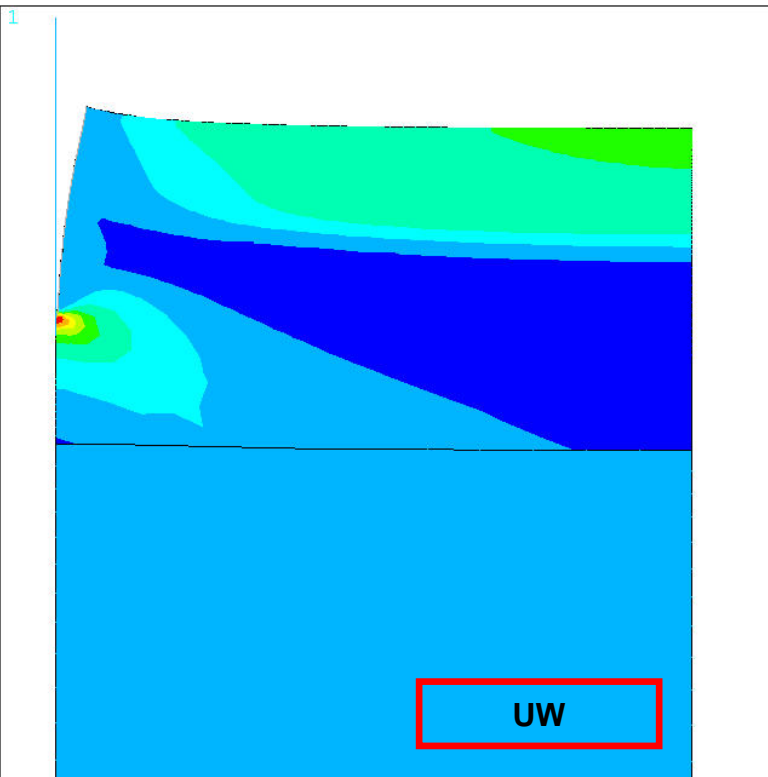
# Bond Integrity and Strength

- Three approaches used to assess bond properties
- Laser spallation measures mechanical strength
- IR heating simulates temperature history at interface
- Aging studies look at compatibility
- Results are uniformly excellent

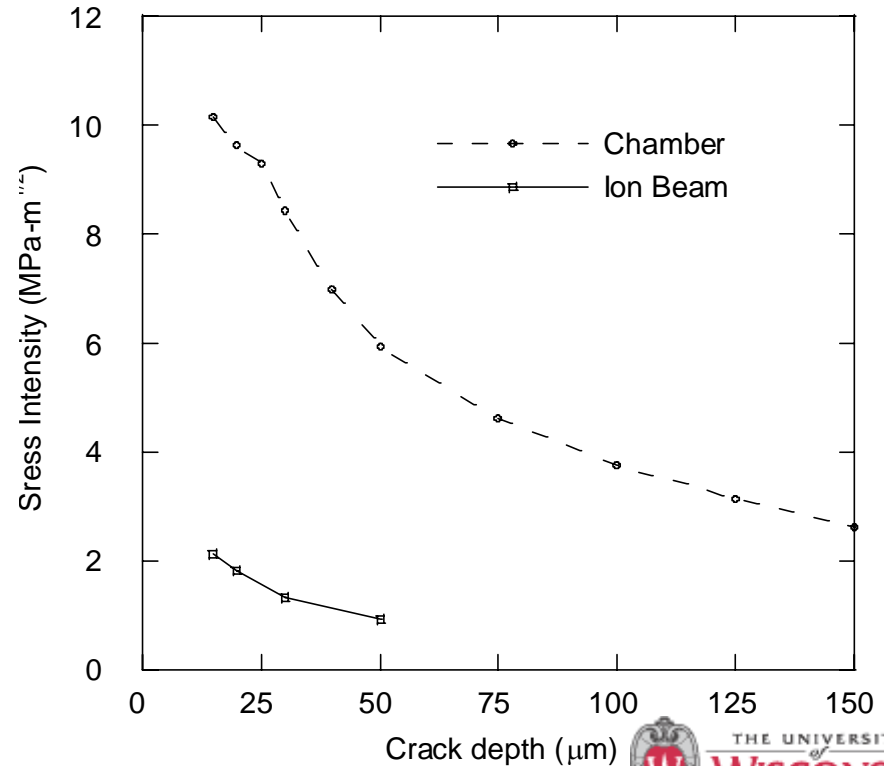


# Modeling of Surface Cracking

- Stress intensity factor decreases as cracks grow further from surface
- Crack growth will arrest
- Crack arrest will be more shallow for short pulse experiments (like RHEPP)



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JUL 8 2003  
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EFACET=1  
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SMX =2606



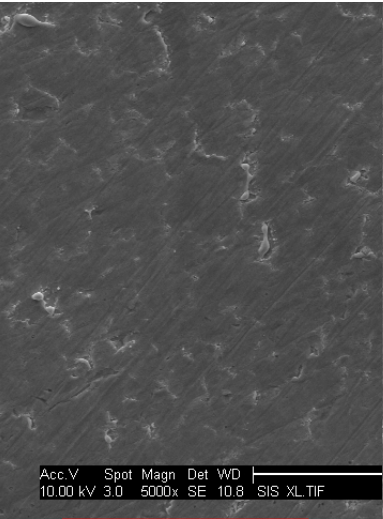
# Exposure Facilities

- **Ion beams (RHEPP - Sandia)**
  - Up to 800 keV for singly-charged He; up to 1.6 MeV for doubly-charged N ions with a pulse-width of 100-300ns.
  - Energy within the range expected for IFE but pulse-width shorter than few  $\mu\text{s}$  expected for IFE.
- **Laser (Dragonfire – UCSD)**
  - Use 1 micron YAG laser with 9 ns pulse width at 10 Hz to simulate thermal profiles
  - Allows more cycles than RHEPP
  - High-speed optical thermometer measures temperature
  - High-temperature sample holder is included to allow testing at prototypical “equilibrium” temperature.

