Radiation Hydrodynamic Simulations of the Inertial Fusion Energy Reactor Chamber

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Studies of the proposed Inertial Fusion Energy Engine Chamber are performed using the 1-D BUCKY radiation hydrodynamics code. Chamber dynamics focusing on the Marshak heat wave propagation, shock wave propagation, first wall temperature rise and maximum overpressure are investigated. Simulations show a maximum first wall temperature of 1135 K and a maximum overpressure of 5.83×10^{-3} MPa. Analysis of changes in dynamics due to chamber radius, gas fill and densities are also explored.

Inertial confinement fusion (ICF) is a process through which a target containing deuterium and tritium fuel is compressed to achieve extremely high temperatures (10,000,000's C), densities (100's of g/cm^3) and pressures. The figures below show the design of an indirect drive target and timeline of the compression and ignition process.

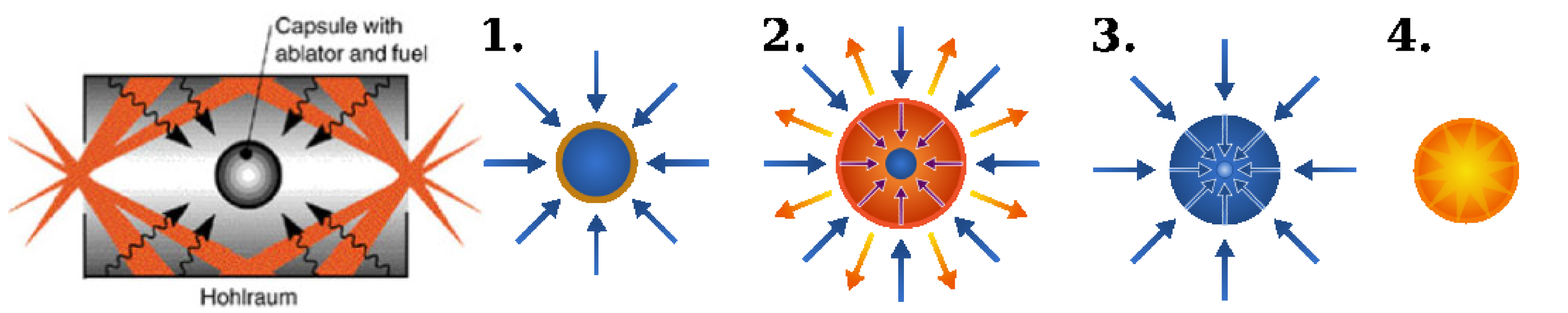

Figure 1: The left section shows a hohlraum[a], which is comprised of a high Z material, surrounding a fuel capsule, made of plastic and containing a layer of frozen fuel and the rest gaseous fuel being illuminated by lasers (red cones) to produce x-rays (black lines) which will heat and compress the target. The right section[b] shows the heating of the target by the x-rays (1) which causes an ablation of the plastic capsule (2) and leads to compression of the fuel by a rocket-like effect (3) which in turn leads to ignition (4).

The reactor design consists of the following components[c,d]:

•12 m diameter chamber with steel first wall
•6 µg/cm^3 (~0.8 Torr) xenon chamber gas
•1 g lead hohlraum containing a DT fuel pellet which yields 132 MJ
•16 Hz target injection repetition rate

For an idea of how the energy output can be recovered the chamber gas response must be understood. This analysis has three timescales:

•Ignition, burn, and prompt x-ray emission; 10 ns
•Marshak heat front propagation; 10-100's µs
•Blast wave propagation; 2-4 ms

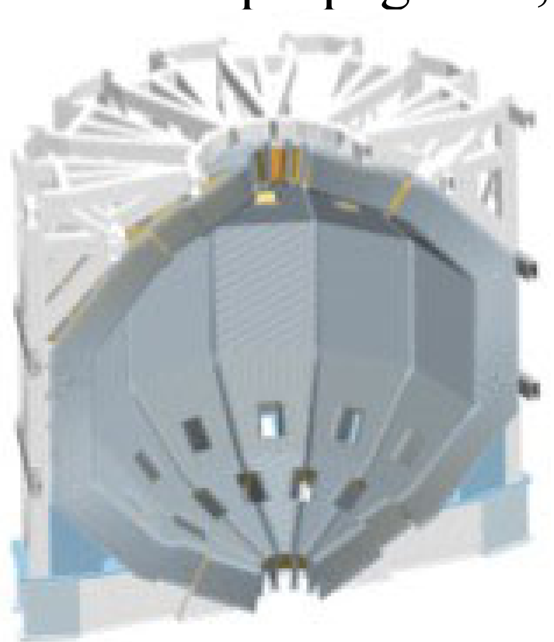

Figure 2: Conceptual design for the reactor chamber of an inertial fusion energy engine.

