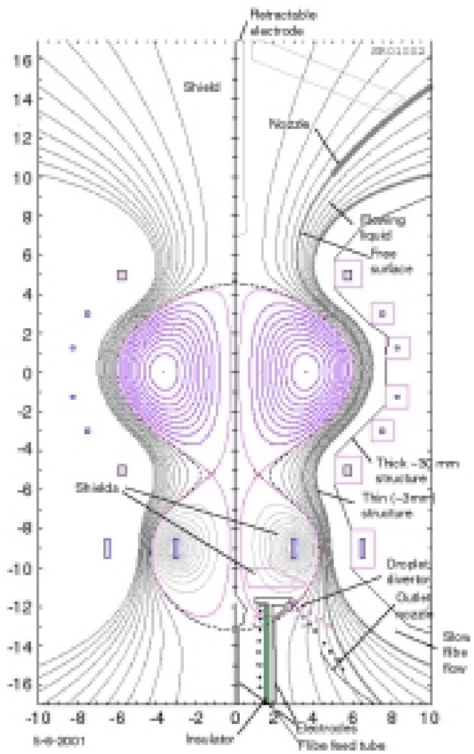
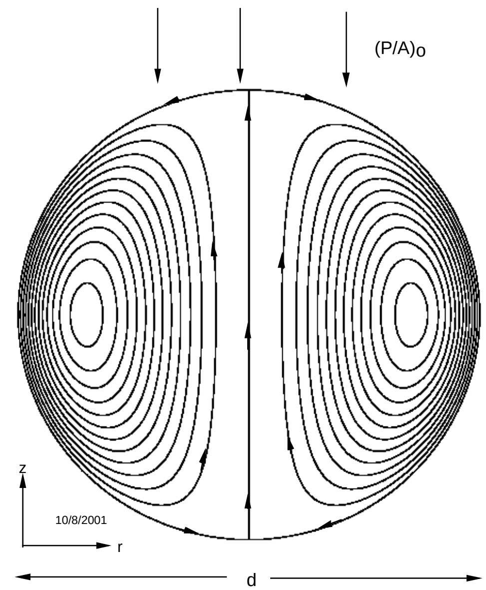
Spheromak update and droplet /jet divertor



