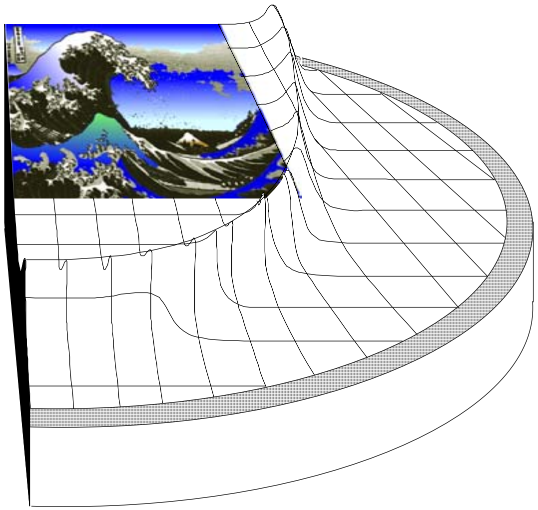

Gas Transport and Control in HIF Thick-Liquid Target Chambers and Beam Tubes

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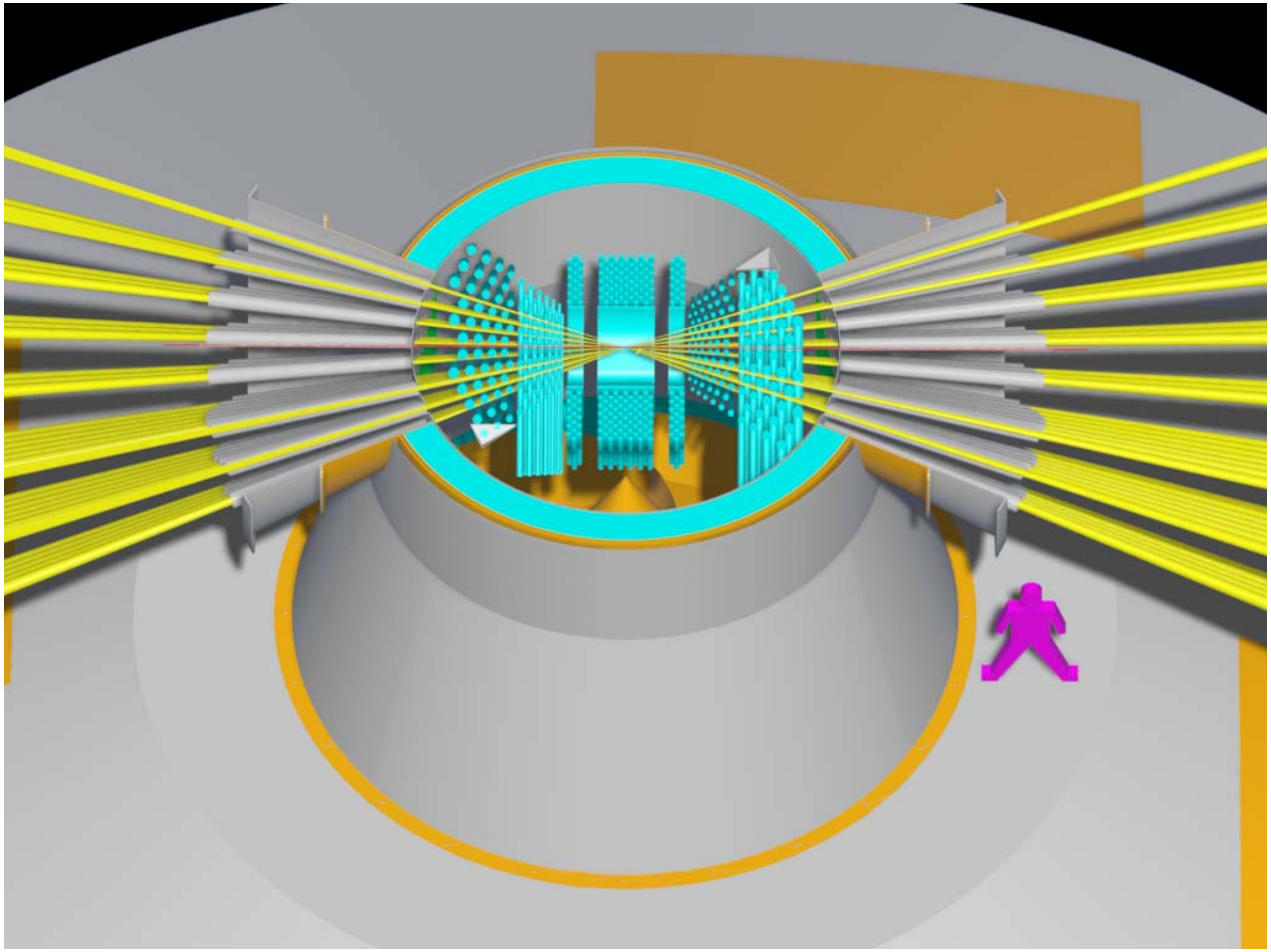
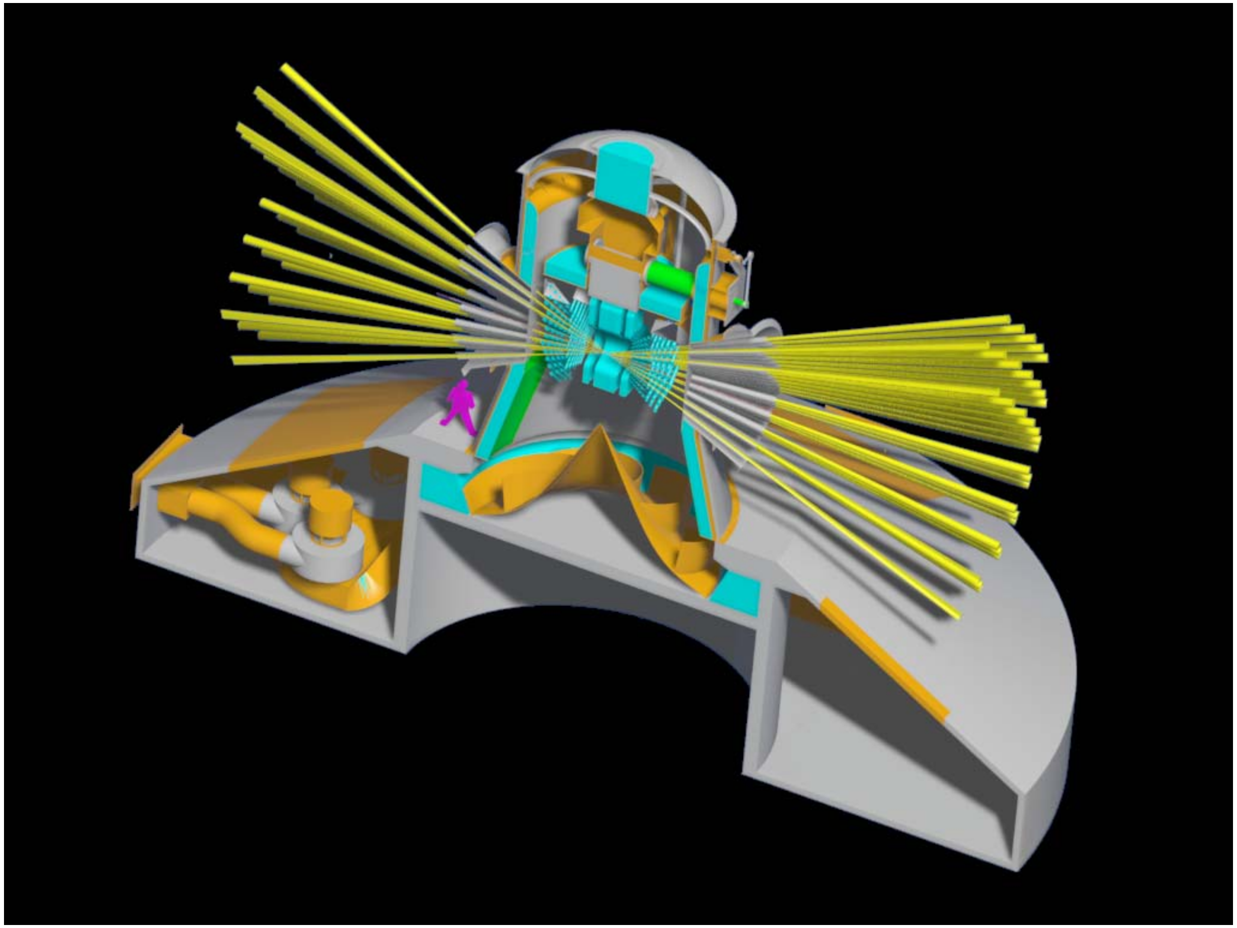
ARIES Town Meeting on Liquid Wall Chamber Dynamics
Livermore, May 5-6, 2003