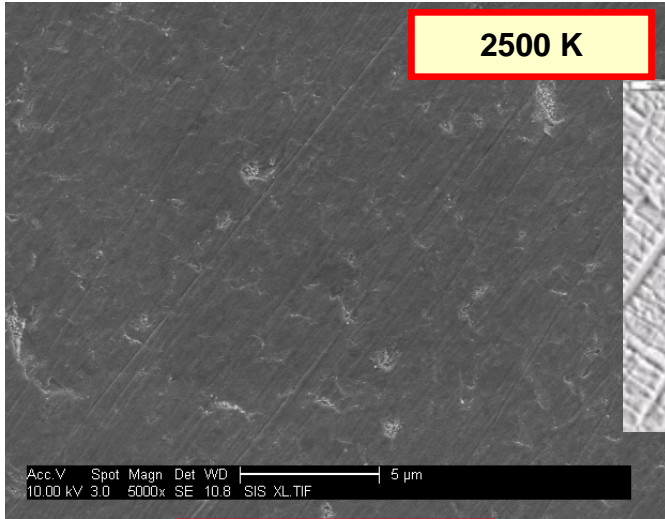


# Tungsten Exposures

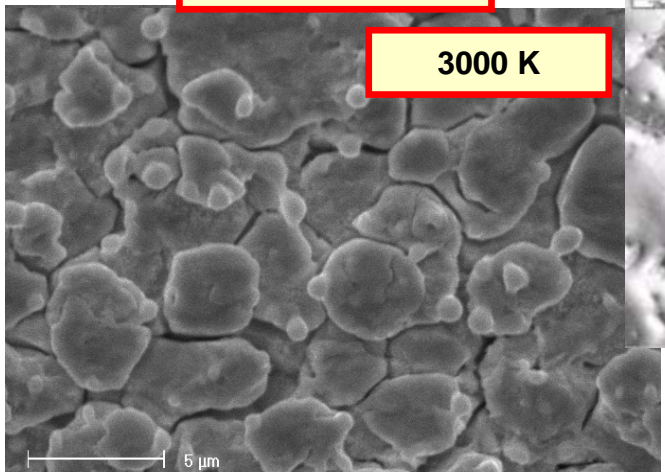
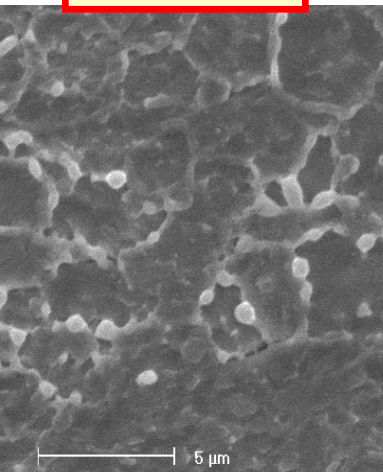
## Powder Met



1,000 shots



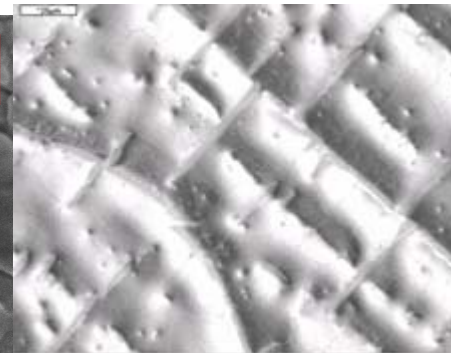
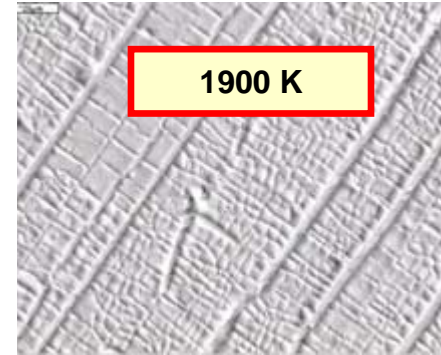
100,000 shots



