

Chamber Dynamics and Clearing

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Electronic copy: <http://aries.ucsd.edu/najmabadi/TALKS>
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Statement of Purpose and Deliverables

➤ **Statement of Work:**

- ✓ Initiate development of a fully integrated computer code to model and study chamber dynamic and clearing. Deliver the core of the code including the input/output interfaces, the geometry definition and the numerical solution control for multi-species (multi-fluid), 2-D transient compressible Navier Stokes equations. Provide chamber wall-interaction modules, which include physics of melting; evaporation and sublimation; sputtering; macroscopic erosion; and condensation and redeposition.
- ✓ Scope the range of chamber dynamics and clearing experiments that can be carried out in a facility producing 100-10,000 J of X-ray.

➤ **Deliverables:**

- ✓ The core of the code including the input/output interfaces, the geometry definition and the numerical solution control, and 2-D hydrodynamics module: Oct. 1, 2001
- ✓ Implementation of various physics modules: Jan. 31, 2002
- ✓ Experimental plans: Jan. 31, 2002

➤ **Budget:** Code development: (190k UCSD, 175k ANL), Experiment planning (75k UCSD)

Understanding Chamber Dynamics and Clearing is a Critical R&D Item

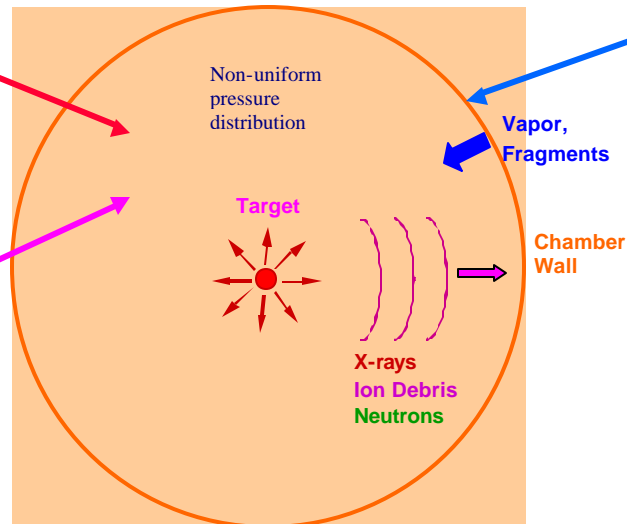
- The rep-rate is limited by the time it takes for the chamber environment to return to a **sufficiently quiescent and clean, low-pressure state** following a target explosion to allow a second shot to be initiated (goal: 100-200 ms).
- Many complex phenomena should be understood and modeled.

Gas dynamics:

- ✓ Compressible
- ✓ Radiation heat transport
- ✓ Dissipative processes
- ✓ ...

Volume interactions:

- ✓ In-flight evaporation
- ✓ In-flight re-condensation
- ✓ Chemistry
- ✓ ...