HYLIFE-II Chamber---Courtesy of R. Abbott, LLNL



HYLIFE-II Chamber---Courtesy of R. Abbott, LLNL



Part I

•*Early-Time Gas Transport and Control---TSUNAMI Modeling of Target and Ablation Debris Venting*

Motivation

- Target chamber density control
  - Beam propagation sets stringent requirements for the background gas density
  - Pocket response and disruption

- Beam tube density control
  - Beam propagation requirements
  - Debris deposition in final-focus magnet region may cause arcing with the high space-charged beams and must be alleviated

Strategies to prevent debris deposition in the beam tubes (I)

- Design efficient target chamber structures

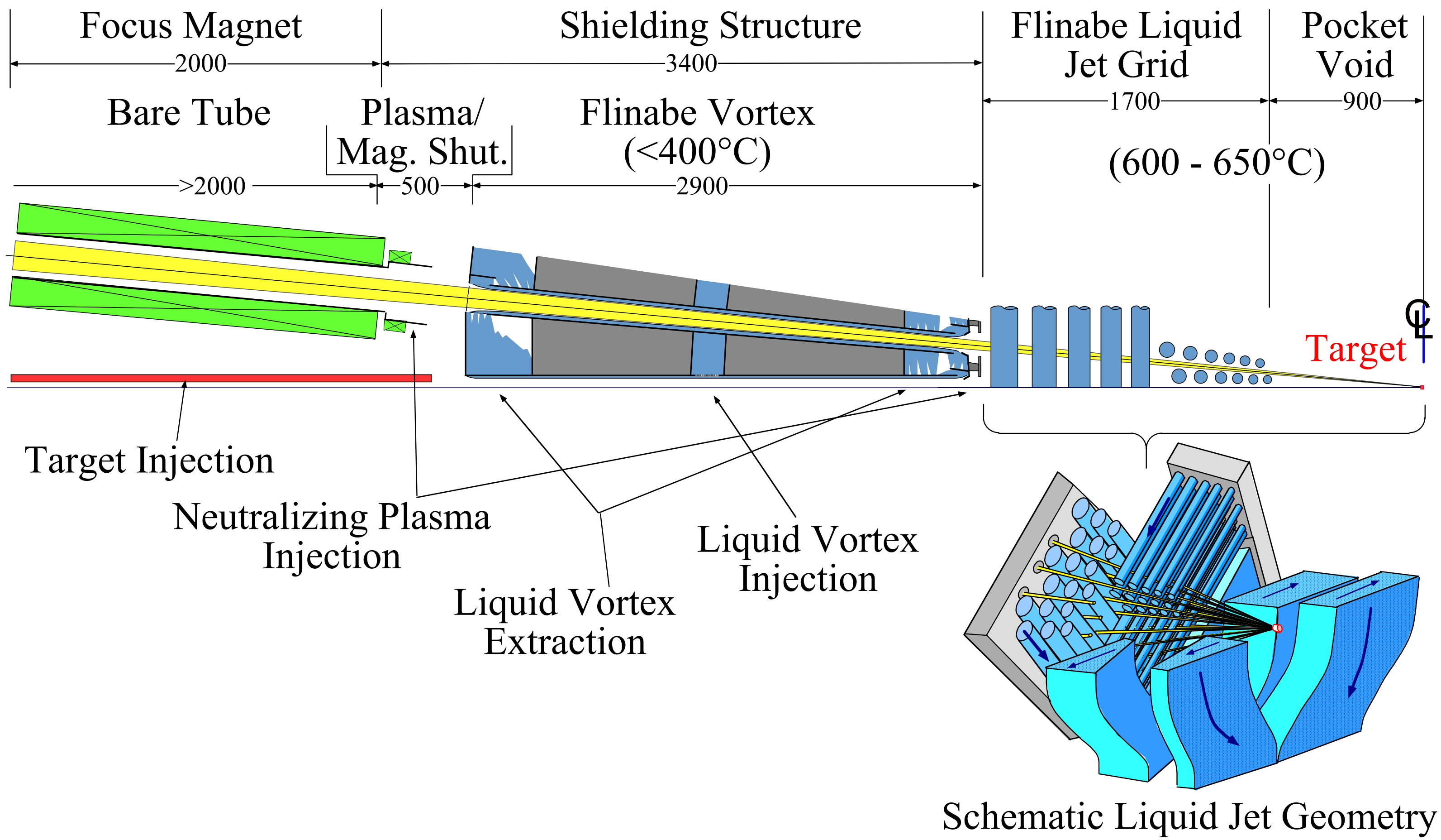
- Debris should vent towards condensing surfaces (droplets), so that mass and energy fluxes at the entrance of beam ports are as low as possible

- Venting in target chamber has been modeled to determine flux to the beam tubes and impulse load to the pocket

Strategies to prevent debris deposition in the beam tubes (II)

- A new beam tube:
  - Liquid vortex coats the inside of the beam tube
  - Magnetic Shutters
    - Debris is ionized by plasma plug injected into the beam tube
    - Moderate strength dipole diverts debris into condenser

The Robust Point Design (RPD-2002) beam line



TSUNAMI

- TranSient Upwind Numerical Analysis Method for Inertial confinement fusion

- Provides estimates of the gas dynamics behavior during the venting process in inertial confinement energy systems

- Solves Euler equations for compressible flows

- Real gas equation (adapted from Chen's---includes Zaghloul's correction)

