OVERVIEW OF U.S. MAGNETIC FUSION TECHNOLOGY PROGRAM

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TECHNICAL COMMITTEE AND WORKSHOP
ON
FUSION REACTOR DESIGN AND TECHNOLOGY
YALTA, USSR
26 MAY - 6 JUNE 1986

MAGNETIC FUSION ENERGY

Mission:

- Establish the scientific and technological base for fusion energy

Strategy:

- Broad domestic R&D program on basic elements (components or subsystems) of science and engineering technology.
- International collaboration to advance program in a timely fashion, particularly through joint facilities for testing integrated systems.

Program is organized around four key issues:

- Development of Improved Confinement Concept
- Understanding Physics of Burning Plasmas
- Development of Materials
- Development of Nuclear Technology

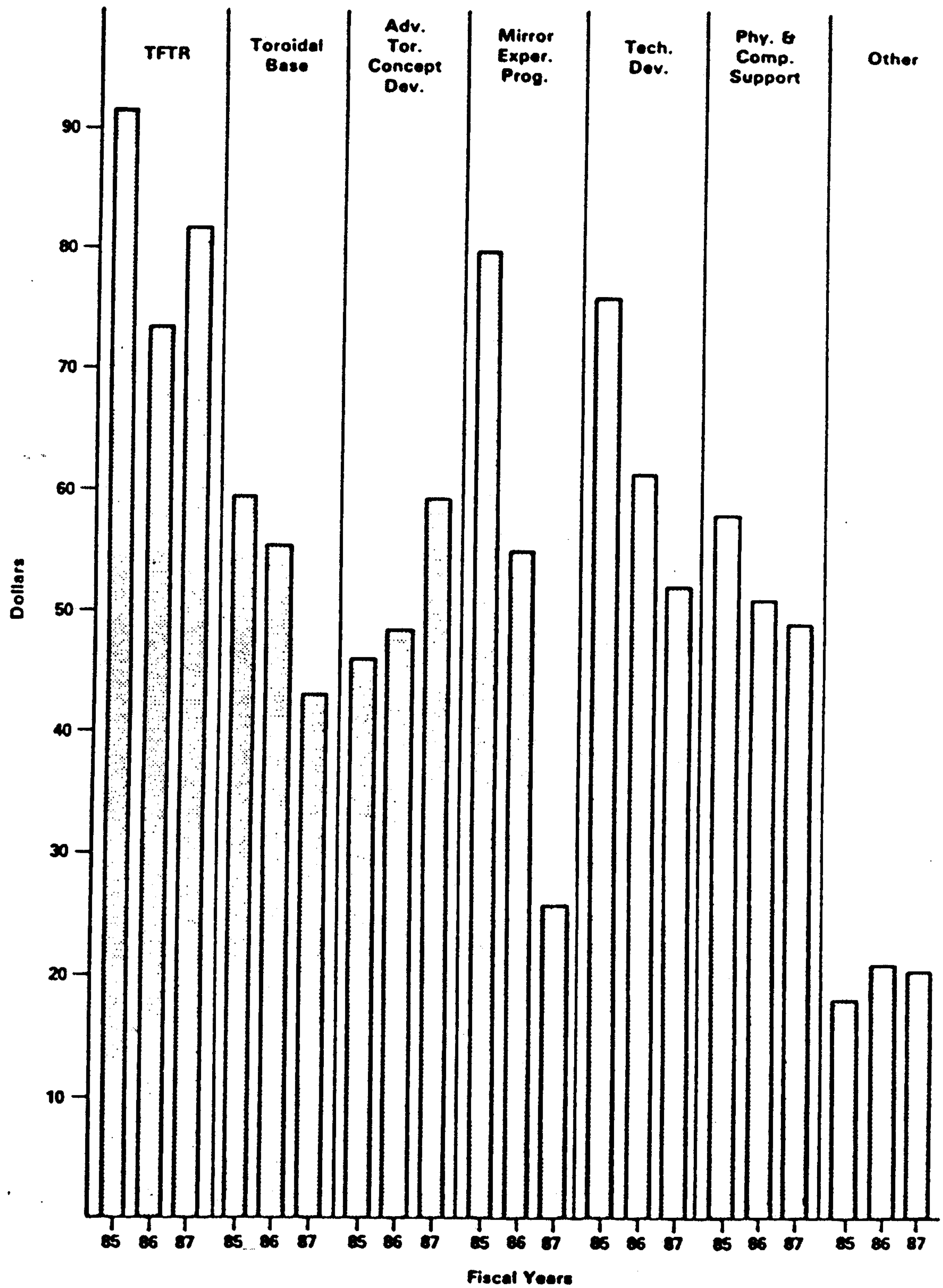
Magnetic Fusion Energy
Budget Overview

	FY 1985	FY 1986	FY 1987
Operating	369.6	324.5	307.5
Capital Equipment	27.5	28.3	17.3
Construction	32.5	12.7	8.2
	429.6	365.5	333.0

Major Themes of FY 1987 Budget

- Focus on toroidal concept development
- Continue ignition design studies
- Maintains minimum level of nuclear technology and materials programs in preparation for an international effort
- Meets existing international commitments

Magnetic Fusion Energy Program Budget
($ Millions; BA)



Development and Technology
FY 1987 Budget Request
($BA in millions)

	FY 1985	FY 1986	FY 1987	Change
Magnetics	$19.0	$14.8	$10.4	-4.4
Heating and Fueling	12.8	10.1	10.0	-0.1
Fusion Nuclear Technology	7.1	6.3	6.0	-0.3
Education and Environment	1.7	1.5	1.5	0
Fusion Materials	18.4	17.0	14.5	-2.5
Fusion Systems Analysis	14.0	11.7	10.0	-1.7
TOTAL	$73.0	$61.4	$52.4	-9.0

Explanation of Major Changes from FY 1986

- Fund completion of IEA Large Coil Task
- Maintain minimum magnet technology effort
- Increase ICRF support and maintain fueling program
- Continue PMI programs
- Continue liquid metal studies
- Continue reduced activation and fundamental studies on neutron effects with transition from ORR to HFIR
- Continue design studies of an ignition facility

