U.S. Perspective on Blanket Technology Development

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OUTLINE

- Design Options
- Issues
- Types of Experiments and Facilities
- EXISTING Experiments and Facilities
- PROPOSED Experiments and Facilities

INTRODUCTORY REMARKS

- U.S. blanket program planning has focused on developing the data base and prediction capability to design, construct and operate EXPERIMENTAL TEST MODULES for testing in a fusion facility
  - Begin fusion testing by about the year 2000 (appears consistent with most recent ETR-type schedule)
- U.S. has not developed plans for full blankets to supply ETR with its own tritium
  - Such topic can be discussed if necessary
  - Special technical/cost/risk problems
- Experimental test modules in a fusion facility (by about the year 2000 or sooner) appear to be an area of strong COMMON INTEREST to all countries

INTRODUCTORY REMARKS (contd.)

- An international workshop on fusion nuclear technology was held (at UCLA) in March 1985. The findings of the workshop participants concerning international cooperation were very positive. (Proceedings Available)

- The larger part of present R&D needs for nuclear technology relates to critical issues and fundamental data. This part is not greatly sensitive to likely variations in fusion development strategy.

  Work on this part of "critical issues and fundamental data":

  - Needs to be started now
  - Appears to represent areas of strong common interest to all countries.

INTRODUCTORY REMARKS (contd.)

- Blanket testing in non-fusion facilities:
  - Most of the needs for solid breeder blankets are for experiments in fission reactors.
  - Most of the needs for liquid metal blankets are for non-neutron test facilities.

- Key features of experiment/facility needs:

  Relatively large number of relatively small-scale (modest-cost) experiments and facilities.
  - Discussions (cooperation) need to consider more than one or two experiments.
  - Upgrade of existing facilities, albeit important, is <u>not</u> the key item. Need to discuss new facilities.
  - These features should actually facilitate international cooperation.

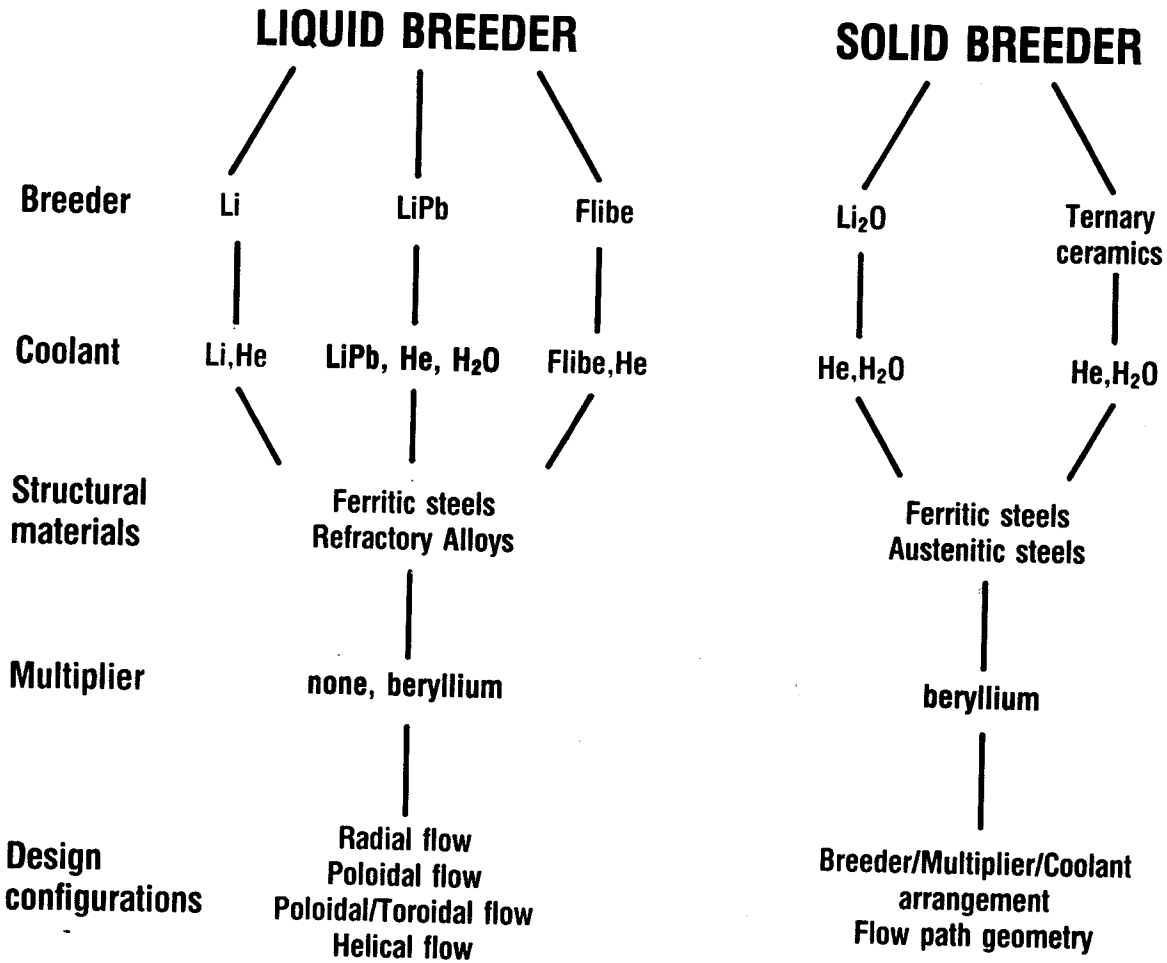
- Much work needs to be done on theory, modelling and analysis
  - Beneficial to include in cooperation

INTRODUCTORY REMARKS (contd.)

