# First Wall Studies for Dry Wall IFE Chambers

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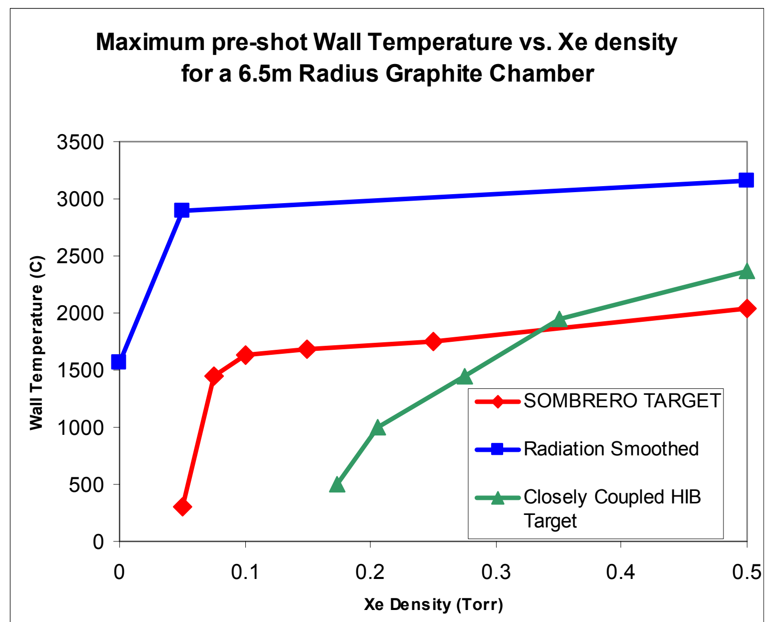


*Presented at the American Physical Society's Division of Plasma Physics Meeting, Long Beach, CA, 29 October 2001.*

# Abstract


- Every implosion of an IFE target produces a threat spectrum of x-rays and ions. For the multiple-Hz rate at which targets would be imploded in current proposed reactor designs, the first wall of a dry wall reactor must survive each shot with no evaporation. We explore several criteria for first wall survivability for several proposed IFE targets. These criteria include buffer gas composition and opacity modeling; first wall material, operating temperature, and radius; and target output, including output from a 160MJ directly driven radiatively pre-heated target proposed by NRL and a 400 MJ indirectly driven HIB target proposed by LLNL.

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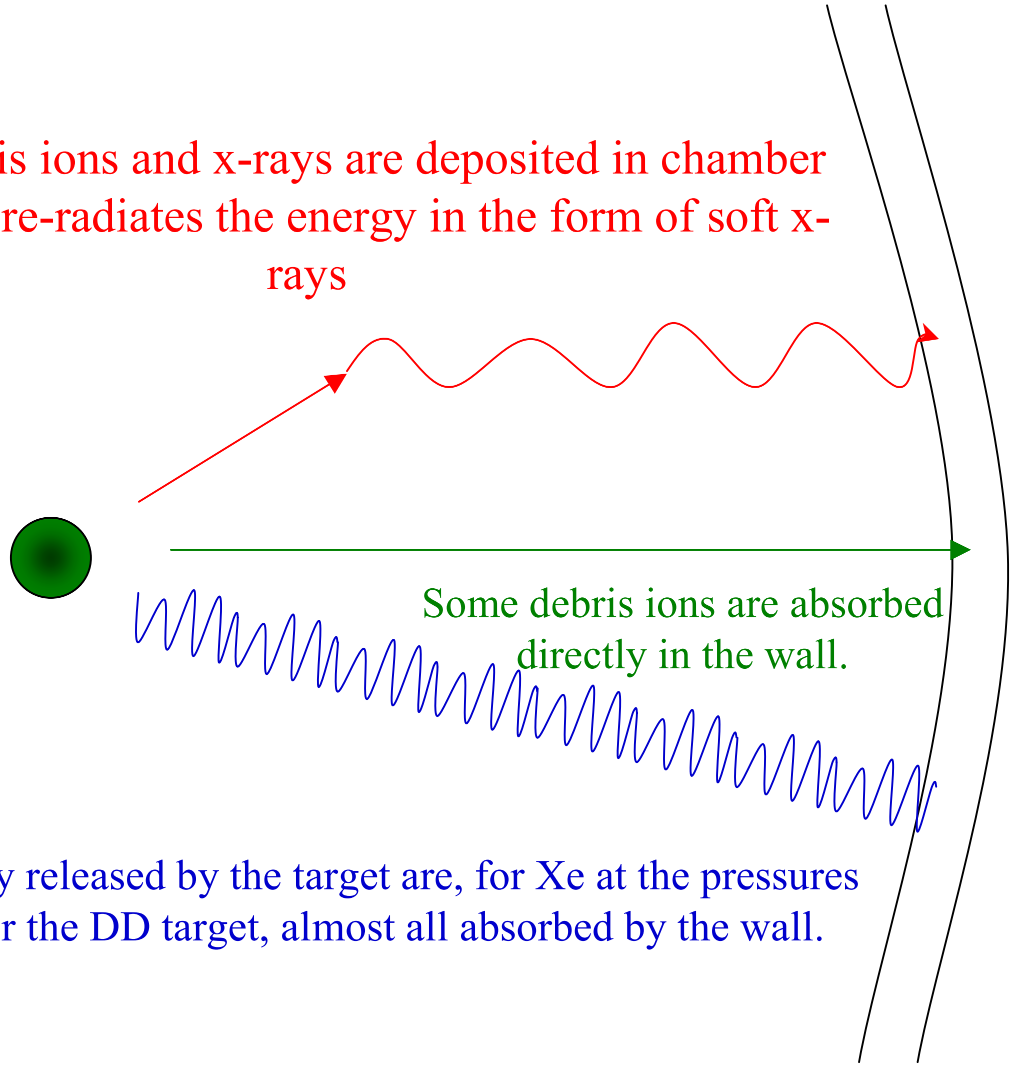
# The threat spectrum can be thought of as arising from three contributions: fast x-rays, unstopped ions, and re-radiated x-rays

Some debris ions and x-rays are deposited in chamber gas, which re-radiates the energy in the form of soft x-rays

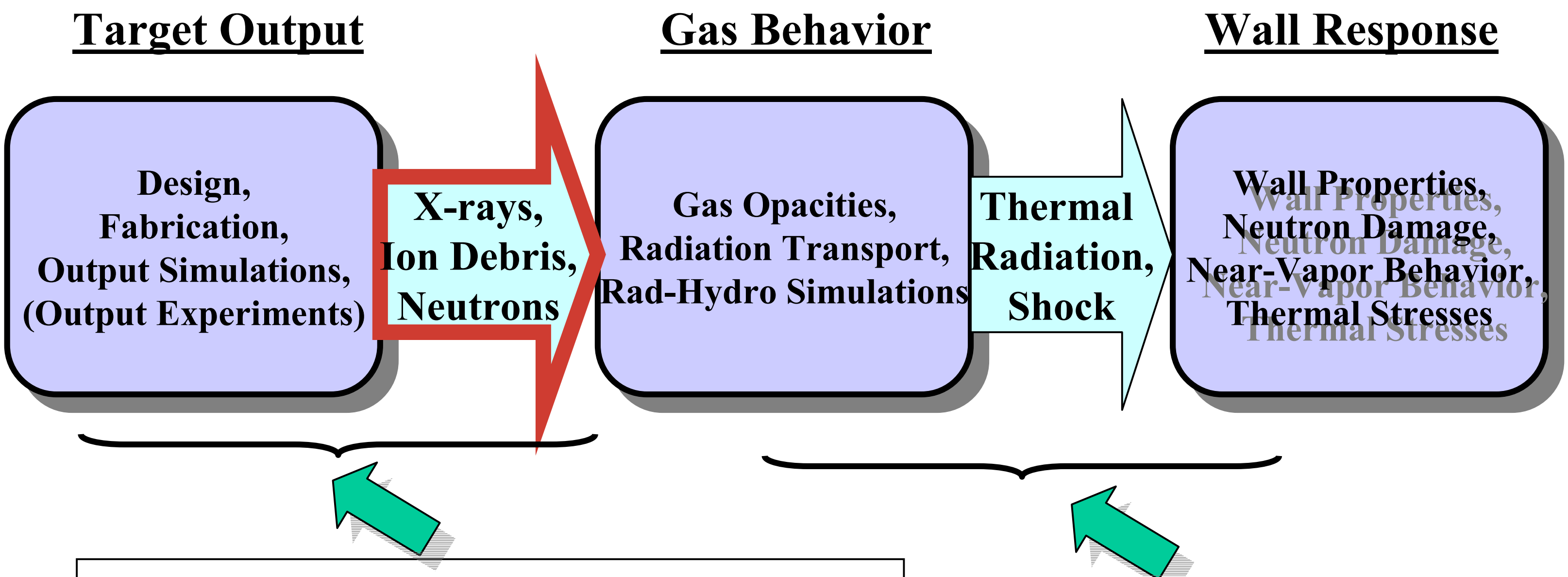


Some debris ions are absorbed directly in the wall.