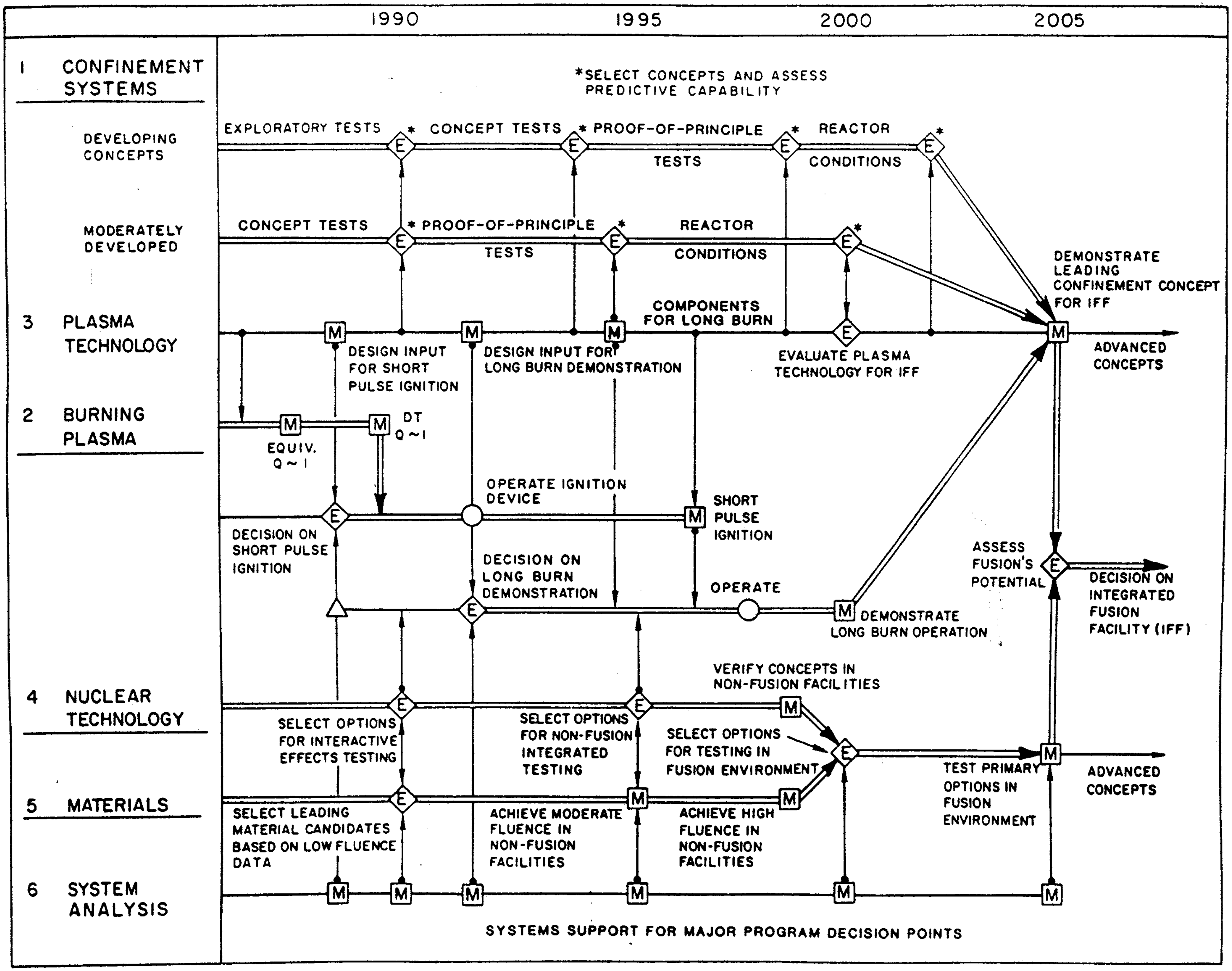
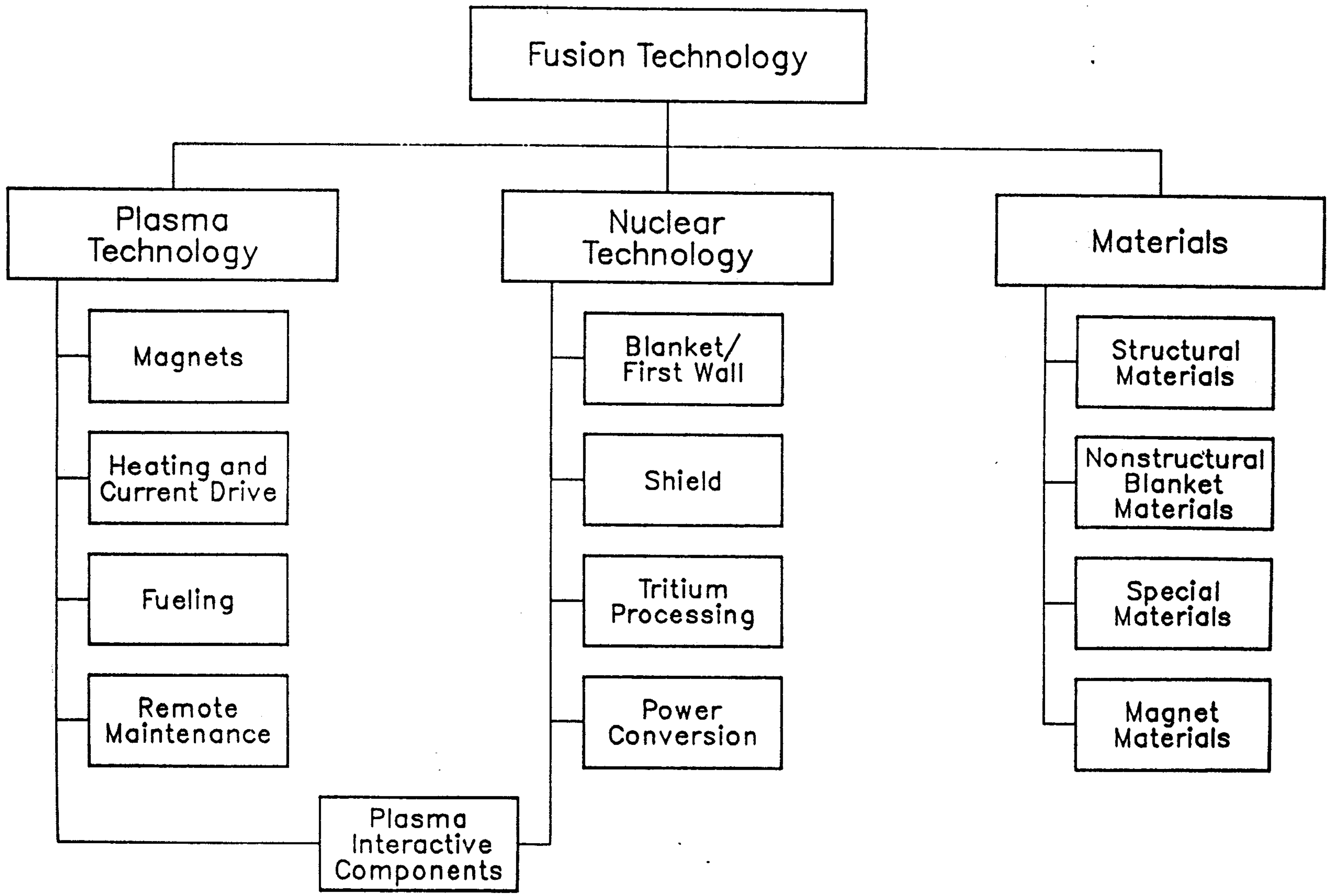