- This presentation:
  - Aimed at the big picture
  - Classes of issues, facilities
  - Larger and broader tasks

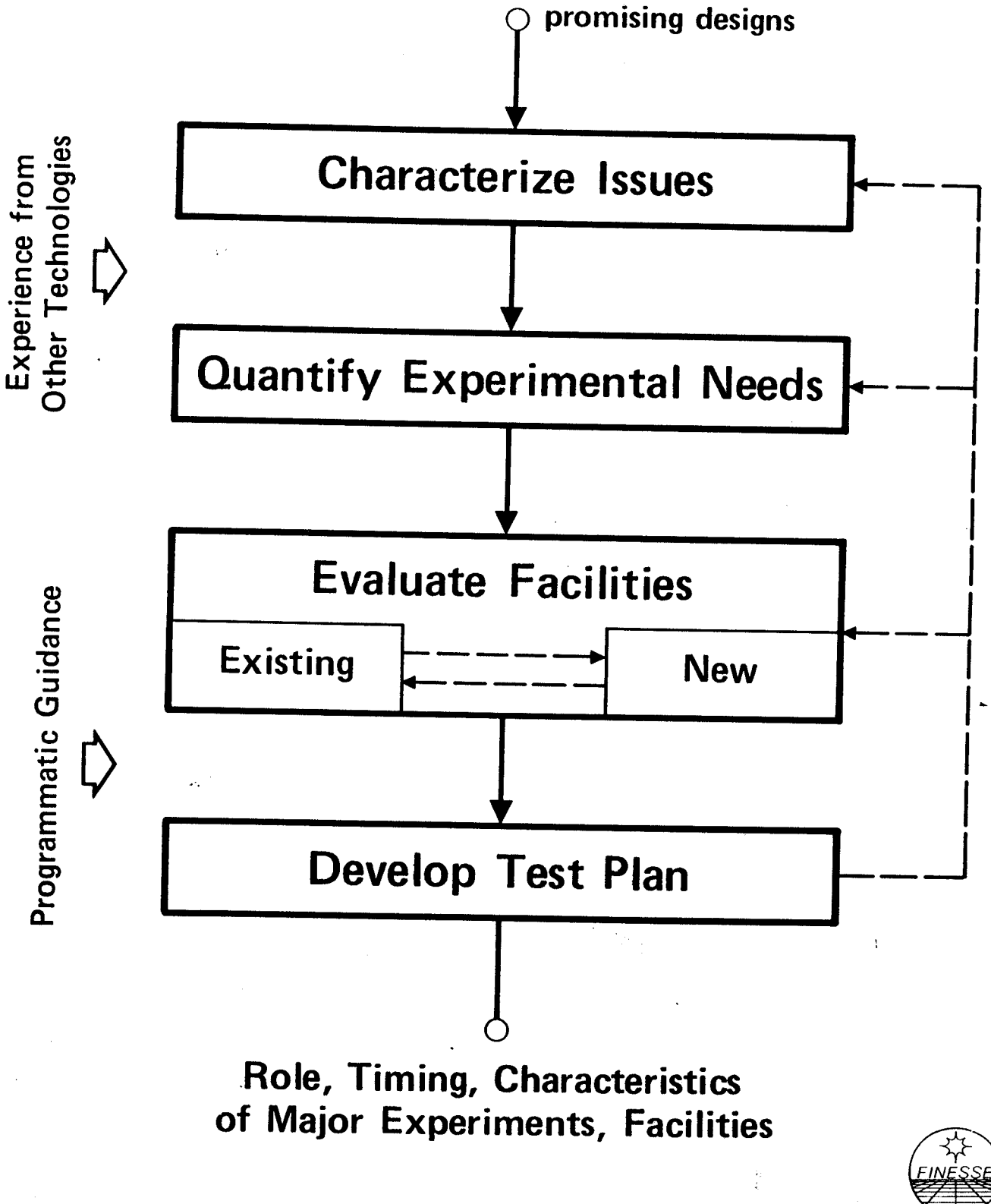
- Details are given in the FINESSE Report (December 1985) Volumes I and II

Primary Options
For Blanket Materials and Configurations



—Further experimental work is required prior to selection.