The x-rays directly released by the target are, for Xe at the pressures contemplated for the DD target, almost all absorbed by the wall.

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




Please see Golovkin's poster (this session), and Peterson's talk (this afternoon) for details of BUCKY target implosion and output simulations.

This poster.

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

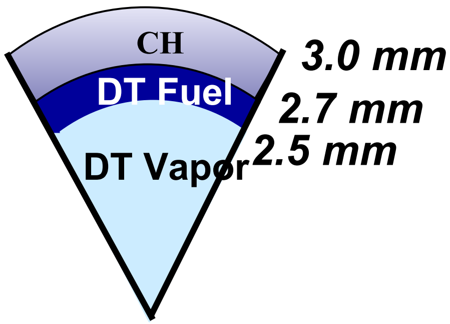
# BUCKY is a Flexible 1-D Lagrangian Radiation-Hydrodynamics Code: Used to model implosion, burn, target output, blast wave propagation, and first wall heating, vaporization and re-condensation

- 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 $K_\alpha$ emission, …
- Platforms: UNIX, PC, MAC

# Several IFE targets have been proposed and their wall threats assessed

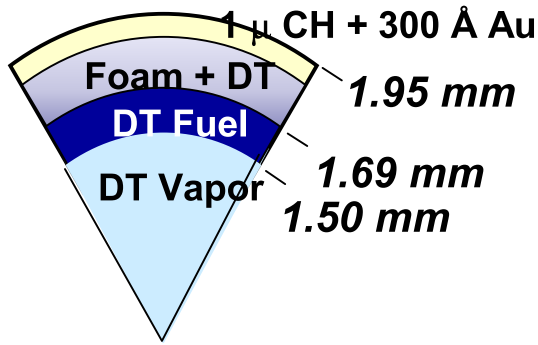
**Direct-drive Laser Targets**

**SOMBRERO (1990)**
Standard Direct-Drive



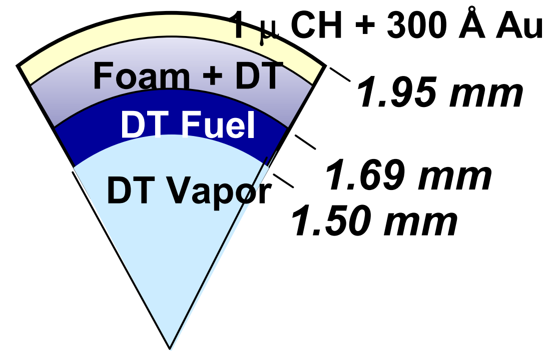

Laser Energy: 4 MJ
Laser Type: KrF
Gain: 100
Yield: ~400 MJ

**NRL (1999)**
Radiation Tailored-Wetted Foam



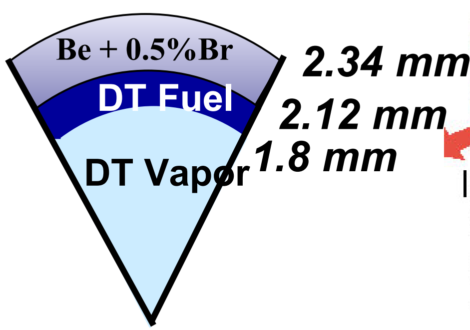

Laser Energy: 1.3 MJ
Laser Type: KrF
Gain: 127
Yield: 165 MJ

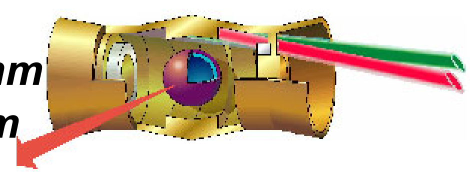
**NRL (1999)**
Radiation Tailored-Wetted Foam




Laser Energy: 2.9 MJ
Laser Type: KrF
Gain: 135
Yield: ~400 MJ

**HIB Target**

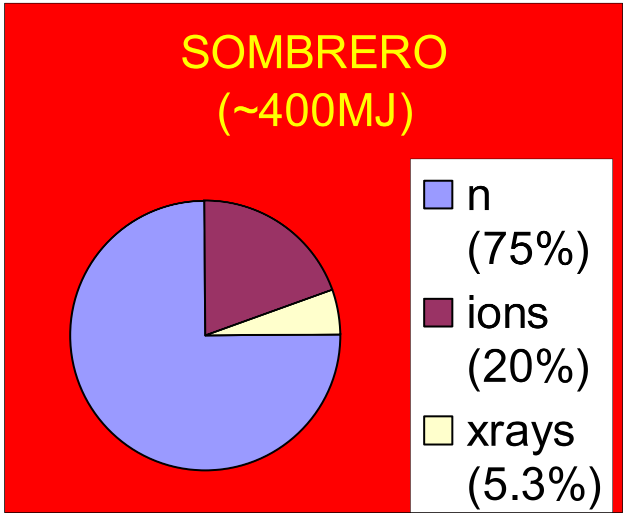


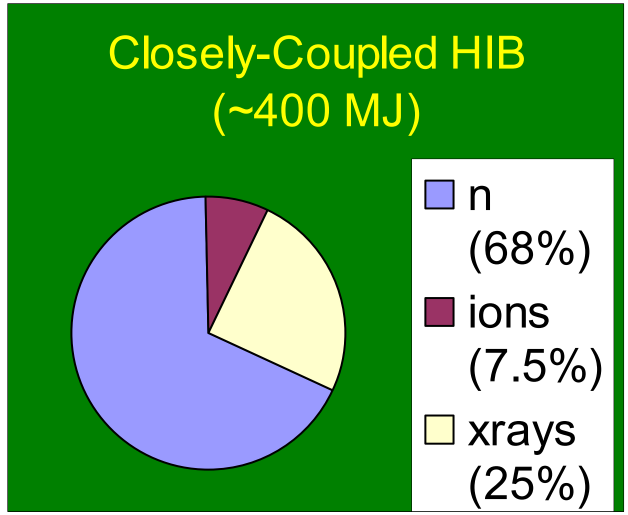



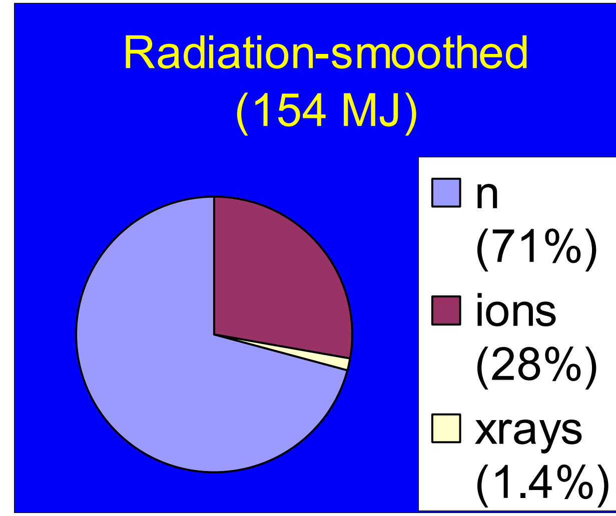
Ion beam characteristics:
3.5 GeV Pb+ ions
3.3 MJ input energy
1.7 mm effective radius spot

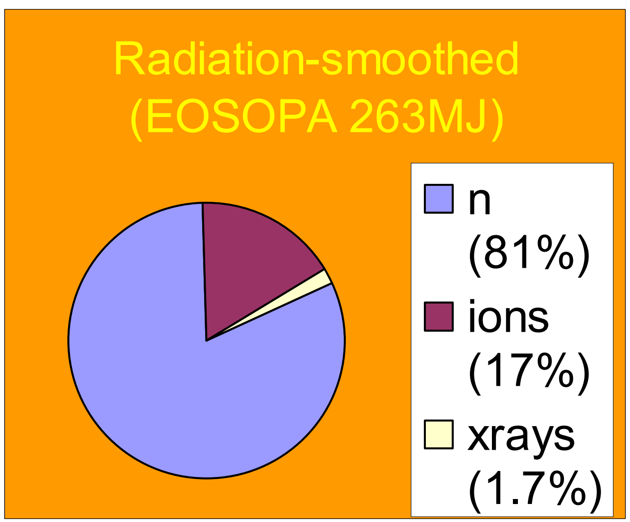
**Yield: ~400 MJ (Closely Coupled HIB target from D. Callahan-Miller, LLNL)**

