Exploration of Plasma-Jet Magnetized-Target Fusion Burn Dynamics

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Abstract*

Magneto-inertial fusion (MIF) implodes a conducting liner, compressing a magnetized plasmoid to fusion-relevant temperatures. The target's magnetic field reduces thermal conduction and the liner's inertia provides transient plasma stability and confinement. The present work explores the burn dynamics of using plasma jets to form the MIF liner [1]. Preliminary results indicate burning of a thin layer of the liner--a feature of the original analytic results. This exploration of MIF parameter space yields promising fast shock and long dwell time implosion modes. The investigation uses UW's 1-D Lagrangian radiation-hydrodynamics code, BUCKY, which solves single-fluid equations of motion with ion-electron interactions, PdV work, table-lookup equations of state, fast-ion energy deposition, and pressure contributions from all species. Extensions to the code include magnetic field evolution as the plasmoid compresses plus dependence of the thermal conductivity and fusion product energy deposition on the magnetic field.

[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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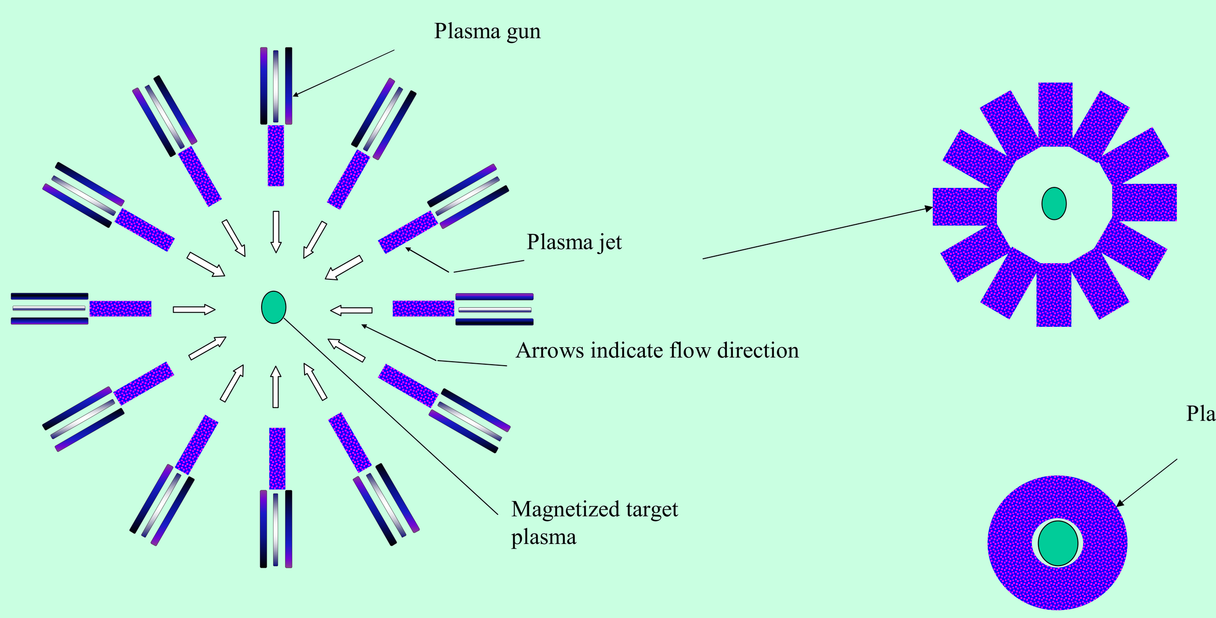
Overview of Plasma-Jet Magnetized-Target Fusion

