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Magnetized Target Fusion

The MTF Proof-of-Principle Team

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PPPL Meeting
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by
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Abstract

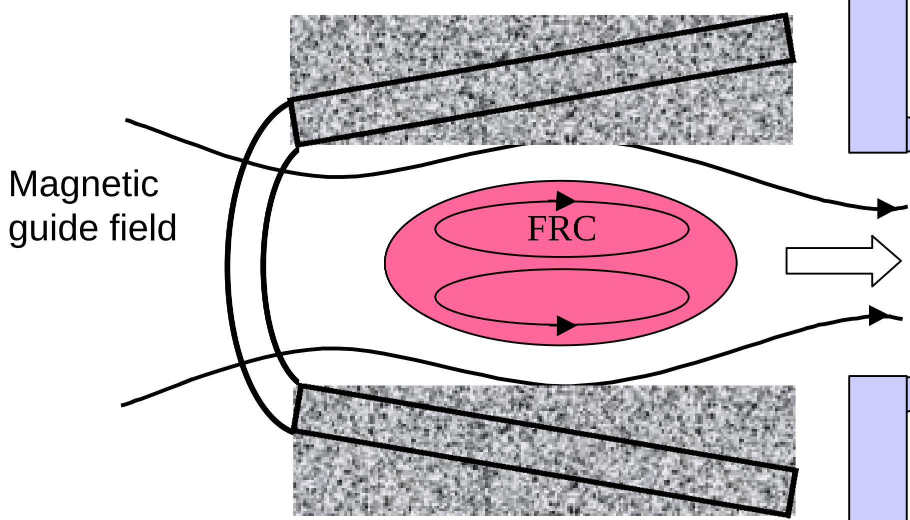
This presentation to the Fusion Energy Sciences Advisory Committee addresses the programmatic metrics identified in recent subpanel discussions. Budget scenarios are presented for doing the MTF proof-of-principle experiment. Recent success with tests of liner implosions at the Air Force Research Laboratory are described. The prospects for applying MTF to practical energy production are given special attention.

Proposed PoPs make excellent portfolio

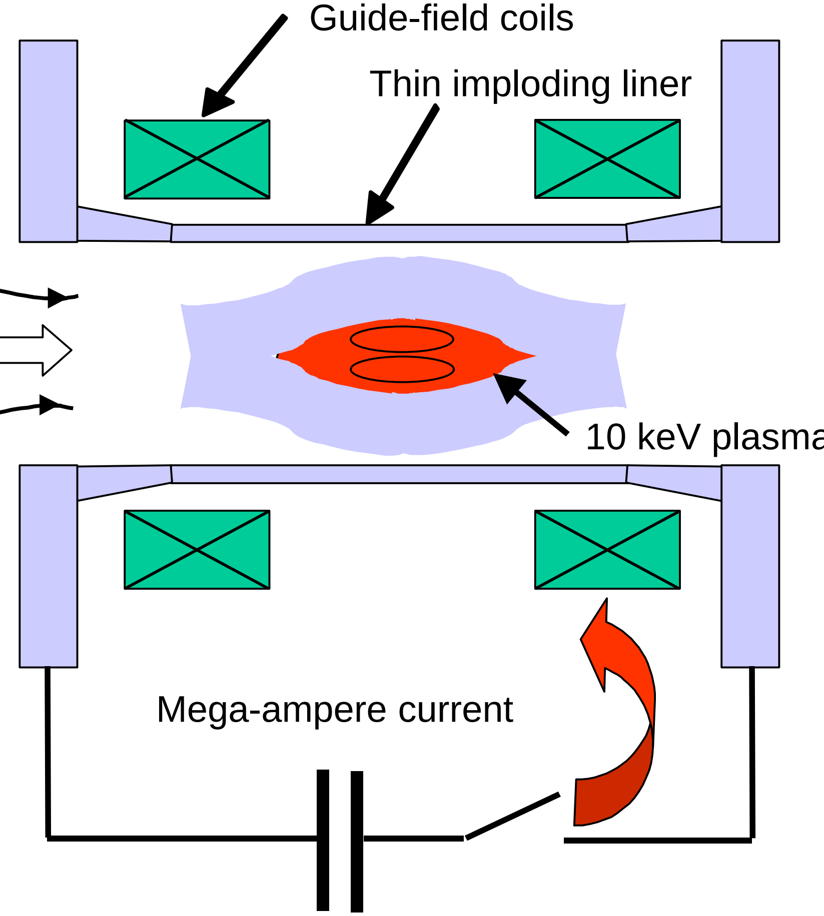
Compact stellarator:	Leverages off large international program for fusion development; steady state; no disruptions; well-understood physics.
Reversed Field Pinch:	Low-field toroidal magnet allows economical reactor development; physics understanding is advancing.
MTF:	Lowest-cost fusion development path; qualitatively different pulsed system with ICF-like engineering; least-understood physics.

Elements of MTF

Plasma preheater and injector



Liner implosion system



Typical parameters:

	Initial	Final
n	10^{17} cm^{-3}	10^{20} cm^{-3}
T	300 eV	10 keV
B	100 kG	10 MG

Comments on Program Evaluation Criteria

Quality of science--Proposal based on decades of compact-torus research, recent advances in liner technology, and expertise of the proposing team.

Confidence for Next Step--Given requested budget, knowledge base developed is likely to permit evaluating MTF for performance extension experiments. Must be realized however that surprises are likely.

Plasma Science/Technology Benefit--Physics of FRCs (spheromaks later) advanced by working in interesting new parameter regime; technology benefits are most likely related to inertial fusion energy.

