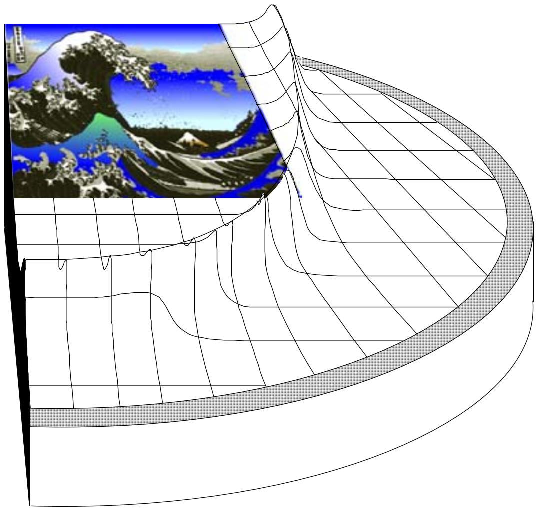
Gas Transport and Control: Challenges, Opportunities, and Plans for the Future



Christophe S. Debonnel[1,2]

(1) Thermal Hydraulics Laboratory
Department of Nuclear Engineering
University of California, Berkeley

(2) Lawrence Berkeley National Laboratory
Heavy-Ion Inertial Fusion Virtual National Laboratory

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Outline

•**Part I:** ***Gas Transport and Control, Challenges, and Opportunities---a Review***

- **Why? How? Can it work?**

•**Part II:** ***Development of Efficient Radiation Hydrodynamics Codes for Thick-Liquid Protected Inertial Fusion Target Chambers and Beam Tubes***

- **Methodology**
- **Physical models**
- **Boundary conditions**
- **Initial conditions**

Part I

- ***Gas Transport and Control, Challenges, and Opportunities---a Review***

Motivation

- **Target chamber density control**
  - **Beam (and target) propagation sets stringent requirements for the background gas density (>1 ms)**
  - **Pocket response and disruption---too high an impulse would make design of a cheap liquid pocket too challenging (<1 ms)**

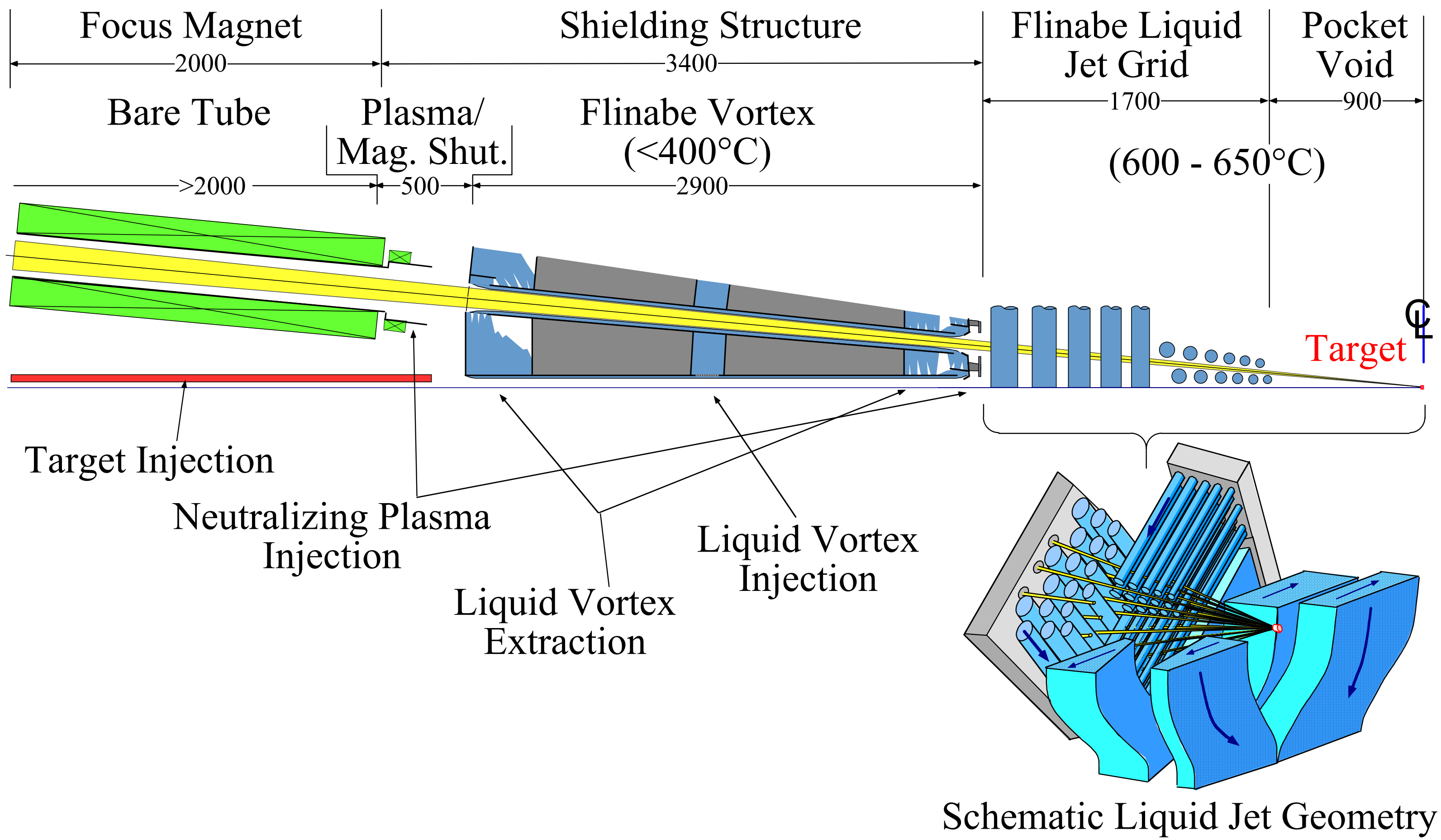
- **Beam tube density control**
  - **Beam propagation requirements (> 1 ms)**
  - **Debris deposition in final-focus magnet region may cause arcing with the high space-charged beams and must be alleviated (all the time!)**

