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Appendix F

LLNL - Contributions to MPD Thrusters for SEI

LH075075

MPD Thruster Technology Workshop
NASA, Washington, D.C.

E. Bickford Hooper

May 16, 1991

LLNL CAN CONTRIBUTE TO MPD THRUSTER DEVELOPMENT FOR SEI

Near term:

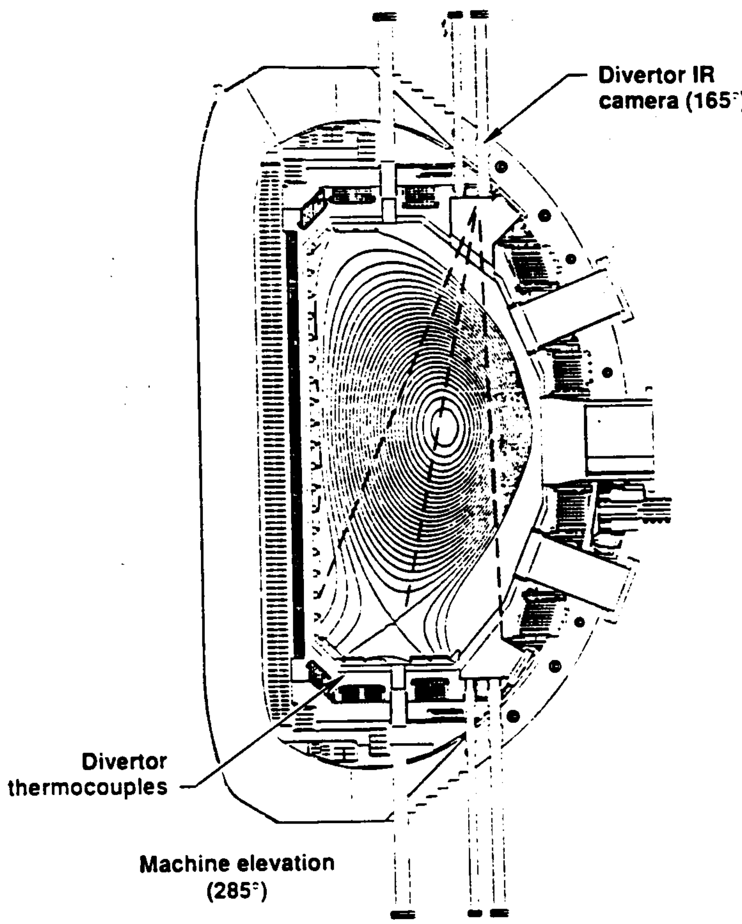
- Modeling of MHD characteristics using the TRAC code, which has been benchmarked against the RACE experiment at LLNL
- Application of tokamak "divertor" physics
  - o Modeling of atomic – plasma interactions (gas penetration, ionization, excitation, radiation) using the Brahms and Degas codes
  - o Measurements of MHD and atomic effects
  - o Modeling of erosion/sputtering and redeposition of refractory materials
- Remote measurements of density, temperature, magnetic field using fusion diagnostics

These contributions can best be made in collaboration with ongoing experiments

Long term:

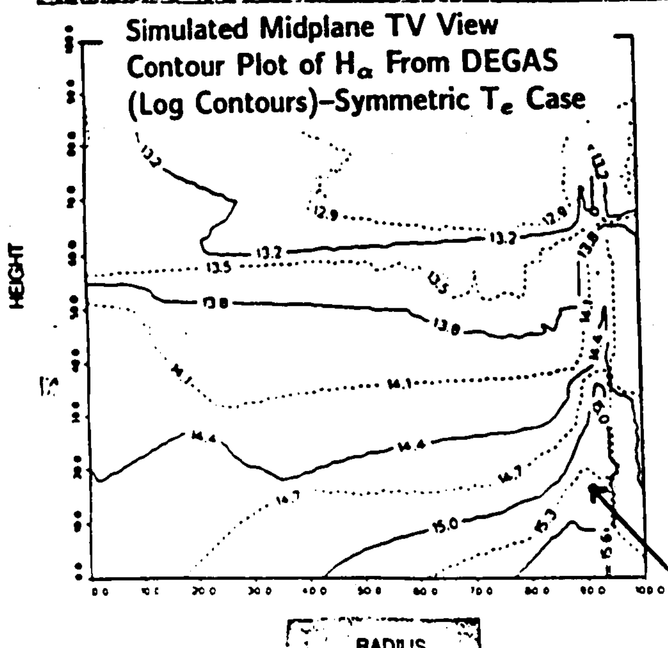
- High power tests for lifetime validation using the MFTF-B facility

Divertor IR camera



COMPARISON OF TANGENTIAL H_α DATA WITH DEGAS

Neutral H density in and near plasma calculated using the DEGAS code; H-alpha emission evaluated and compared with measurements



Experimental Data From Midplane Tangential Camera– Note Decrease From X-point To Midplane

X-POINT

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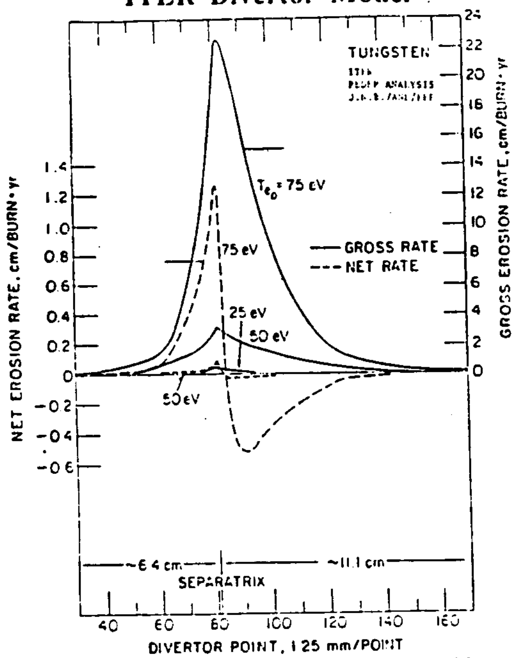
The MFE community has developed considerable expertise in plasma-induced erosion/redeposition

