Burn Dynamics of Plasma-Jet Magnetized-Target Fusion

John F. Santarius, Fusion Technology Institute, University of Wisconsin

Objective:

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

Abstract

Magnetized-target fusion (MTF) constitutes one form of pulsed power. MTF relies on the magnetic field of the target to reduce thermal conduction and an incoming liner's inertia to provide transient plasma stability and confinement. The attractiveness of MTF as an electric power-plant option stems from its position intermediate in plasma density and energy between magnetic fusion energy (MFE) and inertial fusion energy (IFE). That position potentially leads to lower costs for MTF than for MFE and IFE, in large part because MFE magnets are eliminated and the required driver energy compared to IFE drops significantly [1]. Almost all of the research on magnetized-target fusion has focused on solid or liquid liners. This poster gives preliminary results of burn-dynamics exploration in the reactor regime of the recently invented concept of using plasma jets to form the liner [2]. The investigations use the University of Wisconsin's 1-D radiation hydrodynamics code, BUCKY, described below.

[1] R.E. Siemon, I.R. Lindemuth, and K.F. Schoenberg, "Why Magnetized Target Fusion Offers a Low-Cost Development Path for Fusion Energy," Comments on Plasma Physics and Controlled Fusion 18, 363 (1999).

[2] 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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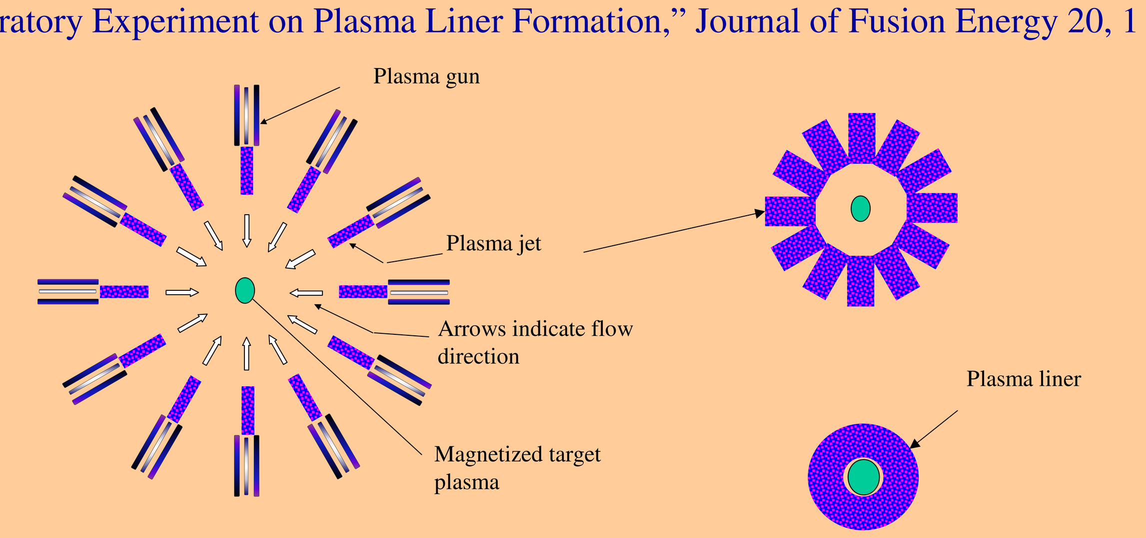
Overview of Plasma-Jet Magnetized-Target Fusion

- In place of the solid or liquid liner previously considered for MTF, plasma jets of 100-500 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 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*

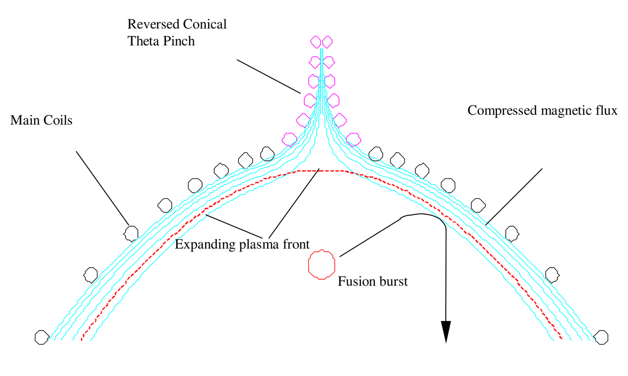
Typical MTF Reactor Parameters

- Input parameters from 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. (NRC Press, National Research Council of Canada, Ottawa, Canada, 1999), p. 113.