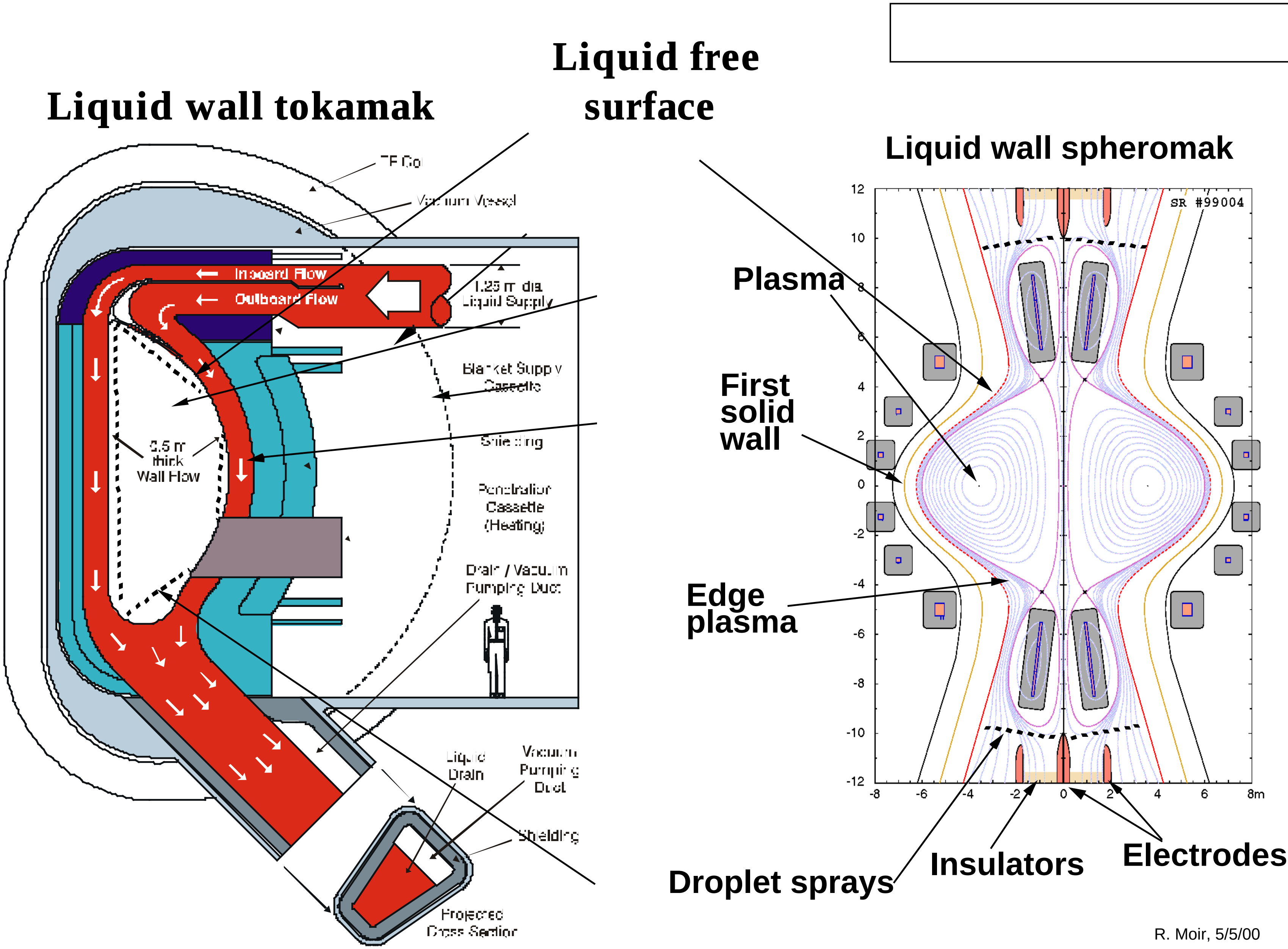


R. W. Moir **Nov. 8, 2001**

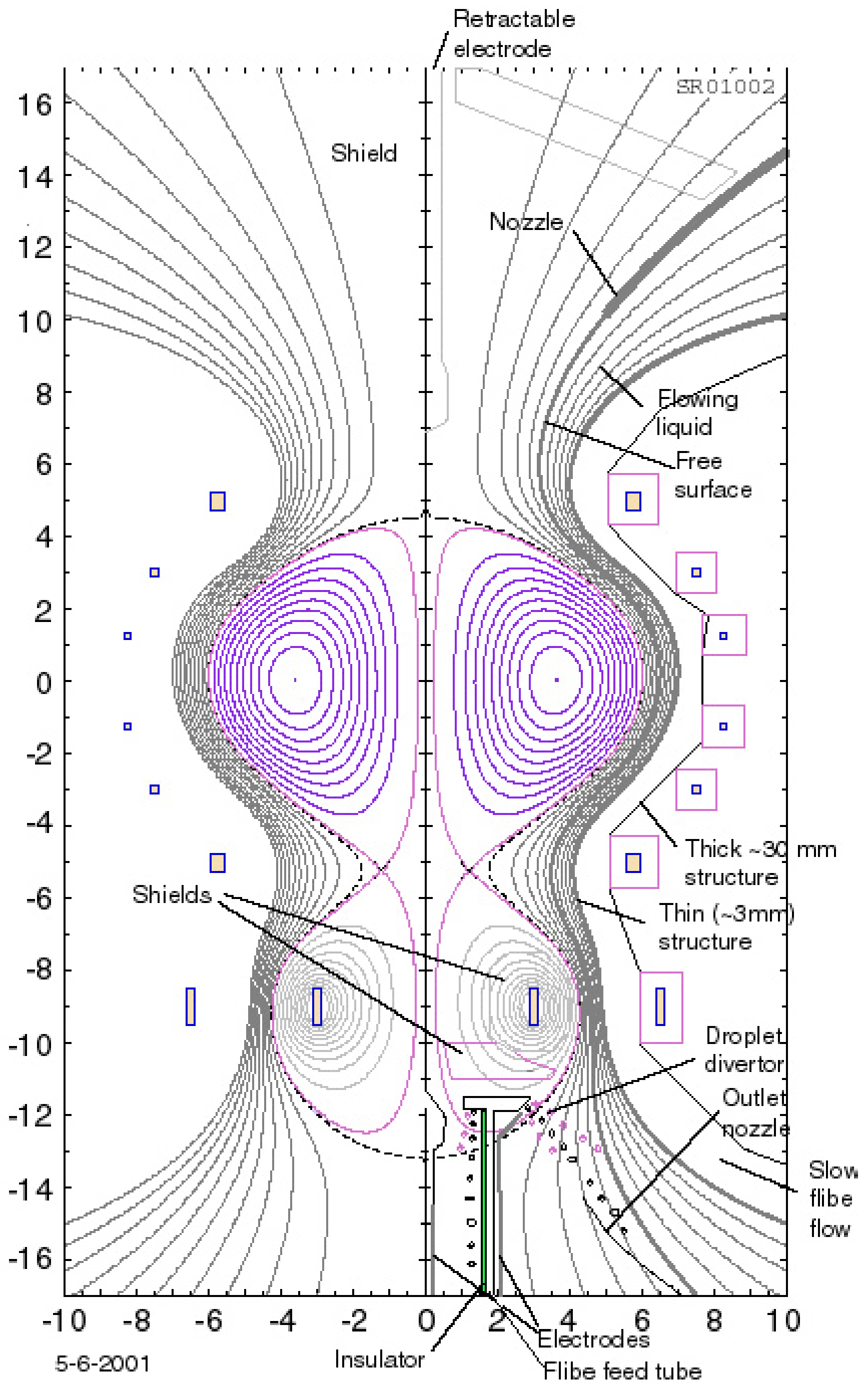
Lawrence Livermore National Laboratory

APEX meeting Nov 7-9, 2001, Scottsdale, AZ

The spheromak has the advantage of no toroidal coils

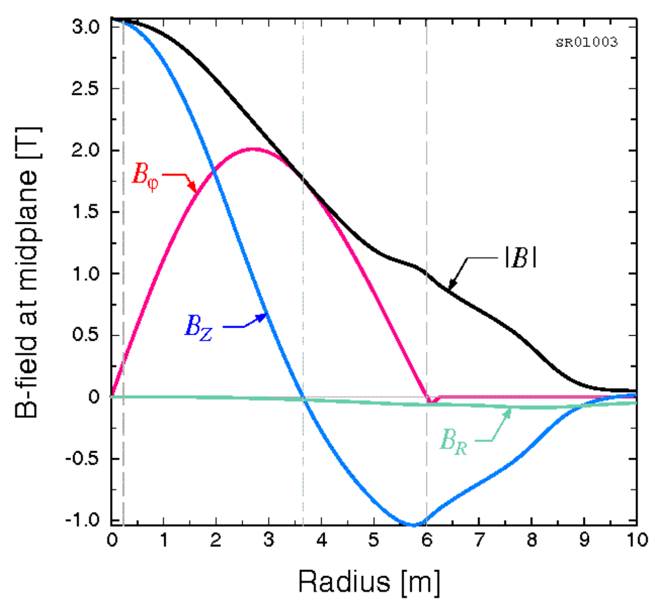


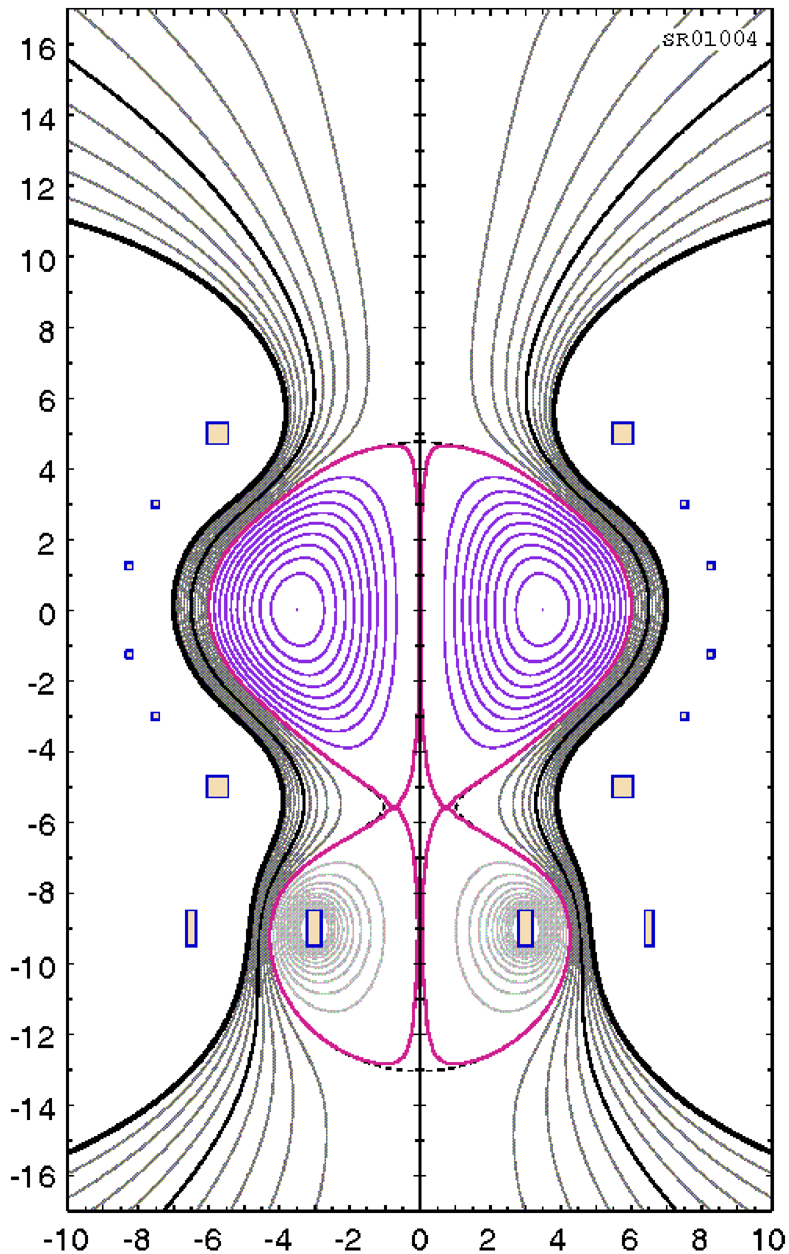
R. Moir, 5/5/00



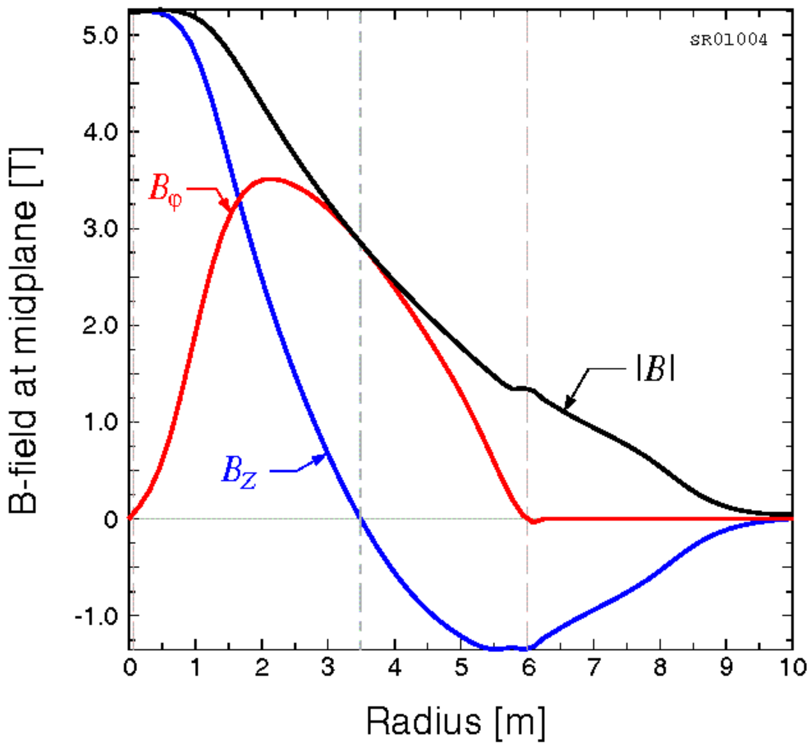
Status as of

Equilibria calculations by





Status as of 11/1/2001



Typical spheromak power plant parameters.

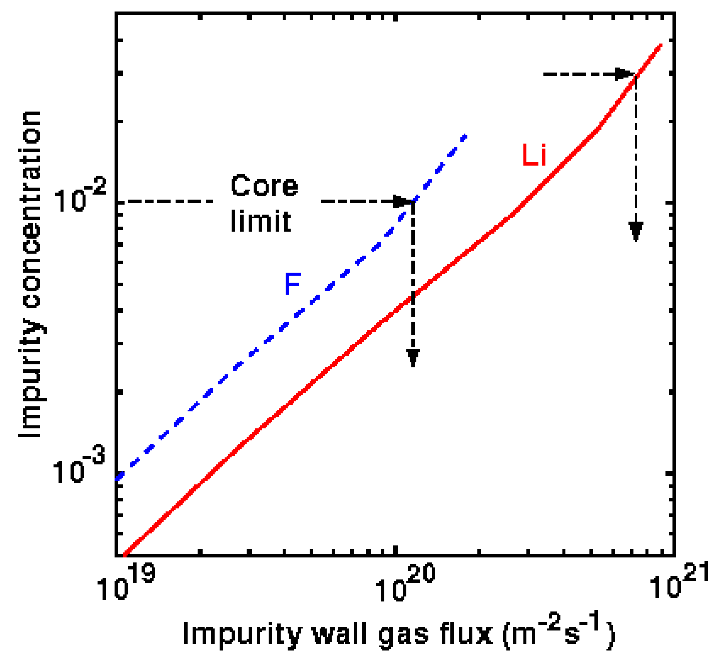
	Spheromak	FRC	FRC
Liquid wall radius, m	6.5	1.5	2.0
Separatrix radius, m	0.068, 6.0	0.39	1
Magnetic axis, m	3.49		
Separatrix length, outside and inside, m	15, 10	8	8
Liquid flow path length nozzle to nozzle, m	27		
Core plasma volume, m^3	652	2.6	25
Outer plasma area, m^2	362	75	100
Average ion temperature, keV	12	12	18
Average ion density, 10^{20} m^{-3}	1.65	26	6.2
Peak ion density, 10^{20} m^{-3}		31	6.8
Z_{eff}	1.5	1.5	1.5
s = plasma radius/ average larmor radius		7.5	26
Helicity current drive, kA Helicity power, MW	18.2		
Toroidal current, MA	40		40
Volume-averaged beta	0.1	0.97	0.78
Magnetic field, T Poloidal Toroidal	Bz=5.24 @r=0 Bϕ=2.89@r=3.49	5.5	3.6
Flux inside separatrix, Wb	0.08		
Flux from separatrix to mag axis, Wb	75.8		
Energy confinement time, s		0.08	0.33
Ash particle conf. time, s		0.16	0.65
Neutron wall load ave, MW/m^2	5.9	27	18

