Parametric Studies of Dry-Wall IFE Chamber Dynamics: Xe Pressure and Radius

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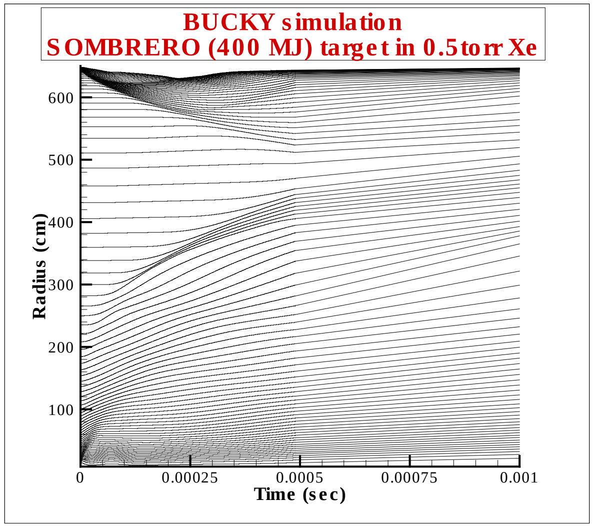
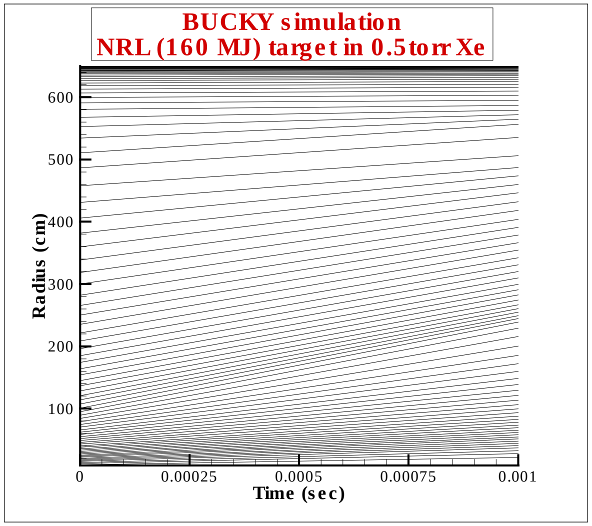

BUCKY simulation
SOMBRERO (400 MJ) target in 0.5 torr Xe

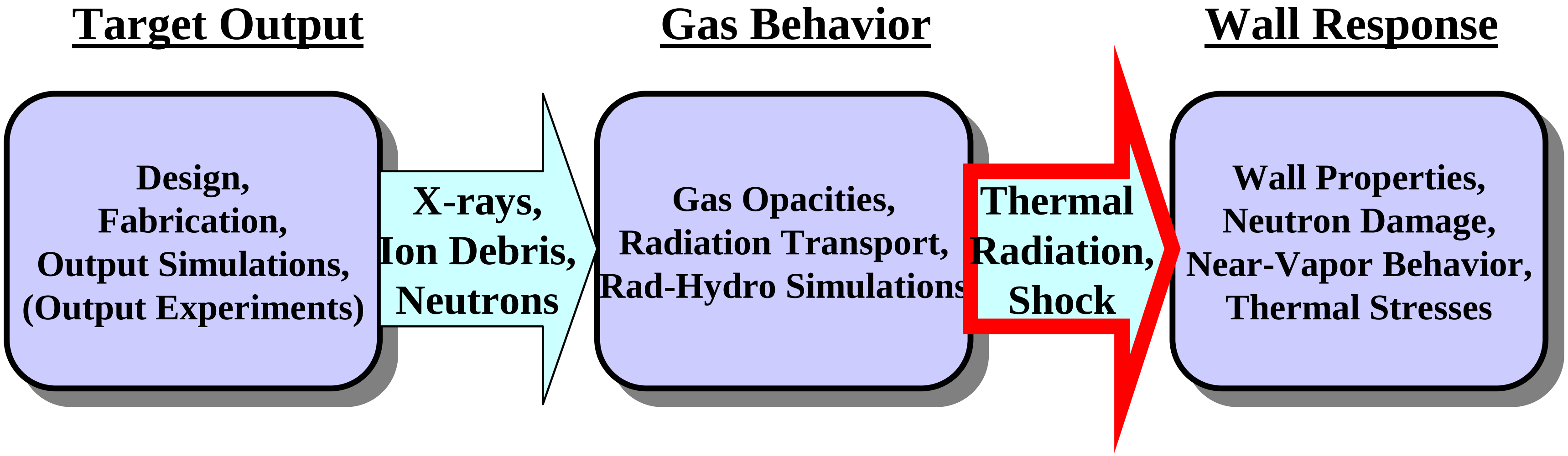

BUCKY simulation
NRL (160 MJ) target in 0.5 torr Xe

Summary and Outline

We have performed parametric surveys of dry wall chamber dynamics (focussing on blast wave propagation and first wall vaporization) for the SOMBRERO (400 MJ) and NRL (160 MJ targets). First wall vaporization is found to depend critically on both Xe gas pressure and radius as it is crucial to keep the prompt x-ray fluence below a threshold value.