Fig. 1 Magnetic Fusion Overview


Fusion Technology
Plasma Technology
Magnets
Heating and Current Drive
Fueling
Remote Maintenance
Plasma Interactive Components
Nuclear Technology
Blanket/ First Wall
Shield
Tritium Processing
Power Conversion
Materials
Structural Materials
Nonstructural Blanket Materials
Special Materials
Magnet Materials

Large Coil Task (LCT)

GD/ Convair	GE	West.	EURATOM	JAPAN	SWITZ
NbTi	NbTi	Nb_3Sn	NbTi	NbTi	NbTi
10 KA	10 KA	17^{3} KA	11 KA	10 KA	13 KA
P.B.	P.B.	F.F.	F.F.	P.B.	F.F.
4.2 K	4.2 K	3.7 K	3.7 K	4.2 K	3.7 K
1 atm	1 atm	1 atm	15 atm	1 atm	1 atm
Various Winding and Structure Configurations					

Progress

- Installation of all coils was completed in 1985

- Tests of the six-coil array began in January 1986

  - Demonstrated capability of all coils to be cooled to operating temperature without excessive thermal stress or opening of helium leaks

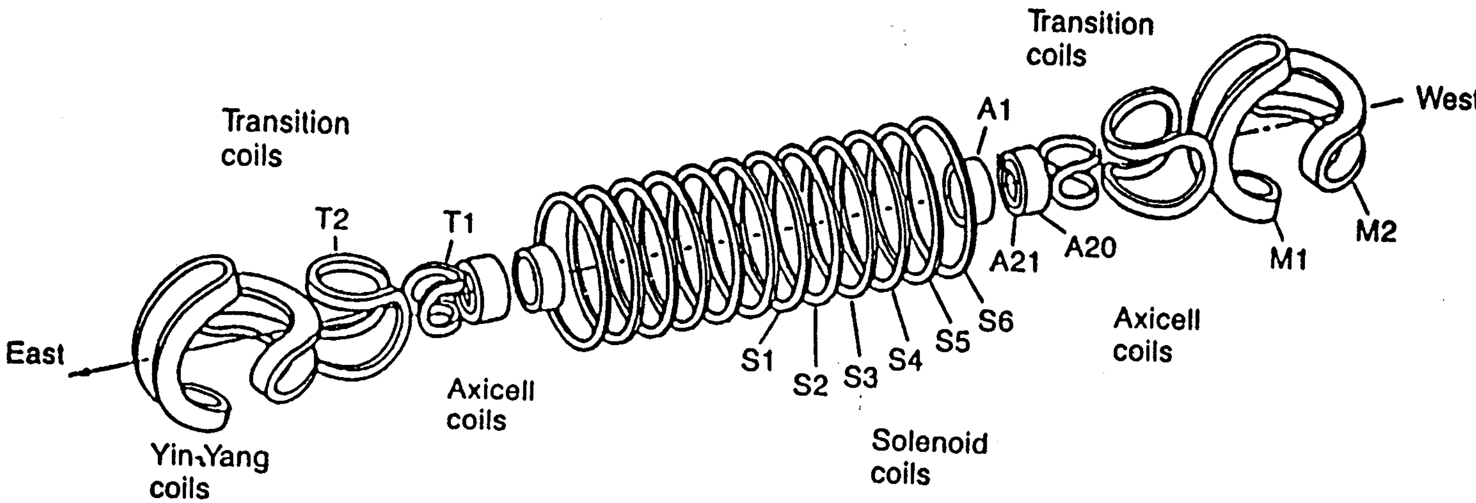
  - Each coil was energized to its rated current while internal heaters were used to simulate fusion heating

  - Present tests are exploring reliability and effectiveness of quench detection and protection provisions

- Planned Test Program will be completed in 1987

PRIMARY MAGNET SYSTEM FOR MFTF-B
(Trim Coil Deleted for Clarity)

Coils	Designation
12 solenoid coils (5m)	S1 through S6 (east & west)
4 transition coils	T1 and T2 (east & west)
4 axicell coils (NbTi)	A1 & A2 (east & west)
2 axicell insert coils (Nb_3Sn)	A2I Inner (east & west)
2 Yin-Yang coil pairs	M1 & M2 (east & west)



MAGNET SYSTEM, INCLUDING 11 KW REFRIGERATION SYSTEM, WAS SUCCESSFULLY TESTED IN FEBRUARY 1986.