Initial parameters for target and jet regions		Target	Jets
Number of zones used by BUCKY calculation	zones	25	100
Zone mass-change factor	zonfac	0.05	0.0315417
Region thickness	Δ_{region}(m)	0.05	0.024
Region outer radius	r(m)	0.05	0.074
Total mass	m(g)	0.00437892	0.2
Density	n(m^{-3})	$2. \times 10^{24}$	4.07472×10^{25}
Electron temperature	T_e(eV)	2	26.7
Velocity	v(km/s)	0	125.231
Confinement time	τ(μs)	0.	0.590908
Ion-acoustic velocity	τ_S(μs)	4.41712	1.7892
Kinetic energy	KE(MJ)	0.	1.56828

Plasma-Jet MTF for Space Propulsion

- **Space propulsion constitutes an interesting potential application of MTF.**
- **Research performed at NASA Marshall Space Flight Center.**
- **Figure at right, from Francis Thio, shows the basic concept of direct thrust by reflecting the expanding MTF plasma off of a magnetic nozzle.**
- **Y.C.F. Thio, B. Freeze, R.C. Kirkpatrick, B. Landrum, H. Gerrish, and G.R. Schmidt, "High-Energy Space Propulsion Based on Magnetized Target Fusion," 35th AIAA/ASMA/SAE/ASEE Joint Propulsion Conference paper AIAA-99-2703 (1999).**
- **G. Statham, S. White, R.B. Adams, et al., "Engineering of the Magnetized Target Fusion Propulsion System," Space Technology and Applications International Forum (STAIF, 2003).**
- **Predicted space-propulsion performance shown at right (see references above).**



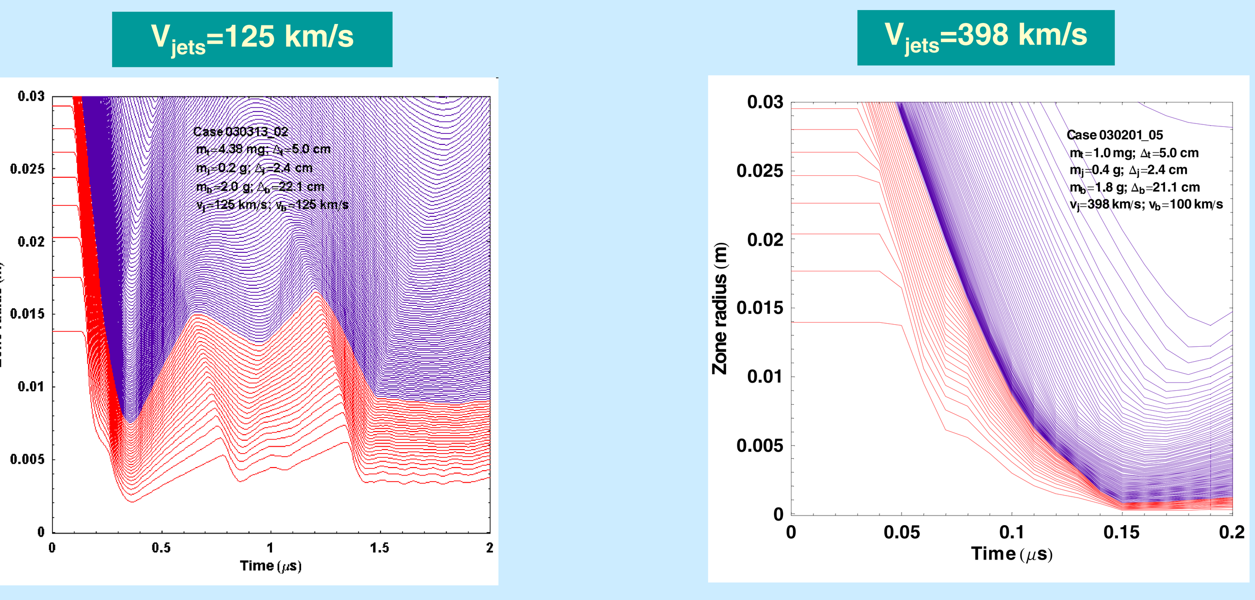
Predicted Plasma-Jet MTF Typical Performance

