Burn Dynamics of Plasma-Jet Magnetized-Target Fusion

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Objective:

Explore plasma-jet magnetized-target fusion (MTF) burn dynamics in the reactor regime.

Abstract

In magnetized-target fusion (MTF), an imploding, conducting liner compresses a magnetized plasmoid, such as a spheromak or field-reversed configuration (FRC). The increasing magnetic field of the target reduces thermal conduction and the liner's inertia provides transient plasma stability and confinement. This poster discusses work in progress on analyzing the burn dynamics of using plasma jets to form the liner [1]. The investigation uses the University of Wisconsin's 1-D Lagrangian radiation hydrodynamics code, BUCKY, which solves single-fluid equations of motion with pressure contributions from electrons, ions, radiation, and fast charged particles, using either ideal-gas or table-lookup equations of state. BUCKY includes ion-electron interactions, PdV work, and fast-ion energy deposition. For this research, the code has been extended to include the magnetic field evolution as the plasmoid compresses plus the dependence of the thermal conductivity on the magnetic field. Fusion product energy deposition is modeled by localized energy deposition or time-dependent particle tracking.

[1] Y.C. F. Thio, E. Panarella, R.C. Kirkpatrick, C.E. Knapp, F. Wysocki, P. Parks, and G. Schmidt, "Magnetized Target Fusion in a Spheroidal Geometry with Standoff Drivers," in *Current Trends in International Fusion Research*, E. Panarella, ed. (NRC Press, National Research Council of Canada, Ottawa, Canada, 1999), p. 113.

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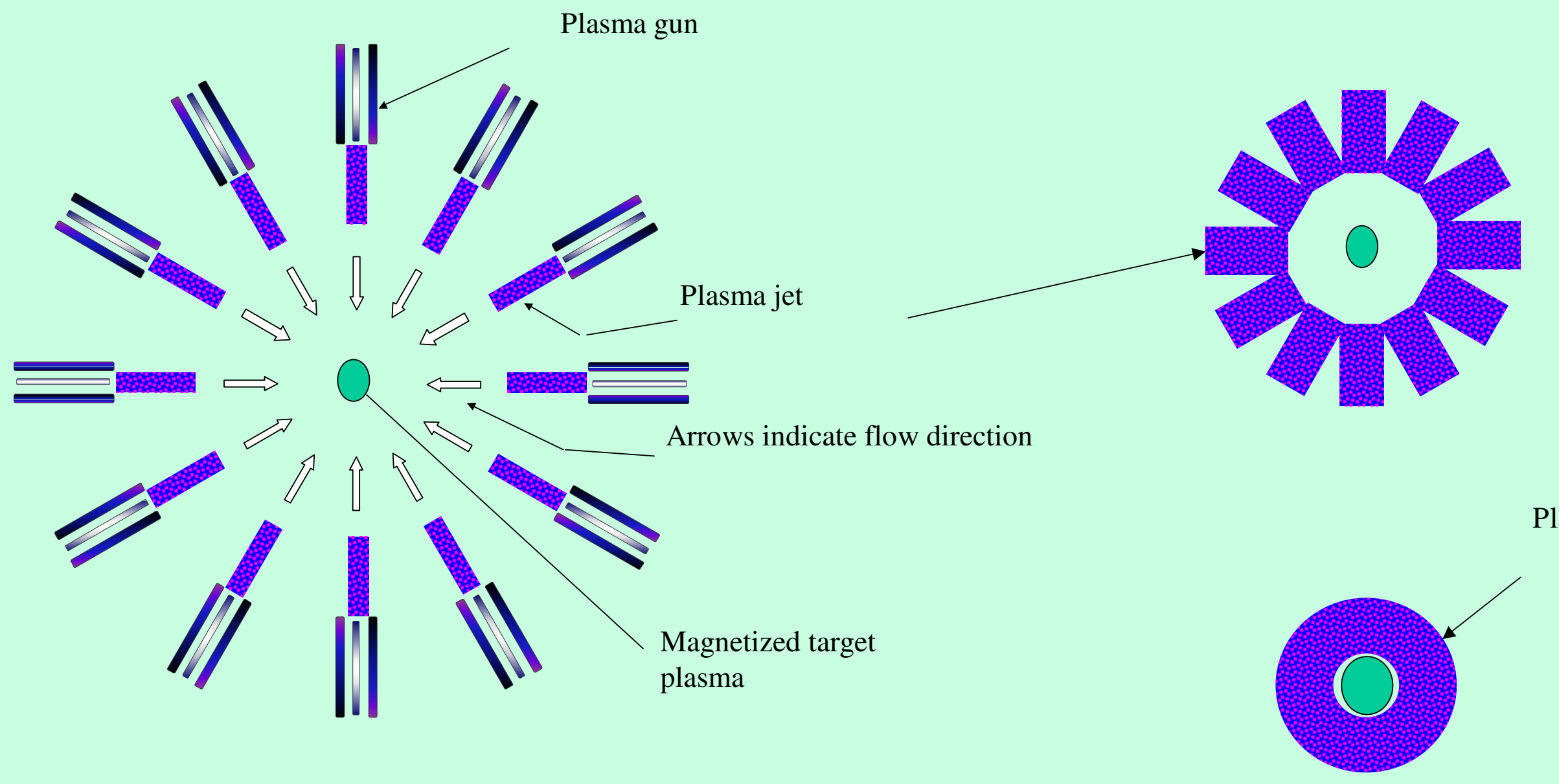
Overview of Plasma-Jet Magnetized-Target Fusion

