Blanket Issues and Near Term R&D Needs and the Role of ITER in Blanket Development

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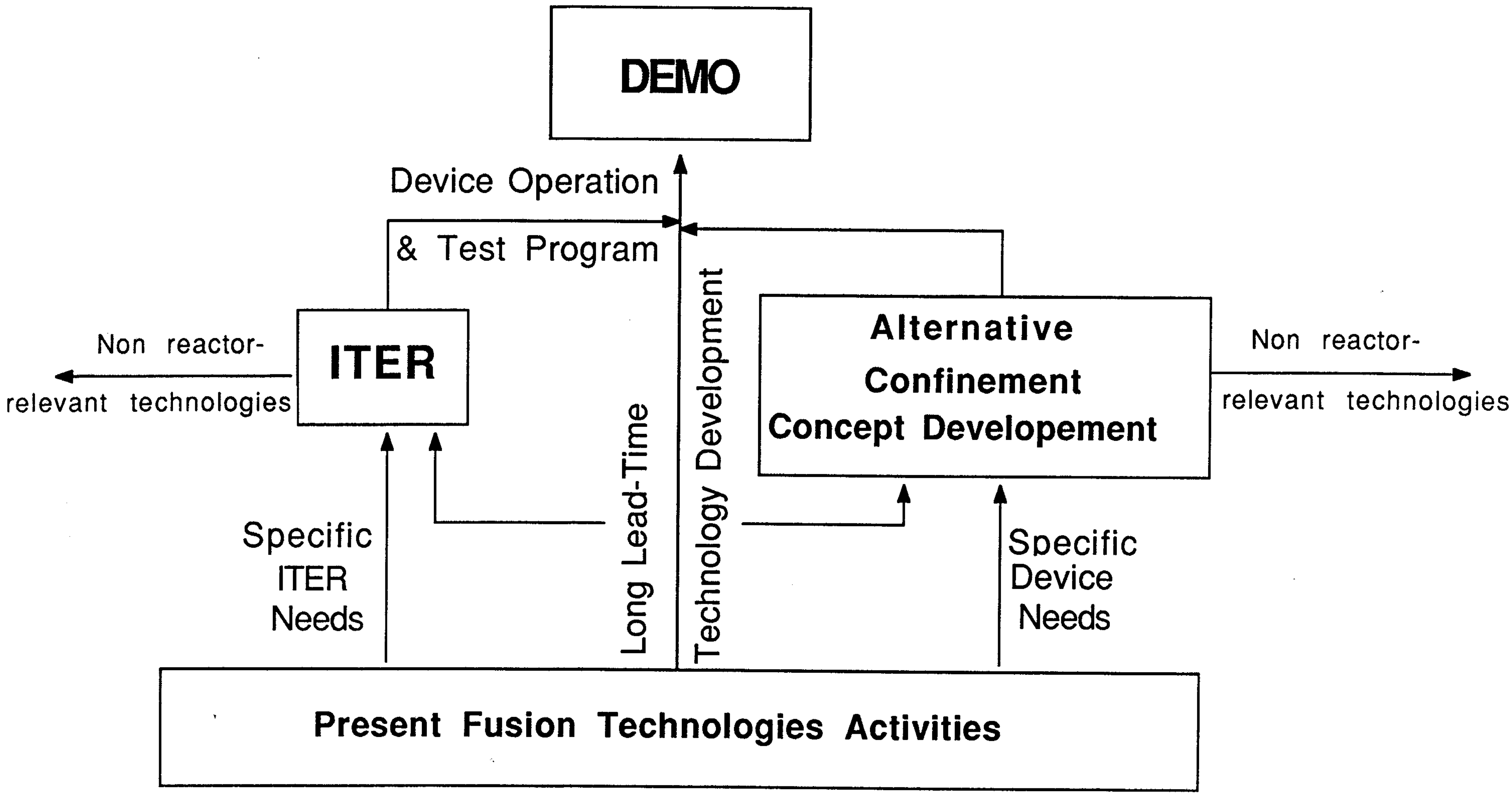
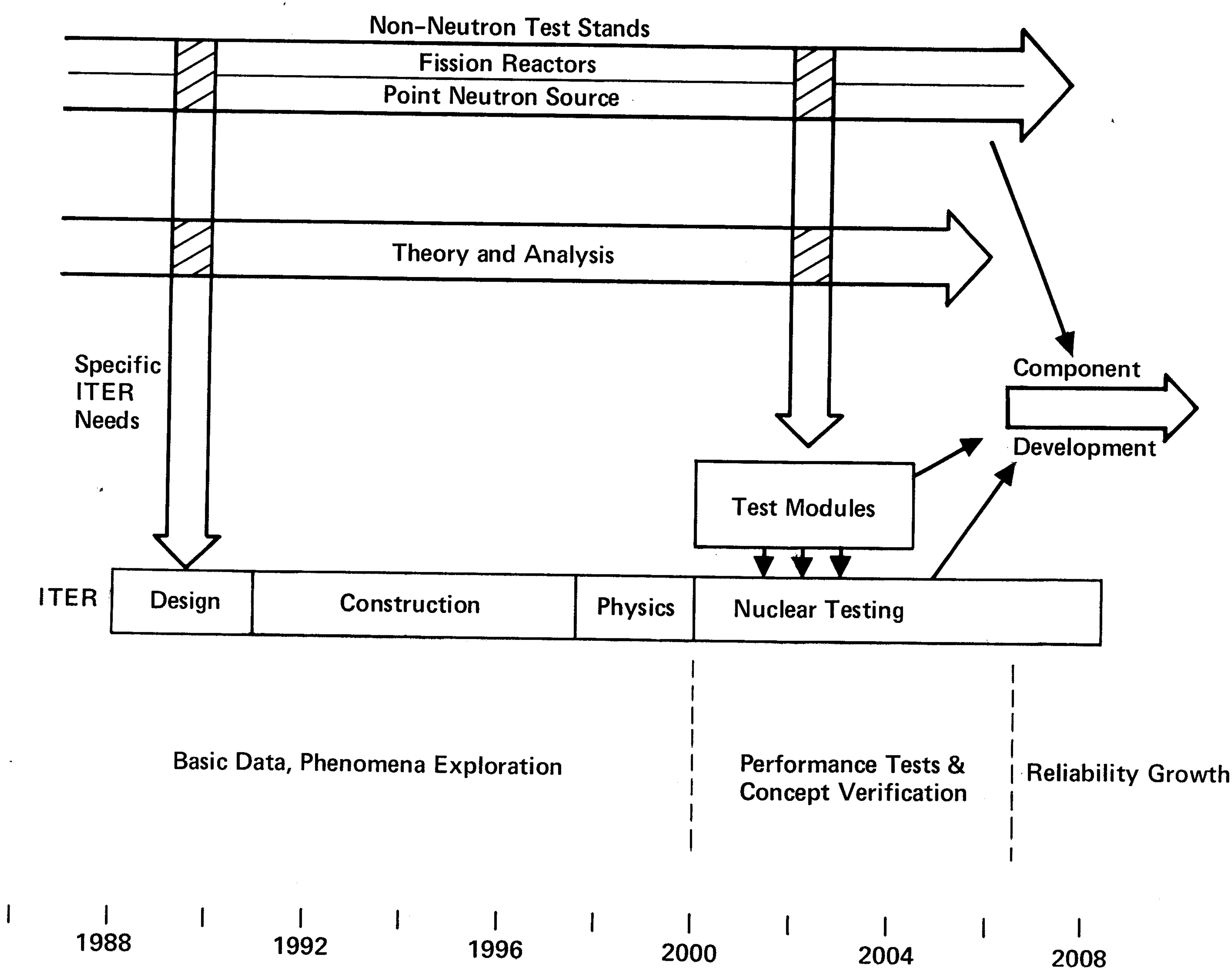
Presentation Outline

- General Framework for Blanket Development
- Issues for Commercial Blankets
- ITER Blanket Concepts, Issues
- Blanket Testing in ITER
- R&D Needs for Next 15 Years
- R&D Needs for Next 3 Years

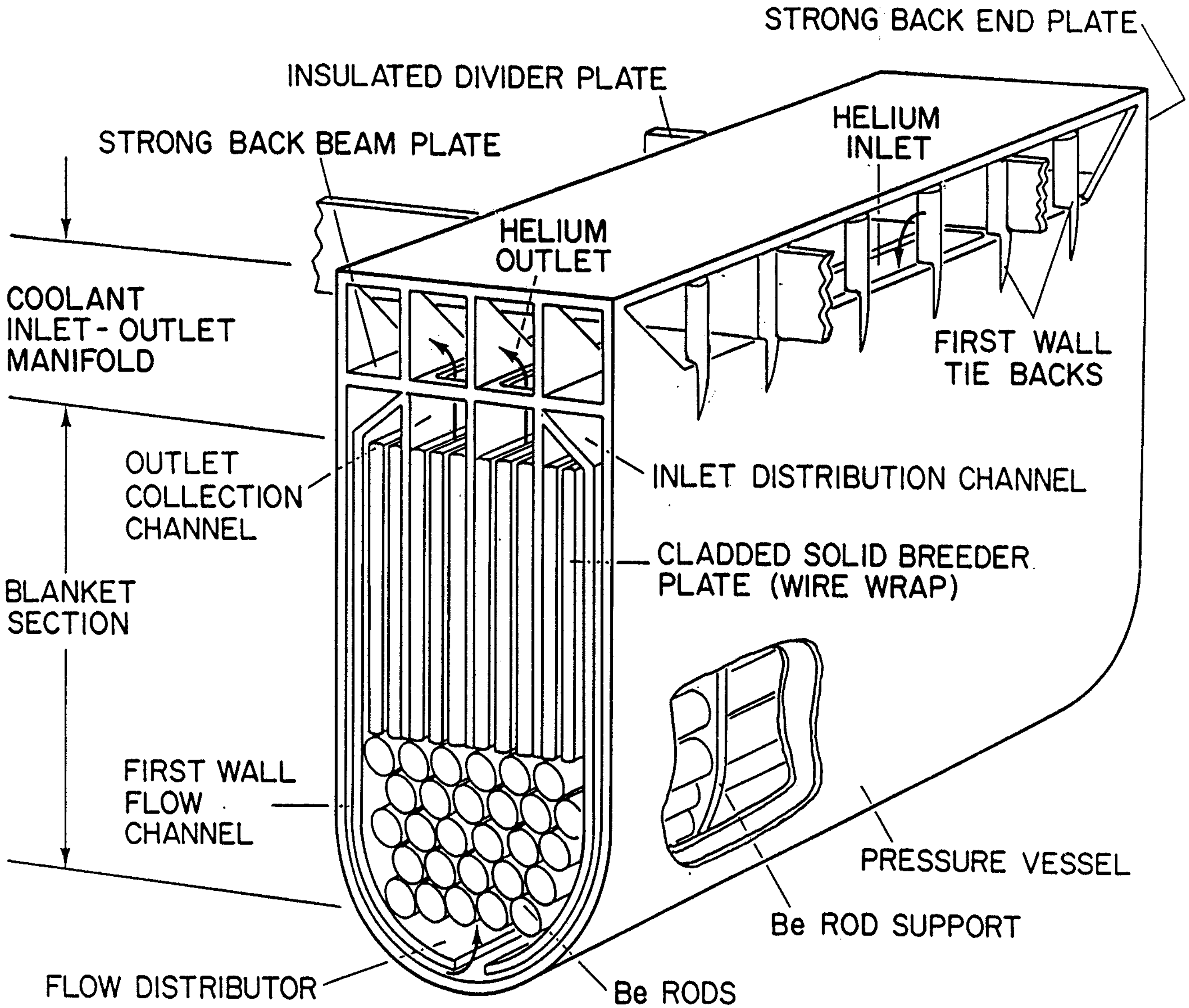

DEMO
Device Operation
& Test Program
ITER
Non reactor-
relevant technologies
Alternative
Confinement
Concept Developement
Non reactor-
relevant technologies
Long Lead-Time
Technology Development
Specific
ITER
Needs
Specific
Device
Needs
Present Fusion Technologies Activities