- Brief review of physics (opacity, Marshak waves, stopping & response)
- SOMBRERO (400 MJ) survey: Xe pressure variation
- NRL (160 MJ) survey: Xe pressure variation
- NRL (160 MJ) survey: chamber radius variation

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

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

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.

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

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

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

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

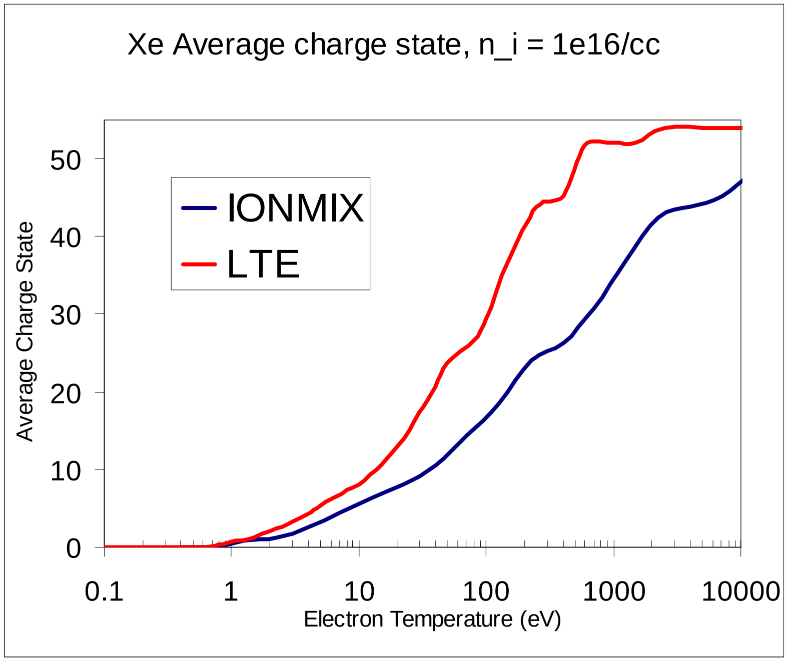
•If collisional processes dominate the rate equations, then the calculation of opacities reduces to the calculation of the energy level structure and statistical weights of the various relevant ionization stages. (Saha-Boltzmann Equilibrium)

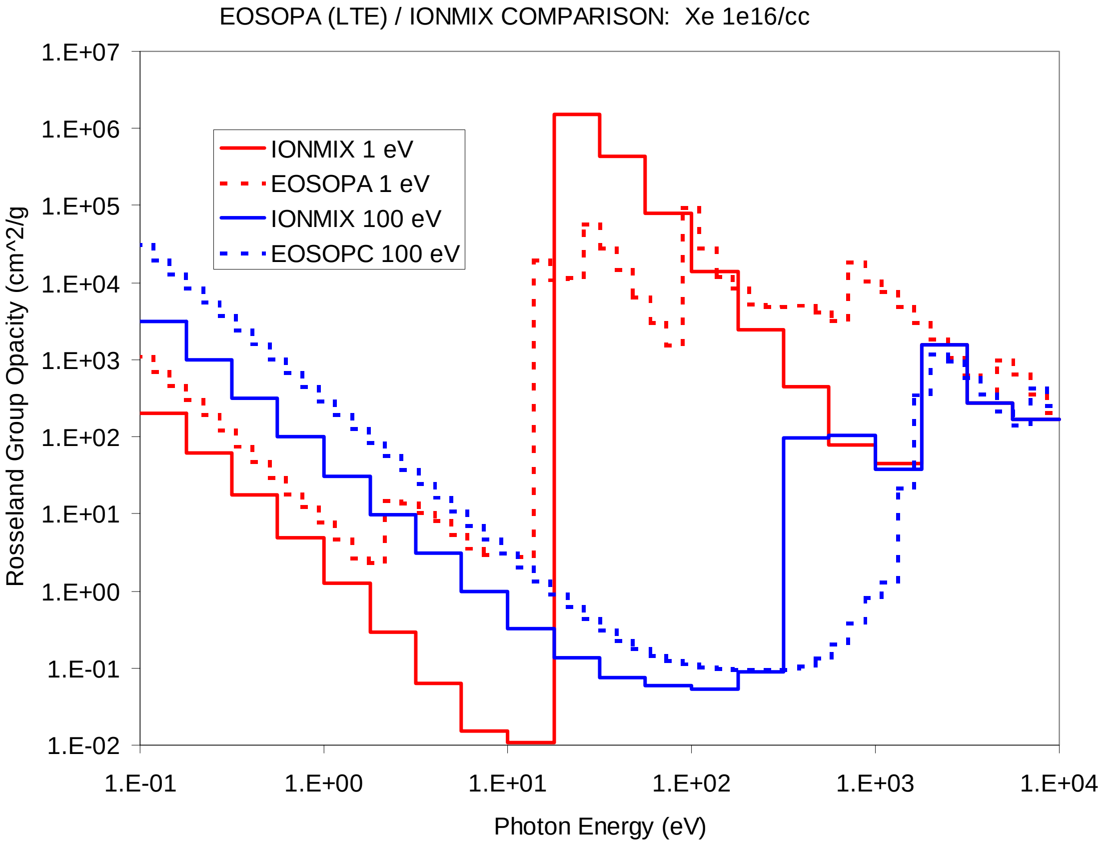
•For that to be the case, the electron density must satisfy

$$N_e \geq 7\times10^{18} Z^7 n^{-17/2} \left(\frac{T}{E_n}\right)^{1/2} \text{cm}^{-3}$$

•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.

