FUSION BLANKET DESIGN ISSUES AND EXPERIMENT PLANNING

Mohamed A. Abdou
Professor
Mechanical, Aerospace & Nuclear Engineering Department
School of Engineering & Applied Science
University of California, Los Angeles

Presented to
Japanese Atomic Society Research Committee on Design and Technology of Fusion Reactors
Tokyo, Japan
June 28, 1985

Emphasis of Presentation

Blanket Design Issues

Blanket Experimental Research Needs

Bases for Information

- BCSS
  Blanket Design Study

- FINESSE
  Technology Research & Development Study

Objectives of BCSS

- Define a small number (3 or 4) of blanket design concepts that should provide the focus of the blanket R&D program.
- Identify and prioritize the critical issues for the leading concepts.
- Provide the technical input necessary to develop a blanket R&D program.

Approach

- Develop reference design guidelines.
  - Tokamak = STARFIRE
  - TMR = MARS
  - 5 MW/m^2
- Develop evaluation methodology and criteria.
- Compile materials data base and develop uniform systems analysis.
- Develop conceptual designs for evaluation.
- Evaluate blanket concepts.
- Identify critical feasibility issues and R&D requirements for leading concepts.

Design Guidelines

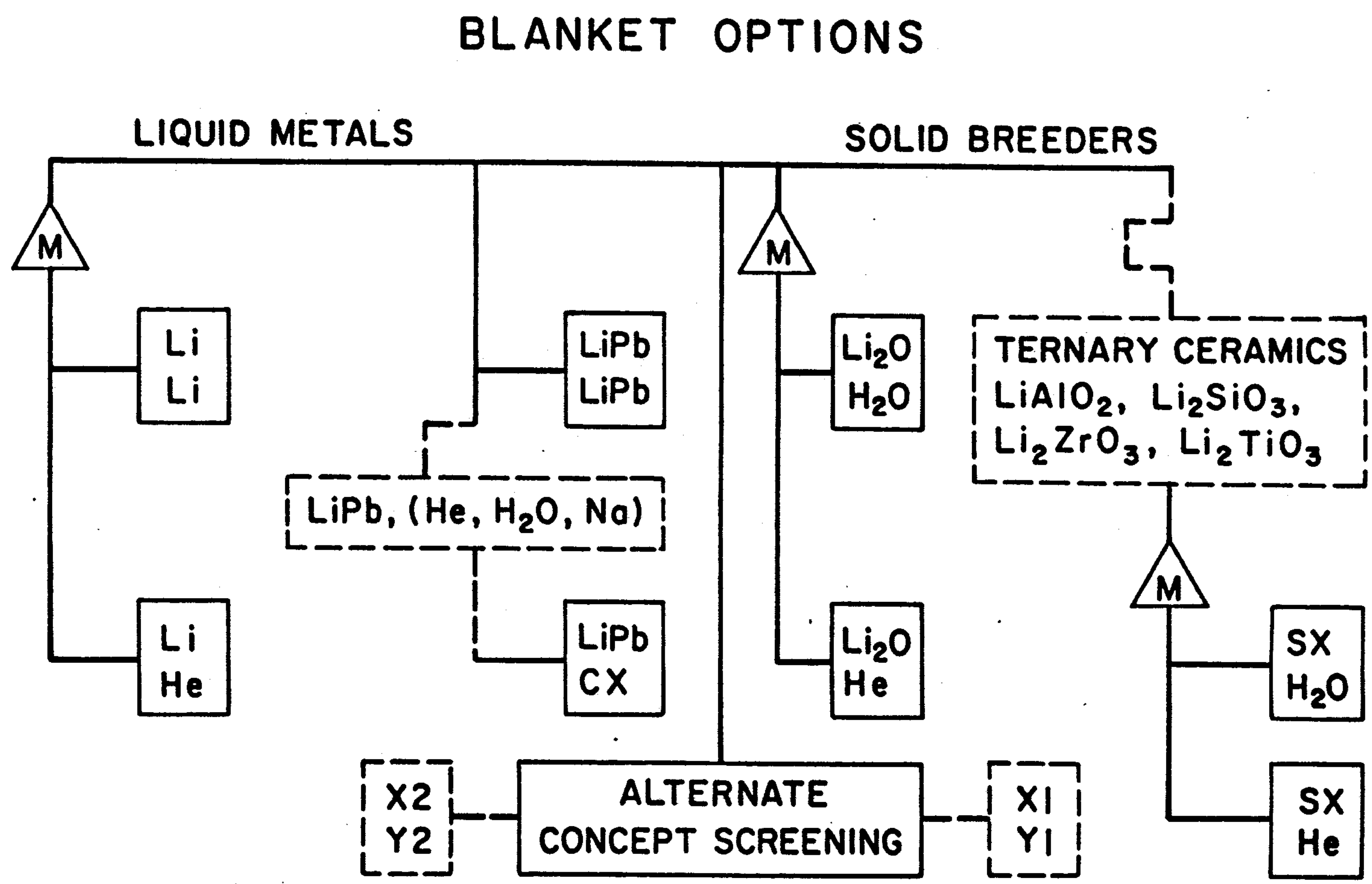
	TOKAMAK	TMR
Reactor Design Basis	STARFIRE	MARS
Peak Magnetic Field, T	10	5
Neutron Wall Load, MW/m^2	5	5
First Wall Heat Flux, W/cm^2	100	5
First Wall Erosion, mm/y	1	0.1