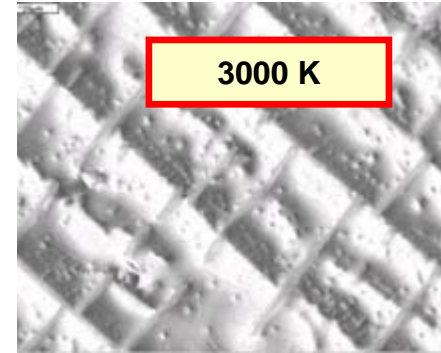
## Single Crystal



1900 K



1200 pulses

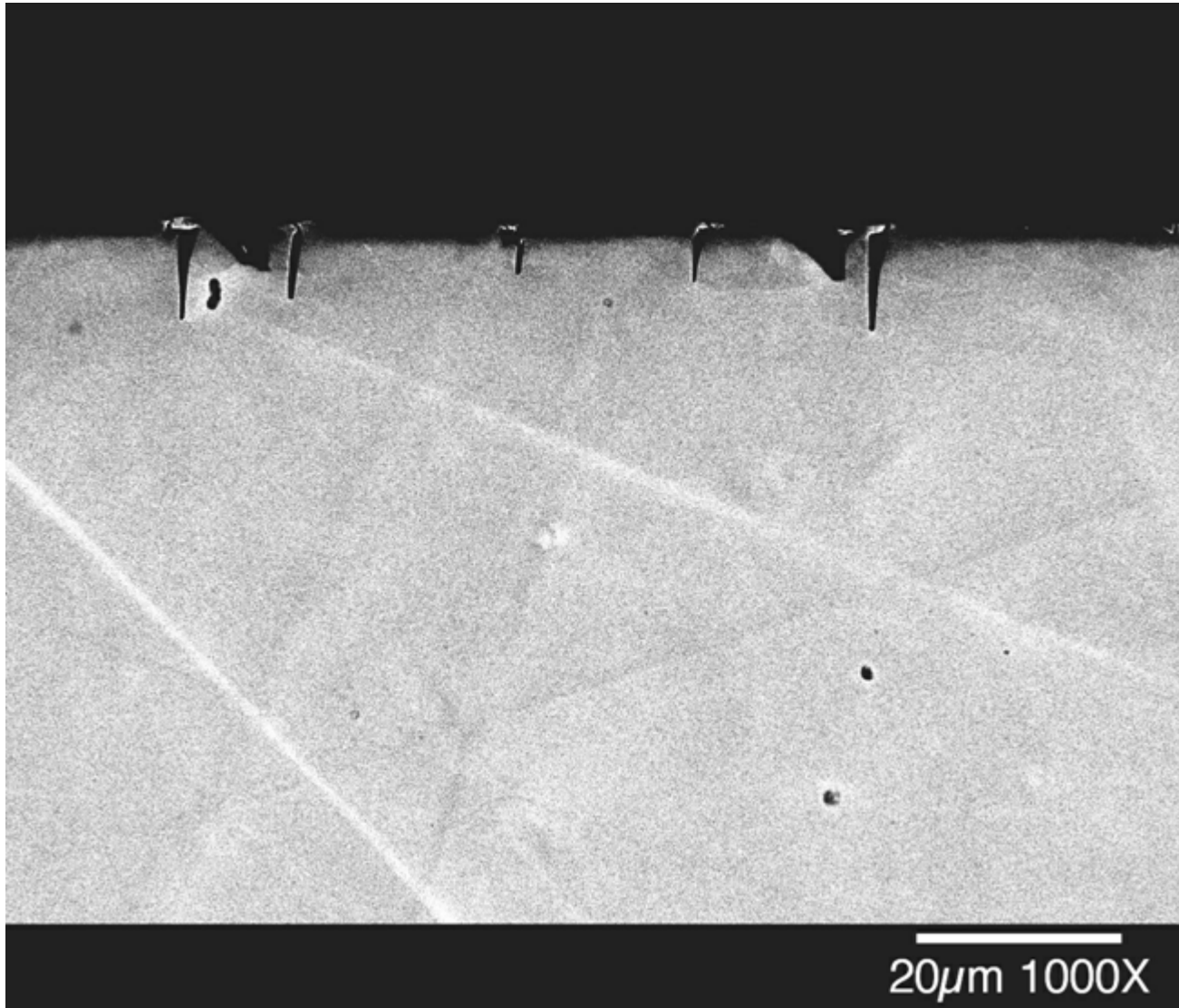


1600 pulses

Dragonfire - UCSD

RHEPP - SNLA

# Crack Depth Measurements in RHEPP

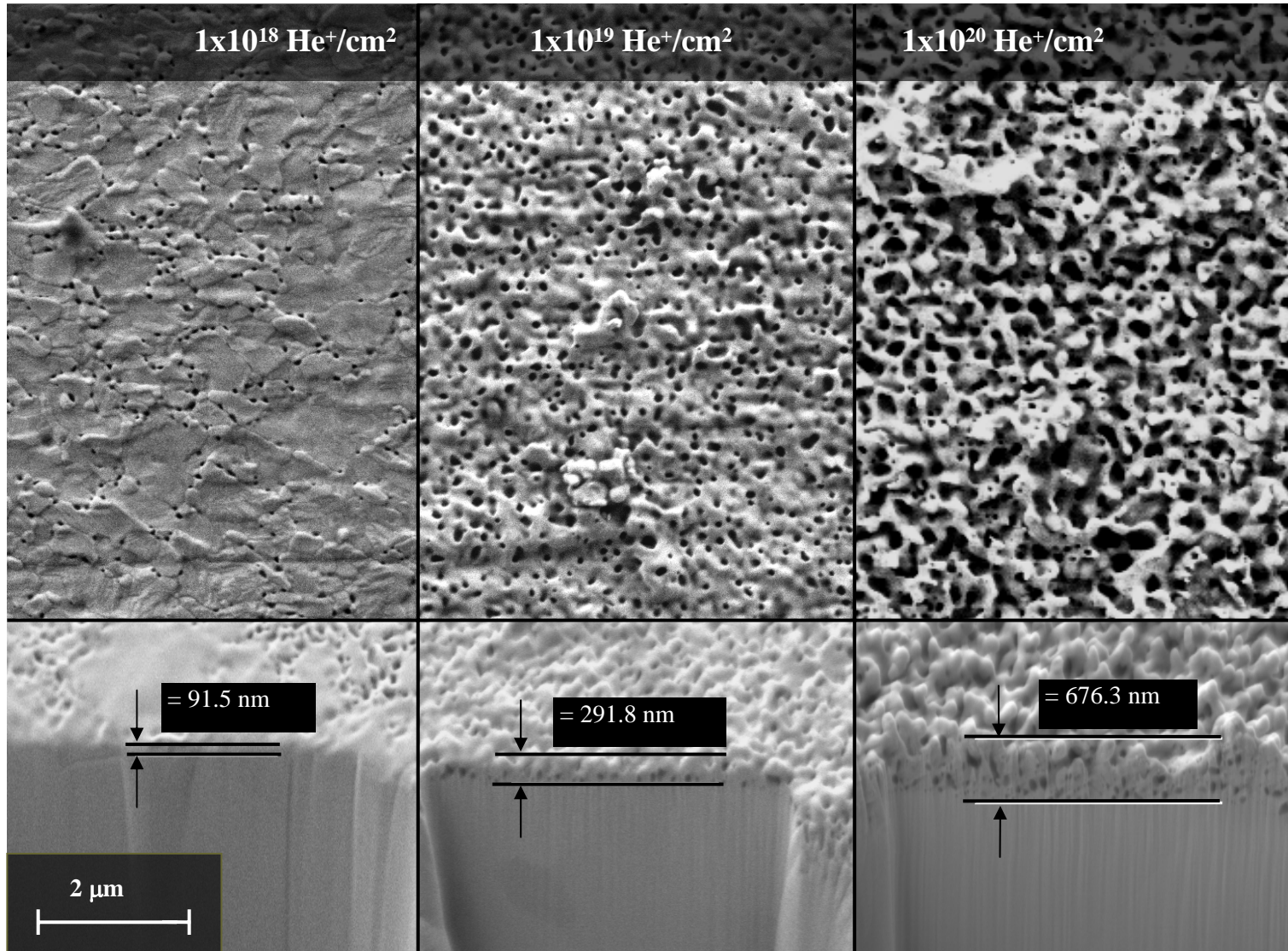


# IEC Exposures

- UW is exposing samples to He and H ions at temperature using inertial electrostatic confinement device
- Initial exposures were steady state, but more recent results were pulsed (though with pulses long compared to IFE values)
- Both tungsten and SiC samples have been exposed
- Energies are lower than in RHEPP