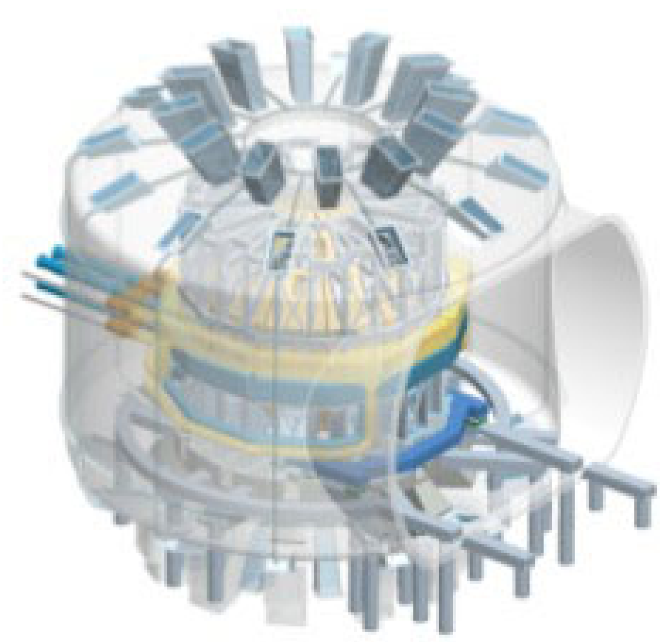

Figure 3: Conceptual design for the reactor chamber and vacuum vessel assembly.