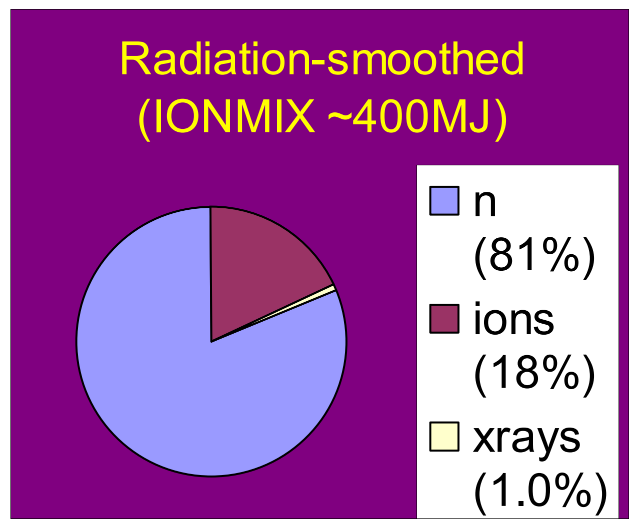
# Energy Partitioning for Various IFE targets



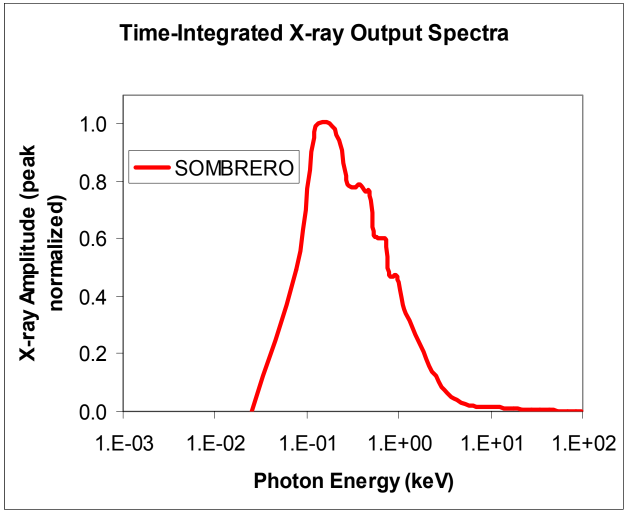



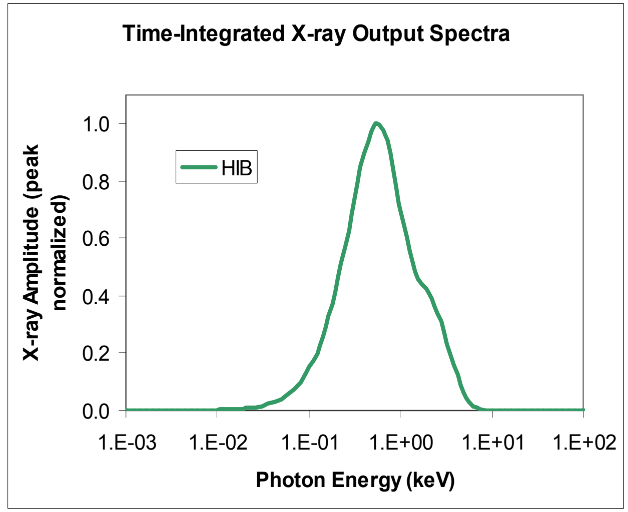



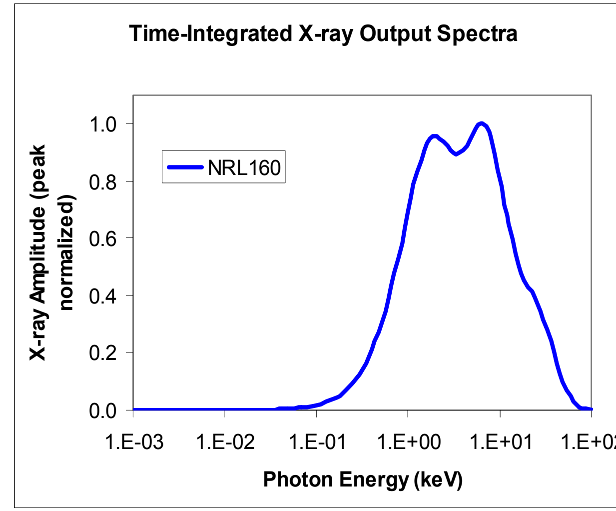



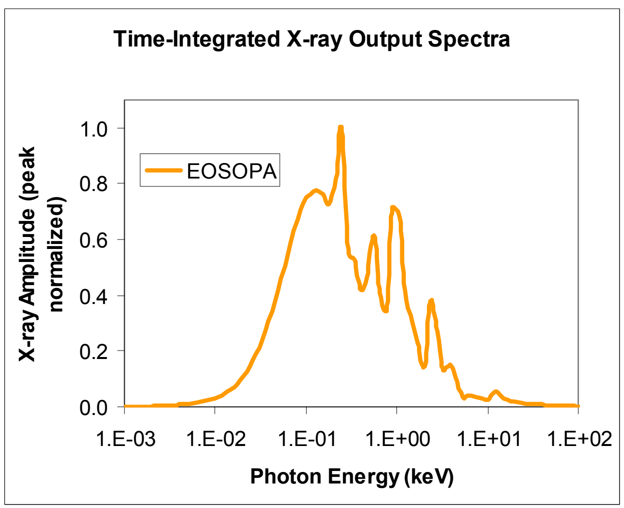



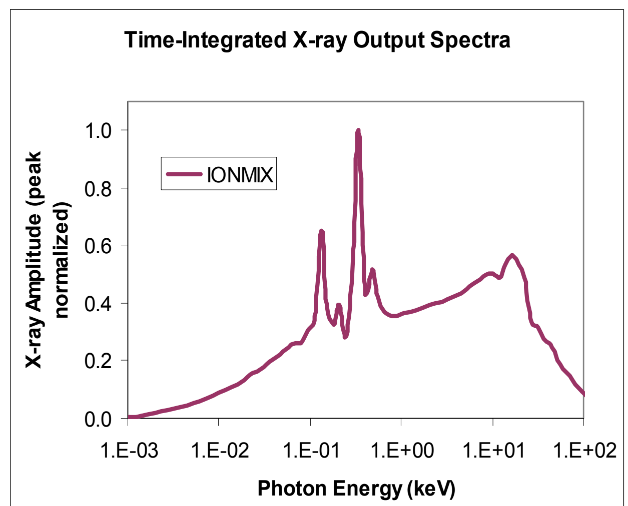
# Time-integrated X-ray Output for Various IFE targets



# Blast wave propagation depends crucially on the opacity of the chamber gas

The opacity depends on:

•detailed (and in the case of chamber Xe, highly complicated) atomic physics, and

• $Z^*$, the average charge state, and the population of the individual atomic levels.

$$\tau_\nu(\text{lines}) = \sum_{\text{lines}} \frac{\pi e^2}{mc^3} \bar{f} \hat{\varphi}_\nu N_l d$$

$$\tau_\nu\left(\text{free-free}\right) \propto \left\langle Z^2 \right\rangle / \nu^2$$

$$\tau_\nu\left(\text{bf, hydrogenic}\right) \propto \sum_{\text{ion}} \frac{1}{Z_{\text{ion}}^2} \sum_n \left(\frac{\nu_n}{\nu}\right)^3 N_{\text{ion},\,n} d$$

# For the simulation of blast waves, the simplifying approximation of LTE is NOT appropriate

•If collisional processes dominate the rate equations, then the calculation of opacities reduces to the calculation of the energy level structure and statistical weights of the various relevant ionization stages. (Saha-Boltzmann Equilibrium)

•For that to be the case, the electron density must satisfy

$$N_e \geq 7 \times 10^{18} Z^7 n^{-17/2} \left( \frac{T}{E_n} \right)^{1/2} \text{ cm}^{-3}$$

•For propagation of blast waves in an IFE target chamber gas, the electron density is orders of magnitude too small to satisfy this relation, indeed, the coronal approximation is appropriate.

