Progress Report on Chamber Clearing Code Development Effort

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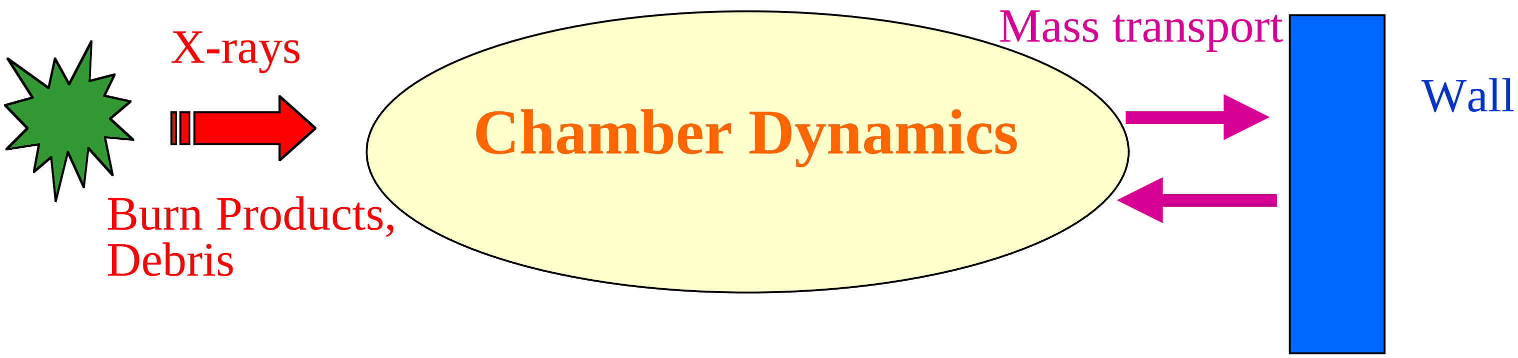
Strategy Include Careful Planning and Analysis Effort for Most Efficient Code Development

- **Form team (UCSD, INEEL, ANL) and clearly define responsibilities** 4
- **Identify major processes, evolve model and determine key variables** 4
- **Perform scoping calculations to assess relative importance of competing parameters and help prioritize inclusion of different processes in computer code** 4
- **Planning of code development includes:** 4
  - **Evolving overall code architecture**
  - **Identifying numerical solver package (already coded)**
  - **Identifying and assessing existing codes for calibration purposes of controlled cases, e.g.**
    - **CFDRC**
    - **HEIGHTS**
    - **RECON**
- **Code implementation and integration of packages**

Team Assembled to Focus on Different Modules of the Chamber Physics and Clearing Code



INEEL

Chamber Mass Transport Module, including:

- **In-flight condensation**
- **Aerosol formation and transport**

Progress reported by: P. Sharpe

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UCSD

Main Module, including:

- **Geometry**
- **Input/output interface**
- **Cavity hydrodynamics**
- **Energy Deposition**
- **Heat Transfer**

Progress reported by: R. Raffray

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ANL

Chamber Wall Interaction Module, including:

- **Vaporization, melting & condensation**
- **Sputtering**
- **Thermo-mechanics & macroscopic erosion**

Progress reported by: A. Hassanein

Major Processes Have Been Identified and Modeled
e.g. Surface Vaporization

Physics	Kinetic model based on surface temperature, activation energies and su rface conditions.
Model	● Velocity of receding surface from surface vaporization, V(T), is a highly nonlinear function of surface temperature (T) and is given by: $$V(T) = 5.8\text{x}10^{-2} \frac{\alpha \sqrt{A}\, P_V(T)}{\rho(T)\sqrt{T}} \left[0.8 + 0.2e^{-t/10\tau_c} \right] \quad cm/s$$ where α = sticking probability or accommodation coefficient ($\approx$ 1) A = atomic mass number of target material P_V = vapor pressure of target material (torr) τ = vapor collision frequency (s^{-1}) ρ = density of wall material
Key Parameters	Surface temperature and accommodation coefficient.
Key Uncertainties	Comparison of simple equilibrium- basis equation with dynamic case; might require correction terms.
Relative Importance	One of major mechanism for chamber wall erosion.
Time-Scale	Comparable to energy-deposition time-scale
Spatial Location	Wall surface.
Inter-relation with Other Processes	All processes affecting surface temperature evolution (i.e. energy deposition; thermal diffusion, condensation)
Inclusion in Model	Above model is included from the start.