Issue Resolution--Key issues identified are compressional heating to thermonuclear temperature and study of wall-plasma interactions. See original proposal for thorough discussion of issue resolution.

Leading Edge--The proposed MTF program will lead the world in new understanding and has the potential to create a new pathway to fusion energy.

Energy Vision--Surprisingly hopeful. Arguments being developed in a white paper: (fusionenergy.lanl.gov).

Program Issues--Highly cost-effective use of existing facilities. Universities and small groups can also do exciting low-cost experiments utilizing diagnostics and expertise developed in PoP program.

Portfolio Balance--Major MTF advantage is its qualitative difference, in terms of failure modes in physics and technology compared with conventional approaches to fusion.

Science/Technology Goals--Science of high-energy density physics and extremely strong magnetic fields is seen in astrophysics and should be included in a comprehensive plasma science program.

Milestones--The key milestones to be achieved in 3-4 years depending on funding are:

1. Demonstrate heating to keV temperatures using liner compression.

2. Achieve $n\tau T$ corresponding to Q_{DT} =0 .01-0.10

Appropriate intermediate milestones are documented in the proposal.

Proposed MTF Budget ($K)

FY	2000	2001	2002
Liner experiments (AFRL)	1000	1000	1000
FRC plasma experiments (LANL)	3000	3000	3000
Theory and computing (LANL, LLNL, GA, …)	1500	1500	1500
Energy system analysis* (LANL, LLNL, UCSD, UC Berkeley, …)	900	900	900
Supporting exploratory work	600	600	600
TOTAL	7000	7000	7000

*increased from $500K in proposal

NOTE: MTF is ready for overall fusion program review by FY2003!

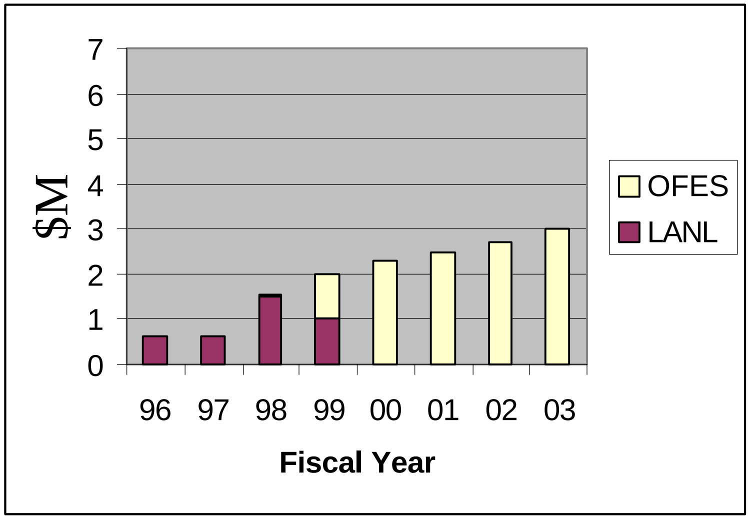
MTF Funding Considerations

- MTF program *depends upon* multi-institutional participation
- LANL institutional funding will likely end this year
- Four critical elements needed:
  - -theory and modeling of liner and plasma
  - -liner development for MTF implosions
  - -plasma target development for liner implosion
  - -energy system studies
- There is a minimum efficient program size

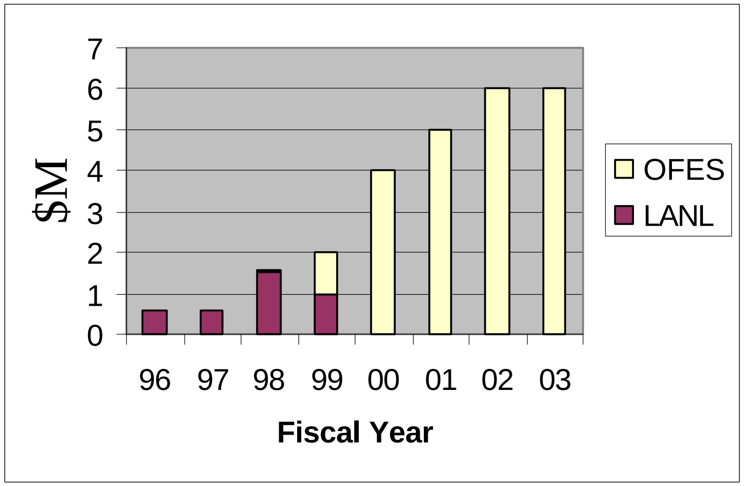
  about 2x to 3x present $2M level
- Three scenarios warrant examination
  - A. Divide $3.9M by three
  - B. Ramp-up funding; 4-year program
  - C. Proposed funding; 3-year program

MTF Funding Profiles*

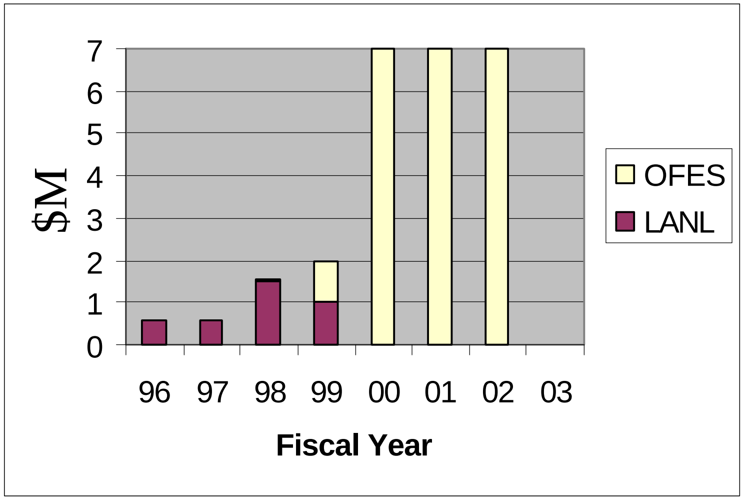
Case A



Case B



Case C



*includes both LANL and OFES

Approximate funding by institution

FY99 includes both OFES and LANL institutional funds

Institution	FY99	A FY00	B FY00	C FY00
LANL	1500	1100	2200	4100
AFRL	250	700	700	1000
LLNL	75	200	300	400
Others	225	300	500	900
C.E.	0	0	300	600
TOTAL	2050	2300	4000	7000