- In place of the solid or liquid liner previously considered for MTF, plasma jets of 100-400 km/s would be used [1], as shown in the figure below.
- Figure from Y.C.F. Thio, C.E. Knapp, R.C. Kirkpatrick, R.E. Siemon, and P.J. Turchi, "A Physics Exploratory Experiment on Plasma Liner Formation," *Journal of Fusion Energy* **20**, 1 (2002).



- Magnetic field of the field-reversed configuration (FRC) or spheromak target plasmoid reduces electron thermal conductivity as the target compresses.
- Shock waves propagate inward and outward, heating and compressing the plasma.
- The inertia of the plasma jets confines the target plasma for ~100 ns.
- Typical volume compression ratios are ~1000.
- Fuel probably D-T, but D-^{3}He is under consideration.
- Coaxial plasma guns would be used to produce the plasma jets.

Features of the University of Wisconsin's 1-D Radiation Hydrodynamics Code, BUCKY

- **Lagrangian approach**
- **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**

B-Field Effects Implemented in BUCKY

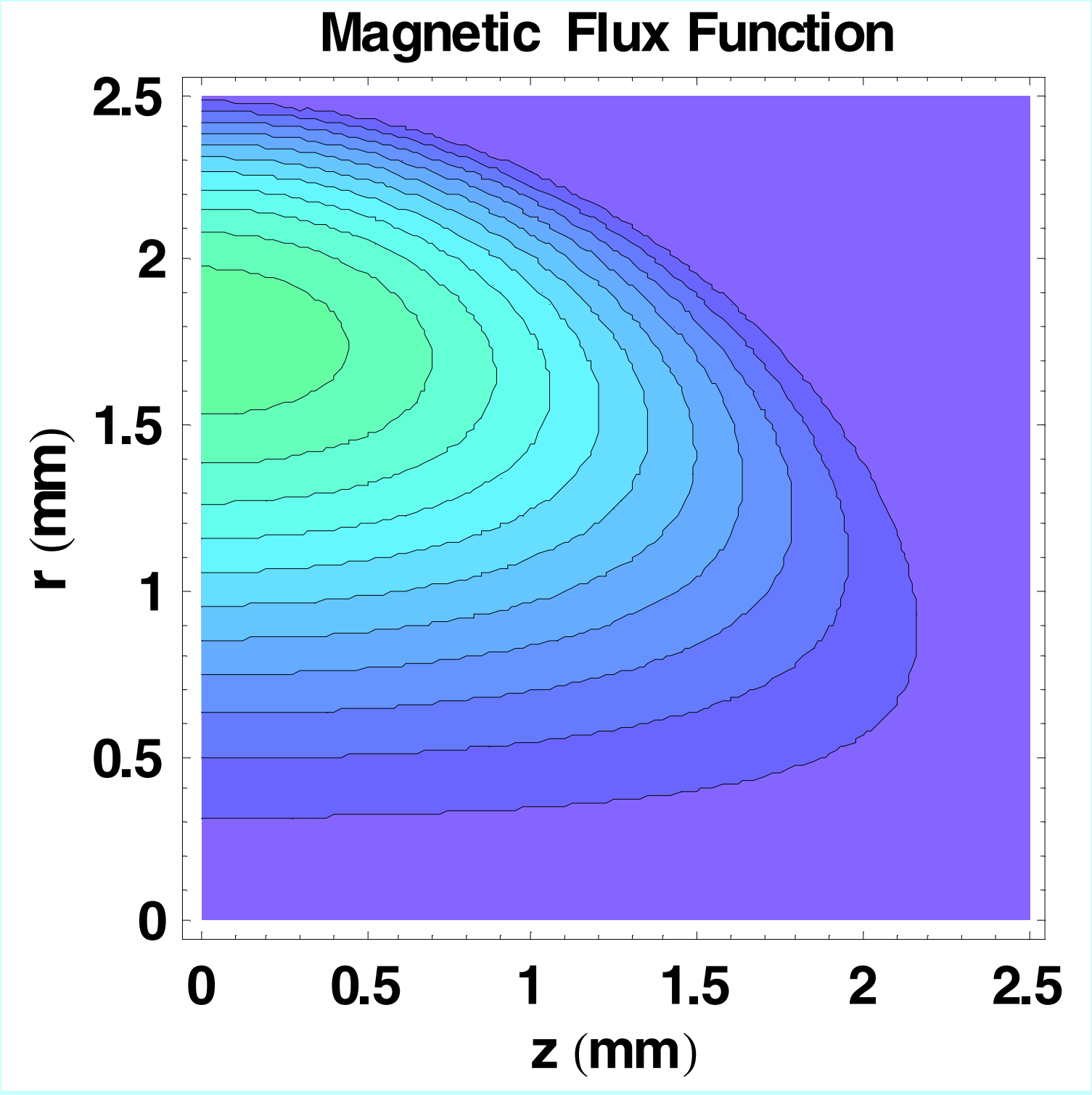
- **Uniform, azimuthal magnetic field assumed for initial calculations.**
- **Magnetic-field enhanced Braginskii thermal conductivities [1]:**

$$\kappa = \kappa_{\perp e} + \kappa_{\perp i}$$

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

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

- **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 particle tracking.**
- **Future modifications to the BUCKY code will include:**
  - **more realistic equilibria, such as the Hill's vortex shown at right, and**
  - **detailed following of alpha-particle energy deposition along slowing-down gyro-orbits.**