ITER Divertor Model



J. Brooks (ANL) Fusion Techn. 18 (1990) 239

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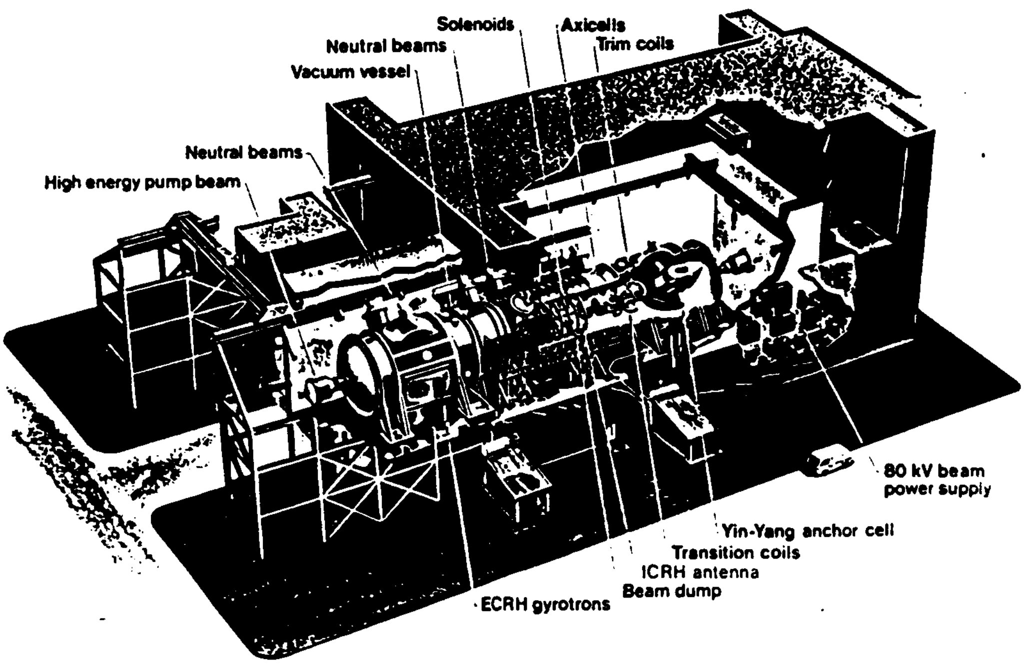
- Computer codes such as REDEP are used to predict net erosion including redeposition effects
- These calculations are benchmarked against measurements in tokamaks and off-line simulation facilities

THE MFTF-B



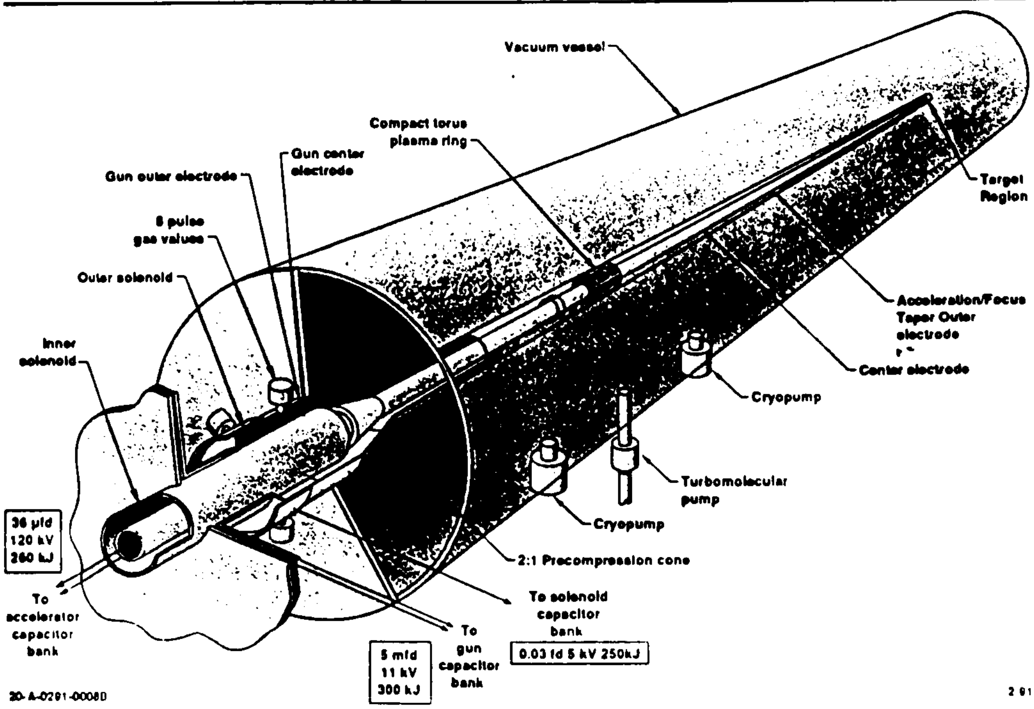
PROPOSED THRUSTER LIFETIME TEST FACILITY

- MFTF-B: Size 35' diameter by 200' long
  1000 m3 of cryopanels
  11 kW of LHe cooling available for pumping
  500 kW closed loop LN_2 system
  250 MVA power line

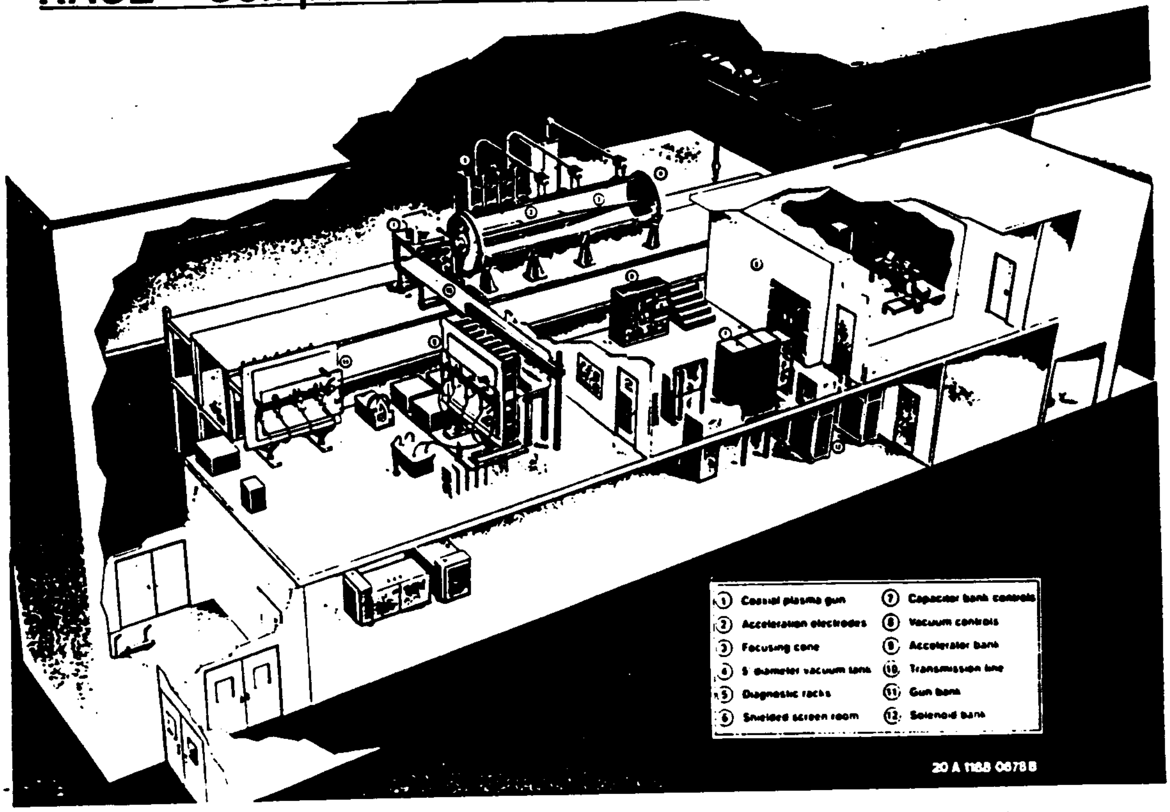
- Example test conditions: mass flow = 0.4 g/s (thruster power = 1 MW at $v = 7\times10^4$ m/s)