Case A: focus first year on liner development
Case B: slow-start development of both liner and plasma
Case C: Proposed full funding of $7M for 3 years

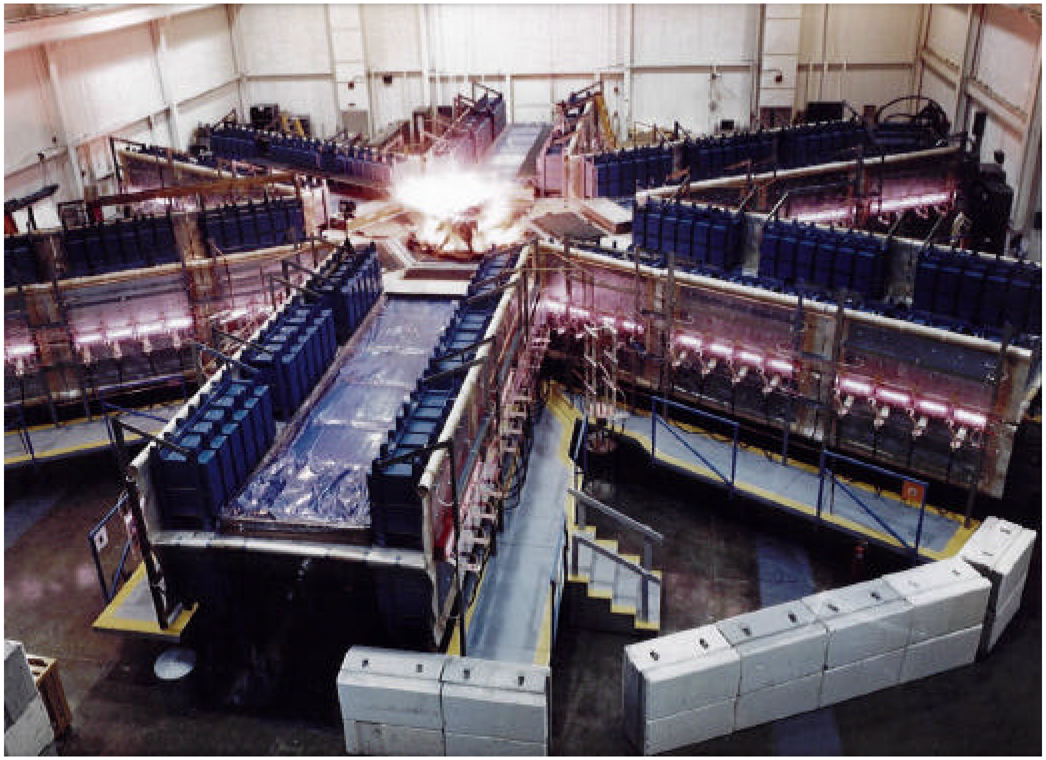
Impact of funding cases

A: **$1.3M increment in FY2000 followed by slow ramp**
Must attack the critical issues in series. Implode liners at AFRL as first program step to ensure Shiva Star stays available. Plasma formation studies delayed. Theory, computation, and system analysis would be limited. Serial attack on coupled problems is inefficient and more likely to fail; much better to develop compatible liner and plasma formation method in parallel. Hard to sustain team in serial approach. Funding at this level would increase the total cost by about a factor of two and would delay results by a decade or more.

B: **$4M in FY2000 growing to $6M in FY2002-3.**
Progress would be slower than optimum, but work on all critical elements could proceed in parallel. Essential that funding continue to grow to accomplish goals. Funding profile shown delivers results at end of FY 2003.

C. **Proposed program of $7M per year for three years.**
Makes good use of available facilities and expertise. In three years either MTF finds unexpected problems and should be stopped (or narrowly focused on identified issues), or it succeeds and is ready to move forward with a performance enhancement phase.

AFRL "Shiva Star" facility to drive liners



- Includes auxiliary power for plasma injection.
- Staff is experienced
- 5 MJ energy storage enough for DT-equivalent fusion energy gain 0.01-0.1

Liner implosion experiment

Radiographs will go here when Degnan gets them digitized

Is MTF Relevant to Practical Energy?

Summer 1998 OFES peer review:

The panel said MTF is "…an innovative proposal that represents a true alternative to existing magnetic and inertial fusion concepts," but the majority of the panel felt "…it is unlikely that this concept will ultimately result in commercial fusion energy production."

On the second point, MTF advocates DO NOT AGREE, and we have expanded our efforts to address this issue.

MTF Application Workshop

Los Alamos National Laboratory
February 18-19, 1999
Follow-on including fast Z pinches
Sandia National Laboratory
April 27-28, 1999

Main Conclusions

- Original study of slow and fast liners was impressive and forms good foundation for work today.
- More resources needed for system studies than originally estimated.