Surface heat load, MW/m^2		1.7	1.2
Neutron power, MW	1920	2000	1844
Bremsstrahlung radiation power, MW	46 MW,0.14 ____MW/m^2	46	49
Line radiation, core @15% P_{alpha}, MW	72 MW, 0.22 ____MW/m^2		
Line radiation, edge@ 10% P_{alpha}, MW	48 MW, 0.15 ____MW/m^2	78	69
Charged-particle transport power, MW		415	383
Input power, MW		40	40
Fusion power, MW	2400	2500	2306
Net electric power, MWe	1000	1000	1000

Spheromak temperature limits are between those for tokamaks and FRCs

(T. Rognlien)

Spheromak edge plasma, $R_h = 0.25$



SUMMARY OF LOW-RECYCLING CASES
allowable wall temperatures in degrees C

	Li	Flibe	SnLi
Tokamak	380	480	590
Spheromak	410	520	630
FRC	480	620	720

FRC is compact, high density

Future work on liquid wall spheromak

1-Liquid wall and liquid divertor analysis resulting in evaporation rates

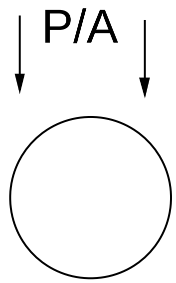
2-Edge plasma analysis resulting in allowed compared to expected evaporation rates

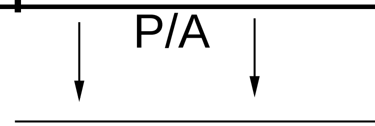
3-Gun analysis (helicity injection) resulting in denominator of $Q=P_{fusion}/P_{gun}$

4-Write report

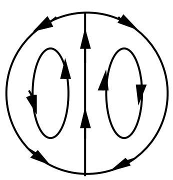
Jet/droplet divertor---status a year ago--->>

Two effects substantially decrease the surface temperature rise on droplets





$$T_{rise} = 2\ P/A\ (\alpha\tau/\pi)^{0.5}$$



Manangoni effect convects the hot surface to the cold region and induces internal convection