Framework For Fusion Nuclear Technology Development



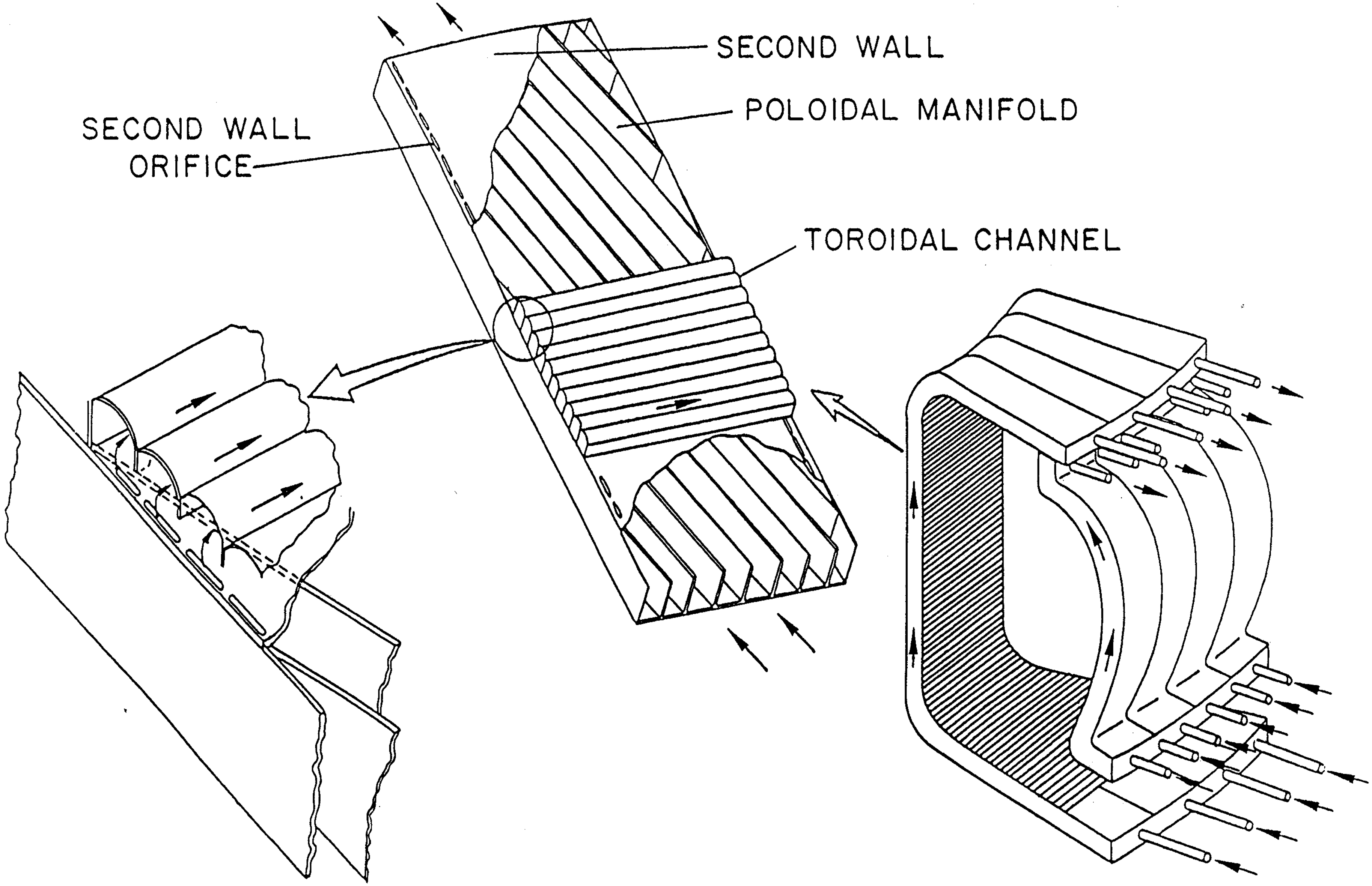
Primary Options
For Blanket Materials and Configurations
For Commercial Reactors

	LIQUID BREEDER			SOLID BREEDER	
Breeder	Li	LiPb	Flibe	Li_2O	Ternary ceramics
Coolant	Li, He	LiPb, He, H_2O	Flibe, He	He, H_2O	He, H_2O
Structural materials		Ferritic steels Refractory alloys		Ferritic steels Austenitic steels	
Multiplier		none, beryllium		beryllium	
Design configurations		Radial flow Poloidal flow Poloidal/toroidal flow Helical flow		Pin, Plate, Block Breeder/Multiplier Sintered Pellet or Sphere-pac Radial, Poloidal, or Toroidal Cooling	



Helium-Cooled Solid Breeder Blanket Design

Li/Li/V BLANKET



Specific Blanket Issues

- Key Issues were evaluated and documented in terms of:
  - Issues description
  - Status of data base
  - Required data
  - Required resources

  The issues have not changed and have not been resolved.
  PACE of World Blanket R&D Programs is Very Slow

- The most important *structural material* R&D issues are *welding/fabrication* and *radiation induced embrittlement* concerns for both ferritic steels and vanadium alloys. *Chemical reactivity of vanadium* is also an important issue.

- Major issues for *liquid metal blankets* include *MHD* and *corrosion* concerns. MHD research should include the testing of insulators. Lithium (and to some extent LiPb) *chemical reactivity* is a key issue. Development of *non-water cooled near-plasma components* will be necessary, particularly for blankets that contain lithium.

- *Tritium recovery/control* is a *major* issue for all designs except those using liquid lithium as a breeder and coolant. The form of the released tritium (T_2/HT or T_2O/HTO) and the chemical form of tritium in various fluid streams are important issues for tritium control for solid breeders.

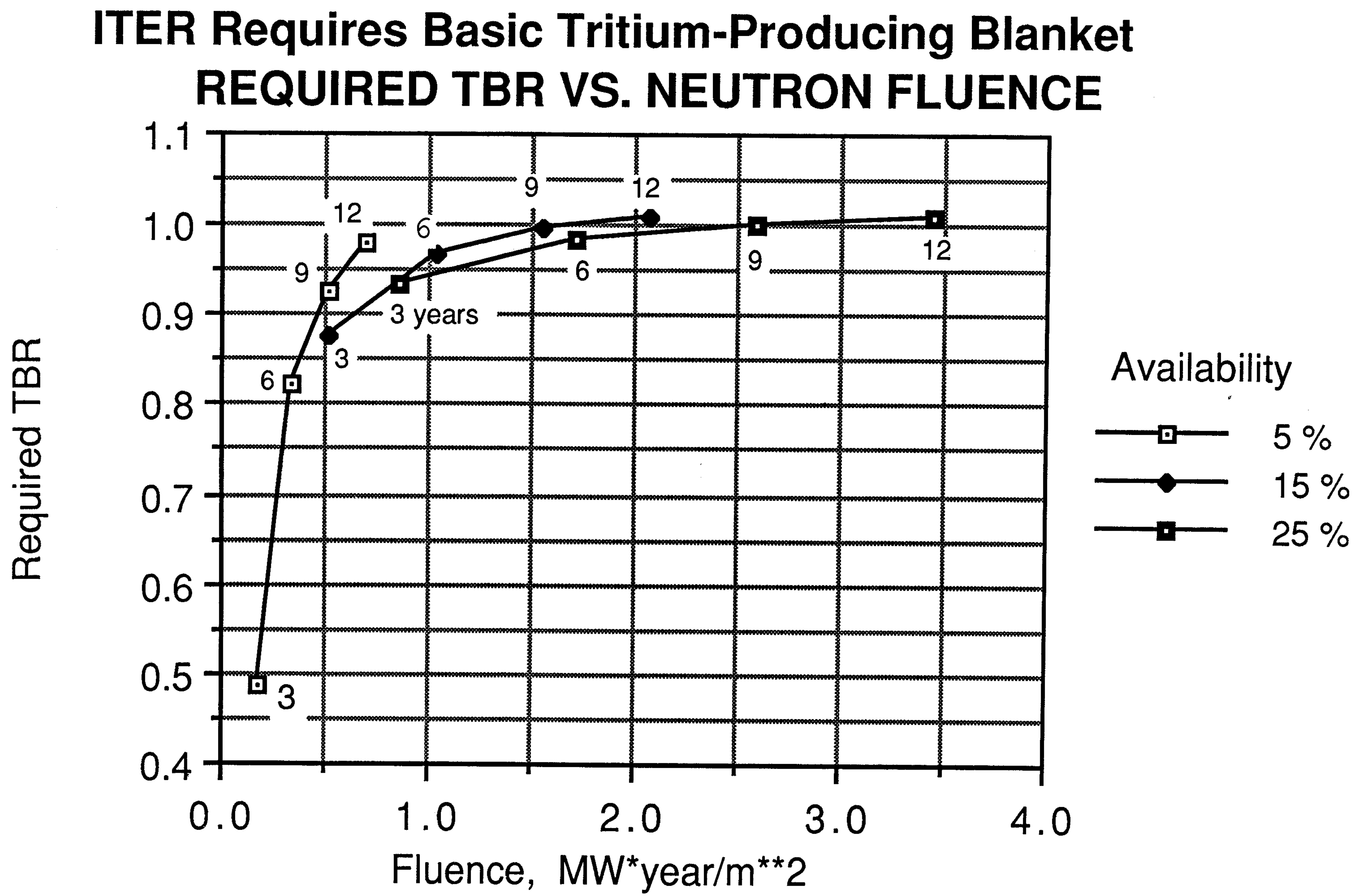
Specific Blanket Issues (cont'd.)

- Achieving adequate *tritium breeding* is a *key* issue for many designs. In general, it is more severe for solid compared to liquid breeders.

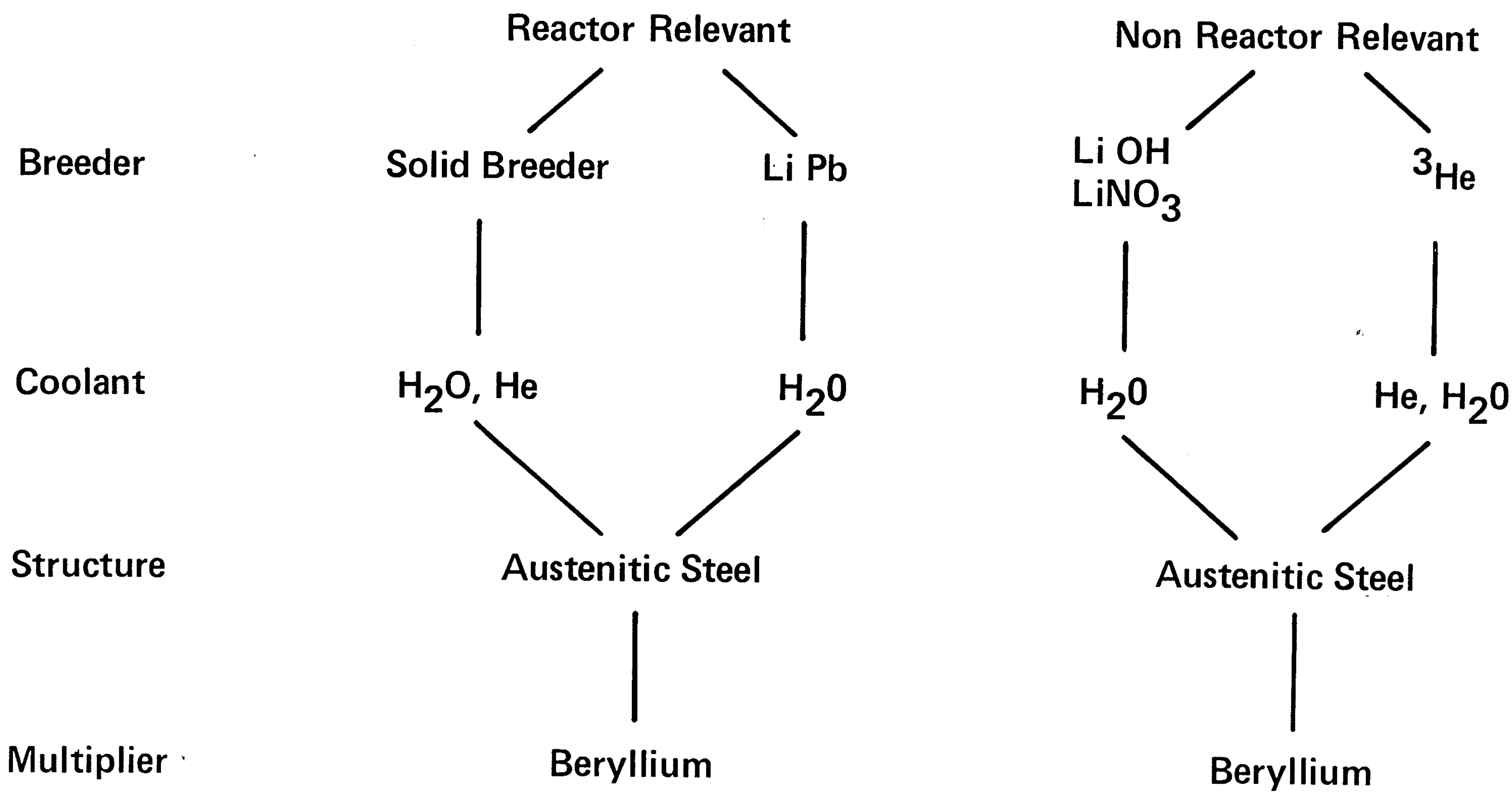
- The key issues for *solid breeders* (in addition to those discussed above) include the *temperature limits* for tritium release, *heat transfer control* between the lithium ceramic and coolant, difficulty of handling *power variations* and the *radiation induced swelling* of the ceramic (particularly Li_2O). Initial fabrication of sphere-pac breeder and beryllium and refabrication (recycling) of all forms by remote handling techniques are also areas of concern.