1978 Fast Liner Reactor

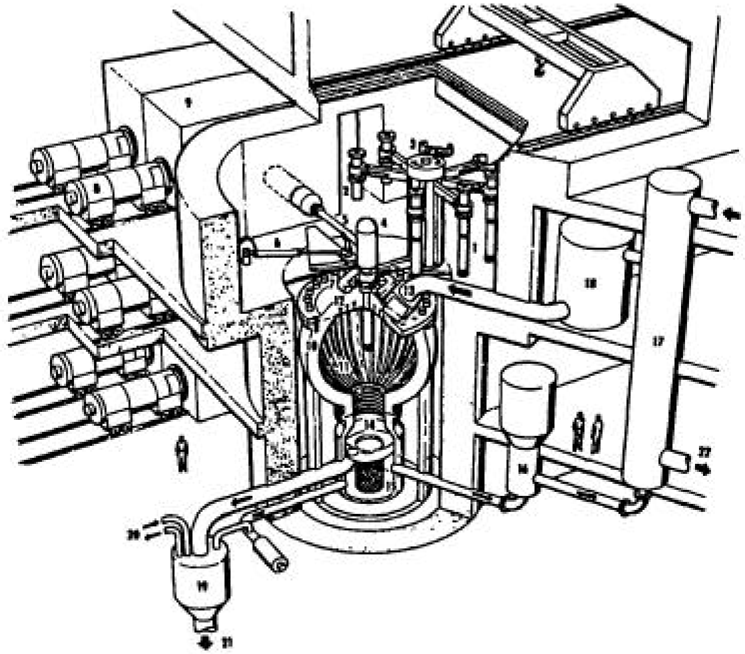


Fig. II-1. Isometric drawing of Fast-Liner Reactor nuclear island for the low-yield case given on Table II.I. Component identification: (1) liner/leads assembly ready for implosion; (2) remains of imploded-liner/leads assembly; (3) liner/leads carousel; (4) plasma preparation; (5) power leads; (6) hydraulic arm to move power connection; (7) blast vessel head and liner/leads feedthrough; (8) homopolar motor/generator; (9) inductive transfer element, transfer capacitor, and switches; (10) blast vessel (2.6-m radius, 013-m wall thickness); (11) shock extending ribs; (12) lithium-spray spargers; (13) lithium inlet and control valve; (14) solid debris skimmer; (15) lithium sump and storage; (16) lithium pump; (17) Li/Na heat exchanger; (18) lithium surge and storage tank; (19) solid debris separation; (20) lithium drag stream to tritium recovery; (21) solids debris to recovery and refabrication; (22) secondary sodium coolant.