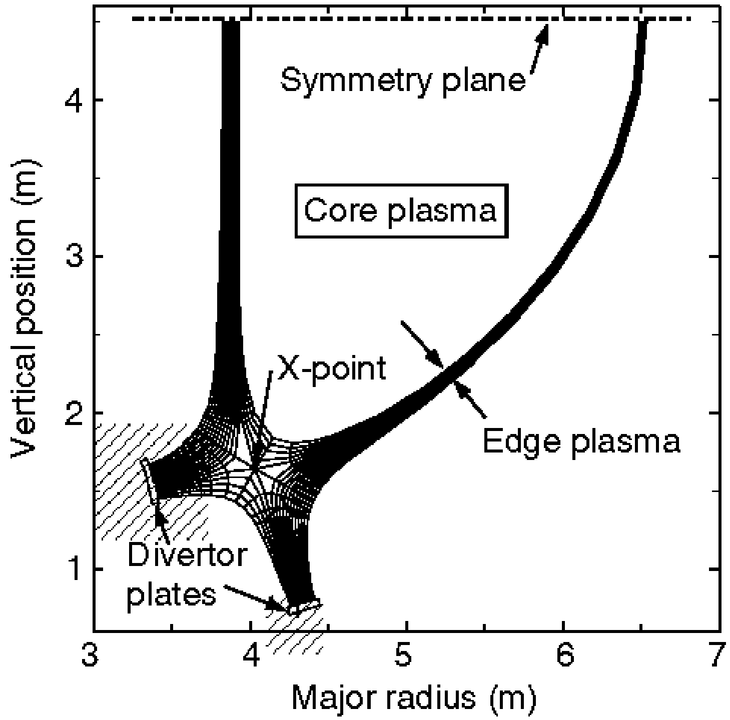
1-P/A down factor 4 for area averaging
2-Another factor of ??? for convection into the cool interior

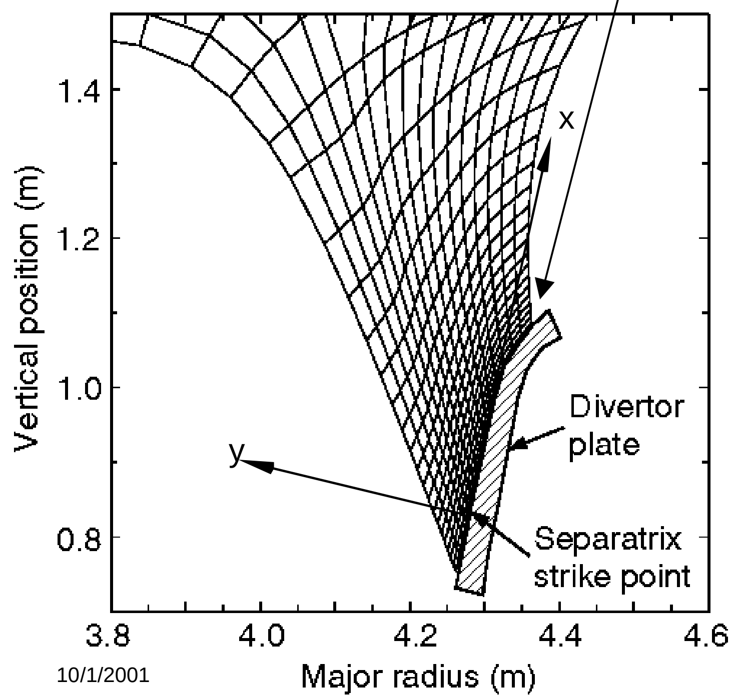
90 MW/m^2 predicted Fus. Tech 15 (1989) 674-679.

11/10/2000

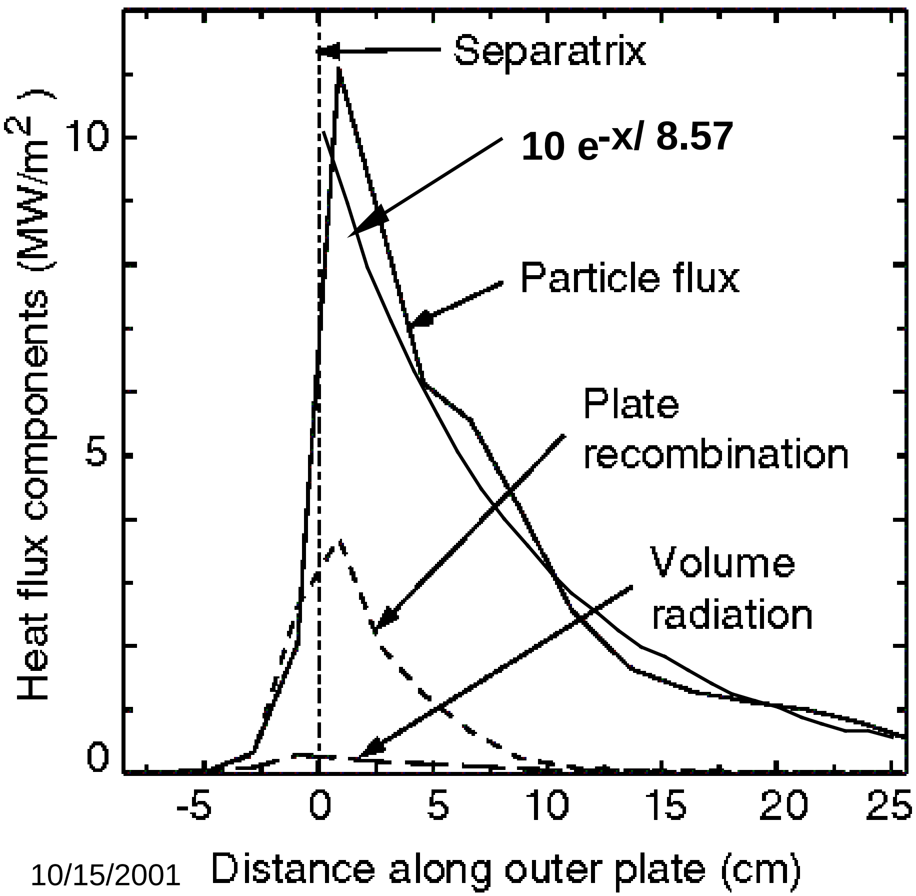
Evaporation rates will be decreased

Present liquid divertor work-Tokamak geometry-Substitute liquid jets or droplets for divertor plate