FINESSE PROCESS For Experiment Planning

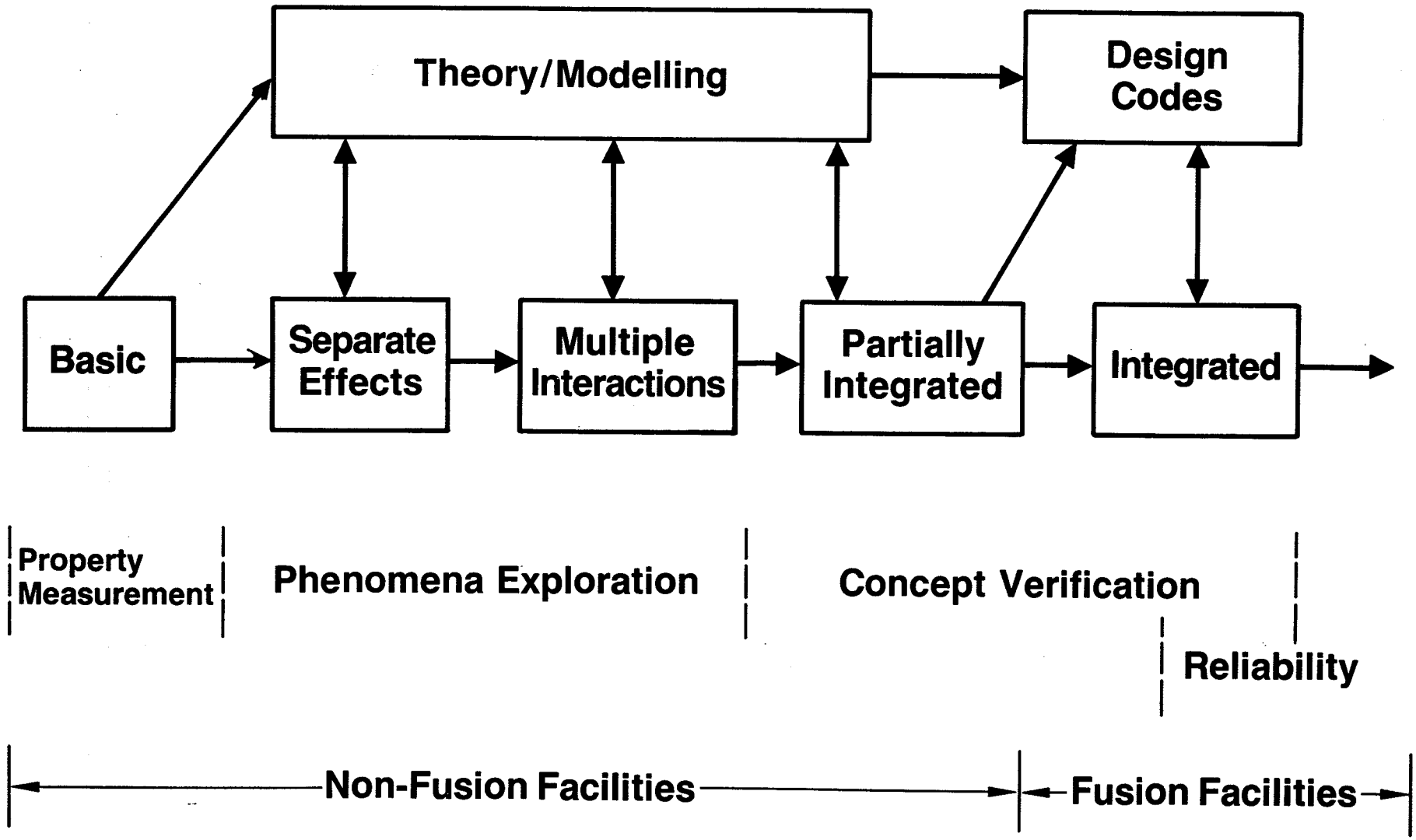


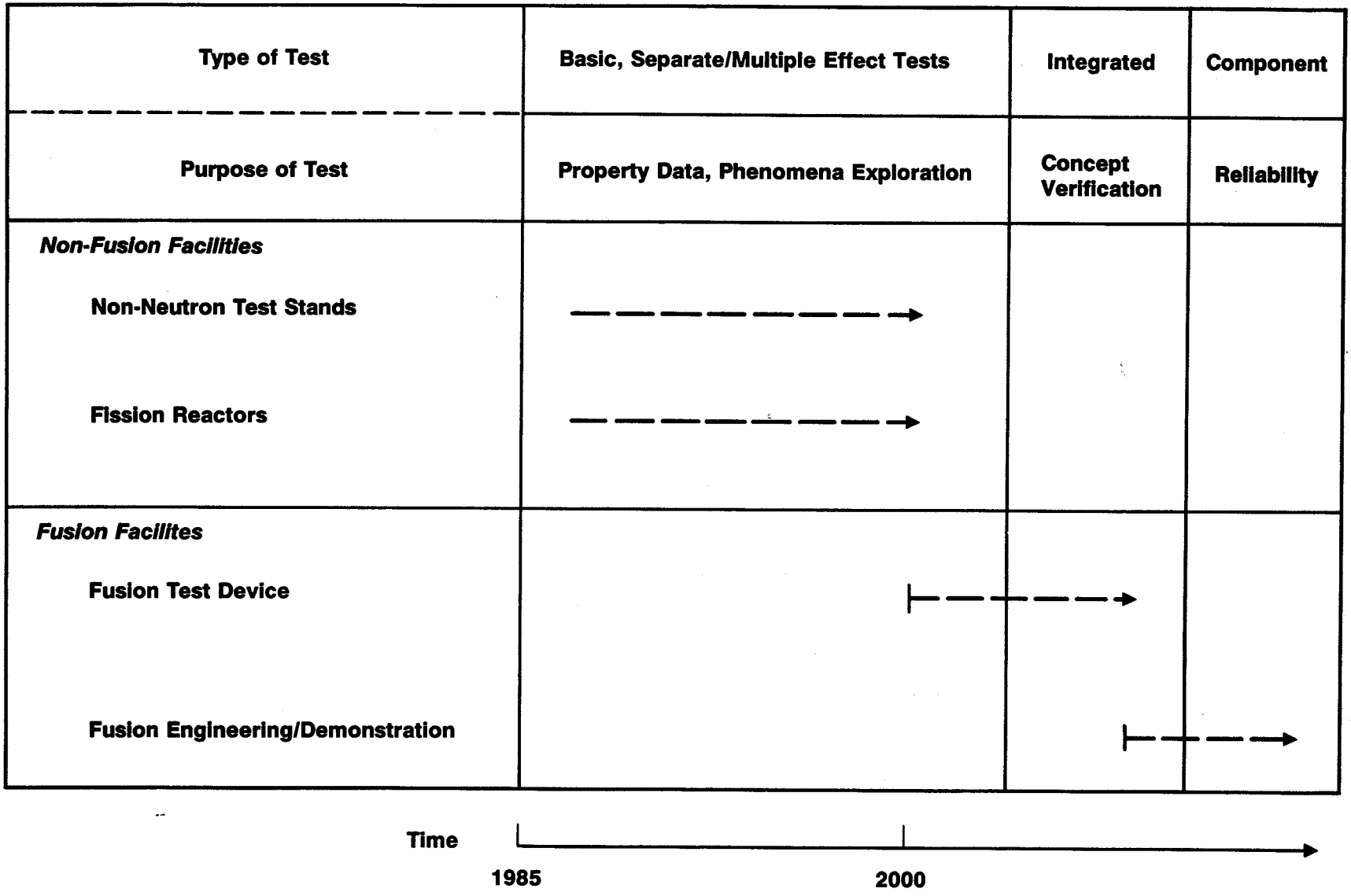
Generic Liquid Metal Blanket Issues

- Tritium Self-sufficency
- Magnetohydrodynamic (MHD) Effects
  —Fluid Flow (including pressure drop)
  —Heat Transfer
- Material Interactions (e.g., Corrosion)
- Structural Response in the Fusion Environment
  —Irradiation Effects on Material Properties
  —Response to Complex Loading Conditions
  —Failure Modes
- Tritium Recovery and Control