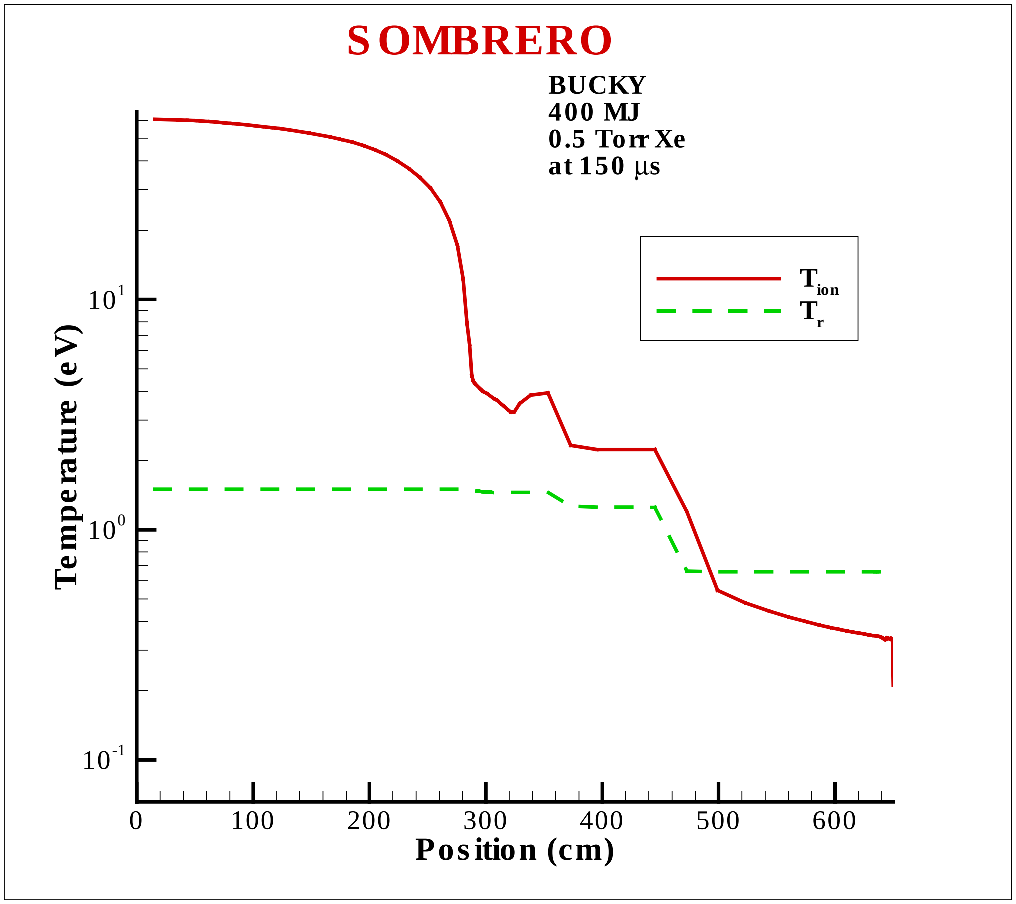
For the current calculations, IONMIX has been used to generate NLTE Xe opacity tables





For the blast wave propagation $T_r \neq T_e$, rendering the use of tabulated opacities suspect.

Issue: Radiation Transport in fireballs is far out of equilibrium and flux-limited radiation diffusion must be validated. Though $T_r \neq T_e$ table lookup methods do exist (Busquet approach), we are implementing an Average Atom model.



A **Marshak Wave** is a High Temperature Front that Propagates Through a Medium Via Radiation

- **Examples**

—Astrophysics (super-novas, shocks in stellar wind).

—Explosions in earths atmosphere.

—Radiative burn-through of indirect drive hohlraum.

—**Blast in IFE target chamber gases (gas protection fill gas and vapor from liquid protection)**

- **Types**

—Standard: low opacity hot core inside high opacity cold medium; radiation diffusion valid and dominates.

—Low opacity: very low opacity hot core inside moderately low opacity cold medium; radiation diffusion NOT valid and emission from core dominates.