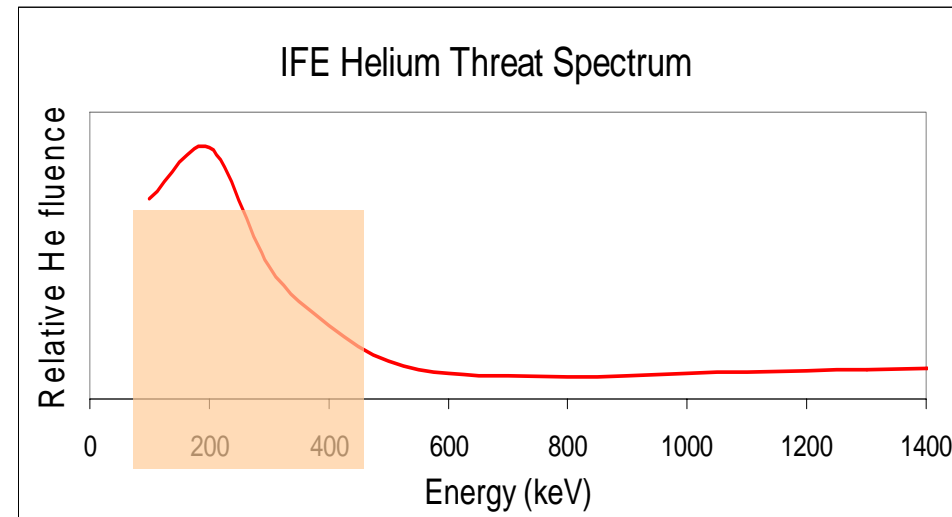
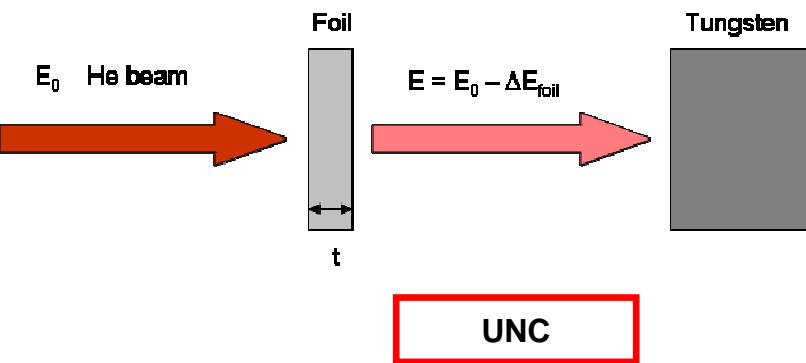


# Helium Ion Irradiation of W at 800 °C Shows Significant Surface Damage at Modest Exposures



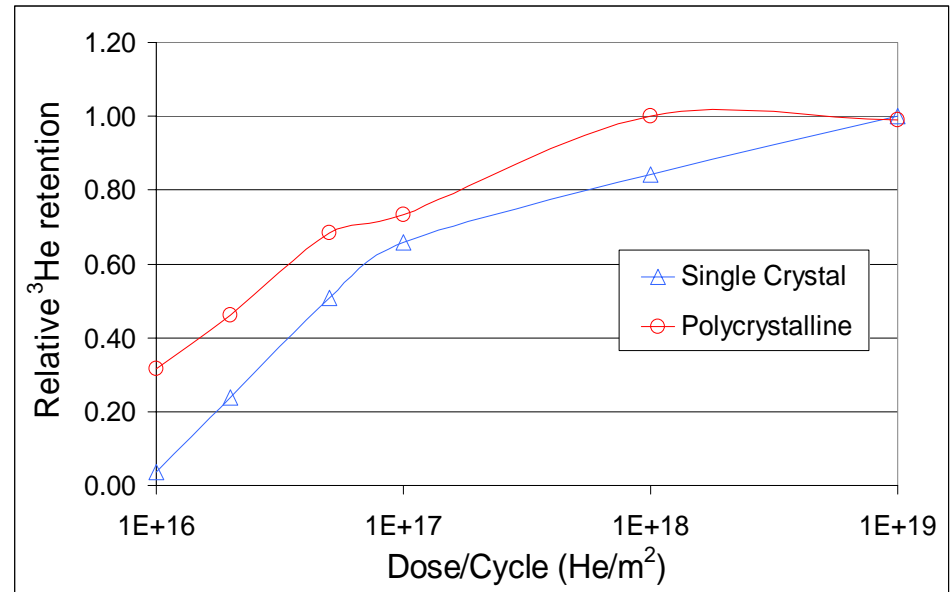
# He Studies Focused on Investigating He Retention and Surface Blistering Characteristics of W

- We must ensure that He is not retained in tungsten
- A key uncertainty is the effect of rapid thermal cycling as ions are implanted
- Experimental activities:
  - Ion implantation with intermittent annealing to simulate IFE chamber wall
  - Implant carbon to study implications of carbide formation
- Modeling activities:
  - HEROS code (UCLA)



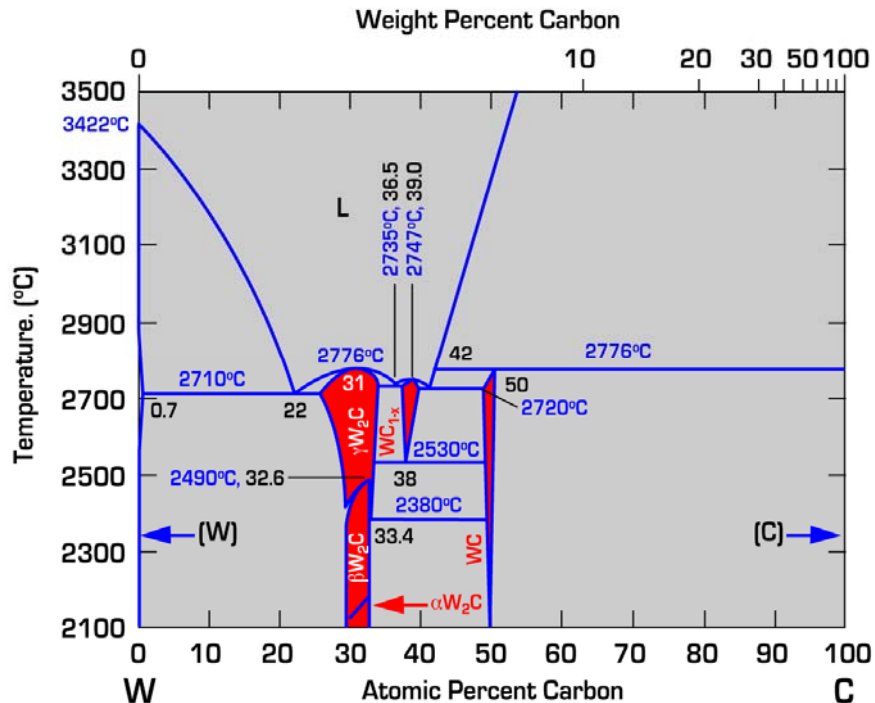
# IFE Conditions May Mitigate He Retention Effect