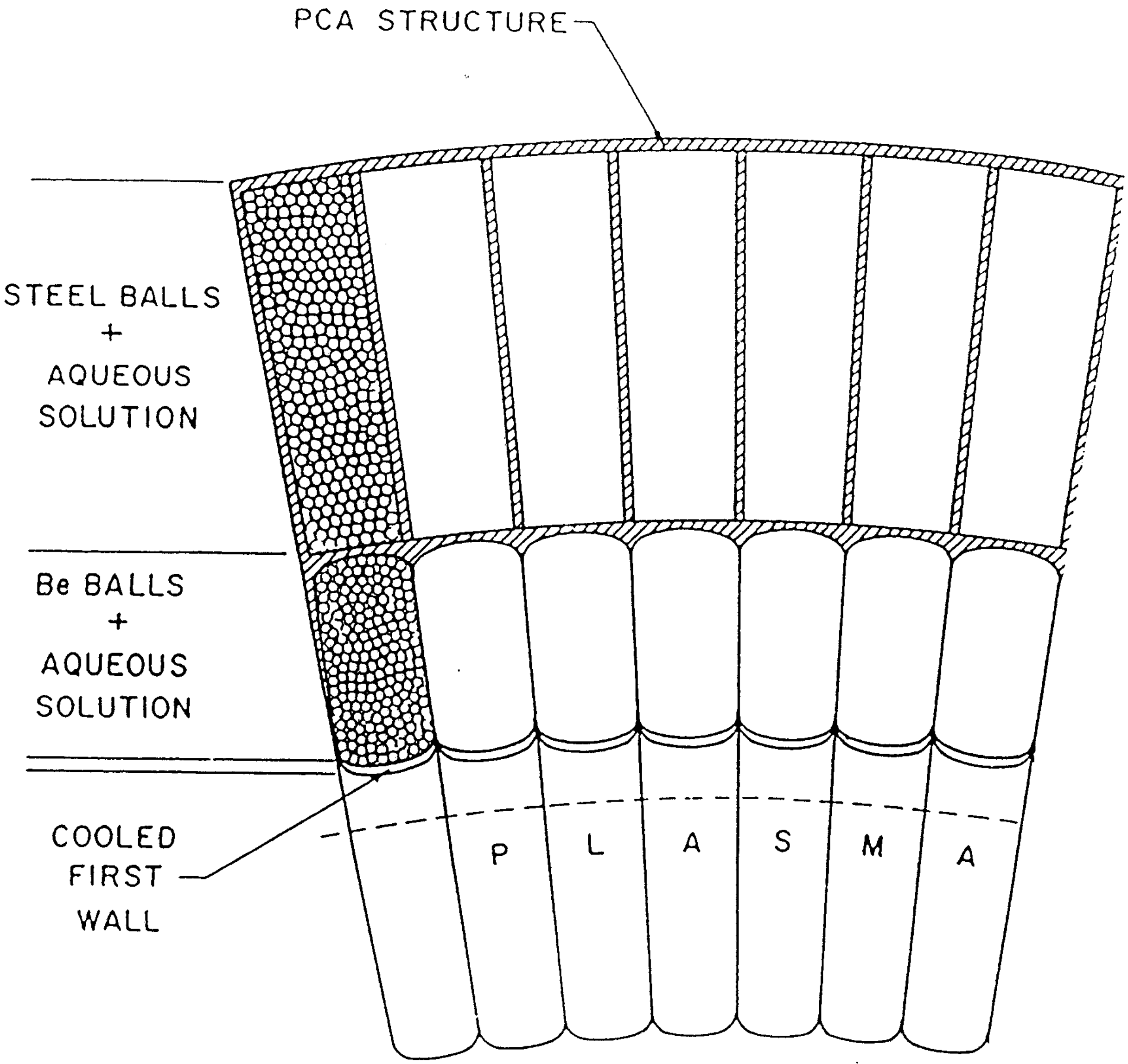
- The most important concern related to *first wall issues* is the verification of the capability of a *stress relief structure* (orthogonally grooved first wall) to simultaneously handle heat and particle fluxes.

- Additional items include: thermal, chemical and radiation stability of molten salts; Be reprocessing efficiency; Be chemical interaction with molten salts; activation of LiPb and molten salts; and electromagnetic effects such as large pressures and torques due to plasma disruptions.

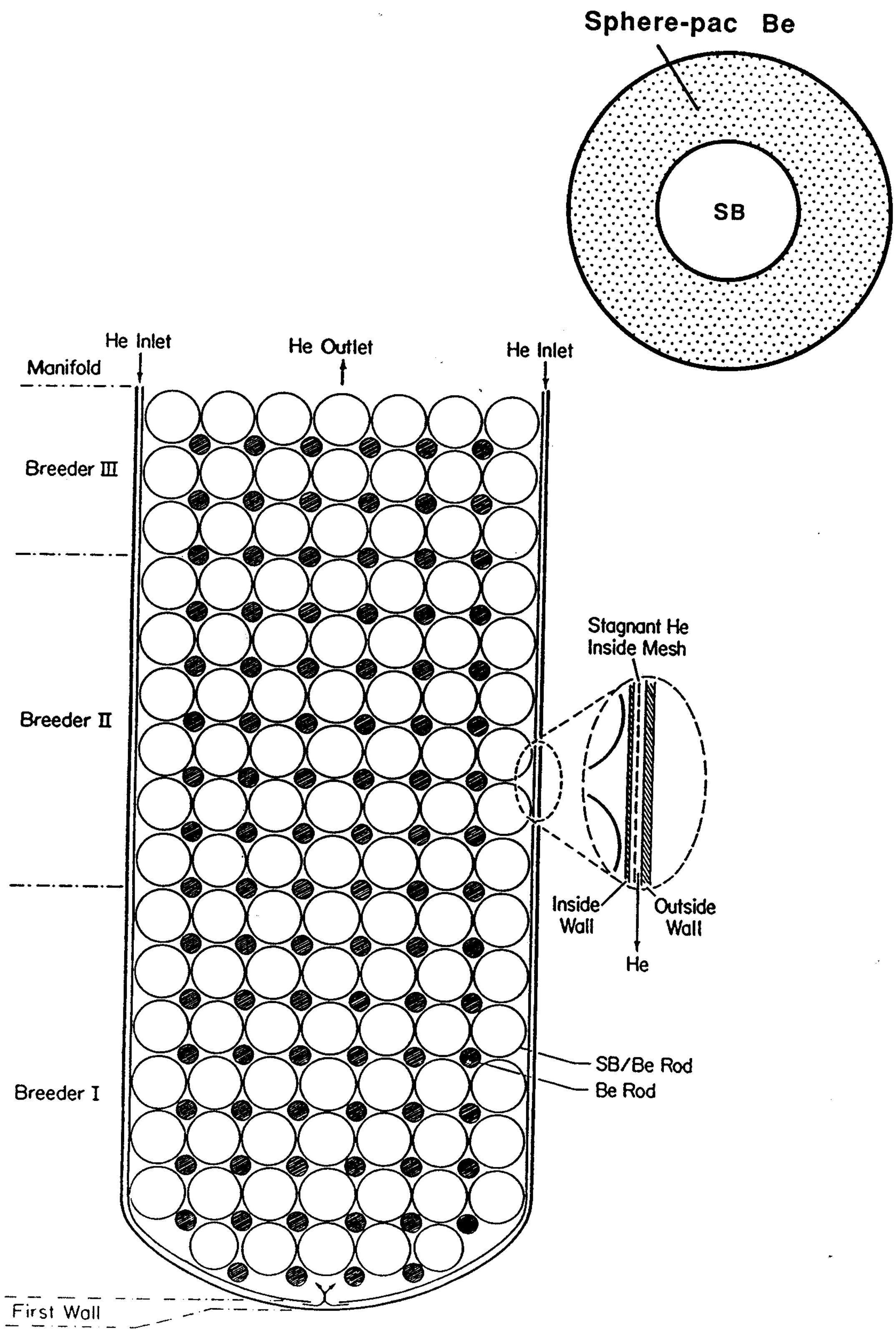

ITER Requires Basic Tritium-Producing Blanket
REQUIRED TBR VS. NEUTRON FLUENCE
Required TBR
Fluence, MW*year/m**2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.0
1.0
2.0
3.0
4.0
3 years
3
6
9
12
Availability
5 %
15 %
25 %

Blanket Material Options Considered For ITER

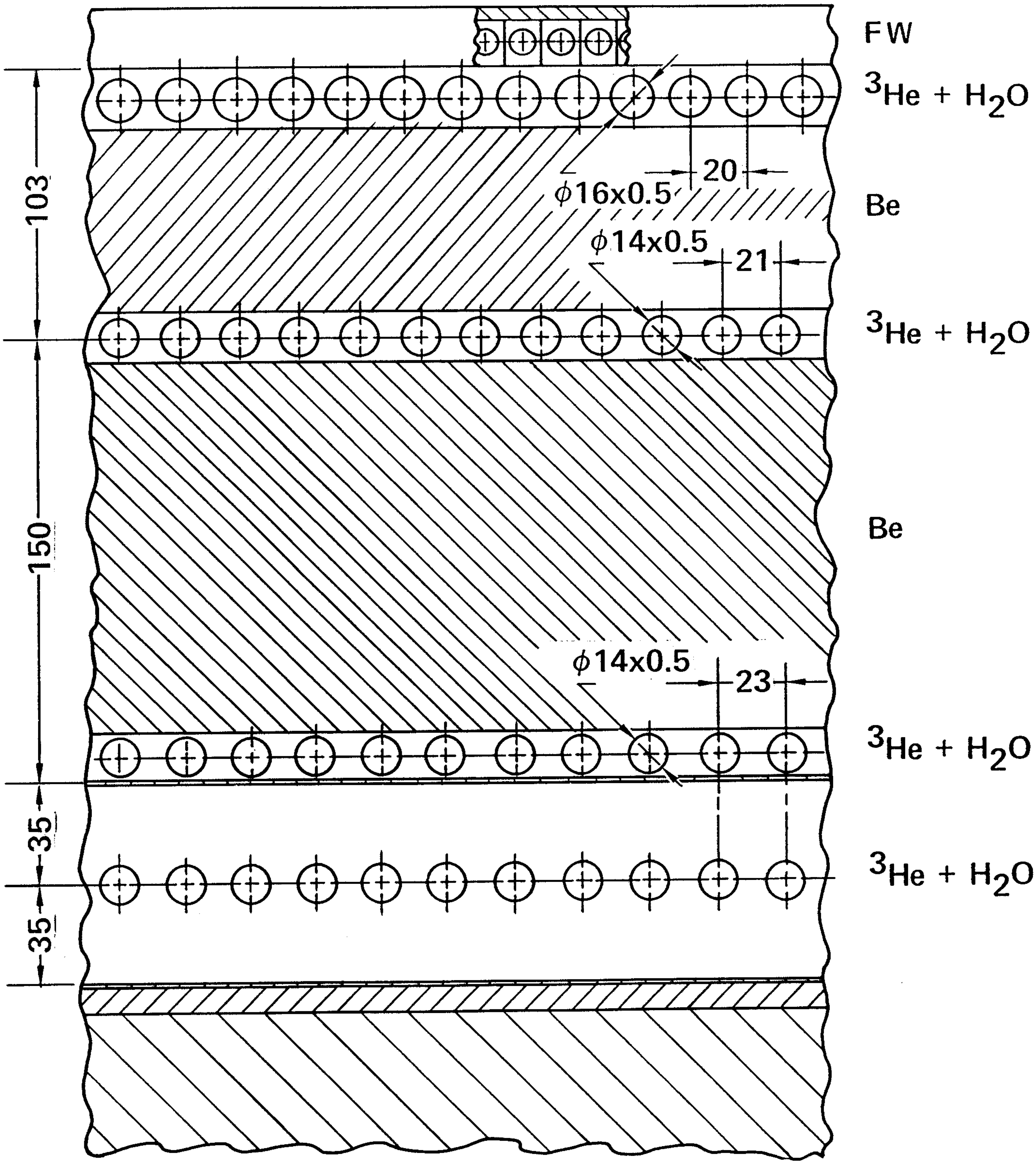




AQUEOUS LITHIUM SALT BLANKET DESIGN FOR ITER



He-Cooled Solid Breeder Blanket Design for ITER



^{3}He Blanket for ITER (USSR)

Observations on Concepts Proposed for ITER Basic Blanket by All Countries

- No Lithium

- Water-cooled LiPb only Proposed by USSR

- Aqueous Blanket Proposed as an Option by EC, USA
  - Simple design, fabrication
  - Not reactor relevant
  - Has most safety/environmental concerns

- Solid Breeder Blankets Proposed by All Countries
  - Water-cooled: at low temperature
  - Helium -cooled:
    Most reactor relevant
    Most safety advantages

- The Most Innovative Idea is ^3He Proposed by USSR, USA

  Primary concern: Helium supply

  ^3He Burnup: 8-10 kg/yr (25% availability)