From T. Rognlien

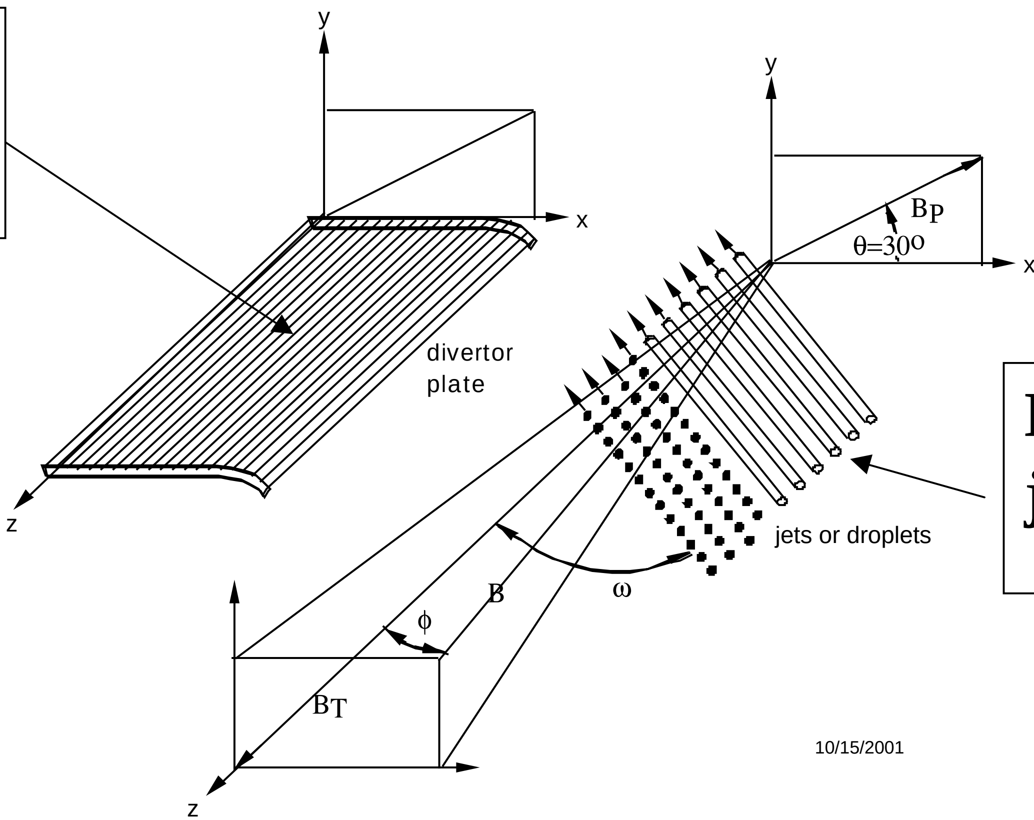


$(P/A)_{average}$=3.24 MW/m^2

10/15/2001

Geometry and trigonometry are important!

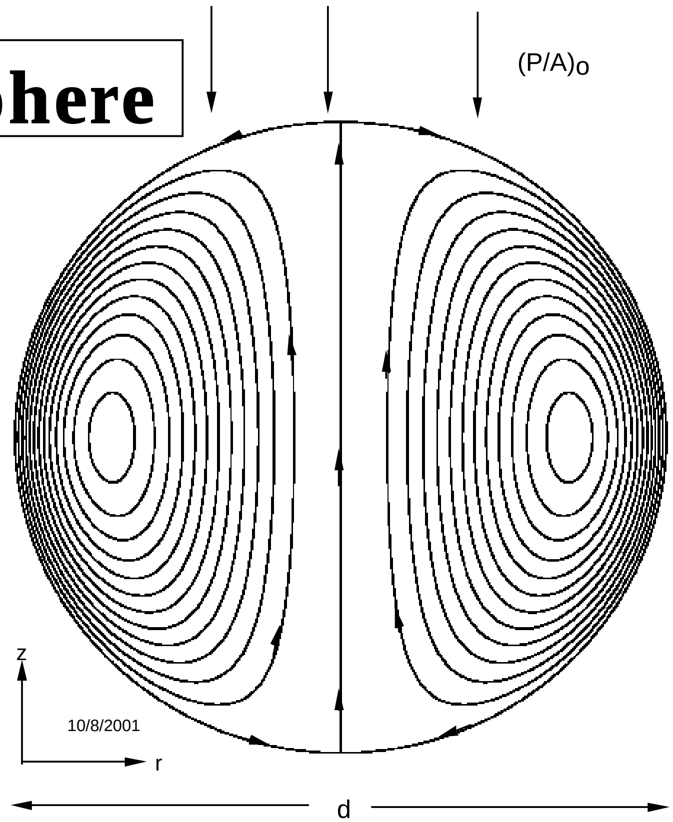
Solid divertor



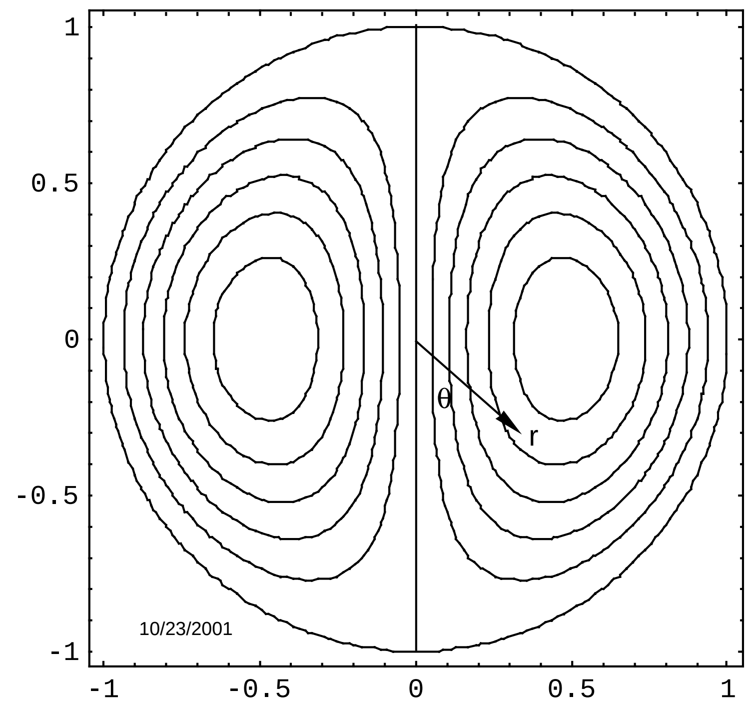
Liquid jets or

Droplets (jets) will have internal circulation due to temperature dependent surface tension (Marangoni effect). This presents ≈4.3 times the frontal area for spheres and 5.14 times for cylindrical jets.