- He retention decreases drastically when implantation is pulsed, with annealing in between
- IFE He dose per shot is  $\sim 10^{17}$  ions/m<sup>2</sup>
- Annealing is at 2000 C, whereas expected W temperature is likely to be 2400 C
- Carbide formation is expected



Implanted  $10^{19}$  <sup>3</sup>He/m<sup>2</sup> at 850°C followed by a flash anneal at 2000°C

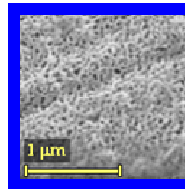
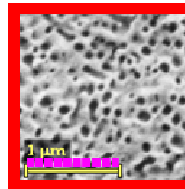
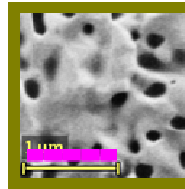
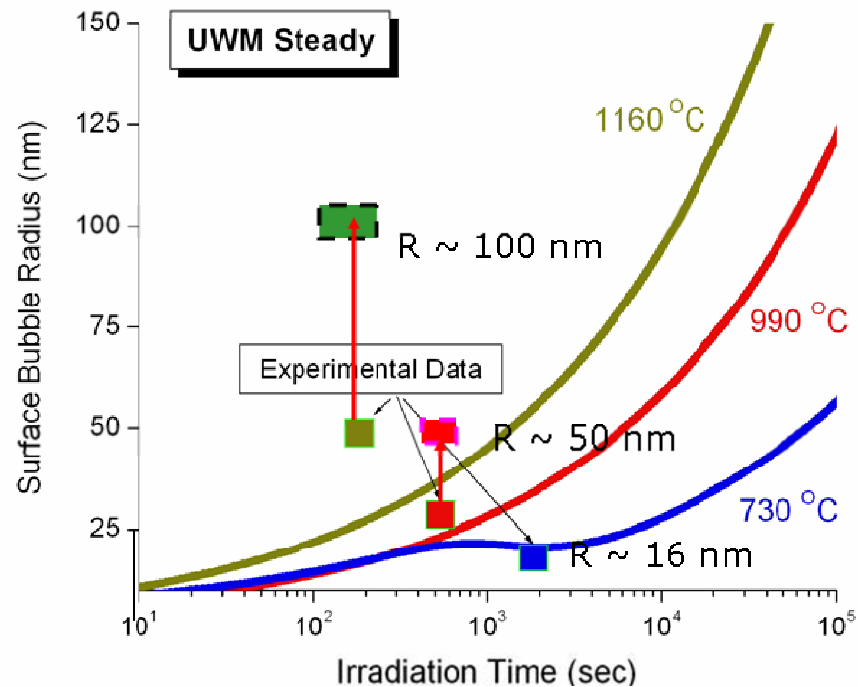
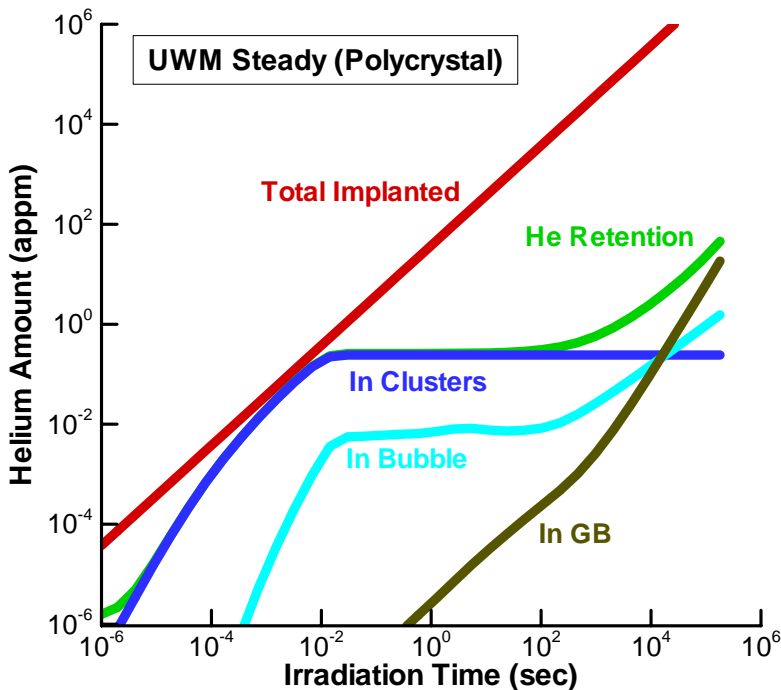
UNC



# Modeling of Ion Transport and Clustering

- Employ reaction-diffusion rate equation:

$$\frac{\partial C^{(i)}}{\partial t} = \text{Generation} + \text{Reaction}(C^{(i)}, C^{(j)}) + \text{Diffusion}(C^{(i)}) + \text{Drift}(C^{(i)})$$



**UCLA**



# Unified Simulation

- Work is under way to unify the various simulations
- Existing suite is susceptible to inconsistencies
- New tool will model:
  - **Heating profile (xrays and ions)**
  - **Transient temperatures, stresses, strains**
  - **Ion deposition profile, diffusion, and clustering**
- Future goals include fracture, sputtering, etc.



