Fusion Test Facilities

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FPA meeting
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With thanks to Mohamed Abdou, Vincent Chan,
Steve Obenschain, Martin Peng, Tom Simonen,
Ron Stambaugh, and their colleagues

Destructive Testing

- It is common practice to test engineered components to destruction prior to deployment of a system e.g.,
  - Automobile crash tests
  - Airplane wing flexing tests
  - Testing nuclear fuel assemblies to meltdown—PHEBUS reactor

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Released on February 28, 2008: Boeing 787 Dreamliner Successfully Completes Fuselage Barrel Test

Boeing engineers proved the composite technology barrel design of the 787 by first taking the barrel to limit load, a test condition that simulates the most extreme conditions expected to be experienced in the life of the airplane.

Next, the test article was taken to 150 percent of limit load -- a condition called "ultimate load," the level required for certification.

Finally, the team pushed the composite section well beyond ultimate load to a destruct-condition maneuver beyond two and a half times the force of gravity.

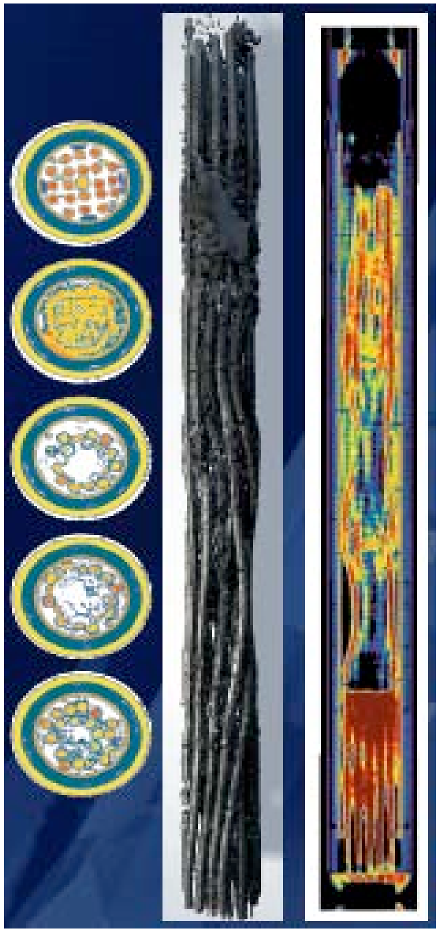
Testers observed audible indications of damage as the test progressed but the piece did not reach the level of destruction that had been anticipated. Boeing engineers now are performing an extensive inspection of the barrel and analysis of test results.

PHEBUS REACTOR--CADARACHE

- **Purpose: studies of hypothetical accidents in pressurized water reactors**
- **Type: pool with an open core**
- **Power: capable of operating at between 20 and 40 MW thermal**
- **Fuel: uranium enriched to 2.78%**
- **The reactor was transformed into a miniature PWR (scale 1/5000) for the program Phébus PFF, a study of the fission products released by a melting core. In ten years, six core fusion experiments were undertaken.**

PHEBUS TESTS

- Tomography of damaged fuel rod, following meltdown in the PHEBUS reactor



A FUSION DEMO WILL REQUIRE LIFETIME & DESTRUCTIVE COMPONENT TESTING

- The Finesse study (Abdou et al, 1994) provides an analysis of the kind of nuclear testing required for in vessel components such as the first wall and blankets.

- While ITER will provide some data, it will have quite a low fluence of 14 MeV neutrons. Furthermore, its mission does not require testing components to destruction; although this may happen, it can not be considered as an adequate basis for qualifying all of the DEMO components.

- Even the Europeans are now considering this need – "R&D Needs and Required Facilities for the Development of Fusion as an Energy Source," October 2008.
  - **A Components Test Facility** could be a desirable risk reduction for DEMO associated to the qualification of nuclear technology components.

SIGNIFICANT FUSION DEMO COMPONENTS

- Blanket/First Wall
- Divertor
- Antennas or Final Focusing
- Diagnostics & Controls
- Remote Maintenance

SOME TESTING REQUIREMENTS

- Neutron Wall Load 1-2 MW/m^2
- Plasma Mode: Steady state (>80% duty cycle) or a few times a second for IFE
- Minimum continuous operating time: 1-2 weeks

• Neutron Fluence at Test Module	MW.y/m^2
Stage I: Initial Fusion “Break-in”	0.3
Stage II: Concept Performance Verification	1-3
Stage III: Component Engineering Development and Reliability Growth	4-6
Total Neutron Fluence for Test Device	> 6