Sphere



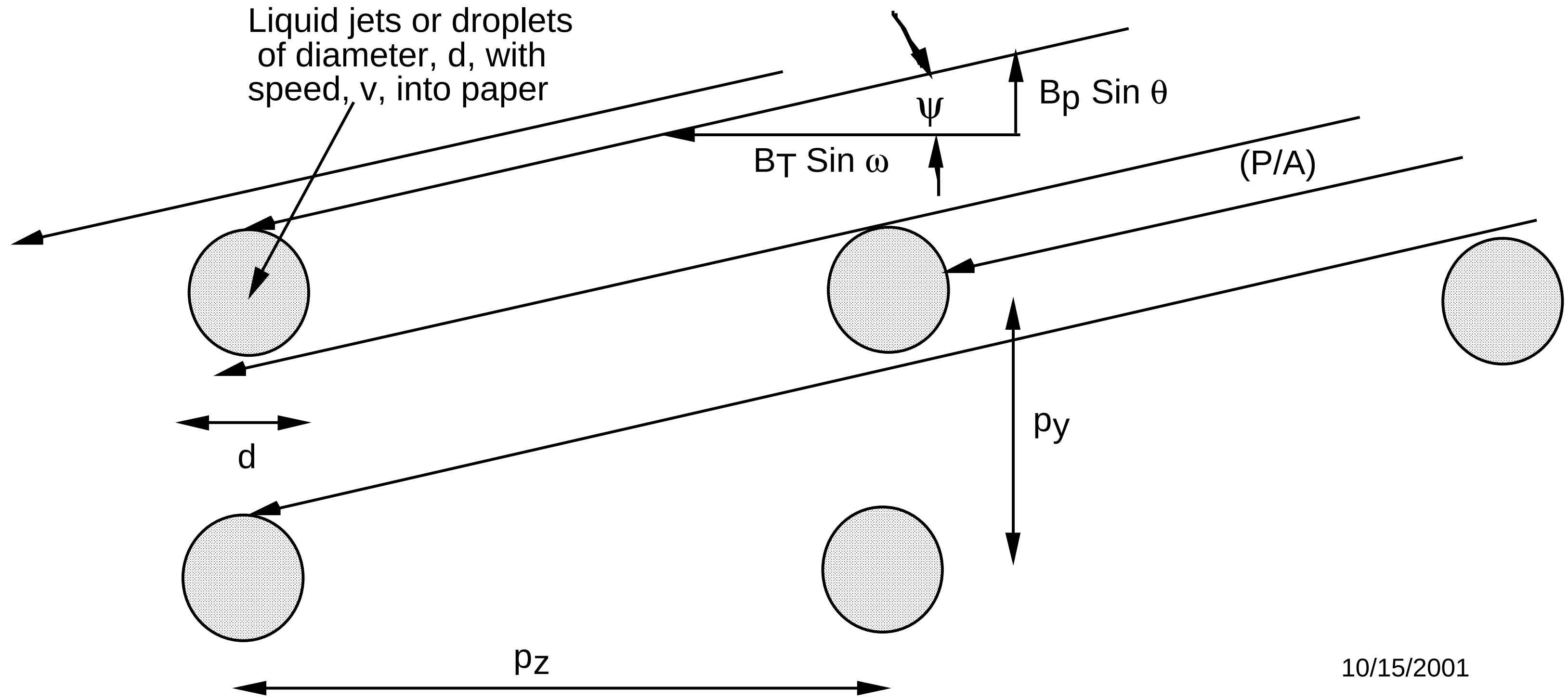
Jet



The staggering heat load in the divertor is spread out by a

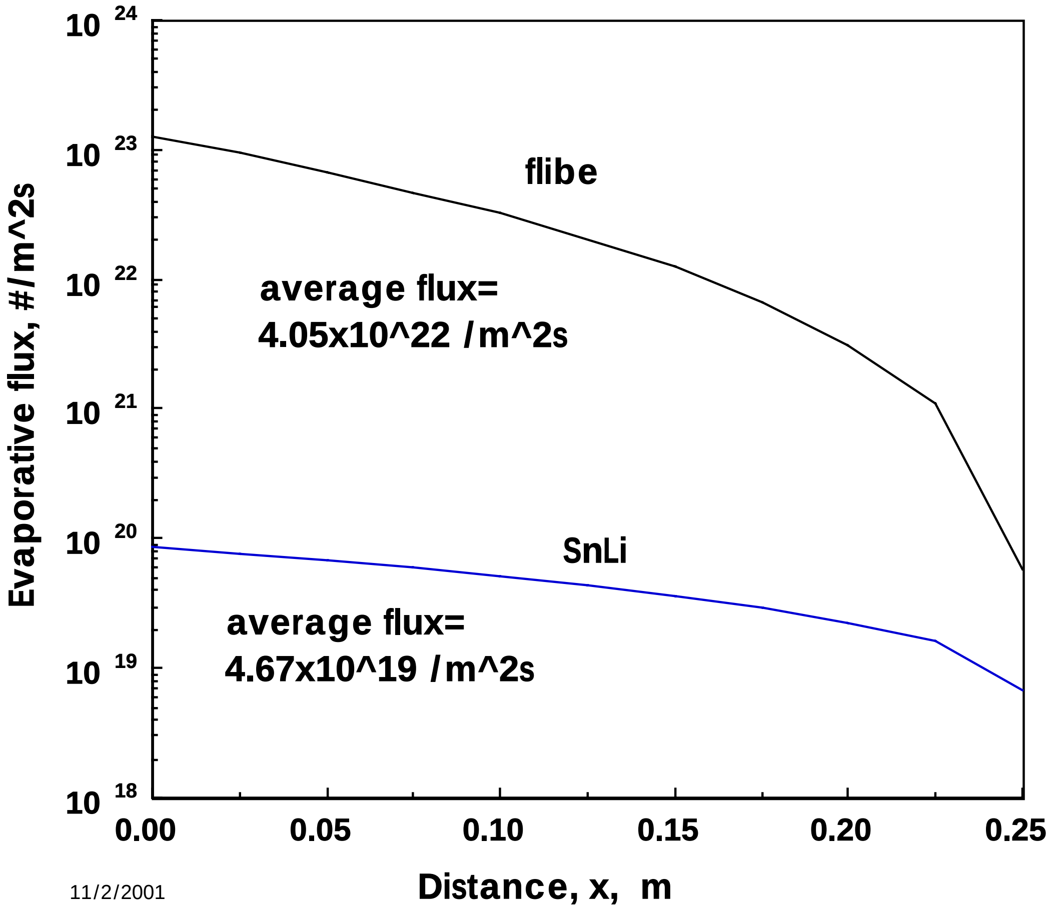
factor of 4.3 to 5.14!

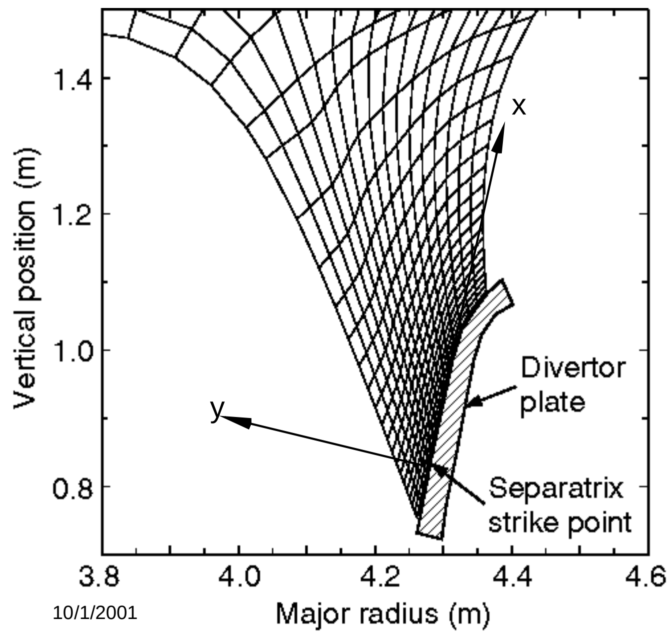
The shallow angle of heat flux results in one jet screening its neighbor.



