Integrated TSUNAMI Simulations for the Heavy-Ion Point Design

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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

- Robust Point Design (RPD-2002) motivated new set of gas dynamics simulations
The Robust Point Design (RPD-2002) beam line

Focus Magnet

2000

Bare Tube

>2000

Plasma/Mag. Shut.

500

Shielding Structure

3400

Flinabe Vortex

(<400°C)

2900

Target Injection

Neutralizing Plasma Injection

Liquid Vortex Injection

Liquid Vortex Extraction

Flinabe Liquid Jet Grid

1700

Pocket Void

900

(600 - 650°C)

Schematic Liquid Jet Geometry
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 (~1200 Pa s)
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)

• Two-dimensional, axially symmetric pocket
RPD-2002 – TSUNAMI Density Contour Plots

Density at 1e-006 s [kg m\(^{-3}\), log scale] Density at 3e-006 s [kg m\(^{-3}\), log scale]

Density at 9e-006 s [kg m\(^{-3}\), log scale] Density at 2e-005 s [kg m\(^{-3}\), log scale]
RPD-2002 – Impulse load

Integrated pressure on the target-facing side of the pocket

Integrated pressure (Pa s) vs Time (s)
Strategies to prevent debris deposition in the beam tubes (II)

• A new beam tube design:

  • Liquid vortex coats the inside of the beam tube

• Magnetic Shutters
  • Debris is ionized by plasma plug injected into the beam tube
    (same plasma at a different density is used to neutralize the beams)
  • Moderate strength dipole diverts debris into condenser
Cylindrical Jet Grids

- Beam access requires multiple round beam ports in the target chamber wall
- Cylindrical jet grids provide a square lattice of jet liquid
Vortex Tubes

• 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
**TSUNAMI Predictions up the Vortex Region**

Integrated flux in 1 ms…

- Mass = 6.7e-5 kg m\(^{-2}\)
- Energy = 9.5e4 J m\(^{-2}\)

- Debris Average…
  - Molecular density = 1.6e19 m\(^{-3}\)
  - Axial velocity = 4.0e4 m s\(^{-1}\)
  - Radial velocity = 3.4e2 m s\(^{-1}\)
  - Thermal velocity = 9.2e4 m s\(^{-1}\)
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
$V_{drift} = 9 \text{ cm/\mu s}$
$T_e = T_i = 100 \text{ eV}$

Plasma
$B_{y0} = 0$

Vacuum
$B_{y0} = 1 \text{ kG}$
Conclusions

• 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 line:
  • Beam tube can be coated with liquid vortex
  • Debris can be ionized and diverted by a moderate strength magnetic field