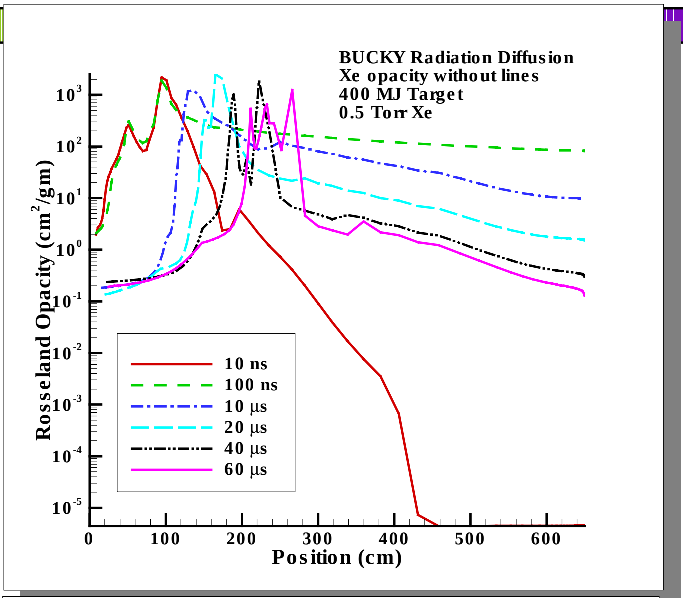
- **Issues**

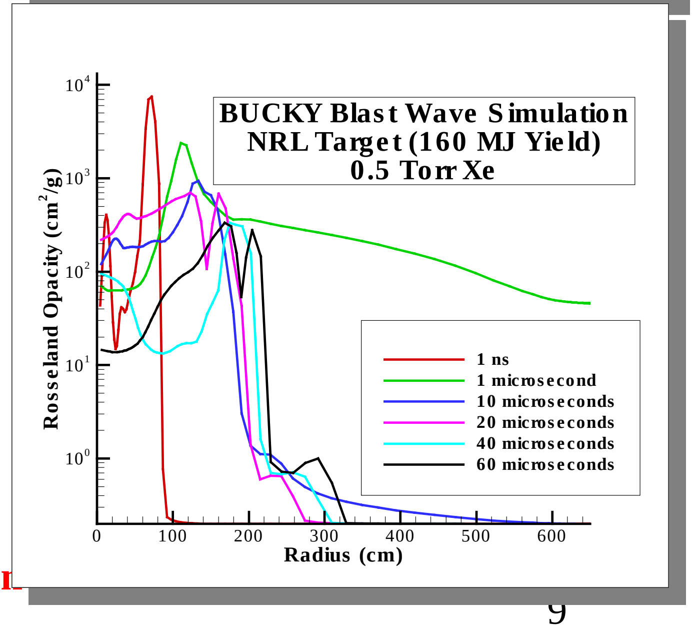
—Atomic physics of gas (need experiments).

—Computer Modeling of radiation-hydrodynamics of gas (need experiments).

For **SOMBRERO and NRL** targets in SOMBRERO chamber, Radiation Flow is Governed by Emission, NOT Transport

- Highest opacity at the edge of the fireball is the barrier to radiation transport.
- In this barrier, $\sigma_{Ross}\rho \approx 10^{-3}$ 1/cm, or the radiation mean-free-path is 1000 cm.
- Therefore, radiation flow to the wall is limited by emission.





BUCKY is a Flexible 1-D Lagrangian Radiation-Hydrodynamics Code

- 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 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.
- 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

BUCKY X-ray and Ion Stopping in Gases, Liquids and Solids

•X-ray Deposition: In low temperature matter, band effects and continuum lowering are important to x-ray deposition. Bleaching is important for high photon fluences.

➢X-ray source is either a radiation temperature boundary condition on radiation diffusion <u>or</u> is a volumetric energy source based on cold opacities and a multifrequency time-dependant spectrum in a exp(-κx) profile.

➢Opacities: Below a temperature threshold, elemental cold opacities based on Biggs and Lighthill fits to experimental data are mixed stoichiometrically for each zone. Above the threshold, EOSOPA or IONMIX multigroup opacities are read from tables.

➢Bleaching is the reduction in opacity due to depletion of absorbing levels by photo-ionization; simple model in BUCKY.

•Ion Deposition: In low temperature matter, inelastic scattering from bound electrons and nuclear elastic scattering, dominate ion deposition.

➢Ions in BUCKY are represented as many mono-chromatic packets, each with a particular position, particle energy and population at a given time.

➢The packets are sourced as a function of position and time.

➢For particle energies below a threshold, the Lindhard model is used for ion energy deposition; above that threshold, the Bethe model is used.

➢Range shortening (increased deposition due to ion-free electron scattering) is modeled.