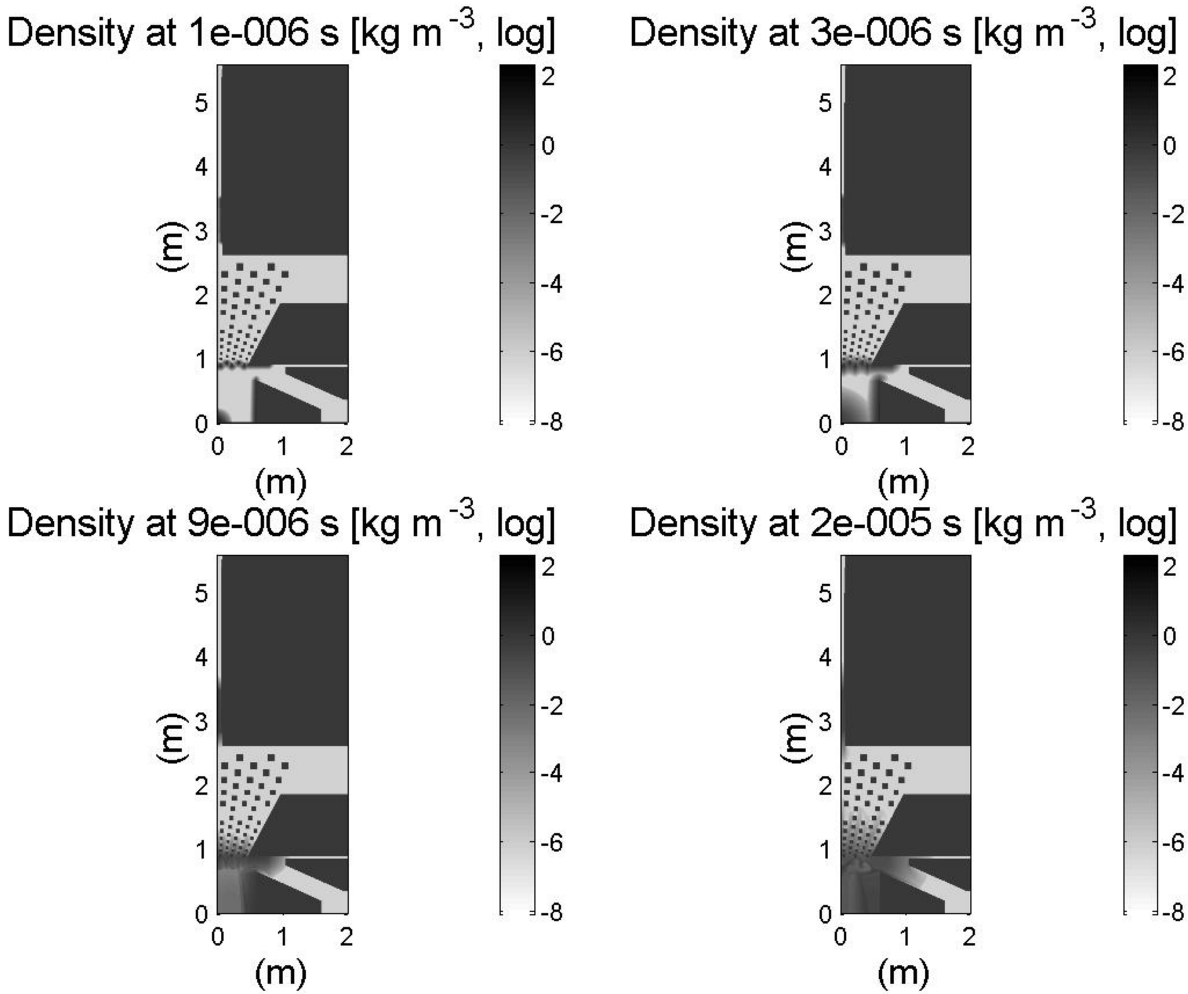
- Two-dimensional, axially symmetric pocket

Initial ablation: TSUNAMI versus ABLATOR

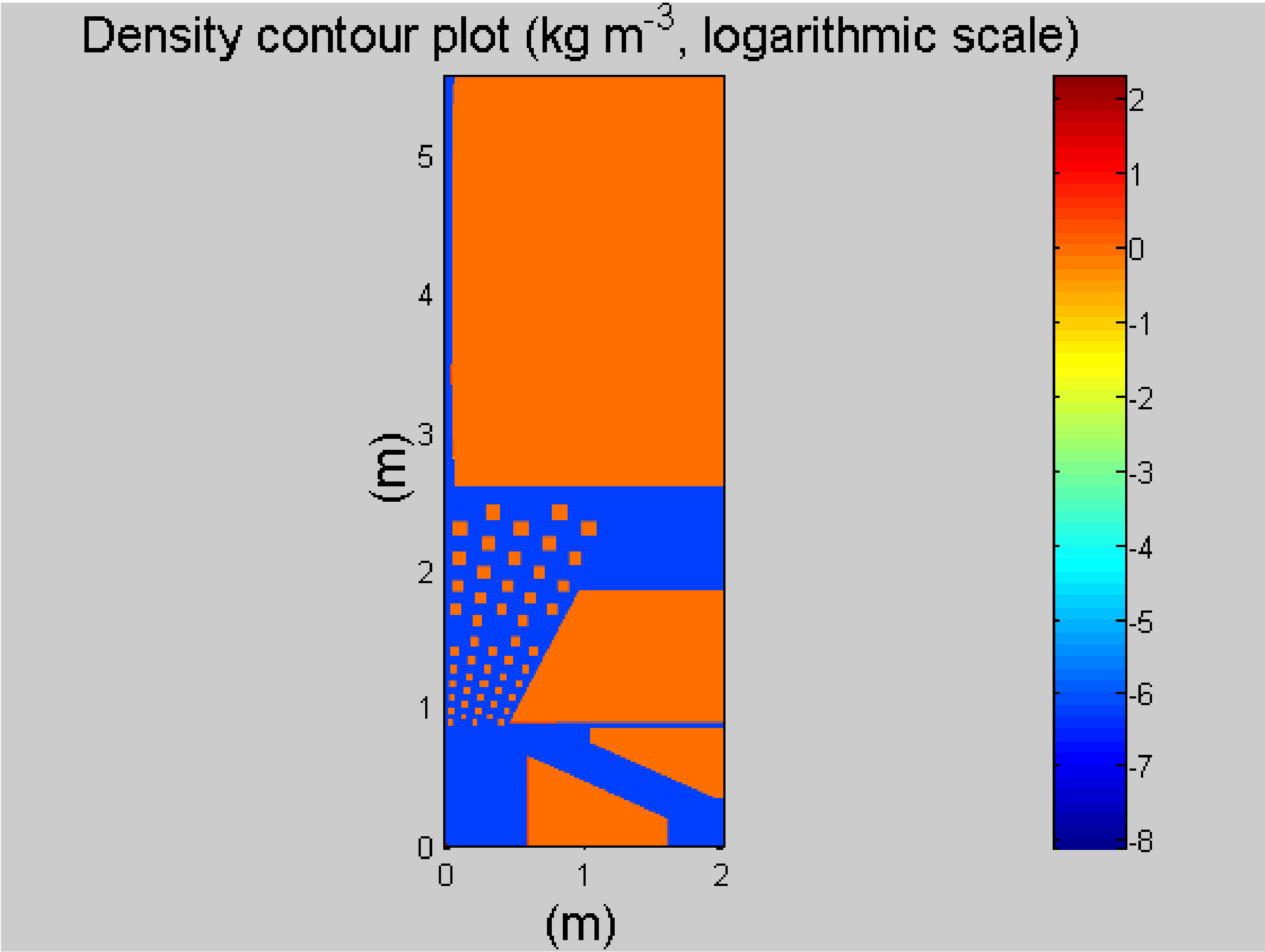
fluence (J cm^{-2})	TSUNAMI (microns)	ABLATOR (microns) courtesy of Susana Reyes, LLNL
1	0.19	0.15
2	0.24	0.20
5	0.30	0.27
10	0.35	0.32
20	0.40	0.37
30	0.43	0.40
3000	0.84	0.82