1990s HYLIFE: IFE plant design strategy

Moir IFE PLANT DESIGN STRATEGY

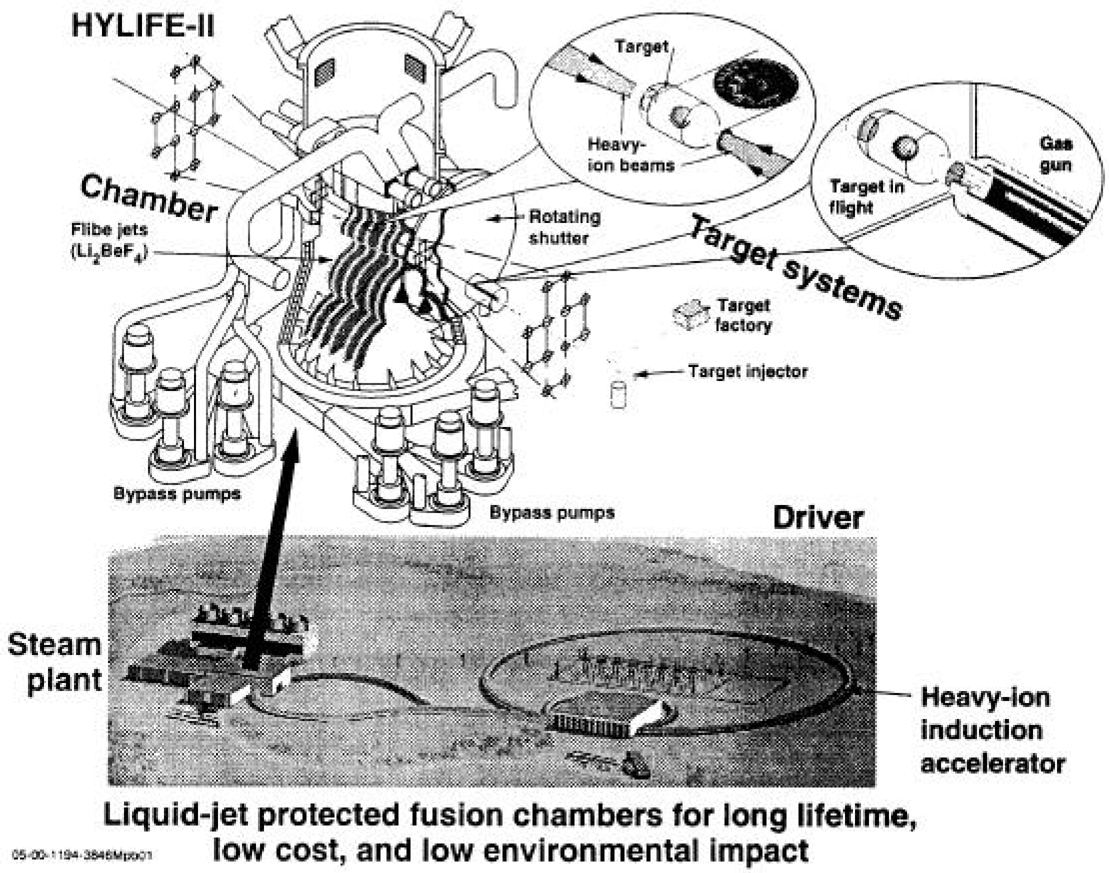


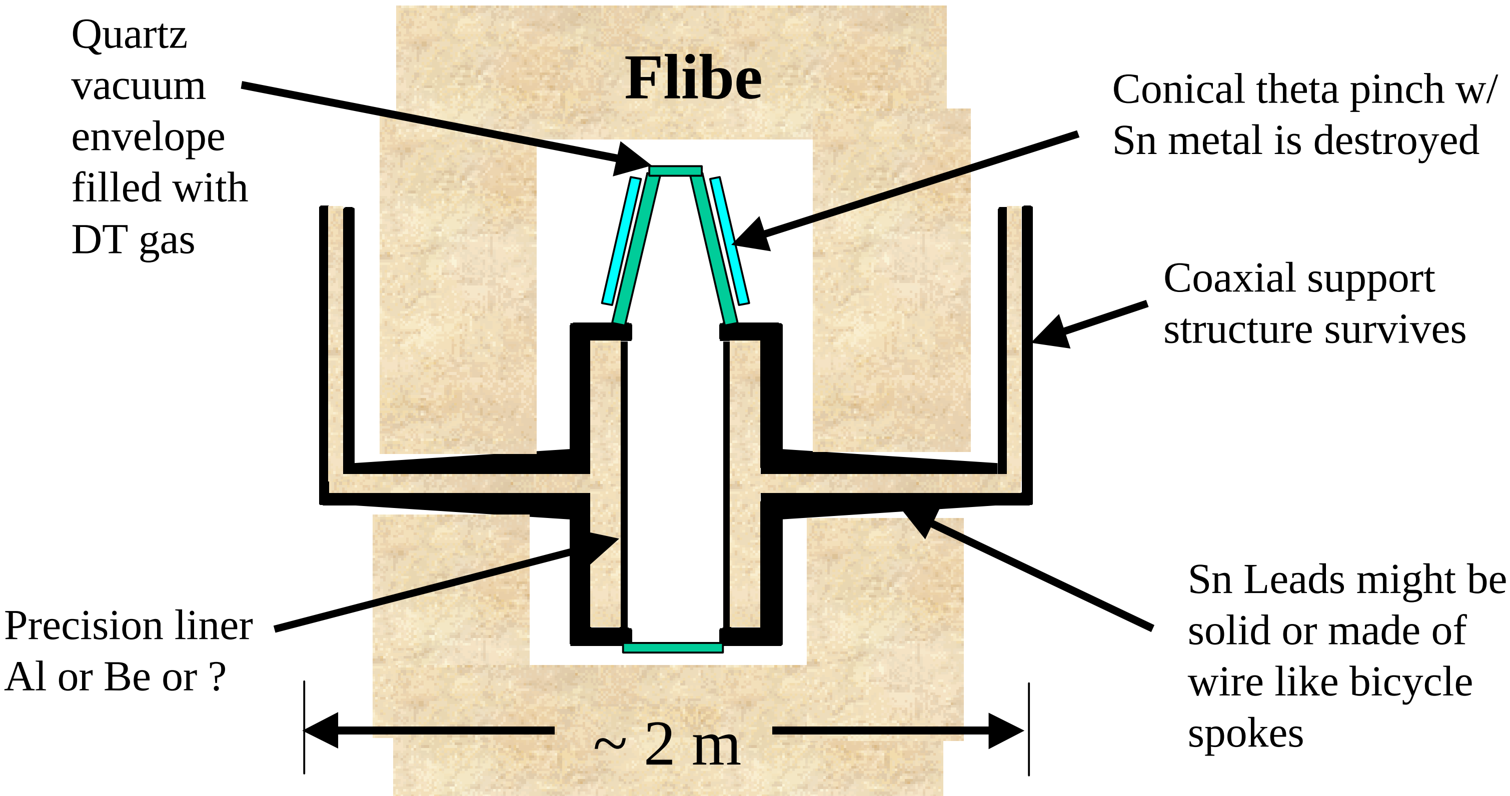
Figure 1. The HYLIFE-II IFE power plant is shown with a two-ended target, illuminated from two sides and a recirculating heavy-ion driver. The liquid wall protection is provided by pumping molten salt (Flibe) through the chamber

R. W. Moir, Fusion Technology **30**, 1613 (1996)

Attractive features of HYLIFE

- Very low activation achieved using non-flammable, renewable liquid FLiBe (Li_2BeF_4) as neutron breeding blanket and coolant
- Upon decommissioning reactor materials qualify for shallow burial disposal
- Neutron sources to develop first wall materials are probably not necessary
- Stainless steel containment vessel predicted to last for plant life of 30 years with less than 100 dpa
- System requires mostly conventional engineering and materials.