Scoping Calculations Performed to Assess Importance of Different Effects and Conditions

- **Chamber Gas**
  - **At high temperature (> ~ 1 ev), radiation from ionized gas can be effective**
  - **In the lower temperature range (~ 5000K back to preshot conditions)**
    - **Conduction (neutrals and some electrons)**
    - **Convection**
    - **Radiation from neutrals**
    - **Other processes?**
  - **The temperature of the gas might not equilibrate with the wall temperature**
    - **May have implications for target injection**
  - **Xe at low pressure (~10-50 mTorr) might not be effective in reducing ion energy deposition and flux on chamber wall**

- **Other scoping calculations**
  - **Chamber mass transport (presented by P. Sharpe)**
  - **Chamber wall interaction (presented by A. Hassanein)**

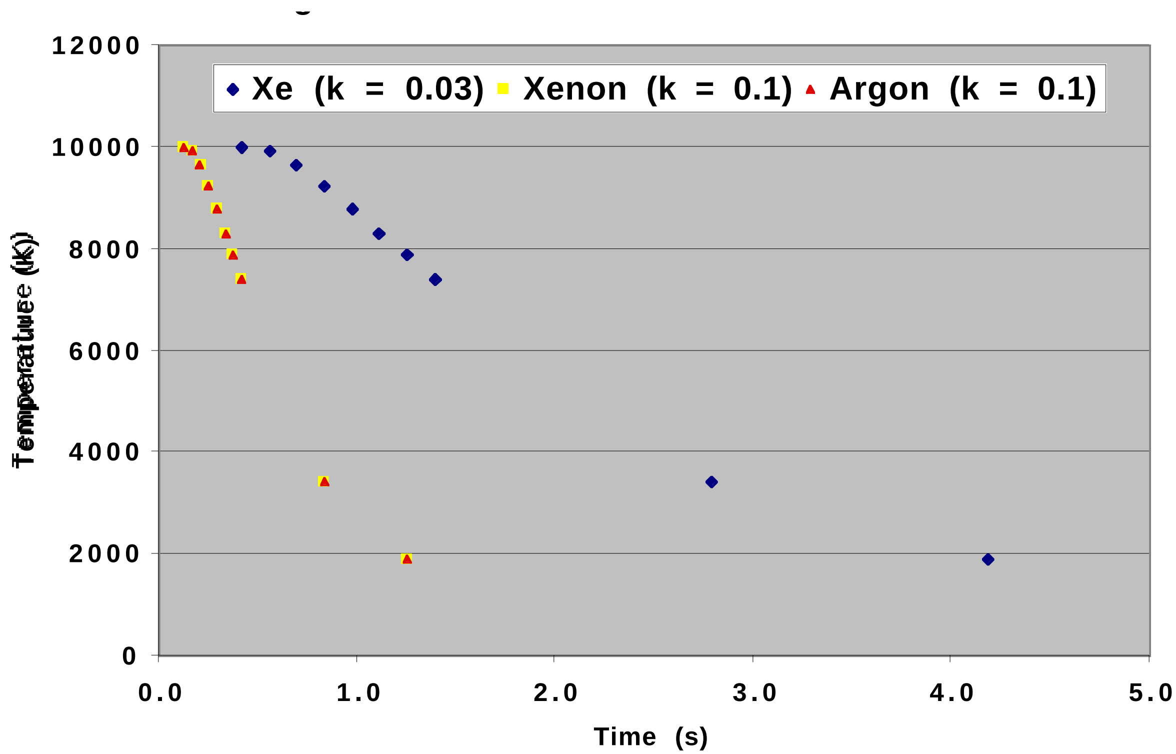
Effectiveness of Conduction Heat Transfer to Cool Chamber Gas to Preshot Conditions