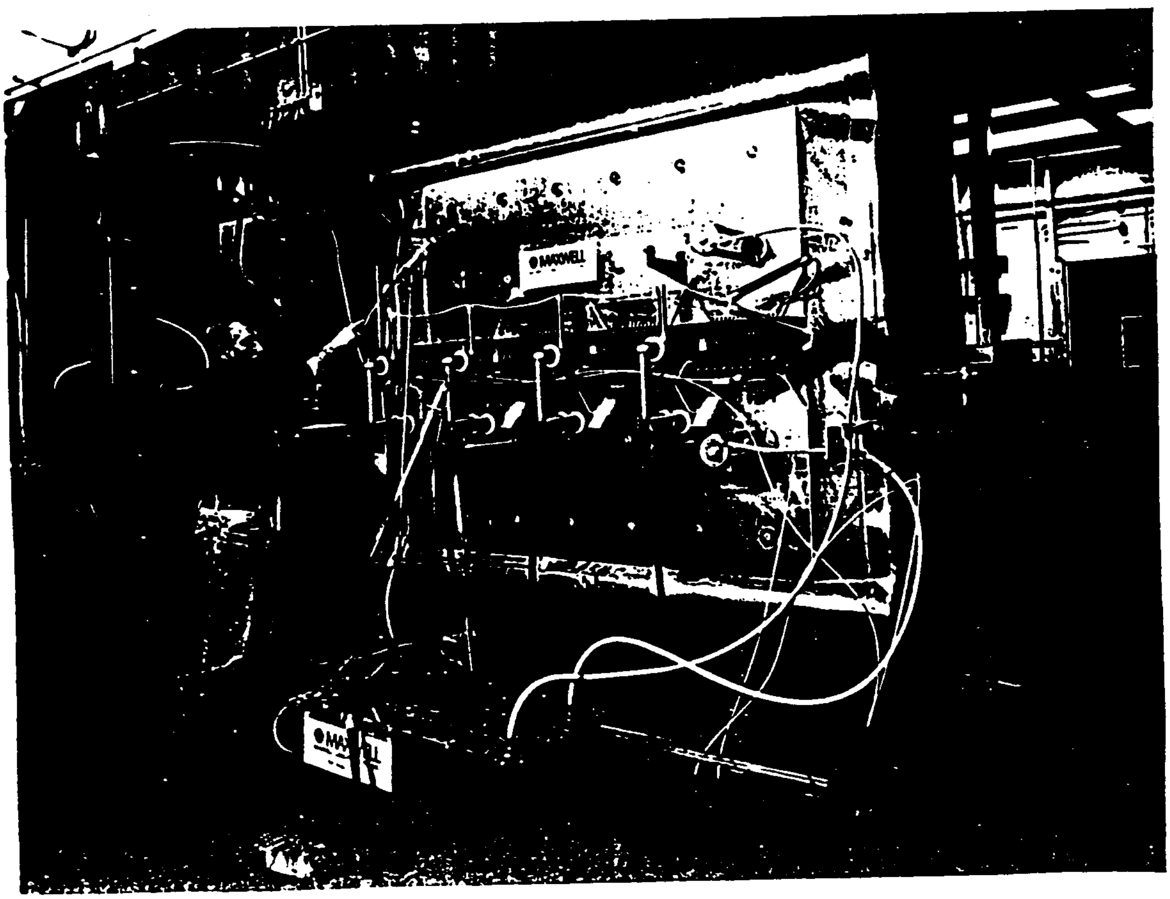
Pumping speed	67×10^6 liters/s, D_2	
	$67\times10^6\ (4/A)^{1/2}$ liters/s, Mass A	
Equilibrium pressure		
	Hydrogen	5.2×10^{-5} torr
	Argon	1.6×10^{-4} torr