ITER, FDF, and IFMIF Solve the Gap Issues for DEMO

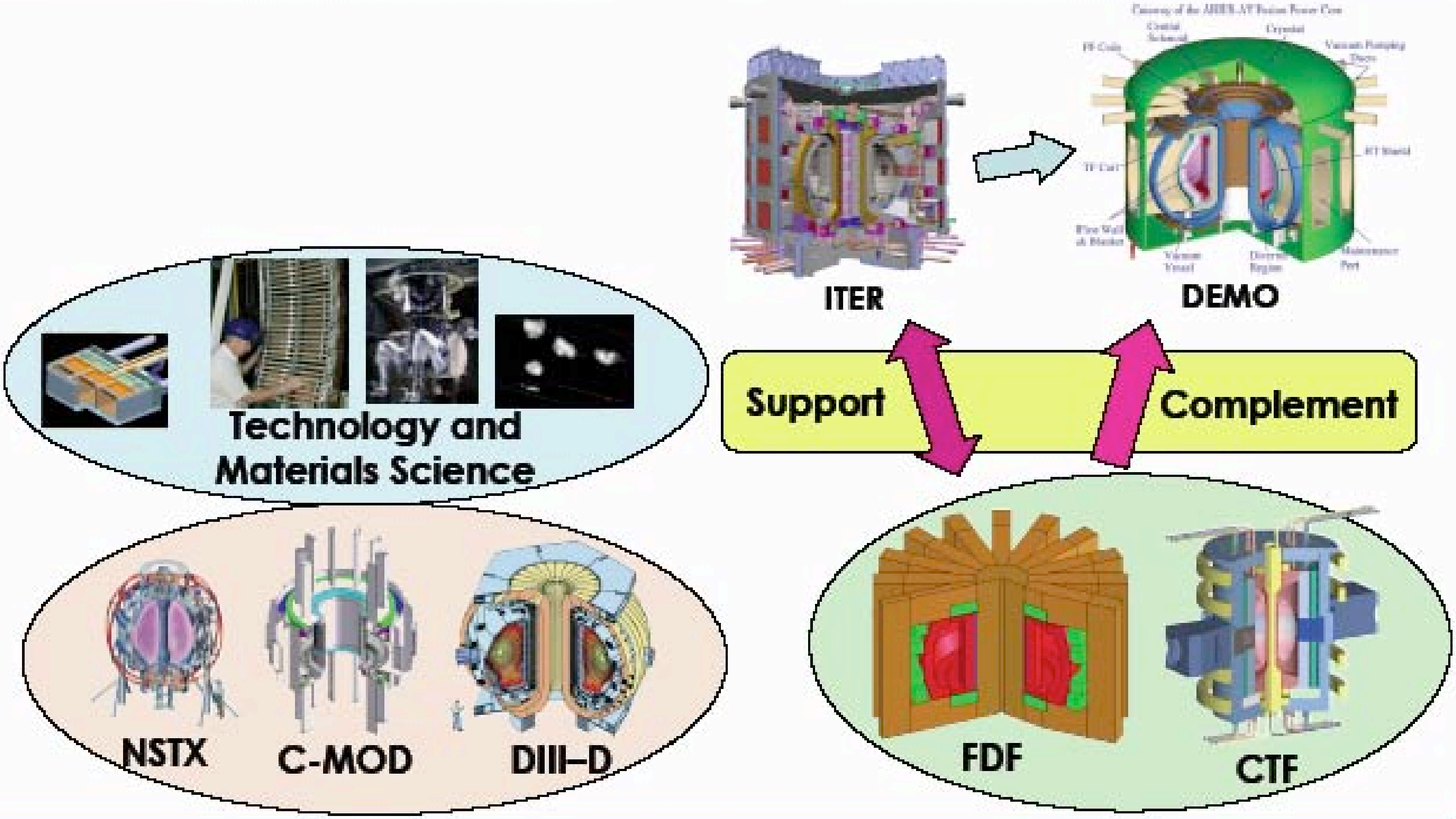
Issue	Today's Exp'ts	ITER	FDF	IFMIF	ITER +IFMIF +FDF	DEMO
High Gain Q > 10		3	2		3	R
Alpha Containment & Physics	1	3	2		3	R
Confinement at Large Size	1	3	1		3	R
Pulsed Heat Loads	1	3	1		3	R
Reactor Scale Superconducting Technology	1	3			3	R
Exhaust Power Handling (~10 MWm^{-2})	1	3	3		3	R
Tritium Handling and Safety	1	3	3		3	R
Integrated Plasma Performance in SS	1	2	2		3	R
Steady-State @ High Beta (β_N, f_{bs})	1	2	3		3	R
High Neutron Wall Loading (Γ_n ~ 2 MWm^{-2})	1	2	3		3	R
Tritium Self-Sufficiency (TBR > 1)		1	3		3	R
PFC and Divertor Materials Lifetime	1	2	3		3	R
FW/Blanket Materials/Components Lifetime		1	3	1	3	R
Materials Characterisation (>100 dpa)		1	2	3	3	R
High Temperature Blankets (electricity, H_2)		2	3		3	R

Key:

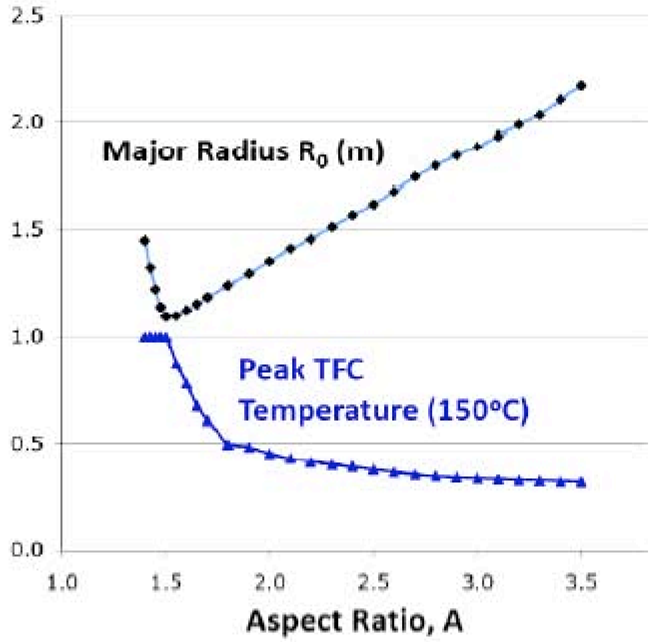
1	Will help to resolve the issue
2	Will contribute significantly to resolution of the issue
3	Should resolve the issue
R	Solution is essential

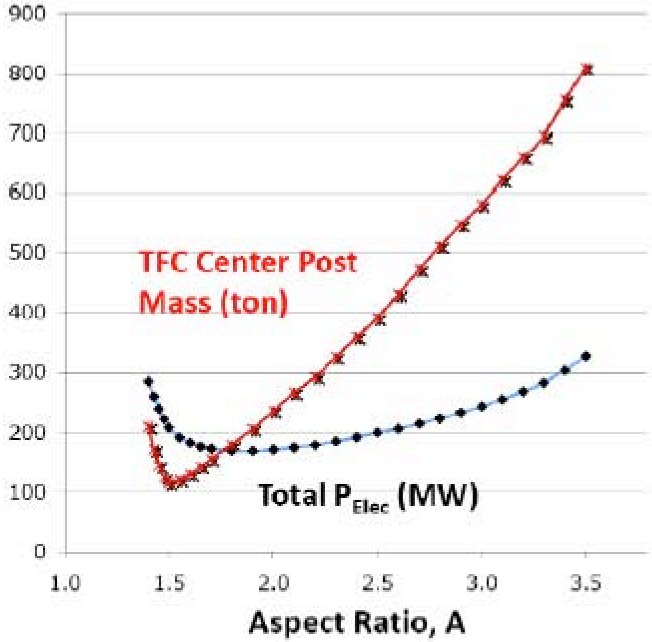
Today's Expt's = DIII-D, C-Mod, NSTX, JT-60U, JET, ASDEX-U, Tore Supra, JT-60 SA, KSTAR, EAST, SST-1