- Simple transient conduction equation for a sphere containing gas with an isothermal boundary condition(T_w)
  - k_{Xe} is poor (~0.015 W/m-K at 1000K, and ~0.043 W/m-K at 5000 K)
  - At higher temperature electron conductivity of ionized gas in chamber will help
    (assumed ~ 0.1 W/m-K for $n_e = n_o$ and 10, 000 K)
  - Argon better conducting gas

- T decreases from 5000K to 2000K in ~2 s for k_g = 0.03 W/m-K

- Even if k_g is increased to 0.1 W/m-K, it does not help much (~ 0.6 s)

Temperature History Based on Conduction from 50 mTorr Gas in a 5 m Chamber to a 1000K Wall

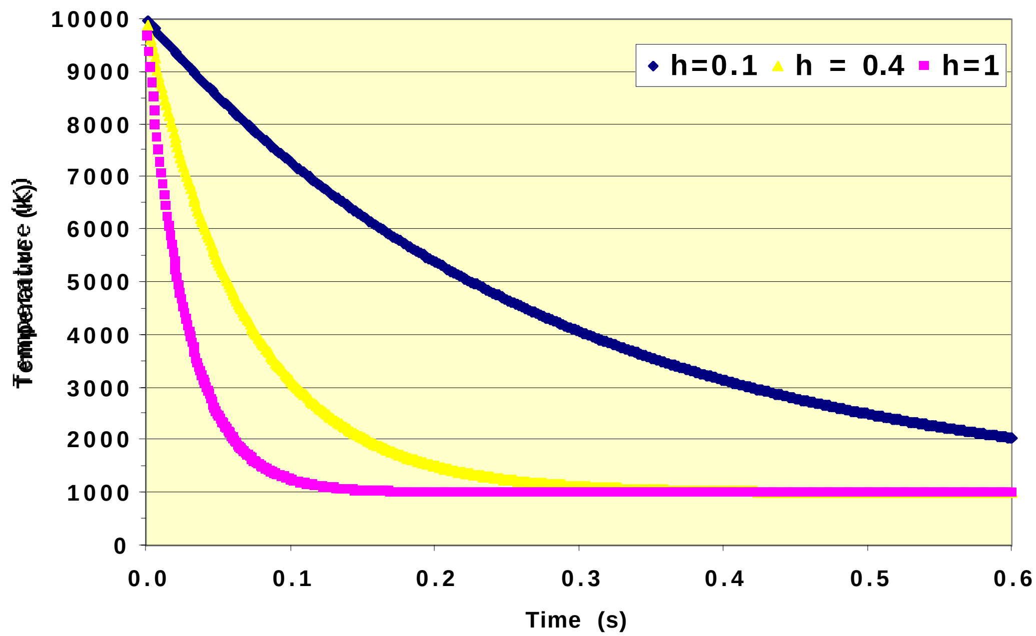


UCSD

Effectiveness of Convection Heat Transfer to Cool Chamber Gas to Preshot Conditions

- Simple convection estimate based on flow on a flat surface with the fluid at uniform temperature
- Use Xe fluid properties
- Assume sonic velocity
  - c ~ 500 m/s
  - Re ~ 700 for L = 1 m
  - Nu ~ 13
  - h ~ 0.4 W/m^2-K
- Lower velocity would result in lower h but local eddies would help
  - Set h between 0.1 and 1 W/m^2-K representing an example range
- T decreases from 5000K to 2000K, in ~0.1 s for h = 0.4 W/m^2-K
- Increasing h to 1 W/m^2-K helps but any reduction in h rapidly worsens the situation (e.g. ~0.4 s for 0.1 W/m^2-K)

Temperature History Based on Convection from 50 mTorr Gas in a 5 m Chamber to a 1000K Wall



