Coming attractions

- This is the first of five related presentations:
  - Graphite Chamber Issues and trade-offs (Haynes)
  - CONDOR: a flock of badgers (Moses)
  - W armored ODS designs (Blanchard)
  - How UW will support HAPL 3 year plan (Kulcinski)
  - Validation of wall response models (Peterson (tomorrow))

Response of Dry Wall Graphite Chamber Designs to the Output Spectrum from a Directly Driven Laser IFE Target

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Fusion Technology Institute
University of Wisconsin

and the High Average Power Laser HAPL team

§Currently X-1, LANL

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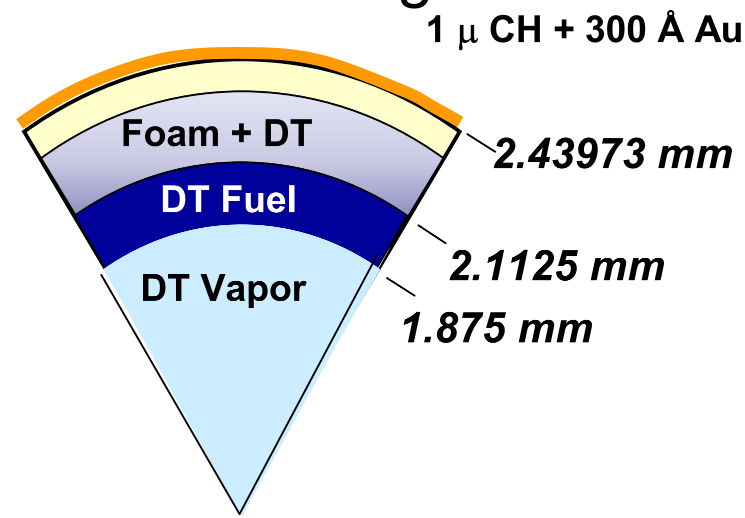
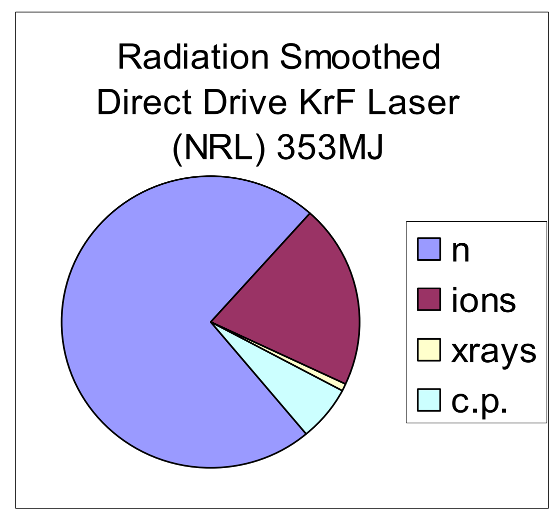
Inertial Confinement Fusion is a proven method of achieving gain.

"A joint Los Alamos/LLNL program using underground nuclear experiments, called *HALITE* at LLNL and *Centurion* at Los Alamos (collectively called H/C) demonstrated excellent performance, putting to rest fundamental questions about the feasibility of achieving high gain." (John D. Lindl, *Inertial Confinement Fusion* (AIP Press, Springer-Verlag, New York 1998) p.12)

It is, however, still to be demonstrated that the wide gap between ICF and IFE can be bridged.

Radiatively-smoothed direct drive laser target





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Chamber Physics Critical Issues Involve Target Output, Gas Behavior and First Wall Response

Target Output

Design,
Fabrication,
Output Simulations,
(Output Experiments)

X-rays,
Ion Debris,
Neutrons

Gas Behavior

Gas Opacities,
Radiation Transport,
Rad-Hydro Simulations

Thermal
Radiation,
Shock

Wall Response

Wall Properties,
Neutron Damage,
Near-Vapor Behavior,
Thermal Stresses

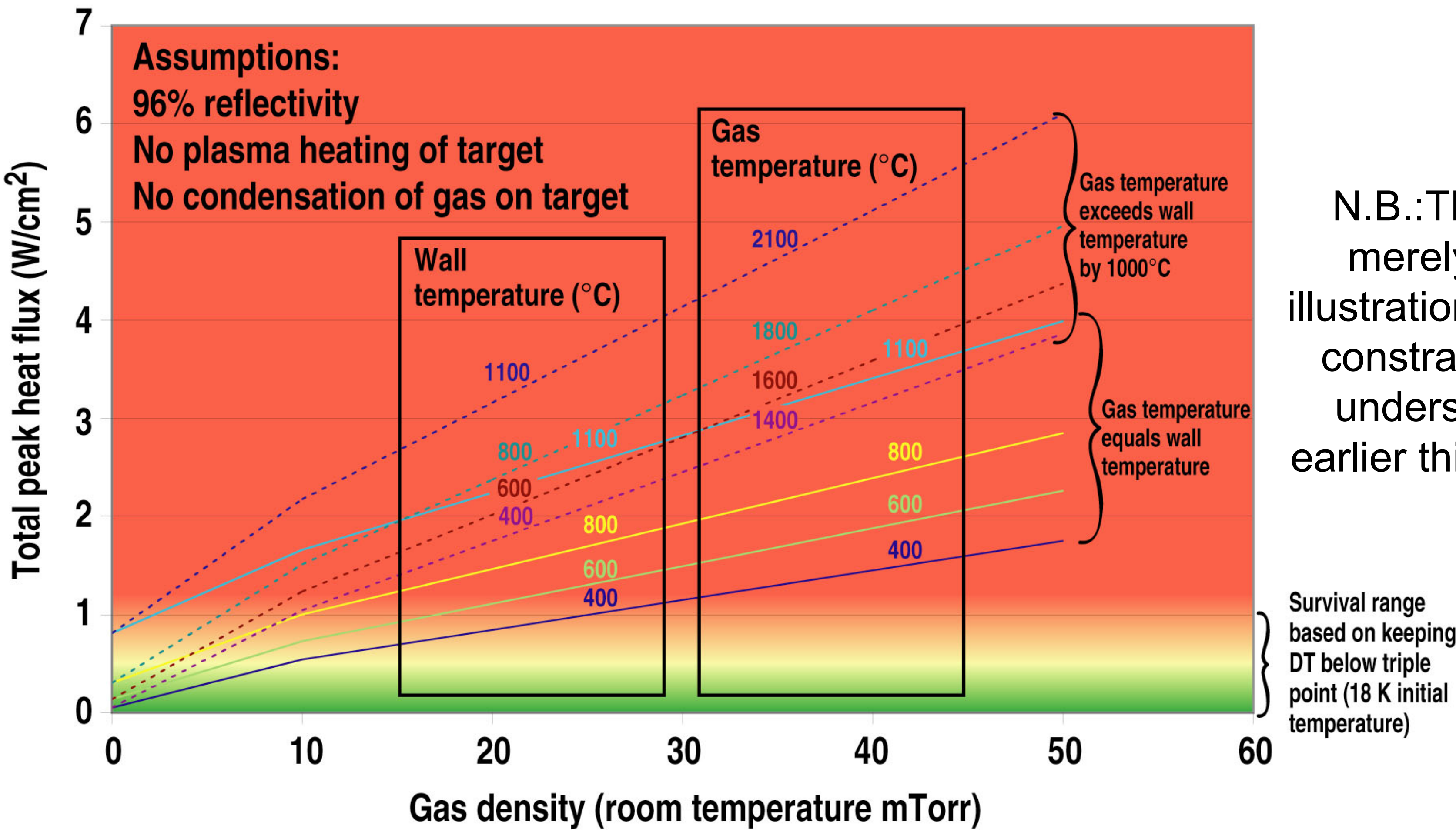
See R. R. Peterson's presentation for a report on validation experiments of material response to xrays and ions.

UW uses the BUCKY 1-D Radiation-Hydrodynamics Code to Simulate Target, Gas Behavior and Wall Response.

A successful chamber design must simultaneously satisfy many constraints.