Strategies to control gas density (<1 ms)

- **Design efficient target chamber structures (pocket with venting path, cylindrical jet array): Debris should vent towards condensing surfaces (droplets), so that mass and energy fluxes at the entrance of beam ports are as low as possible**

- **A new beam tube: vortex and magnetic shutters**

The Robust Point Design (RPD-2002) beam line



TSUNAMI

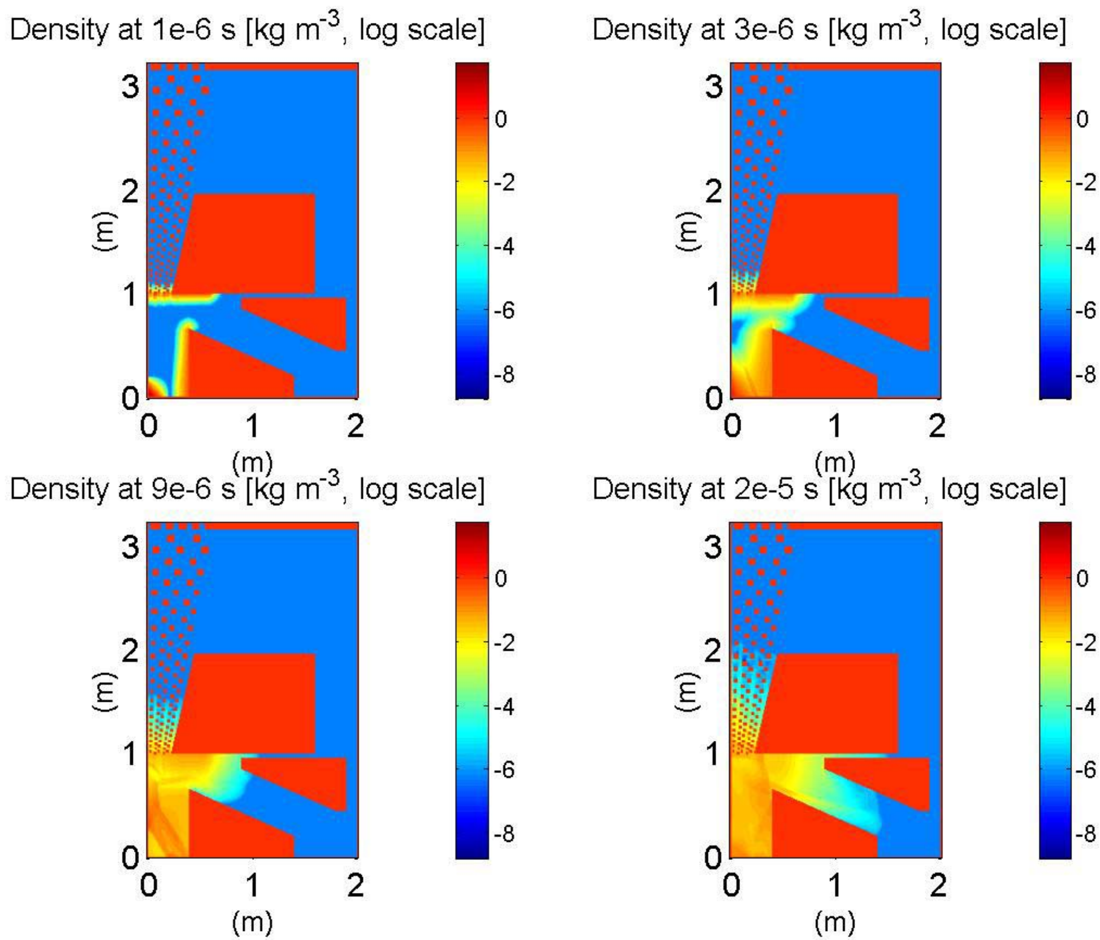
- TranSient Upwind Numerical Analysis Method for Inertial confinement fusion