- **IONMIX**
  - Takes as input ionization potentials of the ground states of all the ionization stages of an element.
  - Assumes **hydrogenic** energy level structure for excited states and the cross-sections of collisional and radiative properties.
  - Solves **CRE** equations to determine ionization balance and level populations.

STRENGTH: ZBar which interpolates appropriately between coronal and LTE values.

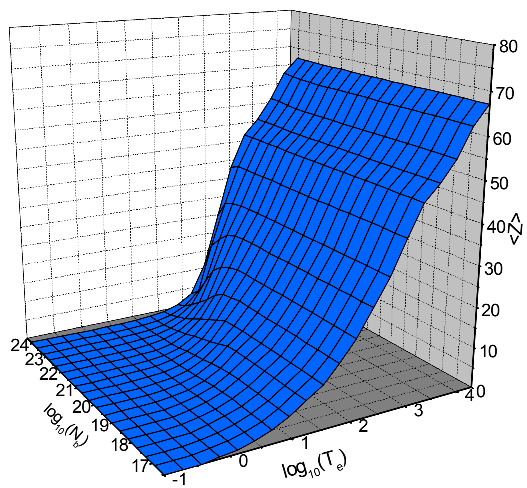
WEAKNESS: Simplified atomic physics.

- **EOSOPA (Z>18)**
  - Takes as input a list of configurations for each ionization stage.
  - Generates **detailed multi-electron** atomic physics data (energy levels and dipole matrix elements) for all ionization stages by solving Hartree-Focke equations with relativistic corrections.
  - Solves **LTE** (Saha) equations to determine ionization balance and UTA level populations.
  - Linear Muffin Tin Orbital approximation to dense plasma effects

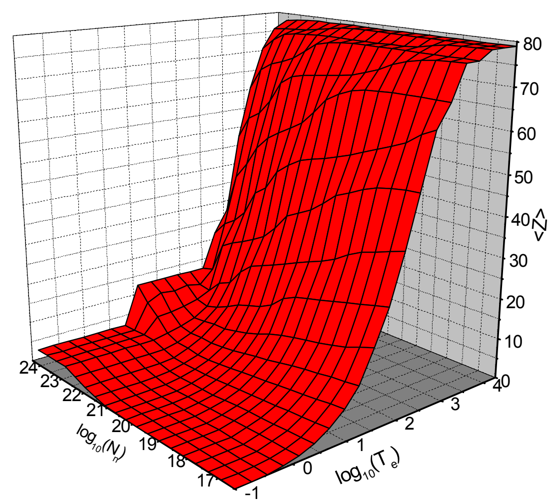
STRENGTH: Spectroscopic quality atomic physics.

WEAKNESS: No radiative rates taken into account. Strictly LTE for Z>18.