- Target injection
  - Heating
  - Tracking
- Driver injection
- First wall survival: per shot
  - no sublimation (graphite)
  - at most brief melting (W)
- First wall survival: long term
  - accumulation of ions
  - repeated thermomechanical stresses

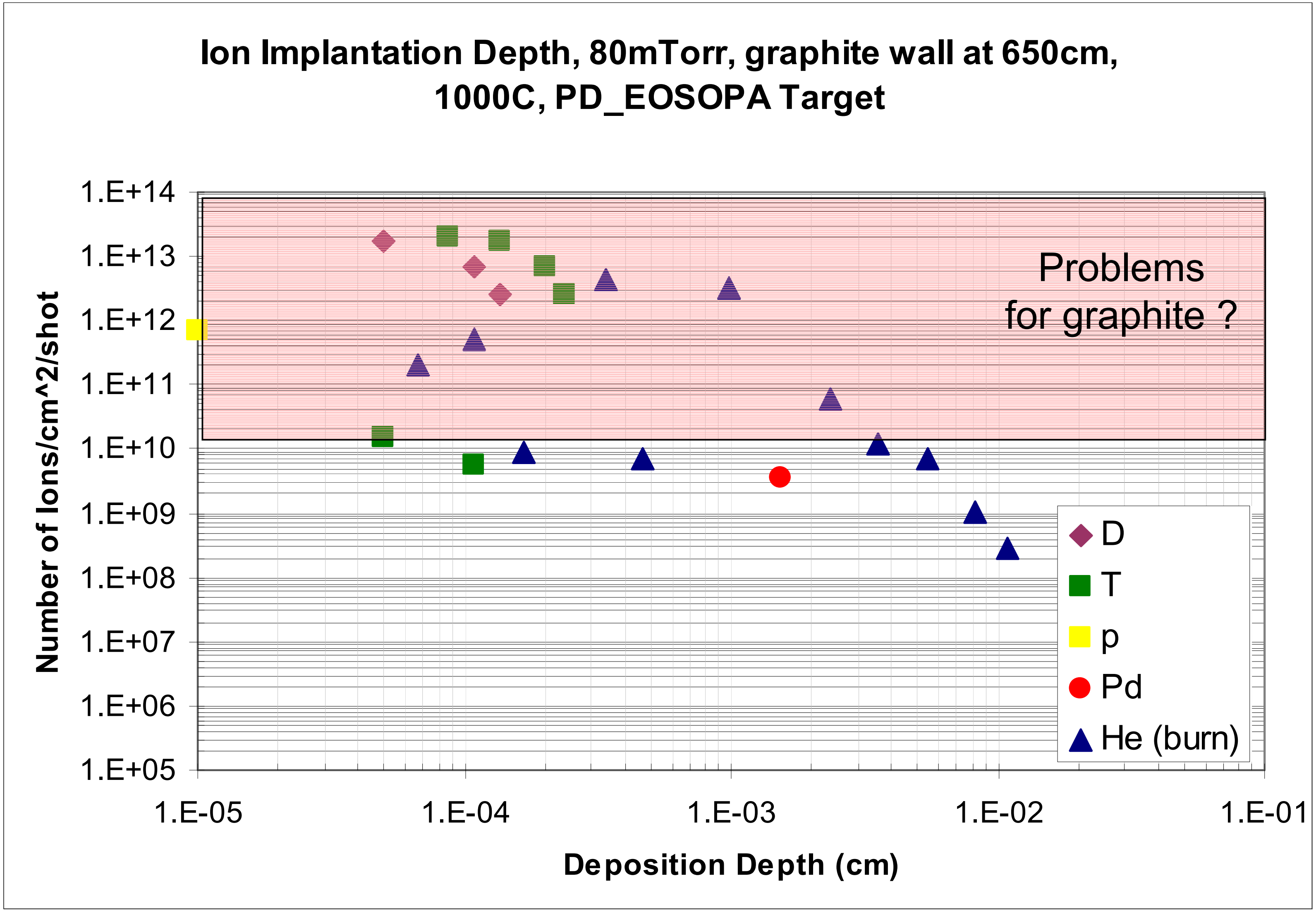
General Atomics and UCSD are working to establish constraints on Xe density from target survival requirements.



N.B.:This is merely an illustration of the constraint as understood earlier this year.

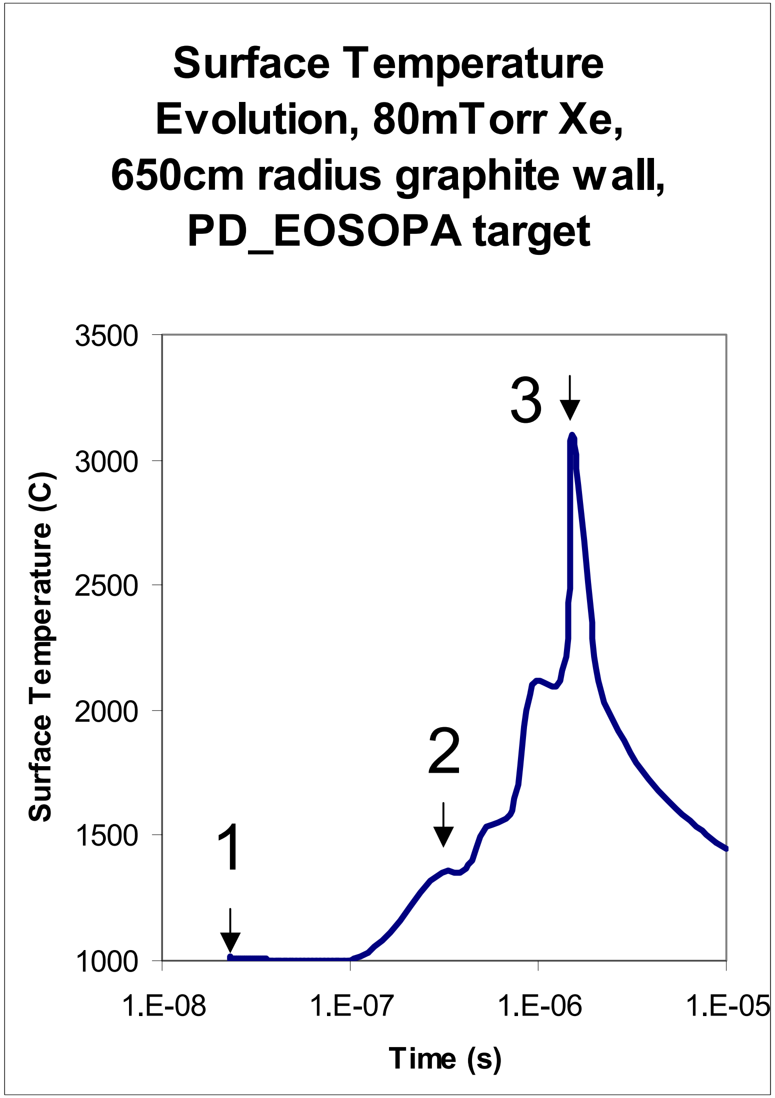
*R.W. Petzoldt, D.T. Goodin, A. Nikroo, E. Stephens, N. Siegel, N.B. Alexander, A. R. Raffray, T.K. Mau, M. Tillack, F. Najmabadi, S. I. Krasheninnikov, R. Gallix, Direct drive target survival during injection in an inertial fusion energy power plant, Accepted for publication in Nuclear Fusion, Manuscript No. 7282 (2002).

At the threshold Xe density for vaporization of a graphite wall at 650cm from the PD_EOSOPA target (80mTorr), ion deposition depth varies from 0.1 to 100 microns.



BUCKY simulations of chamber response allow the prediction of first wall surface temperature evolution.

- Roughly speaking, there are three peaks in the first wall temperature:
  1) A response to the prompt, unattenuated x-rays hitting the wall (heating it practically volumetrically, in the case of a graphite first wall).
  2) Response to soft xrays re-radiated after the Xe slows and captures the least penetrating ions.
  3) Bursts of temperature rise as the unstopped ions strike the wall. This effect is somewhat exaggerated in these simulations due to the coarse binning of the ion spectum.