- Gas dynamics

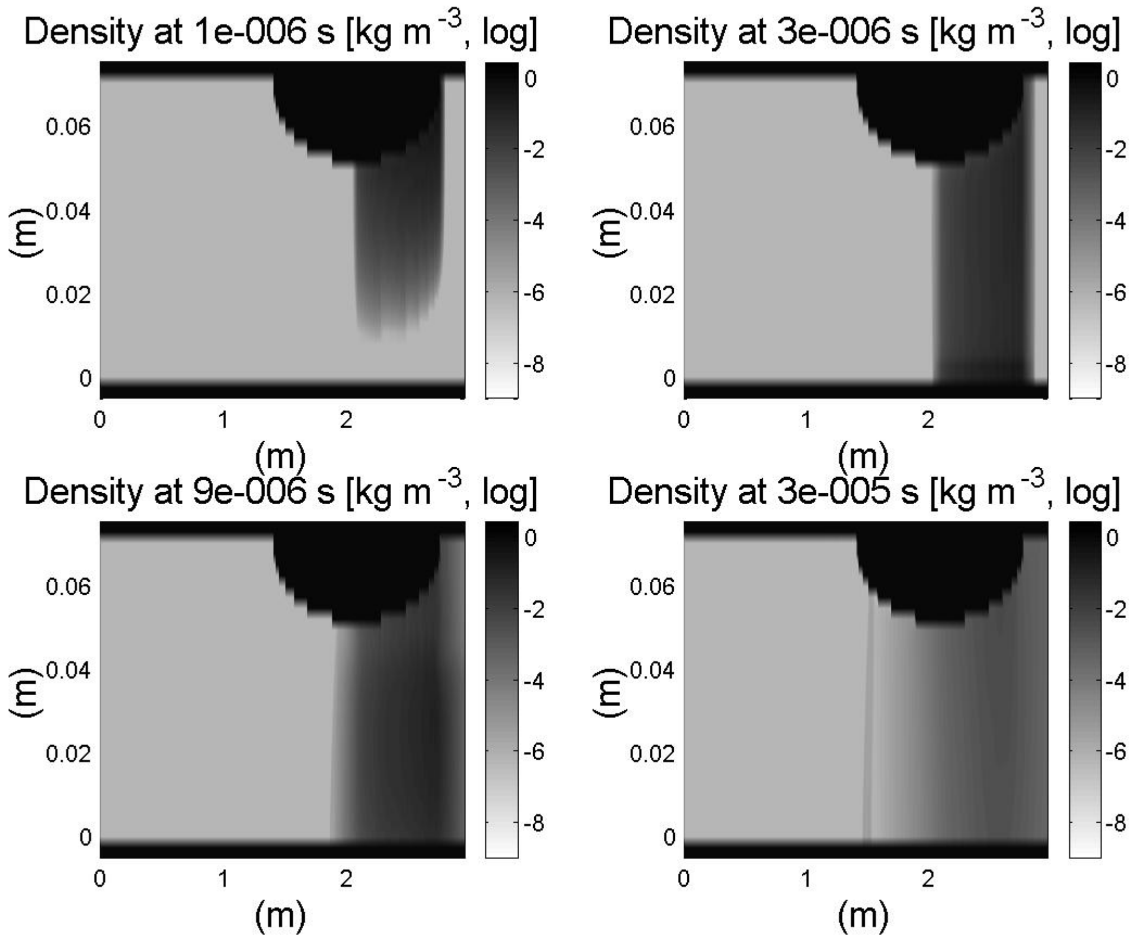
- Solves Euler equations for compressible flows;
- Real gas equation (adapted from Chen's---includes Zaghloul's correction)
- Two-dimensional