φ

Candidate First–Wall/Blanket Materials

Breeding Materials	Coolants	Structure	Neutron Multiplier
Liquid Metals	H_2O	Austenitic Steel	Be
Li	Li	PCA	Pb
17Li–83Pb	17Li–83Pb	Mn Steel[A]	
	He		
	Salt[C]		
Ceramics		Ferritic Steel	
Li_2O		HT–9	
Li_8ZrO_6		Mod. Ferr. St.[A]	
$LiAlO_2$[B]			
Salt		Vanadium Alloy	
FLIBE[D]		V15Cr5Ti	

[A] Low–activation structural alloys. V15Cr5Ti is inherently low activation.
[B] $LiAlO_2$ is representative of ceramics that include Li_2SiO_3, Li_2ZrO_3, etc.
[C] Nitrate salt.
[D] Fluoride salt.



STRUCTURAL MATERIAL

- BIG DIFFERENCE IN R&D
  - (1) PCA
  - (2) FERRITIC
  - (3) VANADIUM ALLOY

M = NEUTRON MULTIPIIER

- ALL BREEDERS (EXCEPT LiPb) MAY REQUIRE MULTIPLIER.
- IS BERYLLIUM THE ONLY CHOICE ?
- BERYLLIUM ASSESSMENT.

Leading Blanket Concepts Evaluated in BCSS
(Breeder, Coolant, Structure, Neutron Multiplier)

Li/Li/V

Li/Li/FS*

LiPb/LiPb/V*

Li/He/FS

Li_2O/He/FS

$LiAlO_2$/He/FS/Be

$LiAlO_2$/H_2O/FS/Be

$LiAlO_2$/NS/FS/Be

Flibe/He/FS/Be

---

* Evaluated for TMR only.