PLASMA HEATING AND FUELING

- COMPLETED DEVELOPMENT OF LONG PULSE NEUTRAL BEAM SOURCES (80 KEV/30 SEC) FOR INSTALLATION ON DIII-D AND TFTR. (LBL)

- THE 60 GHZ, 200 KW, CW GYRATRON DEVELOPMENT PROGRAM HAS BEEN COMPLETED. (ORNL/VARIAN) DEVELOPMENT WORK ON 140 GHZ, 100 KW GYRATRON CONTINUES. (LLNL)

- THE RADIO FREQUENCY TEST FACILITY HAS BEGUN OPERATION WITH A CONTINUOUS PLASMA. IMPROVED RF FEEDTHROUGHS HAVE BEEN PROVIDED TO SEVERAL EXPERIMENTS. (ORNL)

- PELLET INJECTORS HAVE BEEN INSTALLED ON TFTR; INJECTORS WILL BE PROVIDED FOR TORE SUPRA AND JET. (ORNL)

SUMMARY OF EXISTING U.S.
PMI / HHF LABORATORY FACILITIES

NAME	LOCATION	STATUS
Plasma Materials Test Facility E-Beam, Multiple-Beam (PMTF)	SNLA	Operating
Plasma-Surface Interaction Experiment (PISCES)	UCLA	Operating
Tritium Plasma Experiment (TPX)	SNLL	Operating
Hot-Cell Electron Beam Facility (Neutron Irradition) (HEBF)	HEDL	Operating
Continuous Current Drive Tokamak (CCT)	UCLA	Operating/Funded for RF Heating and Current Drive
RF Test Facility (RFTF)	ORNL	Commissioning/Funded for RF Component Development
Electromagnetic Forces (FELIX)	ANL	Unfunded (Mothballed)

Plasma Materials Test Facility (PMTF)

Objective

Dedicated to development and testing of high heat flux components.

	Electron Beam System	Multiple Beam System
Source	30 KeV, 30 KW	40 KeV, 1.6 MW H-Beam
Target Area	1-100 cm^2	800 cm^2
Pulse Duration	0.05 sec - contin.	continuous
Maximum Heat Flux	30 KW/cm^2	2 KW/cm^2
Cooling	Closed Loop Water	

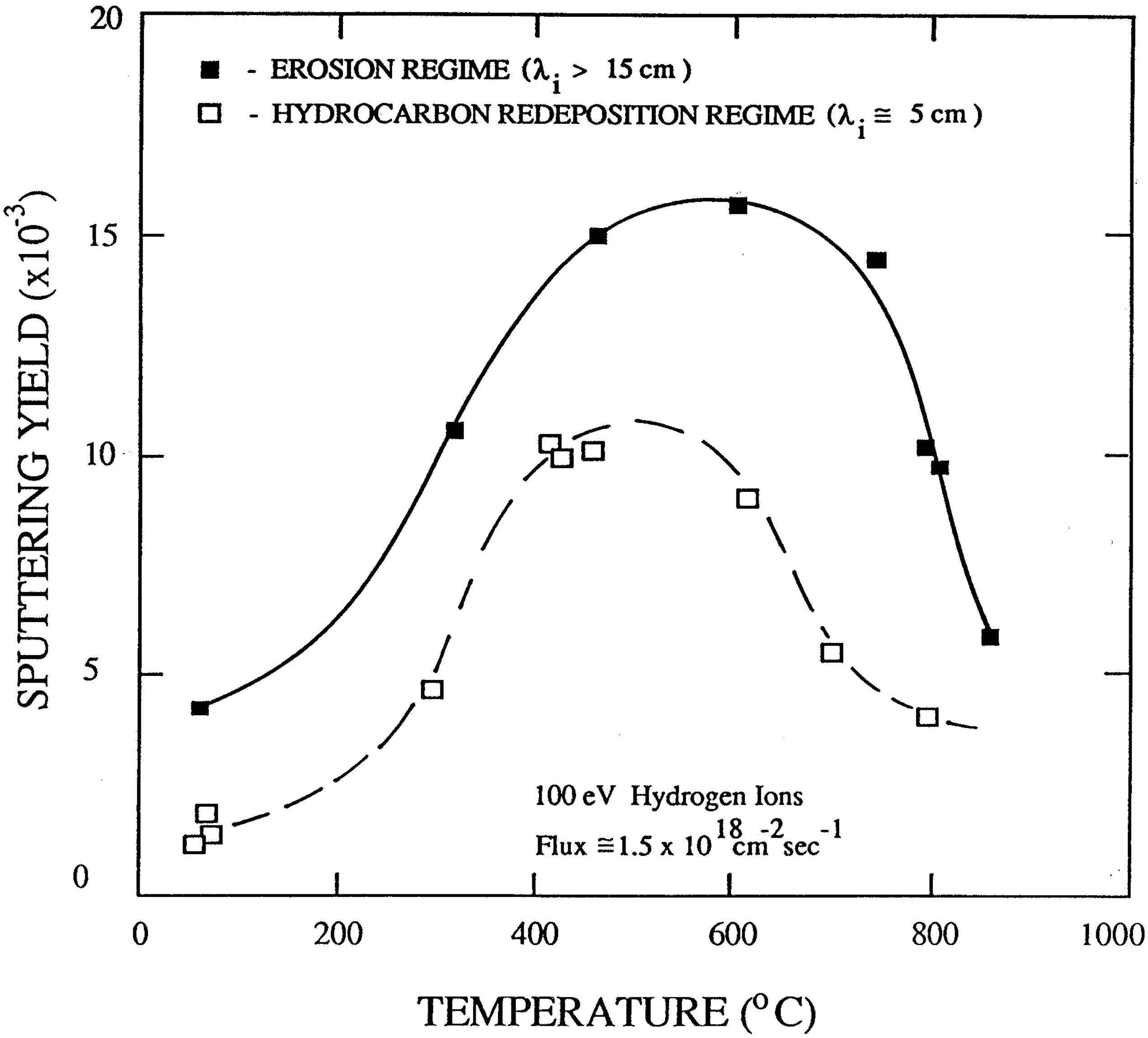
Plasma-Surface Interactions Facility (PISCES) - UCLA

Objectives

- Material Behavior During Continuous Bombardment Using Plasma With SOL Parameters
  (e.g., erosion/redeposition)

- Plasma Edge Simulation of SOL Behavior in Confinement Experiments
  (e.g., pump limiter simulation experiments)

