Modeling Integrated High-Yield IFE Target Explosions in Xenon Filled Chambers

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Abstract

We will present the results of several radiation-hydrodynamics simulations which model the aftermath of an exploding high yield (~200 MJ) indirect drive target in a xenon filled reactor chamber. The goal is to determine the radial extent to which debris from the target and hohlraum expands into the target chamber. The 3D radiation-hydrodynamics code Cooper has been used in two modes. First, 1D integrated simulations beginning from ignition until a time of 100 µs have been performed. Second, two-dimensional simulations model the growth of fluid instabilities as the target material expands into the xenon gas. These simulations are also used to investigate the early-time interaction between the burning target and hohlraum shortly after ignition.

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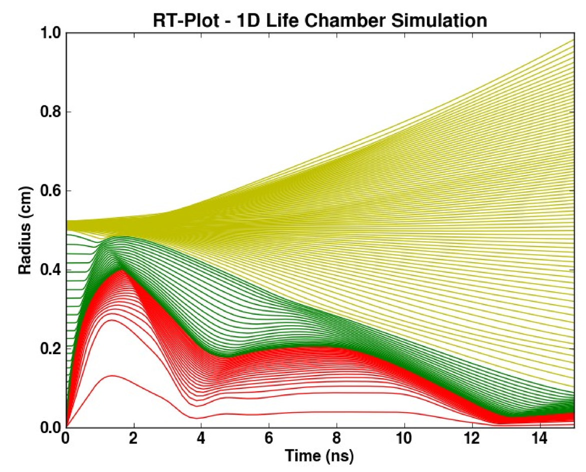
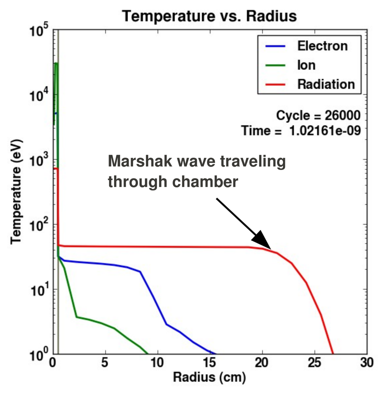
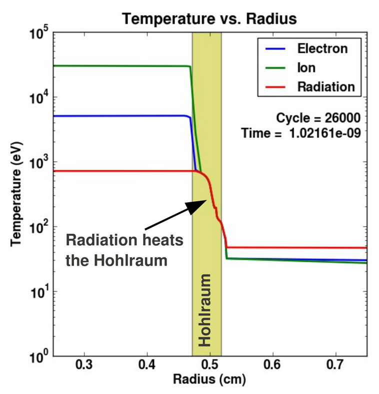
At early time, radiation heats the hohlraum and travels through the chamber

- A Marshak wave is generated within the fuel very early in the simulation and travels through the chamber
- The hohlraum absorbs radiation, heats and expands
- The inward moving hohlraum interacts with a strong shock launched from the fuel.