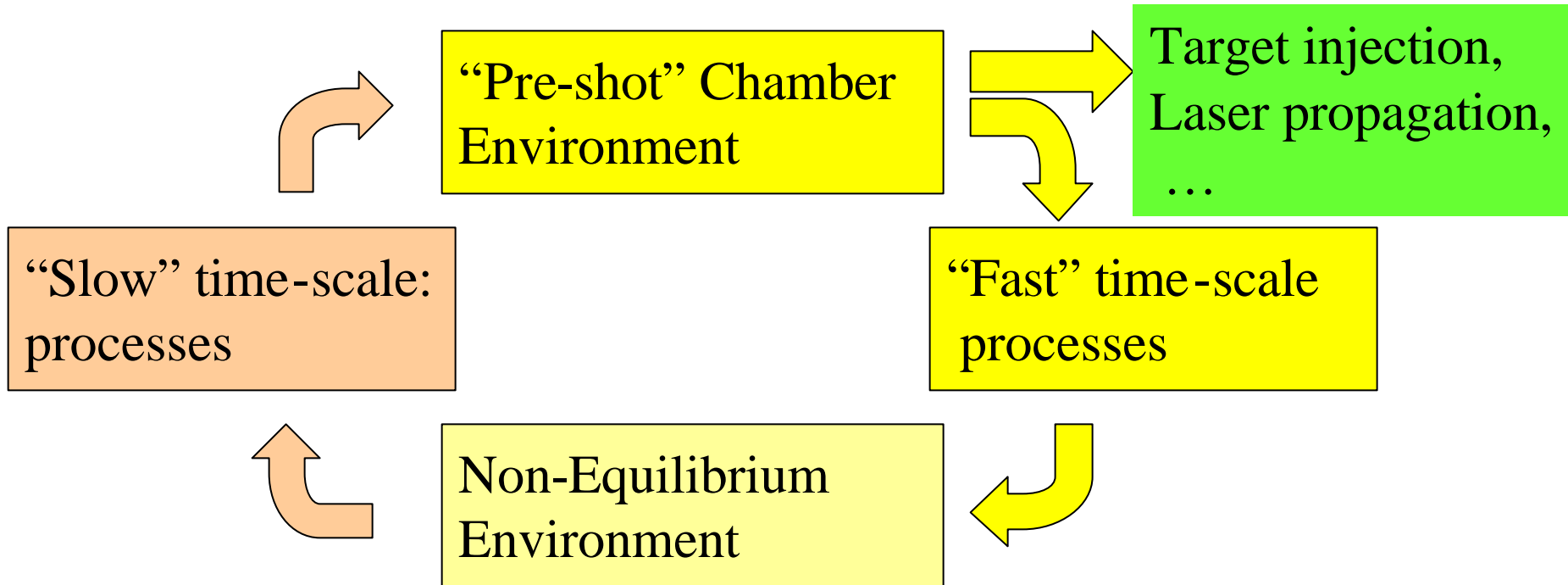
Surface Physics:

- ✓ Melting & melt layer behavior
- ✓ Evaporation/sublimation
- ✓ Sputtering
- ✓ Macroscopic erosion
- ✓ Condensation and redeposition
- ✓ ...

Response of Chamber to Target Explosion Covers Two Vastly Different Time Scales

- “First pass” of target-released energy through the chamber – “fast” time scale (ns to several μs).
 - ✓ Propagation of X-rays and ions through the chamber;
 - ✓ Re-radiation of the ions & X-ray energy deposited in the chamber gas.
 - ✓ At the completion of this phase, chamber volume is in a non-equilibrium state and material is released from the wall.
- Relaxation of chamber environment to a equilibrium state – “slow” time scale (several μs to hundreds of ms).
 - ✓ Mass and heat transport in the chamber & to/from chamber wall
 - ✓ Relaxation to “residual” chamber environment (“pre-shot” environment)
 - ✓ The “pre-shot” environment affects target injection & tracking, laser propagation, ...

Response of Chamber to Target Explosion Covers Two Vastly Different Time Scales



- Codes such as TSUNAMI (2-D) and DSMC (3-D)
- Previous research is mainly for thick liquid walls

- 1-D Codes such as Bucky & Ablator
- Experiments such as shots on Z

TSUNAMI & DSMC Codes Have Been Used for Chamber Clearing Modeling

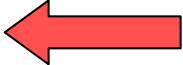
- TSUNAMI (UC Berkeley) :
 - ✓ 2-D gas-dynamic equations with no viscosity, no heat conduction (not important), no radiation heat transport,
 - ✓ Relatively simple wall boundary conditions: p =saturated vapor pressure, $u=0$, and n derived from EOS in the outer cell,
 - ✓ Mainly exercised for thick liquid wall concepts,
 - ✓ Used to model solid wall chambers as Master thesis by one our students.
- DSMC* (NASA):
 - ✓ DSMC solves Boltzman's equation via Monte Carlo Method
 - ✓ Used by ILE researchers to model KOYO chamber (wetted wall concept)
 - ✓ Results were compared with TSUNAMI models