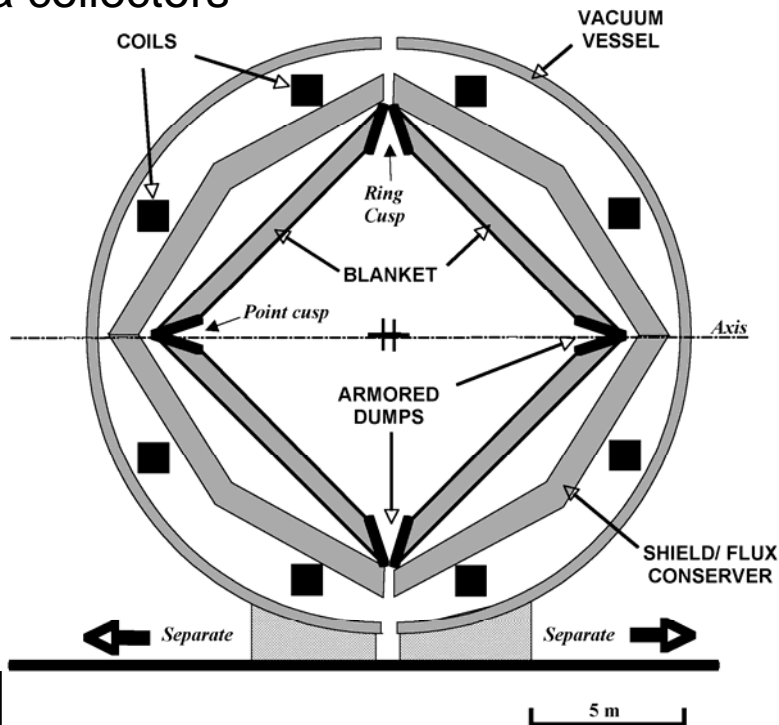
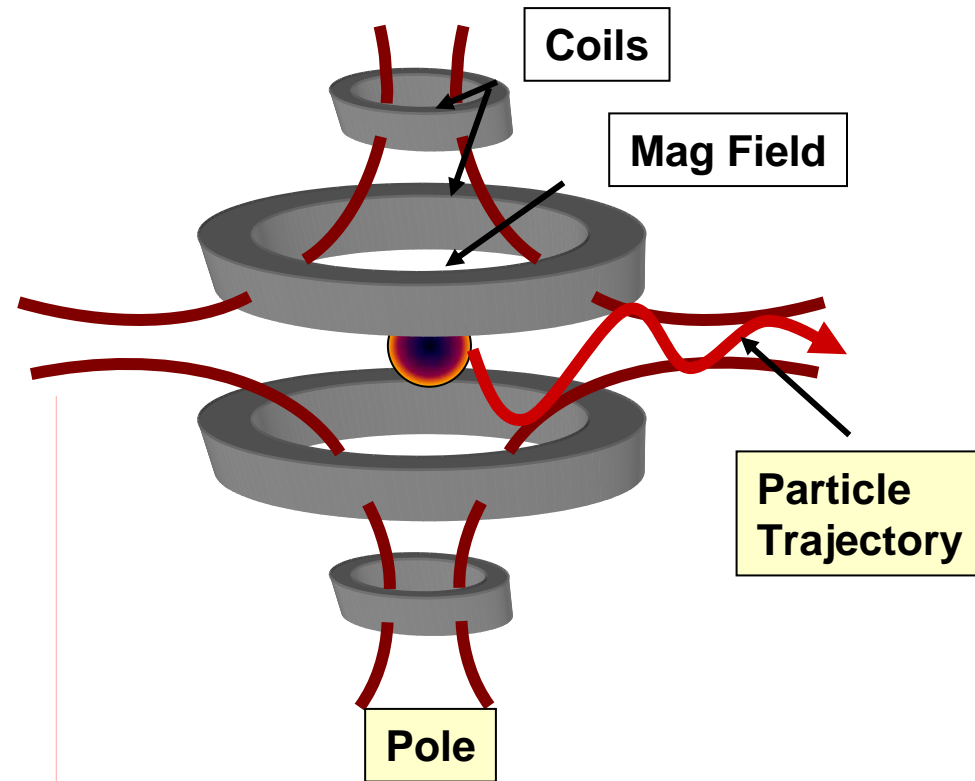
# Ion Mitigation Efforts

- Cusp fields can be used to divert ions outside chamber
- Gas in chamber will stop ions
- We could switch to wetted or liquid walls