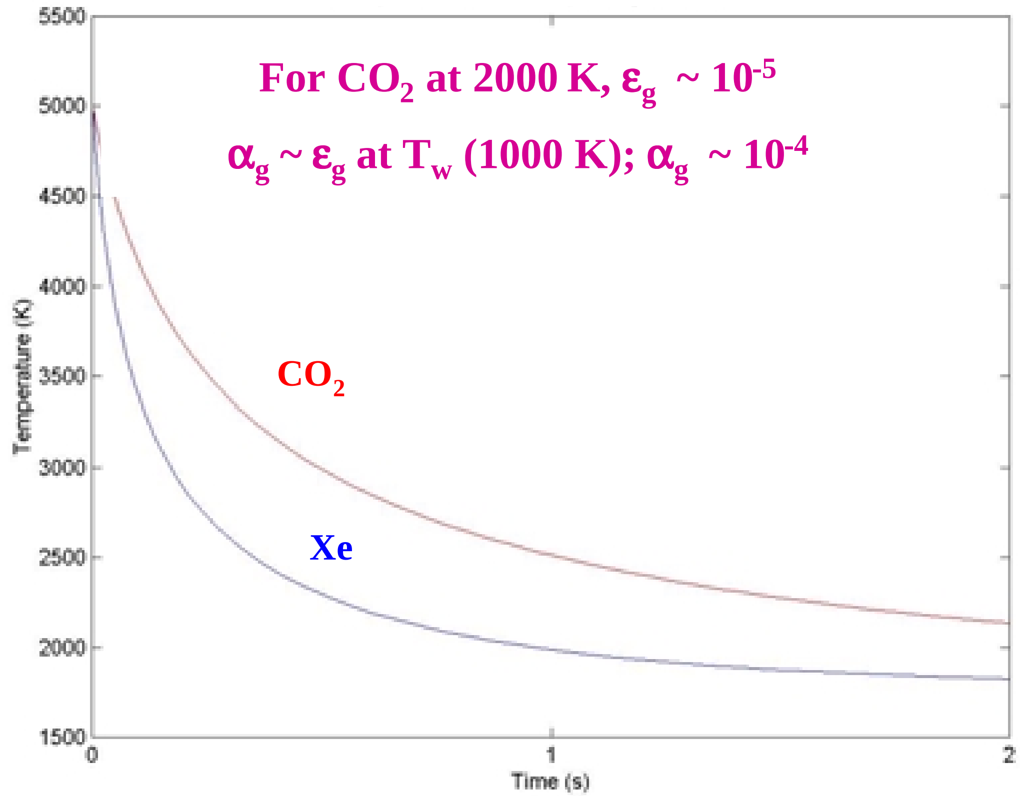
Effectiveness of Radiation Heat Transfer to Cool Chamber Gas from Mid-level Temperature (~5000K) to Preshot Conditions

- **Xe is monoatomic and has poor radiation properties**
  - Complete radiation model quite complex
  - Simple engineering estimate for scoping calculations
  - No emissivity data found for Xe
  - Simple conservative estimate for Xe using CO_2 radiation data

  - T decreases from 5000K to 2000K, in ~1 s
    (would be worse for actual Xe radiation properties)

$$q_r'' = \sigma \varepsilon_w (\varepsilon_g T_g^4 - \alpha_g T_w^4)$$

Temperature History Based on Radiation from 50 mTorr Gas in a 5 m Chamber to a 1000K Wall



Effectiveness of Heat Transfer Processes to Cool Chamber Gas (Xe) to Preshot Conditions is Poor