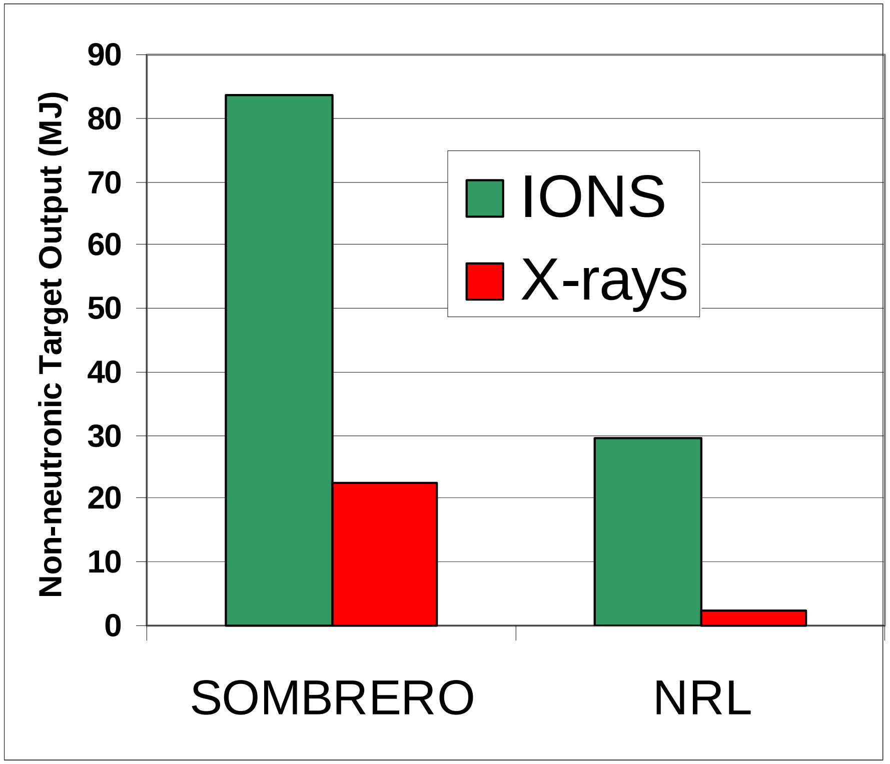
➢Ions are deposited where they range-out.

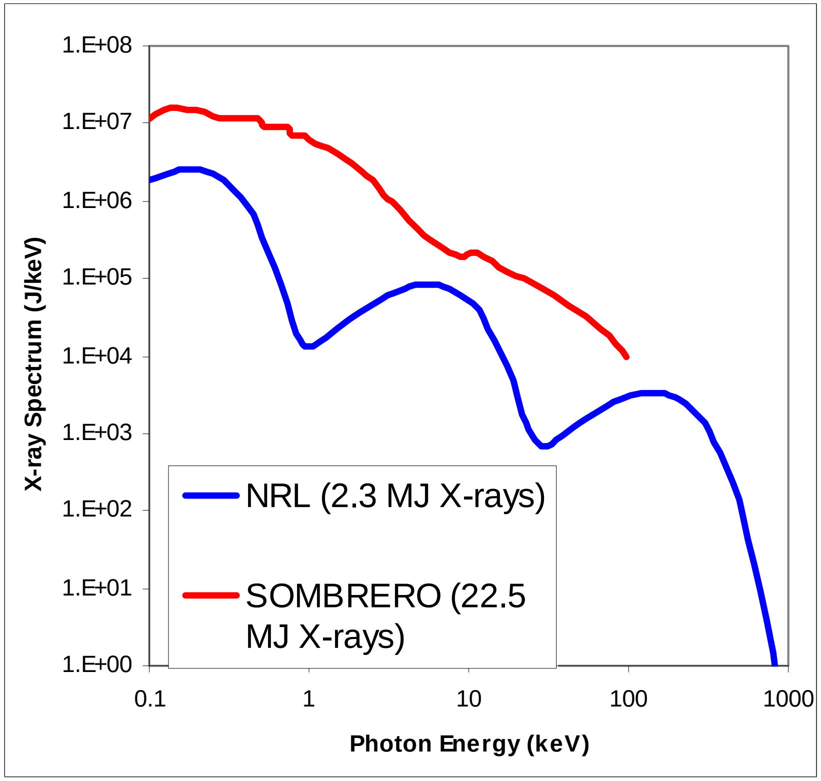
➢Corrections for straggling (off normal transport) are optional.

Response of Gases, Liquids and Solids to Energy Deposition

- **Fireballs:** Intense deposition heats gases to the point where they radiate and move. Both the radiation and shocks are threats to the chamber walls.
  - Radiation transport: multigroup radiation diffusion with flux-limiters.
  - Opacities: Below a temperature threshold, elemental cold opacities based on Biggs and Lighthill fits to experimental data are mixed stoichiometrically for each zone. Above the threshold, EOSOPA or IONMIX multigroup opacities are read from tables.
  - Hydro-motion: Lagrangian.
- **Vaporization, Melting and Recondensation:** Phase changes in liquids and solids is an important aspect of chamber dynamics. Latent heats are important.
  - BUCKY has two options: 1) no hydro but careful modeling of thermal conduction and phase changes or 2) hydro with less careful solid state physics.
  - In Option 1: Thermal conduction using temperature dependent thermal properties is calculated in a mesh without radiation transport or hydro motion. Vaporization rate is calculated from a balance between the local gas pressure an stagnation pressure at the vaporizing surface. When a zone becomes full vaporized, it is added to the Lagrangian mesh and experiences radiation diffusion and hydro motion. The position of the melt-solid interface are recorded from temperatures. Latent heats are explicitly included.
  - In Option 2: Wall material is treated as part of the same mesh as gas. Phase transitions are treated through the equation-of-state or the quiet start option. Spitzer conductivities are used for thermal conduction.
  - Option 1 is used for the calculations presented here. Carbon thermal conductivity assumed = 115 W/m-K.