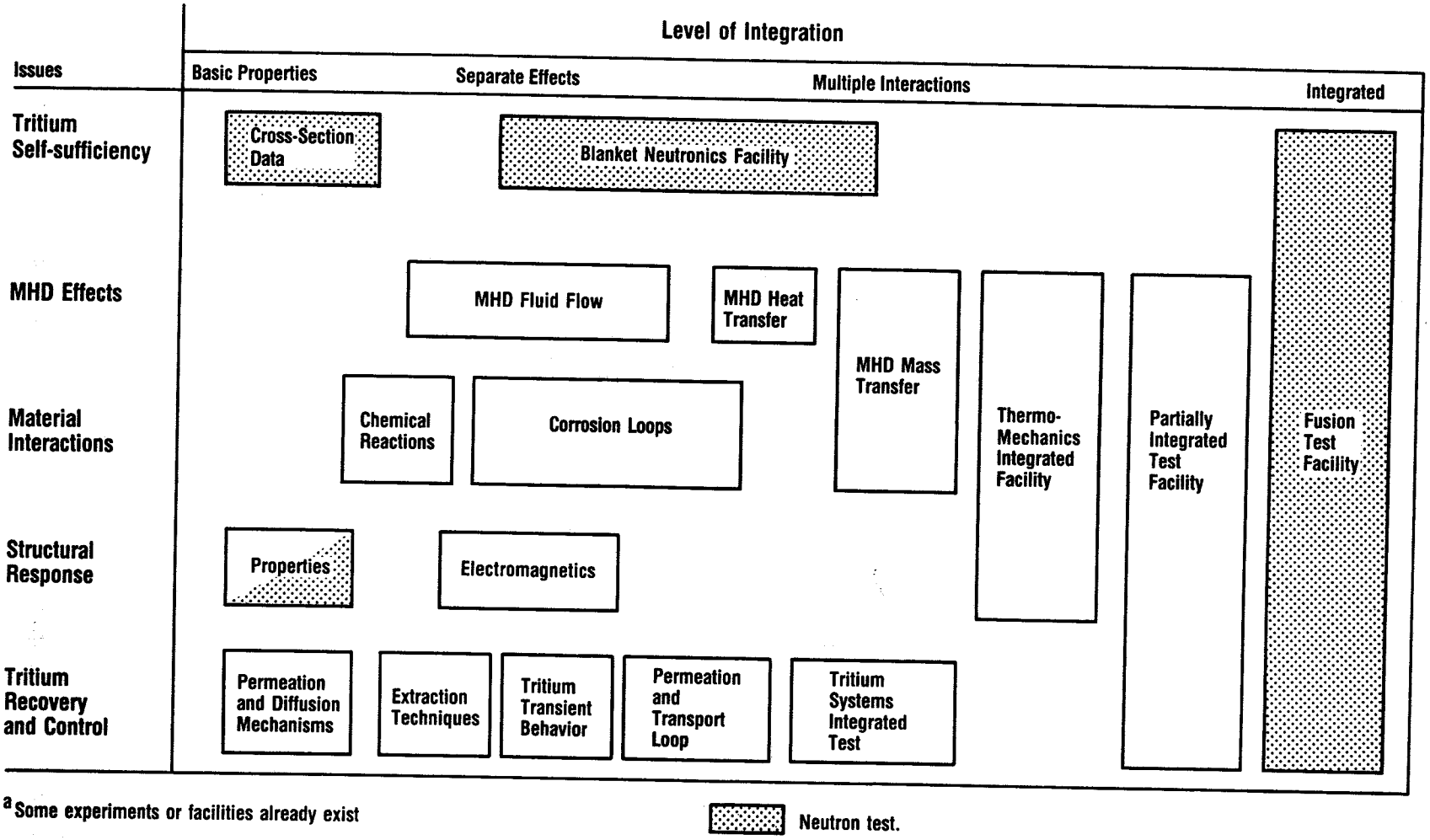
Generic Solid Breeder Blanket Issues

- Tritium Self-sufficiency
  —Achievable Breeding Ratio
  —Required Breeding Ratio
- Breeder/multiplier Tritium Inventory and Recovery
- Breeder/multiplier Thermomechanical Behavior
- Corrosion and Mass Transfer
- Structural Response and Failure Modes in Fusion Environment
- Tritium Permeation and Processing from Blanket


Theory/Modelling
Design Codes
Basic
Separate Effects
Multiple Interactions
Partially Integrated
Integrated
Property Measurement