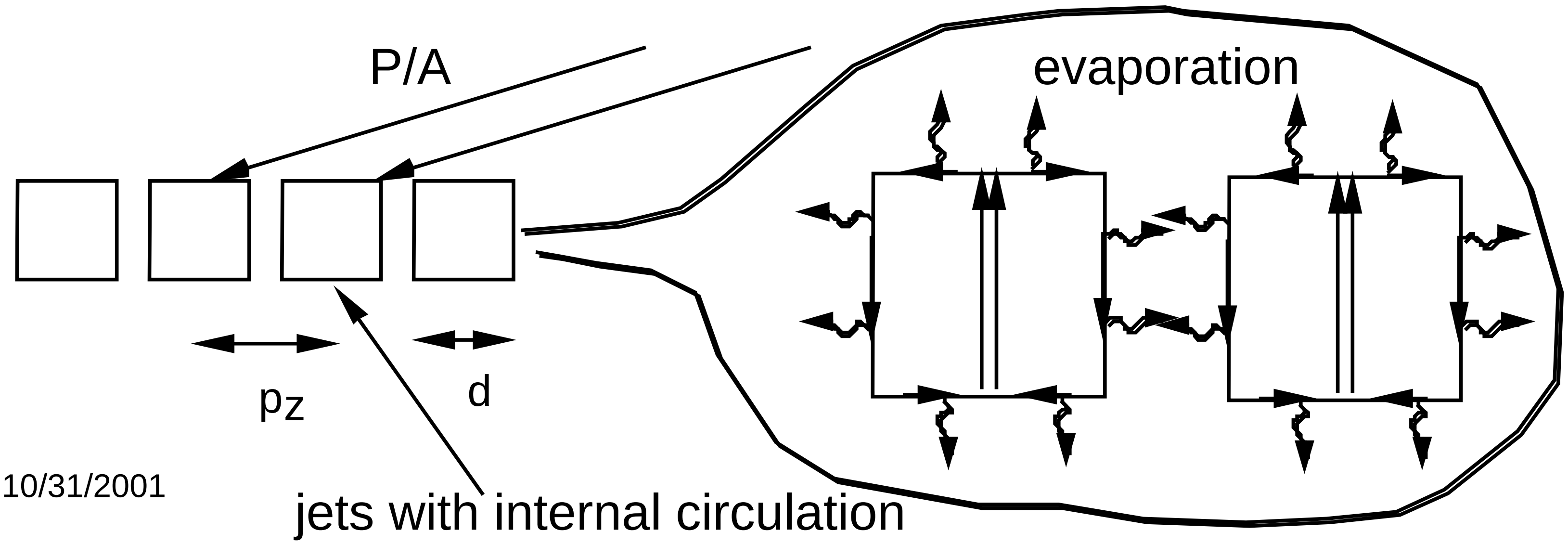
10/15/2001

Liquid slab reference case, P/A $_{average}$=3.24 MW/m^2





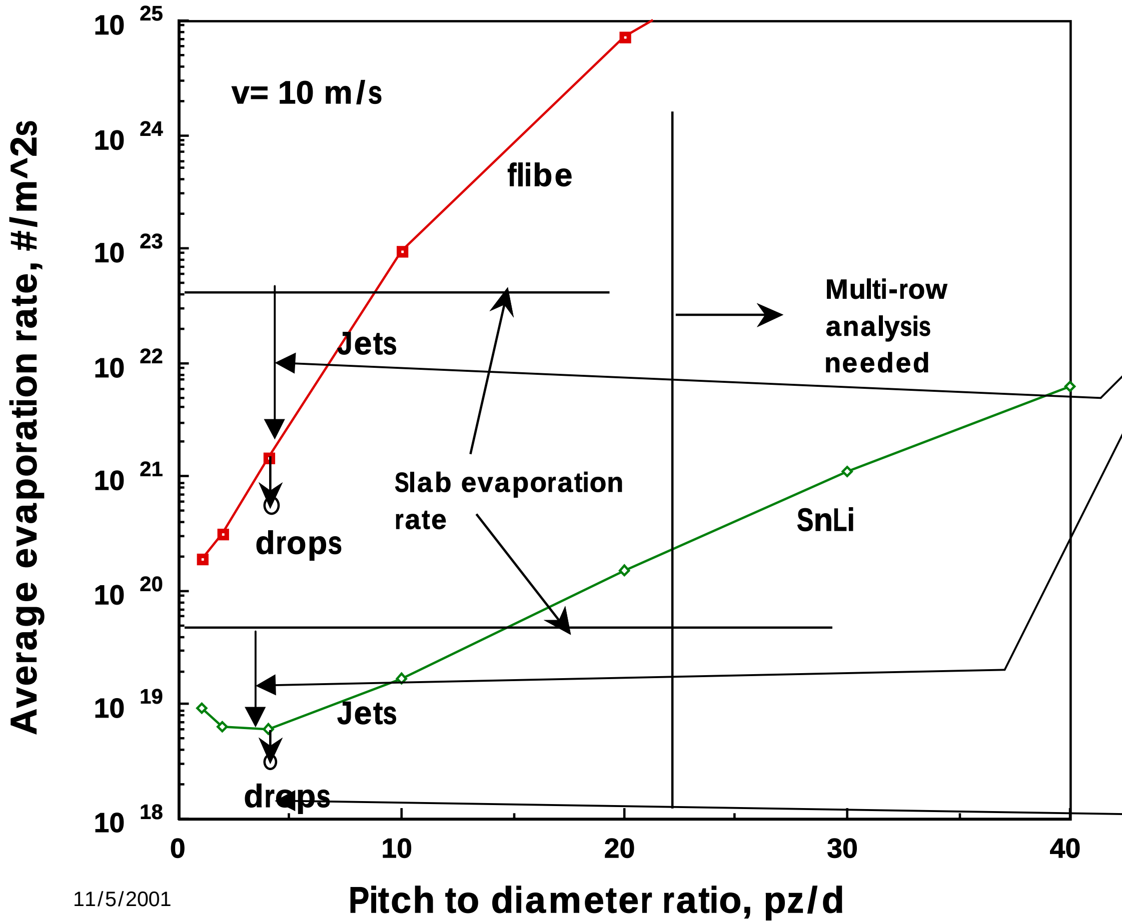
Simplified model for illustration
“Square” jets