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

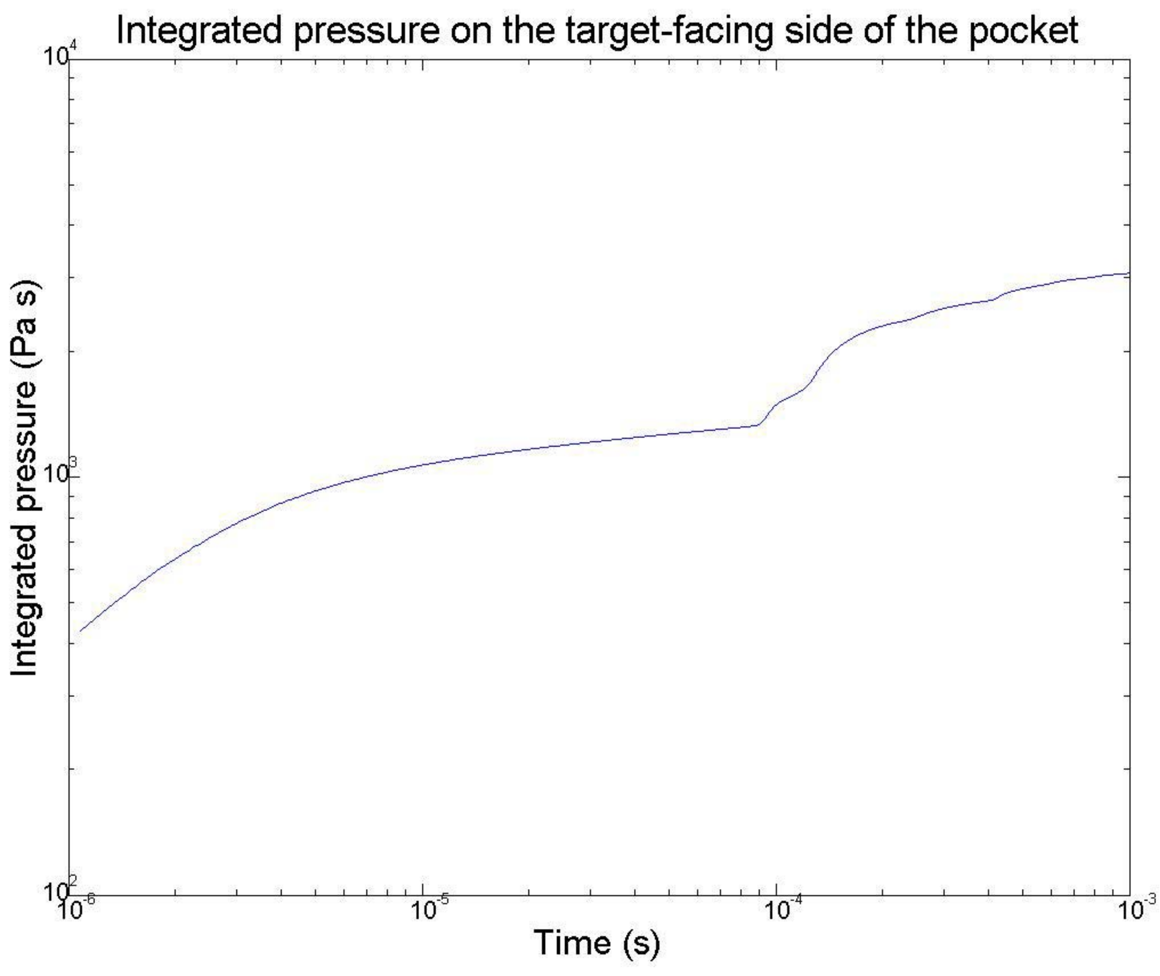
RPD-2002: TSUNAMI Density Contour Plots



Movie time!