- User-friendly input files builder and output files processsor
- Taylored to model HYLIFE-II type of geometry (RPD-2002)

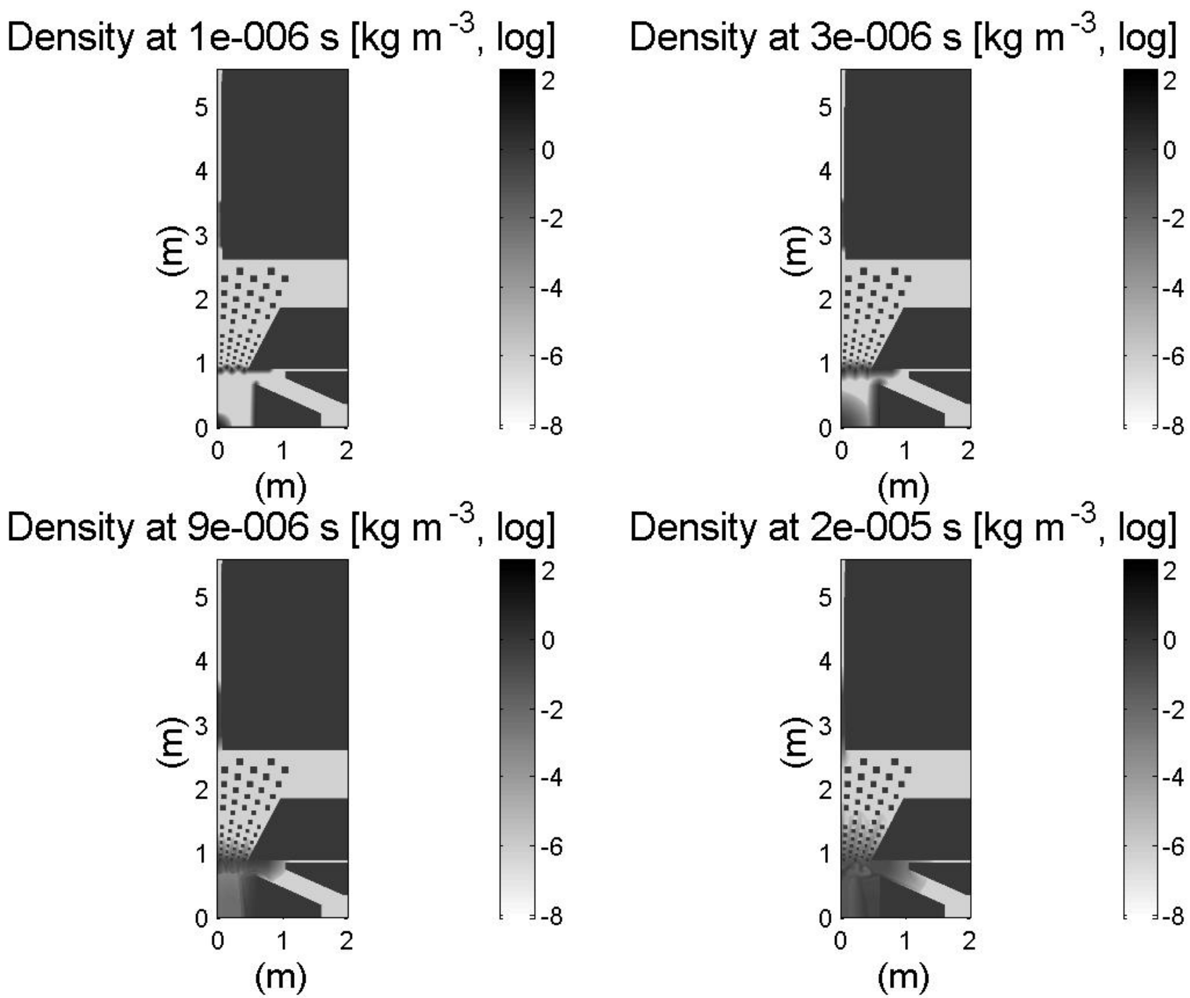