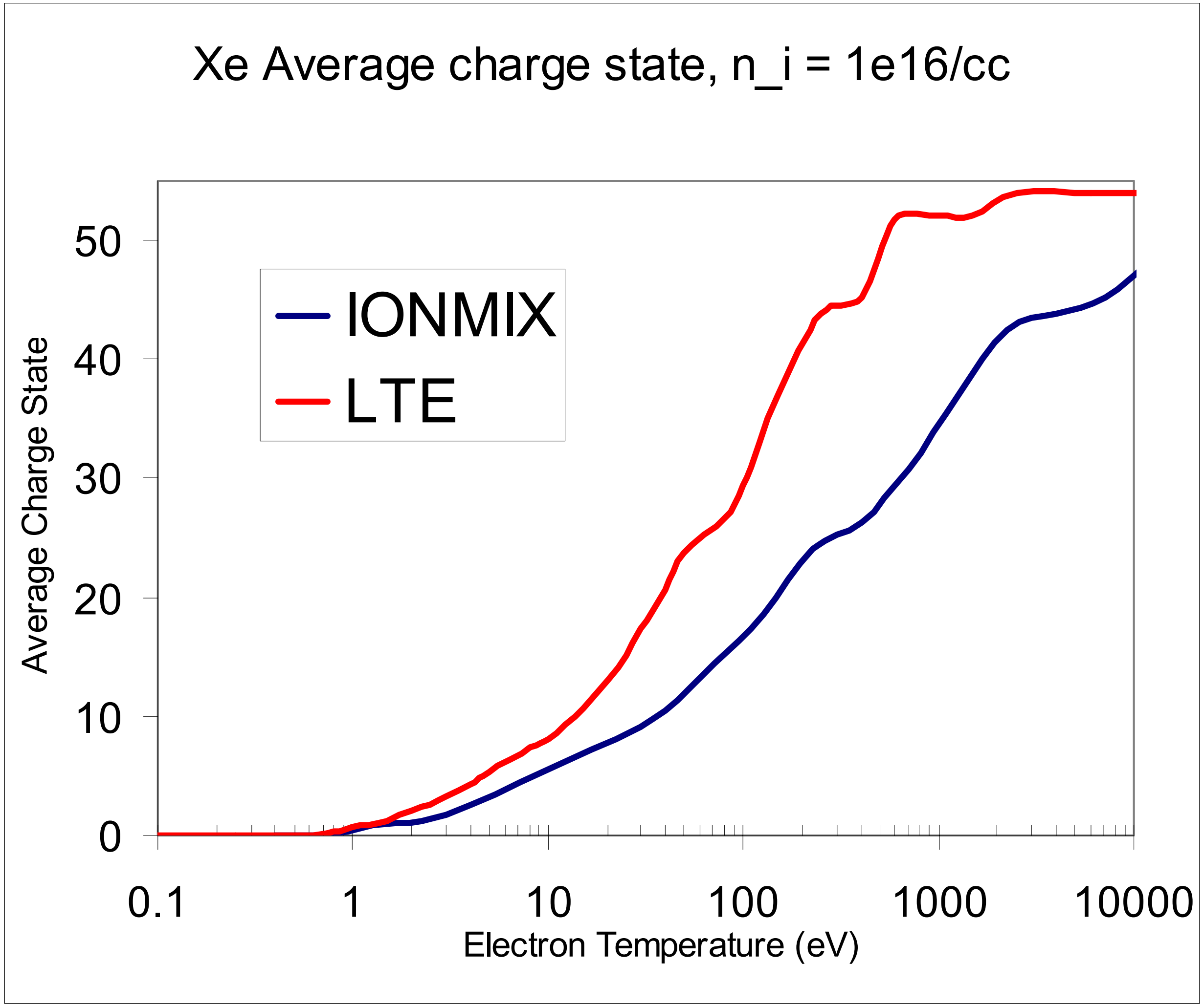
IONMIX



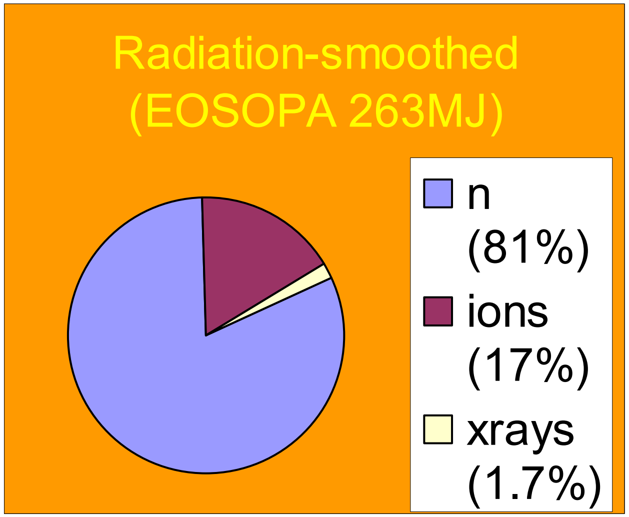

EOSOPA

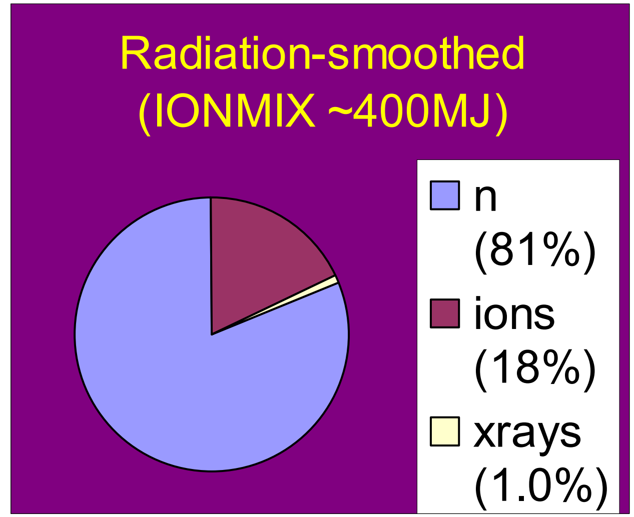


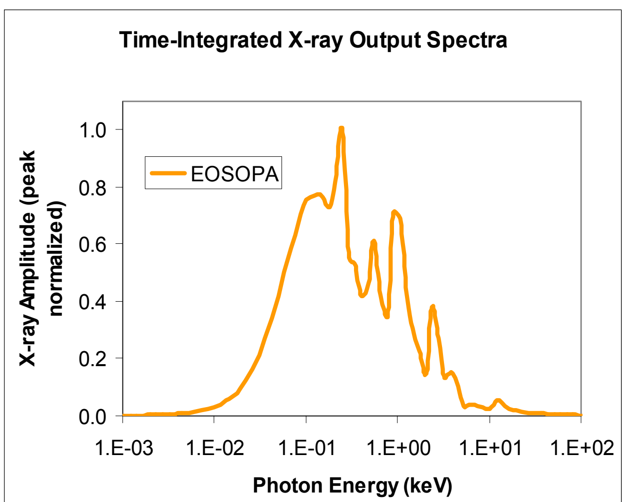
# For the current calculations, IONMIX has been used to generate NLTE Xe opacity tables

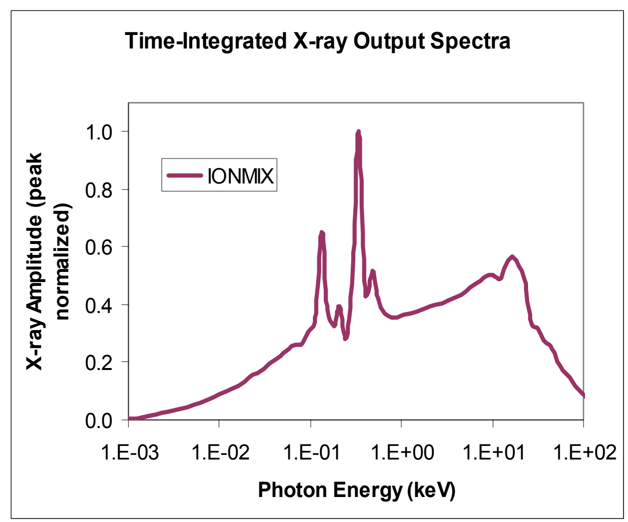


# Validated NLTE EOS and Opacity files are needed both for the buffer gas, Xe, and for the outer layer of Au in the radiatively-preheated targets

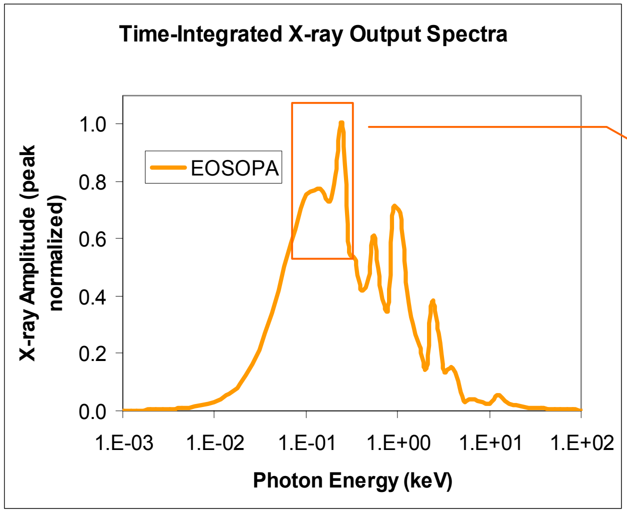


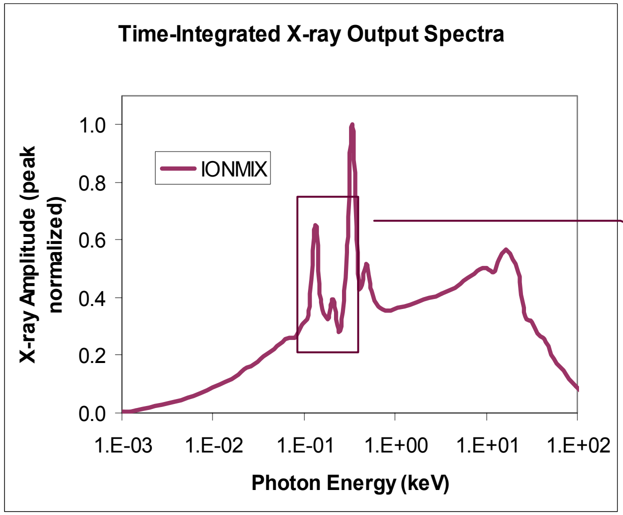



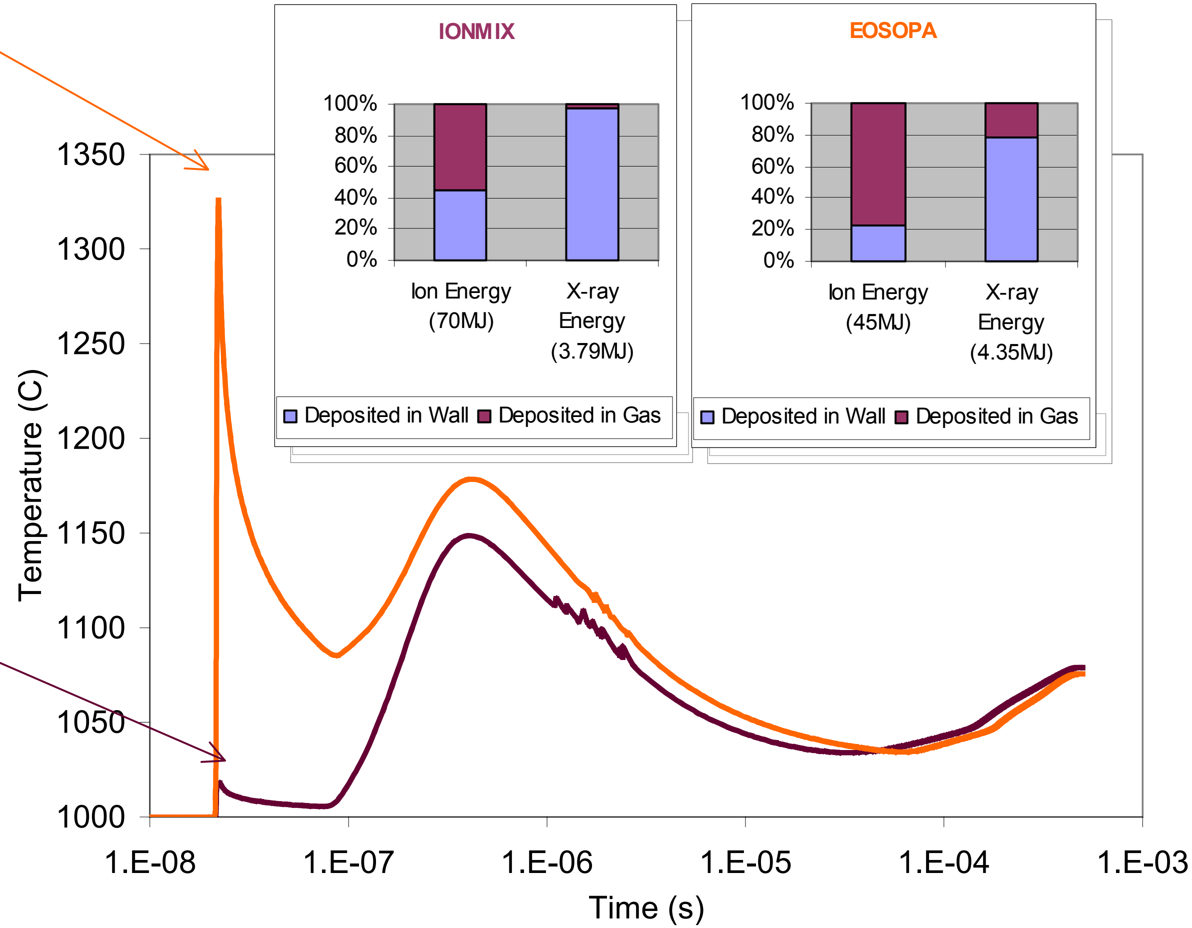



Different EOS/Opacity models used in the calculation of the 0.03 micron Au later in the NRL radiatively pre-heated target lead to vastly different x-ray output, and thus to significantly different chamber response.