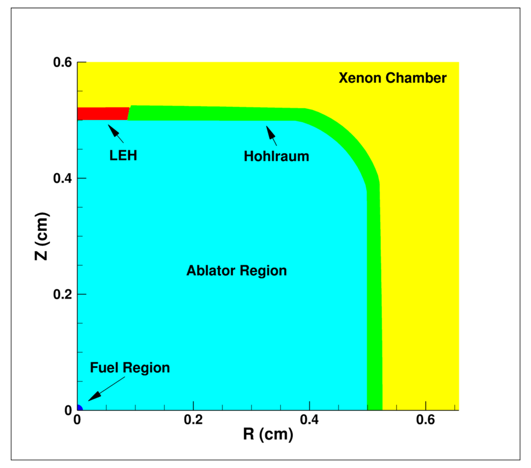


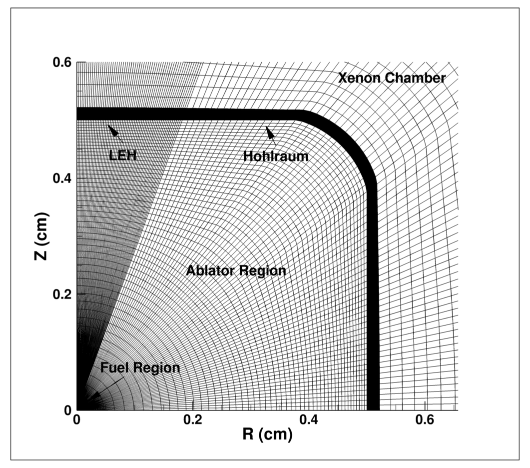




Early time two dimensional simulation setup

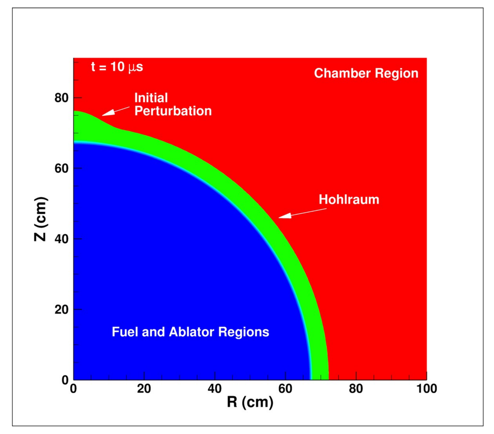
- Simulations are performed either with or without an LEH
- The LEH is modeled using the same state/EOS as the hohlraum to prevent severe grid distortions. However, the opacity of DT is used to make the LEH more transparent than the hohlraum
- The hohlraum is given rounded corners to avoid zone tangling which occurs immediately shortly after the simulation begins.

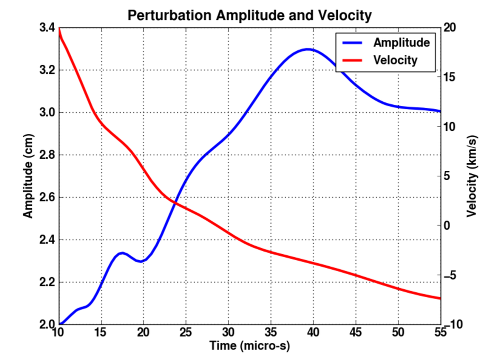




Perturbations are placed on the outer hohlraum surface at late time

- One dimensional simulations show the hohlraum expanding, then contracting at ~15 µs, reaching a maximum radius of ~80 cm.
- Any perturbations placed on the surface of the hohlraum may continue to grow and could penetrate deeper into the chamber.
- Several 2D simulations are performed beginning at 10 µs. Initial conditions are taken from the 1D simulations.
- Perturbations are placed on the outer surface of the hohlraum and their growth is measured. An example is shown to the right.
- Additional simulations with varying wavelengths and initial amplitudes are needed to definitively address this issue.