The RACE experiment test the basic concepts of ring acceleration



RACE Compact Torus Accelerator Facility





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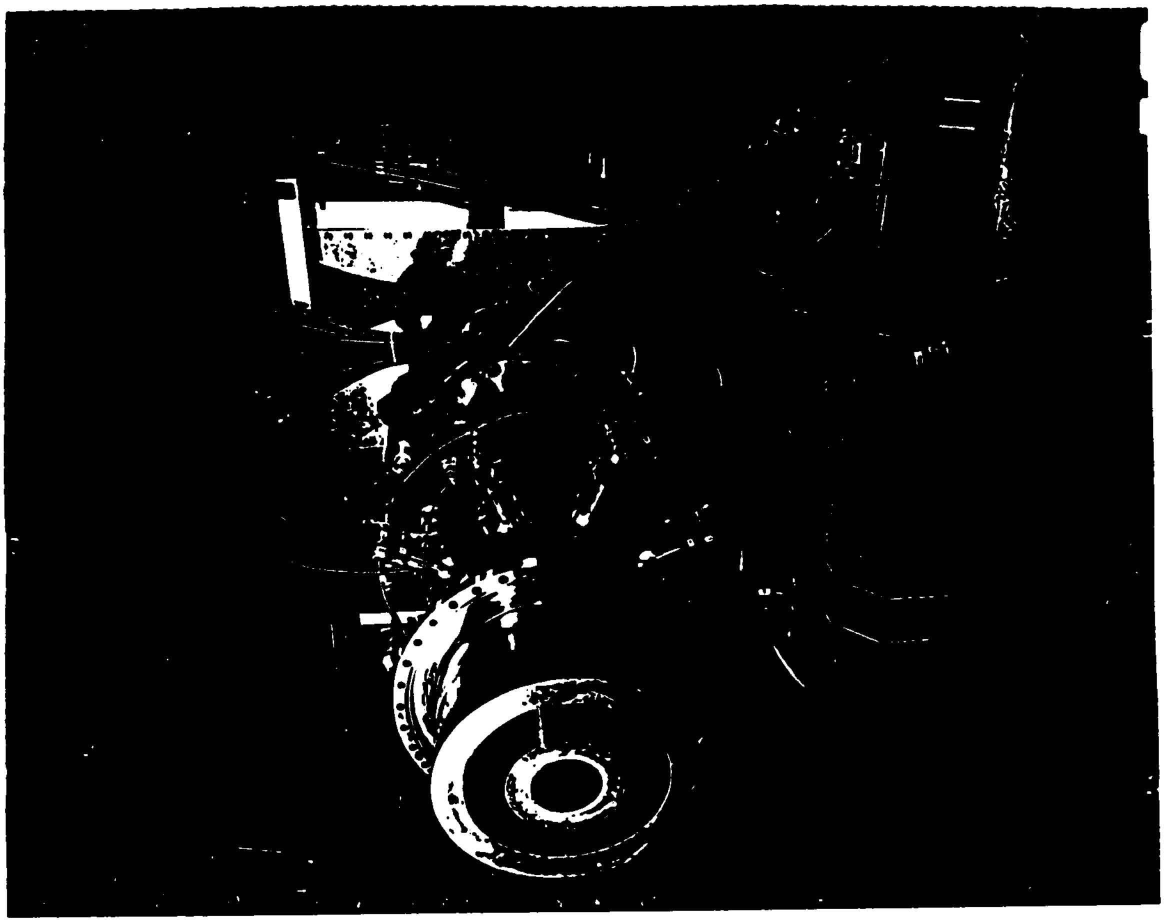

RACE program summary

Goals	Predictions		Results to Date
Demonstrate ring formation	Magnetic energy	2–40 kJ	2–10 kJ
	Mass	5–500 microgram	5–500 microgram
	Length	70 cm	50–100 cm
Demonstrate acceleration in linear coaxial system	Velocity	1–2 x 10^8 cm/sec	1–3 x 10^8 cm/sec
	Energy	Up to 100 kJ	50 ~~20~~ kJ*
	Efficiency	0.4	0.3–0.4
	$U_{kinetic}/U_{magnetic}$	5	10
Demonstrate ring focusing	R_{focus}/R_0 ~	1/5	~1/3

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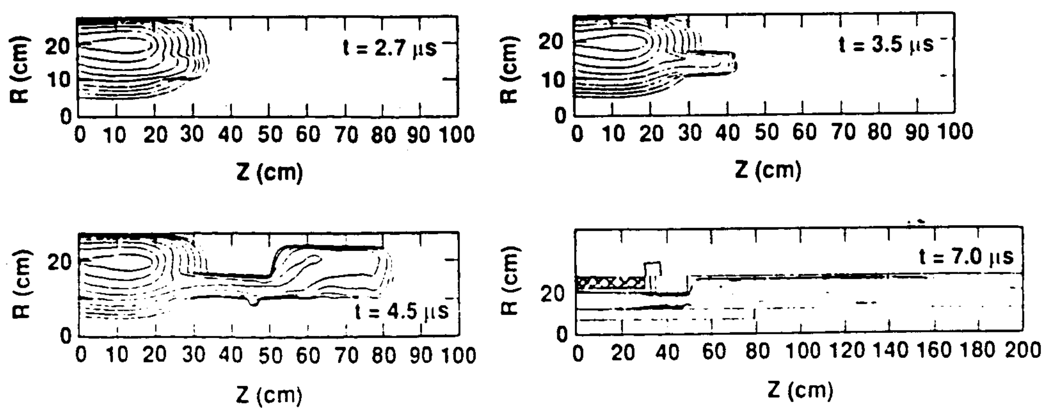
Comparison of race data of plasma ring formation with the HAM 2D-MHD code

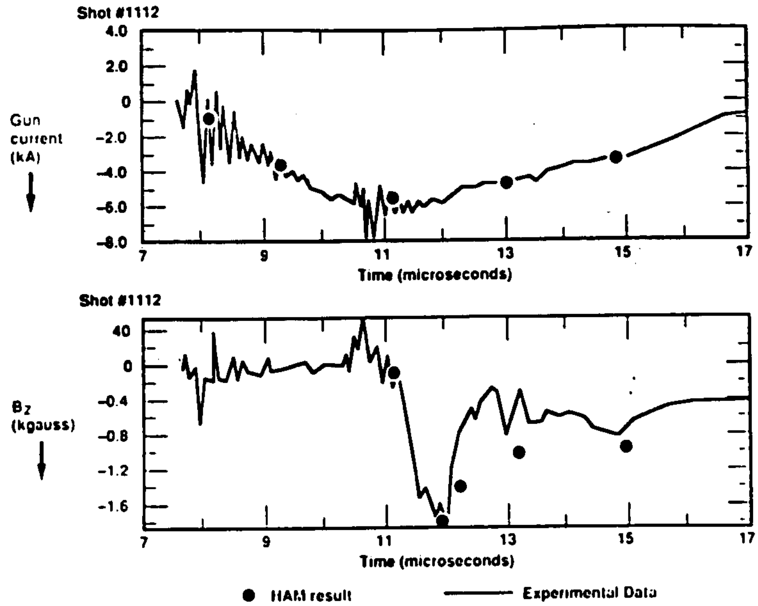
For these calculations HAM:

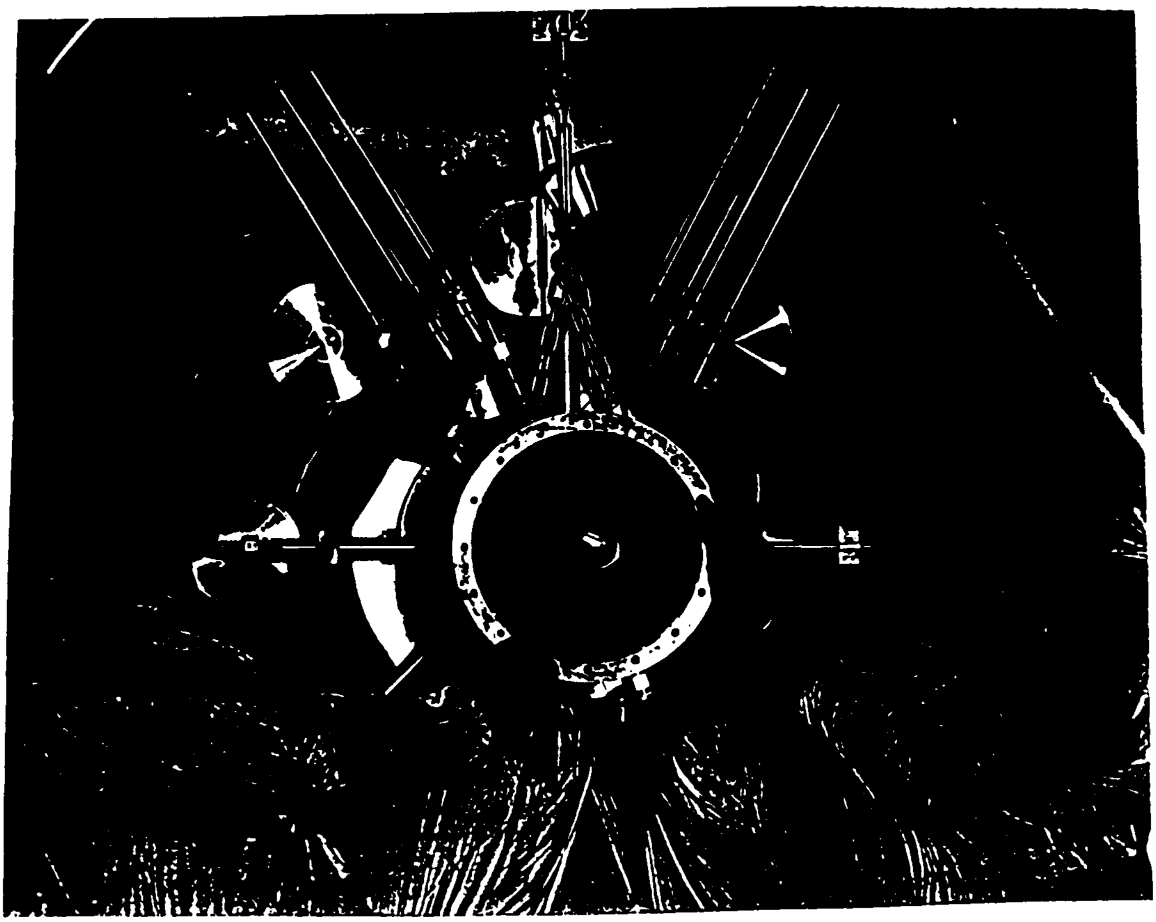
1. **Calculates the initial poloidal field allowing for diffusion through conducting electrodes**
2. **Calculates the time-dependent gas density distribution from an injected puff of gas**
3. **Calculates gas breakdown and plasma ring formation using the gun capacitor bank parameters**

Flux contours for HAM simulation



2D MHD simulations agree with the experimentally observed current





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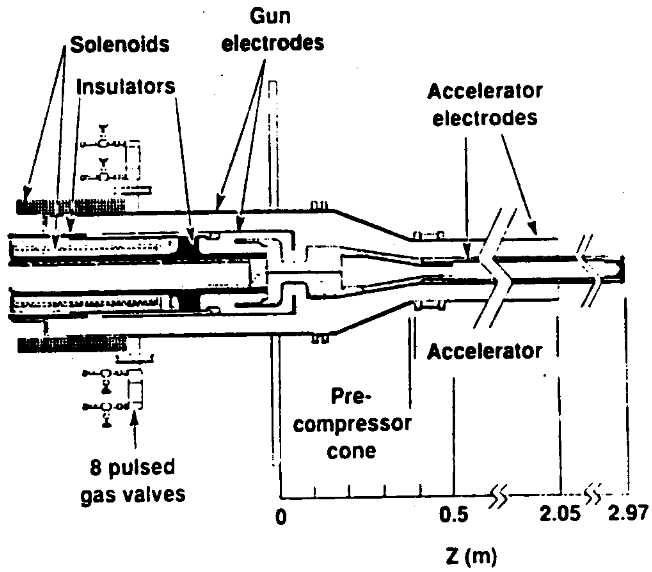
RACE, the Ring ACcelerator Experiment, configuration during precompressor tests



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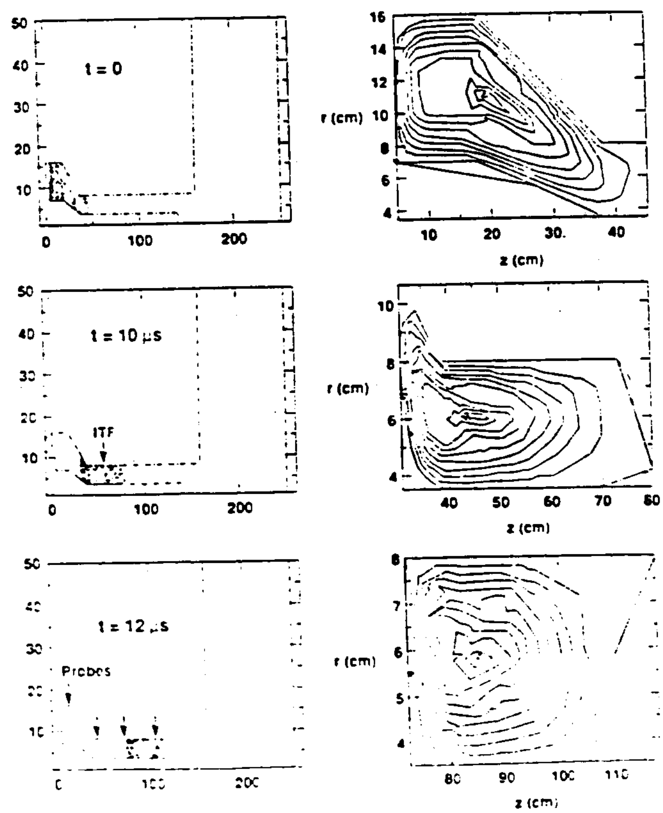
TRAC (Two-dimentional Ring Acceleration Code) has been used to model the RACE pre-compressor