Electrical power delivery needs no line-of-sight



Thermal hydraulics: Per Peterson, UC Berkeley
Advanced manufacturing for low cost: Ron Miller, UCSD

HYLIFE vs. MTF 1-GW Capital Costs ($M)

Rough guesses (MTF)

		HYLIFE II	MTF
	Balance of plant	637	637
Different →	Driver	909	300
Different →	Target Chamber	117	234
	Flibe coolant	35	35
	Structures	67	67
	Remote Maint.	50	50
Different →	Target Factory and tritium mgmt.	121	363
	Total	$1935	$1800

Electricity ~ 5 cents/KW-hour

LINUS: The survivable imploding liner

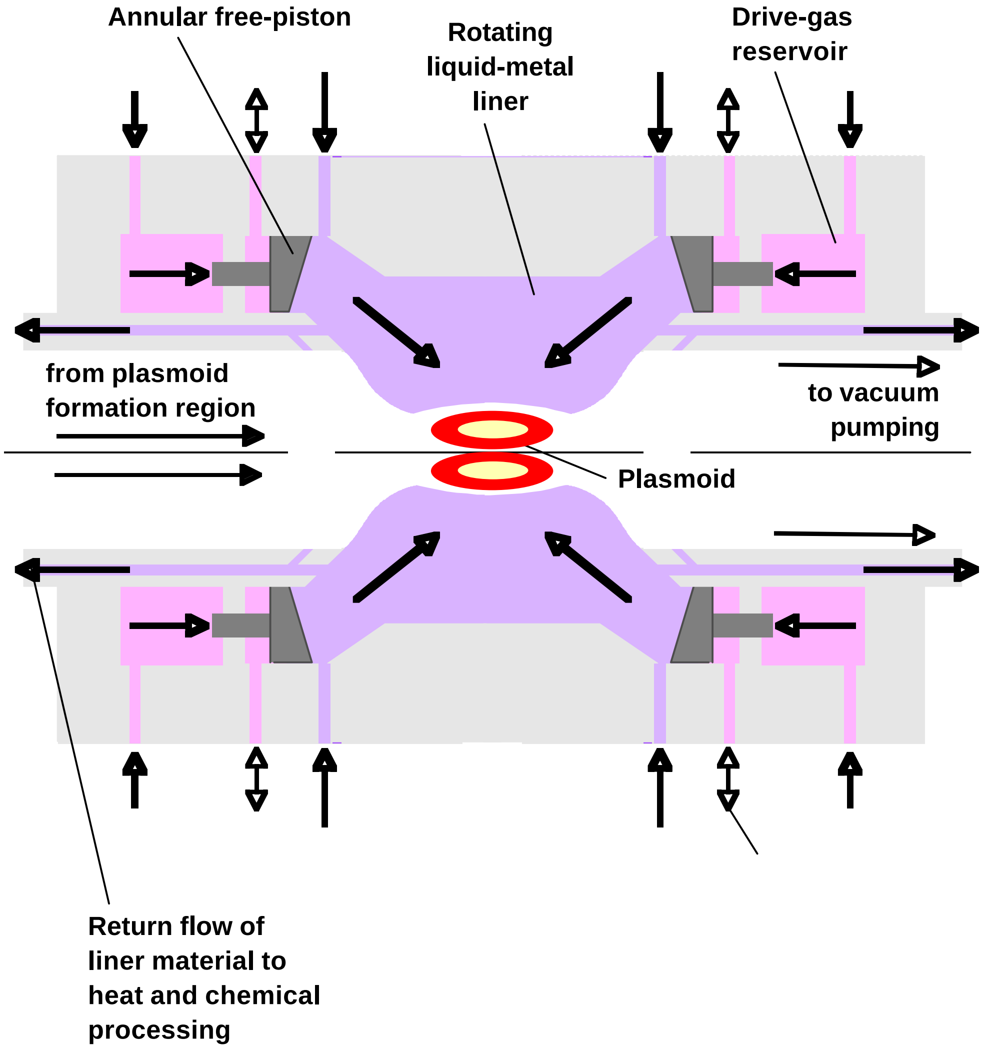
Pioneers: R. Robson, P. Turchi at NRL in 1970s
Plasma physics was less developed.

New perspective: K. Fowler, UC Berkeley analyzed
liquid metal liner compression of spheromaks.

