*Plasma-Jet Magnetized-Target Fusion Dynamics and Stability Issues**

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Abstract*

Magnetized-target fusion (MTF) uses an imploding, conducting liner to compress a magnetized plasmoid, such as a field-reversed configuration (FRC) or spheromak. The increasing magnetic field of the target reduces thermal conduction and the liner's inertia provides transient plasma stability and confinement. This poster explores issues for MTF when plasma jets form the liner [1]. Particular attention will be paid to the formation of the liner by the merging of the highly supersonic plasma jets and to the radiation hydrodynamics of compression and expansion. The investigations use analytic analyses plus, for the burn dynamics, the University of Wisconsin's 1-D Lagrangian radiation hydrodynamics code, BUCKY. This code solves single-fluid equations of motion with pressure contributions from electrons, ions, radiation, and fast charged particles. BUCKY includes fusion reactions, ion-electron interactions, PdV work, fast-ion energy deposition, and magnetic-field dependent thermal conductivity.

[1] Y.C.F. Thio, et al., "Magnetized Target Fusion in a Spheroidal Geometry with Standoff Drivers," in Current Trends in International Fusion Research, E. Panarella, ed. (National Research Council of Canada, Ottawa, Canada, 1999), p. 113.

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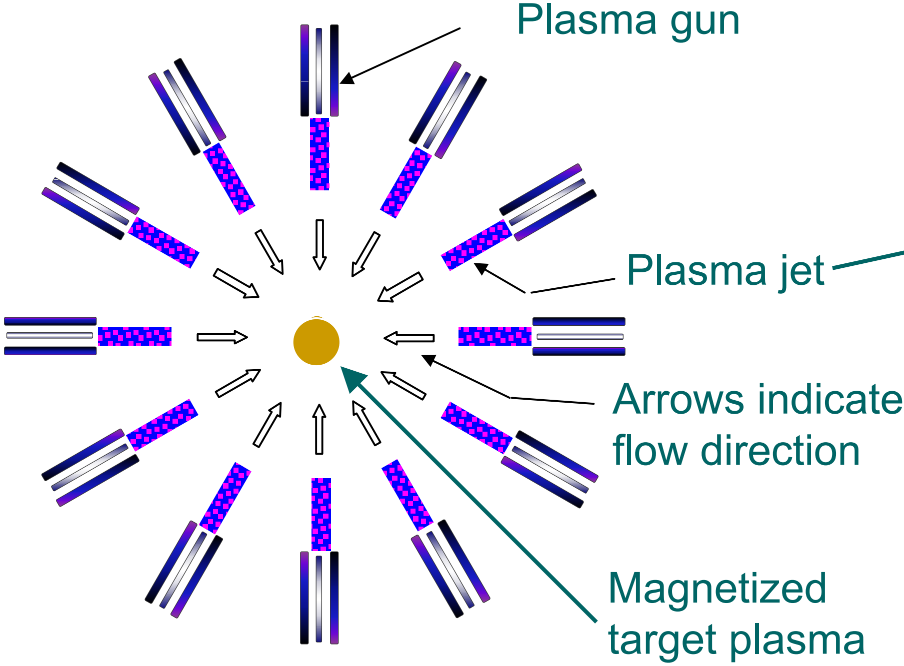
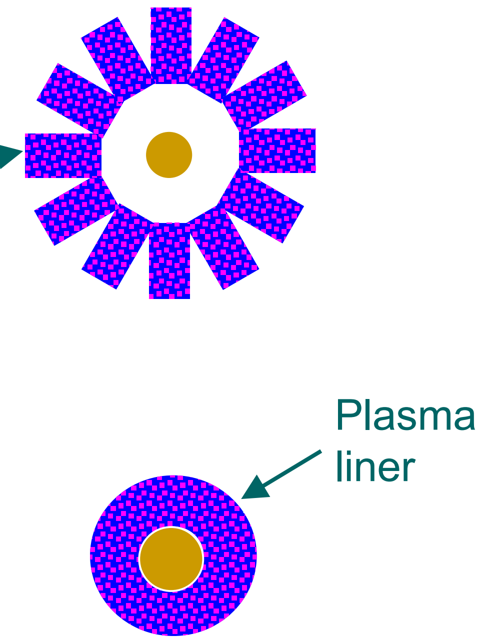
Plasma-Jet Magnetized-Target Fusion Allows Liner Standoff from the Target