Features	Characteristics
Plasma	n $5 \times 10^{11} - 2 \times 10^{13}$ cm^{-3} T_e 3-30 eV
Target Area	100-400 cm^2
Pulse Duration	Continuous
Ion Energy	50-500 eV (bias)
Cooling	Air or Water
Maximum Heat Flux	200 W/cm^2
Plasma Flux	$10^{17} - 2 \times 10^{19}$/cm^2-s

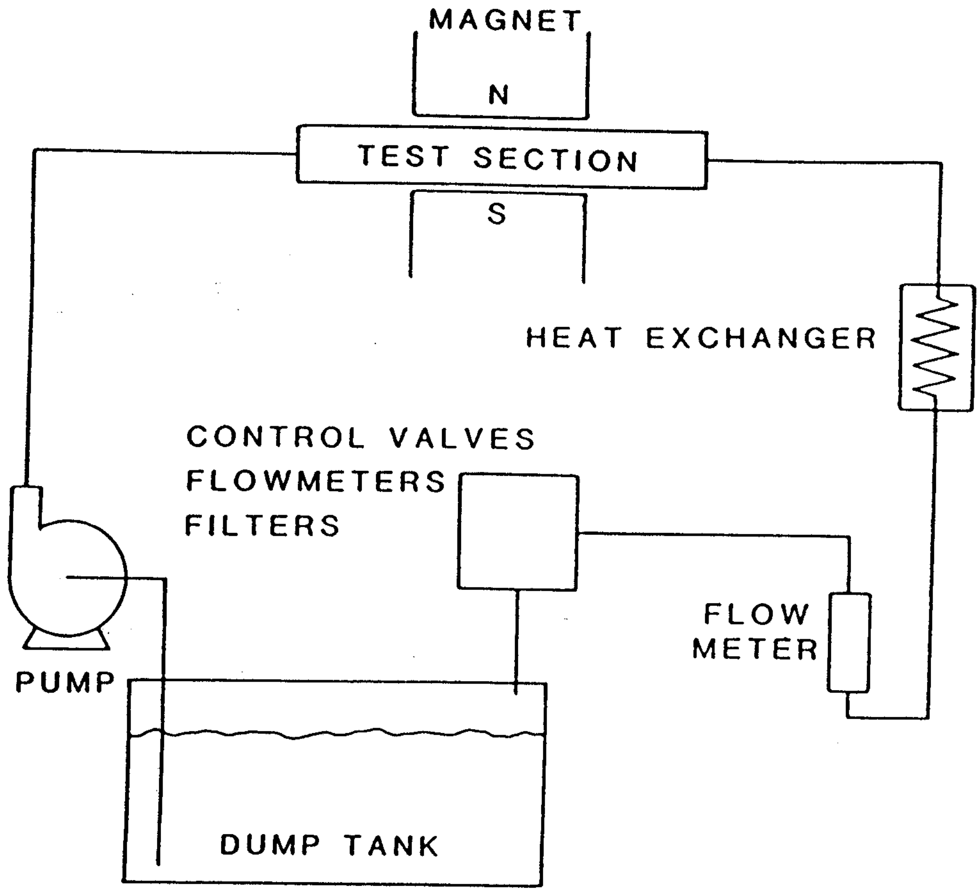


■ - EROSION REGIME (λ$_i$ > 15 cm)
□ - HYDROCARBON REDEPOSITION REGIME (λ$_i$ ≅ 5 cm)
SPUTTERING YIELD (x10^{-3})
20
15
10
5
0
0
200
400
600
800
1000
TEMPERATURE (°C)
100 eV Hydrogen Ions
Flux ≅ 1.5 x 10^{18} cm^{-2} sec^{-1}

Present U.S. Liquid Metal Facilities

Facility	Location	Parameters	Comments
MHD			
ALEX	ANL	B = 2T, N ~ 10^{14}, Volume ~ $0.2m^3$, NaK	MHD data at high interaction parameters; upgrade under evaluation
LM Flow	U. of Texas	B = 0.6T, N ~ 10^3	LM flow through pebble bed
Corrosion Loops	ANL	Li/SS, FS; LiPb/Iron ΔT, 5 – 50ℓ	Forced convection loops
	ORNL	Li/SS, FS, LiPb/SS	Thermal convection loops
	Others		HEDL, UW (non-operational)
Electromagnetics	FELIX	1.0T(SS), 0.5T(ramp) 5ms, $1m^3$	transient tests