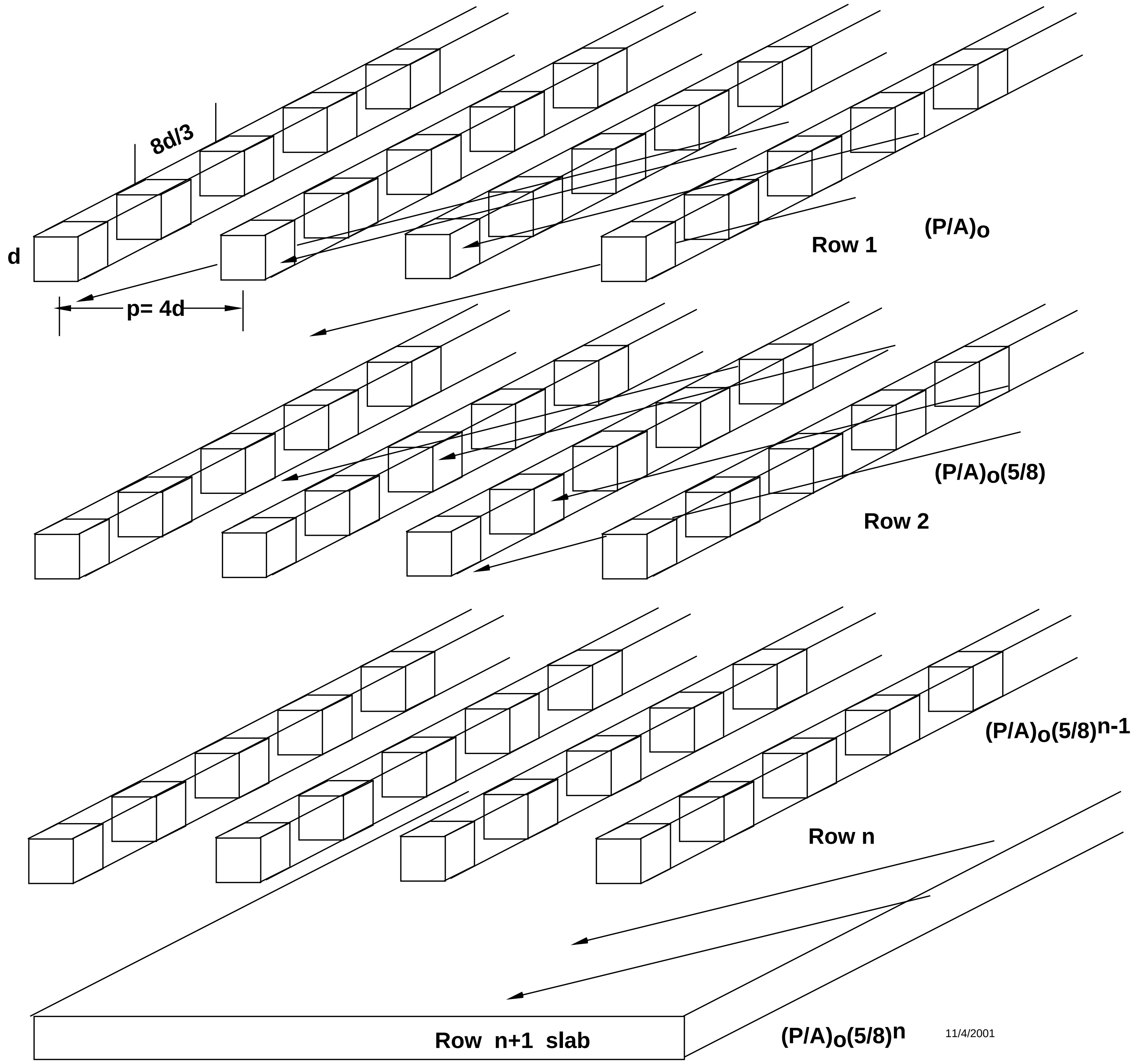
10/31/2001

Model is simplified in many ways

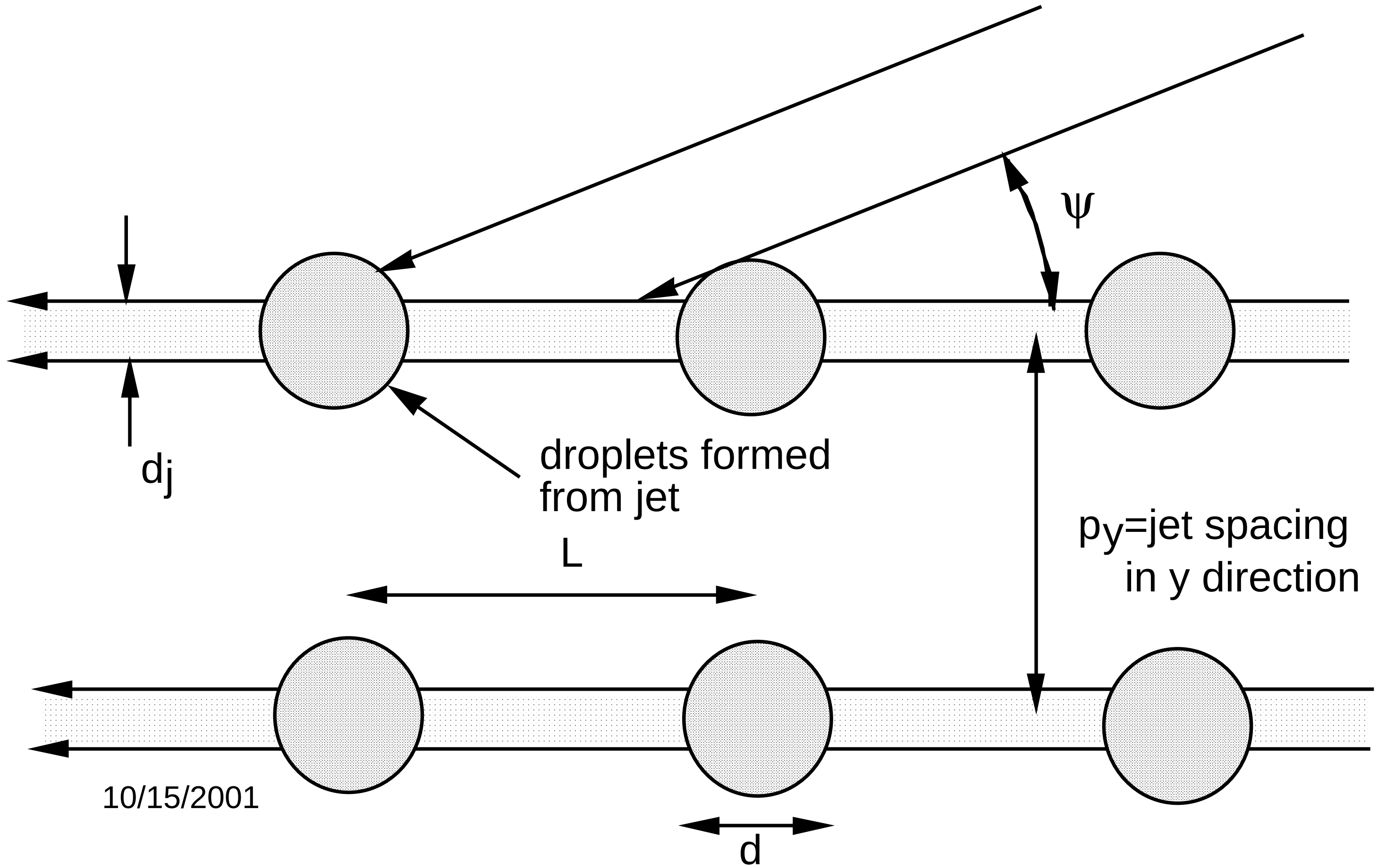
Evaporation versus pitch between jets



For p/d=4 evaporation is reduced a factor of 28 for flibe and 8 for SnLi compared to a slab. Droplets with multiple rows


8d/3
d
p= 4d
Row 1
(P/A)o
(P/A)o(5/8)
Row 2
(P/A)o(5/8)n-1
Row n
Row n+1 slab
(P/A)o(5/8)n
11/4/2001

Droplet analysis is underway



Future work

- Run more geometric variations
- Run more liquid cases
- Put in time dependent heat flux in calculation
- Show jet and droplet dimensions
- Put in evaporative cooling correction and others
- Work up case of ω= 4.45° rather than 90°, that is, jets along field lines
- Work up circulation rate due to convection
- Include MHD effect in circulation
- Put in condensation correction

Conclusions

Jets and droplets seem to have a big advantage over a liquid slab by spreading the incident power over more area and causing half or more of the evaporation to go away from the plasma.

The resulting surface temperature rise is reduced by a factor of several, which reduces evaporation.