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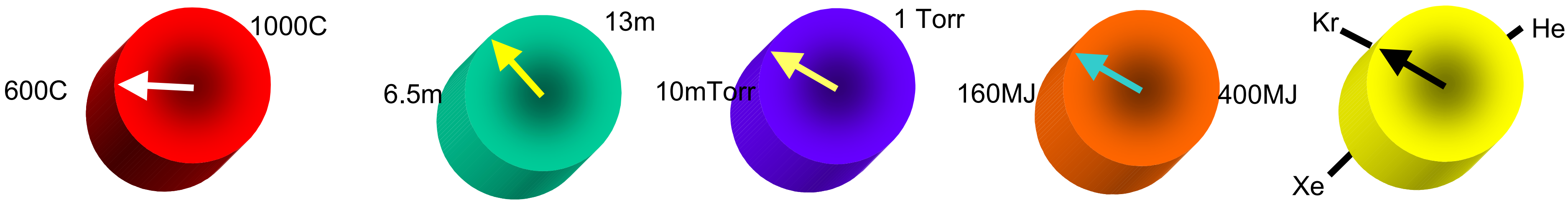
For a fixed target output, there are several parameters which can be simultaneously varied to obtain a successful chamber design

Initial Temperature	Chamber Radius	Xe Density	Yield	Gas



Initial Temperature	Chamber Radius	Xe Density	Yield
•354MJ	•354MJ	•354MJ	•173.5MJ
•25mTorr	•25mTorr	•80mTorr	•25mTorr
•600C	•1000C	•1000C	•1000C
•6.5m	•8.1m	•6.5m	•6.5m
•372 g/shot	•0 g/shot	•0 g/shot	•0 g/shot

Gas:

•Kr requires ~10% more density to achieve same protection as Xe.

•He requires ~1000% more density to achieve same protection as Xe.

•Molecular gases are under consideration.

N.B.-None of these knobs will strongly effect the number of ions getting implanted in the wall. Yield variation is approximated here by varying ion flux, not energy spectrum. In this approximation, ion implantation dominated lifetime is inversely proportional to yield.

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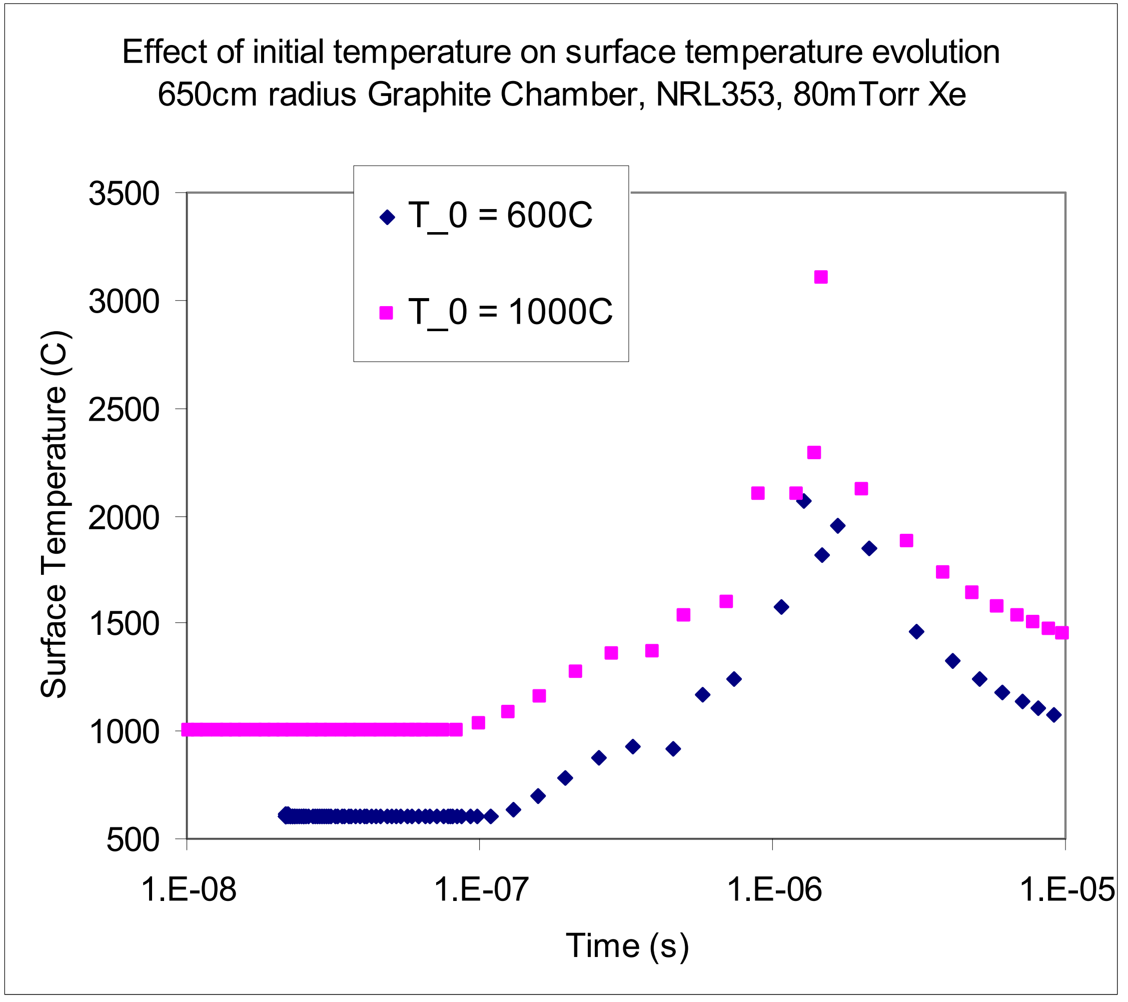
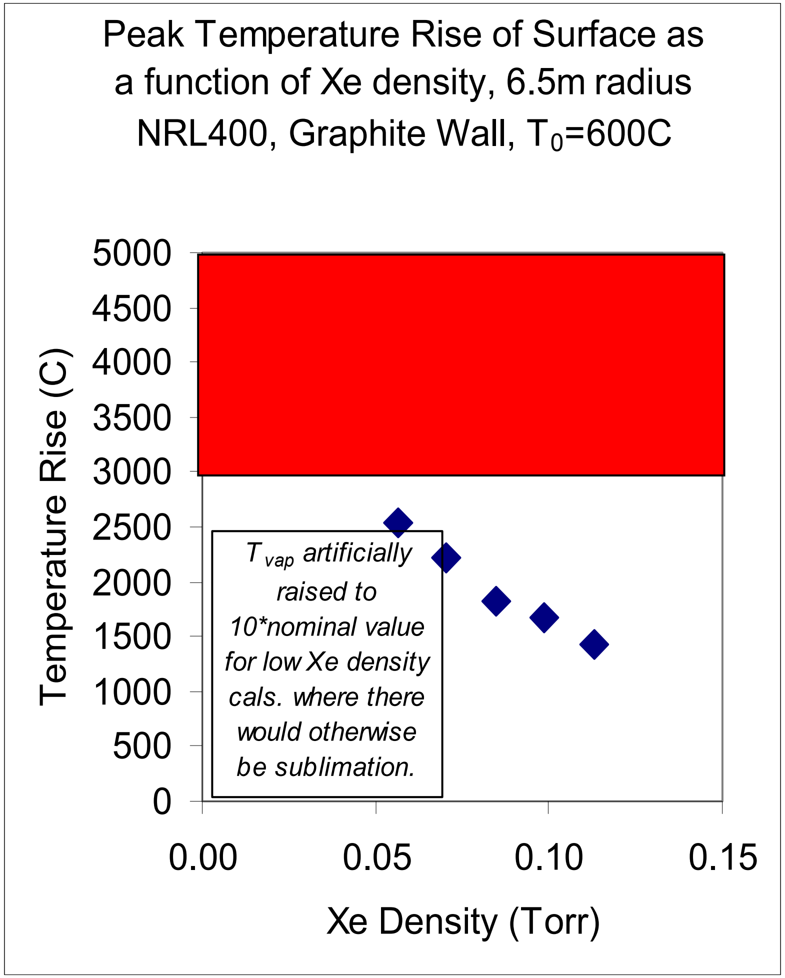
To a very close approximation, temperature rise is independent of initial temperature.

- The small differences arise from the temperature dependence of the thermal conductivity and the heat capacity.
- The output is discretized according to cycle.



Decreasing the Xe density leads to increased temperature rise at the surface of the first wall.