  Supply
  1 kg/yr in US market from US
  1 kg/yr in US market from USSR

Present Status of Blanket Design Option Selection

- Many Options Have Been Proposed for Commercial Reactors
  - All have problems
  - Require extensive R&D

- New Ideas for Substantially Different Concepts are Still Being Proposed

  e.g.,
  - MHD generators
  - Solid-state conversion of radiation
  - Helium/ceramic particulates

- Options for ITER
  - Some reactor relevant:
    can benefit from present R&D
  - Some not reactor relevant
    require new specific R&D

Many Proposed Concepts Need Extensive R&D, New Facilities Present World Funding is Not Sufficient

Suggested Strategy
For the Many Blanket Options

- Maintain Strong Core R&D Program for Liquid Metal and Solid Breeder Blankets
  - Objective: Provide data base necessary to construct, operate test modules, sectors in ITER
  - Attempt to narrow options whenever possible
  - Should stabilize, protect from near-term device frequent change in focus
- Pursue ITER Specific R&D Program
  - Minimize by selecting reactor-relevant options
  - The list will change from year to year
- Encourage Small but Significant Amount of Research on New Innovative Ideas. Need Improvements in:
  - Economics potential
  - Inherent safety
  - Environmental impact

Testing in ITER

- ITER will be the First Opportunity for Fusion Testing

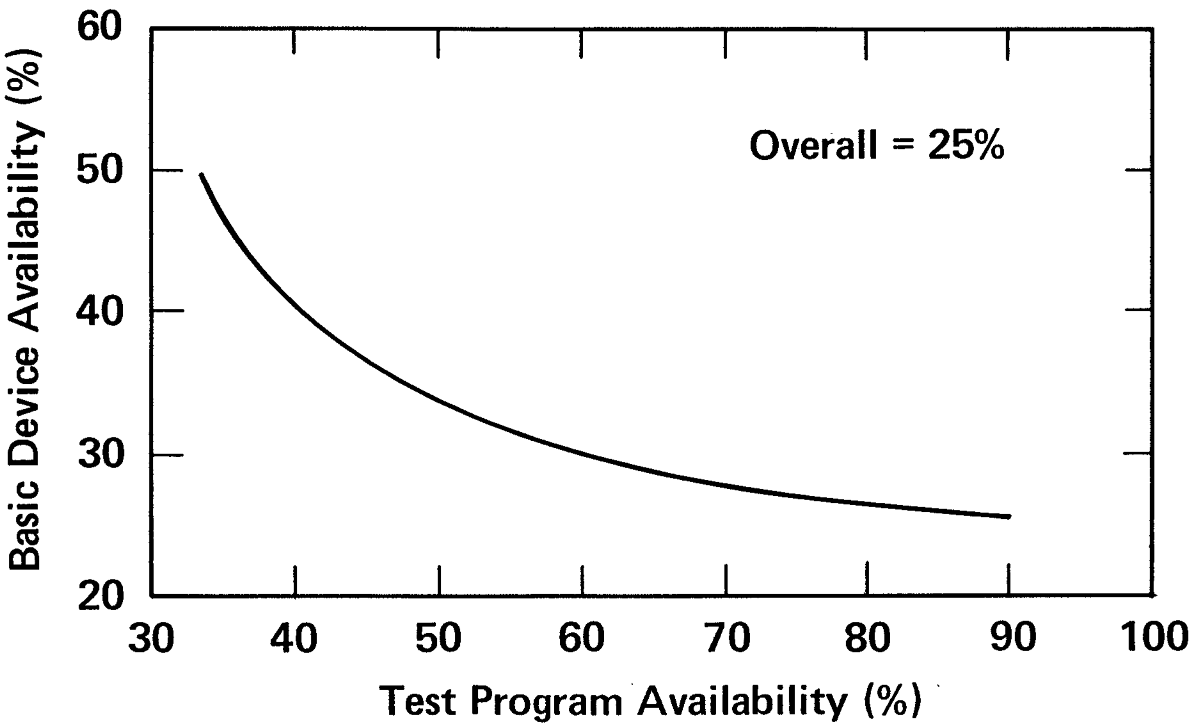
- Successful Nuclear Testing in ITER Requires

1. Extensive R&D in non-fusion facilities prior to ITER because:
    - ITER testing is expensive and time-limited
    - Need a reasonable level of confidence in test modules prior to insertion in ITER to assure reasonable ITER availability

2. ITER design has certain performance parameters and features to achieve the desired goal (provide definitive data for the DEMO)
    - Wall load (> 1 MW/m^2)
    - Neutron fluence (> 3 $MW \cdot y/m^2$)
    - Steady state
    - Ease of replacement/maintenance

Overall ITER Availability Depends on:

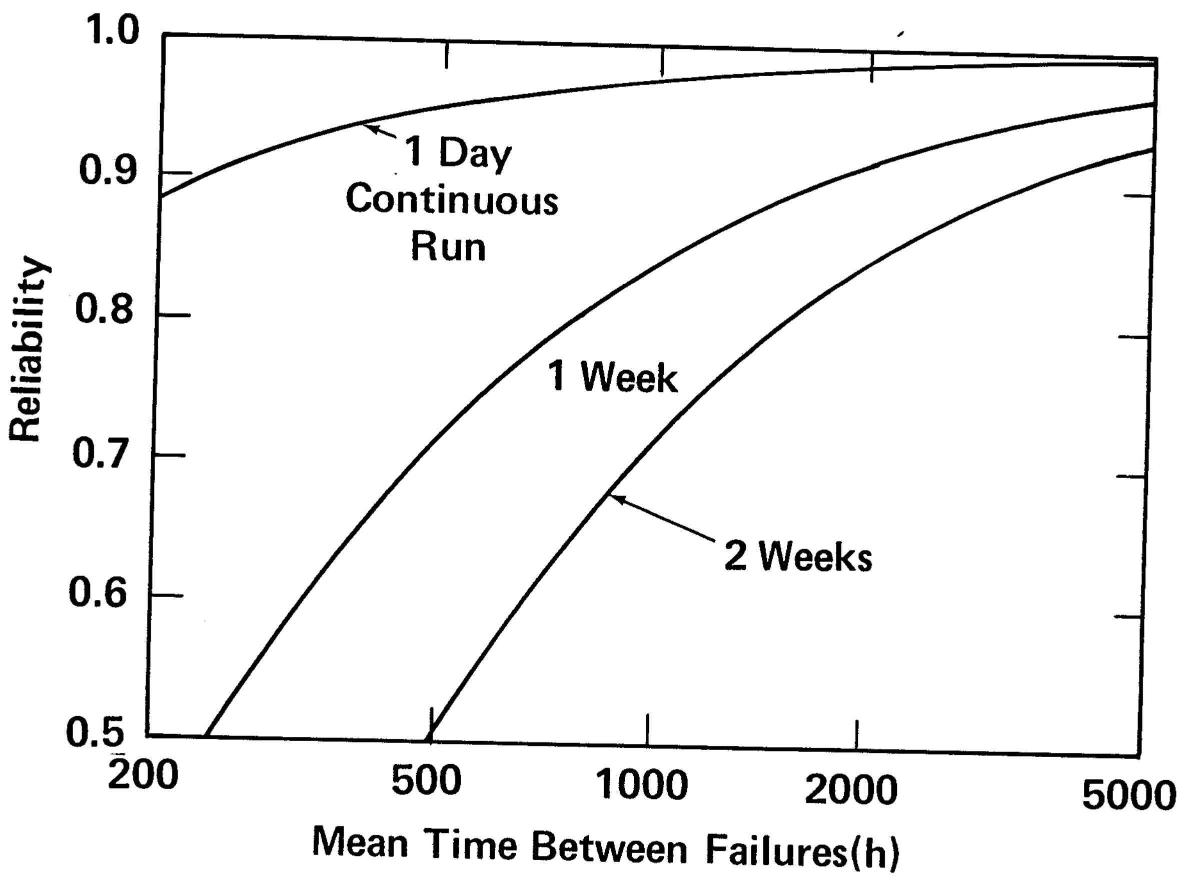
- —Availability for Basic Device Components
- —Availability for Test Program Elements

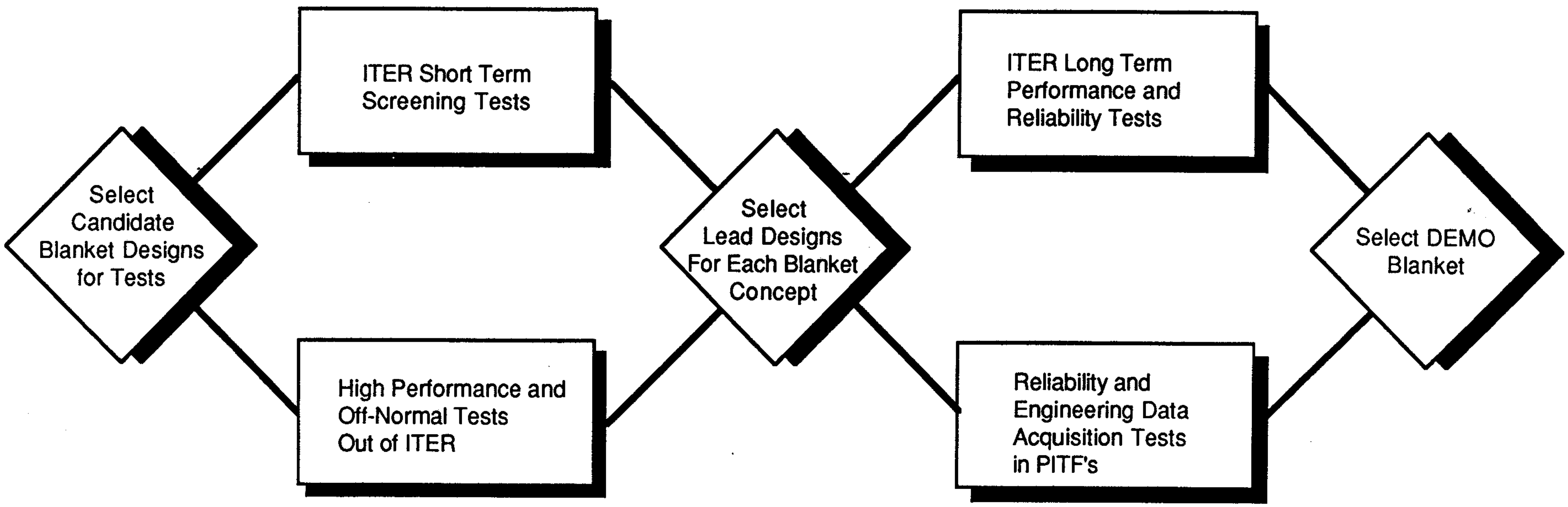


Successful Testing in ITER Requires Extensive Testing in Non—Fusion Facilities Prior to ITER

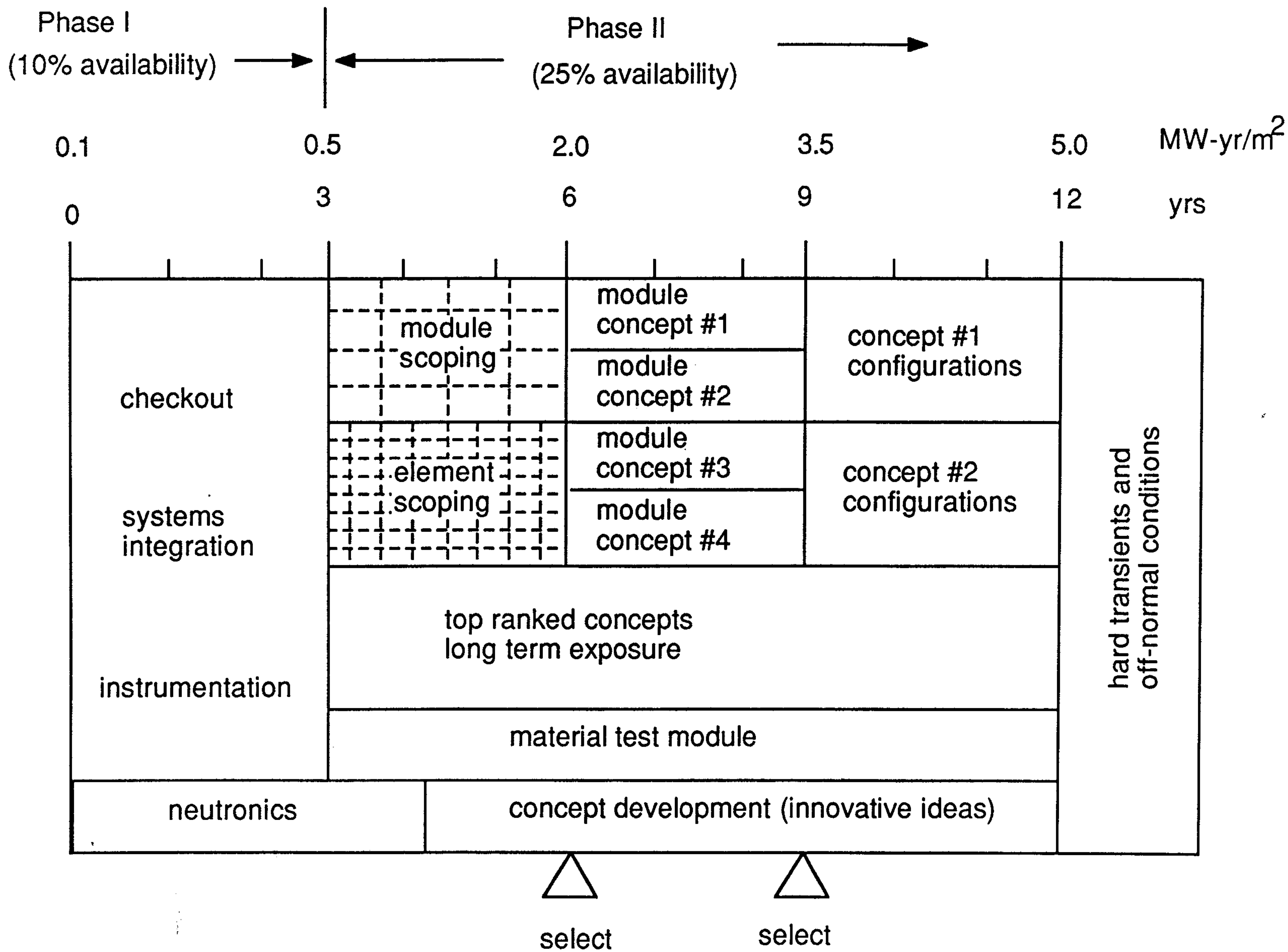
—Many Blanket Tests in ITER Require Continuous Operation (weeks at 100% availability)