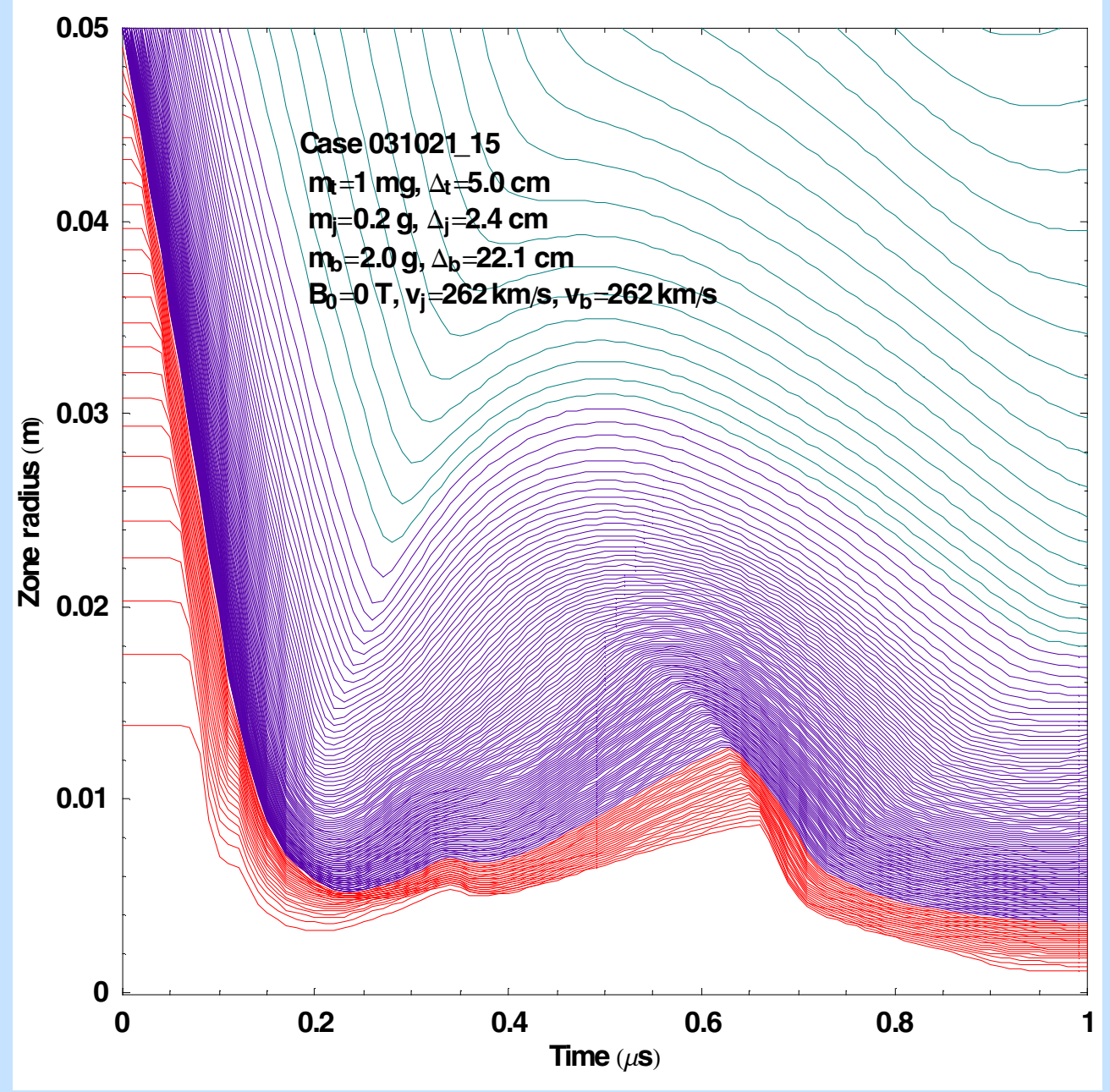


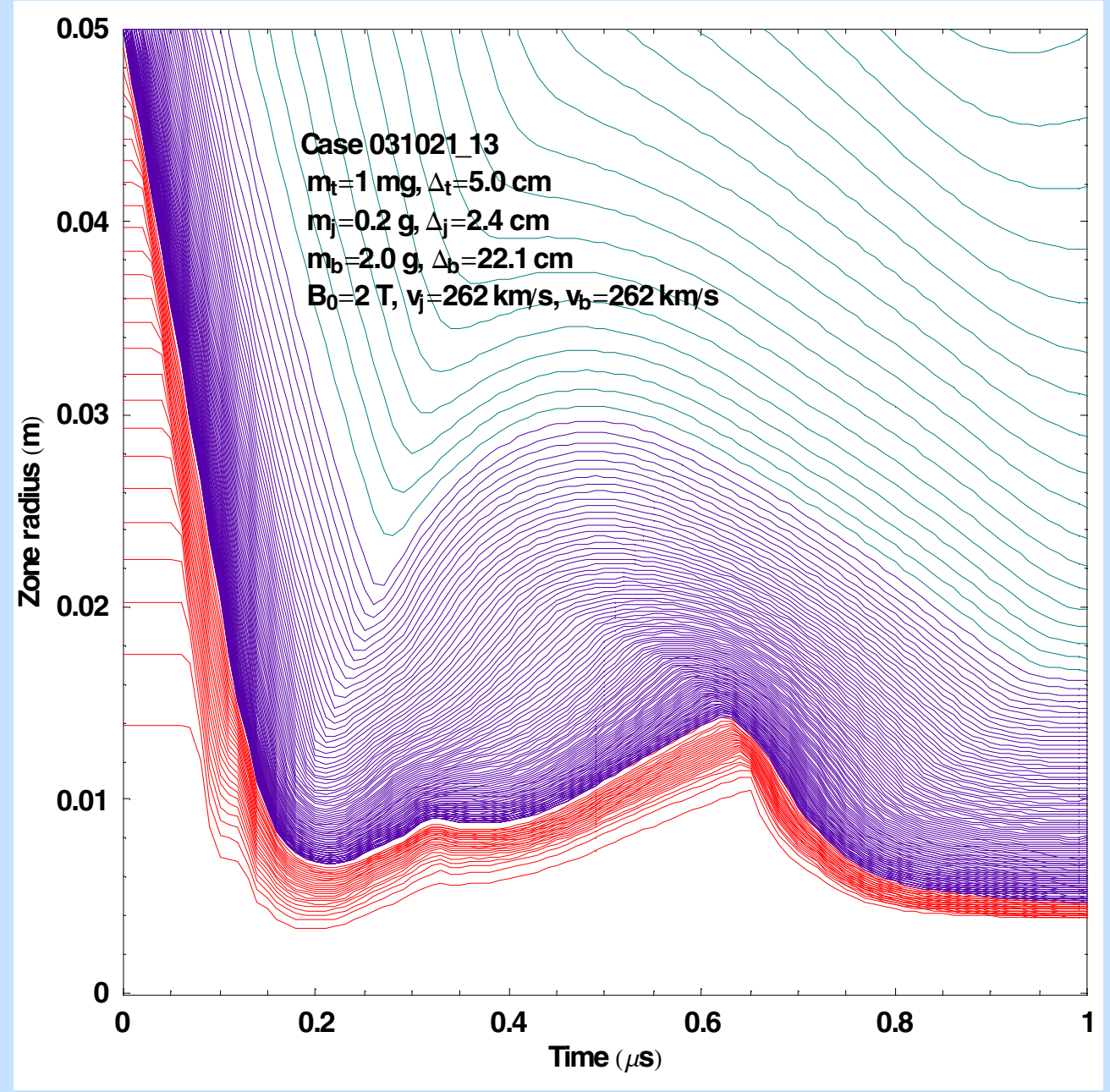
Preliminary Modeling Results for B=0 T and B=2 T Cases