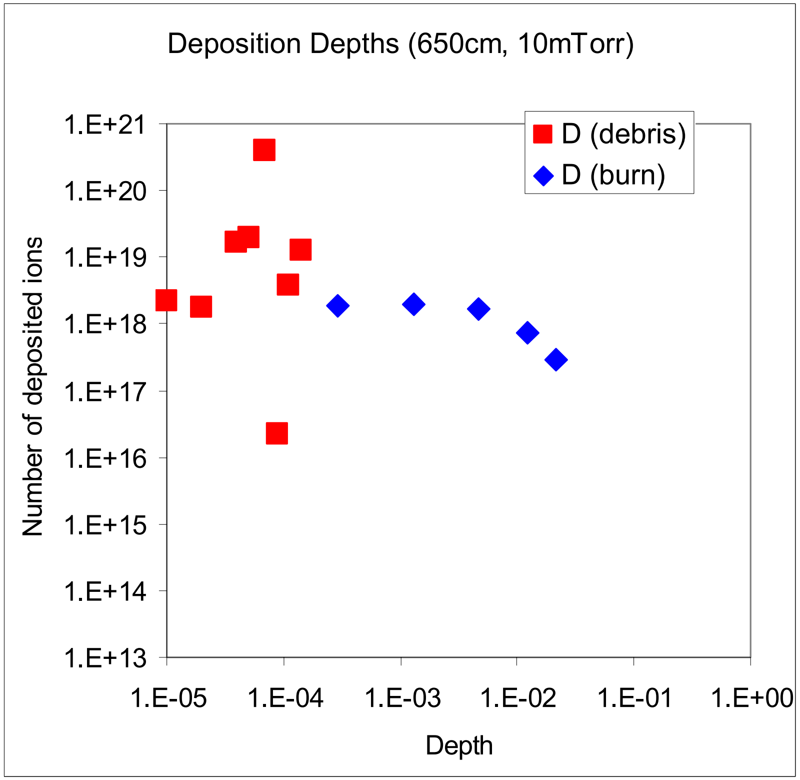
- For a 6.5m radius graphite chamber, lowering the wall temperature all the way to 600C does not lead to an acceptable design in terms of wall survival.
- Note: we deliberately use a conservative 15 bin coarse ion spectrum for both the low and high yield targets.



The effects of varying chamber radius have been studied for a lower (154MJ) yield version of this target at 10mTorr Xe. The partitioning and spectra of the threat are close to that of the higher yield target.

Energy deposition (in MJ) as a function of radius and threat component

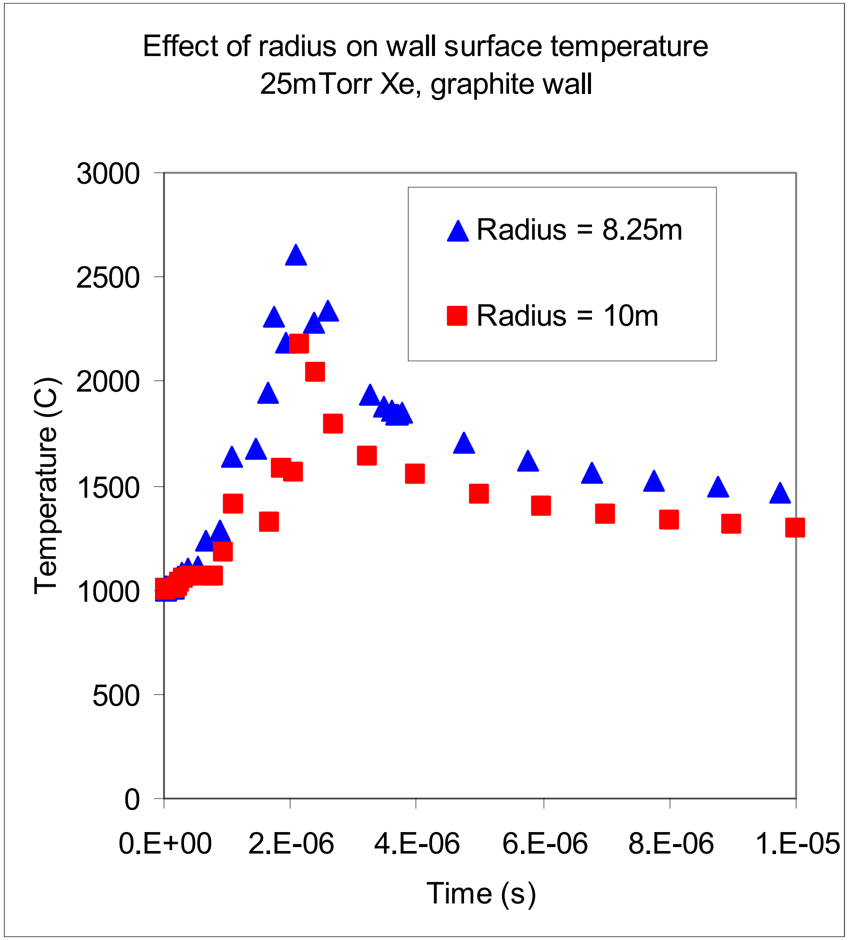
	X-rays		Burn Ions		Debris Ions	
	Gas	Wall	Gas	Wall	Gas	Wall
550cm	0.19	2.14	0.18	17.6	6.73	18.41
600cm	0.20	2.12	0.19	17.5	7.07	18.06
650cm	0.22	2.11	0.20	17.9	7.43	18.14



The debris ions are potentially the most immediately threatening, as they penetrate shallowly.

The effect of increased chamber radius aids chamber survival at the cost of pre-shot time spent in the chamber

- Two advantages are gained:
  - Increased surface area
  - Increased time of flight spreading
- Two disadvantages are increased:
  - Target heating during injection
  - Target tracking
- Radius increasing ad absurdum: Towards the “big dumb chamber”?



Alternate protective gases such as He have been considered. He, with only two electrons, is a very poor alternative on a per atom basis.

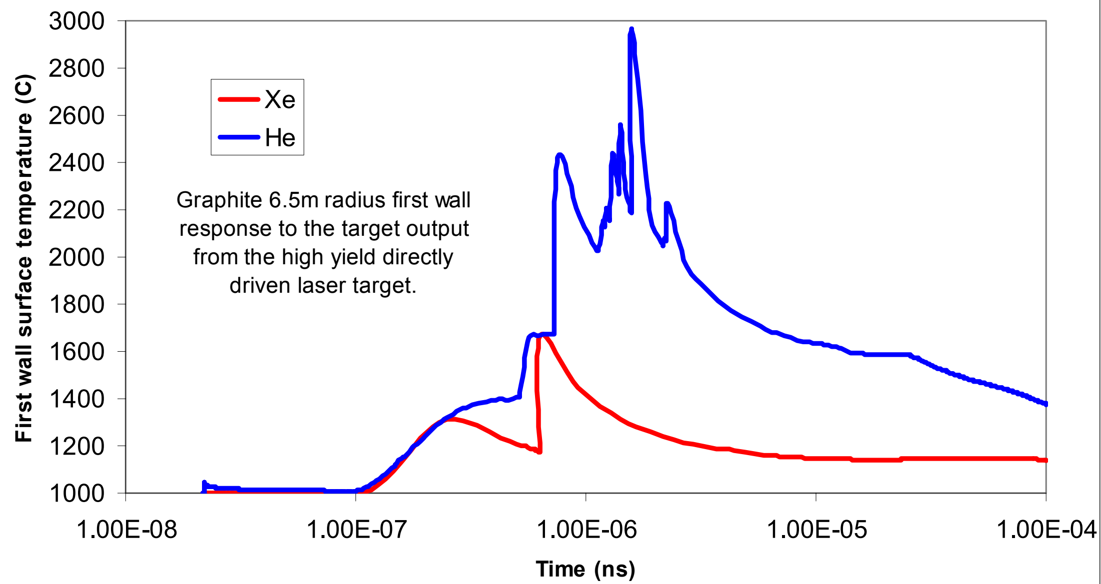
- 80mTorr of Xe (not 25mTorr) is required to prevent first wall vaporization for a graphite wall at 6.5m from the threat of the high yield directly driven laser IFE target.
- 883mTorr of He is required to afford similar protection.
- Neither amount prevents the possibly deleterious implantation of H and He burn products.

He does have some attractive characteristics, *e.g.*:

- Very low non-linear index of refraction.
- Simple EOS/opacity calculation
- No cryo-plating on target.