—This requires that the overall test program has high reliability, long mean time between failures





TEST SCENARIO FOR BLANKET TESTING AND SELECTION



SPACE-Time Utilization Logic for ITER Tests

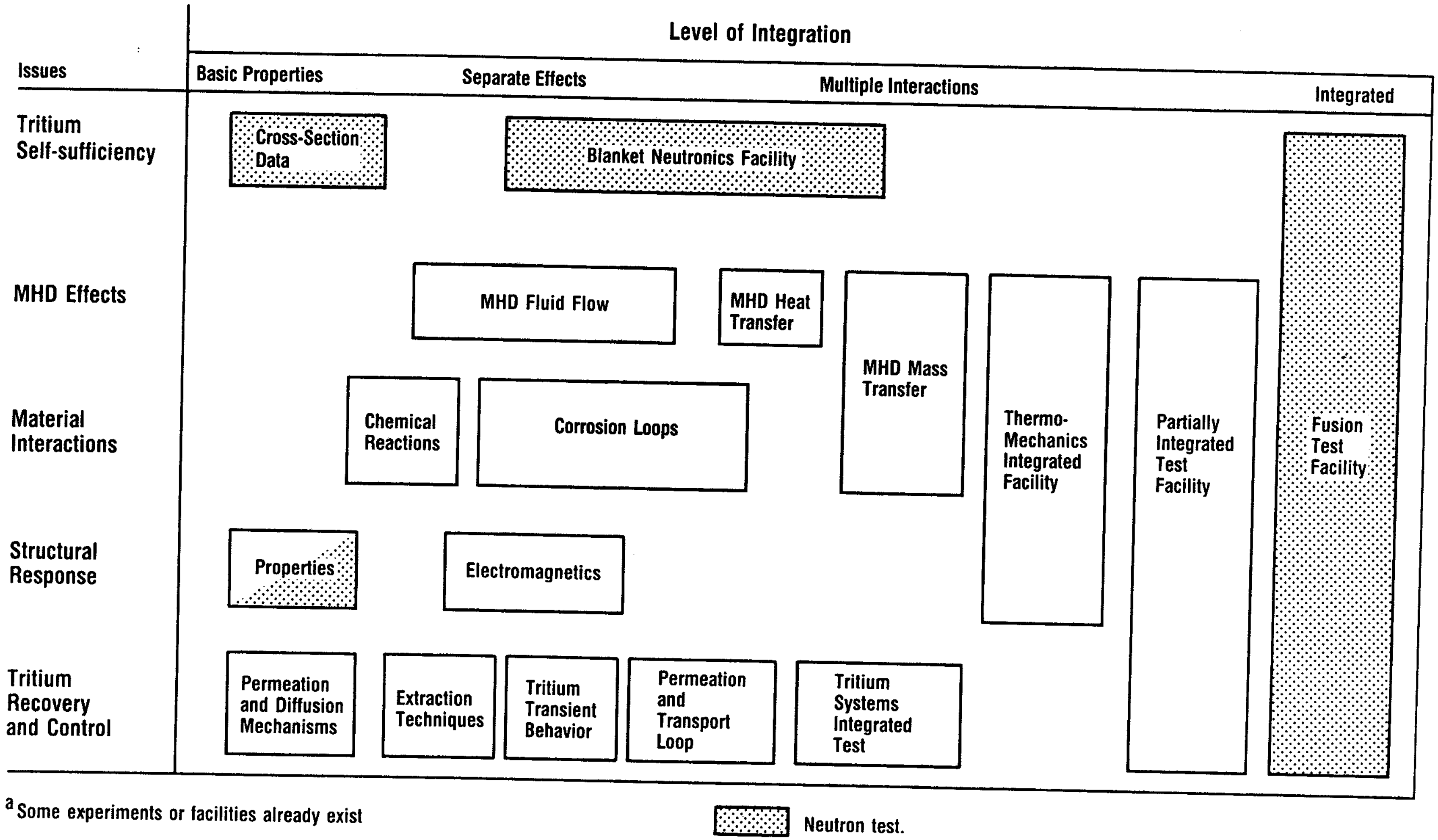
Some Conclusions on Blanket Testing in ITER
(Based on USA Study)

- In addition to blanket submodule and module tests, some SECTOR Tests will be necessary for
  - Verification of tritium self-sufficiency (e.g., solid breeders)
  - Blanket concepts whose unit size is large (e.g., some self-cooled liquid metals)

- Water Cooling of the Basic Machine (blanket and/or divertor) Hampers Testing of Hot Surfaces and Lithium Blanket

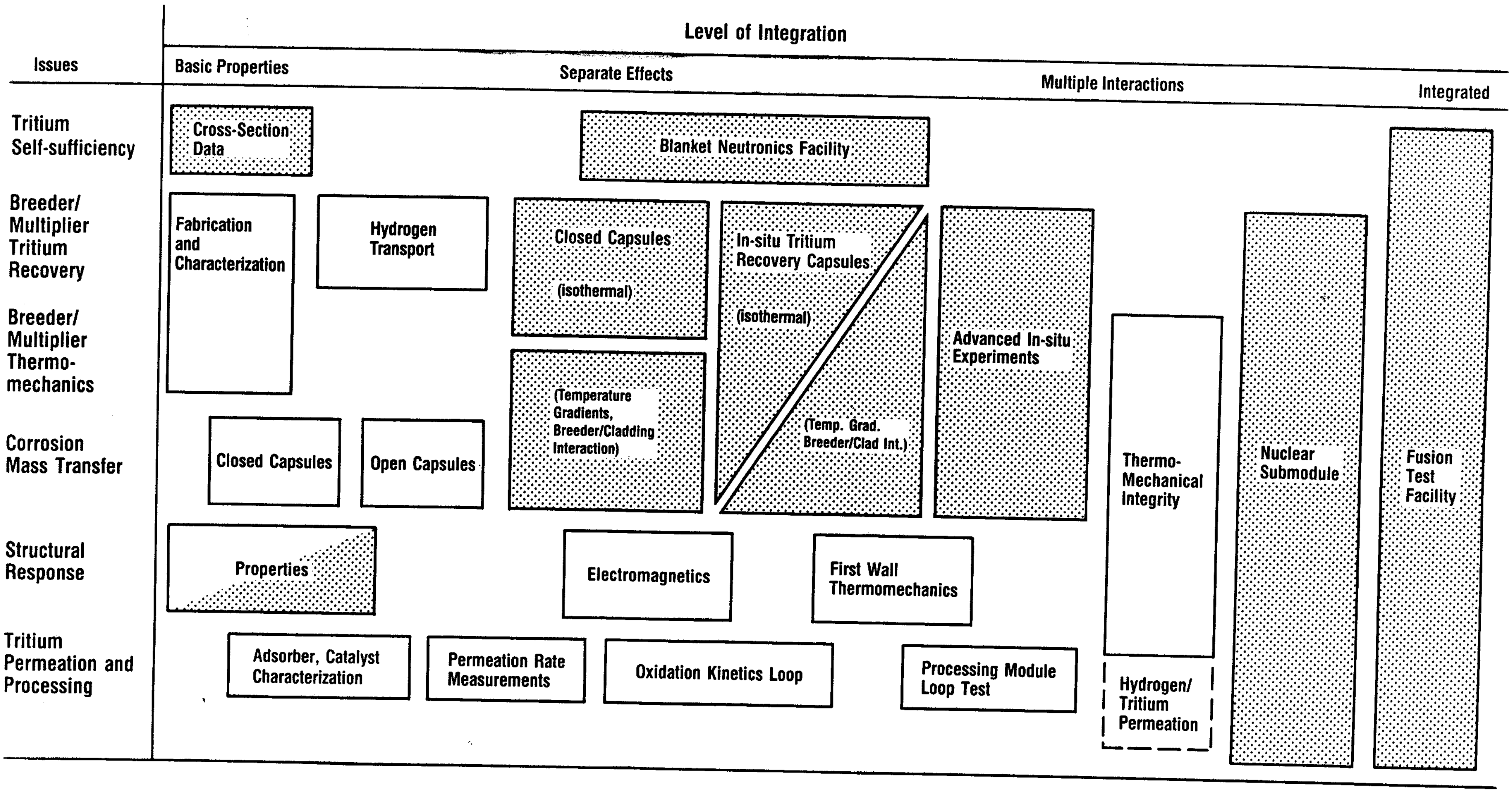
- Safety Guidelines
  - Limit lithium volume to ~1 m^3
  - Double-wall test module except at first wall
  - For large volume lithium, double wall at the first wall is also necessary

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



[a] Some experiments or facilities already exist

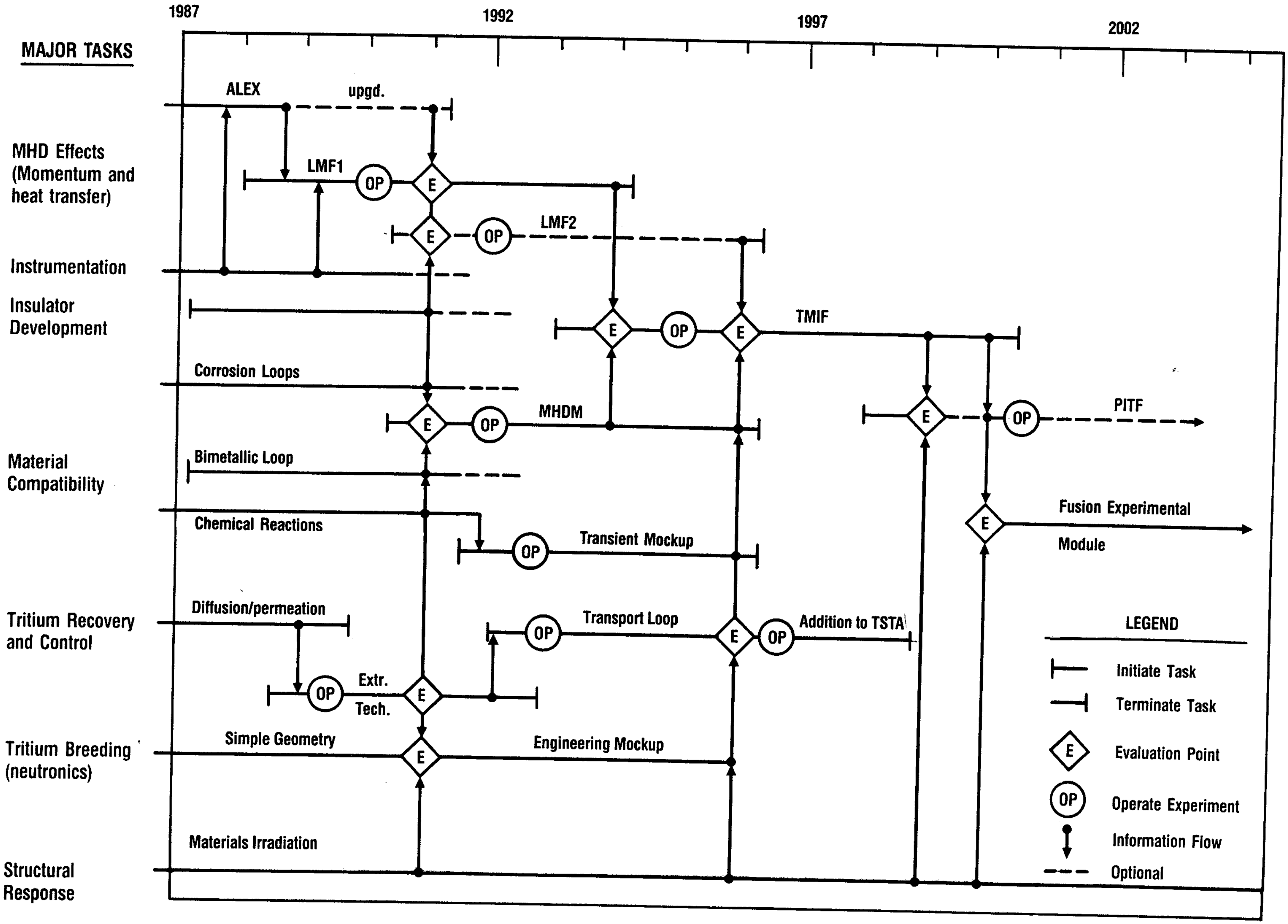
TYPES OF EXPERIMENTS AND FACILITIES FOR SOLID BREEDER BLANKETS[a]