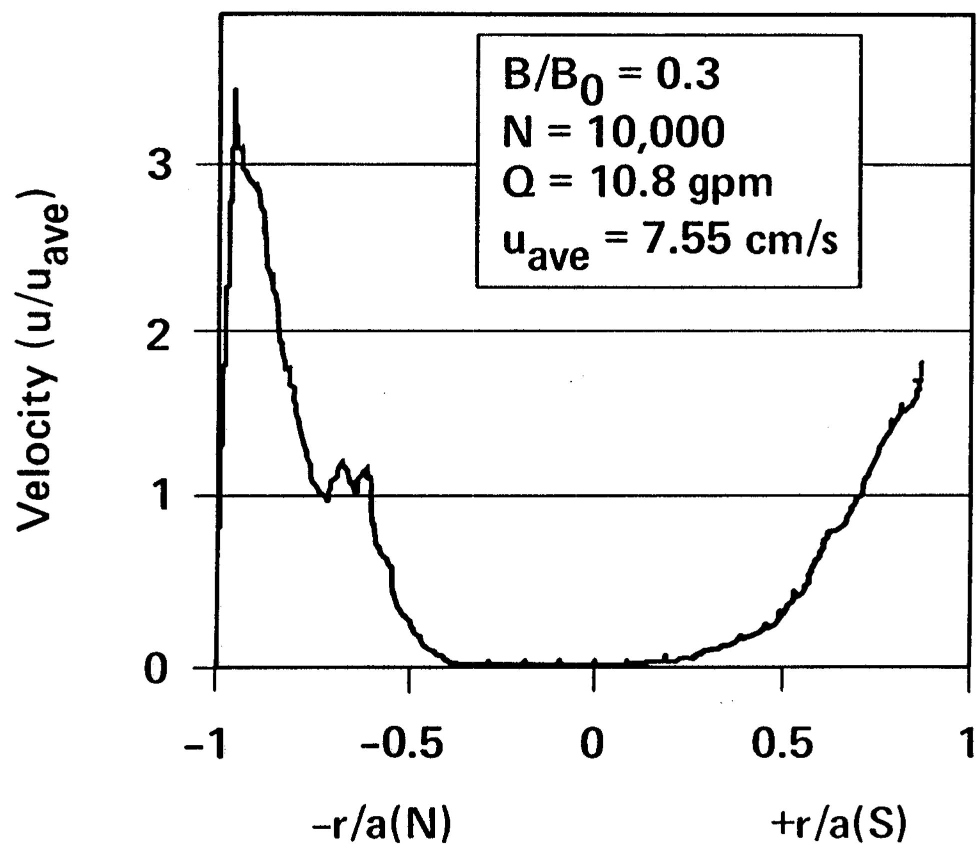
FACILITY SCHEMATIC



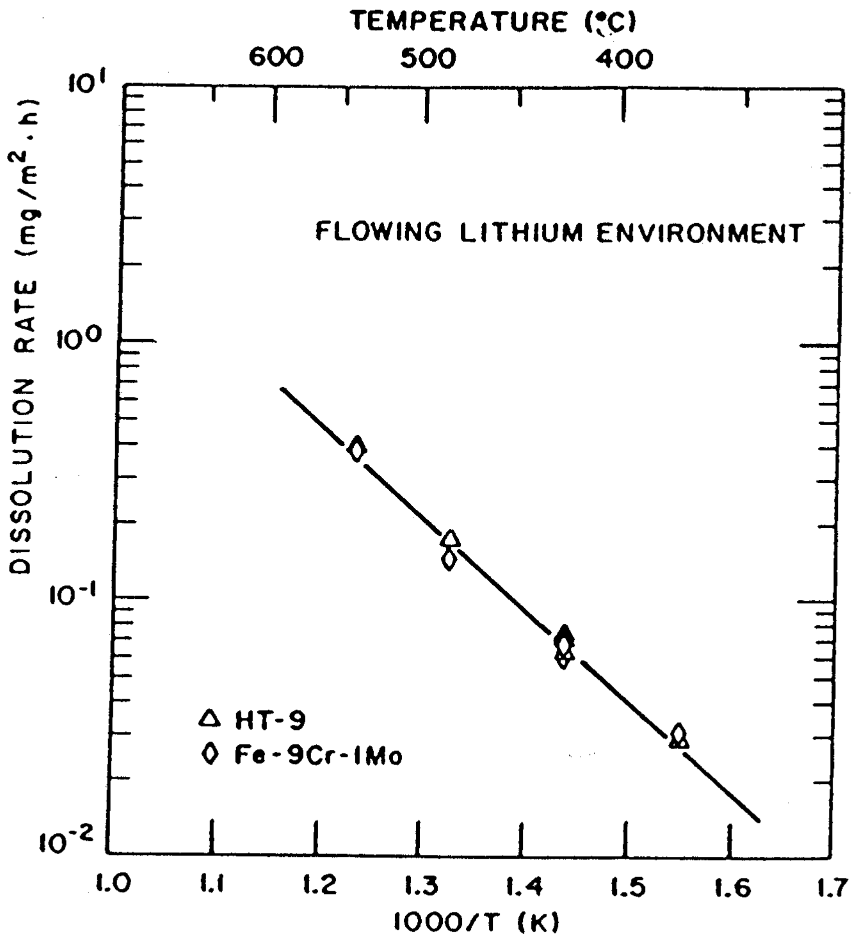
FACILITY PARAMETERS

• FLOW RATE :	5-300 GPM (.3-19 l/s)
• MAGNETIC FIELD :	0-2.5 T
• PRESSURE :	0-150 psi (0-1 MPa)
• TEMPERATURE :	20-40° C
• WORKING FLUID :	NaK
• MAGNET GAP :	6 INCHES (15 cm)
• TRAVERSING MAGNET :	±50 INCHES (±125 cm)

Velocity Profiles From LEVI



Velocity Profiles Taken At Exit Of Magnet



TEMPERATURE (°C)
600
500
400
10^1
10^0
10^{-1}
10^{-2}
DISSOLUTION RATE (mg/m^2·h)
FLOWING LITHIUM ENVIRONMENT
△ HT-9
◇ Fe-9Cr-1Mo
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1000/T (K)

Present U.S. Solid Breeder Experimental Activities

- Carried out mostly in collaboration with other countries
- Primary organizations: ANL, HEDL
  Support: ORNL, GA
- Fabrication
  —BEATRIX/FUBR-1B
  —LBM
- Irradiation
  —Completed: TRIO, FUBR-1A
  —Active: FUBR-1B/BEATRIX
- Material Characterization
  —Li_2O, $LiAlO_2$ (at ANL)

Capabilities of Selected U.S. Fission Reactors

Reactor	Site	Neutron Flux $n/cm^2 \cdot s$	Experiment Size cm OD × cm	Comments
FFTF EBR-II	HEDL ANL-W	5×10^{15} (fast) 2×10^{15} (fast)	10 × 91 6 × 33	Operational; Suitable for T-Recovery Experiments
HFIR	ORNL	1.3×10^{15} (fast) 0.2×10^{15} (thermal)	3 × 51	Presently used (structural, other materials)
ORR		0.5×10^{15} (fast)	8 × 38	Scheduled for shutdown
Others	A number of reactors not presently utilized			