Unbound electrons dominate ion stopping

He provides substantially less first wall protection than does Xe for a given density (883mTorr) of gas



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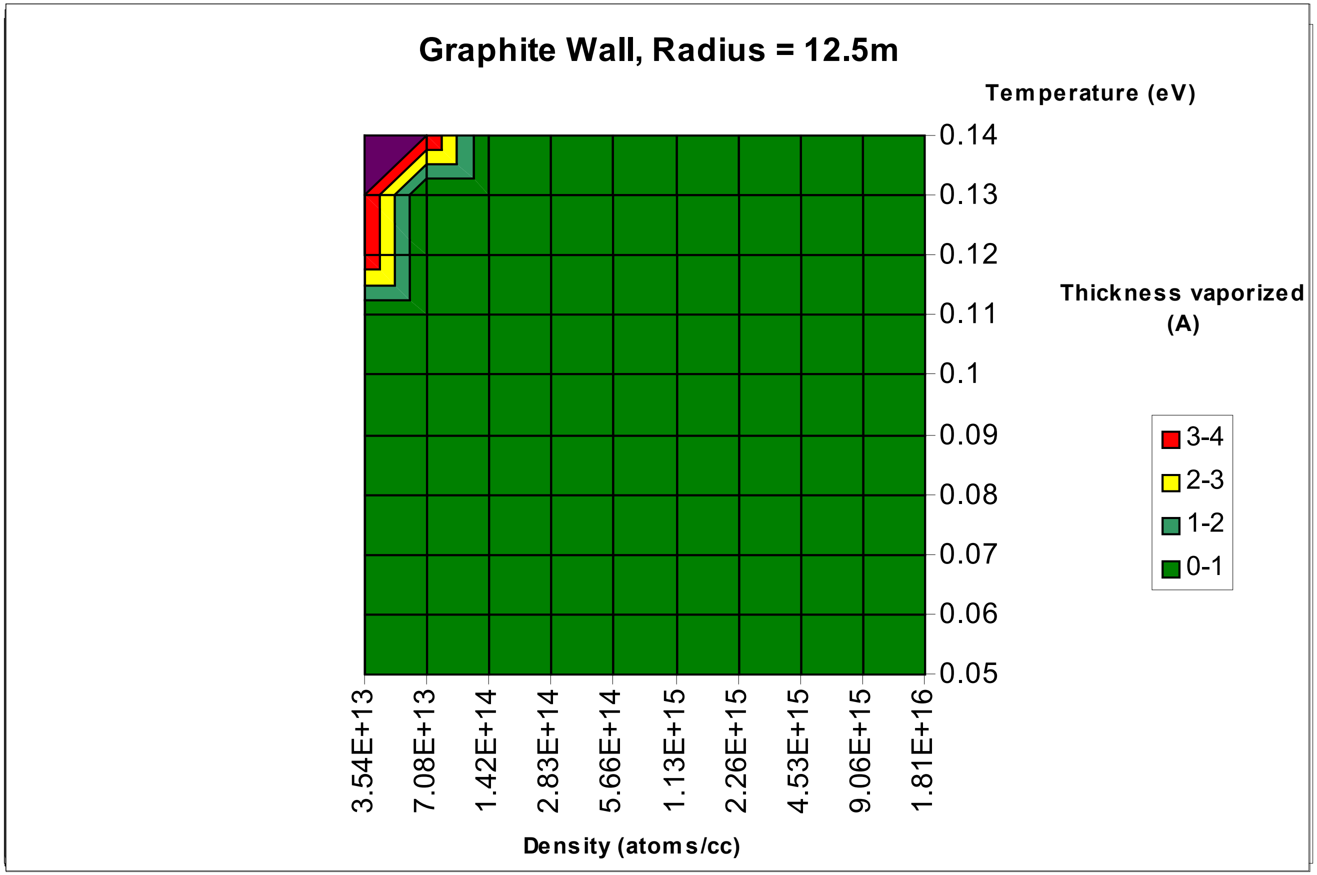
A scan through radius, temperature, **and** density space has defined the per shot evaporation operating window for graphite chambers and the high yield target.



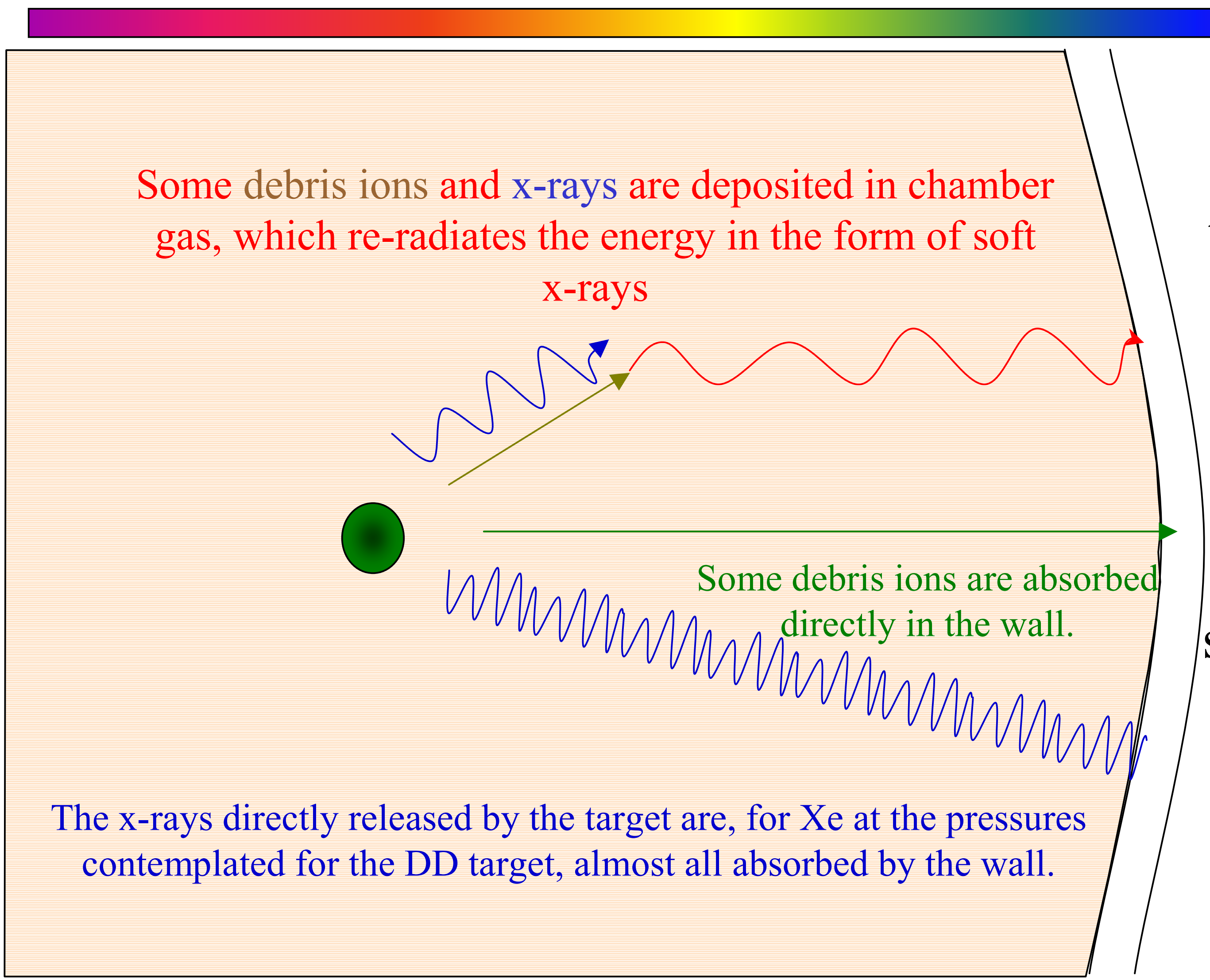
These 900 results were produced over a weekend.

Conclusions

- 80mTorr of Xe (not 25mTorr) is required to prevent first wall vaporization for a graphite wall at 6.5m from the threat of the high yield radiatively smoothed target from NRL.
- This combination of Xe density and chamber radius is not acceptable from the point of view of target survival during injection.
- Increasing the chamber radius above 8m and keeping the Xe fixed at 25mTorr avoids vaporization, and would be on the margin of acceptable target heating if the afterglow problem can be solved.
- Because ion energy deposition in the chamber plasma depends strongly on electron density, the buffer gas should have many electrons per particle which contributes to target heating. Thus, He is a poor choice from this point of view.
- Ion implantation occurs up to remarkably high densities, with the He4 from the burn of the target requiring the most gas to prevent implantation.
- For the high yield target considered, a workable graphite wall design seems near at hand, by increasing the radius slightly and decreasing the target yield slightly.