Double Shockwave Propagation

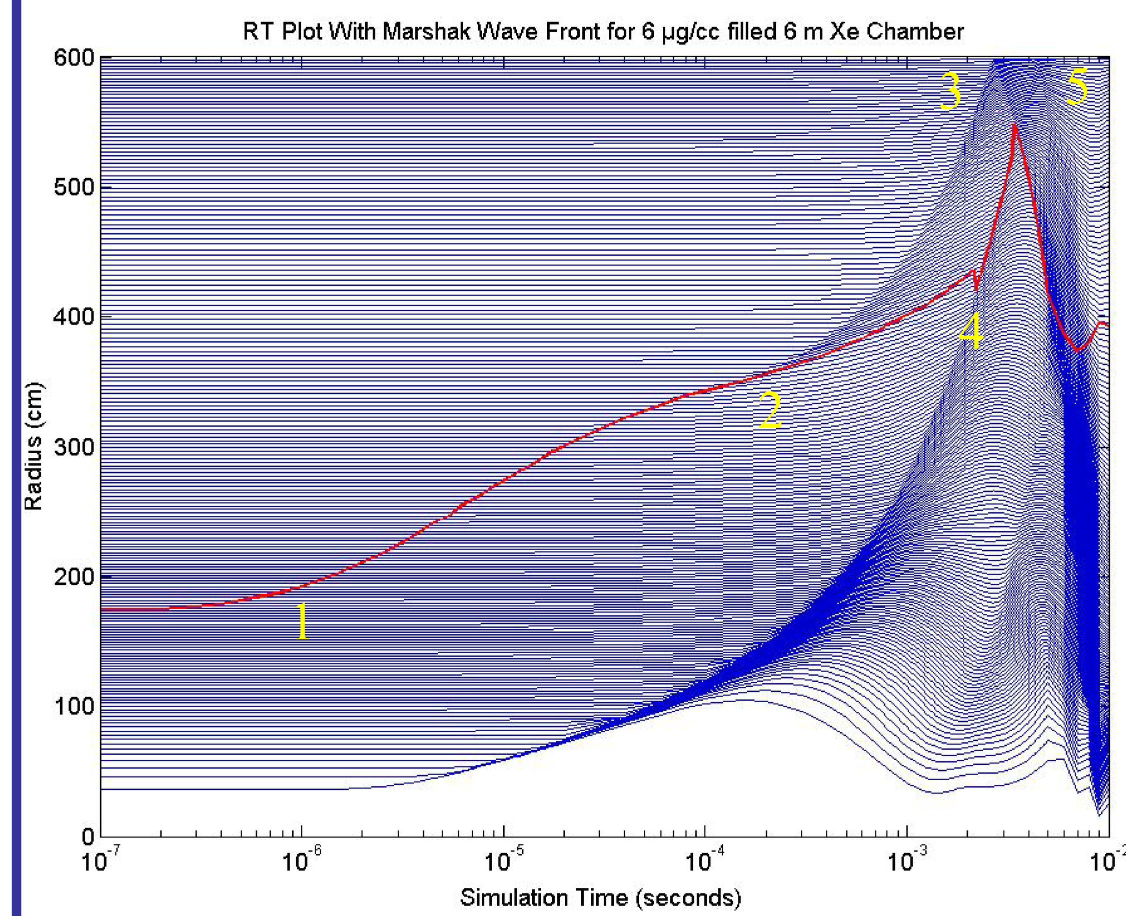

Figure 4 (left): Radius vs Time plot for a reactor chamber simulation. Superimposed in red is the position of the Marshak heat front. The front is produced by heating of the gas from x-rays released by the target explosion. There are 5 points of interest on the graph.

1) Generation of the Marshak heat front.
2) The Marshak heat front slowing and generating an outer shock.
3) The outer shock reaching the chamber first wall.
4) The inner shock, generated by expanding target ions, meeting with the Marshak heat front.
5) The inner shock reaching the chamber first wall after passing through the rebounded outer shock.

Discussion

•The outer shock is caused by the slowing down of the Marshak heat front below the ion sound velocity of ~7.43×10^4 cm/s.

- The launching of the second shock occurs at 0.3 ms (point 2) when the front velocity is 7.33×10^4 cm/s
- This double shock has not been observed in previous reactor studies

•The launching of the outer shock produces a compression heat wave that is incident on the first wall at ~2.7 ms (point 3).

•The phenomenon is seen in a target with a 13.2 MJ yield, which is possible to reproduce on NIF.

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[a]E.I. Moses, *Nuc.Fusion*, 49 (10), 2009
[b]Taken from Wikipedia "Inertial Confinement Fusion" page, author Benjamin D. Esham
[c]Private communications with Vincent Tang and Kevin Kramer, LLNL
[d]J.F. Latkowski *et. al*, *Fusion Sci. Tech.*, **60** 54 2011

Parameter Study

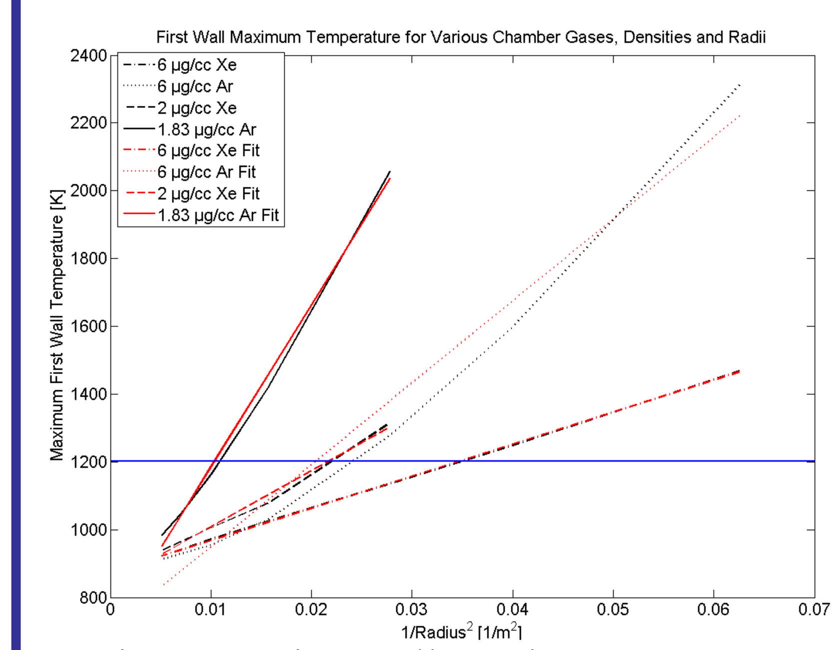

Figure 5: First wall maximum temperatures for simulations (black) and fits (red) for various chamber gases, densities and radii. The blue line represents a safety limit of 1202 K.