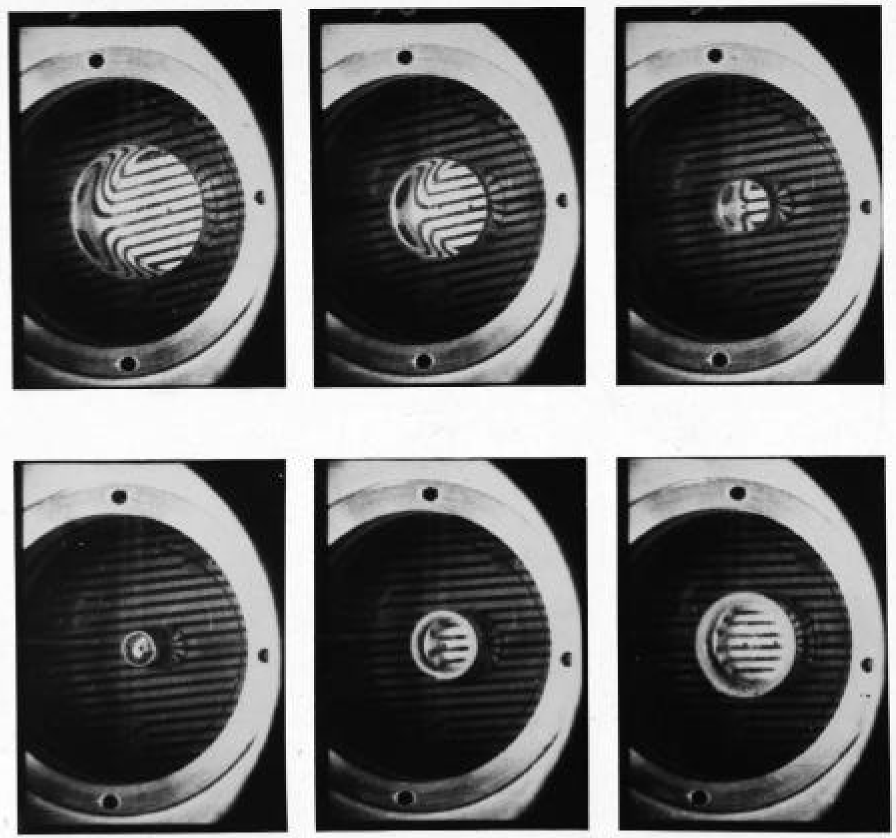
Key features of LINUS

- Liquid-metal first wall (*viz.* Pb-Li) serves as imploding liner, blanket, and coolant.
- Low gain (Q ~ 2) feasible because inexpensive liner KE is created by and then recaptured in energy of compressed gas
- Rotating liquid is Raleigh-Taylor stable at peak compression and returns to pressurized reservoir between pulses
- Typical parameters: B_{max} ~ 0.5 MG
  Liner velocity ~ 0.2 mm/μs
  Compressed plasma radius ~ 20 cm
  Dwell time ~ 1 ms
  Yield ~ 2 GJ
- Plasma performance assumed in 1978 surprisingly close to scaling laws obtained afterwards in FRC research