A Steady-State Burning Plasma Fusion Nuclear Science Facility Will Support and Complement ITER Toward DEMO



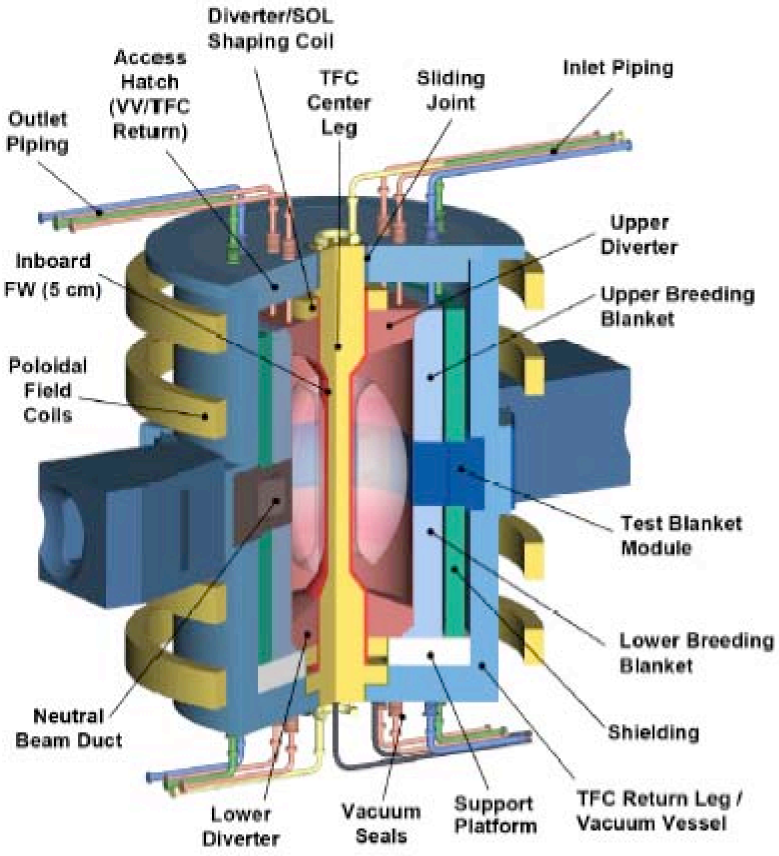
Smallest R_0 obtained near A = 1.5





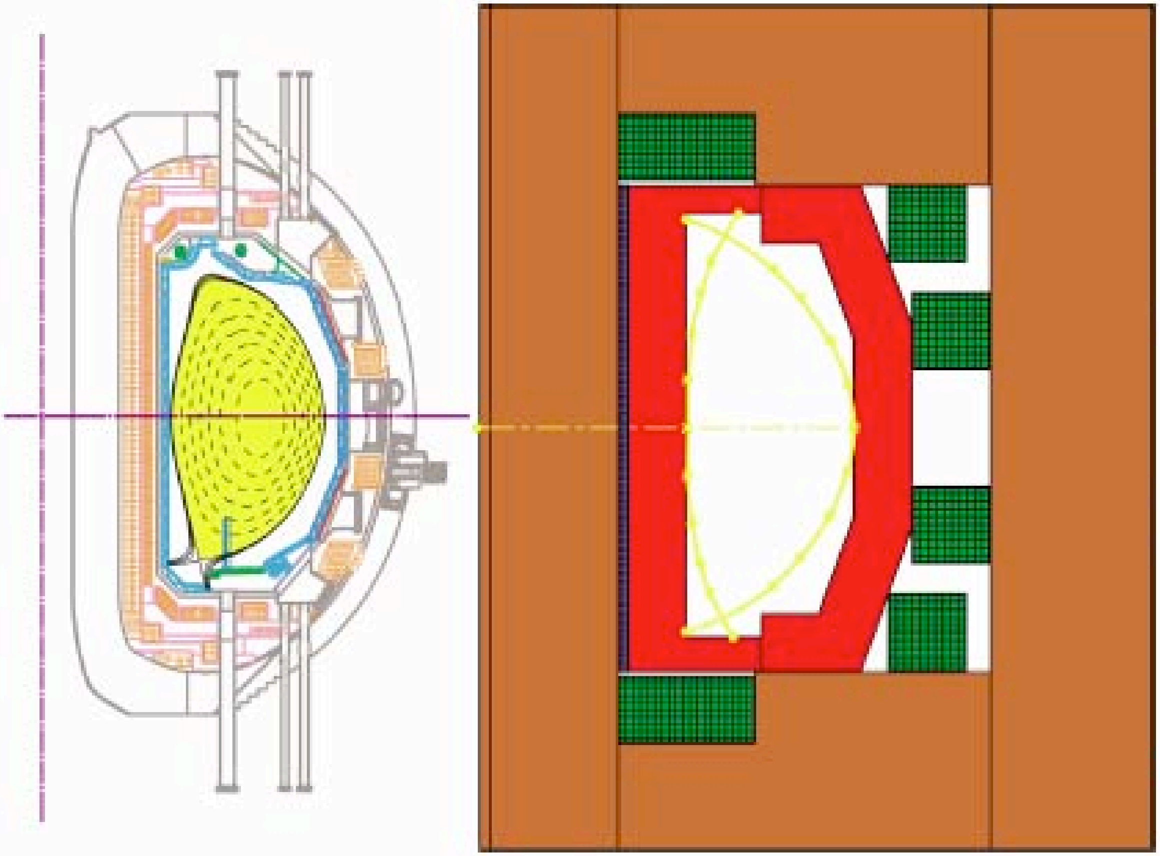
- Constant outboard mid-plane area for test modules
- Peak TFC center post temperature limited to 150°C
  - Smaller A than 1.5 leads to increased R_0
- TFC center post mass ~ 100 ton at A = 1.5
- Total electric power (TFC + H&CD) < 200 MW

Device example uses conservative plasma parameters, modest tritium consumption, and challenges