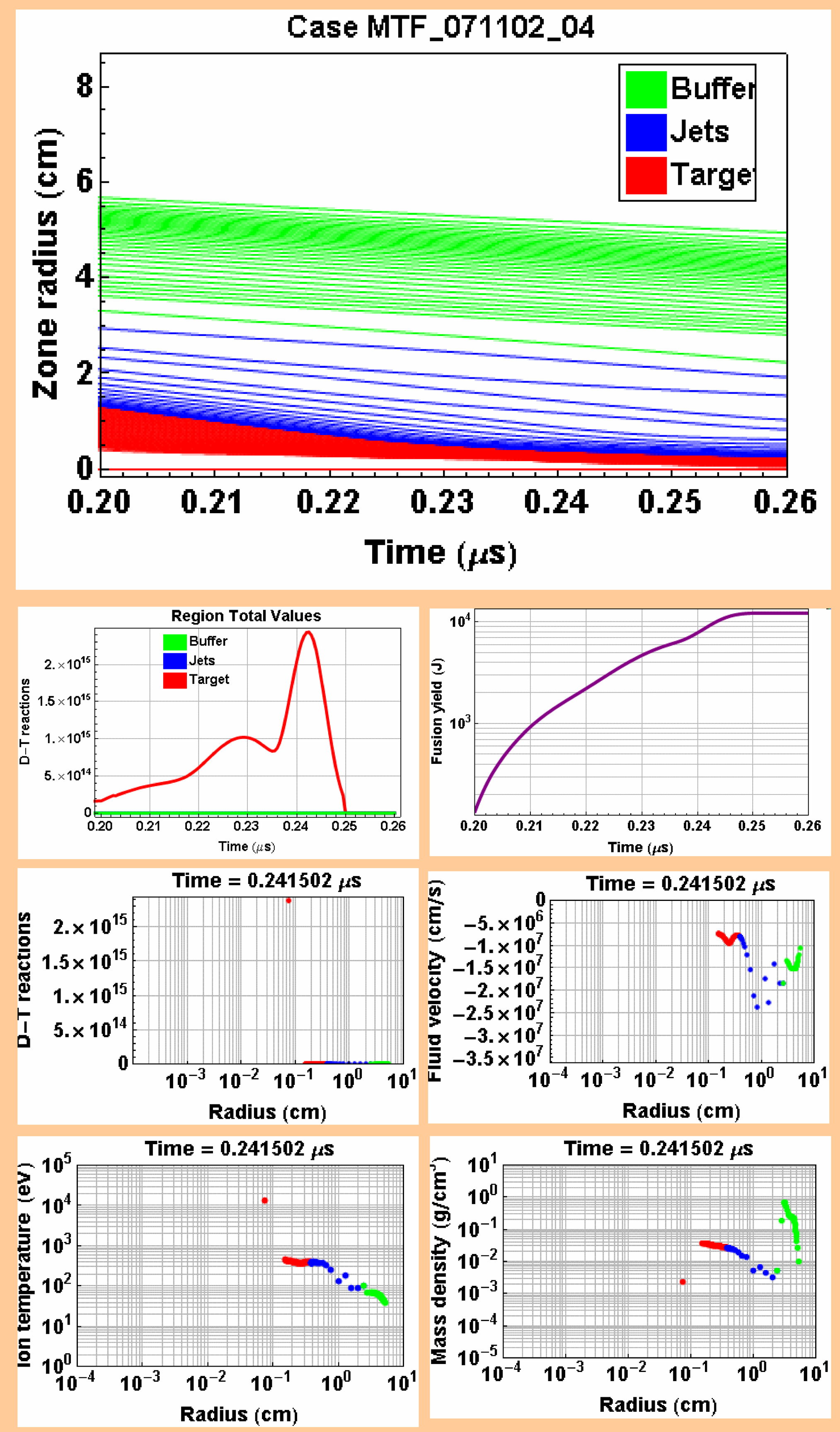
- In place of the solid or liquid liner previously considered for MTF, plasma jets of 100-400 km/s would be used [1], as shown in the figure below.
- Figure from Y.C.F. Thio, C.E. Knapp, R.C. Kirkpatrick, R.E. Siemon, and P.J. Turchi, "A Physics Exploratory Experiment on Plasma Liner Formation," *Journal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