B_0 = 0 T

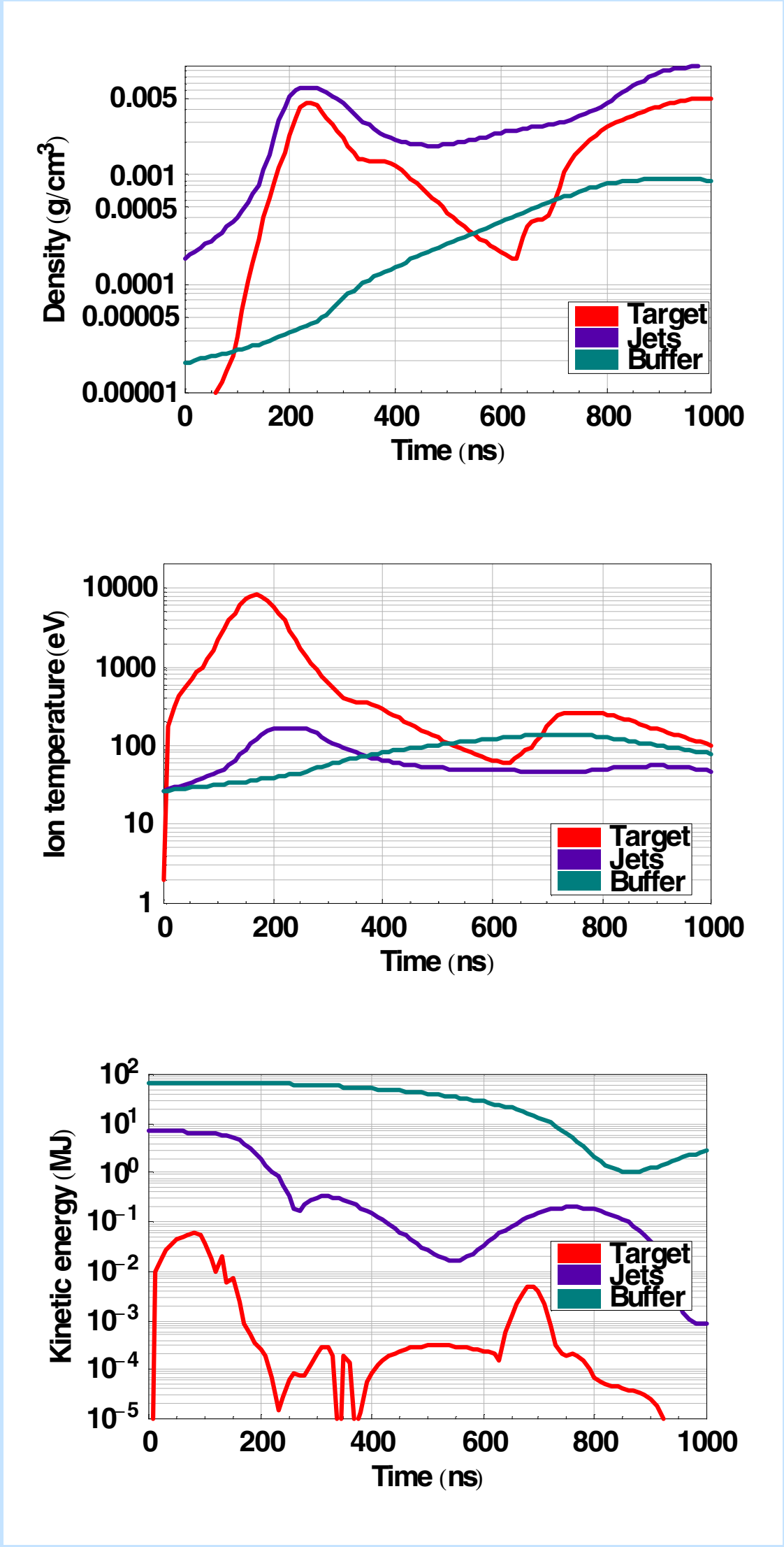
B_0 = 2 T

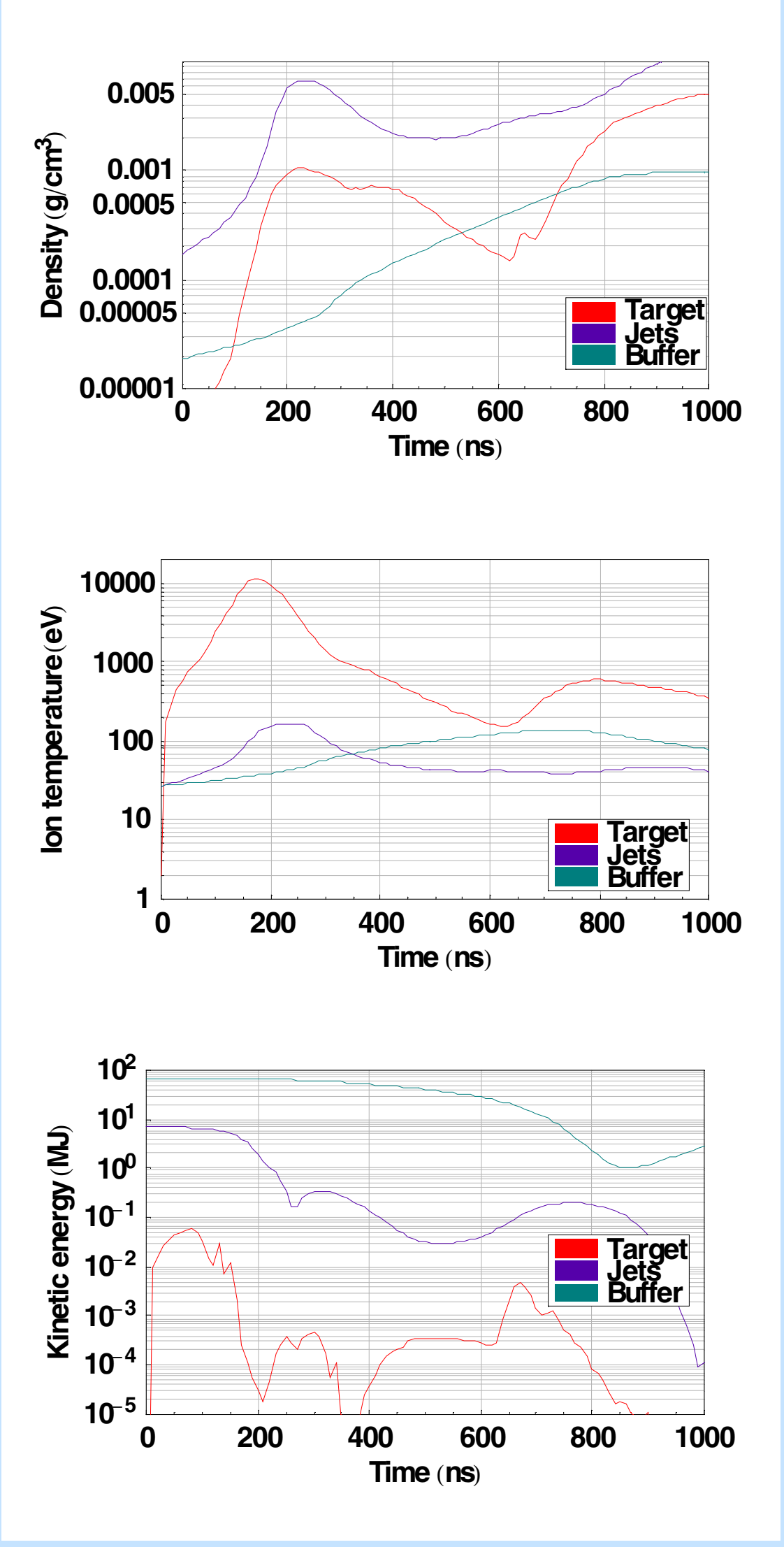
- **Lagrangian zone-radius development in time; note that:**
  - **The B=0 T plasma compresses more (near 1 μs).**
  - **Shock-wave timing is critical!**





- **Development of region parameters in time; note that**
  - **B=0 T case gives more target compression because the plasma is cooler than in the B=2 T case**
  - **Density and temperature peak at slightly different times. This led to fusion energy outputs smaller than anticipated from the analytic calculations [1]. Cases with better matching of the peaks are being sought.**





Summary

- **A simple MTF B-field model and the dependence of thermal conductivity on the B-field have been implemented in BUCKY.**
- **BUCKY calculations have begun to investigate the details of plasma-jet burn dynamics.**
- **Future work will focus on optimizing the performance of plasma-jet MTF burn dynamics in the concept-exploration, proof-of-principle, and reactor regimes.**

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