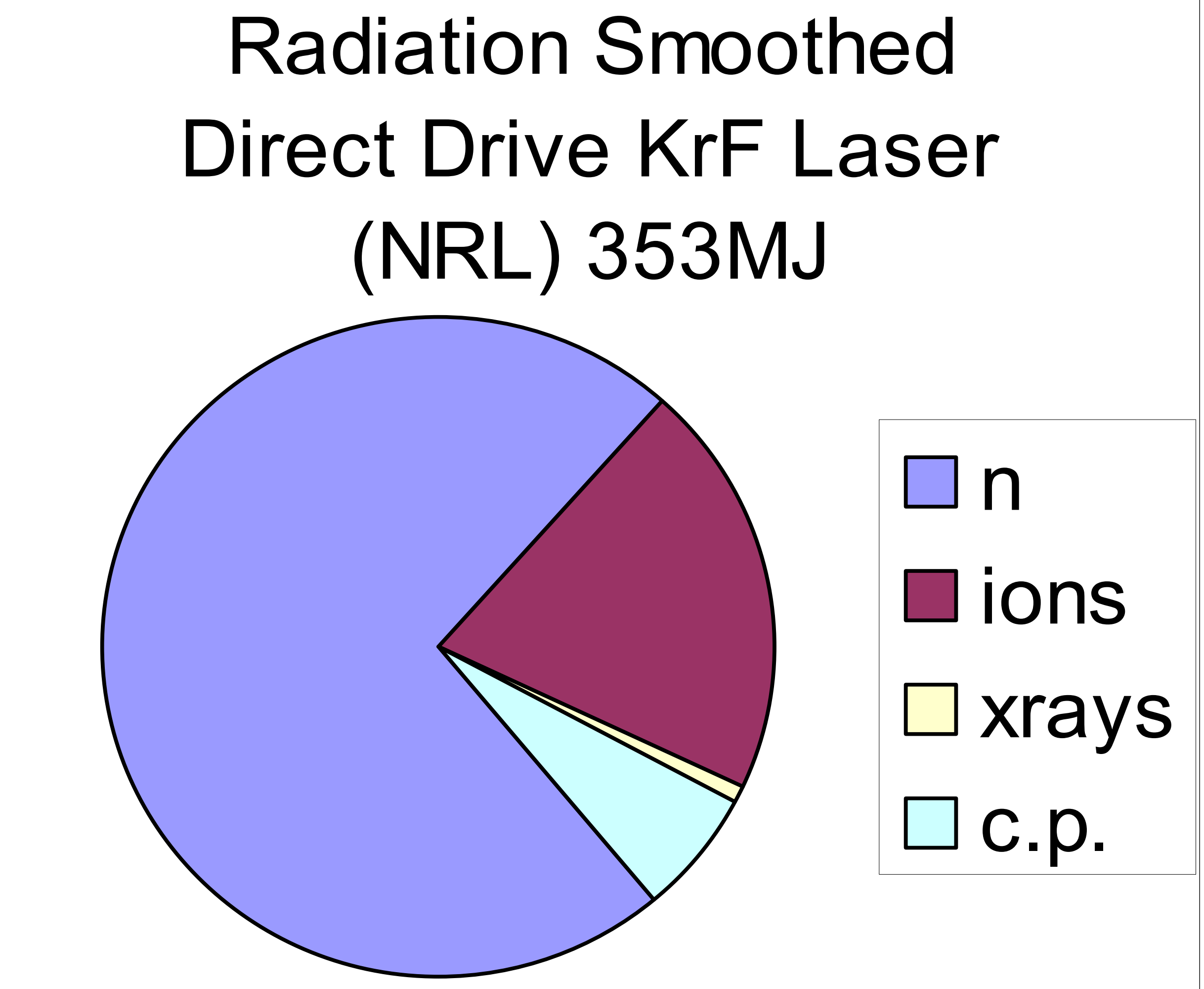
BACKUP SLIDES

The threat spectrum can be thought of as arising from three contributions: fast x-rays, unstopped ions, and re-radiated x-rays



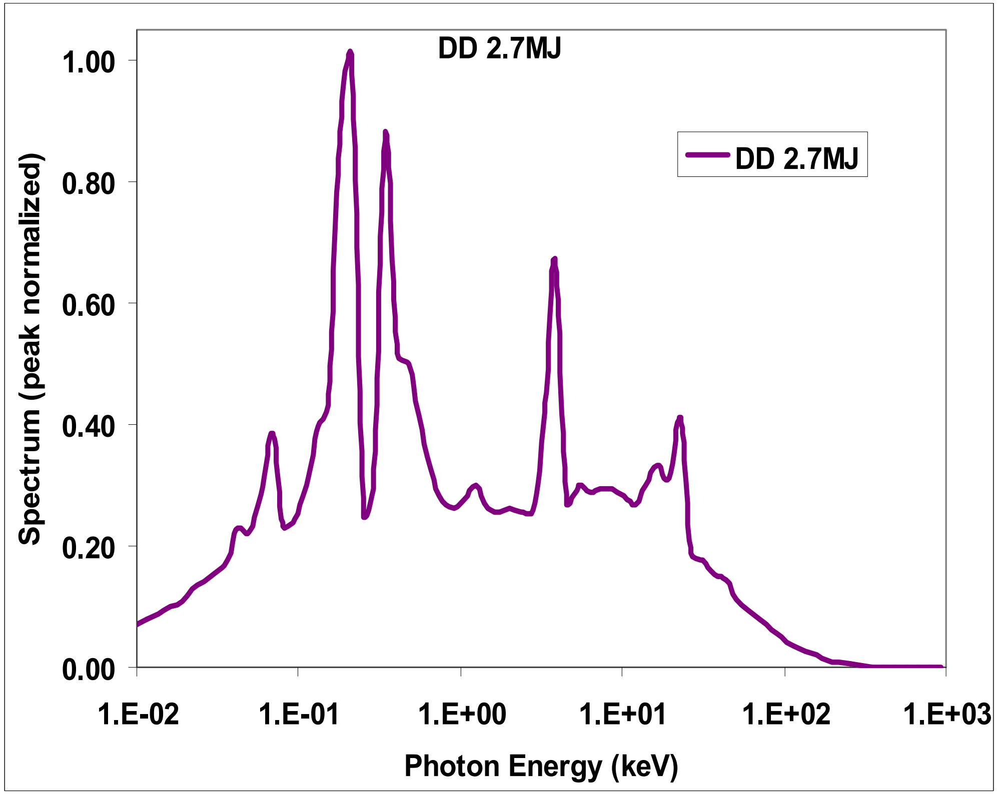
The wall (or armor) reacts to these insults in a manner determined by it's material properties (X-ray and ion stopping lengths, thermal conductivities and heat capacity)

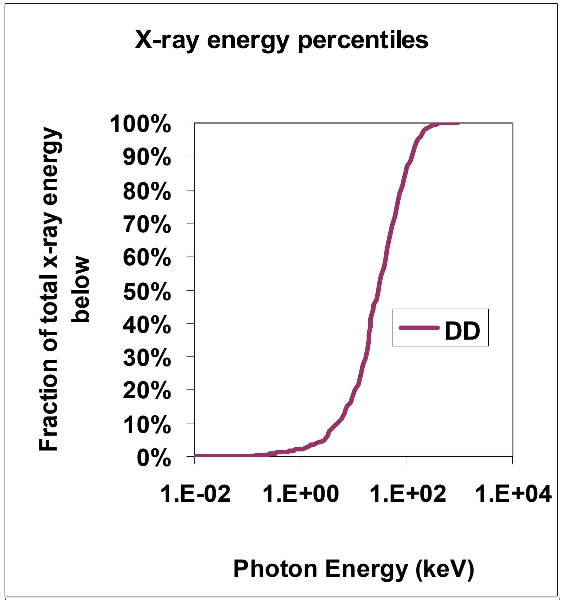
Chamber Design is Driven by Target Output

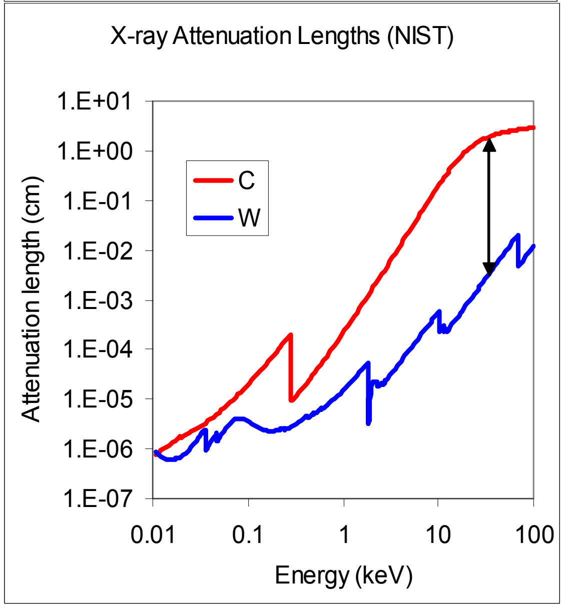


Output spectrum from R. R. Peterson, UW

The x-ray component of this directly driven target is fairly benign: only 2.7MJ, and mostly above 30keV.