Phenomena Exploration
Concept Verification
Reliability
Non-Fusion Facilities
Fusion Facilities


Type of Test
Basic, Separate/Multiple Effect Tests
Integrated
Component
Purpose of Test
Property Data, Phenomena Exploration
Concept Verification
Reliability
Non-Fusion Facilities
Non-Neutron Test Stands
Fission Reactors
Fusion Facilites
Fusion Test Device
Fusion Engineering/Demonstration
Time
1985
2000

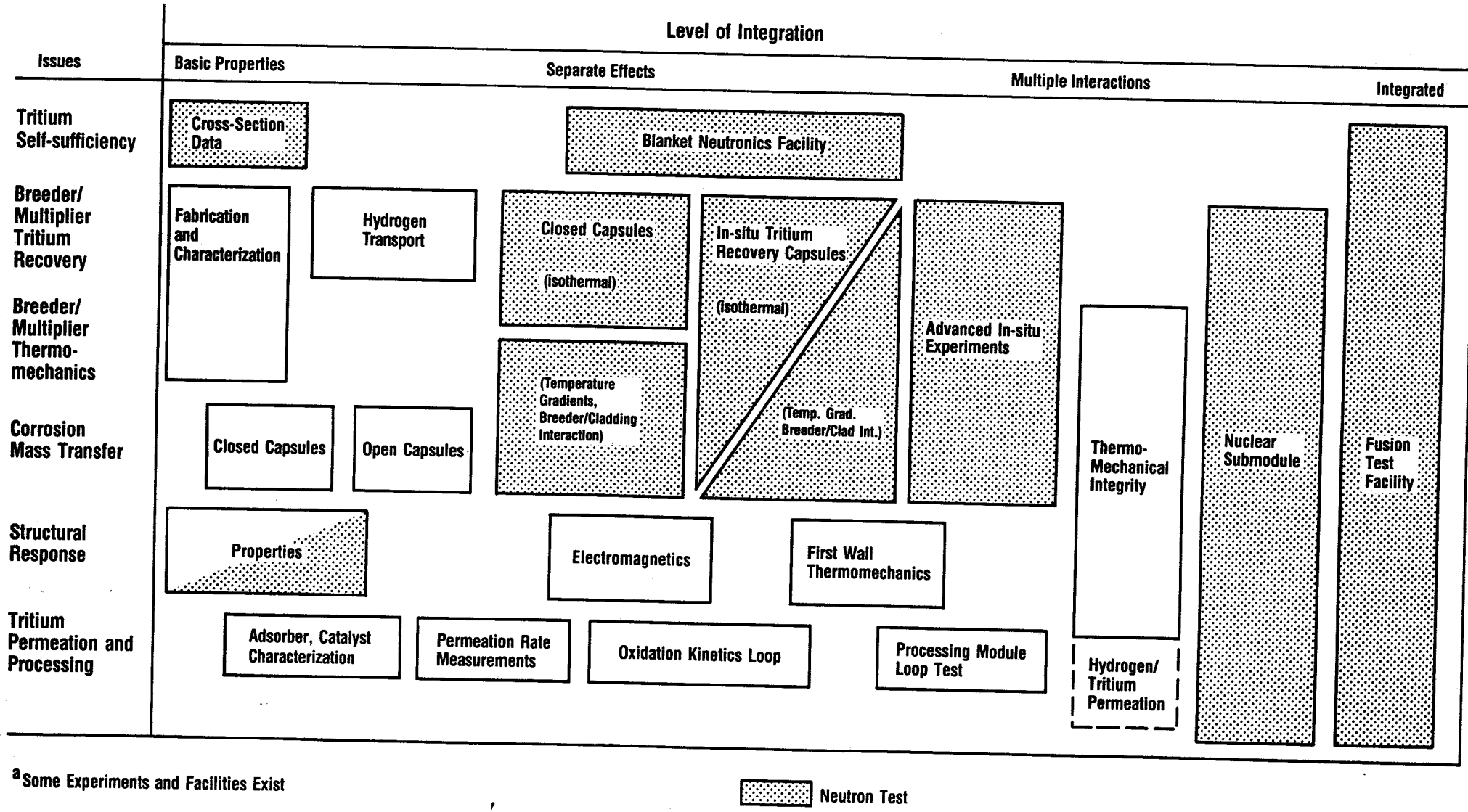
TYPES OF EXPERIMENTS AND FACILITIES FOR LIQUID METAL BLANKETS[a]