Target chamber simulations



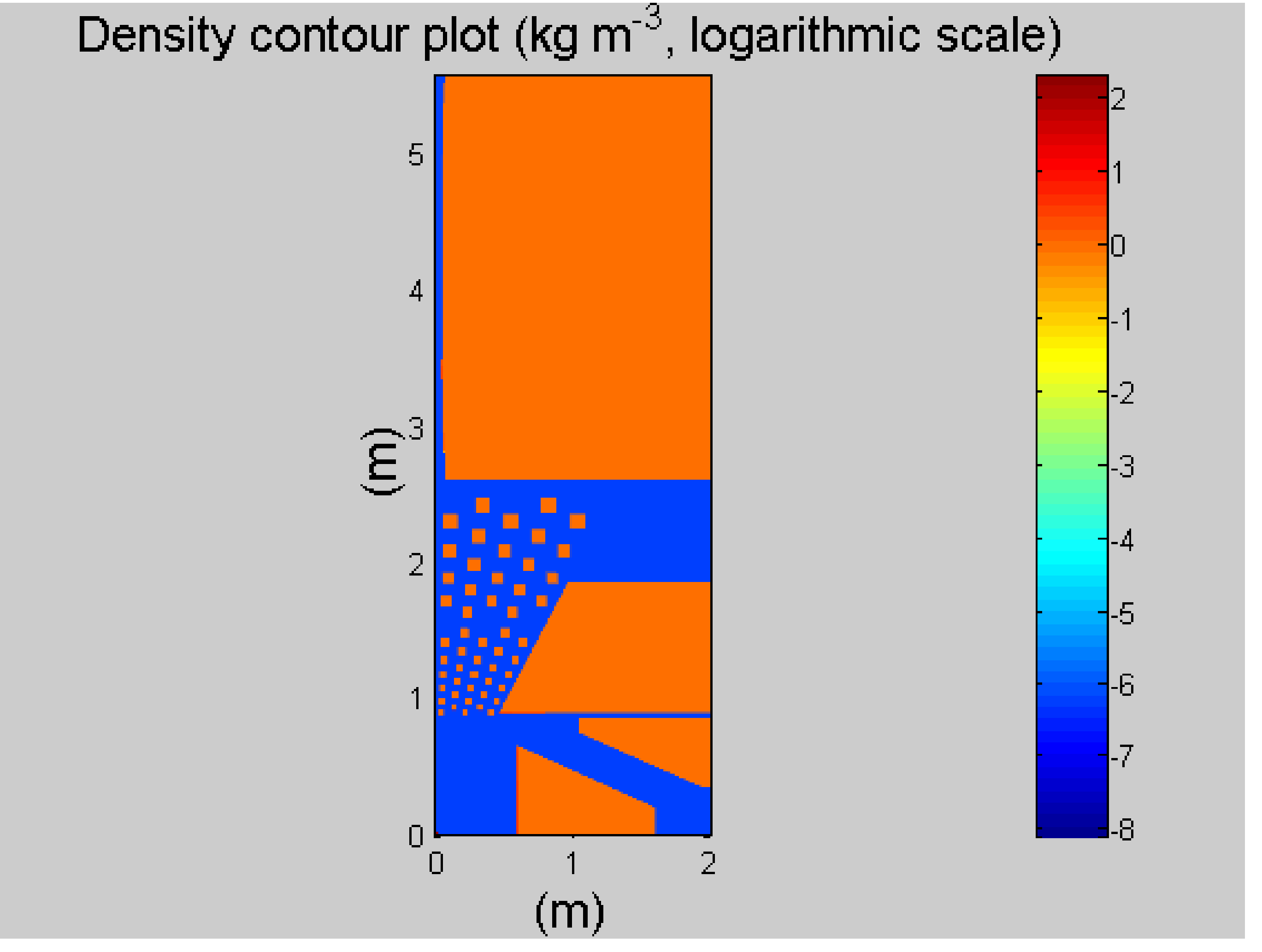
Beam tube simulations



RPD-2002: TSUNAMI Density Contour Plots



Movie time?