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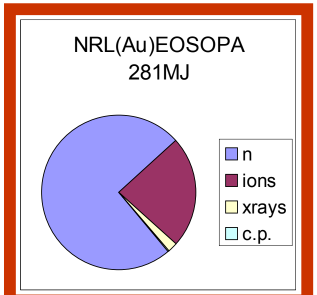
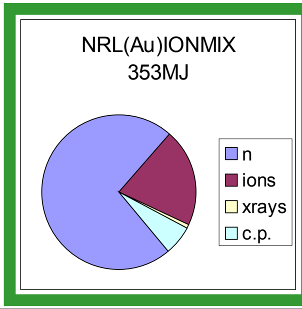
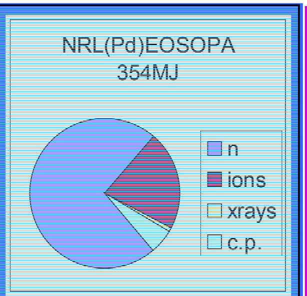
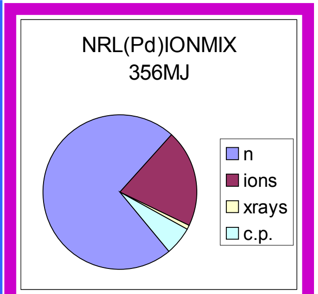
Three of the four BUCKY results, and Perkin's calculation, all show a that significant fraction of the ion threat comes from He4 fusion products..

Results from RRP, last meeting





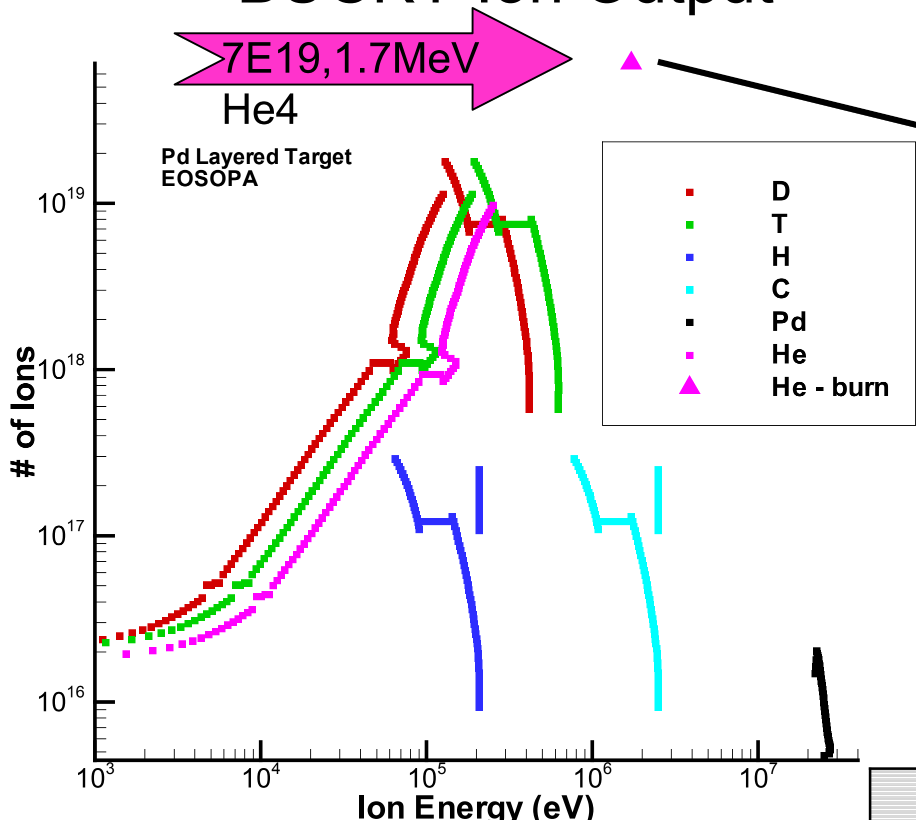




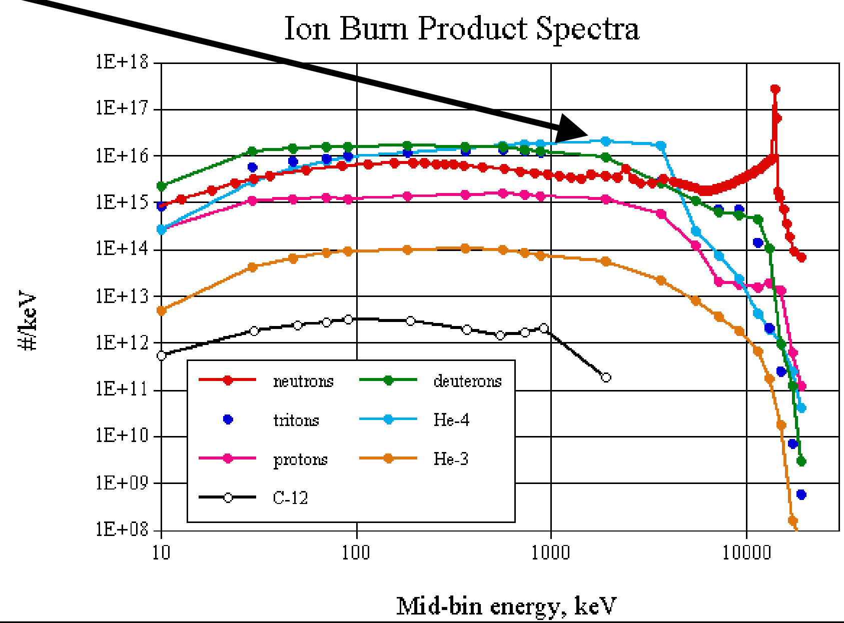
	Au EOSOPA	Au IONMIX	Pd EOSOPA	Pd IONMIX
Yield (MJ)	281.1 (99.0 %)	353.1 (99.2 %)	353.7 (99.2 %)	355.7 (99.2 %)
Neutron (MJ)	209.6 (73.8 %)	257.0 (72.2 %)	256.7 (72.0 %)	260.1 (72.5 %)
X-ray (MJ)	4.94 (1.74 %)	2.66 (0.75 %)	2.68 (0.75 %)	2.71 (0.76 %)
Target Debris (MJ)	68.4 (24.8 %)	74.6 (21.0 %)	78.1 (21.9 %)	68.4 (19.1 %)
Charged Fusion Product (MJ)	1.08 (0.38 %)	21.7 (6.1%)	19.1 (5.4 %)	20.9 (5.8 %)

The dominant threat to first wall survival arising from this target are the ions.

BUCKY Ion Output



LASNEX Burn Ion Output



Ion	#	Total Energy (MJ)	Average Energy (keV)	Energy/amu (keV)	q/m
He4 (debris)	2.2E20	6	179	45	0.5
He4 (burn)	6.9E19	19.1	1700	425	0.5
Pd	6.1E17	2.6	27000	255	0.43
T	8.9E20	39	275	92	0.33
D	8.9E20	26	183	92	0.5
p	1.4E19	0.3	135	135	1
C	1.4E19	3.7	135	11.25	0.5