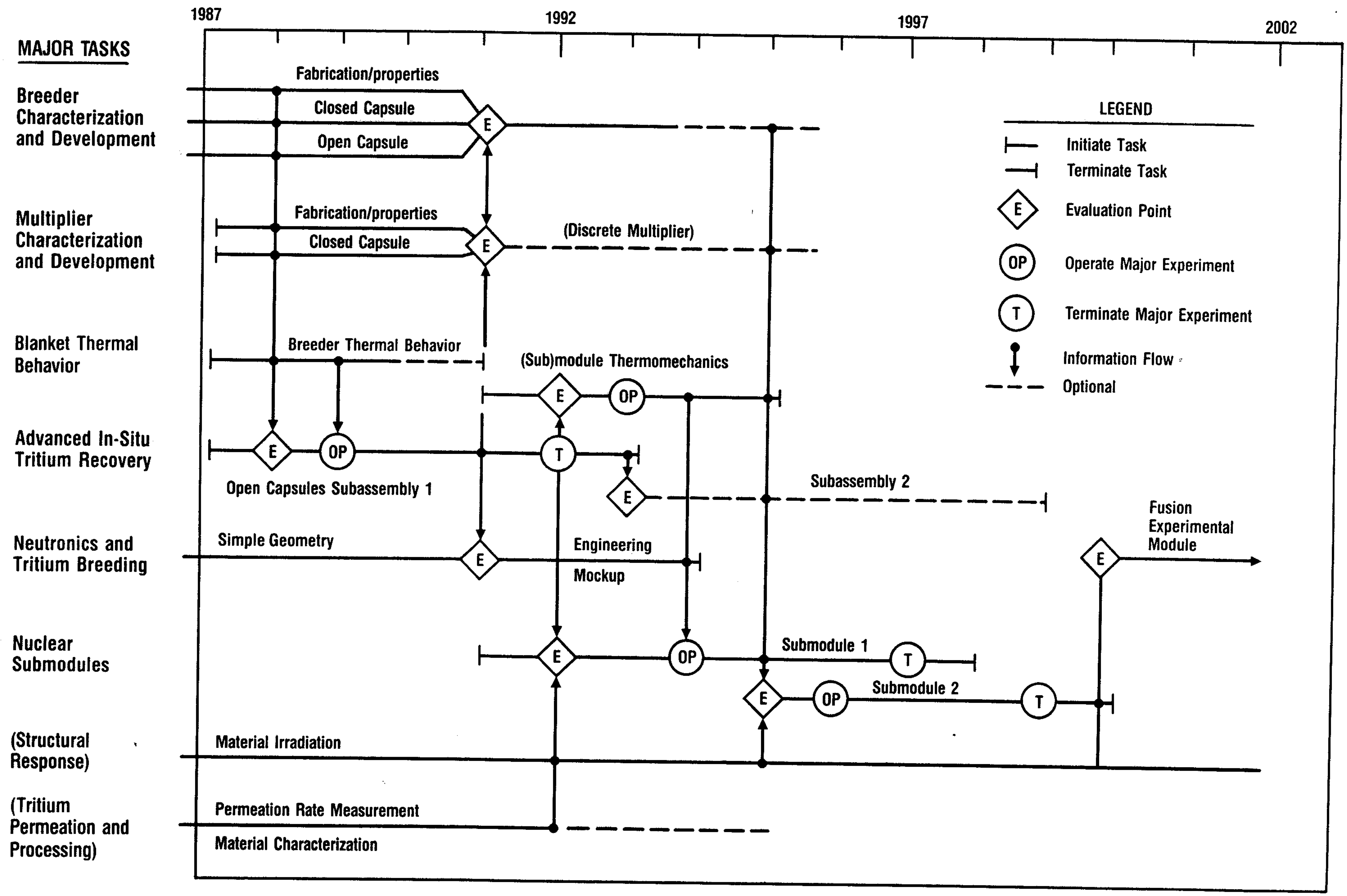
[a] Some Experiments and Facilities Exist

Neutron Test

LIQUID BREEDER BLANKET TEST PLAN



SOLID BREEDER BLANKET TEST PLAN



Major Tasks for Liquid Breeder Blankets
(Next 15 years)

- MHD Effects
  - Momentum and heat transfer facilities (LMF1, LMF2)
  - Instrumentation development
  - Insulator development
- Material Compatibility
  - Corrosion loops (including bimetallic loop)
  - 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)
- Analysis and Model Development

Major Tasks for Solid Breeder Blankets
(Next 15 years)

- SB 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
  - Breeder/multiplier compatibility

- Blanket Thermal Behavior
  - Corrosion, mass transfer and chemical interaction kinetics
  - Breeder/multiplier temperature profile and thermo-mechanical effects of breeder/cladding interaction
  - Non-neutron blanket (sub)module thermomechanics

- 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

NEAR-TERM INITIATIVES
(NEXT 3 YEARS)

<u>Note</u>

- Agreed upon in the U.S. Fusion Technology Community
- Assumes International Cooperation

Examples of Major Near-Term Needs (Next ~3 Yrs)

1. Liquid Metal Flow Facility (LMF1)

   Facility with capabilities for experiments on MHD fluid flow, heat transfer and pressure drop in relevant geometry

2. Advanced Solid Breeder Tritium Recovery Experiment

   Experiments in fission reactor to study (in-situ) tritium recovery with local reactor-relevant conditions

3. Engineering Tritium Breeding Experiments

   Extend the capabilities of tritium breeding experiments to include more prototypical neutron source and test section geometry and materials

4. Blanket Tritium Processing

   Part of simulation of the full tritium fuel cycle

5. New/Innovative Ideas

   Initiate small but significant effort to stimulate and evaluate new innovative design ideas to improve economics, safety and environmental impact potential

Objectives of LMF1

Testing of MHD Fluid Flow, Heat Transfer, and Pressure Drop in Basic Geometric Elements of the Blanket and Plasma-Interactive Components

- Measure velocity, pressure, temperature, and electric potential distributions

- Develop and test instrumentation (in NaK environment)

- Validate MHD flow, pressure, and heat transfer predictive capability for:

  - Segments of blanket modules

  - Sections of divertor/limiter

- Obtain design data for segments of blanket modules and high heat flux components

- Explore techniques to reduce pressure drop and enhance heat transfer

Characteristics of Required Major Liquid Breeder Experiments

Characteristic	Existing (e.g., ALEX)	Needed LMF[a]	Needed MHDM[b]	Needed TMIF[c]
Fluid	NaK (100°C)	NaK	actual materials	actual materials
Testing volume	0.2 m^3	1-5 m^3		1-5 m^3
Magnetic field	2 T	4-6 T		4-6 T
Configuration	simple geometry	elements of complex geometry		submodule/ prototypic

[a]Liquid Metal Flow Facility
[b]MHD Mass Transfer Facility
[c]ThermoMechanical Integration Facility

LMF Facility Parameters

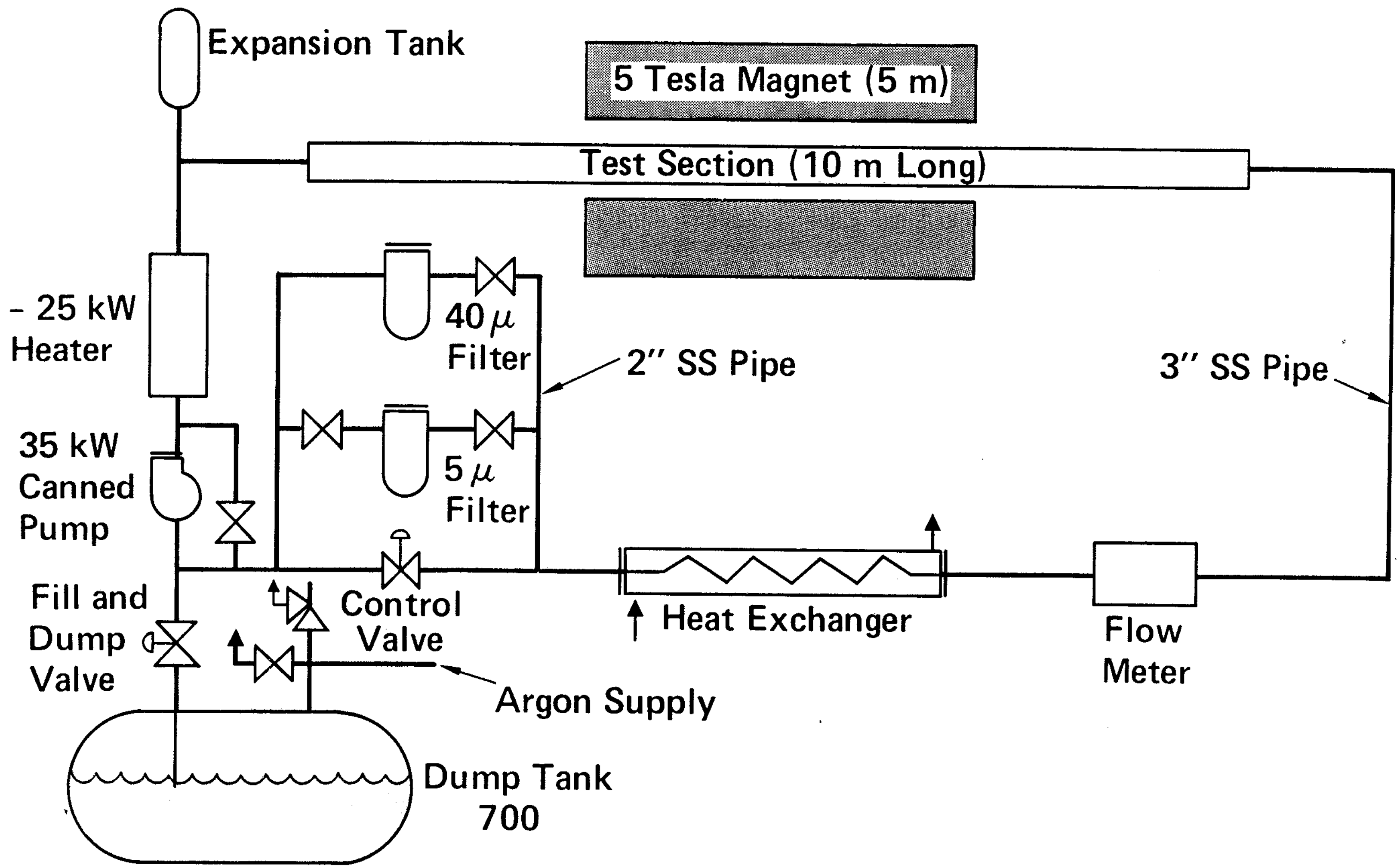
Loop Parameters

Working Fluid	NaK Eutectic
Inventory of Working Fluid	700 liters
Loop Materials	Predominantly 300 Series S/S
Volumetric Flow Rate Through Test Articles	1-25 liters/s
Pump Outlet Pressure	1 MPA
Pump Outlet Temperature	≤ 100°C
Test Article Conditioning Temperature (at low pressure and flow rate)	300°C
Overall Length of Test Article (between flanges for test section replacement)	~10 m
Cost (excluding cost of test articles)	$1 M