Density contour plot (kg m-3, logarithmic scale)
(m)
(m)
0
1
2
3
4
5
0
1
2
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8

Simulations Results

- Impulse load to pocket OK
- Mass and energy fluxes past vortex low, but not low enough
- Magnetic shutters
    - LSP simulations: order of magnitude of B field OK
    - Can be corrected for
    - May be determined by beam neutralization physics

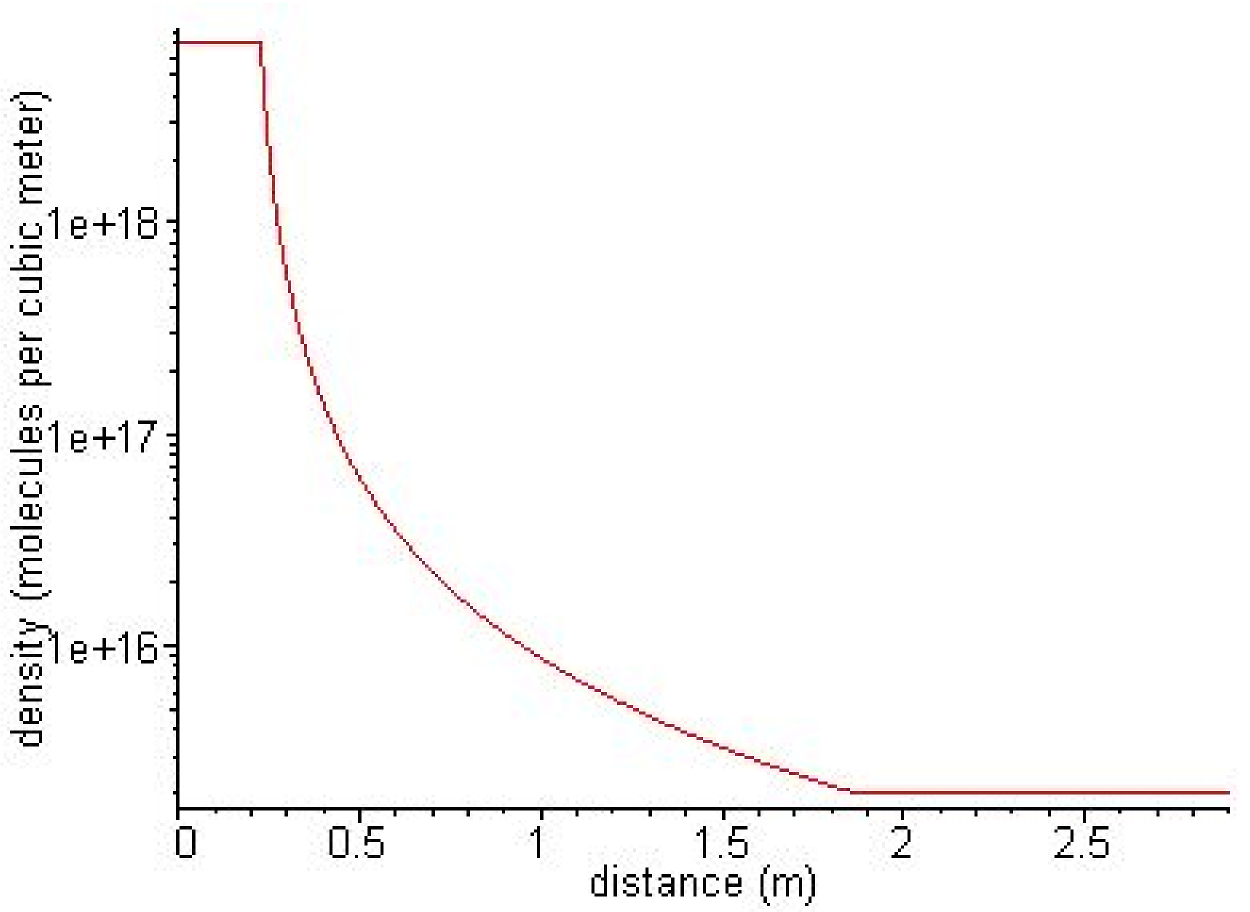
Strategies to control gas density (>1 ms)

- Restore pocket: partially demonstrated by UCB; droplet clearing needs to be shown

- Provide large surface area for ablated molten salt condensation (droplet spray on the side of the target chamber): See UCB papers and current work at UCLA; that's rather straight-forward

- Cold vortex acts as a buffer between target chamber and final-focus magnet region

Steaty-State Gas Pressure in Beam Tubes



Part II

•Development of Efficient Radiation Hydrodynamics Codes for Thick-Liquid Protected Inertial Fusion Target Chambers and Beam Tubes

René Raffray's Chart

- Breath of time scales; phenomena are somewhat decoupled
- TSUNAMI: gas dynamics of forth and fifth columns
- First three columns: only need a few relevant pieces of information
- Can be used to model phenomena in sixth column