Liquid metal walls for compression



Experimental study of LINUS hydrodynamics

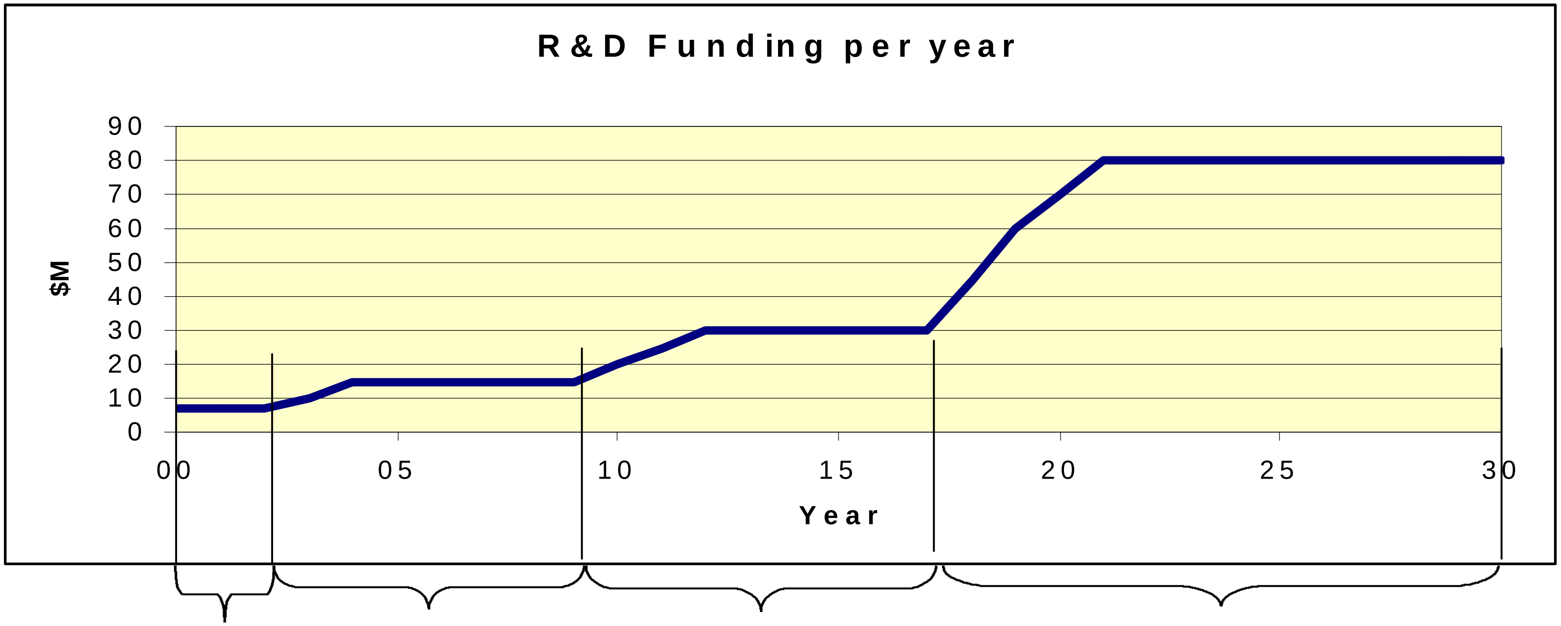


STABILIZED IMPLOSION DRIVEN BY ANNULAR PISTON

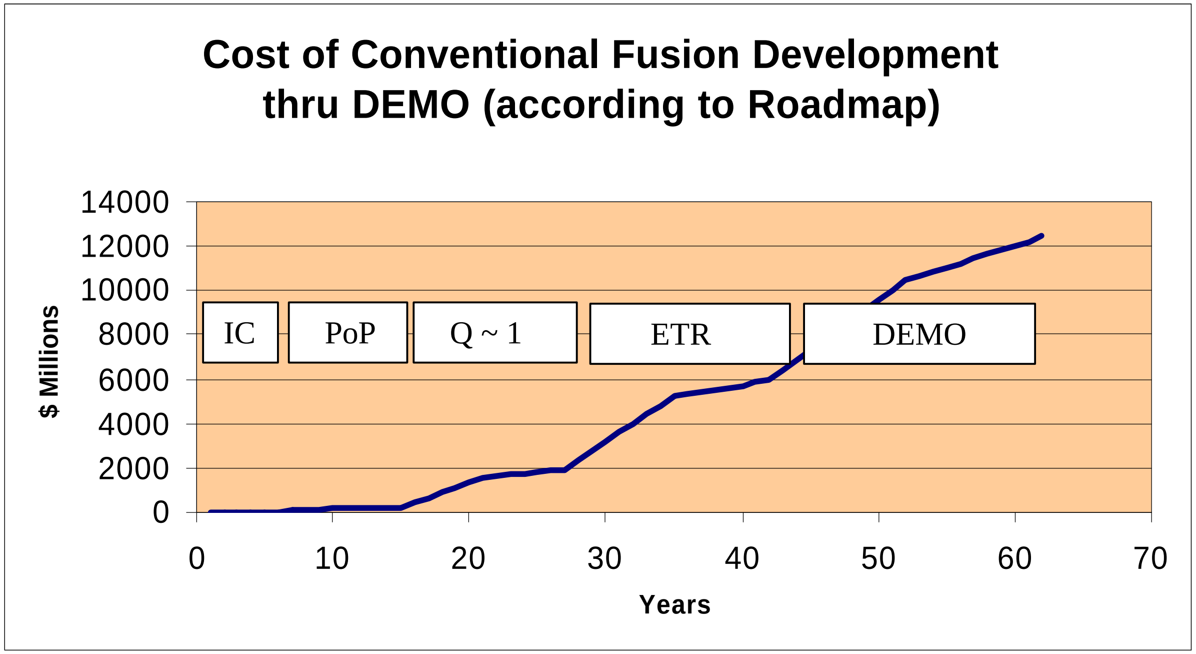
MTF Development Scenario

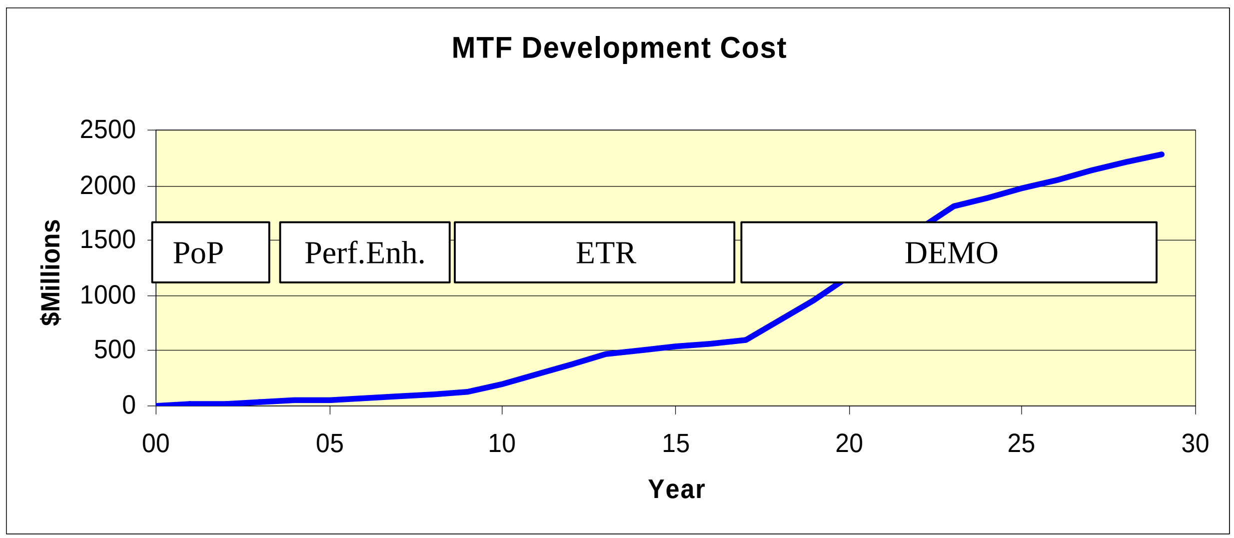
PoP	Use Shiva Star at Phillips Laboratory to document FRC heating to keV temperatures by liner implosion, with Q_{equiv} = (DT equivalent fusion energy)/(liner KE) = 0.01-0.10 3 years at $7M/year ($10M facility already exists)
P.E.	Expand efforts to optimize plasma targets (spheromaks, …) Use ATLAS at Los Alamos to obtain Q_{equiv} = 0.1-1.0 in ~2 years Optimization and assessment requires ~ 7 years at ~ $20M/year ($50M facility available)
ETR	Choose LINUS or FLR approach. Test rep-rated power supply in burst mode. 8 years at ~ $30M/year (requires $250M facility)
DEMO	250-MW unit; 1-10 GJ yield; 0.1-1 Hz; Reliable rep-rated containment. Issues of nuclear materials and tritium handling. 12 years at $80M/year (requires $800M facility)

MTF Roadmap for Development



Stage	PoP	Perf Ext.	ETR	DEMO
Facility cost	Shiva Star	ATLAS	$250M	$800M
Issues	1-10 keV	Qeff ~ 1	Blast or hydro	Nuclear materials and safety
	nτT	Optimize	Burst-mode pulsed power	Tritium processing
				Target fabrication
				Reliable pulse containment


Cost of Conventional Fusion Development
thru DEMO (according to Roadmap)
$ Millions
14000
12000
10000
8000
6000
4000
2000
0
IC
PoP
Q ~ 1
ETR
DEMO
0
10
20
30
40
50
60
70
Years


MTF Development Cost
$Millions
2500
2000
1500
1000
500
0
PoP
Perf.Enh.
ETR
DEMO
00
05
10
15
20
25
30
Year

Conclusions

- The case for increased fusion funding is strong if the restructuring includes:
  -- the proposed portfolio of 3 PoP programs
  -- increased effort on Innovative Confinement Concepts
- MTF is the qualitatively different approach to fusion with potential for truly low-cost development
- Highly desirable for successful MTF program that funding increase from current level of $2M by 2-3x in FY2000