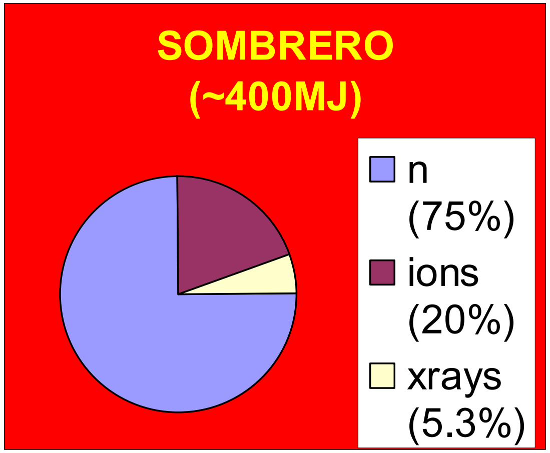


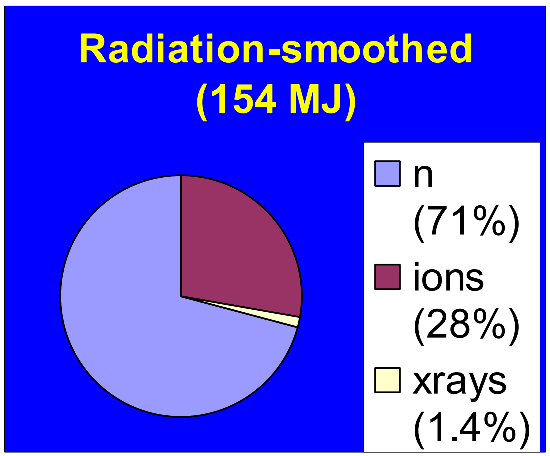



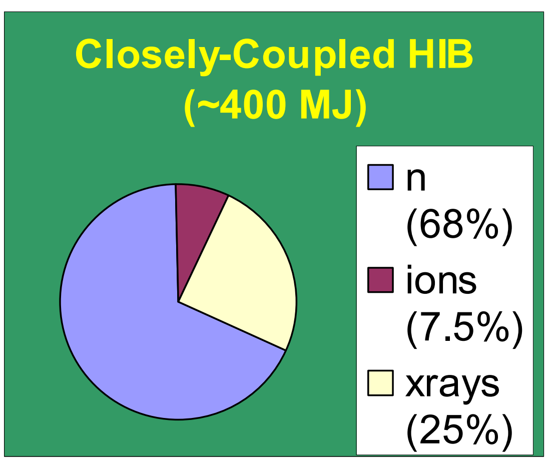

25mTorr Xe, 6.5m radius graphite chamber, starting at 1000C

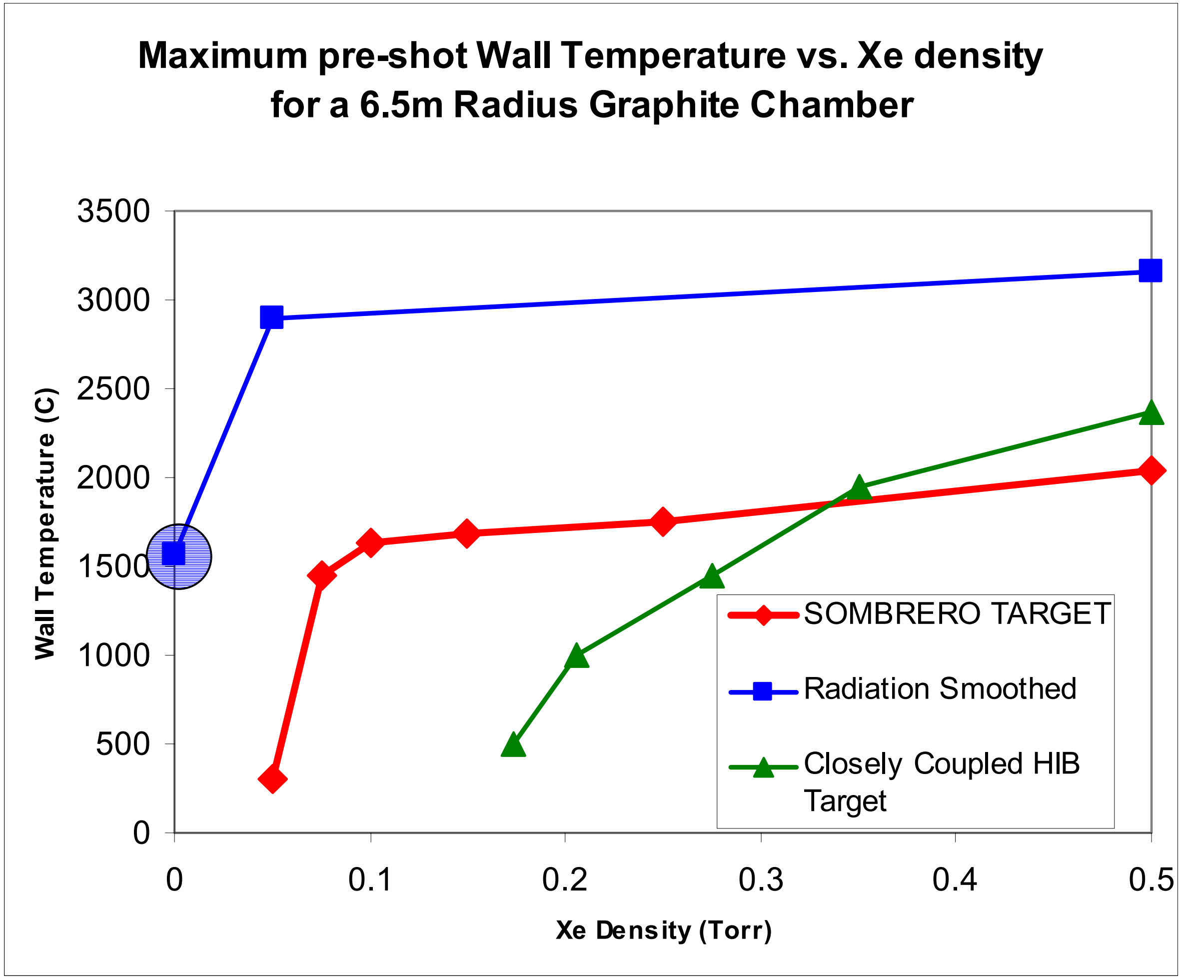


# Chamber wall survival depends on yield, partitioning, and spectra.

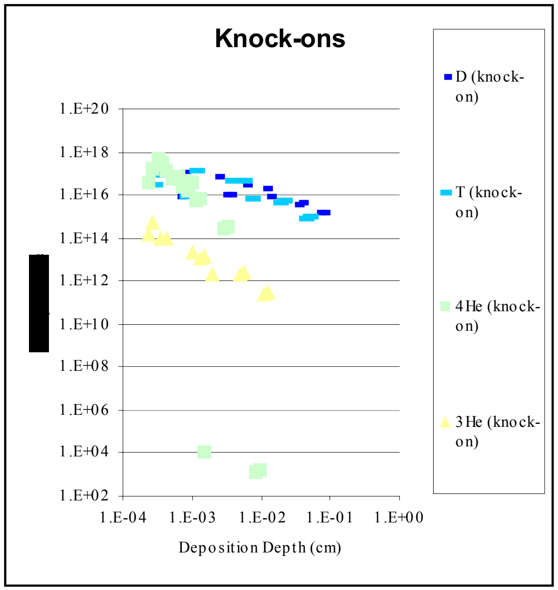


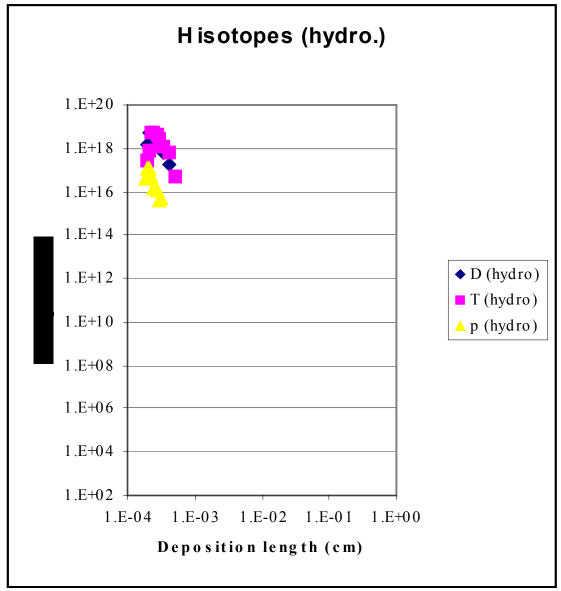



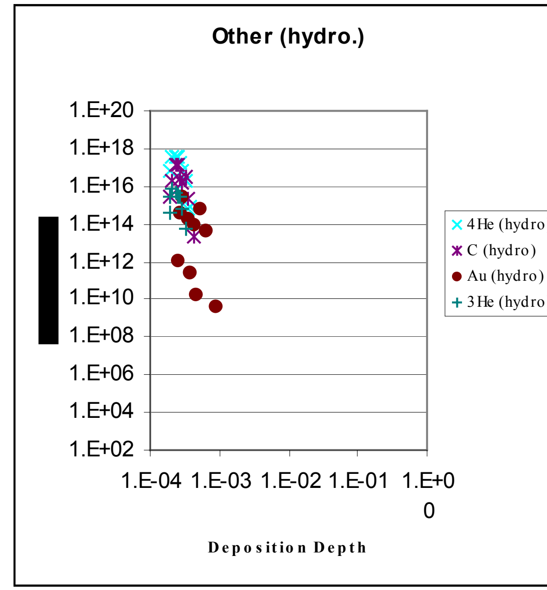



# For the lower yield direct-drive target (NRL160), no Xe is required to protect the first wall from vaporization. However, the effect of accumulation of particles in the wall and particle-induced changes in wall properties needs to be examined.

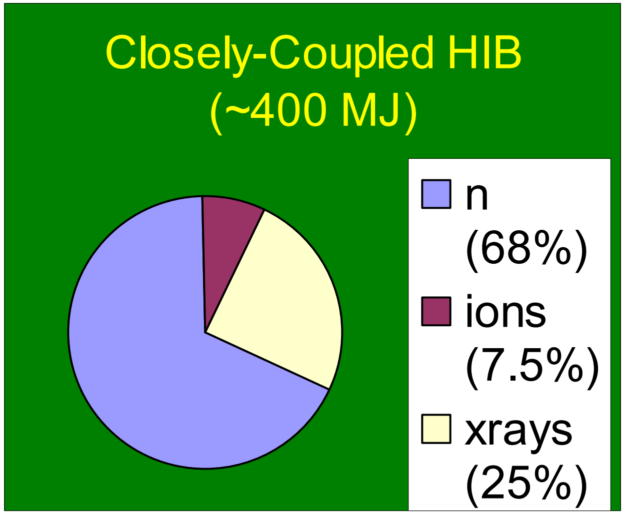