Present U.S. Neutronics Activities

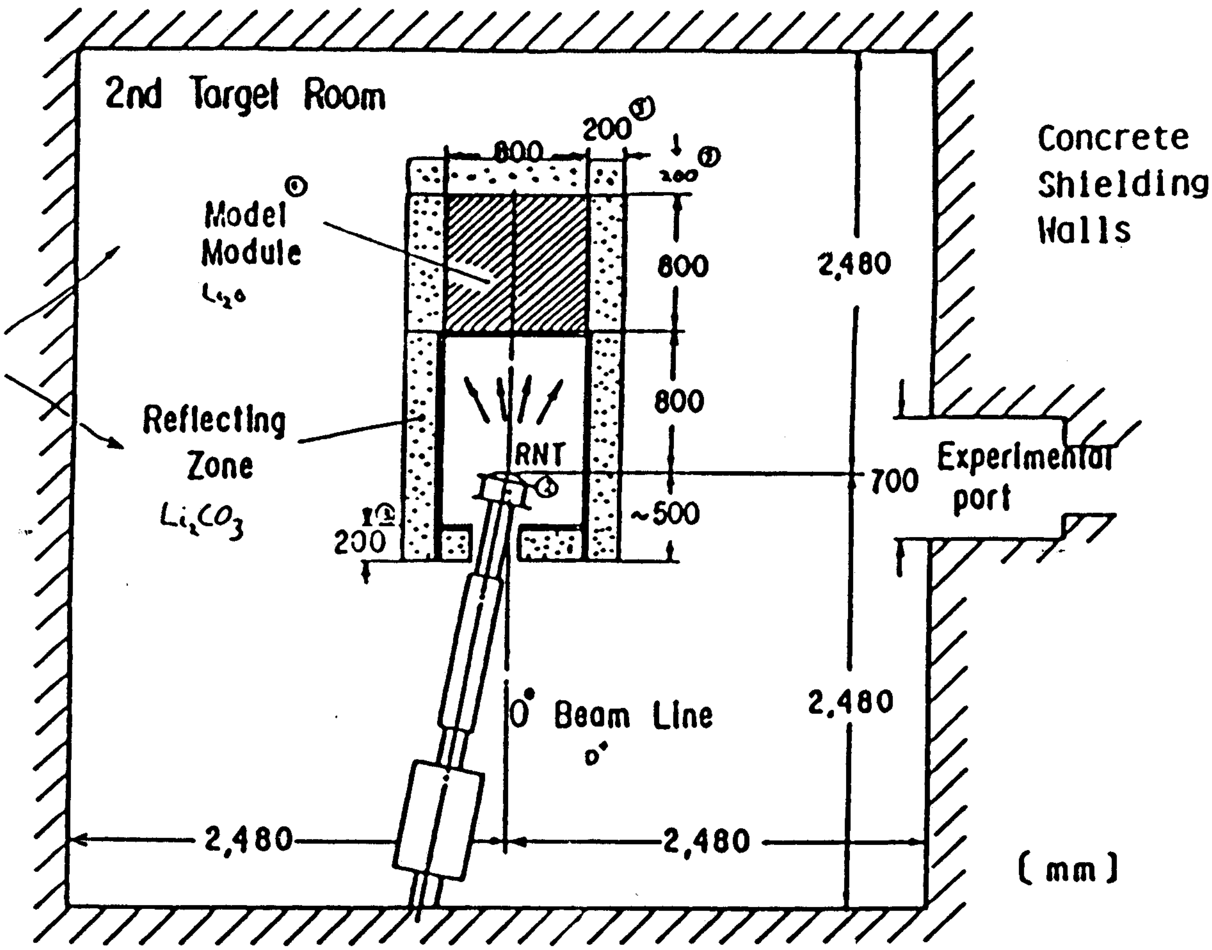
- Almost all activities are part of international agreements

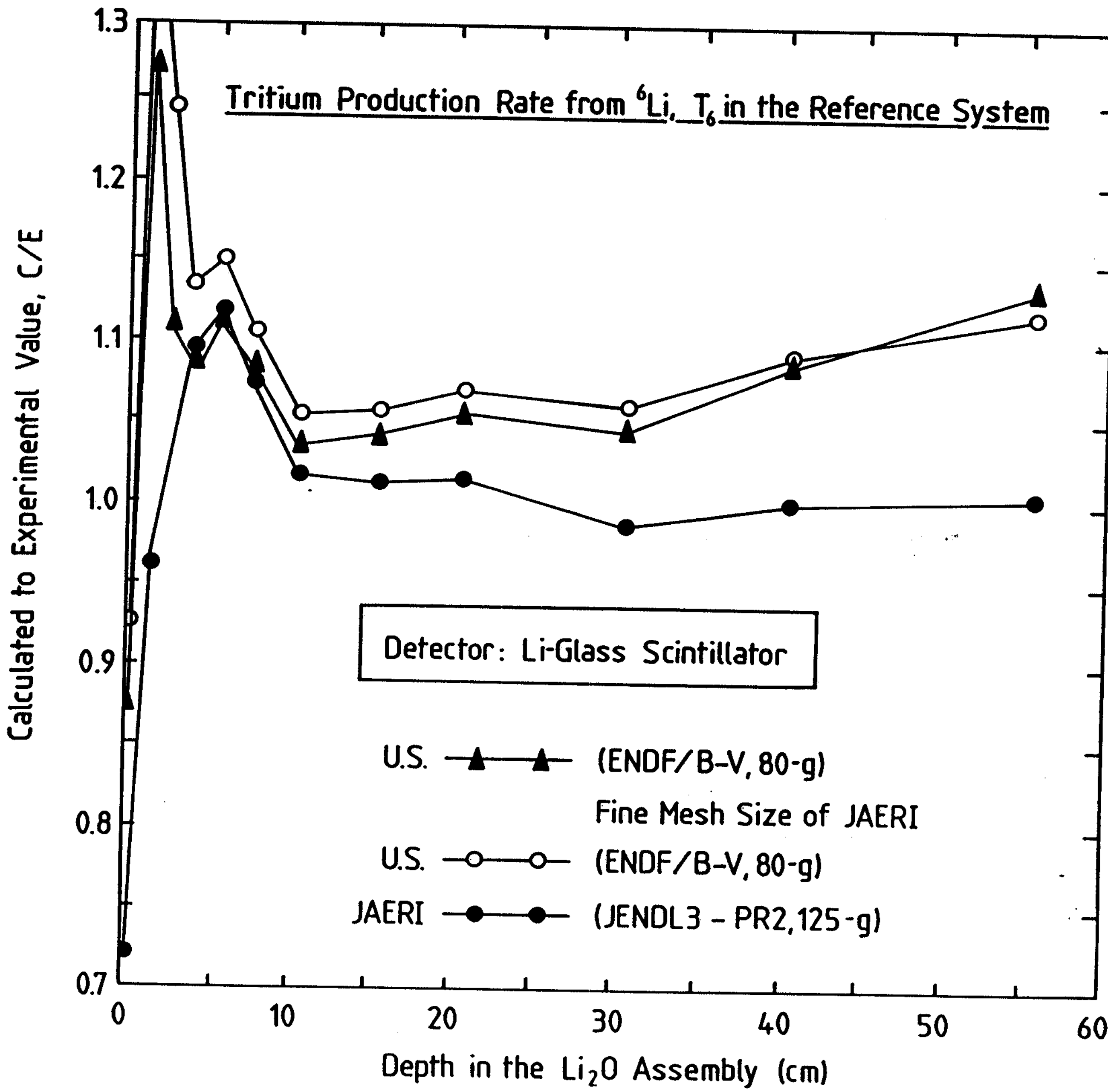
- US—Japan cooperation
  —Facility: FNS at JAERI, Japan (14 MeV neutron source, neutronics mockup facility)
  —US organizations: UCLA, ANL, ORNL
  —Focus: Tritium breeding, nuclear heating with
  —candidate materials and representative configurations