- Time-integrated values used to be ; results were rather independant from models
- Detailed assessment of magnetic shutters woud benefit of acurate peak values -> new version of TSUNAMI

Tentative Methodology

•What really matters: hydrodynamics in (at least) two dimensions, initial ablation

•What should be treated with some care: condensation/evaporation, real gas equation

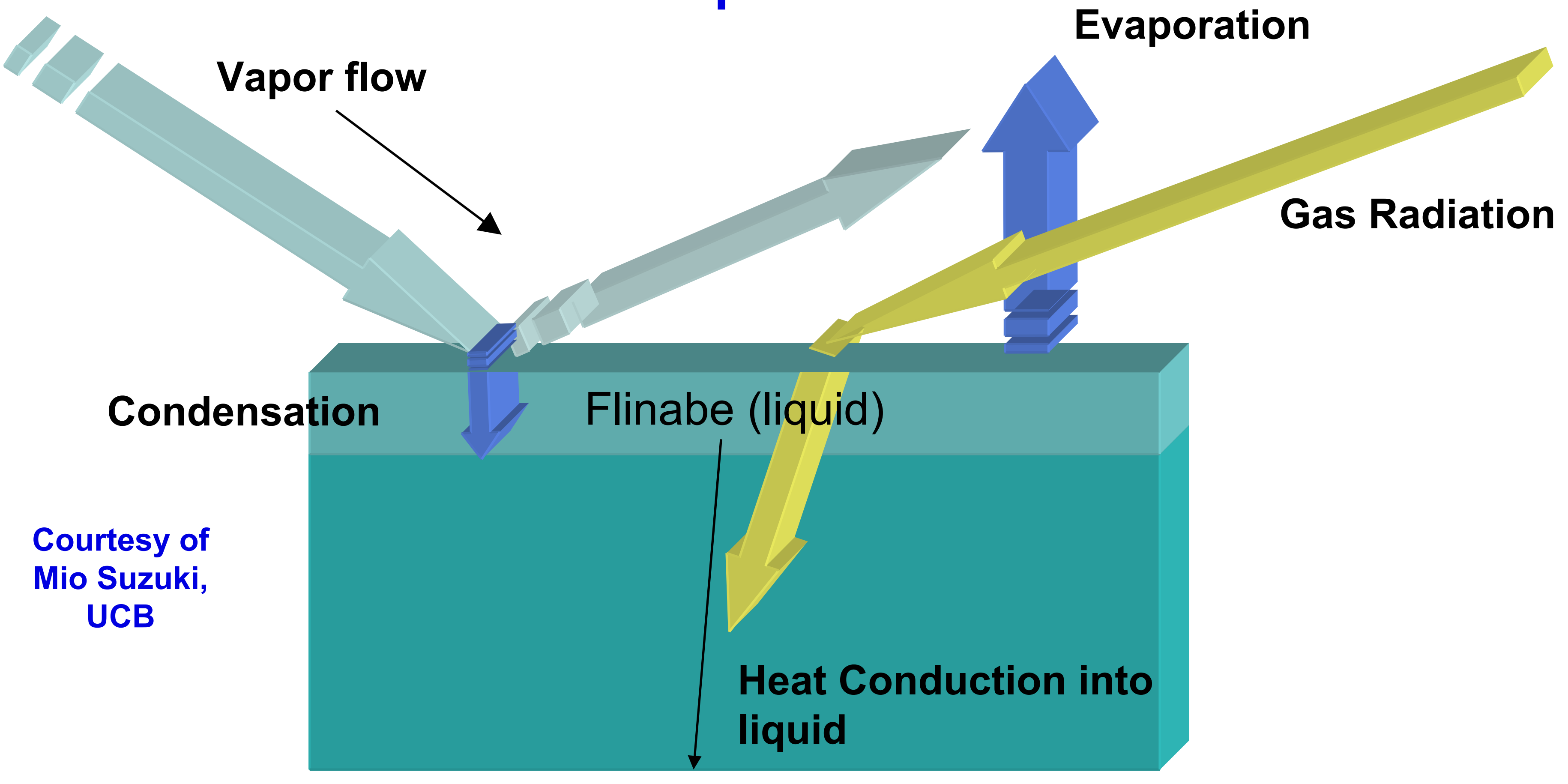
•What can be treated very simply: radiation, fast ions

•What doesn't need to be model (at least for now!): neutrons, oscillation and response of jets, in-flight condensation

