Plasma-Jet Magnetized-Target Fusion

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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. Fusion product energy deposition is modeled by localized energy deposition or time-dependent particle tracking. Magnetized shock interface modeling will be performed in the future using Sandia National Laboratory's 2-D discrete simulation Monte Carlo (DSMC) code, Icarus.

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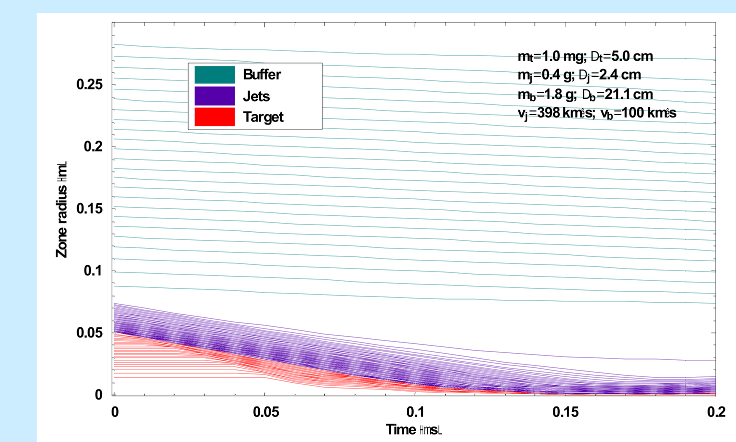
Features of the University of Wisconsin's 1-D Radiation Hydrodynamics Code, *BUCKY*

- *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*
- *Plasma energy transfer treated using either a one-temperature (Te=Ti) or two-temperature model.*
  - *Electrons and ions assumed to have Maxwellian distributions*
  - *Thermal conduction for each species presently treated using either specified or Spitzer constant conductivities, with flux-limited electron conduction*
- *PdV work*
- *Fast-ion (beam or target debris) energy deposition*
- *Heating due to fast charged particles and neutrons during the fusion burn*
- *D-T, D-D, and D-^{3}He reactions*
- *Charged particle reaction products transported and slowed using time-dependent particle tracking*
- *Neutrons deposited in the target using an escape probability model*
- *Fast ions from an ion beam and target microexplosion 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*

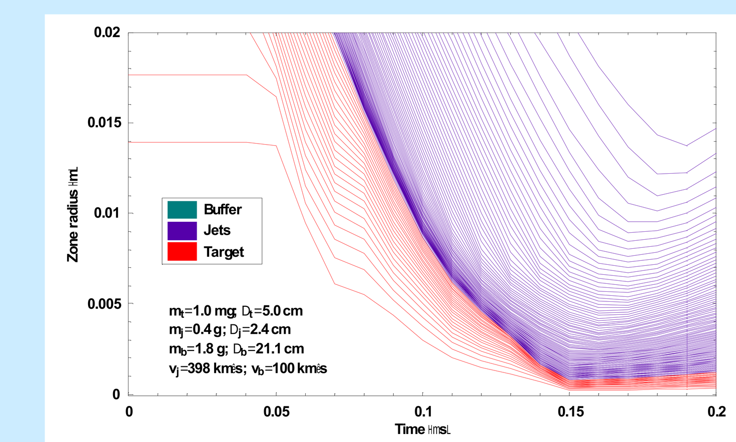
Typical Results of the University of Wisconsin's 1-D Radiation Hydrodynamics Code, BUCKY