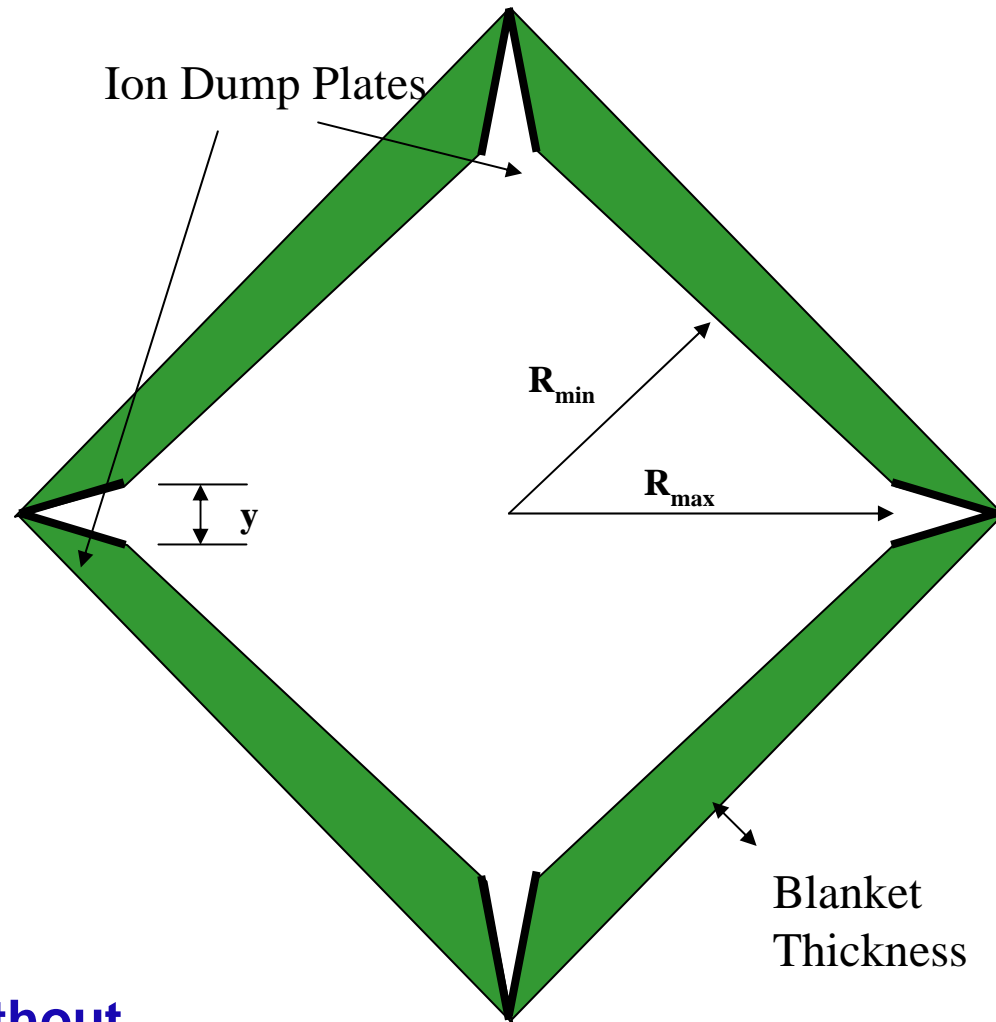
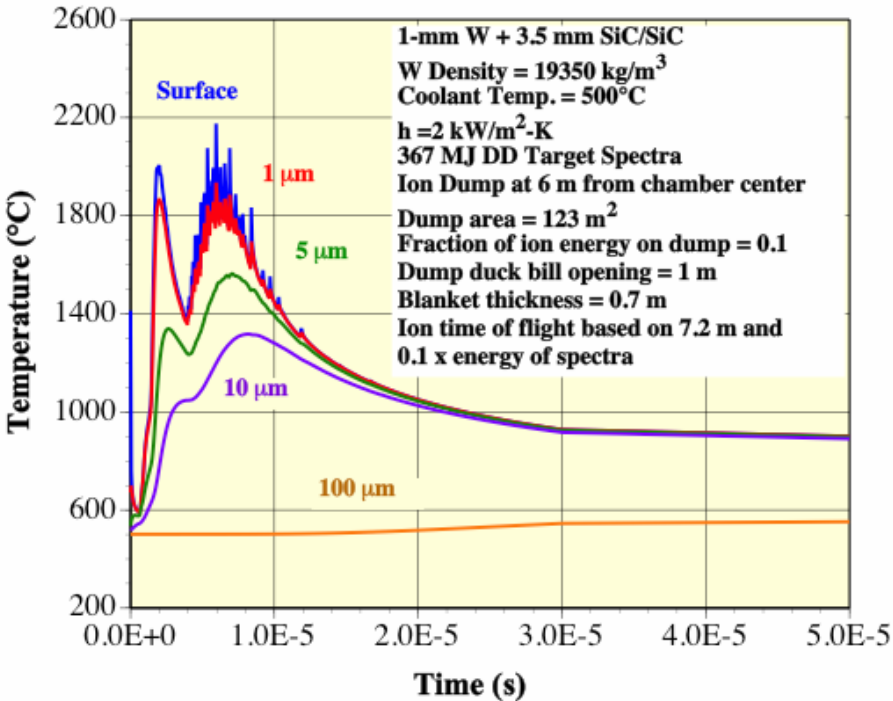
# Magnetic Intervention

1. External Cusp Field diverts ions
2. Ions compress field against the chamber wall
3. Ions never reach wall
4. Ions leak out of cusp ( 5  $\mu$ sec), exit chamber through toroidal slot and holes at poles
5. Magnetic field directs ions to large area collectors



# Ion Energy Deposition and Thermal Response of Dump Plates Estimated for Cone-Shaped Chamber

- For case with ~10% of ion energy on plate, max. W temp. ~ 2200°C



- This does not provide significant advantage over dry wall design without ion diversion