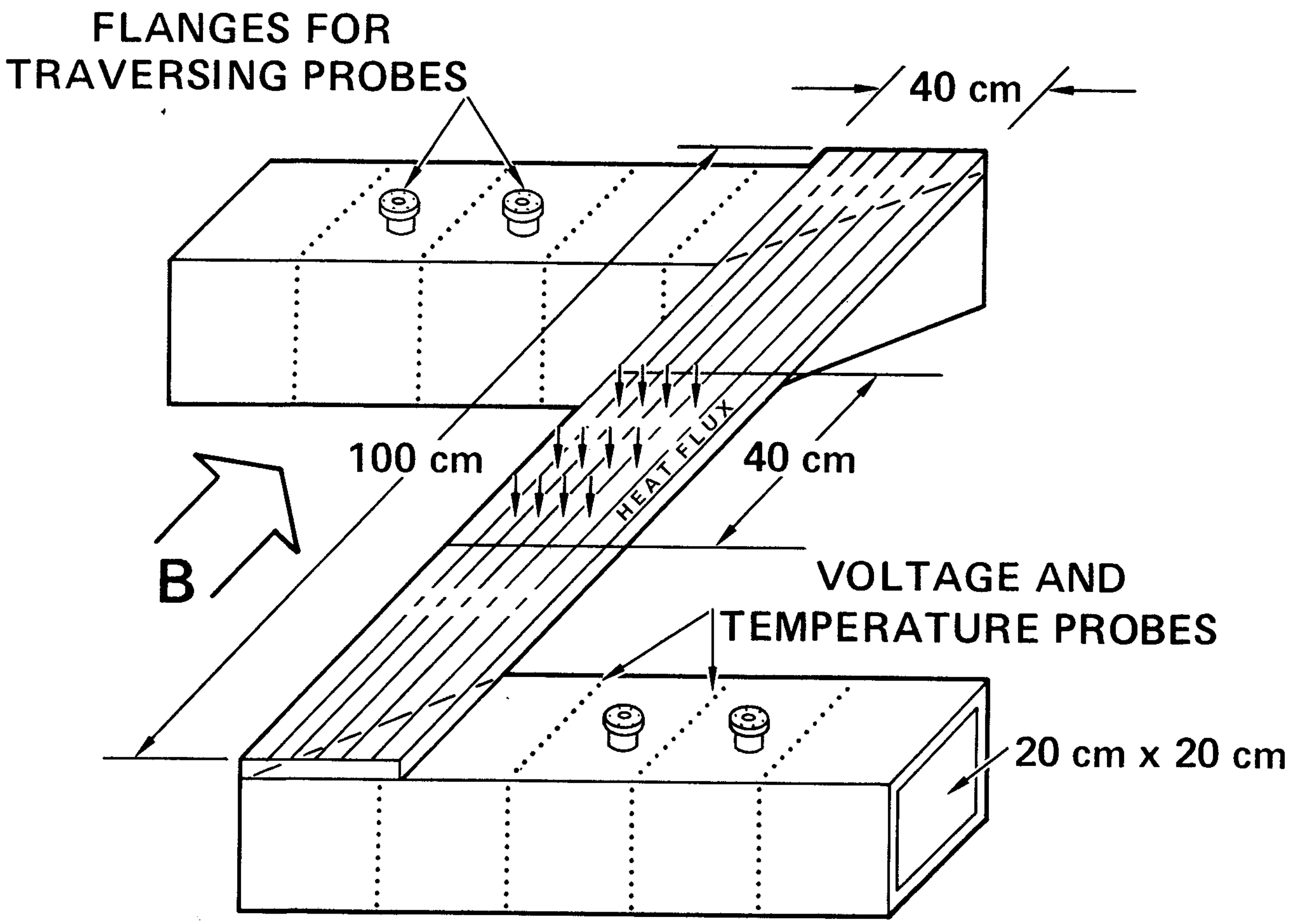
Magnet Parameters

Peak Field	5 T
Warm Bore	1.2 m
Uniform Field volume	1 m x 0.3 m x 3 m
Field Uniformity	± 5%
Magnet Cost	$15 M

SCHEMATIC OF LMF LOOP



Example of a test section simulating the BCSS liquid-metal-cooled blanket design. Measurements of velocity and temperature profiles.



Advanced In-Situ Tritium Recovery Experiments for Solid Breeders

Facilities: Fission Reactors
Fast, Thermal: USA, EC, Japan

Objective:

- Data to Support Selection of Solid Breeder Blanket for ITER
- Study Tritium Recovery with Local Reactor-Relevant Conditions
  - Moderate to high burnup
  - Temperature gradient
  - Purge flow
  - Breeder/clad mechanical and chemical interactions
- Data on Tritium Extraction/Processing Interface

Experiments:

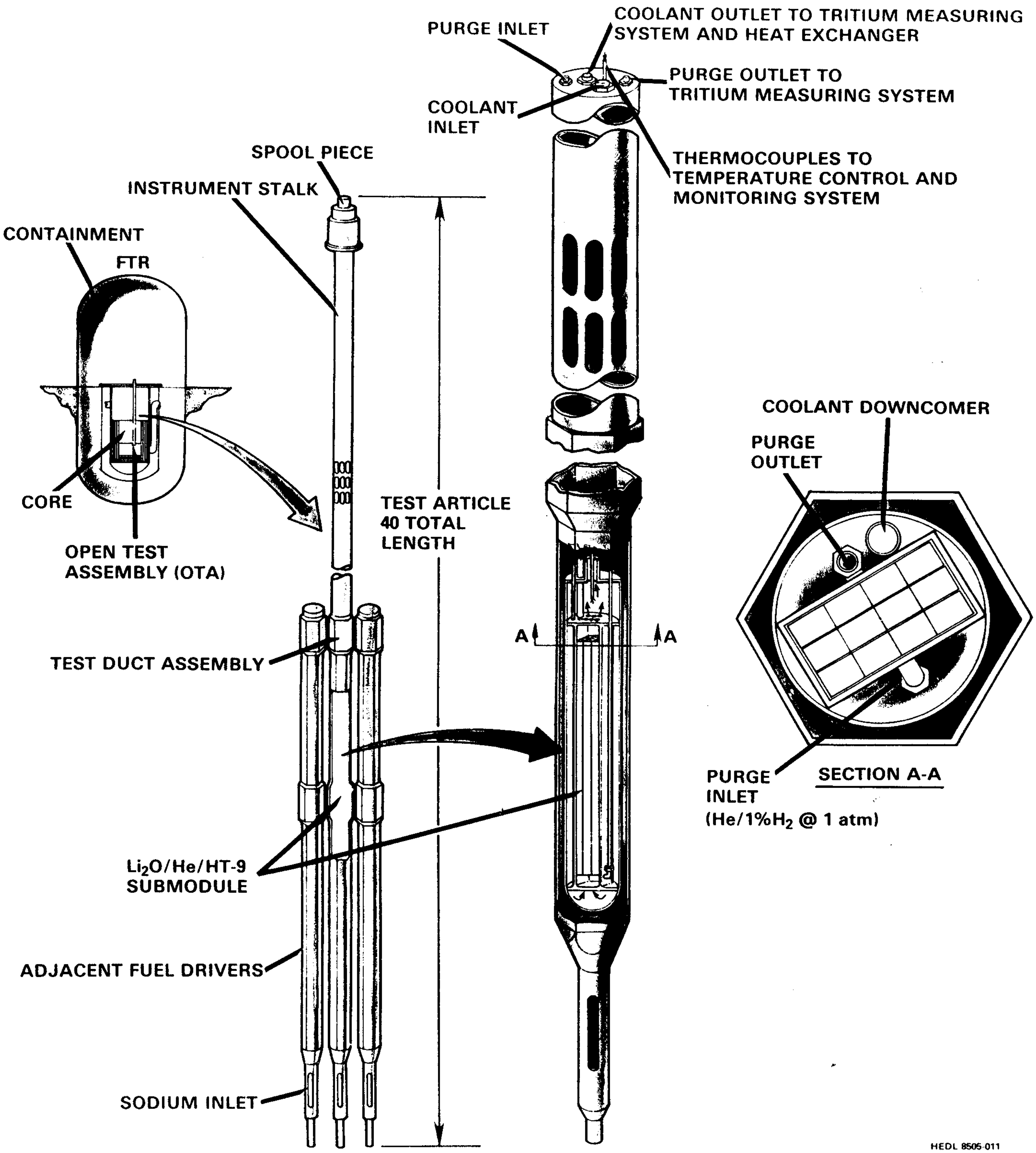
- Key Combinations of Solid Breeder Materials and Neutron Multipliers
- Representative Geometries

Parameters for Near-Term Solid Breeder Experiments in Fission Reactors

	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	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

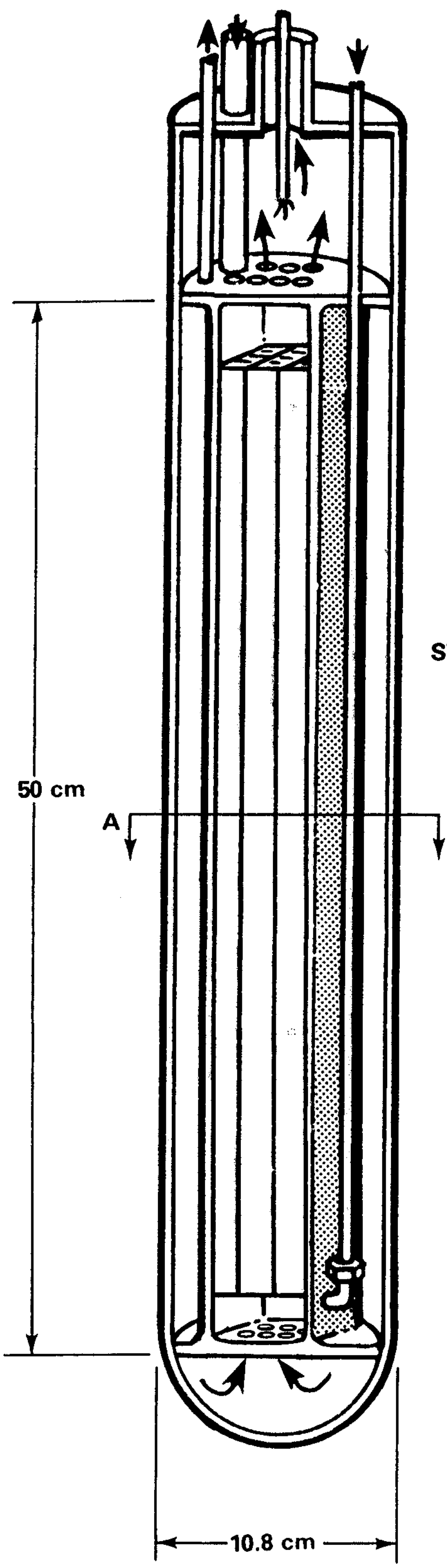
[a]Normalized per gram of solid breeder material