* <http://abweb.larc.nasa.gov:8080/~wilmoth/dsmc.html>

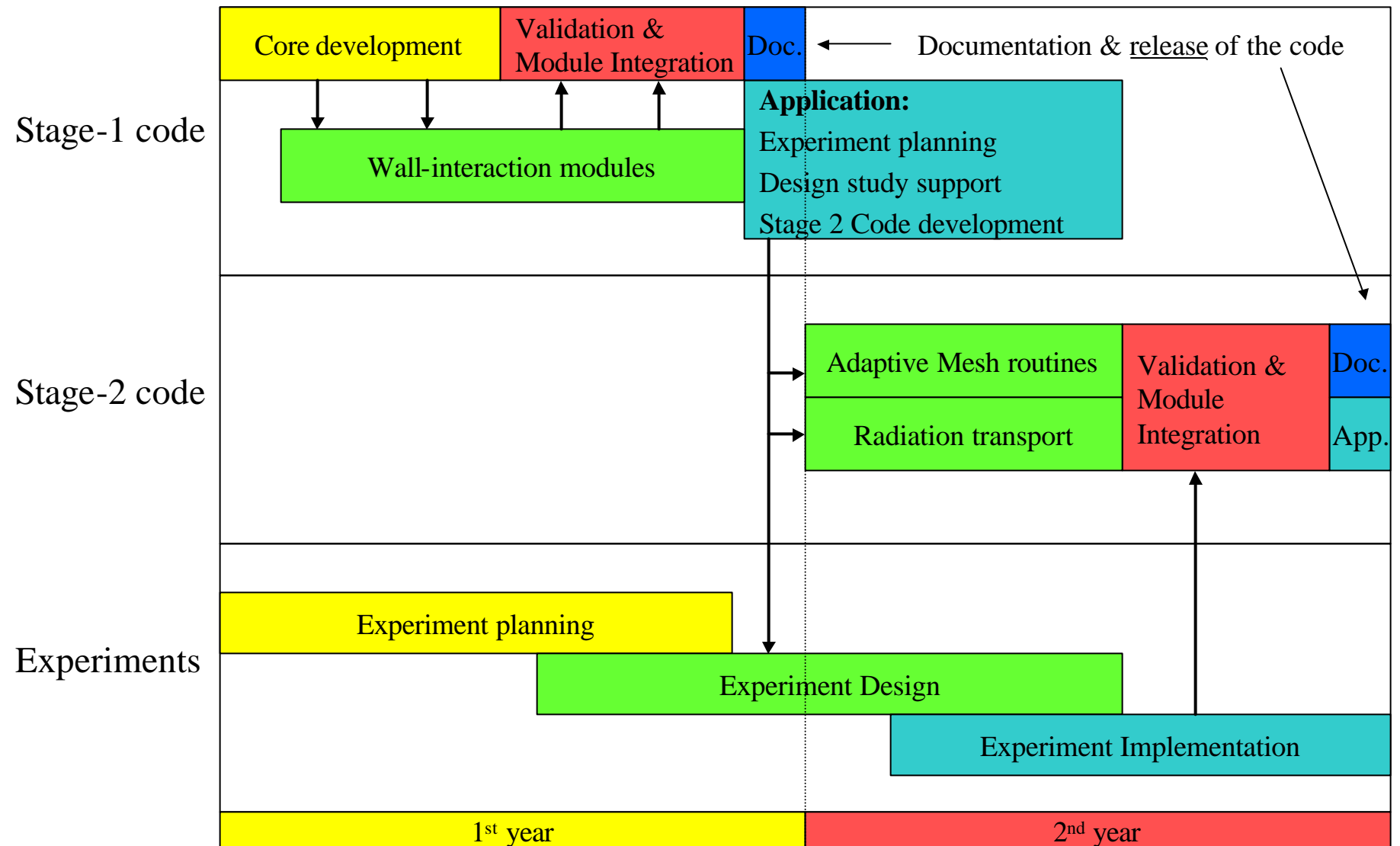
Review of Previous Work

- Literature survey of work with TSUNAMI & DSMC indicates:
 - ✓ It is essential to include proper **initial condition** (energy distribution in the chamber) and **boundary conditions** (wall interaction). Most of the work, however, used simple models and approximations for initial and boundary conditions.
 - ✓ It is essential to include **multi-dimensional** effects (UCB, ILE, UCSD work).
 - ✓ Need to include **viscosity** (ILE, UCSD work) and radiation transport.
- Large body of work in the past 10 years on Computational Fluid Dynamics: relevant to chamber dynamics & clearing: Flame front propagation and combustion, Aerospace plane, ...
 - ✓ Most large scale codes use variation of CGF algorithm with adaptive mesh techniques.
- Simulation experiments to benchmark calculations and validate physics models are essential.