BCSS Evaluation

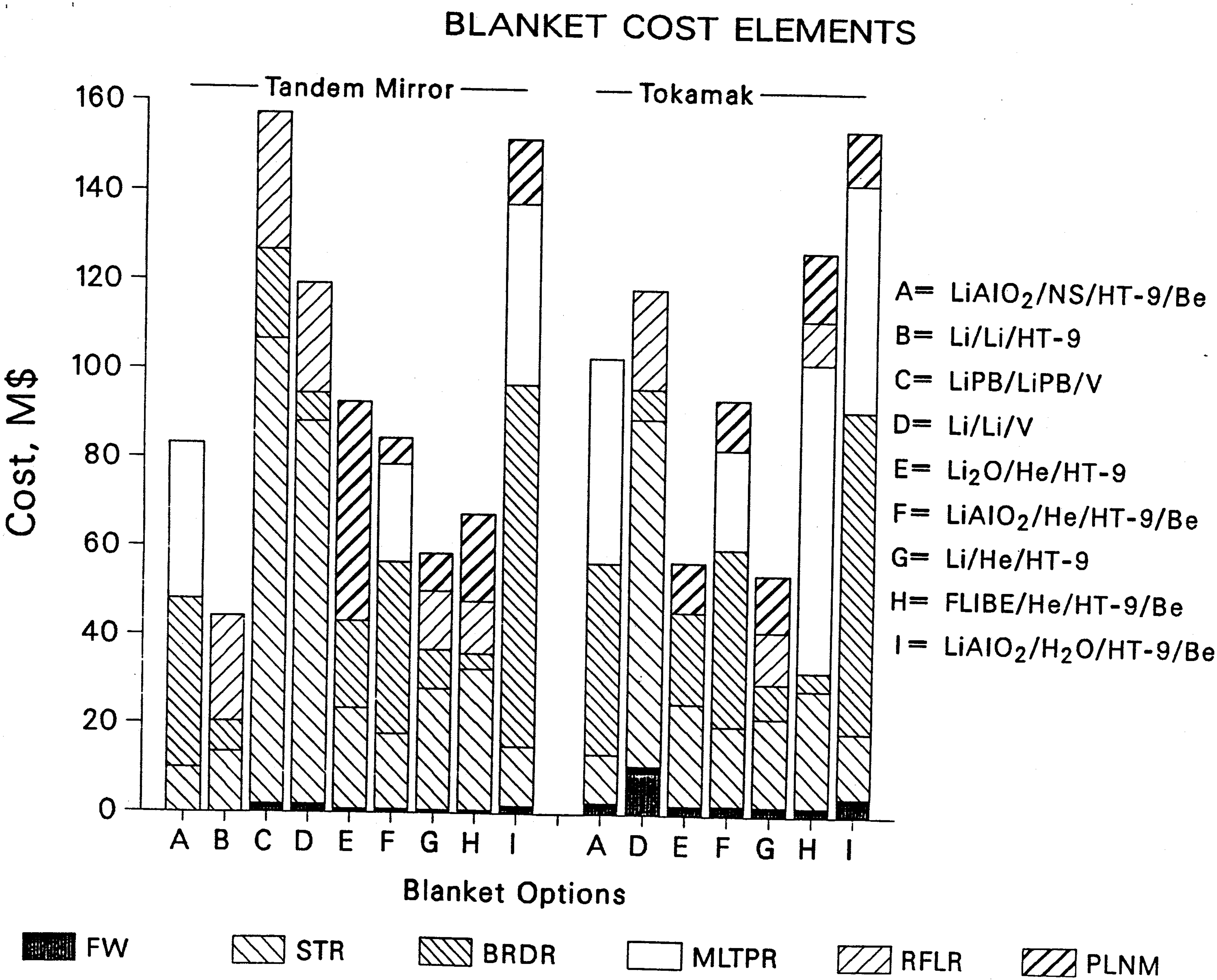
- Developed evaluation methodology and criteria for comparison of blanket concepts.

- Areas of evaluation
  - Engineering feasibility
  - Economics
  - Safety
  - R&D

Engineering Evaluation Indices

Index Name		Weighting Value (W_i)
1. Tritium Breeding and Inventory		25
2. Engineering Complexity and Fabrication		25
3. Maintenance and Repair		15
4. Resources		5[A]
5. Power Swings		10
6. Increased Capability		10
6.1 Increased Neutron Wall Loading	5	
6.2 Higher Surface Heat Flux, Higher Erosion	5	
7. Startup/Shutdown Requirements		10

[A] Assumes go/no–go materials shortage does not exist.


BLANKET COST ELEMENTS
Tandem Mirror
Tokamak
Cost, M$
160
140
120
100
80
60
40
20
0
A B C D E F G H I
A D E F G H I
Blanket Options
A= LiAlO2/NS/HT-9/Be
B= Li/Li/HT-9
C= LiPB/LiPB/V
D= Li/Li/V
E= Li2O/He/HT-9
F= LiAlO2/He/HT-9/Be
G= Li/He/HT-9
H= FLIBE/He/HT-9/Be
I= LiAlO2/H2O/HT-9/Be
FW
STR
BRDR
MLTPR
RFLR
PLNM

Safety Evaluation Indices

Index Number	Index Name	Weighting Value
1	Structure Source Term Characterization	10
2	Breeder/Multiplier Source Term Characterization	10
3	Coolant Source Term Characterization	10
4	Fault Tolerance to Breeder–Coolant Mixing	6
5	Fault Tolerance to Cooling Transients	6
6	Fault Tolerance to External Forces	6
7	Fault Tolerance to Near–Blanket Systems Interactions	6
8	Fault Tolerance of the Reactor Building to Blanket Transients	6
9	Normal Radioactive Effluents	20
10	Occupational Exposure	10
11	Waste Management	10