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

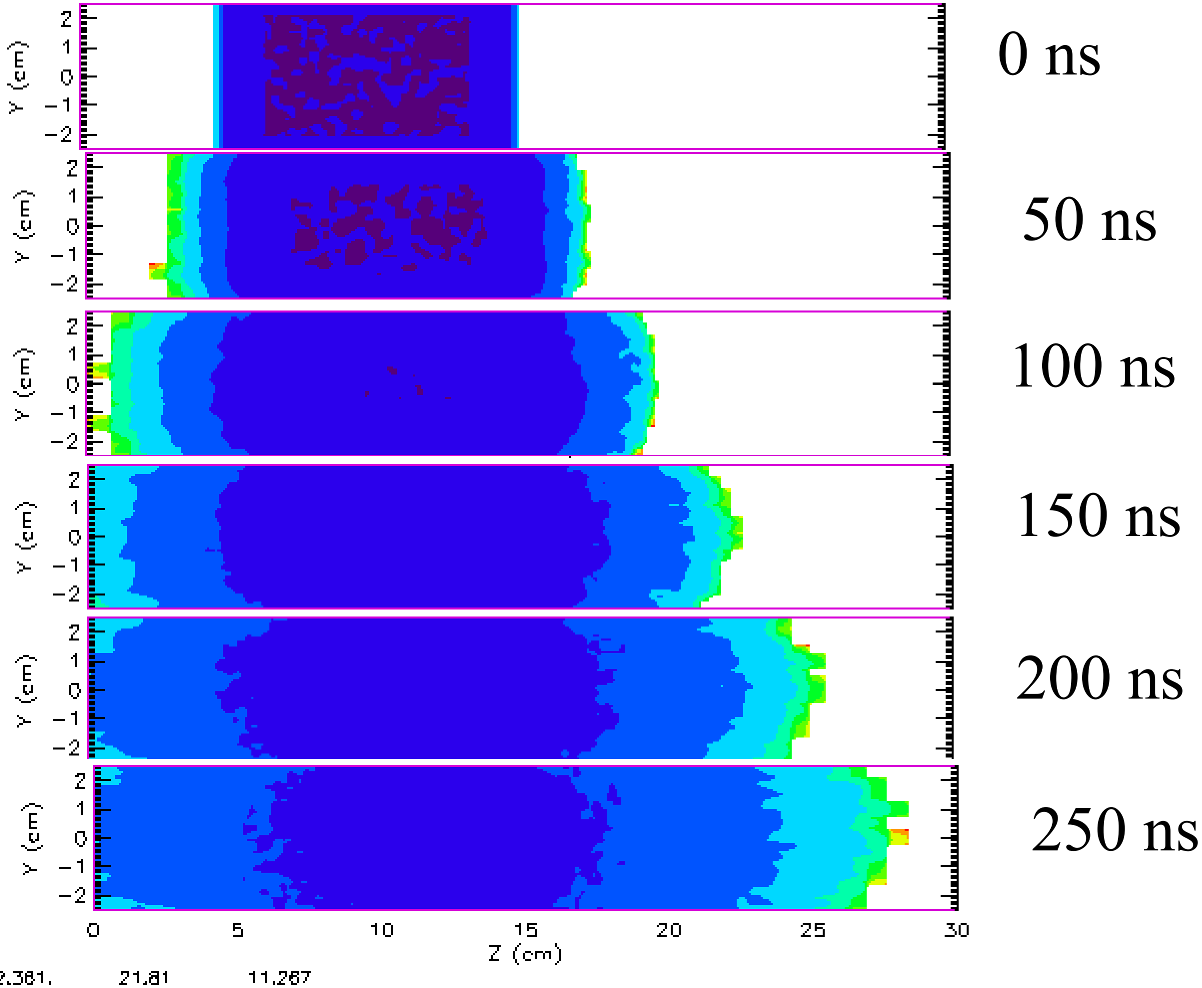
RPD-2002: Impulse load

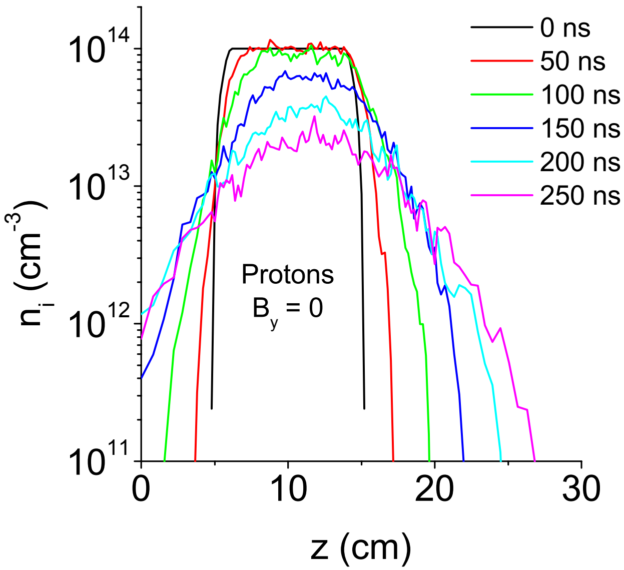


TSUNAMI Predictions up the Vortex Region

- Debris Average…
  - Molecular density = 3e20 m^{-3}
  - Axial velocity = 3e4 m s^{-1}
  - Average temperature = 2e4 K