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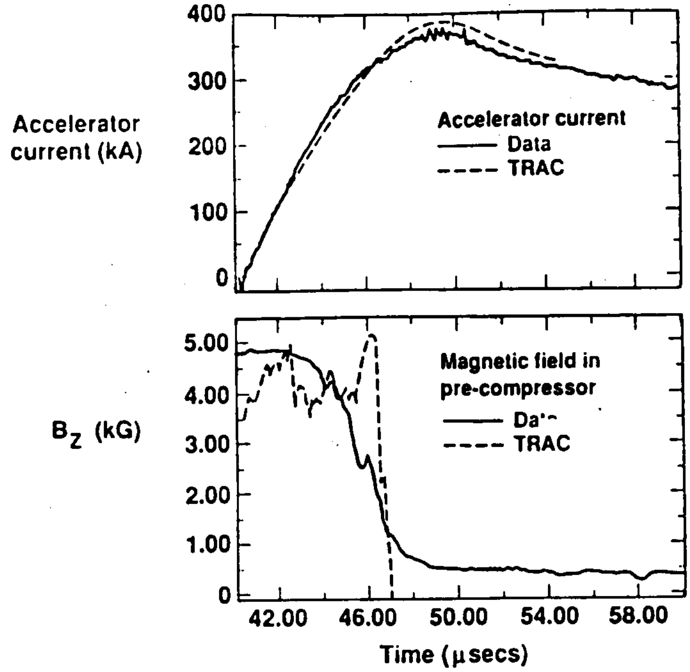
Comparison of trac with shot 5554 (V_{ACC} = 80 kV)



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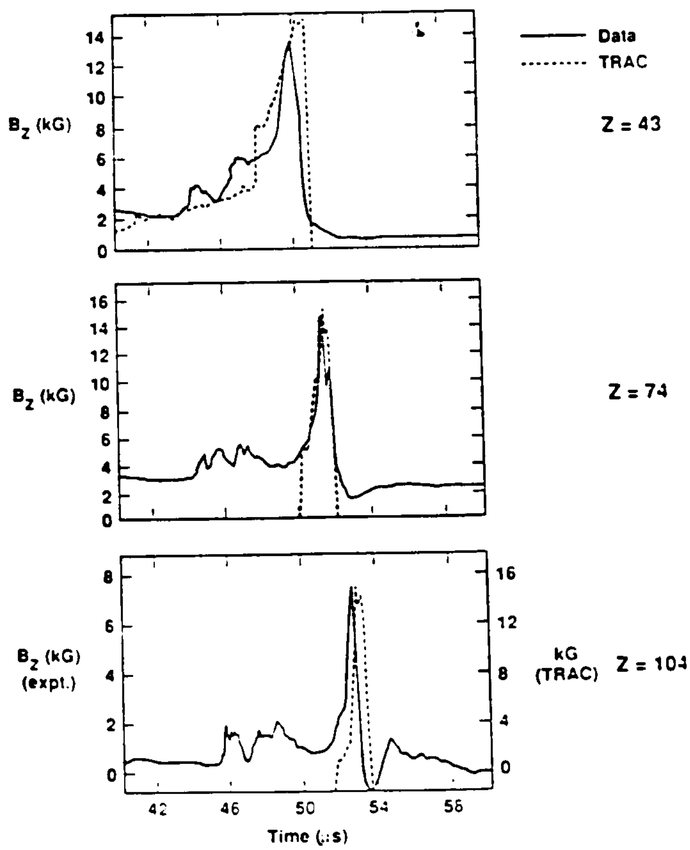
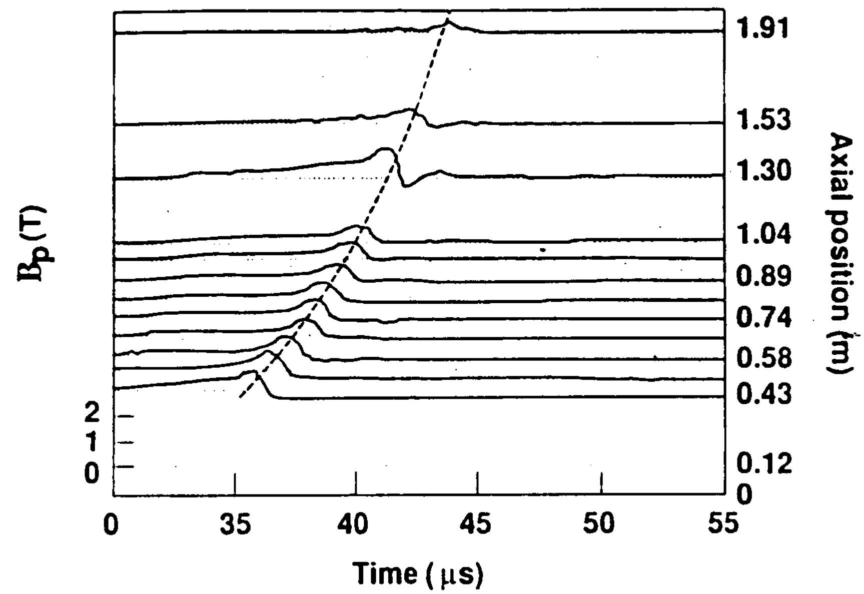
Comparison with shot 5554 cont'd B_Z vs. t at different locations in straight section



CT accelerates and is stable after precompression



(Vertical offsets of B_p probe signals proportional to axial location)

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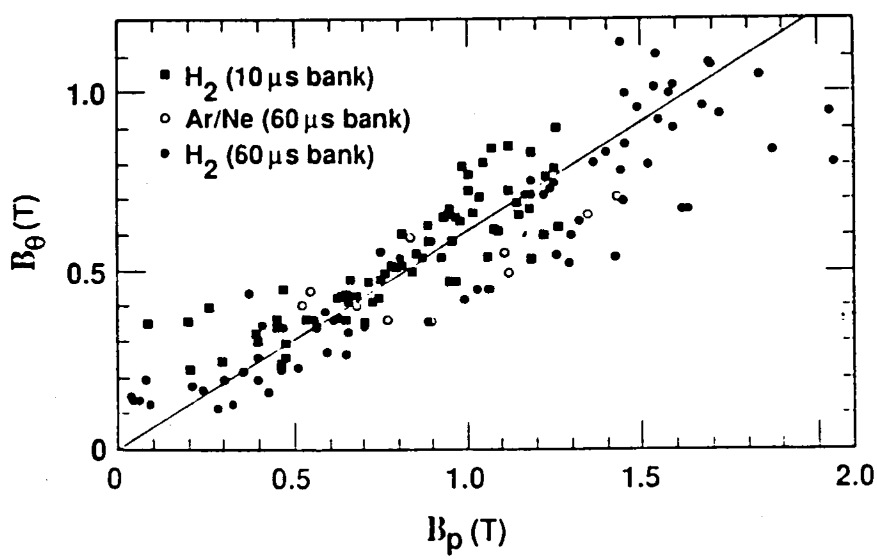
CT in quasi-static pressure balance during compression in conical electrodes



(Accelerator field proportional to poloidal field at 0.43 m for three gun conditions, consistent with line predicted by TRAC code.)