- **Specific power ~ 20-50 kW/kg**
- **Exhaust velocity ~ 800 km/s**
- **Jet power ~ 4-25 GW**
- **Rep rate ~ 40 Hz**
- **Trip time to Mars ~ < 1 month**

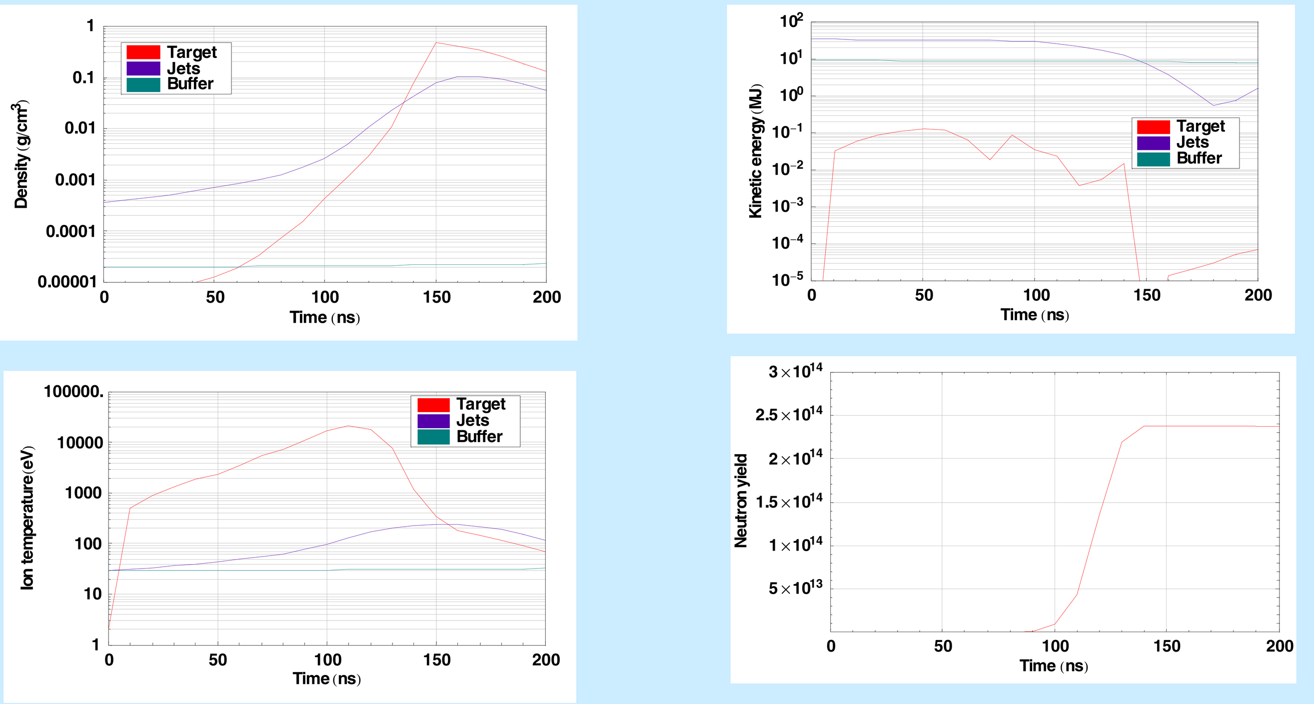
Modeling Results

MTF Explosion/Implosion Process Involves a Complicated Mixture of Shock Waves

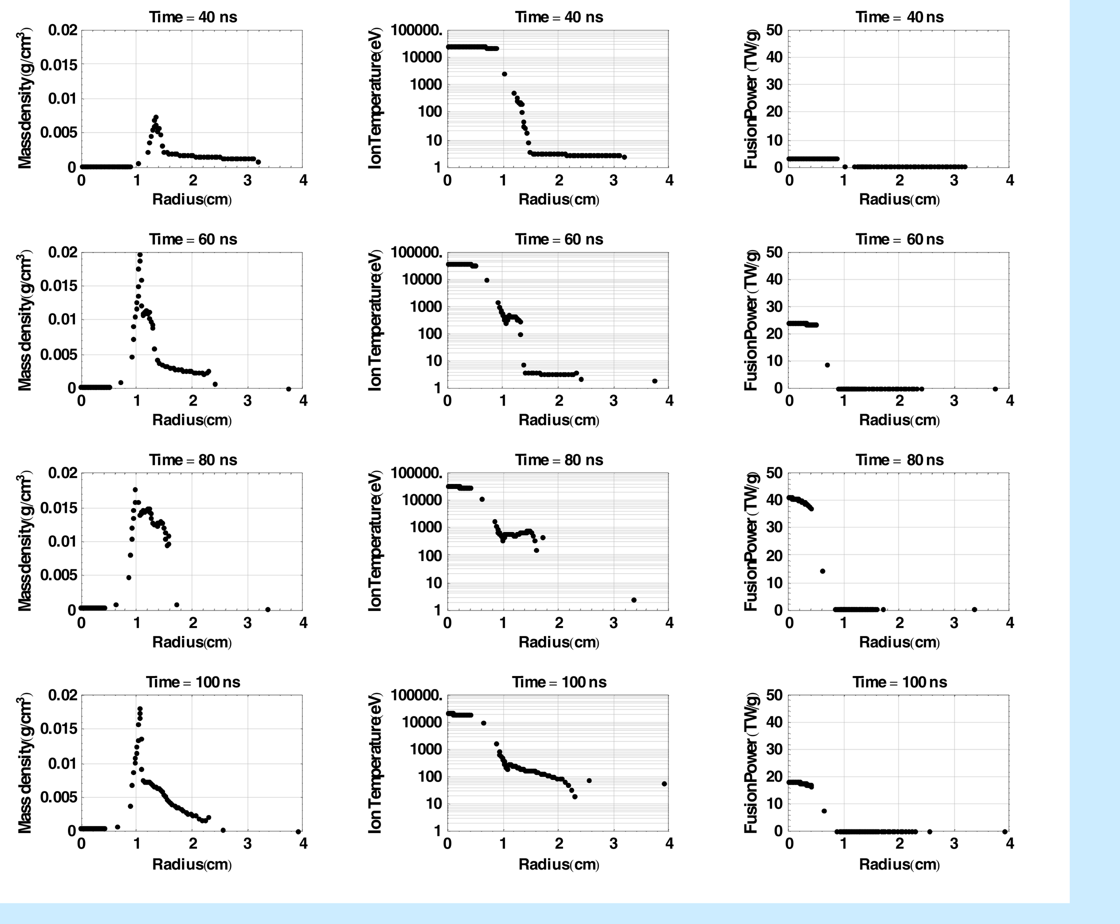
- **Lagrangian zone-radius development in time for case given at center-left**



- **Development of region parameters in time for v_{jet}=398 km/s case**



Mass density, ion temperature, and specific fusion power versus radius near the origin.



Future Work

- **More sophisticated B-field models and the dependence of thermal conductivity on the B-field must be implemented in BUCKY.**
- **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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