HYDRODYNAMIC EVOLUTION OF IFE CHAMBERS WITH DIFFERENT PROTECTIVE GASES AND PRE-IGNITION CONDITIONS

Zoran Dragojlovic and Farrokh Najmabadi
University of California in San Diego

Twenty-first IEEE/NPSS Symposium on Fusion Engineering 2005
Motivation/Thesis

• Motivation:
  – To understand the chamber conditions with different fill gases and initial pressures at 100 ms. The emphasis is on Deuterium and Helium as they will always exist in the chamber.
  – To explore the impact of gas temperature on target survival.
  – To explore the deflection of target during injection by velocity drag and pressure gradient.

• Thesis I:
  – Xenon was chosen as fill gas because it easily absorbs and re-radiates the energy released by the target.
  – Deuterium and Helium absorb less energy. They are expected to be “cooler” and thus have less impact on a target.
IFE Chamber Model

- **SPARTAN numerical algorithm:**
  - Godunov solver of Navier-Stokes equations with state dependent transport properties and radiation heat sink.
  - Embedded boundary.
  - Adaptive mesh refinement.

- **Cylindrical Geometry:**
  - Arrays of beam lines around chamber perimeter replaced by a single beam sheet.
  - A beam line placed on top and bottom.

- **Chamber Initial Conditions:**
  - Chamber state after the target blast and before the impact of the pressure wave with the wall is 1-D.
  - 1-D rad-hydro code BUCKY was used to obtain a matrix of initial conditions for the parametric study.

**Chamber dimensions:**
- radius: 6.5 m
- height: 13 m

**Beam sheet dimensions:**
- length: 20 m
- width: 1 m

BUCKY initial conditions
Final Chamber Temperature
Final Temperature Distributions at 100 ms

Deuterium almost reaches the wall temperature. The difference between the contour lines is 20K.
Final Temperatures of Chamber Gas at 100 ms

Base pressure < 50 mTorr

- Deuterium at both base pressures has a nearly uniform temperature, within 30-40 K from the equilibrium with the wall.

- Average temperature of the Helium is within 200 K from the wall temperature, only the central hot region stands out.

- Even at 3 mTorr, Xenon is considerably hot ($T_{\text{max}} \sim 3000$ K). Reducing the base pressure from 50 mTorr (as shown on the right) to 3 mTorr (as shown on the left) does not help to bring Xe to the thermal equilibrium with the wall.

Base pressure = 50 mTorr
Thermal Regimes in The Chamber

- The initial temperatures are different because the initial conditions are taken at different times.
- Heating due to shockwave compression and subsequent cooling by radiation govern the chamber temperatures in the first millisecond.
- The exponentially decaying parts of the curves correspond to "free cooling".
Final Chamber Velocities
Initially, Deuterium has a much higher velocity than Xenon, due to its lower mass. At 50 mTorr, the peak velocity of Xenon is 2.6 km/s, while the peak velocity of Deuterium is 60 km/s.
Even though the initial velocity of Deuterium was much higher than Xenon, final velocity of Deuterium is similar to that of Xenon, due to the lower final temperature of Deuterium.

Xenon at 50 mTorr shows turbulence – note the “smoky” features. The Reynolds number for this case is 8,600. For all the other cases, the Re ~ 100.
Impact on the Target
Acceleration of Target Due to Drag Force at 100 ms

Base pressure < 50 mTorr

Base pressure = 50 mTorr

• Accelerations are based on velocity field in the chamber (excluding beam lines), gas viscosity, target diameter of 4 mm and target mass of 4.8 milligrams.

• Drag force depends on gas velocity and viscosity. Acceleration of target by Deuterium is smaller than that of Xenon at the same base pressure because the viscosity of Xenon is 5 times higher than viscosity of Deuterium.

• At 3 mTorr, Xenon exerts a drag force on the target, comparable to D and He at ten times higher base pressures.
• Only Deuterium returns to within several pascals from the base pressure, 100 ms after the target ignition.

• Chamber gas pressures of Deuterium and Helium gas are nearly uniform (min ≈ ave ≈ max), while Xenon at base pressure 50 mTorr is highly non-uniform (max/min ≈ 3).
• Accelerations are based on the pressure gradients in the chamber (excluding beam lines), target diameter of 4 mm and target mass of 4.8 milligrams.

• The acceleration of target due to pressure gradients is negligible compared to the acceleration caused by drag force.
Conclusions

• Deuterium and Helium have low impact on the target, at base pressures in the range of 30-50 mTorr.
  – Deuterium cools down to the wall temperature within the 100 ms. Helium remains slightly hotter in the center of the chamber but approaches the equilibrium with the wall, on the average.
  – The flow of D and He is laminar and does not significantly deflect the target from its path.

• Xenon has a significant impact on the target even at base pressures as low as 3 mTorr.
  – The temperature of Xenon is above the specs for target survival at 100 ms past the target blast.
  – The drag force of Xenon acting on the target is comparable to Deuterium and Helium at ten times higher base pressure.