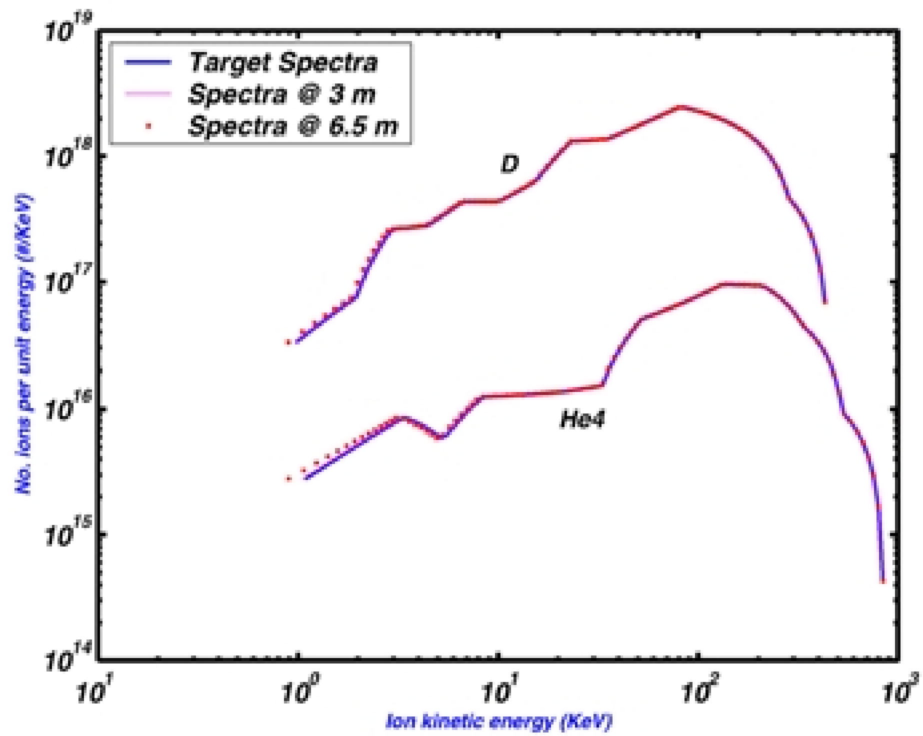
Conservative estimate of Xe temperature (K) following heat transfer from 5000K

Time:	0.1 s	0.2 s	0.5s	~1 s
Conduction:				
k=0.03 W/m-K	4700	4500	3600	2700
k=0.1 W/m-K	3900	3200	2200	1500
Convection:				
h=0.1 W/m^2-K	3800	3000	1650	1200
h=0.4 W/m^2-K	1950	1220	~1000	
h=1 W/m^2-K	*1250*			
Xe Radiation:				
(assum. CO_2 ε and α)	3500	2850	2300	2200

- **Only possibility is convection with high velocity and small length scales (optimistic requiring enhancement mechanisms) and/or appreciable gas inventory change per shot (by pumping)**
- **Background plasma in the chamber might help in enhancing heat transfer (e.g. electron heat conduction, recombination)**

Effectiveness of Chamber Gas (Xe) to Attenuate Ions (e.g. D and He from Direct Drive Target Spectra) is Poor at Low Pressure (~10-50 mTorr)

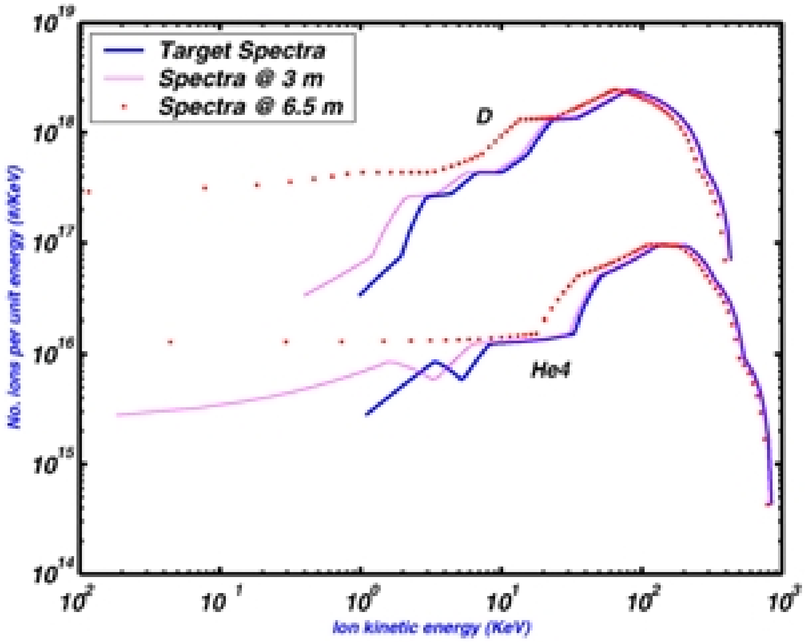
e.g. ~10 mTorr Xe



- **Energy attenuation and ion flux decrease marginal**
  - **Minor effect on wall temperature and erosion**
  - **Minor effect on reducing energy and number of ions potentially causing damage on long term armor integrity**