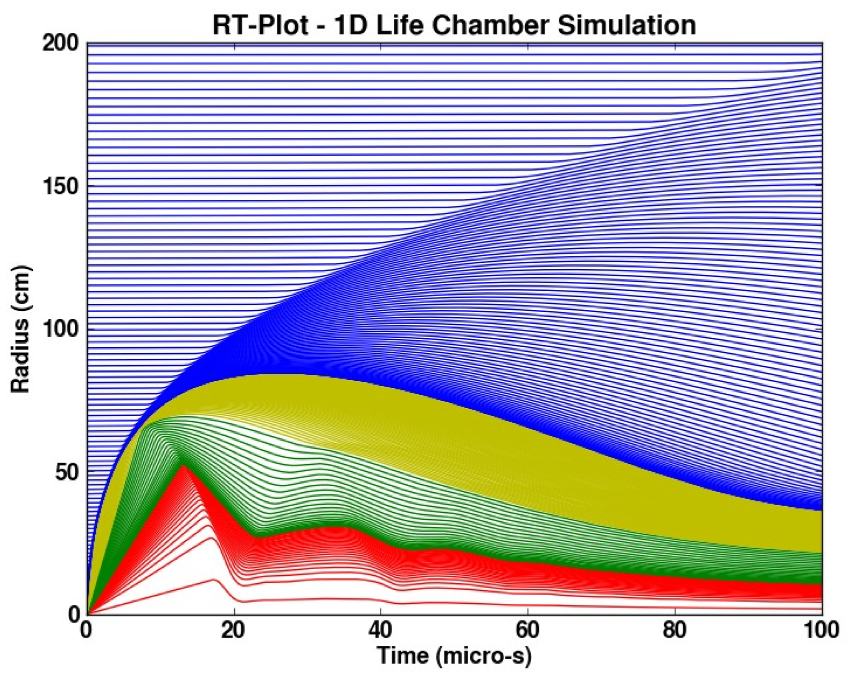




The radiation hydrodynamics code Cooper was used for these simulations

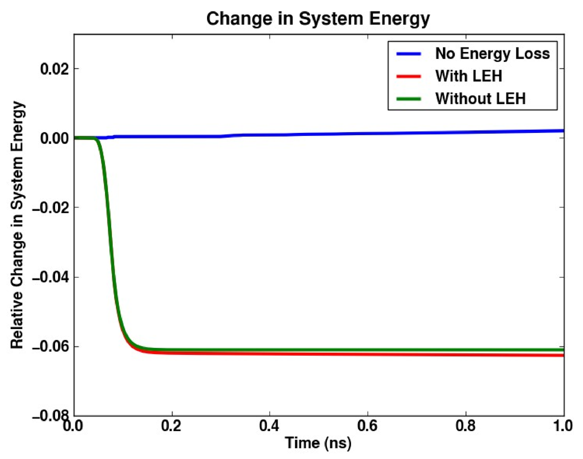
- Cooper is a 3D Lagrangian radiation-hydrodynamics code which operates on a structured hexahedral mesh.
- Cooper uses compatible hydrodynamics to improve energy conservation
  - The edge-centered artificial viscosity is used to capture shocks and subzonal restoring forces are used to suppress anomalous grid distortion
- Radiative transfer is modeled using multigroup diffusion theory. The results presented here used tabulated opacities generated by the IONMIX code.
- DT and Xenon are used in these simulations.
  - The DT is modeled using as a fully ionized ideal gas
  - The Xenon is modeled using an equation of state generate by the IONMIX code.

The hohlraum expands to a maximum radius of ~80 cm



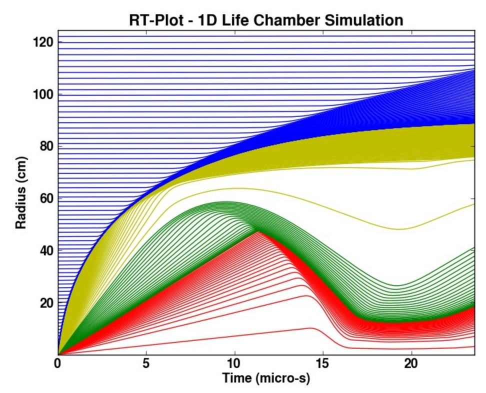
Preliminary simulations attempt to estimate amount of radiation escaping out of the LEH

- The chamber region is removed from these simulations and a vacuum boundary is placed outside of the hohlraum. The change in system energy is then equal to the amount of radiation escaping through the boundary.
- Comparisons are made between simulations which with/without an LEH
- If a substantial amount of energy exits out of the LEH, it will be necessary to modify the 1D simulations to account for this effect.
- Preliminary simulations, with a 10 degree LEH do not show a substantial increase in energy loss.
- Additional simulations will be performed which modify the LEH material, initial conditions and size.



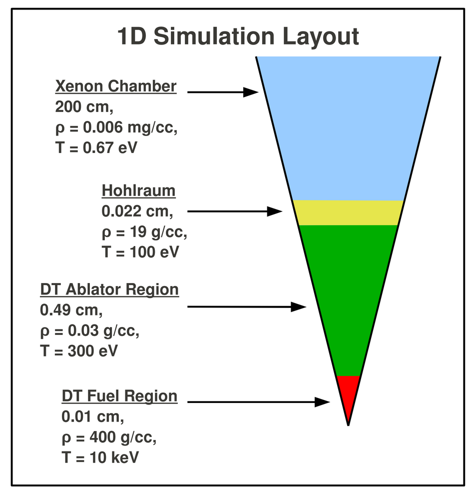
Simulations are beginning using more accurate equations of state

- Cooper uses a tabulated EOS of state to model the Xenon. The tables are generated using the IONMIX code.
- This EOS is not accurate especially in the high density hohlraum region since it uses an ideal gas model for the electrons
- Future simulations will rely on equations of state generated by the newly developed BADGER code written by Thad Heltemes (see NP9.00157). This code uses a QEOS model that can accurately describe the high density conditions found in the hohlraum.
  - An R-T plot of a 1D simulation using BADGER is shown to the right. Preliminary simulation results have not shown a significant difference in the maximum hohlraum expansion radius. Additional simulations are needed to understand the behavior at the hohlraum/ablator interface.
- Future simulations will use an actual gold hohlraum since BADGER is capable of generating gold EOS data.
  - Opacity data is not available for gold at this time.