[a] Some experiments or facilities already exist

Neutron test.

TYPES OF EXPERIMENTS AND FACILITIES FOR SOLID BREEDER BLANKETS[a]



[a] Some Experiments and Facilities Exist

Neutron Test

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)

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)
Electromag-netics	FELIX	1.0T(SS), 0.5T(ramp) 5ms, 1m^3	transient tests

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

Major Tasks for Liquid Breeder Blankets

- MHD Effects
  —Momentum and Heat Transfer Facilities (LMF1, LMF2)
  —Instrumentation Development
  —Insulator Development

- Material Compatibility
  —Corrosion Loops
  —MHD Mass Transfer Facility (MHDM)

- Tritium Recovery and Control
  —Tritium Extraction Tests
  —Tritium Transport Loop

- Tritium Breeding

- Structural Response and Failure Modes

- Thermomechanics Integration Facility (TMIF)

- Partially Integrated Test Facility (PITF)

- Analysis and Model Development

Features and Objectives of Major Liquid Breeder Experiments

	ALEX	Magnetic Transport Phenomena Facilities		TMIF	PITF
		LMF	MHDM		
Features of Experiments	• Simple Geometry of a channel • NaK	• Basic elements of relevant geometry	• Basic elements of relevant geometry • Relevant material combinations • Transport loop • Relevant T, ΔT, impurities, V • Long operating time per experiment	• Actual materials and geometry • Transport loop • Relevant environmental and operating conditions	• Prototypic blanket module • Transport loop • Prototypic environmental and operating conditions
	• Measure velocity profile, electric potential, pressure drop	• Measure V and T profiles; pressure drop, temperature, electric potential	• Measure dissolution and deposition rates	• Measure integral quantities (ΔP, T, corrosion and deposition rates)	• Measure integral quantities
Objectives	• Develop and test velocity profile instrumentation in NaK environment • Validate MHD in simple geometry (basic heat transfer data may be possible in upgrade	• Develop and test instrumentation • Validate MHD heat transfer • Design data (ΔP, T) for configuration screening • Explore techniques to reduce ΔP and enhance heat transfer	• Develop and test instrumentation in relevant environment • Design data on MHD heat and mass transfer • Verify techniques to reduce corrosion and corrosion effects	• Design data for blanket test module • Confirm and refine configurations	• Engineering design data • Reliability data in non-fusion environment

Table 8. Characteristics of Major Liquid Breeder Experiments

Characteristic	ALEX[a]	Magnetic Transport Phenomena Facilities		TMIF[d]	PITF[e]
		LMF[b]	MHDM[c]		
Fluid	NaK (100°C)	NaK	actual materials	actual materials	actual materials
Testing volume (m x m x m)	1.83 x 0.76 x 0.15 (0.21 m^3)	3 x 1 x 0.5 (1.5 m^3)		3 x 1 x 0.5	3 x 1 x 0.5
Magnetic Field	2 T	4-6 T		4-6 T	4-6 T
Configuration	simple geometry	elements of complex geometry		submodule	prototypic

[a]Exists (ANL)