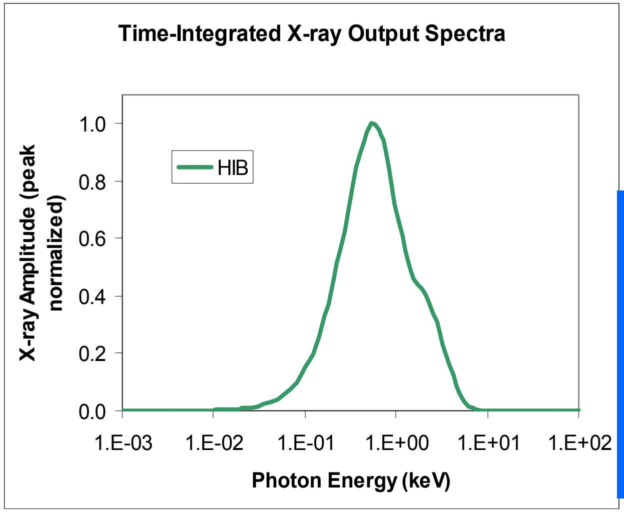



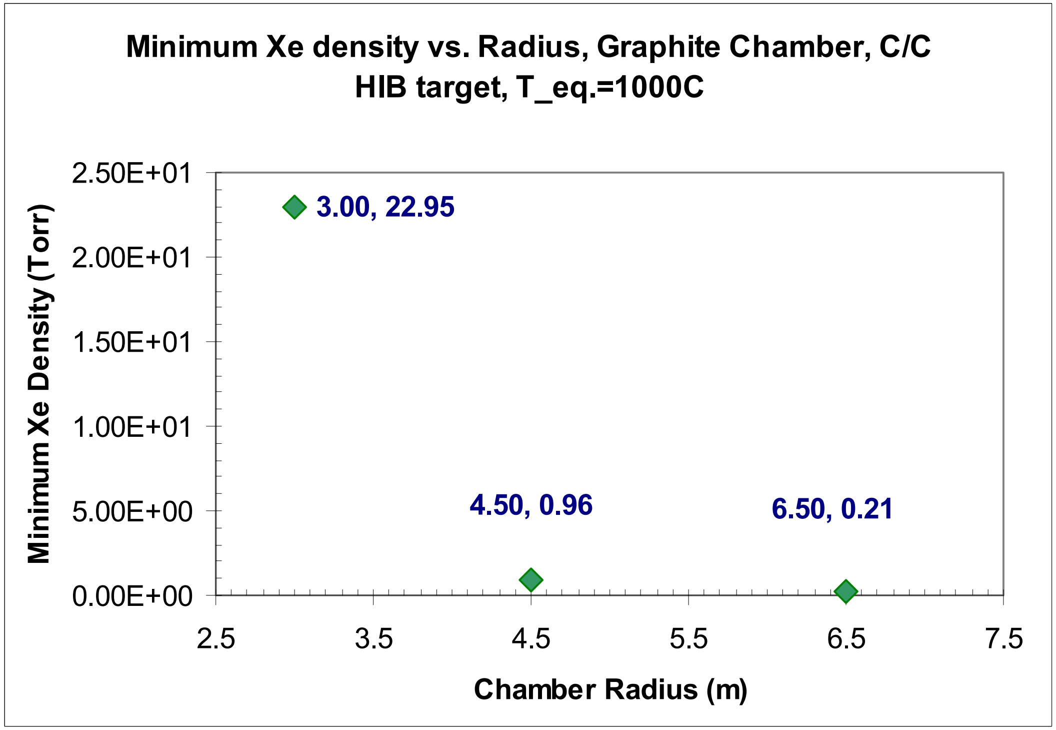




- The knock-ons deposit their energy throughout the first millimeter, while the ions driven by the hydrodynamic expansion of the target accumulate within the first 10 microns.
- What is the effect of the repeated deposition of these ions?

# Some HIB transport schemes rely on a relatively high pressure (>1Torr) chamber gas, allowing the possibility of smaller radii.




**The minimum Xe density required to protect the first wall varies strongly between 3m and 6.5m chamber radius, and the dependence is not well fit by assuming that a constant areal density is required.**