One dimensional simulation setup

- The 1D spherical mesh is divided into four regions as shown in the figure below
  - The fuel region contains highly compressed DT and represents the imploded target
  - The ablator region fills the rest of the hohlraum and contains DT at a much lower density and temperature
  - The hohlraum is modeled as a ~1 gram spherical shell at the solid density of gold. Because EOS and opacity data for gold was not available, the hohlraum is modeled using data for Xenon.
  - The large chamber region surrounds the hohlraum and contains very low density Xenon.
- Ignition is simulated by uniformly introducing 53 MJ of energy within the fuel region over 50 ps. The energy is evenly split between the ion and electron internal energy.

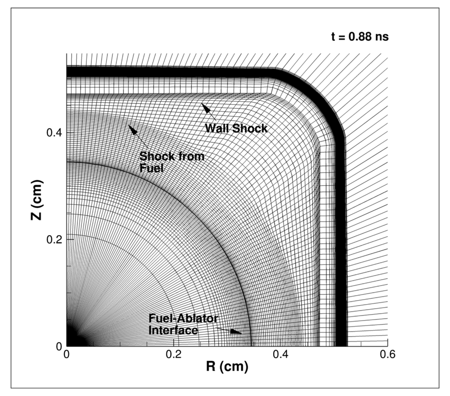


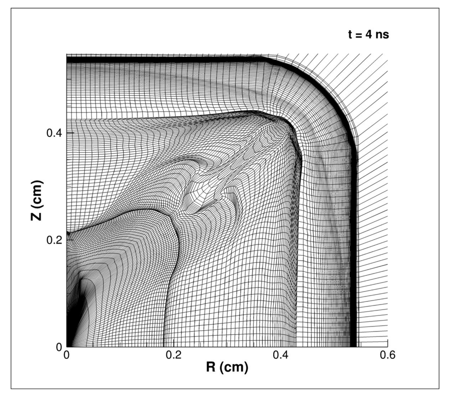
The one-dimensional simulations and results must be modified to account for multidimensional effects

- The R-T plot above shows that at early times, the hohlraum will expand inward, compressing the fuel and ablator regions. This process cannot be described by a 1D code alone since the collapse will not remain spherical.
- At early times, radiation will escape from laser entrance holes in the hohlraum, potentially affecting the energetics of the 1D simulation.
- In one-dimension, the hohlraum expands to a maximum radius of ~80 cm. However, if the system is not spherical, instabilities may grow and penetrate deeper into the chamber.
- Several 2D simulations have been performed to analyze each of these points. The preliminary results are presented here.
- Multidimensional simulations focus on either early or late times. Time step constraints made it difficult to model the entire explosion from start to finish in 2D.

Simulations without an LEH show the hohlraum expanding inward

- Early time simulations without an LEH model the first four nanoseconds.
- 2D simulations show that a strong shock wave launched from the fuel will intersect the inner hohlraum surface leading to severe grid distortions and mixing between the DT and the hohlraum.
- One-dimensional simulations allow shocks to unphysically reflect off of the center
  - The 1D simulations show that the hohlraum substantially compresses the fuel/ablator regions.
  - It may be more accurate model the hohlraum and target as a sphere where the hohlraum, fuel and ablator are mixed together.





Future Work

- Cooper simulations of the LIFE reactor are ongoing. Many of the future simulations will focus on modifying parameters to understand the effects described here
  - The size of the LEH and material used to model it will be varied to see if there is an effect on the overall energy lost from the system
  - Additional late time perturbation simulations will be performed with varying perturbation shapes
- More advanced EOS tables will be used – including tables generated by the BADGER code
- Additional modifications to Cooper will be made to improve simulation results
  - A rezoner is currently being implemented. This will be necessary in the future to avoid grid tangling in 2D simulations.
  - Planned modifications to the code will lead to improved parallel performance.
  - Specialized 1D versions of hydrodynamic and diffusion solvers will be implemented to substantially speed up 1D simulations