W_L [MW/m^2]	0.1	1.0	2.0
R0 [m]	1.20		
A	1.50		
kappa	3.07		
q_{cyl}	4.6	3.7	3.0
Bt [T]	1.13	2.18	
Ip [MA]	3.4	8.2	10.1
Beta_N	3.8		5.9
Beta_T	0.14	0.18	0.28
n_e [10^{20}/m^3]	0.43	1.05	1.28
f_{BS}	0.58	0.49	0.50
T_{avgi} [keV]	5.4	10.3	13.3
T_{avge} [keV]	3.1	6.8	8.1
HH98	1.5		
Q	0.50	2.5	3.5
$P_{aux\text{-}CD}$ [MW]	15	31	43
E_{NB} [keV]	100	239	294
P_{Fusion} [MW]	7.5	75	150
T M height [m]	1.64		
T M area [m^2]	14		
Blanket A [m^2]	66		
$F_{n\text{-}capture}$	0.76		

FDF is Viewed as a Direct Follow-on of DIII-D (50% larger) and Alcator Cmod, Using Their Construction Features

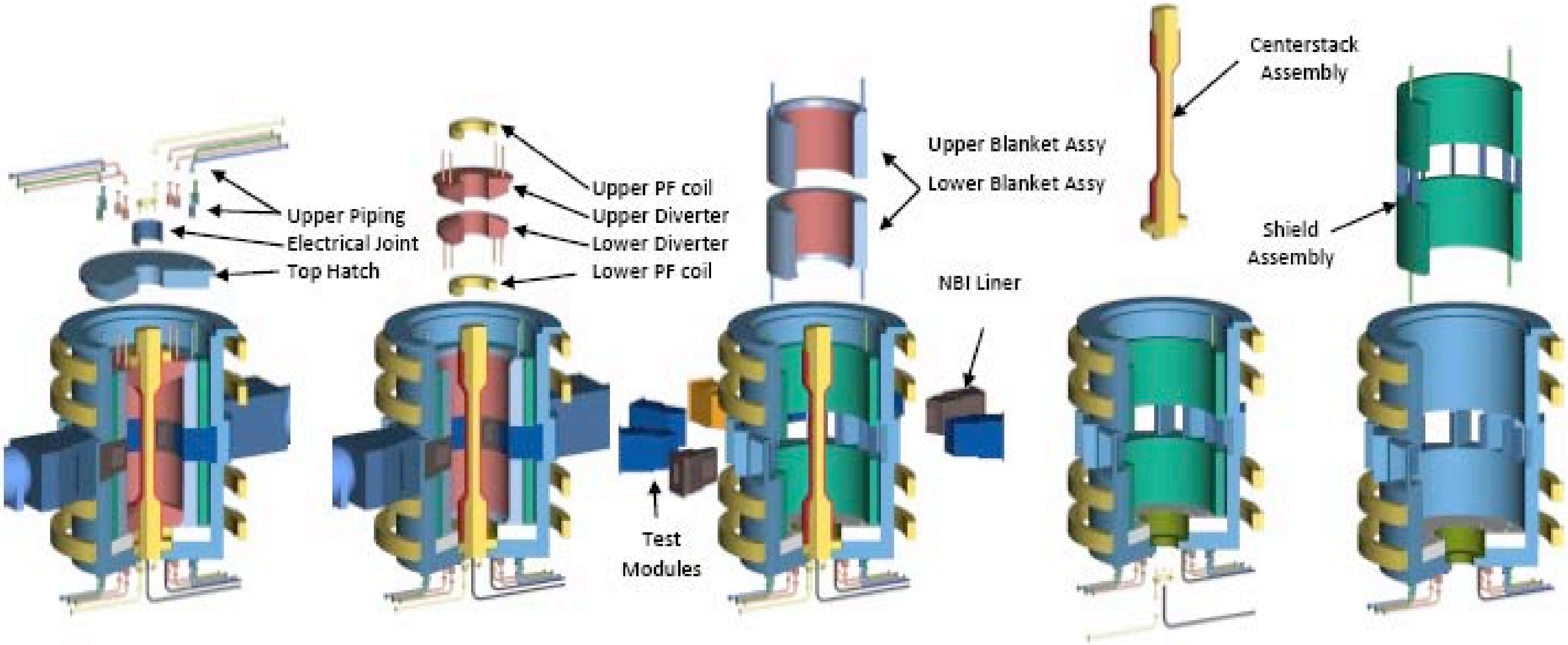


- Plate constructed copper TF Coil which enables..
- TF Coil joint for complete dissasembly and maintenance
- OH Coil wound on the TF Coil to maximize Volt-seconds
- High elongation, high triangularity double null plasma shape for high gain, steady-state
- Red blanket produces net Tritium

High Maintainability via Modularity

Extensive modularity expedites remote handling:

- Large components with linear motion
- All welds external to shield boundary
- Parallel mid-plane/vertical RH operation