R&D Evaluation

- Provide a comparative assessment of the R&D.
  - Requirements
  - Risks

- R&D Figure of Merit (RDFM)
  - Risk Factor (RDR)
    - Probability of unsatisfactory performance.
    - Consequences of unsatisfactory performance.
  - Investment Factor (RDI)
    - Time scale for developement.
    - Annual operating costs.
    - Facility requirements.

$$RDFM = f(RDR) + f(RDI)$$

(Equal weighting)

Tokamak Blanket Ranking

	Engineering	Economics	Safety	R&D	Overall[c]
Li/Li/V Li/Li/FS LiPb/LiPb/V	1.000 (1)	.85[a] (3)	.998[b] (2)	.886 (2)	1.000 (1)
Li/He/FS	.750 (3)	.73 (7)	.925 (3)	1.000 (1)	.842 (3)
Li_2O/He/FS	.719 (4)	.79 (5)	1.000 (1)	.840 (3)	.878 (2)
$LiAlO_2$/He/FS/Be	.611 (7)	.79 (5)	.904 (4)	.754 (5)	.806 (6)
$LiAlO_2$/H_2O/FS/Be	.682 (5)	1.00 (1)	.597 (6)	.723 (6)	.805 (7)
$LiAlO_2$/NS/FS/Be	.849 (2)	.98 (2)	.515 (7)	.692 (7)	.831 (4)
FLIBE/He/FS/Be	.658 (6)	.84 (4)	.807 (5)	.824 (4)	.809 (5)

[a]Assumes switching from vanadium to steel outside blanket is feasible

[b]Assumes no water cooled components close to the blanket

[c]Based on equal weighting for engineering, economic, and safety evaluation results.

R&D Assessment

- A total of 29 issues were evaluated.

- Each is documented in terms of:
  - Issue description
  - Required data
  - Status of data base
  - Required resources

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

R&D Assessment

- Major issues for liquid metal blankets include MHD effects and corrosion concerns. MHD research should include the testing of insulators, particularly for tokamak applications. 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 tokamak 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.

R&D Assessment

- Achieving adequate tritium breeding is a key issue for many designs but particularly for Li_2O without neutron multipliers. In general, it is more severe for tokamaks than tandem mirrors and more severe for solid breeders compared to liquid breeders. Tritium breeding is not an issue for LiPb blankets.

- 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 of all forms by remote handling techniques are also areas of concern. The BCSS has emphasized Li_2O and $LiAlO_2$.

R&D Assessment

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

- Additional items include the 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 in tokamaks such as large pressures and torques due to plasma disruptions.

What Have We Learned From Blanket Design Studies?

- Present Uncertainties Are Too Large To Permit Selection Of Only One Option
- Substantial Experimental Data Needed Before Selection

Problem of R&D Cost

- R&D Cost Is Greatly Affected By Number Of Options Pursued
- Similar Problems For Many Fusion Nuclear Components
- Need Carefully Planned Experiments

How Do We Plan An Effective Experimental Program?