Magnetic Shutters (MRC simulations)
Test Case: Ion expansion *without* applied B_y-field…



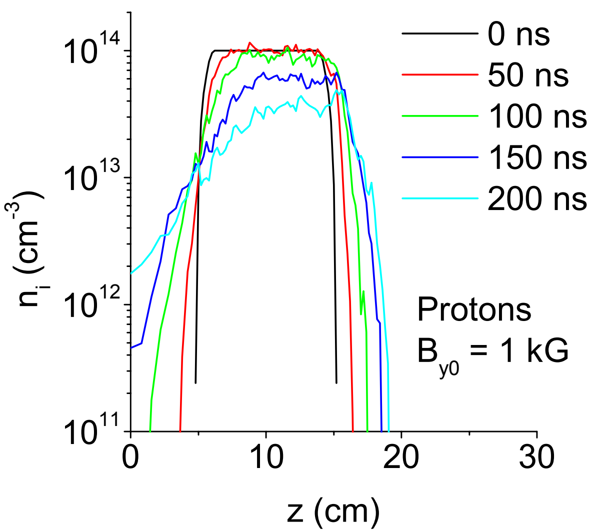


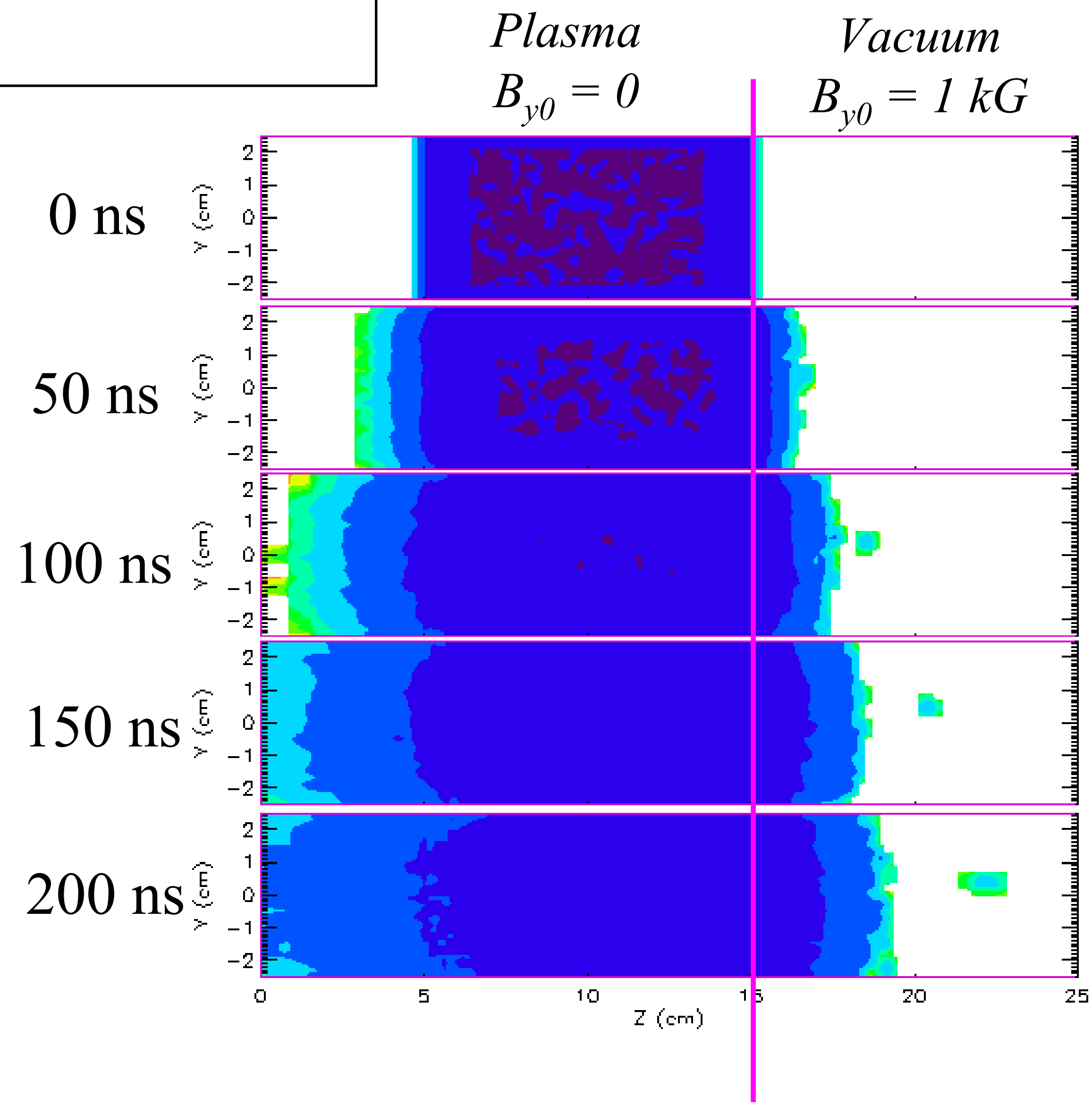
Greater ion expansion into applied B-field is observed in 3D case.