Disconnect upper piping
Remove sliding electrical joint
Remove top hatch

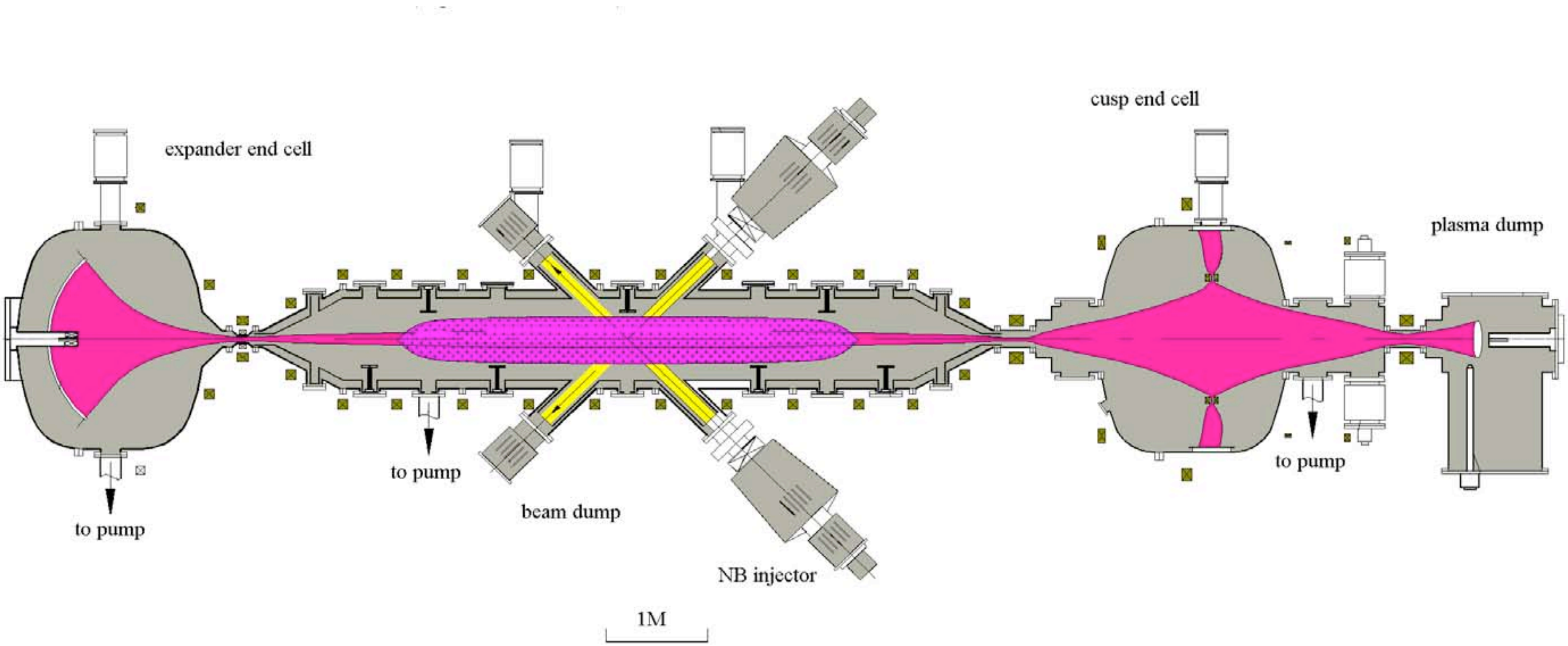
Remove upper PF coil
Remove upper diverter
Remove lower diverter
Remove lower PF coil

Extract NBI liner
Extract test modules
Remove upper blanket assembly
Remove lower blanket assembly

Remove centerstack assembly

Remove shield assembly

Gas Dynamic Trap Neutron Source

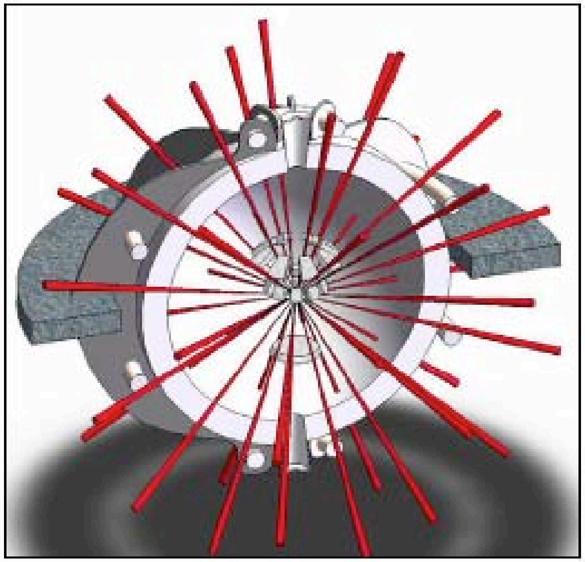


Challenges for laser IFE

- Robust high gain target designs
- Physics base for above
- Inexpensive high-precision targets
- Precise target injection & engagement
- Durable, efficient 5-10 Hz laser driver
- Chambers and final optics that can withstand the "threat spectrum" from pellets (x-rays, ions and neutrons)
- Neutron absorbing blanket and tritium breeding
- Systems design, safety, environmental issues.
- Economics of development and fielding

- Progress on time scale that is relevant (e.g. by ~2025)

A Laser Based Fusion Test Facility (FTF)