20-A-1090-0340A

An Alternate Application of MPD Arc Sources: Plasma "Tethers" for Tapping the Solar Wind EMF for Power > 10 MW

Plasma plumes generated by MPD arc sources can extend of order 1000 km across the solar wind magnetic field. The electric field, $\mathbf{E} = \mathbf{u}_{wind} \times \mathbf{B}$, gives a voltage drop along the plume, and currents are induced as in the AMPTE artificial comet experiments.

The available power is:

$$P = 2 \dot{M}_p v_p v_A \qquad \dot{M}_p = \text{mass ejection rate} \qquad v_p = \text{plume velocity}, \quad v_A = \text{Alfven velocity}$$

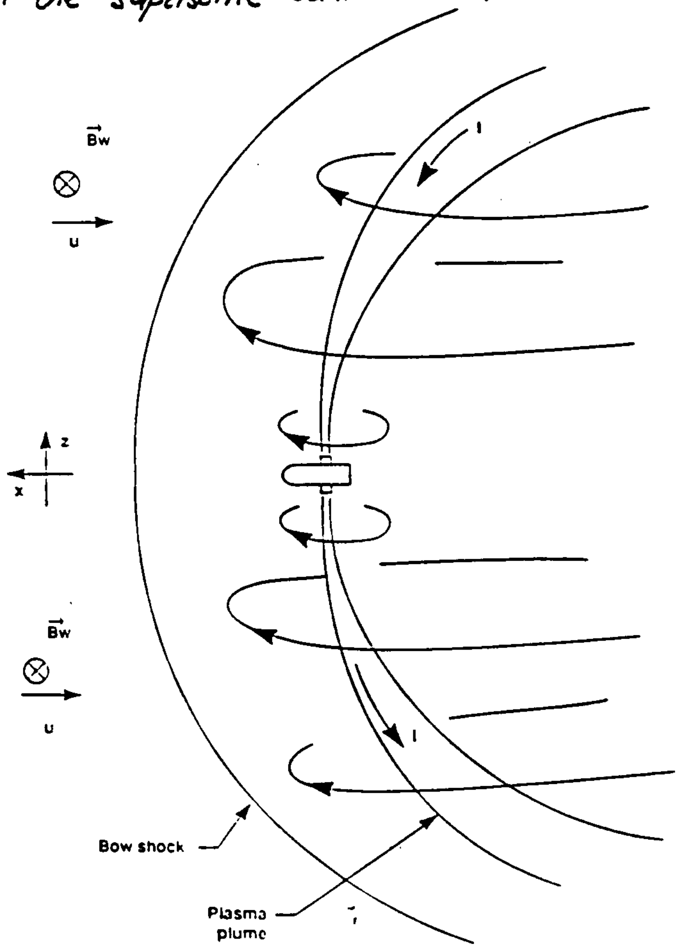
An example:

$$\dot{M}_p = 10 \text{ g/sec}, \quad v_p = 60 \text{ km/sec}, \quad v_A = 80 \text{ km/sec}, \quad P = 100 \text{ MW}$$

The power could drive thrusters with a specific impulse of about 3000 sec.

A lunar power station could extract large amounts of power since there is unlimited available mass. The energy extracted is about 10^{10} Joules/kG