FINESSE

A STUDY OF THE ISSUES, PHENOMENA AND EXPERIMENTAL FACILITES FOR FUSION NUCLEAR TECHNOLOGY

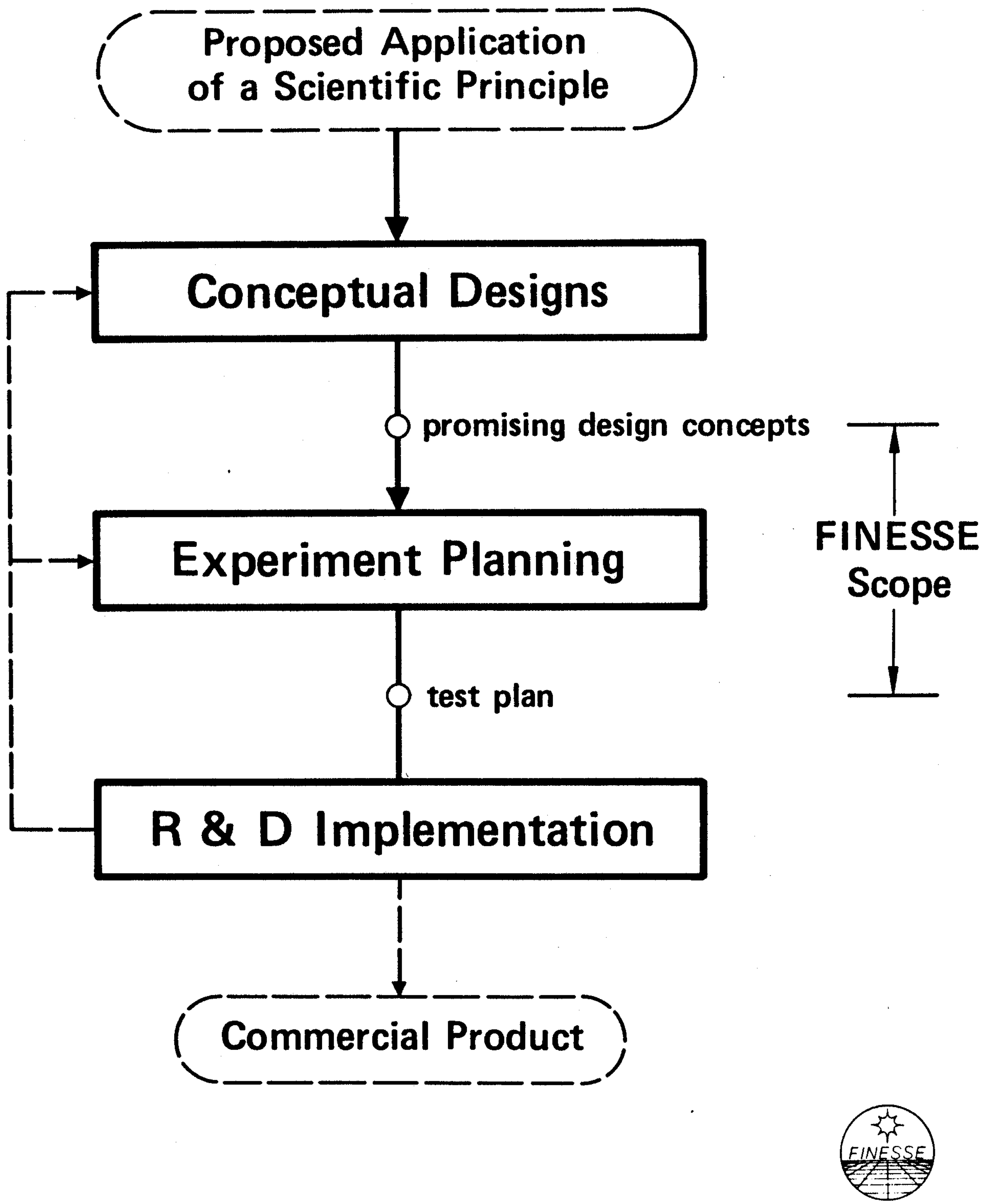
Objectives

- Understand Issues
- Develop Scientific Basis for Engineering Scaling and Experimental Planning
- Identify Characteristics, Role and Timing of Major Facilities Required