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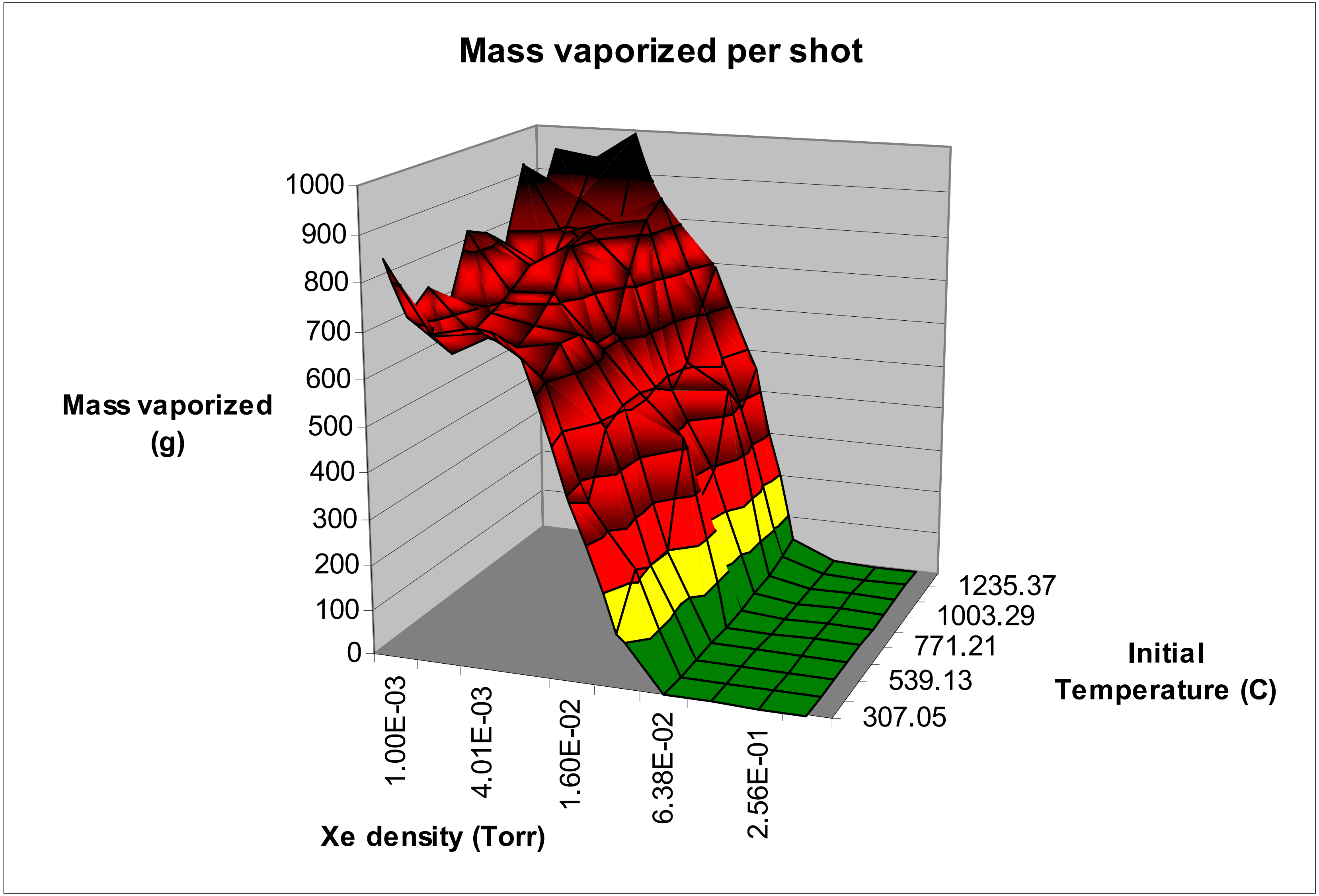
BUCKY is a Flexible 1-D Lagrangian Radiation-Hydrodynamics Code: Used to model implosion, burn, target output, blast wave propagation, and first wall heating, vaporization and re-condensation

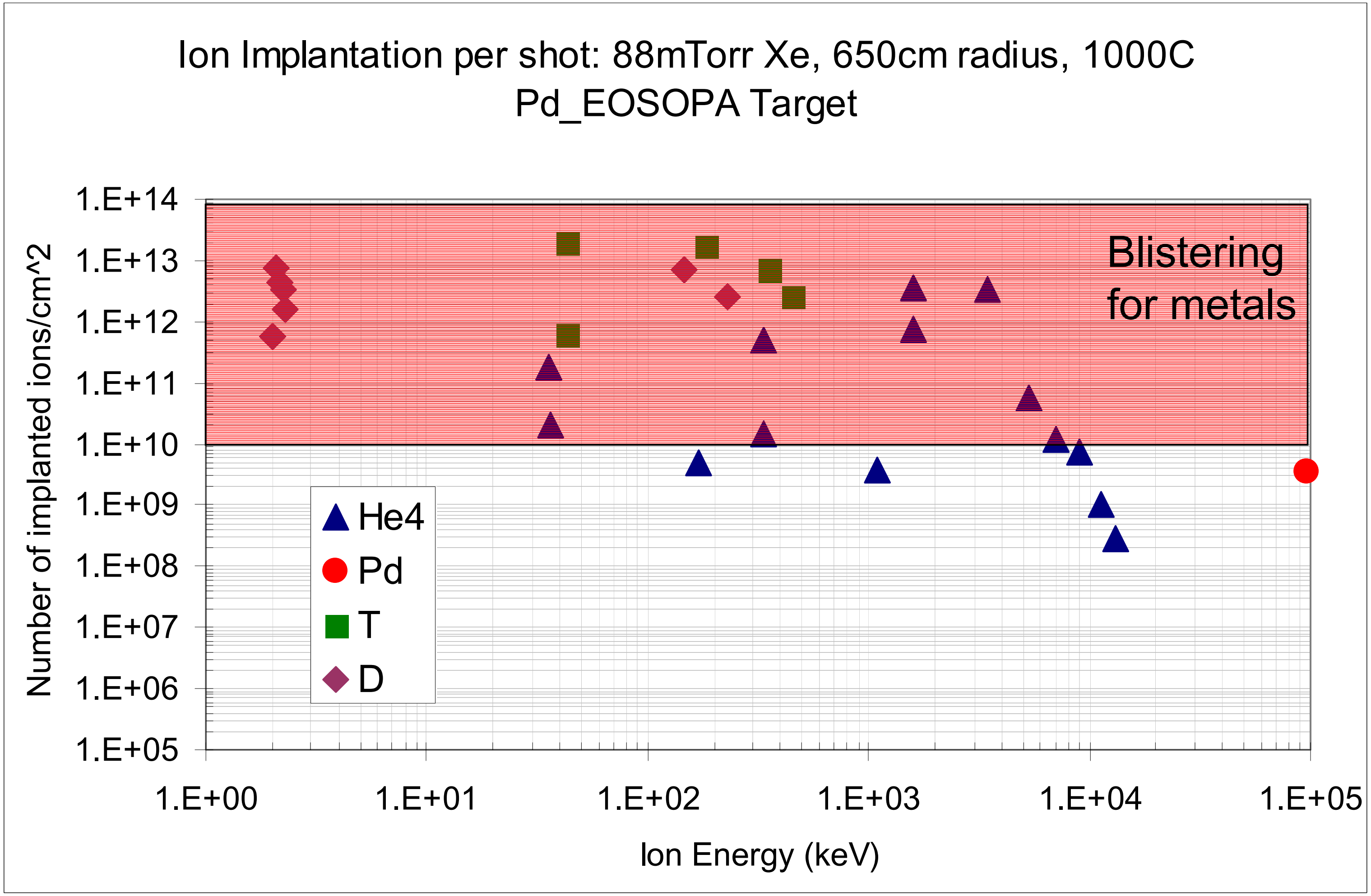
- 1-D Lagrangian MHD (spherical, cylindrical or slab).
- Thermal conduction with diffusion.
- Applied electrical current with magnetic field and pressure calculation.
- Radiation transport with multi-group flux-limited diffusion, method of short characteristics, and variable Eddington.
- Non-LTE CRE line transport.
- Opacities and equations of state from EOSOPA, IONMIX or SESAME.
- Equilibrium electrical conductivities
- Thermonuclear burn (DT,DD,DHe^3) with in-flight reactions.
- Fusion product transport; time-dependent charged particle tracking, neutron energy deposition.
- Applied energy sources: time and energy dependent ions, electrons, x-rays and lasers with recently introduced ray tracing package.
- Moderate energy density physics: melting, vaporization, and thermal conduction in solids and liquids.
- Benchmarking: x-ray burn-through and shock experiments on Nova and Omega, x-ray vaporization, RHEPP melting and vaporization, PBFA-II K_α emission, …
- Platforms: UNIX, PC, MAC

To quickly scan through parameter space, a cycle sharing CONDOR flock has been used at UW-CAE



CONDOR implementation by Milad Fatenejad, details and refinement to be presented at upcoming HAPL meeting.

At a Xe density sufficient to prevent first wall vaporization (graphite, 6.5m, 1000C), Pd, He, T, and D ions implant in the wall.



5Hz = 1.8E4/hr, 4.32E5/day, 1.3E7/month, 1.6E8/year

Different ions range out at different Xe densities.