The SOMBRERO and NRL targets differ significantly in yield, partitioning, and spectra

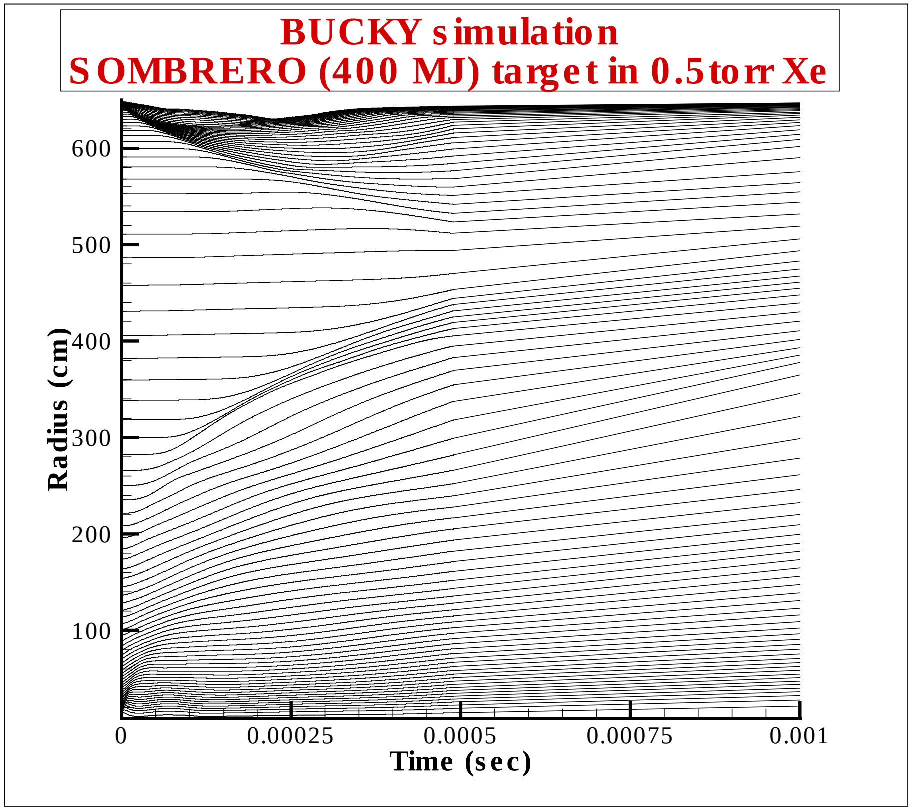




These differences lead to very different target chamber dynamics.

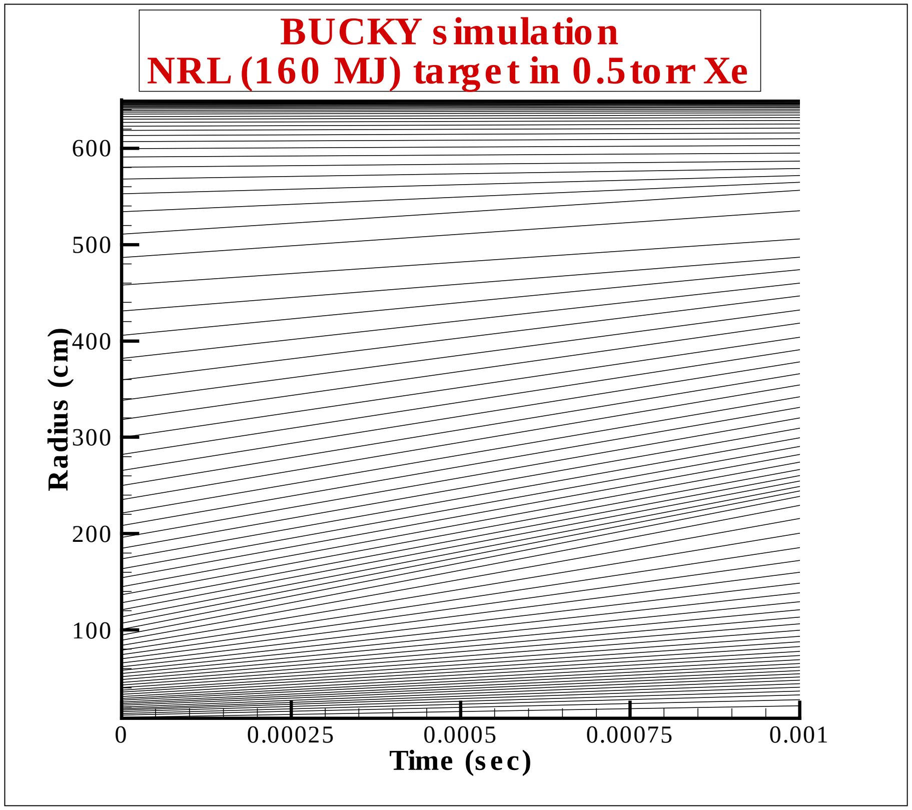
For instance, at 0.5 Torr Xe, the SOMBRERO target launches a stronger shock through the Xe than does the NRL target