- Lagrangian zone-radius development in time

r < 0.3 m

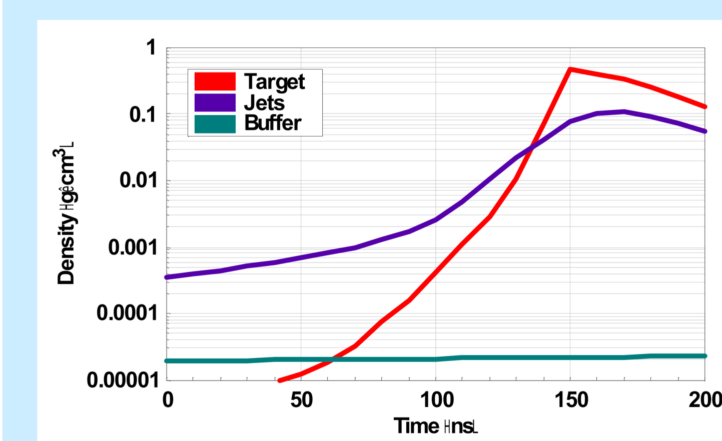


r < 0.02 m

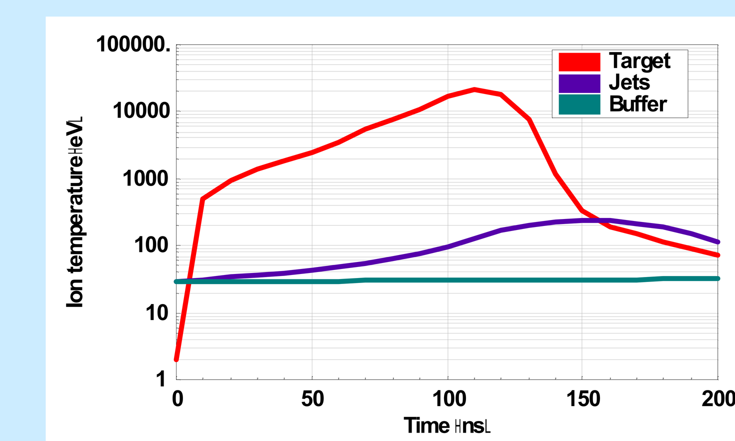


- Development of region parameters in time

Density

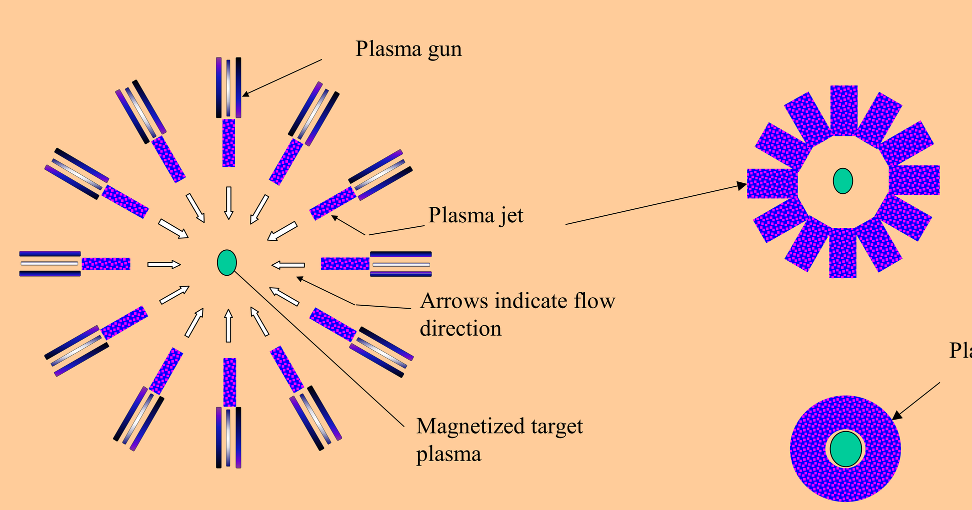


Temperature



Overview of Plasma-Jet Magnetized-Target Fusion

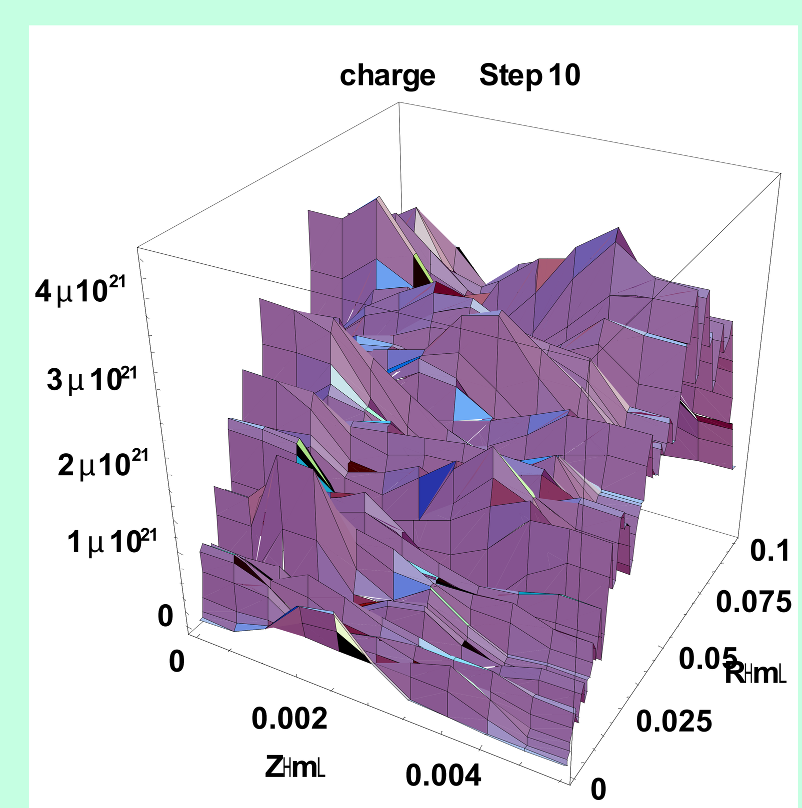
- In place of the solid or liquid liner previously considered for MTF, plasma jets of 100-500 km/s would be used [1], as shown in the figure below.
- Figure from Y.C.F. Thio, C.E. Knapp, R.C. Kirkpatrick, R.E. Siemon, and P.J. Turchi, "A Physics Exploratory Experiment on Plasma Liner Formation," Journal 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 Sandia National Laboratory's 2-D DSMC Code, *Icarus*

- *Feature of most DSMC codes:*
  - ➢ *arbitrary mean free paths,*
  - ➢ *chemical reactions, and*
  - ➢ *gas-surface interactions.*
- *The Icarus code goes beyond most other DSMC codes in that it includes plasma effects:*
  - ➢ *neutral gas collisions with plasma,*
  - ➢ *charged particle collisions with each other,*
  - ➢ *atomic physics reactions,*
  - ➢ *electrostatic fields, and*
  - ➢ *plasma-surface interactions.*
- *Available boundary conditions include:*
  - ➢ *solid,*
  - ➢ *inflow,*
  - ➢ *outflow,*
  - ➢ *arbitrary transparency,*
  - ➢ *stationary,*
  - ➢ *translating, and/or*
  - ➢ *rotating.*
- *Icarus treats x-y or r-z geometry, using:*
  - ➢ *sophisticated grid generation,*
  - ➢ *parallel processing,*
  - ➢ *post-processing, and*
  - ➢ *restart.*



Future Work

- **More sophisticated B-field models and the dependence of thermal conductivity on the B-field must be implemented in BUCKY.**
  - ➢ *Magnetic-field enhanced Braginskii thermal conductivities [1]:*

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

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

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

- **Use BUCKY to investigate the details of plasma-jet burn dynamics.**
- **Use SNL's Icarus code to model α transport across equilibrium and stochastic magnetic fields.**
- **Optimize the performance of plasma-jet MTF plasmas in the concept-exploration, proof-of-principle, and reactor regimes.**

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