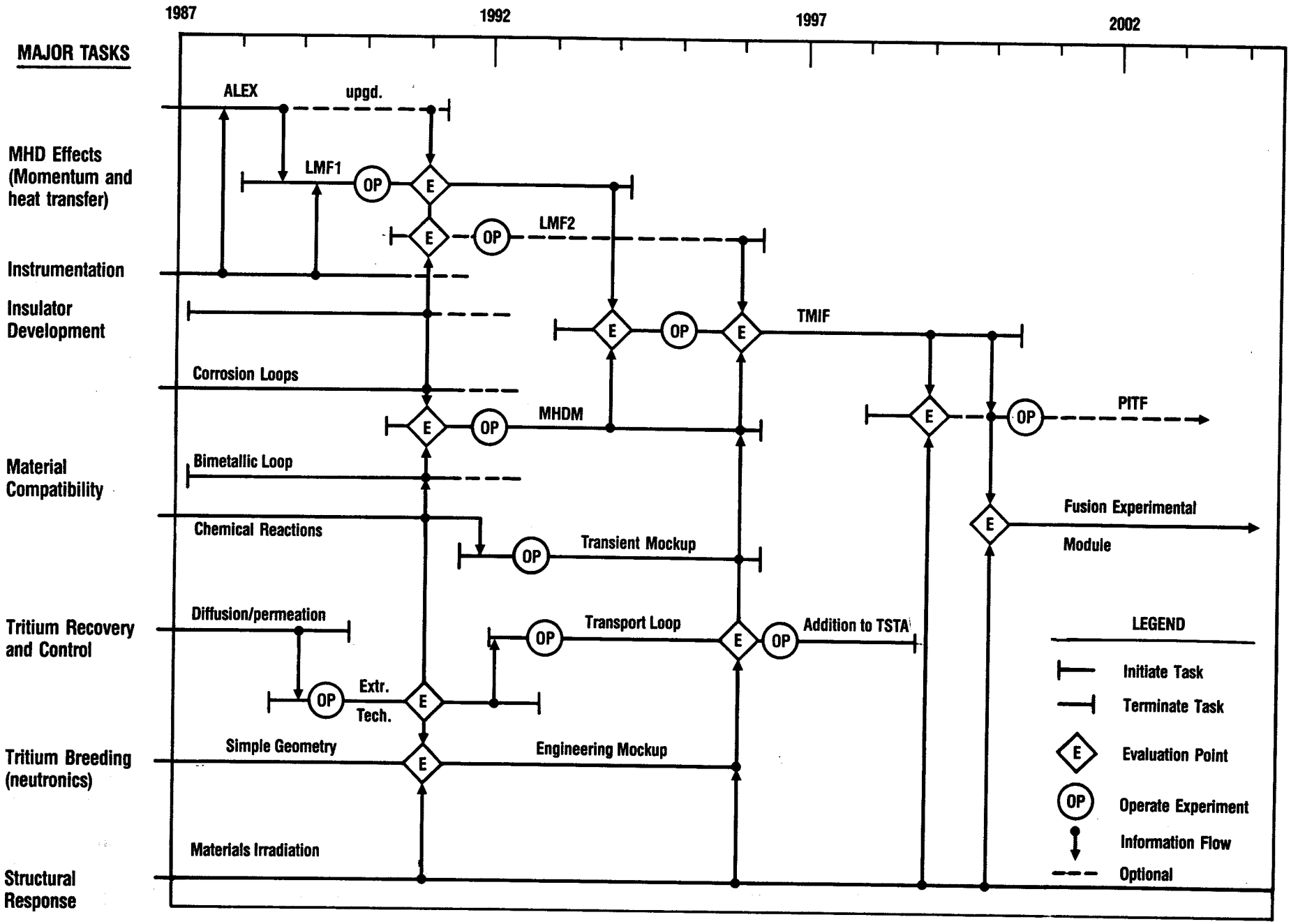
[b]Liquid Metal Flow Facility

[c]MHD Mass Transfer Facility

[d]ThermoMechanical Integration Facility

[e]Partially Integrated Test Facility

LIQUID BREEDER BLANKET TEST PLAN



Major Tasks for Solid Breeder Blankets

- Solid breeder material development and characterization
  - —Tritium retention and release
  - —Thermophysical and thermomechanical properties
  - —Fabrication and recycling techniques.

- Multiplier material development and characterization
  - —Swelling in beryllium
  - —Tritium retention and release.
  - —Irradiation creep and mechanical properties

- Blanket thermal behavior
  - —Corrosion, mass transfer and chemical interaction kinetics
  - —Breeder/multiplier temperature profile and thermomechanical effects of breeder/cladding interaction
  - —Non-neutron blanket (sub)module thermomechanical integrity

- Neutronics and tritium breeding
  - —Simple geometry mockups
  - —Engineering mockups

- Advanced in-situ tritium recovery
  - —Two or more instrumented and purged assemblies with multiple capsules