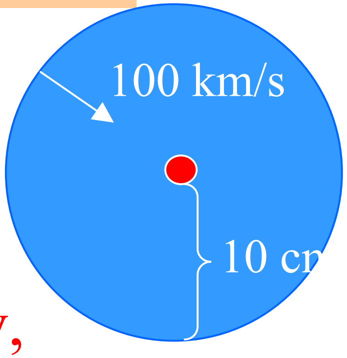


Based on NASA MSFC figures



- An approximately spherical distribution of jets are launched towards the compact toroids at the center of a spherical vessel
- The jets merge to form a spherical shell (liner), imploding towards the center

Plasma Liner Requirements for Breakeven



- Seek an energy confinement time ~ 1 μs
- $P_{burn} \geq$ 10 Mbar
- This pressure is provided by a momentum flux density, ρv^2, with v ~ 100 km/s, and ρ ~ 0.1 g/cc
- The plasma shell is self-compressed to this density
- Assume a spherical radial compression ratio of ~ 10
- The un-compressed plasma shell is ~ 0.01 mg/cc
- The stagnation shock velocity ~ v ~ 10 cm/ μs
- The required un-compressed shell thickness ~ 10 cm
- Liner: mass ~ 420 mg, kinetic energy ~ 2MJ

Magnetized targets allow for the attainment of energy producing fusion regimes at implosion velocities and facility scales much more modest than with traditional MFE or ICF

Plasma-Jet MTF Critical Issues

- Plasma jet merging
- Stagnation pressure and energy containment time
- Burn dynamics of fusion core
- Burn of the cold, dense liner layer

Plasma Jets Must Merge to Form a Reasonably Uniform Liner

- Jet velocity will be 100-400 km/s.
  - Mach number $M_j >> 1$.
- Jets must have good homogeneity.
- Must avoid instabilities due to
  - Transverse jet velocy components, or
  - Discrete nature of jets (~60).

Modeling Plasma-Jet MTF Burn Dynamics

- The UW radiation hydrodynamics code, BUCKY, is applied in 1-D, spherical geometry to model the burn dynamics of plasma-jet MTF.
- Separate target, plasma jet, and buffer zones are used.
- The initial calculations aim to reproduce the analytic model of Y.C.F. Thio, et al., "Magnetized Target Fusion in a Spheroidal Geometry with Standoff Drivers," in Current Trends in International Fusion Research, E. Panarella, ed. (National Research Council of Canada, Ottawa, Canada, 1999), p. 113.

Features of BUCKY—the UW FTI 1-D Radiation Hydrodynamics Code

- Lagrangian approach (constant-mass zones)
- Simulates plasmas in planar, cylindrical, or spherical (used here) geometries
- Single-fluid equations of motion with pressure contributions from electrons, ions, radiation, and fast charged particles
- D-T, D-D, and D-3He reactions
- Plasma energy transfer treated using either a one-temperature (Te=Ti) or two-temperature Maxwellian model
- PdV work
- Fast-ion (beam or target debris) energy deposition
- Heating due to fast charged particles and neutrons during the fusion burn
- Neutron energy deposited in the target using an escape probability model
- Charged particle reaction products transported and slowed using time-dependent particle tracking
- Fast ions from an ion beam and target micro-explosion debris tracked using a time-, energy-, and species-dependent stopping power model
- Stopping powers computed using a Lindhard model at low projectile energies and a Bethe model at high energies