1 kG applied B_y field

$V_{drift} = 9$ cm/μs

$T_e = T_i = 100$ eV





Conclusions to part I

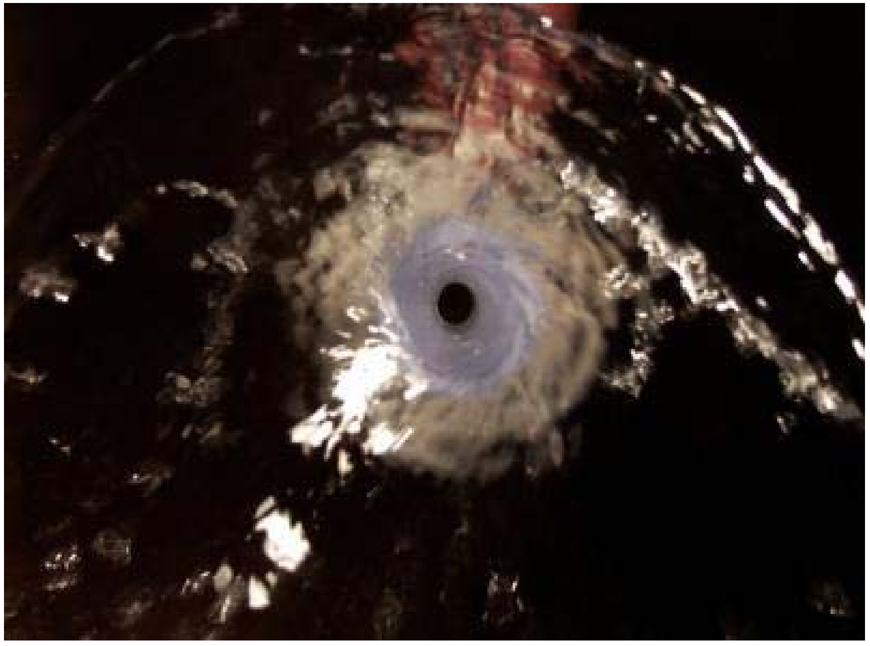
- TSUNAMI predictions indicate that thick-liquid structures in target chamber should be supplemented by other engineering devices in the beam tubes to prevent debris contamination in the final-focus magnet region

- A new beam tube:
  - Beam tube can be coated with liquid vortex
  - Debris can be ionized and diverted by a moderate strength magnetic field

Part II

- ***Late-Time Gas Density Transport and Control***
- **Mitigating Background Blowing into Beam Tubes**
- **Condensation**

Vortex Tubes



- UCB identified ternary molten salt systems ("Flinabe," $LiF/NaF/BeF_2$) with very low melting temperatures (less than 600 K)
  - Equilibrium vapor pressure ($\sim 10^{15}$/cm^3 at 673 K)
- Annular flow in the beam tubes can reduce the apertures in the square lattice to round ports called "Vortex Tubes"
- Stable centrifugal flow provides additional protection in the beam lines
- Mitigate blowing of background gas into the beam tubes

Steaty-State Gas Pressure in Beam Tubes

• Low-temperature, low vapor-pressure flinabe is a very effective getter

• Assuming perfectly absorbing boundaries and a simple geometry, density at last magnet (n_f) is given by

$$n_f = \frac{n_o}{2}\left(\frac{R_o}{L}\right)^2$$

Where n_o = ambient density in chamber

R_o = chamber port radius

L = distance from last magnet to chamber entrance

• For chamber at ~ 0.1 Pa, L=3m, vacuum in magnetic section can reach 10^{-4} Pa range

Clearing the inside of the pocket...

Condensation is NOT the main clearing mechanism inside the pocket. And has never been. Phil Sharpe's simulations confirm that condensation is ineffective inside the pocket.

To first order, inside of pocket heated up by x-rays and too hot for condensation to take place. Ablated gas and target debris vent out instead.

Clearing of target…

How to restore equilibrium background gas density in a timely manner?

Provide enough cold surfaces. Droplets are injected along the walls of the target chamber and provide large condensing area for ablated debris. Temperature below the pre-shot liquid pocket temperature.

How it works…

Cold droplet − > Condensation − > Surface temperature rises (Poor thermal conduction) − > Evaporation

− > Provide a new droplet!

− > Continuous injection of droplets. Estimates of required flow rate: roughly 5 to 10 % of jet flow rate (Bai and Schrock, 1990)

Conclusions to part II

•Cold flinabe has a vapor pressure low enough to allow its use in the beam tubes. Vortex flow has been demonstrated experimentally by UCB group.

•Vortex replaces shutters or pumps to prevent target chamber background gas blowing into final focus region.

•Condensation on cold droplets---not on thick-liquid structures---is main clearing mechanism.

•Expected droplet flow rate reasonable.