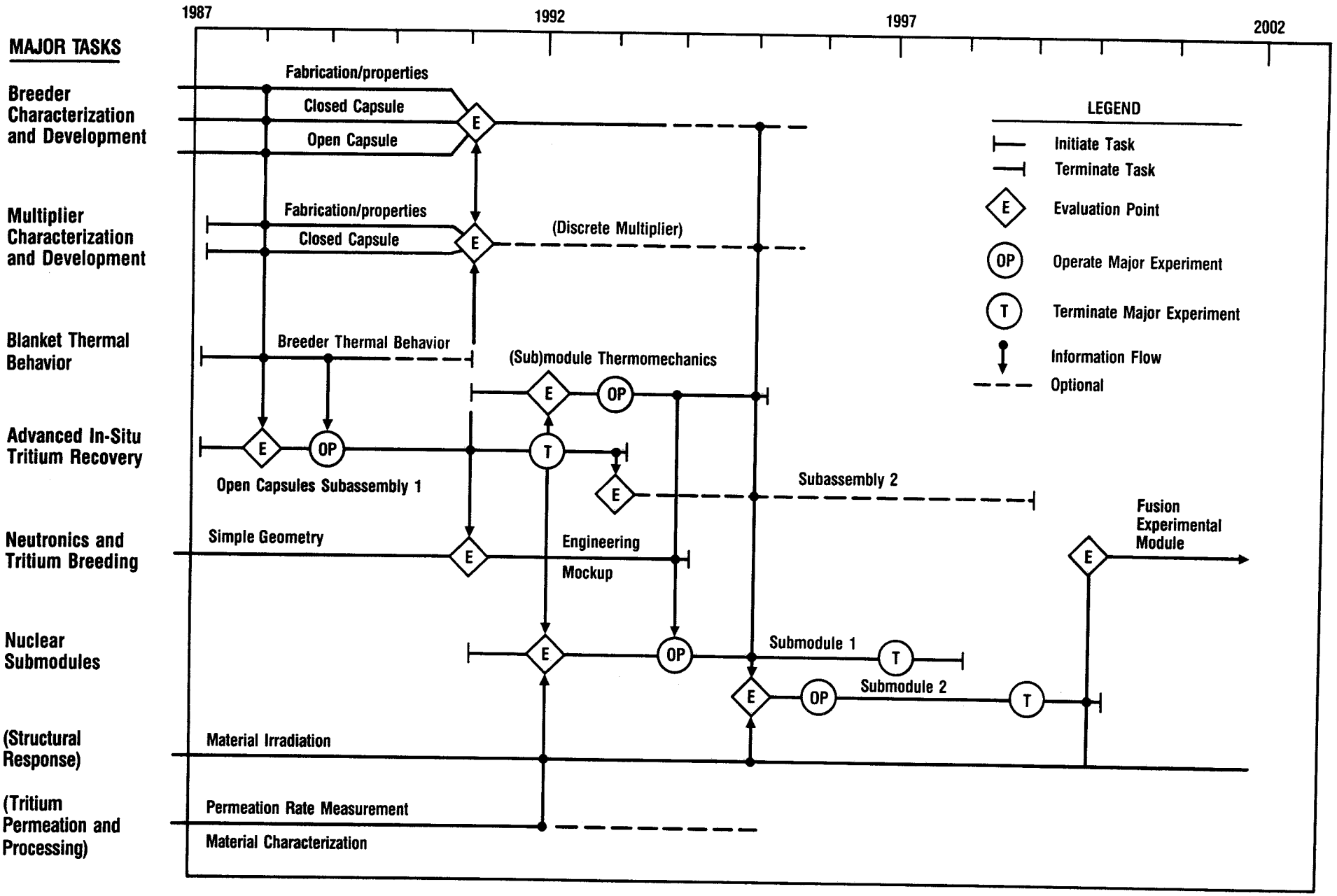
- Nuclear submodule experiments
  - —Two or more nuclear submodule assemblies

Table 2-7. Parameters for Major Integrated Non-fusion Irradiation Experiments

	Advanced In-situ Tritium Recovery	Nuclear Submodule
Test geometry	Subassembly with multiple capsules	Blanket breeder section or unit cell
Material	Multiple	One per submodule
Temperature, °C	350-1200°C	Reactor blanket profile
Temperature gradients, °C/cm	100-1000	100-1000
Breeder thickness, cm	0.5-5	0.5-5
Purge gas	Helium, plus O_2, H_2 and/or H_2O	Helium, plus O_2, H_2 and/or H_2O
Purge flow rate, $m^3/s\text{-}g^a$	0.01-0.1	0.01-0.1
Burnup, at.% Li	3-10	3-10
Heat generation, MW/m^3	30-100	30-100
Irradiation time, yrs	1-3	1-3
Tritium production, T/Li-yr	0.01-0.5	0.01-0.5

[a]Normalized per gram of solid breeder material

SOLID BREEDER BLANKET TEST PLAN



Representative Costs of Key Liquid Breeder Blanket Facilities[a]

Item	Capital Cost (M$)	Operating Cost (M$/yr)	Duration (years)	Total Cost (M$)
Advanced liquid metal flow facility (LMF1)	7-10	0.5	4-6	10-15
Integral Parameter Experiment (LMF2)	7-10	0.5	4-6	10-15
MHD mass transfer facility (MHDM)	8-12	1.0	6-8	15-20
Corrosion Loops	6-10	1.6	8-12	12-20
Tritium extraction test (2)	2-3	0.4	3-4	3-5
Tritium transport loop test	6-8	0.6	5-7	9-12
Partially Integrated Test Facility (PITF)	estimate not available			
Thermomechanical Integrated Test Facility (TMIF)	20-25	2.0-3.0	8-10	35-60
Analysis and model development	0	2.0-4.0	15	30-60

[a]In 1985 constant dollars

Representative Costs of Major Solid Breeder Tasks[a]

Task	Capital cost (M$)	Operating cost (M$/yr)	Duration (years)	Total cost (M$)
Solid Breeder Characterization and Development (Fabrication, properties, closed/open capsule irradiations)	5-7	5-8	5	30-50
Multiplier Characterization and Development (Fabrication, properties, closed capsule irradiations)	1-2	1-2	5	6-12
Blanket Thermal Behavior				
A. Breeder thermal behavior	0.8-1.5	0.8-1.5	3-5	3-8
B. Non-neutron (sub)module thermomechanics	3-8	0.8	4	5-10
Neutronics and Tritium Breeding				
A. Simple geometry	3-6	0.8-1.5	5	7-14
B. Engineering mockup	4-7	0.8-1.5	3	6-12
Advanced In-Situ Recovery (Two sequential subassemblies with multiple open capsules)	3-5 each	0.8 each	6 each	12-16
Nuclear submodules (Two parallel submodules)	5-7 each	1-1.5 each	7 each	20-30
Analysis and Model Development	0	2-3	15	30-45

[a]1985 constant dollars (neutron charges not included)