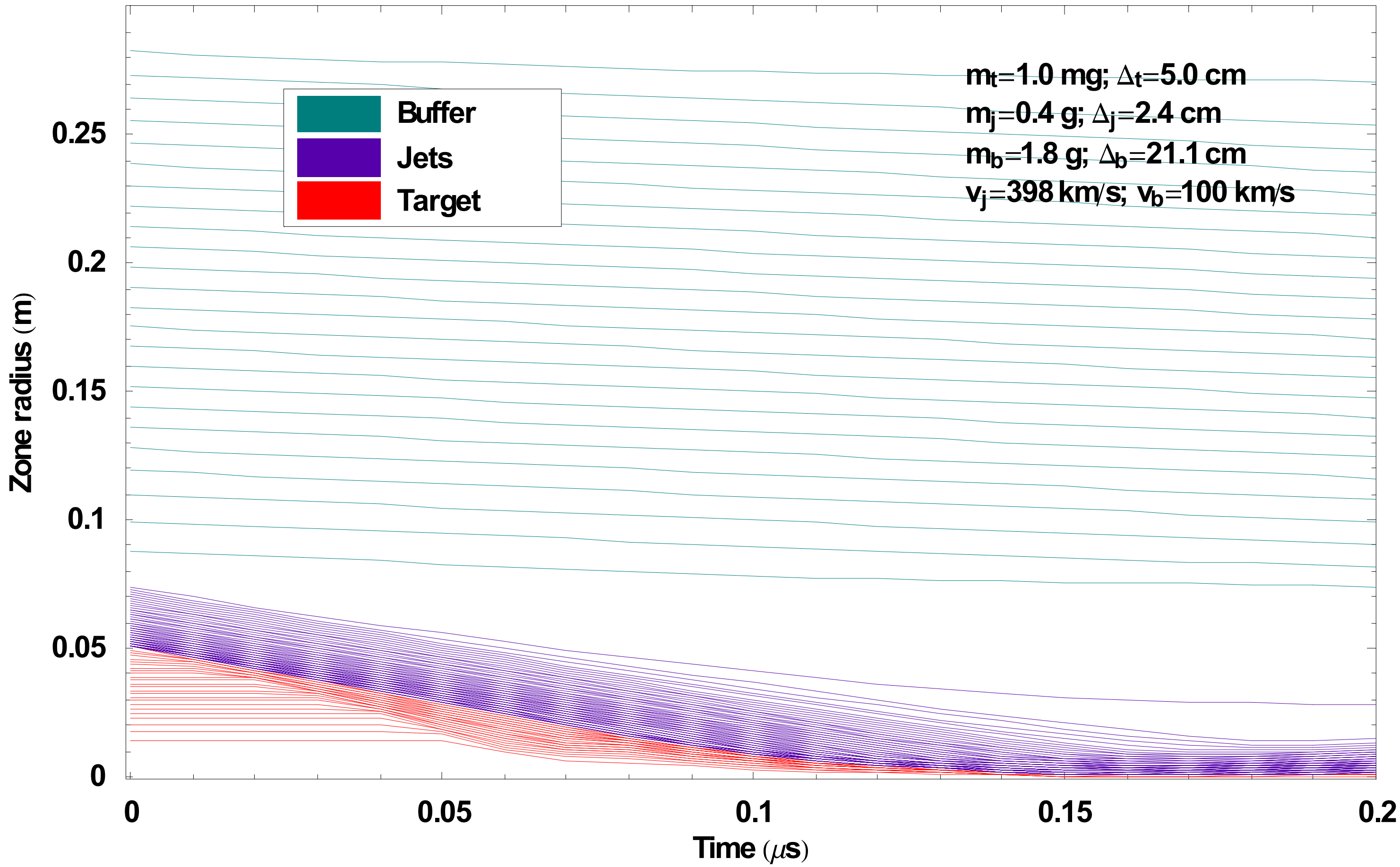
Stagnation Pressure and Energy Containment Are Issues

- In plasma-jet MTF, the inertia of the incoming jets helps confine the plasma, as shown in the Lagrangian zones of constant mass in the figure below.
- If the stagnation radius, r_s, is assumed to be stationary and the jet Mach number minimized, implying M=1 at r_s,