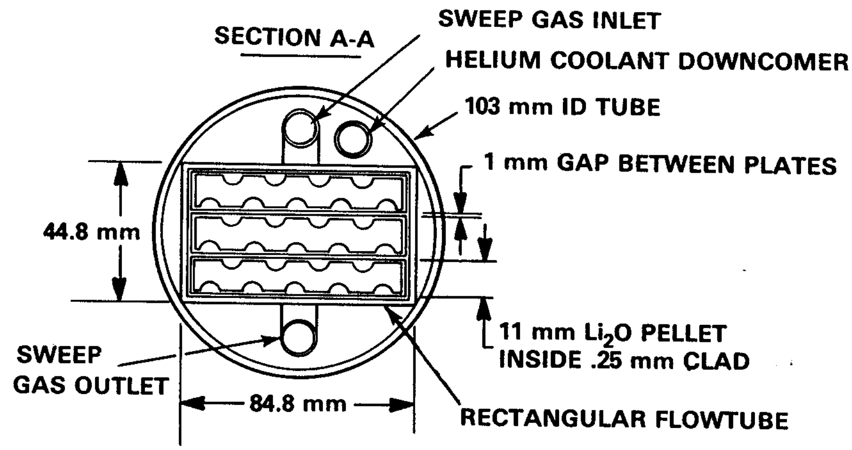
HELIUM COOLED Li_2O / HT-9
FUSION BREEDER MATERIAL INTERACTION TEST

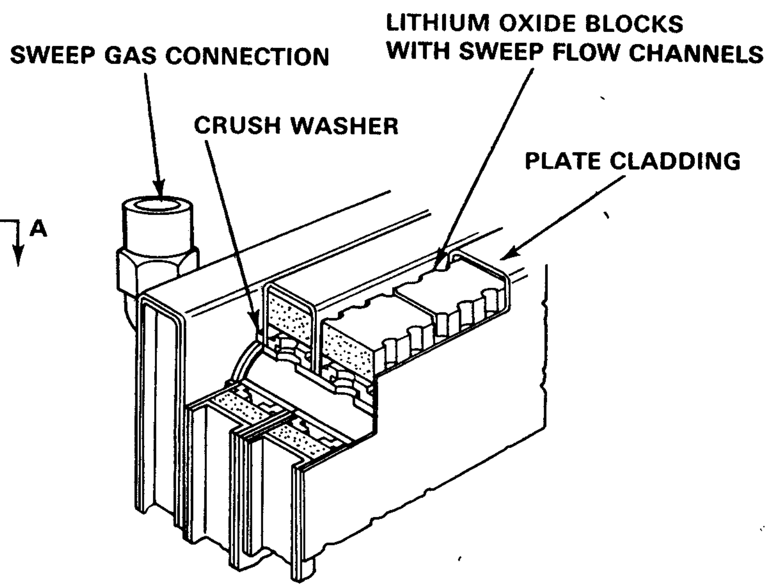


HEDL 8505-011

NUCLEAR SUBMODULE



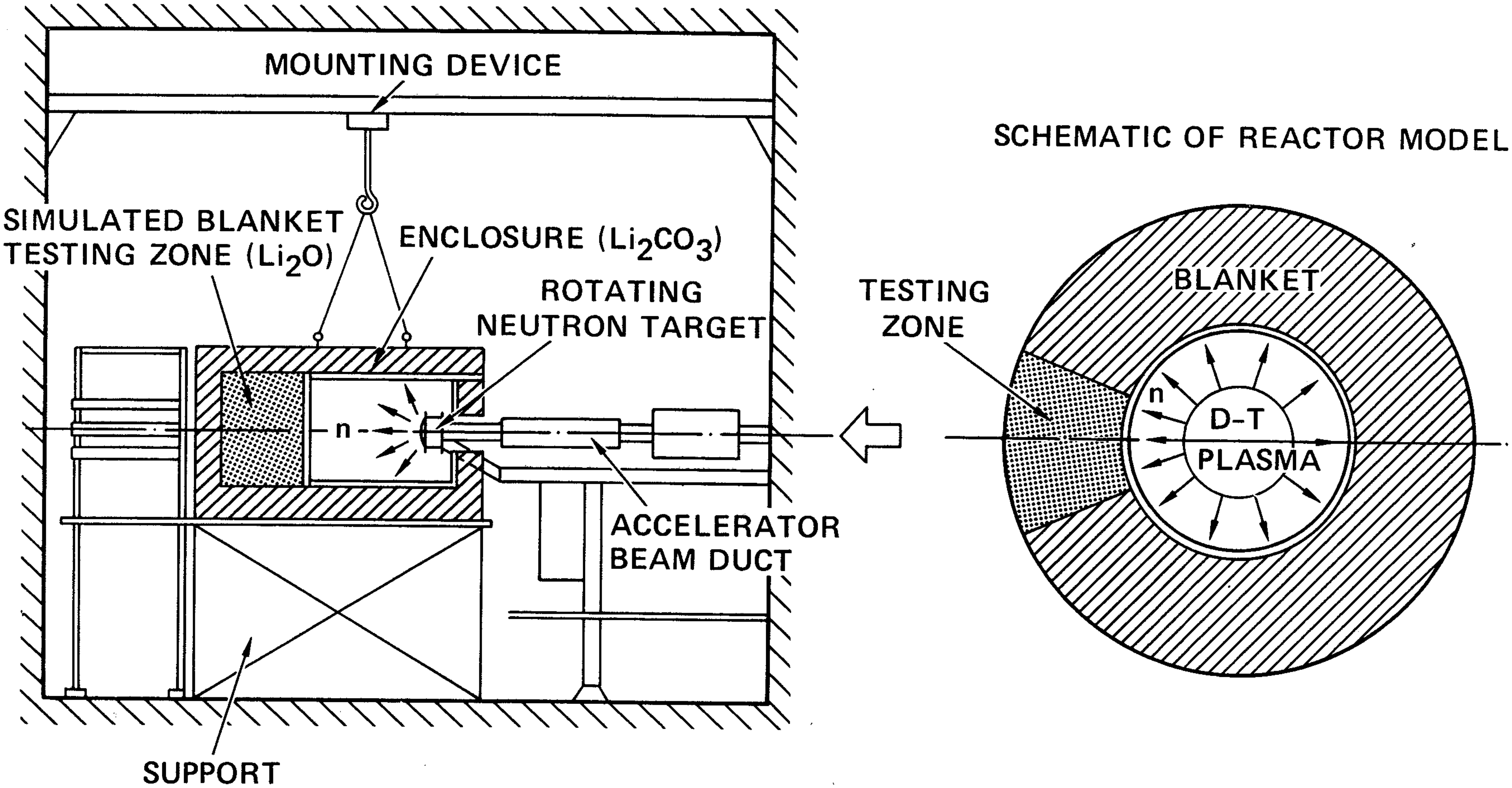




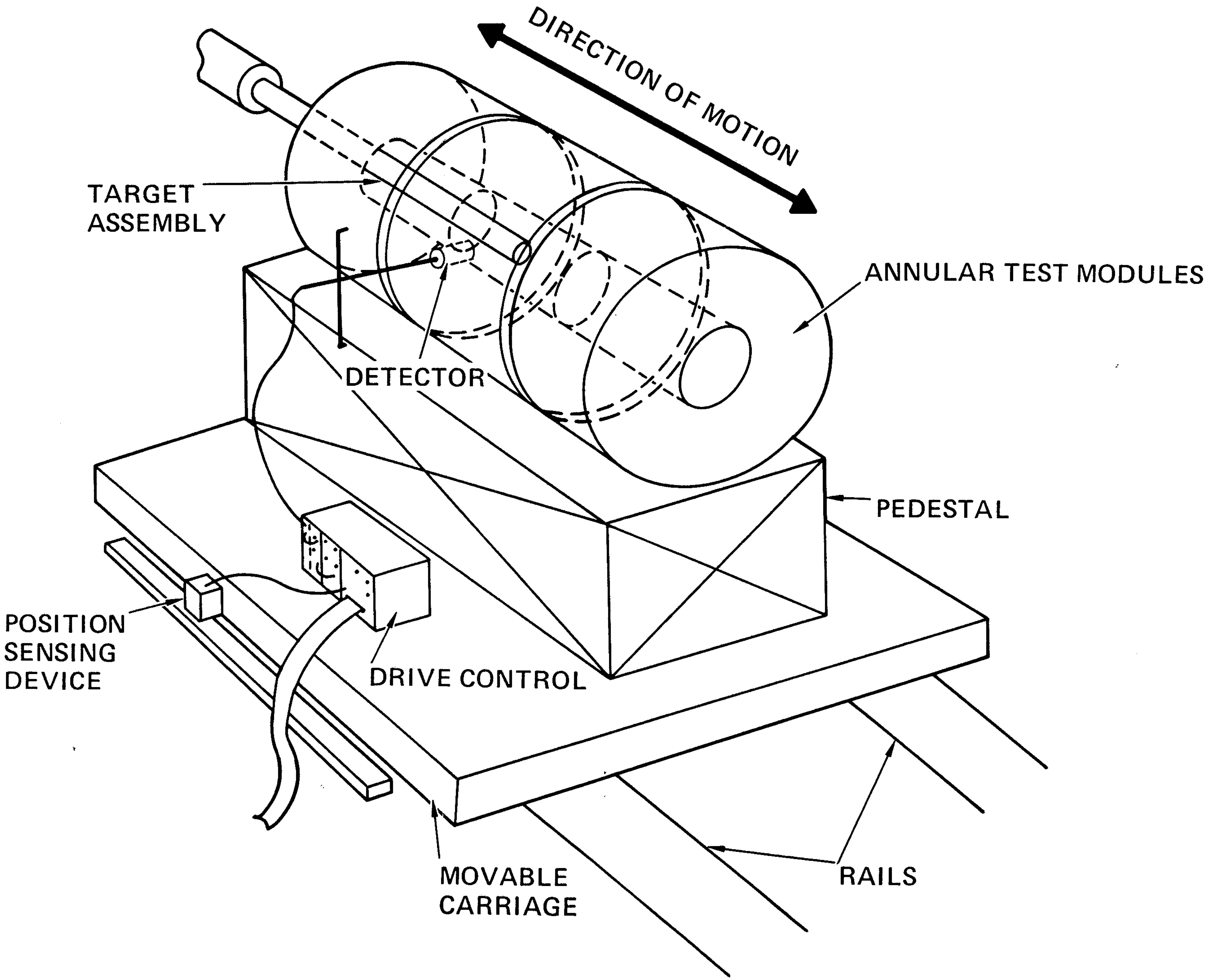
DETAIL OF SWEEP GAS FLOW SYSTEM

HEDL 8509-074.5

EXPERIMENTAL SYSTEM FOR PHASE-2 OF US/JAERI PROGRAM ON BLANKET NEUTRONICS



ADVANCED LINE SOURCE FOR TRITIUM BREEDING EXPERIMENTS



Examples of ITER-Specific Near-Term Blanket R&D

Beryllium Technology

- Irradiation effects on swelling and mechanical integrity
- Reduce uncertainties in (n,2n) multiplication and secondary neutron energy/angular distributions
- Compatibility with solid breeder materials under irradiation
- Compatibility with stainless steel under irradiation
- Thermomechanical performance of beryllium for gap conductance

Solid Breeders

- Purge gas flow heat transfer, pressure drop in sphere-packed beds
- Thermal gap conduction experiments
- (Add tritium release tasks to BEATRIX and other programs)
- Tritium release models
- H_2O/solid breeder safety

ITER Specific Blanket R&D (cont'd.)

Neutronics/Shielding

- Be (n,2n) integral experiments and sensitivity analysis
- Nuclear heating (kerma factor) measurements in integral experiments
- Radioactivity, decay heat measurements
- Streaming/shielding experiments
- Improve radioactivity libraries and codes

Aqueous Blanket

- Radiolysis
- Stress corrosion of austenitic steels
- Tritium recovery
- Chemistry control

LiPb Blanket

- Corrosion
- LM MHD (for test modules)
- Reactions with H_2O and air
- Tritium recovery and permeation barriers

^3He Blanket

- Helium leakage
- Tritium inventory in structure

Concluding Remarks

- Present Status for FNT:
  - We now understand the technical issues
  - Technical R&D plans to resolve the issues exist

- Some Progress has been Made over the Past Several Years But the Present Pace is Too SLOW
  - Almost all issues identified 5 years ago remain the same
  - Only a modest part of R&D identified earlier has been carried out

- Timely Development of FNT will Require Faster Pace, More Resources
  - Need new facilities with adequate capabilities
  - Enhance modelling activities

- Both Liquid Metal and Solid Breeder Blankets Must be Pursued
  - They both have serious issues
    Feasible? Attractive?
  - Definitive selection does <u>not</u> appear possible prior to testing in a fusion facility (ITER)

Concluding Remarks (cont'd.)

- R&D in Non-Fusion Facilities (neutron sources, liquid metal test stands, fission reactors, etc.) has Two Goals

  1) To construct and operate test modules in ITER (LM & SB)

  2) Data for basic ITER blanket (specific type)

Carrying out #2 should not be at the expense of #1

- There are many Benefits for Selecting the ITER Basic Blanket to be Reactor Relevant

- Serious Concerns About the Attractiveness of our Present Concepts for Fusion Reactors Persist

  Need some effort to enhance potential:
  Economic
  Safety
  Environmental Impact

  1. Plasma
     (high β, steady state, disruption free, etc.)

  2. Plasma Technology
     (high field magnets, current drive, plasma interactive components)

  3. Nuclear Technology
     Innovative New Ideas
     - to reduce balance of plant
     - inherent safety
     - low long term activation
     - simpler designs
     - etc.

APPENDIX

U.S. Activities on Liquid Metal Blankets

- Experiments
  - MHD Momentum Transfer
    ALEX Facility at ANL
  - MHD Heat Transfer
    None (plans exist)
  - Corrosion/Compatibility
    - Loops at ANL, ORNL
    - No MHD work yet
  - Electromagnetics
    FELIX Facility at ANL (stand-by)

- Modelling
  (Analytical, Numerical, Computational)

  UCLA
  ANL
  U. of Illinois

U.S. Activities on Solid Breeder Blankets

- Mostly in Collaboration with Other Countries

- Fabrication and Material Characterization
  ANL, Hanford

- Irradiation Experiments (Hanford, ANL)

  BEATRIX - Exchange of materials and shared irradiation testing: Belgium, Canada, England, France, West Germany, Italy, Japan and Netherlands

  1) Closed capsule tests to evaluate lifetime

  2) Open capsule tests to evaluate purge flow tritium recovery

- Modelling (ANL, UCLA)

  - Tritium Transport, Inventory

  - Thermonuclear Behavior

U.S. Neutronics Activities

- Almost All Activities are Part of International Agreements

- Main Program: U.S.-Japan
  - Facility: FNS at JAERI
  - U.S. organizations: UCLA, ANL, ORNL, LANL
  - Objectives:
    1) Validation of methods, data for tritium breeding, nuclear heating, induced radioactivity
    2) Screen candidate materials and configurations
    3) Develop neutronics technology for next device (ITER)

- Modest Effort on Data, Method Improvement

- Observations
  - Fission program decline reduces resources
  - Japan and EC programs are increasing

Features and Objectives of Major Liquid Breeder Experiments

	ALEX	Magnetic Transport Phenomena Facilities: LMF	Magnetic Transport Phenomena Facilities: MHDM	TMIF	PITF
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

Motivations for Fusion Nuclear Technology Program

- Resolve Some of the Most Critical Unresolved Feasibility Issues for Fusion

- Substantially Enhance the Potential Competitiveness of Fusion Reactors
  - Economics
  - Safety and Environment

- ITER: Near-Term Fusion Devices That Burn Tritium Will Have New Challenging Nuclear Issues

  e.g., **BLANKET** to Produce Tritium Radiation Shield for Complex System

- Time Scale for FNT Development is Long