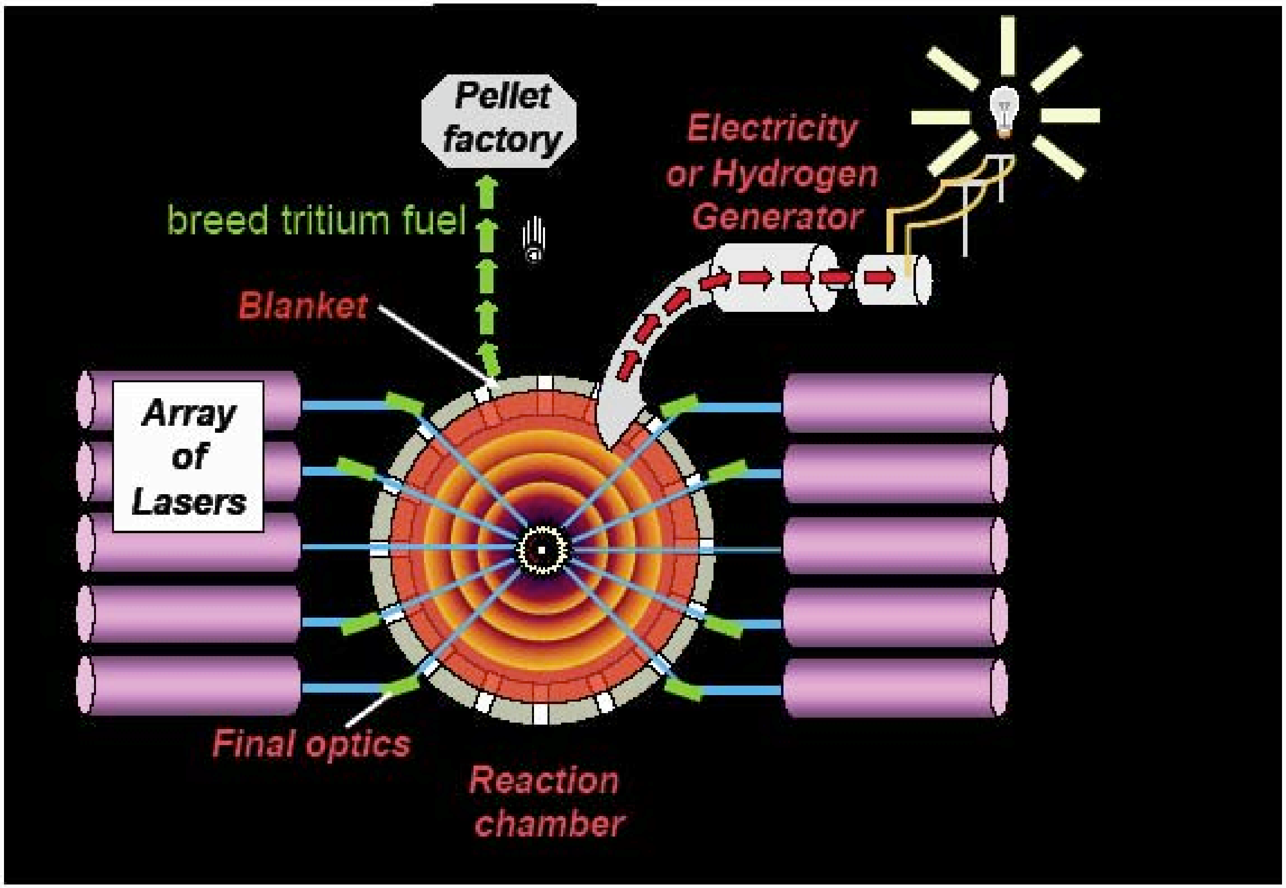
18th TOFE meeting
San Francisco CA

- ~100 MW (thermal) fusion power
- ≤500 kJ laser energy @ 5 Hz
- ~50 to 100× target gain
- based on advanced laser direct drive

The FTF would bridge the gap between large "single-shot" ignition facilities (such as NIF and LMJ) and a fully functioning laser-fusion power plant.

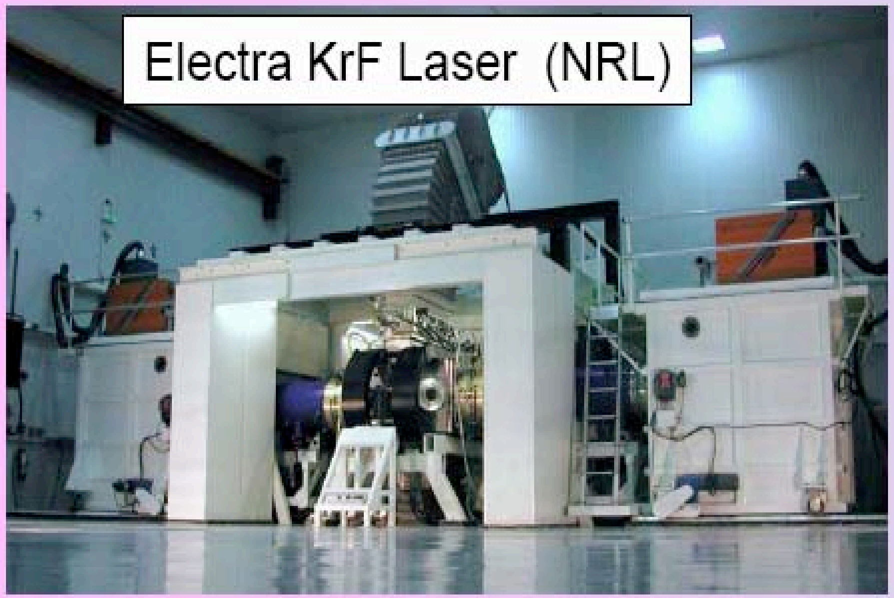
Presented by: Steve Obenschain,
Plasma Physics Division,
U.S. Naval Research Laboratory

A laser fusion energy power plant



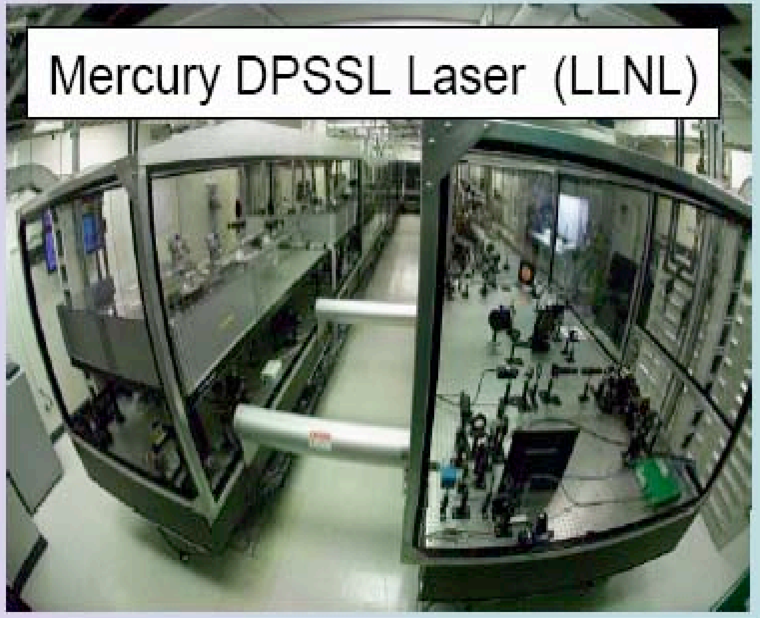
The FTF would demonstrate all of the above except net power production

E-beam pumped krypton fluoride


Electra KrF Laser (NRL)