SOMBRERO (400 MJ)



BUCKY simulation
SOMBRERO (400 MJ) target in 0.5 torr Xe

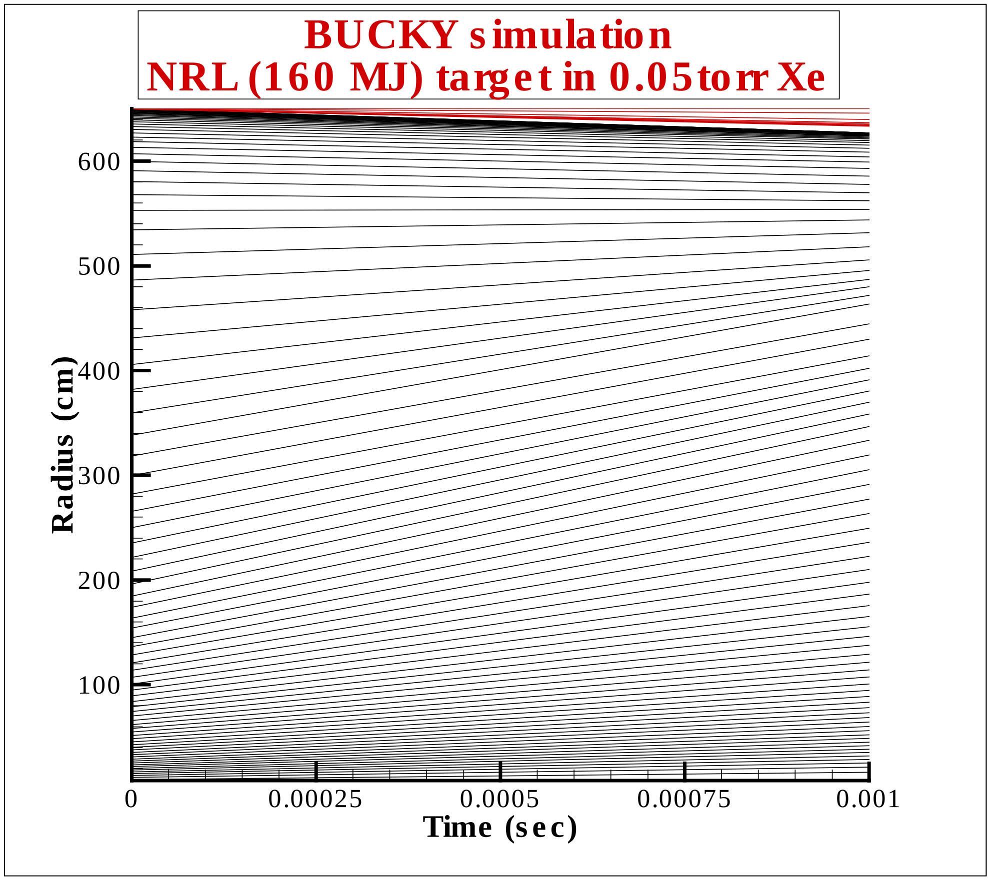
NRL (160 MJ)