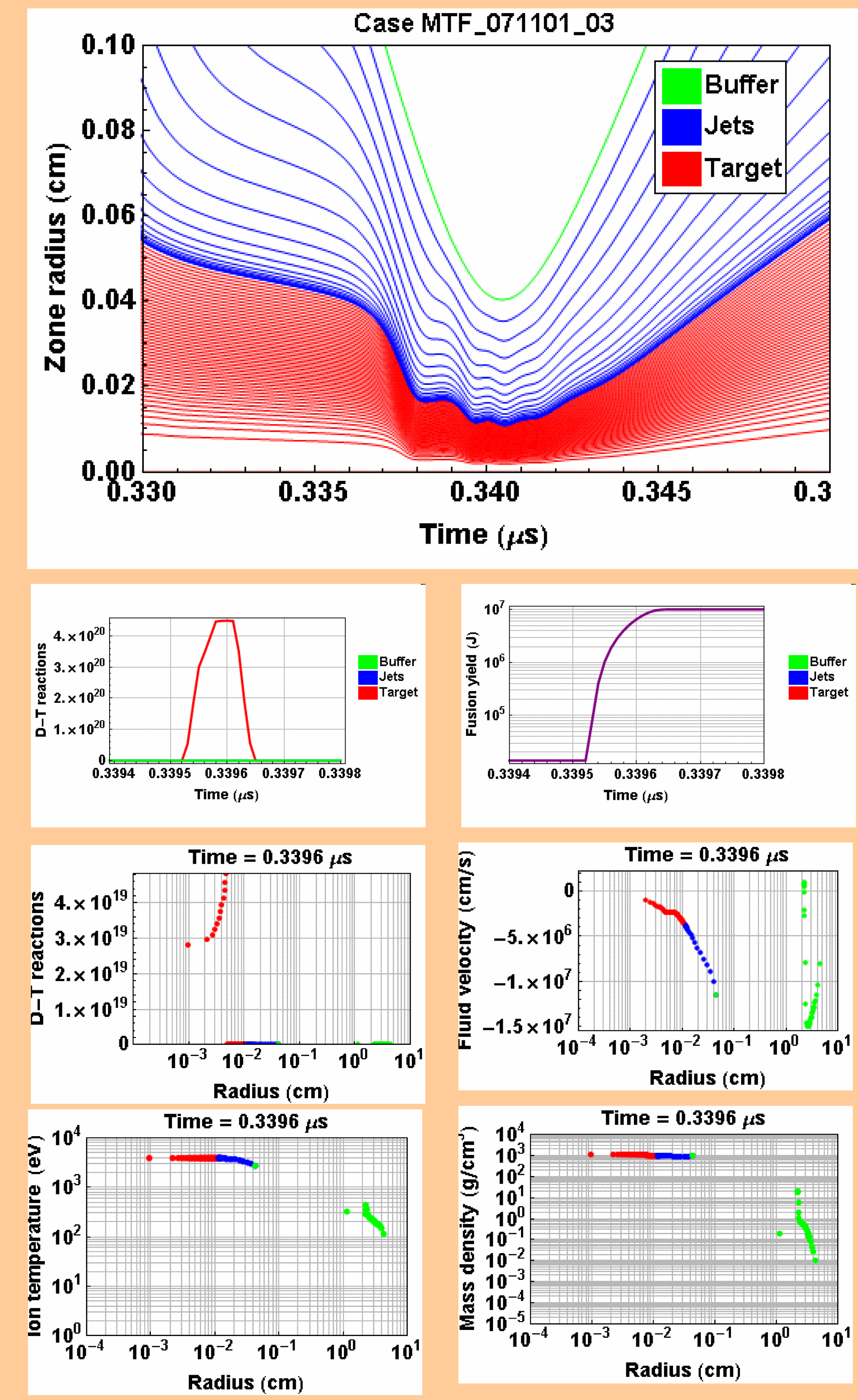
- Magnetic field of the field-reversed configuration (FRC) or spheromak target plasmoid reduces electron thermal conductivity as the target compresses.
- Shock waves propagate inward and outward, heating and compressing the plasma.
- The inertia of the plasma jets confines the target plasma for ~100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

Calculations Indicate Parameter Regime Exists for Burning Liner and Achieving High Q (right column)