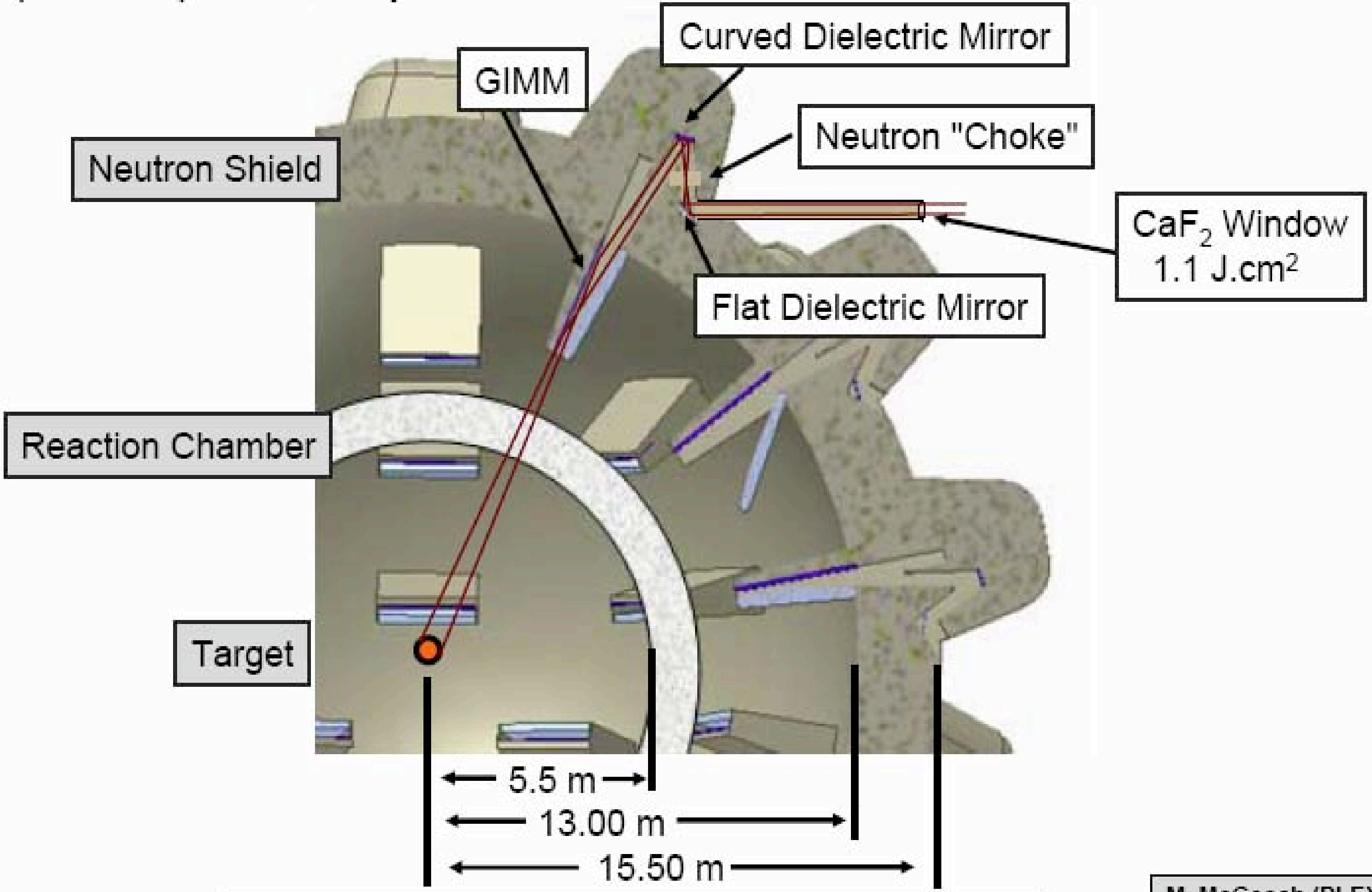
- λ = 248 nm
- 2.5-5 Hz
- 700 J max,
- >16 k shots continuous
- >250,000 shots cumulative

Diode pumped solid state laser


Mercury DPSSL Laser (LLNL)

- λ = 1051 nm (523 & 350nm)
- 10 Hz
- 65 J max
- >18 k shots continuous
- >300,000 shots cumulative