Plasma "Tethers" generate a bow shock in the supersonic solar wind plasma



The plume in cross-section

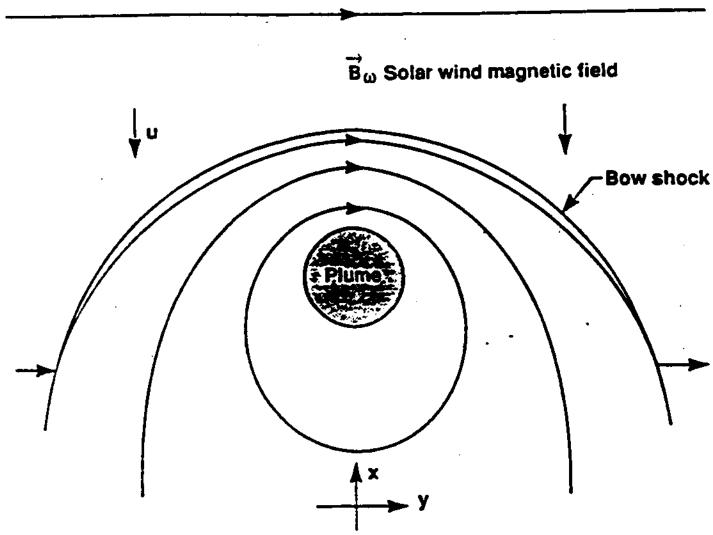


Figure 2

A conceptual solution for self-sustaining plasma guns / thrusters

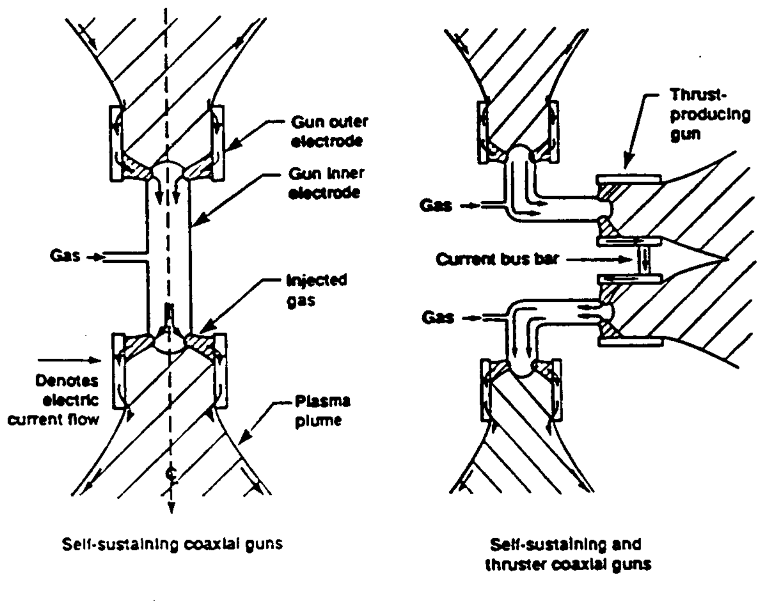


Figure 3

The plume dynamics can be calculated from a simple MHD model

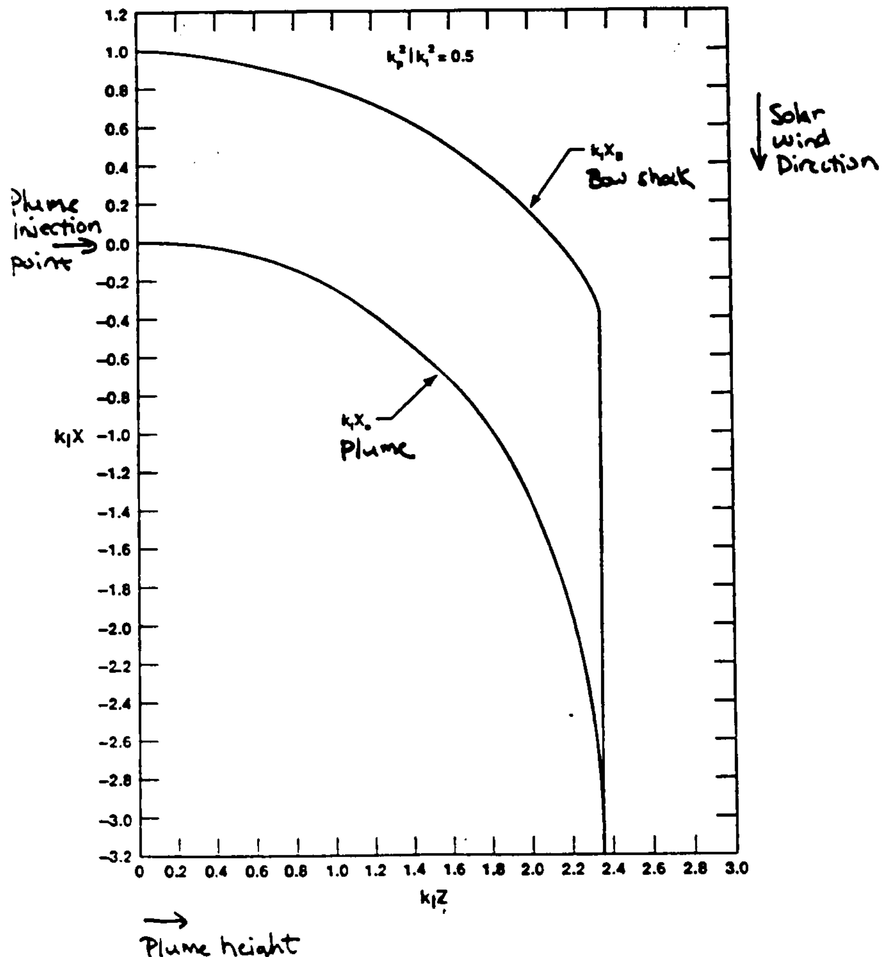


Figure 4

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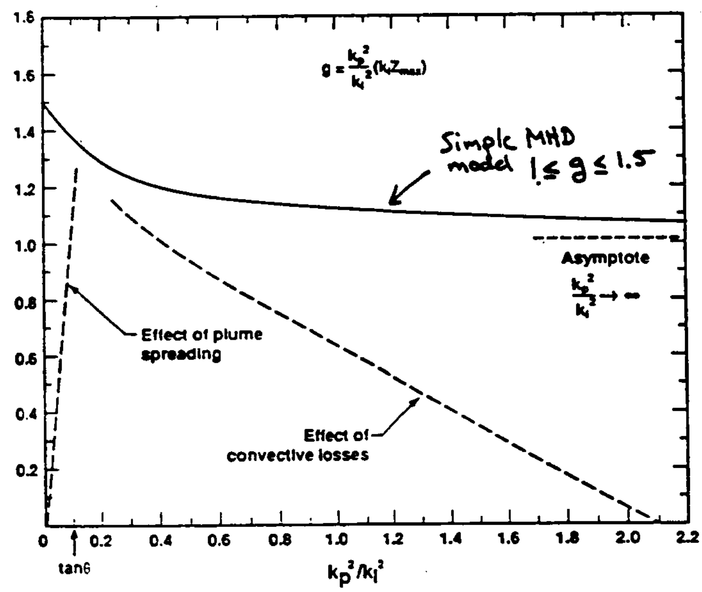
The Plume Power Extraction is
a function of the dimensionless ratio k_P^2/k_I^2

$$P = 2 \dot{M}_p v_p v_A g$$



θ = plume divergence angle

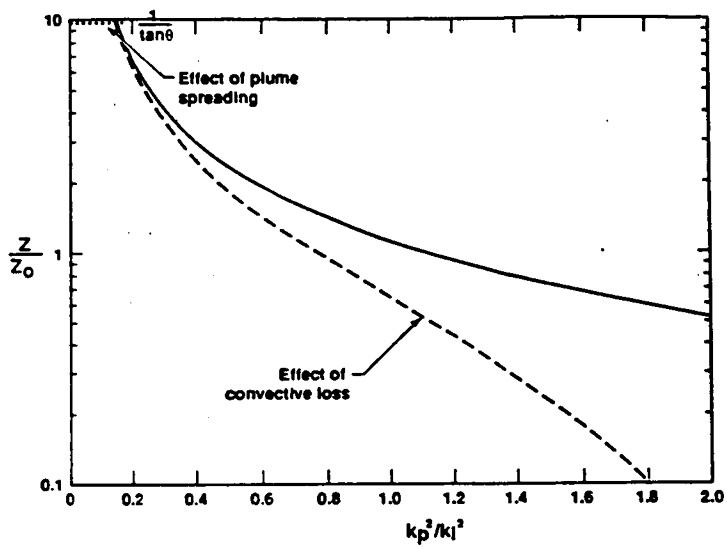
$$\frac{k_P^2}{k_I^2} = \frac{\mu_0}{12} \frac{I^2}{\dot{M}_p v_p}$$

Figure 5

60-X-0491-0021-4

The load impedance is a function of k_P^2/k_I^2 and is of order

$$Z \approx Z_0 = \frac{\mu_0 V_A}{4\sqrt{2}} \qquad V_A = \text{Solar wind Alfvén velocity}$$



Choosing Z sets k_P^2/k_I^2, g

Figure 6

80-Y-0491-0071-5

Conclusion: LLNL has extensive expertise in physics and technology relevant to MPD thruster development

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Areas in which we could contribute include:

Modeling of atomic physics, plasma surface interactions and 2D MHD flows

Results from ongoing high-power plasma accelerator experiments (RACE)

Plasma diagnostics

High pumping speed test stand for lifetime validation studies (MFTF-B)