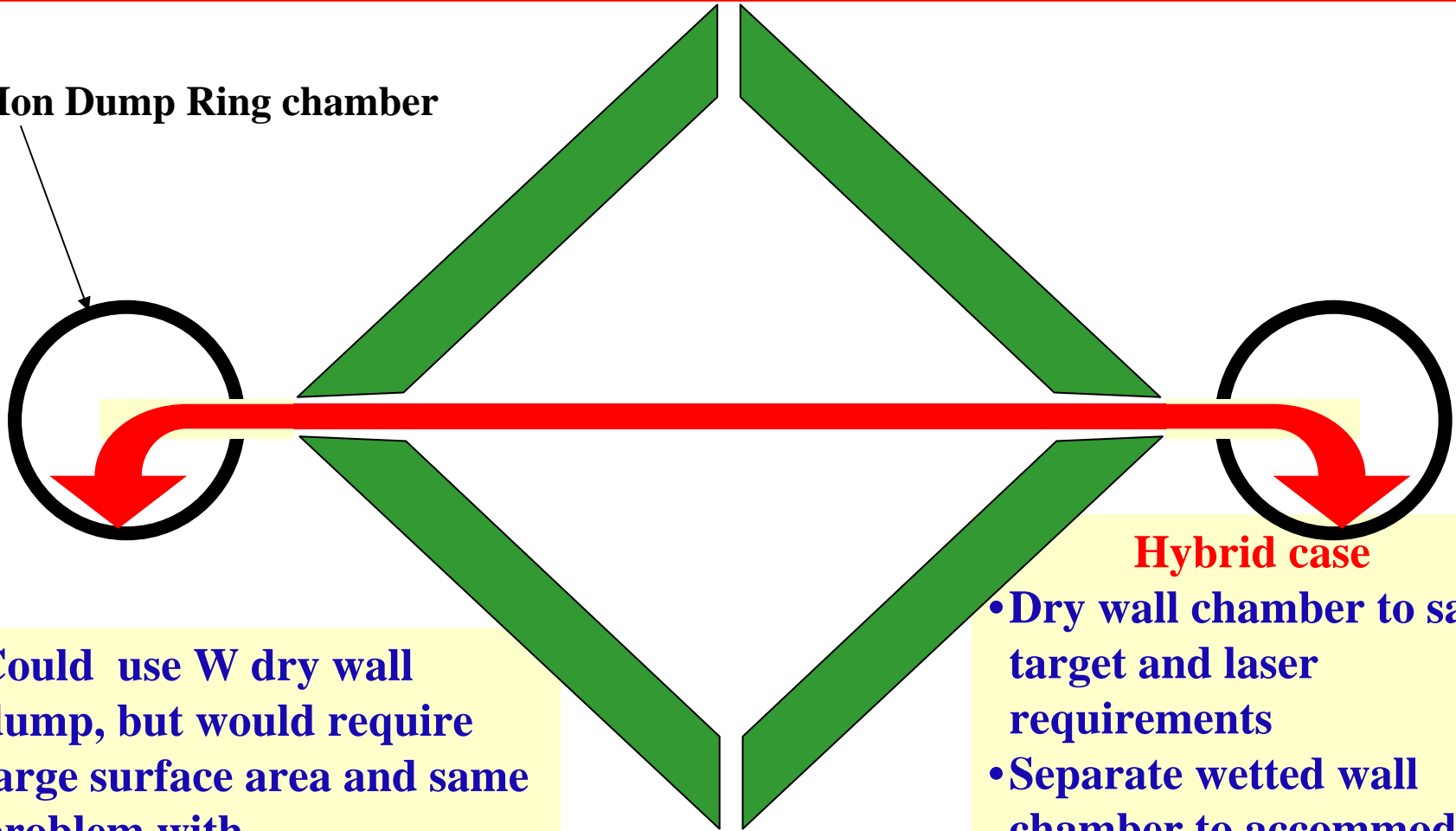


UCSD



# Seems More Advantageous to Position Dump Plate In Separate Smaller Chamber

Ion Dump Ring chamber



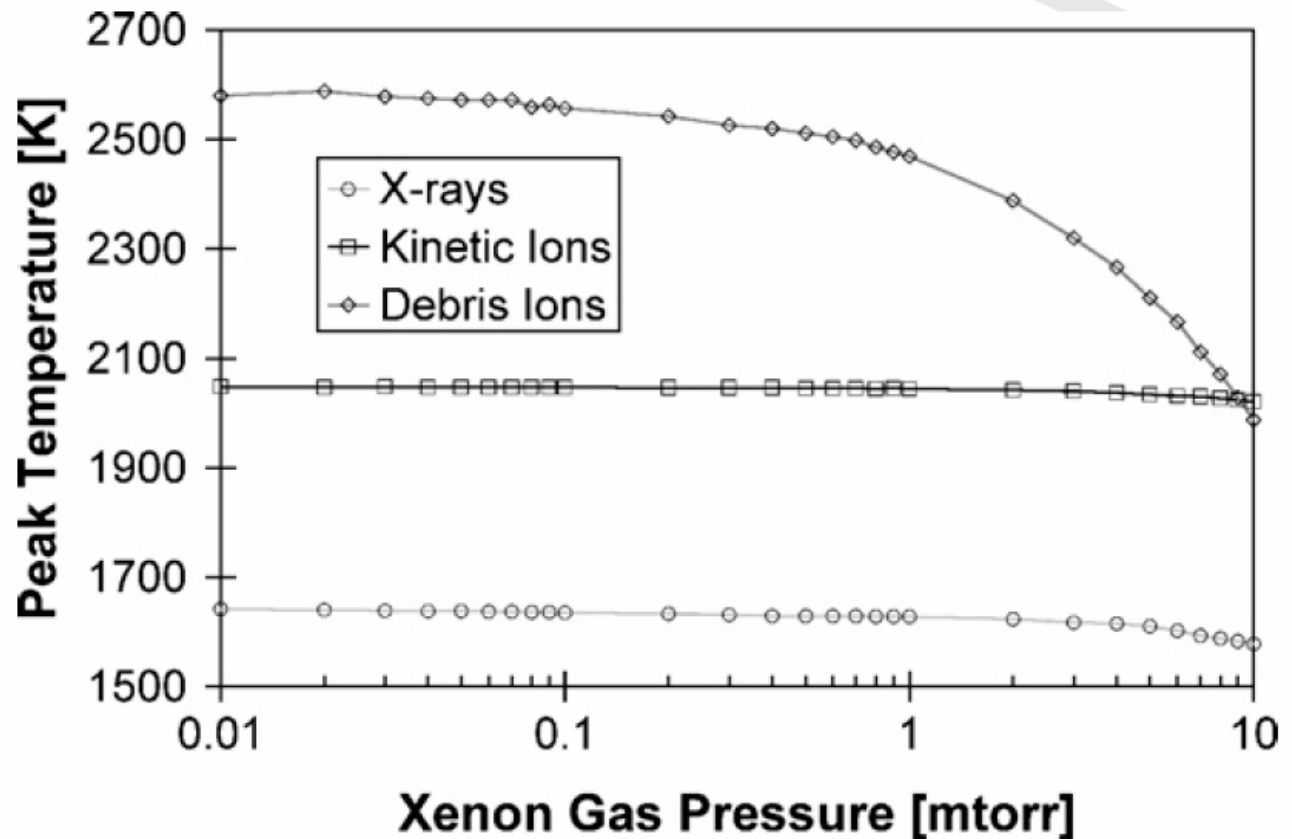
**Hybrid case**

- Could use W dry wall dump, but would require large surface area and same problem with thermomechanical response and He implantation
- Could allow melting (W or low MP material in W)

- Dry wall chamber to satisfy target and laser requirements
- Separate wetted wall chamber to accommodate ions and provide long life
- Have to make sure no unacceptable contamination of main chamber

# Gas in Chamber Can Mitigate Ion Effects

- Inert gas in chamber will slow or stop ions, preventing wall damage
- Energy in ions will re-radiate later
- Target injection is more difficult due to heating
- Laser propagation and chamber clearing are also more difficult



# Conclusions

- The HAPL program is aimed at developing Laser IFE based on a laser driver, direct drive targets and a solid wall chamber.
- The design and R&D effort in the chamber and material area is focused toward the key issues affecting the W/FS armor/FW survival under the ion and photon threat spectra.
- Armor testing shows promise, but there are still unanswered questions (He retention and thermomechanical damage)
- Magnetic diversion of ions or gas in chamber may be desirable