Optical train with Grazing Incidence Metal Mirror (GIMM) Final Optic

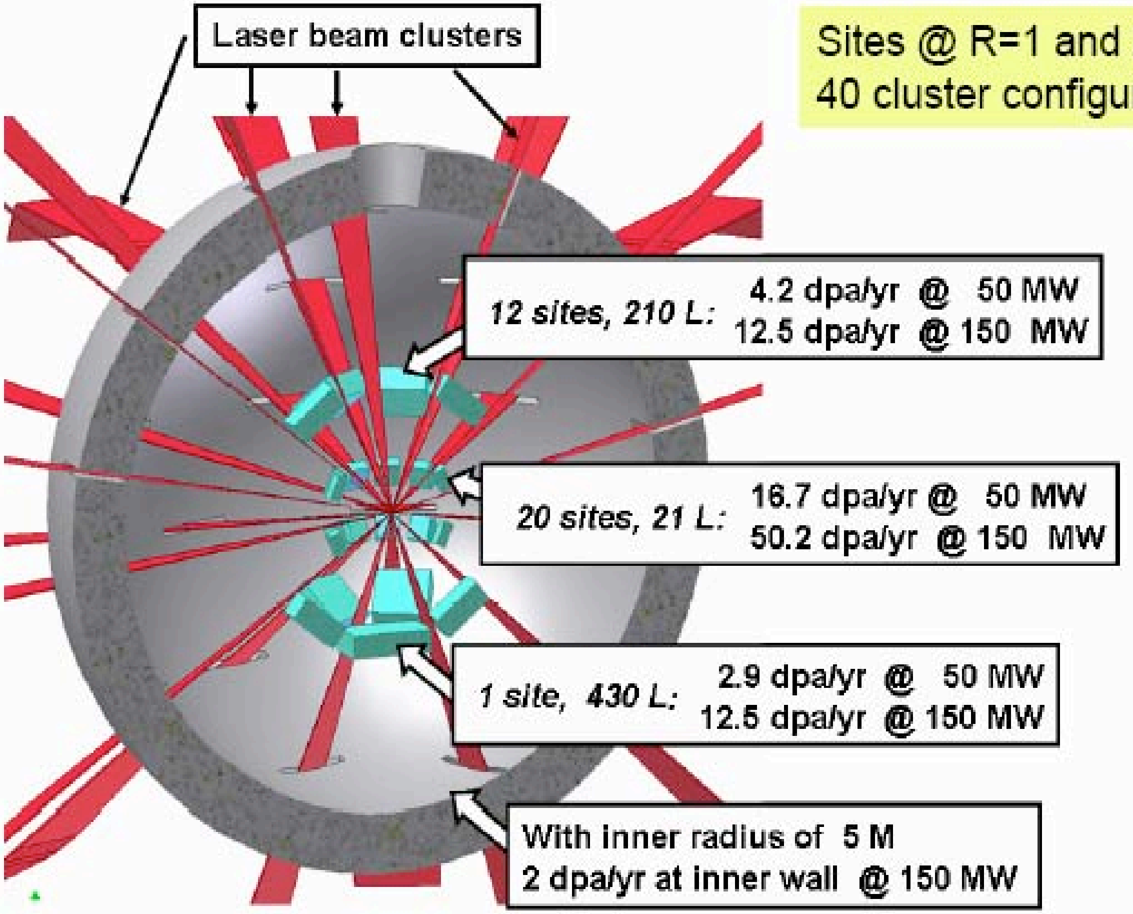


Also evaluating Dielectric Mirror in place of GIMM

M. McGeoch (PLEX)
M. Sawan (Wisc)
L. Snead (ORNL)

There is room between beam clusters to locate large test objects in the FTF target chamber.

Sites @ R=1 and 2 meters
40 cluster configuration



Laser beam clusters

12 sites, 210 L: 4.2 dpa/yr @ 50 MW
12.5 dpa/yr @ 150 MW

20 sites, 21 L: 16.7 dpa/yr @ 50 MW
50.2 dpa/yr @ 150 MW

1 site, 430 L: 2.9 dpa/yr @ 50 MW
12.5 dpa/yr @ 150 MW

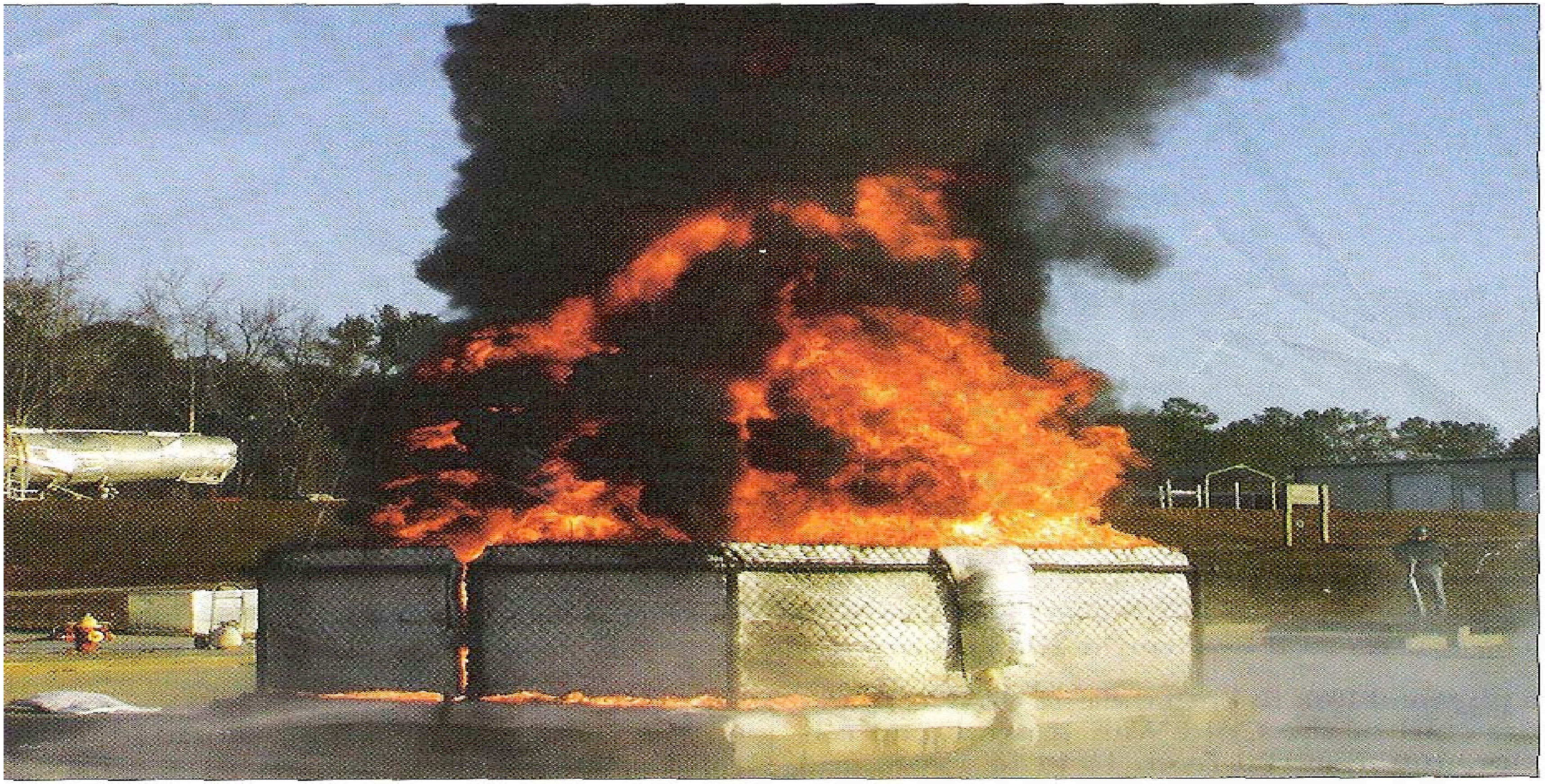
With inner radius of 5 M
2 dpa/yr at inner wall @ 150 MW

Assumes (60 % availability)

Summary

- High repetition ignition is the logical and essential next step for IFE.
- A Fusion Test Facility based on laser direct drive continues to look very promising.
- Gains needed for a power plant may be achievable at sub megajoule energy.

Hopefully, we'll make less of a mess!



Savannah River's radioactive materials container, the 9977, underwent testing by fire to demonstrate its suitability for certification. (Photo: DOE)

SUMMARY SUMMARY

- Fusion Component Test Facilities are an essential step prior to committing to a final design for a DEMO reactor.

- It is encouraging that options exist in both MFE and IFE.

- I hope that they will be built.