$$r_s = r_m \left(\frac{4M_j}{3+M_j^2}\right)$$

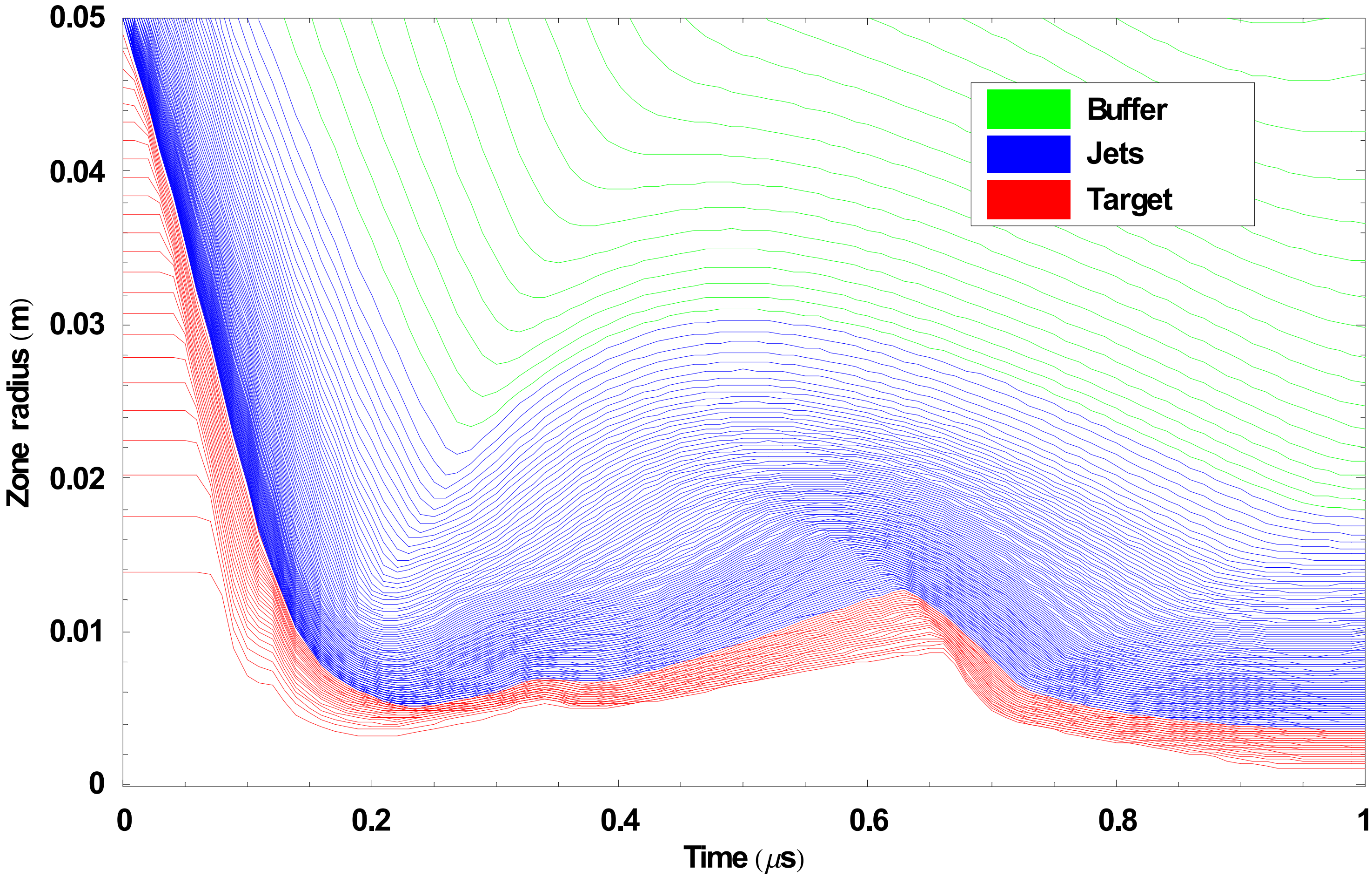
Jet Inertia Can Assist Energy Confinement at High Jet Velocities

- Lagrangian constant-mass zones from BUCKY run of MTF case:

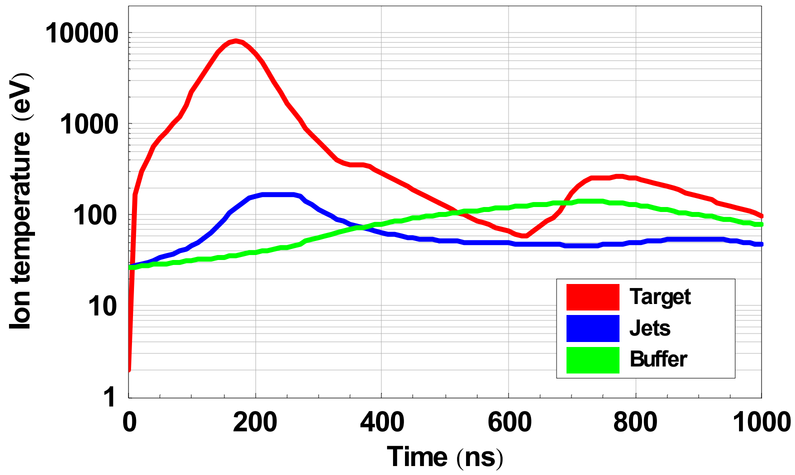


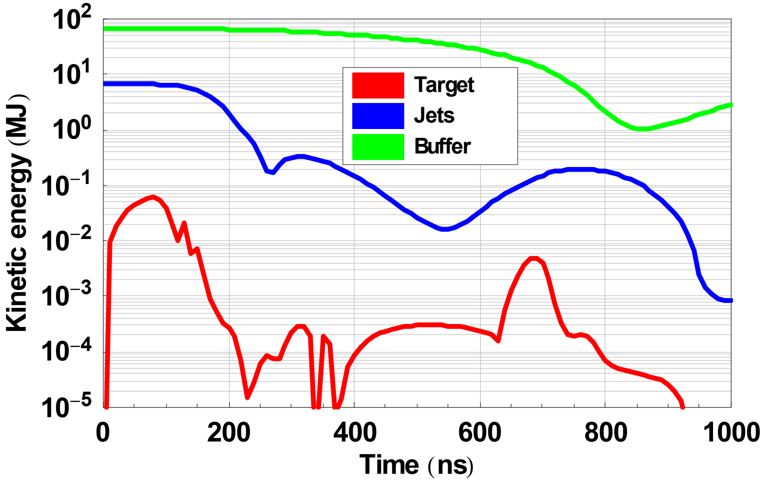
Near Stagnation, a Complicated Mixture of Shock Waves Can Occur

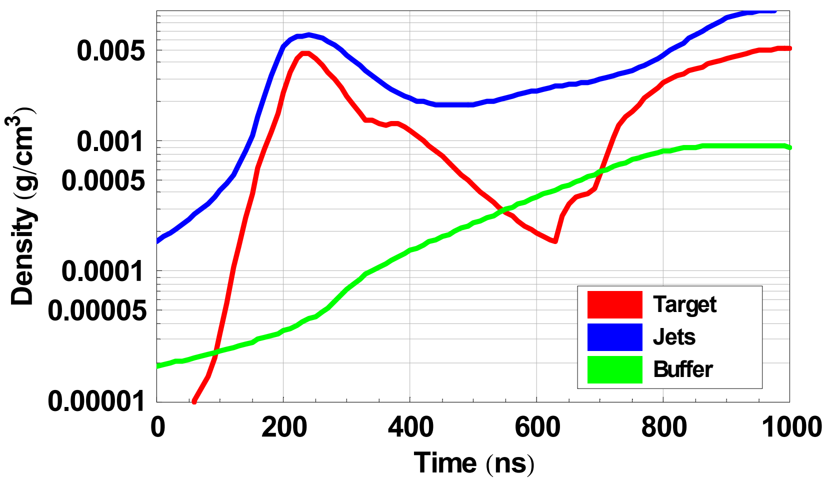
- Lagrangian constant-mass zones from BUCKY run of MTF case:

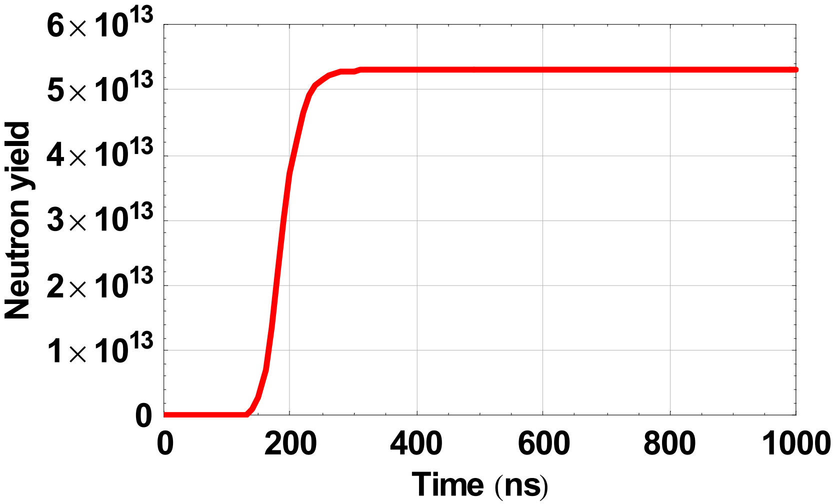


Averaged Zone Parameters Show Compression

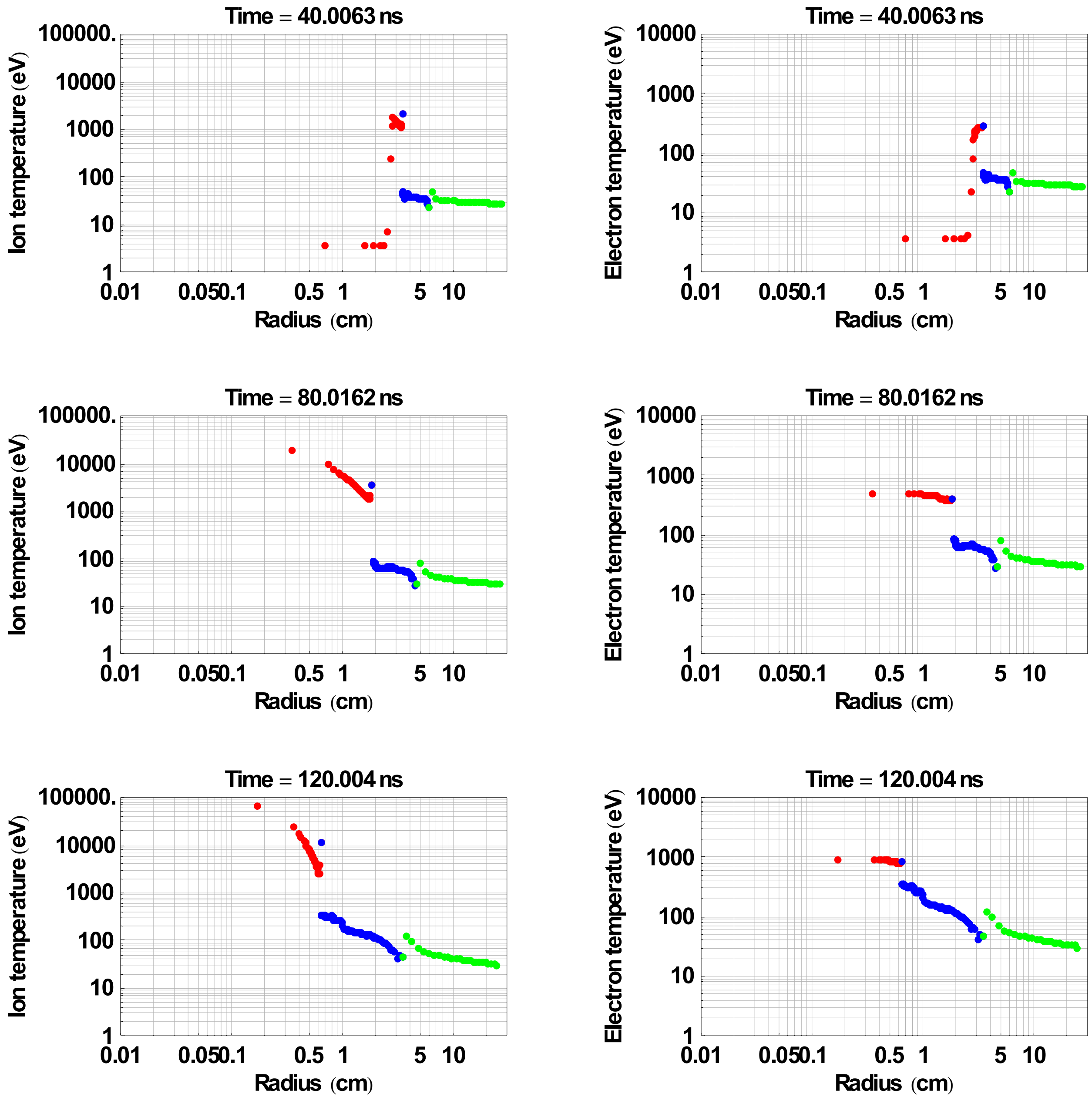




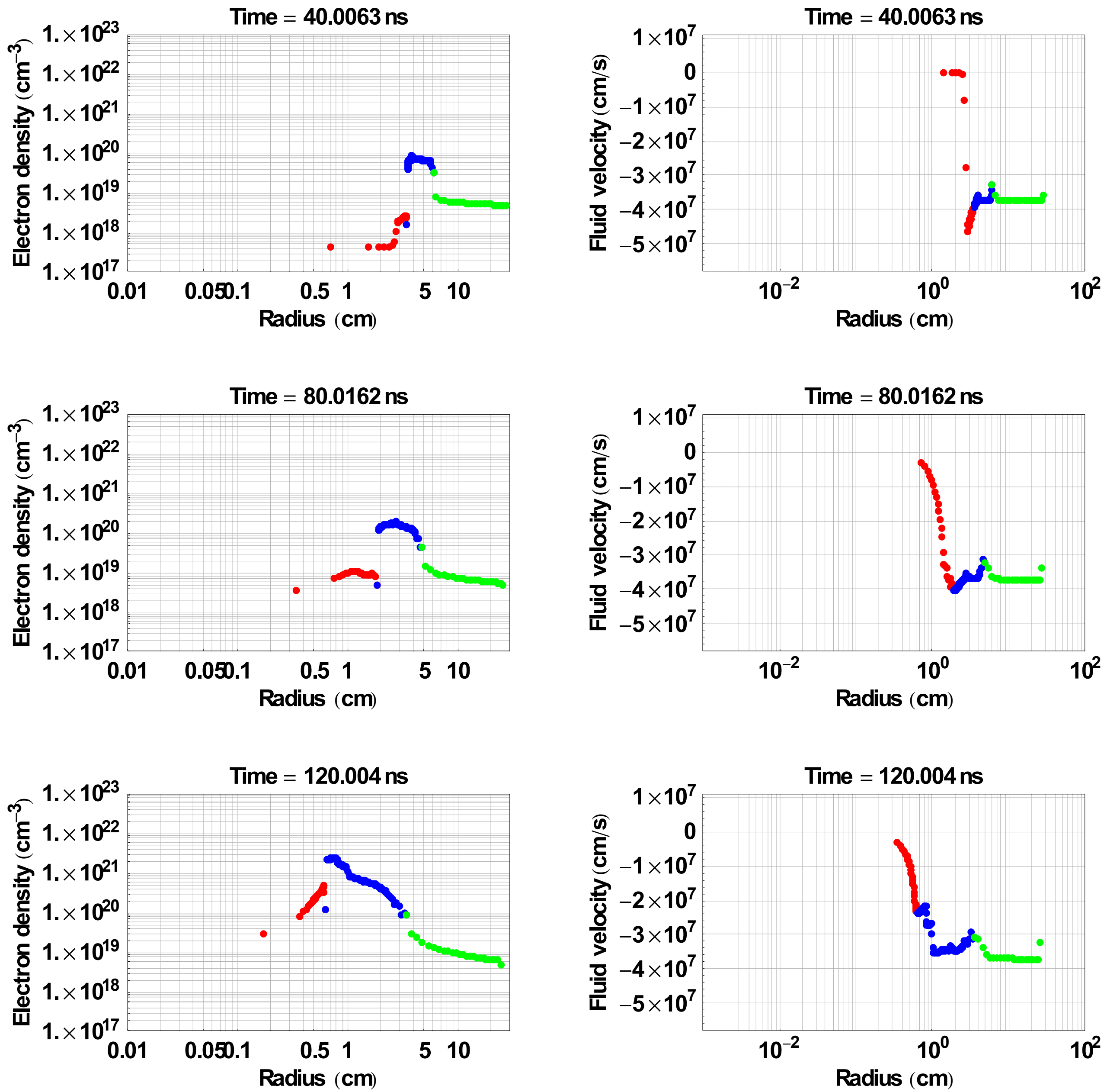




Typical Ion and Electron Temperatures versus Radius at Selected Times



Typical Electron Density and Fluid Velocity versus Radius at Selected Times



Burning of the Cold, Dense Liner Layer

- Ref. 1 (Thio, et al., 1999) calculates that the fusion core will ignite and that the resulting alpha particles will burn a thin layer on the inside of the jets (liner).
- Modifications to the BUCKY code to test these calculations is in progress.
  - Key difficulty is properly modeling the alpha-particle orbits and energy deposition.