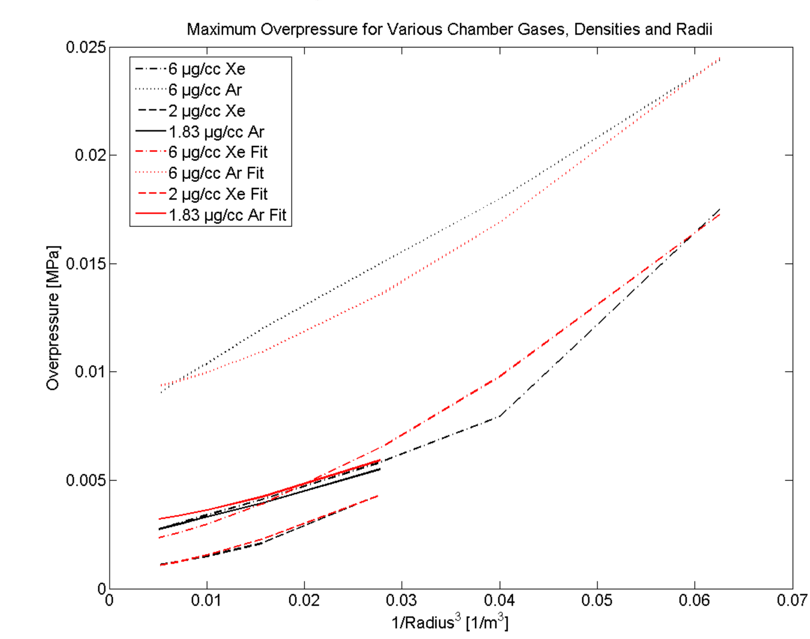

Figure 6: Maximum overpressure for simulations (black) and fits (red) for various chamber gases, densities and radii.

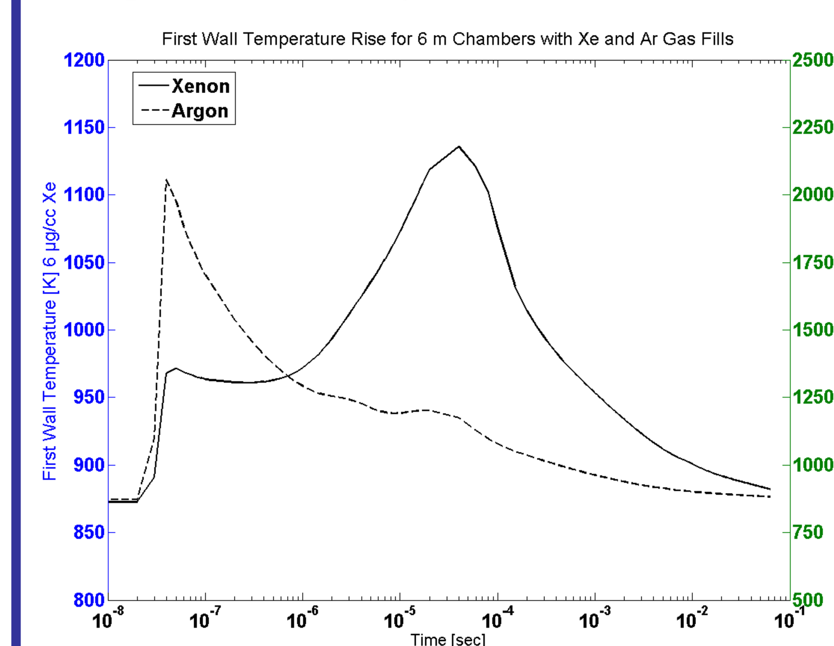

Figure 7: Comparison of first wall temperature rises for 6 meter chambers with 1.83 µg/cc Ar (dashed) and 6 µg/cc Xe (solid) gas fills.

Discussion

•As chamber radius increase both the first wall temperature and the overpressure decrease.

•Ar filled chambers show greater first wall temperature compared to Xe filled chambers due to lower opacity.

- Ar filled chambers also are affected more strongly by the prompt x-ray deposition than Xe filled chambers.

•Fits to maximum temperature and overpressure show good agreement (R^2 of 0.97 or better) and have use in reactor tradeoff studies.

Future Work

•Investigate the effect of mixed gas opacities (Xe-Ar mixtures, atmospheric gas compositions) on the chamber dynamics.
•Investigate the double shock propagation to find what features of the opacity data influence the outer shock generation.
•Add additional physics to the BUCKY code to account for turbulent mixing of chamber gas and target material (BHR mix model).