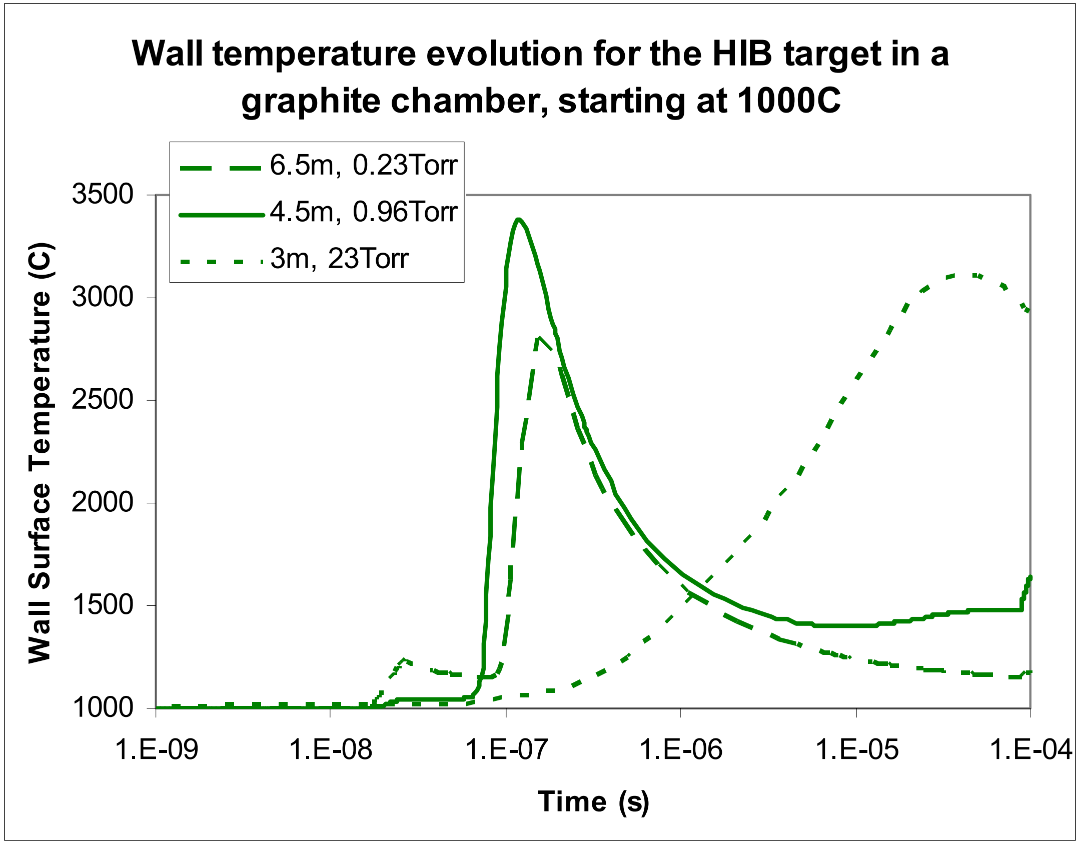
# To protect the first wall from the large soft x-ray threat of the HIB target at 3m chamber radius invokes a different threat mechanism: hot gas remnant at long time..

•3m simulation run out to 0.5ms. The wall survives flash from x-rays, and initial re-radiation.

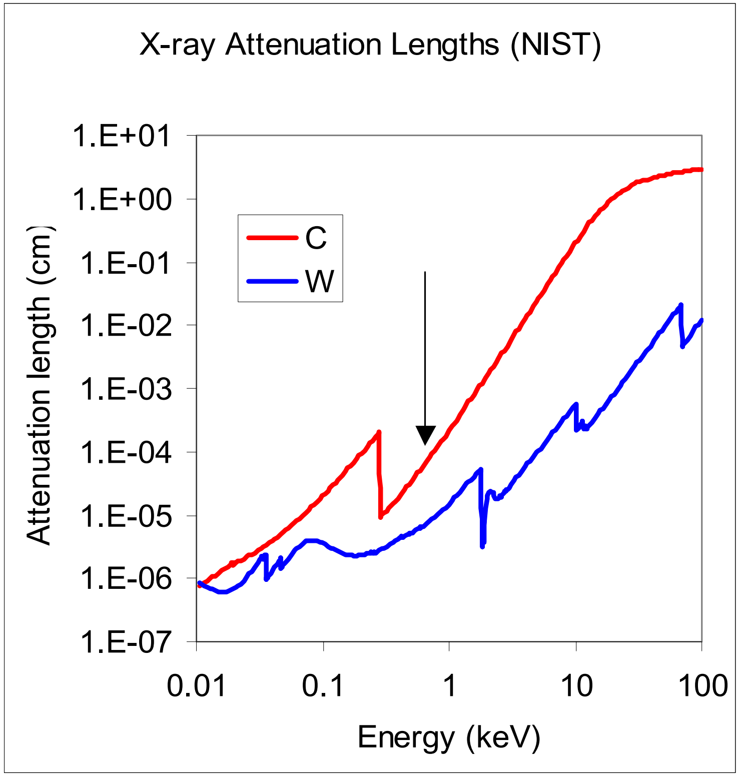
•However, chamber gas is still very hot (>1eV out to 2.4m) and continues to slowly heat the wall after the shock wave reaches it. 60MJ is remains in the gas.

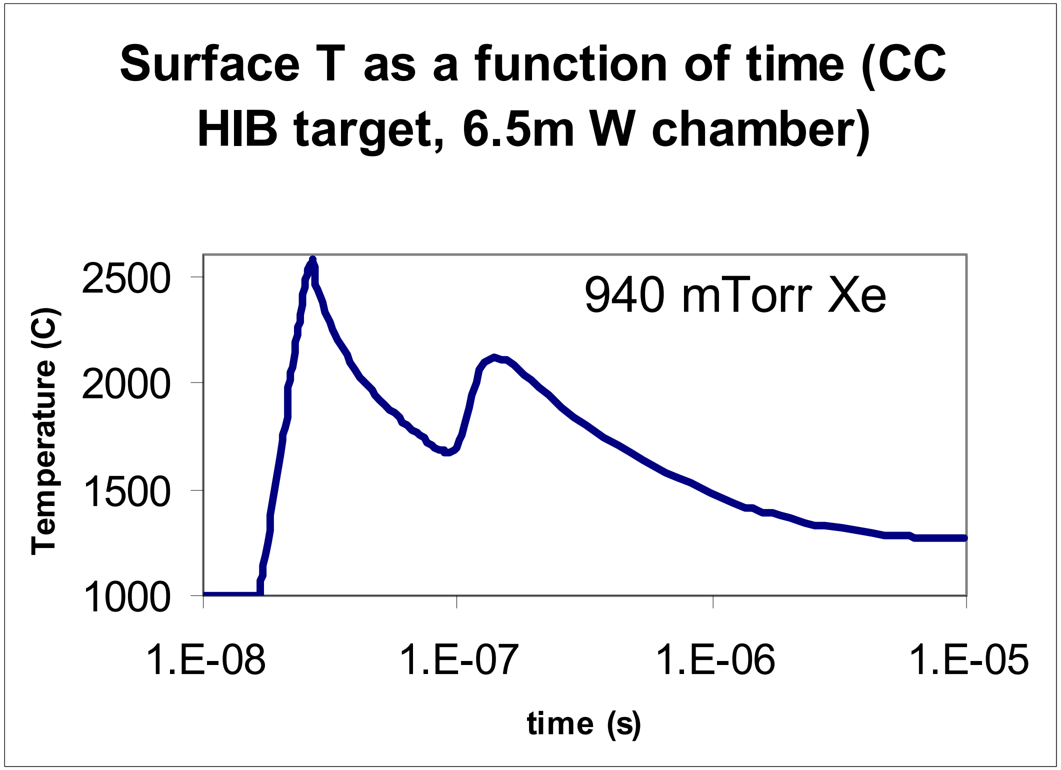
•At the end of the simulation, the wall surface temperature is still above 2000C.

• However, the wall is cooling, and, if one cared to extrapolate, the wall would return to the coolant temperature by the next shot.



# Tungsten armor




Though tungsten armor may be attractive for the directly-driven laser targets, for the HIB target the fact that the x-ray attenuation lengths in W are considerably shorter than that of C forced the use of much more Xe. To avoid first wall degradation, between 0.3 and 1 Torr of Xe is required to protect a W first wall at 6.5m from the CC HIB target, and a T_eq of 1000C.

## In the event that Xe activation should prove problematic, we have studied the possibility of using Kr

- The Kr equation of state and opacity have been calculated using IONMIX.
- A series of BUCKY simulations in which Xe was replaced by Kr was performed to discern the effect of the differing opacities, stopping powers, and equations of state.
- For the NRL160MJ target at a starting temperature of 1450C, **12.5% more Kr is needed to protect a graphite 1$^{st}$ wall at 6.5m**.
- Kr may be more attractive than Xe on two counts:
    - Activation
    - Laser propagation (2-photon interactions with KrF laser)

# Summary

- One method of preventing the first wall of an IFE reactor from vaporizing is to fill the target chamber with a buffer gas, which serves to absorb prompt x-rays and ions produced by the target implosion and slowly re-radiate their energy.
- We have studied this protection system for a variety of IFE targets to define operating windows to inform future IFE reactor designs.
- The emission opacity of the buffer gas must be calculated in a fashion not restricted to LTE ionization and excitation.
- The same radiative-hydrodynamics code, BUCKY, that is used to calculate target burn and output is used for chamber gas dynamics and wall vaporization calculations.

A final, cautionary note: Prevention of first wall vaporization is merely a necessary, and not a sufficient, criterion for a successful chamber design.