Hydrodynamics

- Euler equations
- Second-order accurate scheme
- Details some other time…

Simplified (and slightly misleading!) Schematic of Gas-Liquid Interface



Courtesy of Mio Suzuki, UCB

Various transport phenomena take place simultaneously

Condensation/Evaporation

- Revisited Schrage

- Details some other time…

Liquid heat transfer module

- Heat transfer equation simplifies to standard 1-D heat conduction equation in a stationary solid

- Crank-Nicolson scheme (second-order in space and time implicit discretization)

- Matrix solver: LU decomposition

- Benchmarking: Done in collaboration with Mio Suzuki (UCB)

Radiation module

- Secondary effect, so rather simple treatment believed to be adequate
- Two-temperature flux-limited diffusion
- Matrix solver: Adapted Approximate-Factorization-Method (AFM)
- (Re-)Coding and Benchmarking: Underway, in collaboration with Mio Suzuki

Boundary conditions

•(Disrupted) jets do not have time to move---might help close venting paths to beam tubes

•Ablation does not affect geometry

•Neutron isochoric heating neglected---might help close venting paths

Initial conditions

- **Neutrons: neglected**

- **X-rays: ablation matters!**
  - **More mass, so what? It's not a solid wall, and there's enough condensing area**
  - **The more mass and the colder, the more the slower the venting and the more the pressure builds up inside the pocket.**

- **Slow ions: 1-D model---sphere of molten salt**

- **Fast ions: Just adjust the mass and energy of ablated layer**

Review of cold, instantaneous ablation models

- **Cohesive energy model**
  - **e = cohesive energy**

- **HIBALL**
  - **Redistribute energy and vaporize as much as possible (no physical ground)**

- **A la Chen**
  - **Vapor quality = 0.5 (arbitrary!)**

- **A la Raffray**
  - **Explosive boiling, T = 0.9 Tc (based on kinetic theory)**

Ablation, revisited

•Flibe and flinabe may be retrograde

•Expansion causes vaporization, as unphysical as it may sound!

•Detailed calculations to follow, but this property of flibe and flinabe justifies HIBALL approach

•Same order of magnitude given by different approaches---does not really matter for TSUNAMI

•What cohesive energy should we use?

Can we do better? TSUNAMI versus ABLATOR

fluence (J cm^{-2})	TSUNAMI (microns)	ABLATOR (microns) courtesy of Susana Reyes, LLNL
1	0.19	0.15
2	0.24	0.20
5	0.30	0.27
10	0.35	0.32
20	0.40	0.37
30	0.43	0.40
3000	0.84	0.82

Excellent agreement: Vaporization depths agree within 2% for case similar to IFE!

ABLATOR brings in liquid heat conduction; molten salts poor thermal conductor, so ABLATOR does not provide any real improvement

What about BUCKY?

- BUCKY ablation depth: roughly 20 times TSUNAMI ablation depth (roughly, I am comparing different numbers!)

- That's a big discrepancy! (Well, not too bad for what's a few-line formula competing against a code developed over 30 years.)

- I believe it is due to hot versus cold opacity data.

- Divided the x-ray pulse into two bunches, and adjusting the mean free paths for hot opacity factors brings a factor 10 (back of the envelope calculations for a monoenergetic radiation)

- May get 20 using unexplosive explosive boiling and BBT pulse

Another topic dealt with by ARIES team: flibe EOS

•A flaw (typo?) in Chen's analytical flibe EOS has been identifyed independantly by Debonnel and Zaghloul

•TSUNAMI now uses Chen's analytical Flibe EOS as corrected by Zaghloul (even if it doesn't not affect the gas dynamics, only the output temperature!)

•Zaghloul's flibe EOS is currently being implemented into TSUNAMI

•No real gas EOS is known for flinabe---believed to have similar behavior

Even more code development

- Current version has user-friendly, highly automated set of Matlab programs to process output; highly taylored to fusion systems design (HYLIFE-II simulations)

- In collaboration with Trudie Wang (UC Berkeley), a generic GUI is being developed

- Goal: User-friendly tool to process TSUNAMI output for any kind of simulations

Conclusions

- New modules are being coded to adequately model gas venting in thick-liquid protected systems.
- Choice of relevant physics and numerical methods (solvers of system of linear/non-linear equations); development of appropriate models when required
- New version of TSUNAMI ~7000 lines for the core of the code currrently (previous version ~5700 lines); modular architecture
- Benchmarking and time-profiling are underway