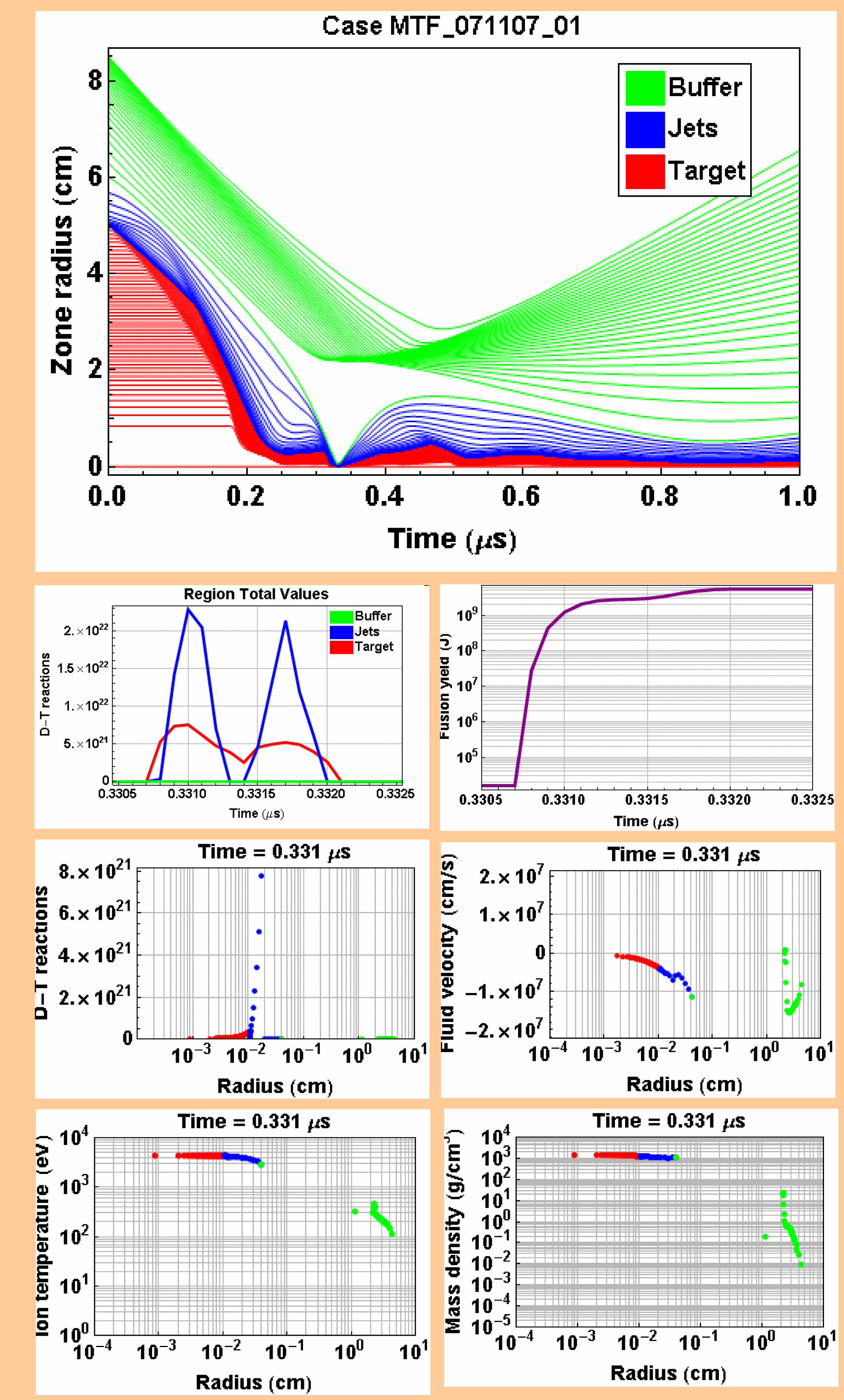
vBuffer=154.6 km/s, Eout=14 kJ



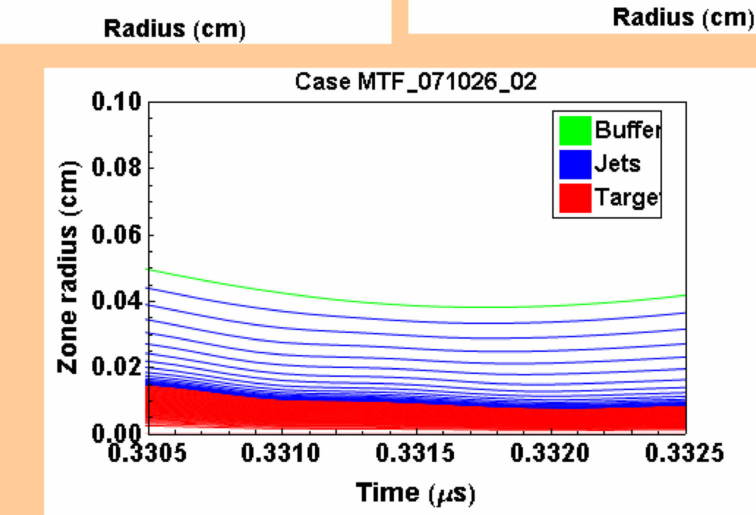
vBuffer=155 km/s, Eout=10 MJ



vBuffer=160 km/s, Eout=5.5 GJ, Q=50



- **Common initial parameters for all cases:**
  - **Buffer zone: argon, m=20 g, n_i=1.0x10^{21}, T_i=T_e=6.24 eV**
  - **Jet zone: D-T, m=4.4 g, n_i=2.2x10^{20}, T_i=T_e=20 eV**
  - **Target zone: D-T, m=0.007 g, n_i=3.2x10^{18}, T_i=T_e=2 eV**



Features of UW's 1-D BUCKY Rad Hydro Code

- **Lagrangian approach in planar, cylindrical, or spherical (used here) geometries**
- **Single-fluid equations of motion with pressure contributions from electrons, ions, radiation, and fast charged particles for D-T, D-D, and D-3He reactions**
- **Plasma energy transfer treated using either a one-temperature (Te=Ti) or two-temperature Maxwellian model, including PdV work and 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.**

Simple B-Field Model Has Been Implemented in BUCKY

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

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

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

- **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.**

Summary

- **A simple MTF B-field model and the dependence of thermal conductivity on the B-field have been implemented in BUCKY.**
- **BUCKY calculations indicate burning of a thin layer of the liner in some case--a feature of the original analytic results.**
- **Future work will focus on checking these results in detail and in optimizing the performance of plasma-jet MTF burn dynamics in the concept-exploration, proof-of-principle, and reactor regimes.**

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