A Simple MTF Magnetic-Field Model Has Been Implemented in BUCKY

- Uniform, azimuthal magnetic field (non-physical) assumed for initial model.
- Magnetic-field enhanced Braginskii thermal conductivities [Thio, et al., 1999]:

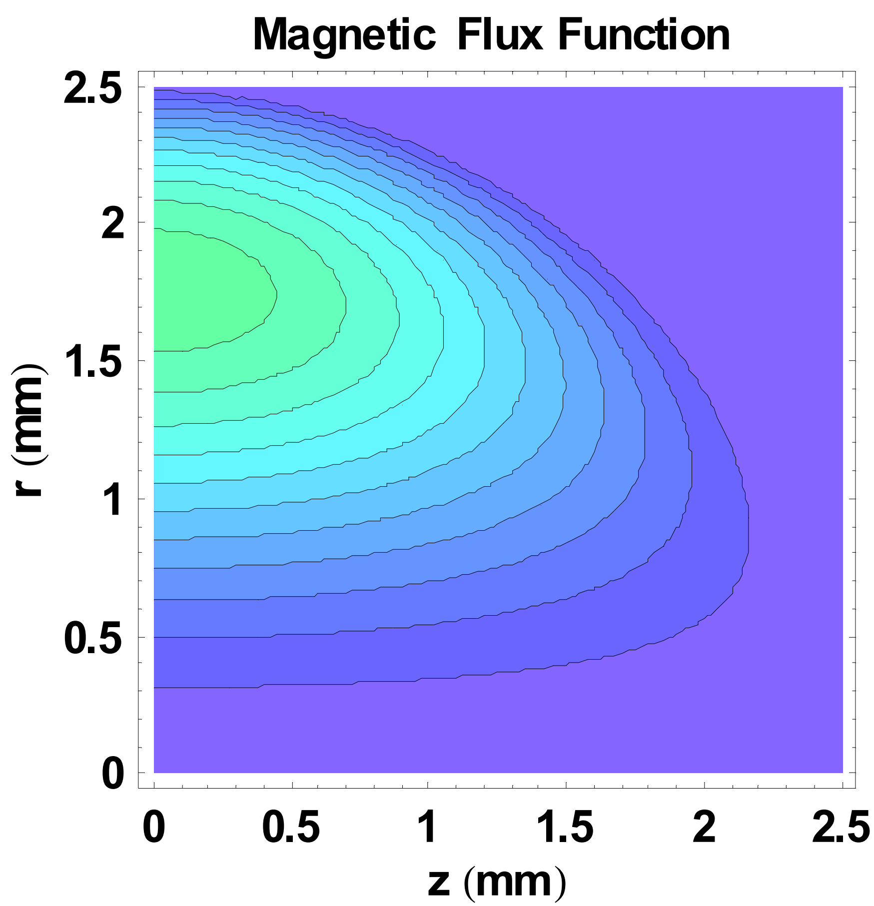
$$\kappa_{\perp e} = \frac{n_e k(kT_e)\tau_{ee}}{m_e}\left(\frac{4.66\omega_{ce}^2\tau_{ee}^2 + 11.92}{\omega_{ci}^4\tau_{ii}^4 + 14.79\omega_{ci}^2\tau_{ii}^2 + 3.77}\right)$$

$$\kappa_{\perp i} = \frac{n_i k(kT_i)\tau_{ii}}{m_i}\left(\frac{2\omega_{ci}^2\tau_{ii}^2 + 2.64}{\omega_{ci}^4\tau_{ii}^4 + 2.7\omega_{ci}^2\tau_{ii}^2 + 0.68}\right)$$

- Plasma-jet pressure strongly dominates magnetic-field pressure, which has been neglected for now.
- B-field effects on alpha-particle energy deposition presently are modeled by local deposition or B=0 time-dependent particle tracking.

BUCKY Modifications to be Implemented Soon

- More realistic equilibria, such as the Hill's vortex shown at right, will be used.
- Detailed following of alpha-particle energy deposition along slowing-down gyro-orbits will be done.



Conclusions

- This work addresses plasma-jet MTF critical issues:
  - Jet merging,
  - Stagnation pressure and energy confinement,
  - Burn dynamics of fusion core, and
  - Burning of a cold, dense liner layer.
- BUCKY, the UW 1-D radiation hydrodynamics code is being used to investigate the Lagrangian zone parameters in detail.
  - Magnetic-field dependent thermal conductivity in place.
  - Alpha particle energy deposition model being implemented.