Chamber Dynamics and Clearing Code Development Is Broken Into Three Stages

- Stage 1:  This year proposal
- ✓ Code infrastructure: module definitions and interfaces, I/O, geometry definition,
 - ✓ Transient compressible Navier Stokes solver (most tests on simple 2-D geometries) including dissipative effects,
 - ✓ Simple model for radiation transport,
 - ✓ Use results from BUCKY as initial condition,
 - ✓ Develop detailed wall-interaction modules (boundary conditions).
- Stage 2:
- ✓ Adaptive mesh routines, most tests with simple and/or complex 2-D shapes.
 - ✓ Detailed radiation transport model,
 - ✓ New physics modules based on stage 1 code results and experiments
- Stage 3:
- ✓ Tuning the code for complex 3-D geometries
 - ✓ New physics modules based on stage 2 code results and experiments

Breakdown of Chamber Clearing Research



Components of Stage 1 Chamber Dynamics and Clearing Code

- Transient compressible Navier Stokes solver:
 - ✓ CFG algorithm-based numerical routines.
- Mesh construction routines:
 - ✓ Map simple 2-D physical domain(s) with regular boundaries (*e.g.*, cylinders) into rectangular logical meshes.
 - ✓ Gross mesh adaptation routines will be tested and implemented in stage 1.
- Radiation transport:
 - ✓ Simple radiation transport model based on implicit time stepping.
- Wall-interaction modules (led by ANL):
 - ✓ Melting & melt-layer behavior
 - ✓ Evaporation & sublimation
 - ✓ Sputtering
 - ✓ Macroscopic erosion
 - ✓ Condensation & redeposition
- Module definition & interfaces (C++)

Chamber Dynamics Simulation Experiment – Exploration and Planning

- Simulation experiments are essential to
 - ✓ Benchmark simulation codes;
 - ✓ Ensure all relevant physical phenomena is taken into account
- Relatively new field. Previous experimental work focused on shock propagation and/or condensation of wetted chamber walls.
- Eventually, we need scaled experiments to screen concepts for implementation on IRE.
- Two major areas should be investigated first:
 1. A source of energy to produce prototypical environment for experimentation,
 2. Experiment characterization and array of diagnostics.

Scaled Simulation Experiments can Help Address Many Chamber Issues

1–10 J

- Beam propagation and focusing
- Near-surface physics
- Diagnostic development and experimental techniques

100–500 J

- Large-volume tests for geometrically prototypical testing

1–10 kJ

- Integrated (simultaneous) surface and volume effects
- Chamber dynamics in limited volume (~1 liter)

>10 MJ

Incl. neutrons

- Integrated prototypical chamber testing

- Possible clean sources of energy include lasers and plasma focus

Chamber Dynamics Simulation Experiment – Experimental Characterization and Diagnostics

- Chamber responses include transient temperatures, pressures, mass composition and physical forms in the chamber volume.
- Three distinct time scales:
 - ✓ Target yield and instantaneous surface response (\sim ns time scale),
 - ✓ Gas-dynamics (10-100 μ s),
 - ✓ Thermal recovery (1-100 ms).
- For example, possible methods for temperature measurement:
 - ✓ Fast time scale: optical spectroscopy?
 - ✓ Gas dynamics & thermal recovery: high-temperature thermal sensors located directly in the medium?
 - ✓ Chamber wall temperature: IR camera?

Long-term goal of this proposal is to develop a predictive capability for chamber dynamics and clearing (available for IRE)

➤ Such a predictive capability requires:

- ✓ Computer simulation of increasing sophistication;
- ✓ Simulation experiments to bench mark the core and ensure that all relevant phenomena are taken into account.

➤ Our Approach:

- ✓ Problem is complex and includes diverse phenomena. A joint proposal from UCSD and ANL to initiate the activity. We encourage and welcome collaborations.
- ✓ Utilize expertise in CFD community, import best numerical algorithms and focus on understanding phenomena relevant to high-average power laser chambers.
- ✓ Staged approach to code development and experiment planning: Clear deliverables at each stage and simulation/experiments progress sets development priorities for next stages.