Effectiveness of Chamber Gas (Xe) at Higher Pressure to Attenuate Ions (e.g. D and He from Direct Drive Target Spectra)

e.g. ~100 mTorr Xe



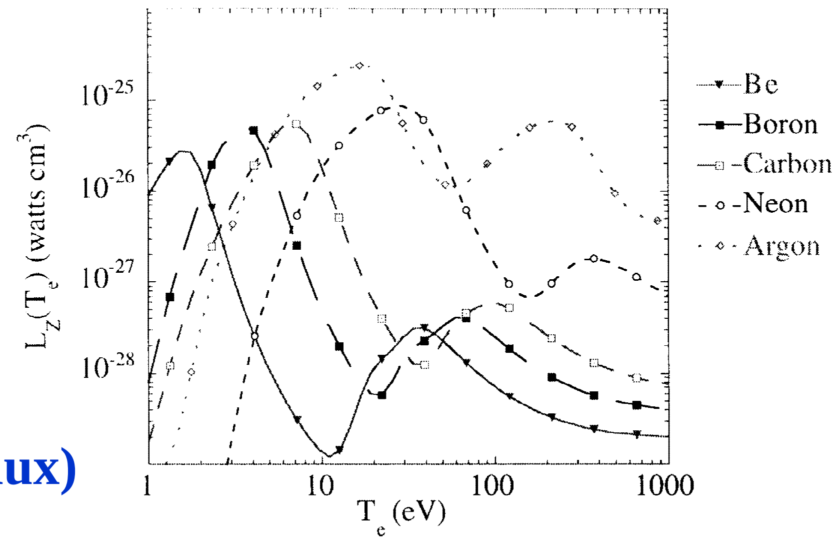
- **Effect on energy attenuation and ion flux decrease becomes significant for gas pressures > ~100 mTorr**

- **Ion attenuation would be markedly enhanced by the presence of ionized gas in the chamber (electron slowing down, collective processes?)**

Plasma Effect Could Help?

- **Need to include impact of plasma on chamber self consistently**

- **Increase in heat transfer**
  - **Recombination processes**
  - **Enhanced radiation**
  - **Electron conductivity**



- **Increase in stopping power (reduce ion flux)**

- **Zero dimensional plasma scoping model to understand relative importance of these effects (just started)**
  - **Cannot assume that system in equilibrium**

Why Xe?

- **Low pressure Xe gas as a neutral will not be effective**
  - Poor heat transfer capability
  - No appreciable reduction in flux and energy of ions
- **If a low pressure gas is needed why not consider another gas based on:**
  - **Minimizing species in chamber**
  - **Facilitating pumping**
  - **Minimizing laser breakdown**
  - **Better heat transfer (more effective chamber gas temperature relaxation)**
- **Tendency to settle on previous design and material choices**
- **It is healthy to reconsider reasons behind some of these choices**
  - **e.g. study starting from fundamental issues to determine which chamber gas to use**

Concluding Remarks on Chamber Physics and Clearing Effort

- **Team has been assembled and responsibilities defined**
- **Major processes, relevant models and key variables have been identified**
- **Several lessons from initial effort**
  - **Chamber physics processes very complex**
  - **Need to understand and characterize them for effective code development**
- **Scoping calculations have been performed and relative importance of processes and parameters assessed**
  - **Poor heat transfer performance and minor ion attenuation effect of low-P neutral Xe gas**
  - **Why Xe?**
  - **Choice of gas should be made on other considerations, such as:**
    - **Pumping**
    - **Minimizing chamber constituents**
    - **Chamber gas temperature relaxation**
    - **Laser breakdown**
- **Plasma effects might help (zero-D model for scoping calculations)**
- **Proceeding with Code implementation**