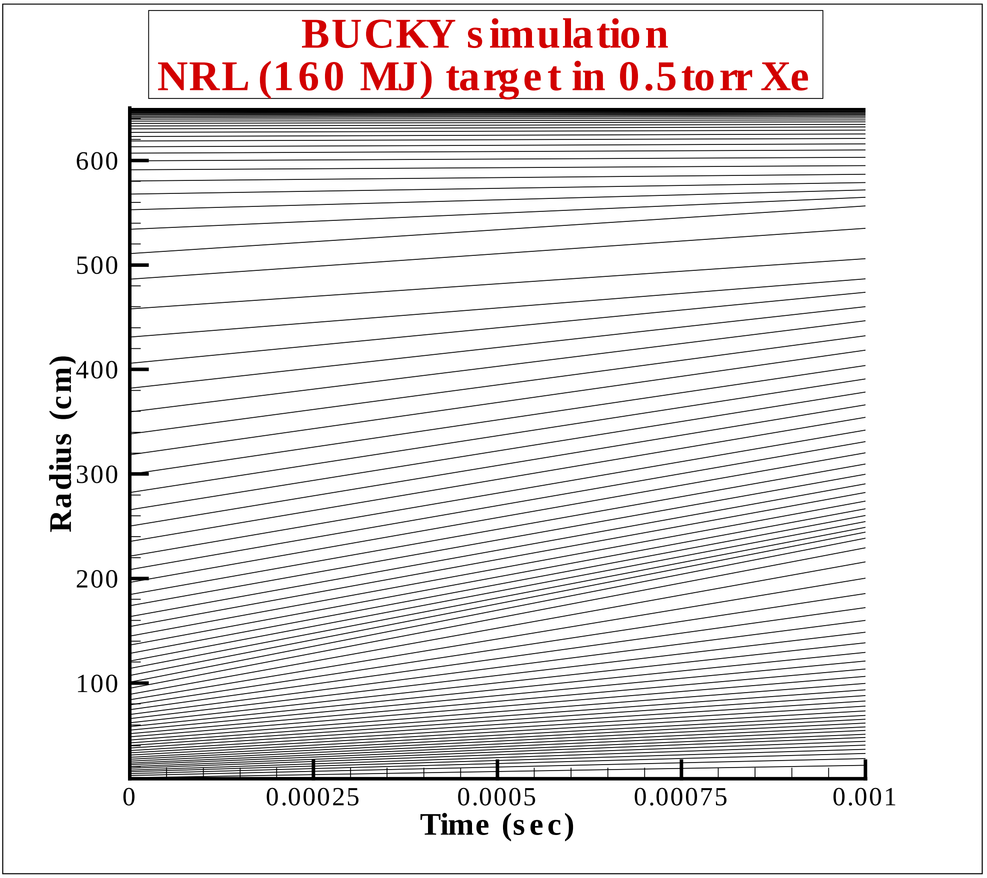


BUCKY simulation
NRL (160 MJ) target in 0.5 torr Xe

Carbon Thermal Conductivity = 115 W/m-K

Varying the Xe pressure changes the speed with which the gas around the target expands, and the amount of vaporization





A sequence of BUCKY runs varying the Xe density were performed for the SOMBRERO target in a 6.5m radius graphite chamber.

Assumed Target Yields: Ions 83.6 MJ, X-rays 22.5 MJ

Xe Density (Torr)	Ion Energy Deposited in Gas (MJ)	Ion Energy deposited in wall (MJ)	X-ray Energy Deposited in gas (MJ)	X-ray Energy Deposited in Wall (MJ)	Vaporized Wall mass (g)
0.005	22.5	61	2	20	1850
0.015	72.4	11.1	5	17.5	610
0.05	83.5	0.1	10.3	12.1	17
0.15	83.5	0	14.8	7.7	16
0.3	83.5	0	15.5	7	1.6
0.5	83.6	0	17.4	5.1	0

Graphite sublimation is a threshold effect, quickly becoming unacceptably large as Xe density is reduced below 0.5 Torr

A similar study was performed for the NRL target in a 6.5m radius graphite chamber

Assumed Target Yields: Ions 29.7 MJ, X-rays 2.33 MJ

Xe Density (Torr)	Ion Energy Deposited in Gas (MJ)	Ion Energy deposited in wall (MJ)	X-ray Energy Deposited in gas (MJ)	X-ray Energy Deposited in Wall (MJ)	Vaporized Wall mass (g)
0.05	24.9	4.8	0.6	1.7	300
0.1	28	2	0.8	1.5	10
0.15	28.2	1.5	1	1.3	0
0.3	28.7	0.95	1.1	1.2	0

Note that, ion energy is deposited in the wall even for 0.5 Torr Xe. Most (~0.9) of the energetic Au ions are deposited in the wall. <u>Also, even for this less energetic target approximately 0.15 Torr of Xe is needed for first wall survival at 6.5m.</u>

As the new target output might cause the team to reconsider the chamber radius, a sequence of BUCKY simulations were performed using the NRL target output and varying the chamber radius, keeping the Xe density fixed at 0.5 Torr

Assumed Target Yields: Ions 29.7 MJ, X-rays 2.33 MJ

Chamber Radius (m)	Load due to Re-radiated Energy (J/cm^2)	Load due to deposited Ions (J/cm^2)	Load due to prompt x-rays (J/cm^2)	Vaporized Wall mass (g)
3	17	0.87	1.15	10.58
4.5	4.4	0.32	0.47	0
6.5	1.5	0.12	0.21	0
8.5	0.8	0.052	0.12	0
12	0.4	0.012	0.055	0

Summary/Conclusions

•BUCKY provides a powerful tool not only for target output calculations, but also for blast wave and first wall response simulations.

•The dependence of SOMBRERO chamber first wall vaporization on Xe densities has been investigated both for the 400 MJ SOMBRERO target and for the 160 MJ NRL target. We observe a rapid onset of significant vaporization (more than one mono-layer) as Xe pressure is lowered.

•For the NRL target, chamber dynamics have been investigated for a variety of chamber radii, with the first wall surviving at 4.5m for 0.5 Torr of Xe.

•The tools are in place to quickly perform similar parametric studies if they should be needed.