- LBM at LOTUS
  —Test module constructed by GA
  —Neutronics experiments at LOTUS in Switzerland

- Activities on data and method improvements

A CANDIDATE FOR BETTER GEOMETRY EXPERIMENT IN PHASE 2




Tritium Production Rate from ^{6}Li, T_6 in the Reference System
Detector: Li-Glass Scintillator
U.S. (ENDF/B-V, 80-g)
Fine Mesh Size of JAERI
U.S. (ENDF/B-V, 80-g)
JAERI (JENDL3 - PR2, 125-g)
Calculated to Experimental Value, C/E
Depth in the Li_2O Assembly (cm)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0
10
20
30
40
50
60

THE OBJECTIVES OF TSTA ARE

1. DEMONSTRATE THE FUEL CYCLE FOR FUSION POWER REACTORS;
2. DEVELOP AND TEST ENVIRONMENTAL AND PERSONNEL PROTECTIVE SYSTEMS;
3. DEVELOP, TEST, AND QUALIFY EQUIPMENT FOR TRITIUM SERVICE IN THE FUSION ENERGY PROGRAM;
4. PROVIDE A FACILITY THAT CAN BE USED FOR DEMONSTRATION AND THAT CAN BE COPIED FOR ETR/INTOR;
5. DEMONSTRATE LONG-TERM RELIABILITY OF COMPONENTS AND SAFE HANDLING OF TRITIUM;
6. INVESTIGATE SYSTEM RESPONSE TO OFF-NORMAL AND EMERGENCY OPERATIONS.


ENVIRONMENTAL AND PERSONNEL PROTECTION SYSTEMS
THE TRITIUM SYSTEMS TEST ASSEMBLY WILL DEVELOP AND EVALUATE TRITIUM TECHNOLOGY FOR THE MAGNETIC FUSION ENERGY PROGRAM
HYDROGEN ISOTOPE SEPARATION SYSTEM CRYOGENIC DISTILLATION
TSTA
COMPUTER CONTROL AND DATA ACQUISITION
Los Alamos

TSTA

HIGHLIGHTS OF JAN. 86 RUNS

* INCREASED TRITIUM INVENTORY TO 30g
* INTEGRATED FUEL CLEANUP SYSTEM INTO LOOP
* OPERATED INTEGRATED LOOP – (NO IMPURITIES ADDED)
* DEMONSTRATED EASY STARTUP/RAPID AND SAFE SHUTDOWN
* DEMONSTRATED MAINTENANCE AND COMPONENT CHANGE–OUT TECHNIQUES
* CONFIRMED OPERATION OF URANIUM STORAGE BEDS

FUSION BREEDER (HYBRID) ACTIVITIES

- National Research Council* Study on Fusion Hybrid Reactors, Chrm. John Simpson, report due Sept. 1986

  1. What are future energy circumstances in which the hybrid might offer significant advantages?
  2. What is the status and what are the prospects of technology in the United States and elsewhere relevant to hybrids?
  3. What is the range of technical options for the hybrid application of fusion energy, and what are the economic and environmental risks and benefits of these options?
  4. What is a reasonable timetable for development and deployment of the hybrid?
  5. If the hybrid application appears to have merit in future U.S. energy circumstances, how might it best be approached?

- As the predicted cost of fusion plants drop from twice an LWR's cost, the calculated equivalent price of uranium from the fusion breeder drops from $100/pound. A fusion plant costing 1.5 times and LWR is calculated to produce fuel at an equivalent price of $50/pound.

* The National Research Council is the principle operating agency of the National Academy of Sciences and the National Academy of Engineering.

A FUSION APPLICATION STUDY HAS BEEN INITIATED

Objectives:

- Review applications and assess the size of each market and the requirements for market penetration

First Output:

- Fall 1986

Identified Applications:

- Electricity
- Fissile fuel for fission reactors
- Material for nuclear weapons
- Hydrogen or other chemicals
- Process heat
- Radioisotopes
- Radiation processing of materials, e.g., food sterilization
- Medical diagnostics and treatment
- Space power and propulsion
- Transmutation or "burning" of nuclear or chemical wastes

SYSTEMS STUDIES

- A SELECTION OF A REFERENCE CONCEPT FOR A COMPACT IGNITION TOKAMAK HAS BEEN MADE. THE RECOMMENDED DESIGN INCORPORATES $B_0 \simeq 10 - 11$ T, $I_P \sim 10$ MA, $R_0 \sim 1.2$ M AND BOTH A LIMITER AND DIVERTOR OPTION. A CONSTRUCTION PROPOSAL WILL BE SUBMITTED IN MAY. (PPPL + NATIONAL TEAM)

- A CONCEPTUAL DESIGN OF A SUPERCONDUCTING LONG BURN FUSION DEVICE WITH NUCLEAR TESTING CAPABILITY (TIBER) HAS BEEN DEVELOPED. (LLNL)

- A NEW, COMPREHENSIVE RFP REACTOR STUDY HAS BEEN INITIATED. (UCLA)

- ADVANCED TOKAMAK POWER REACTOR STUDIES ARE CONTINUING. SEVERAL INNOVATIONS HAVE BEEN IDENTIFIED THAT WOULD LEAD TO MORE ATTRACTIVE REACTORS. (ANL)

- INNOVATION STUDIES HAVE BEEN COMPLETED FOR INTOR. (GIT)