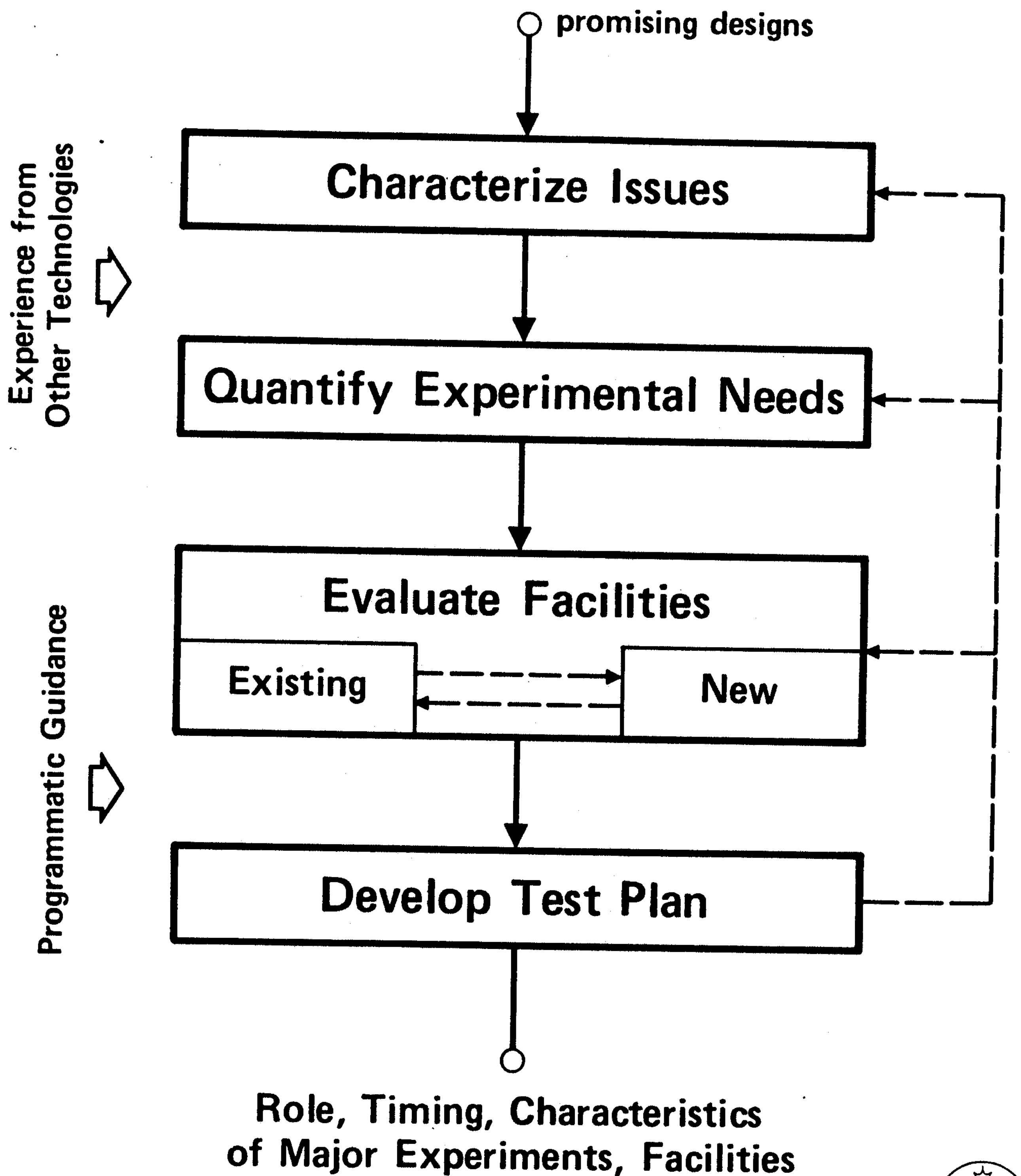
FINESSE ORGANIZATION

- Major Participation by Key U. S. Organizations:
    - UCLA, ANL, EG&G, HEDL, MDAC, TRW, GAC
    - LLNL, PPPL, LANL, SNL, ORNL
- Significant International Participation:
    - Canada, Europe, Japan
- Broad Participation by Fusion Community:
    - Advisory Committee
    - Domestic, International Workshops

EXPERIMENT PLANNING
Is a Key Element of Technology Development



FINESSE PROCESS For Experiment Planning



FUSION NUCLEAR TECHNOLOGY ISSUES HAVE BEEN:

- Identified
- Characterized
- Prioritized

POTENTIAL IMPACT

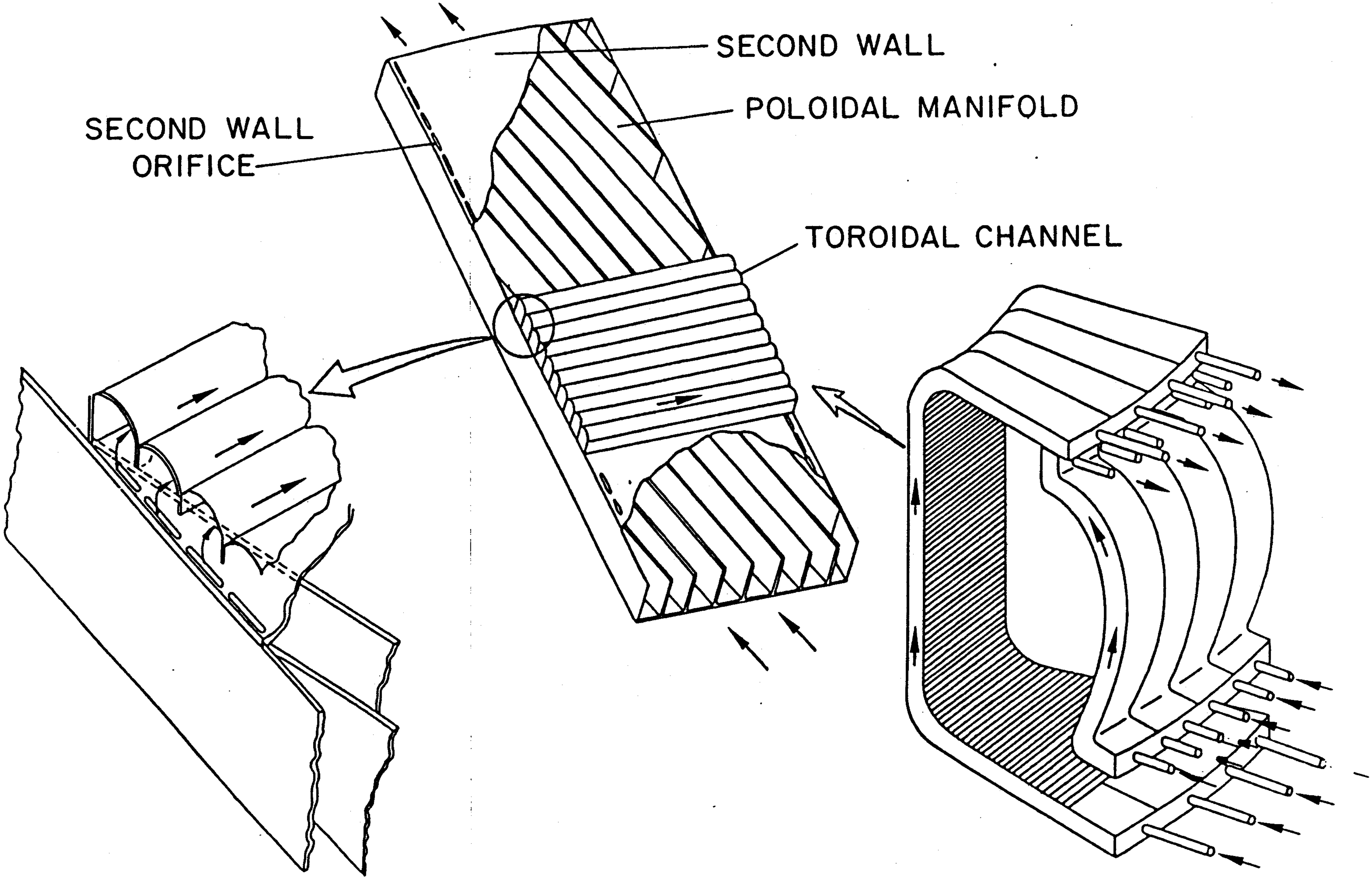
Feasibility Issues

- May Close the Design Window
- May Result in Unacceptable Safety Risk
- May Result in Unacceptable Reliability, Availability or Lifetime

Attractiveness Issues

- Reduced System Performance
- Reduced Component Lifetime
- Increased System Cost
- Less Desirable Safety or Environmental Impact

FINESSE


SECOND WALL
POLOIDAL MANIFOLD
SECOND WALL ORIFICE
TOROIDAL CHANNEL

MAJOR ISSUES FOR LIQUID METAL BLANKETS

- DT Fuel Self Sufficiency
- MHD Effects
  - Pressure Drop
  - Fluid Flow
  - Heat Transfer
- Compatibility, Corrosion
- Structural Response under Irradiation
- Tritium Extraction and Control
- Failure Modes

FINESSE

MHD PRESSURE DROP

- The MHD Pressure Drop Depends on the Device Parameters and the Blanket Wall Thicknesses

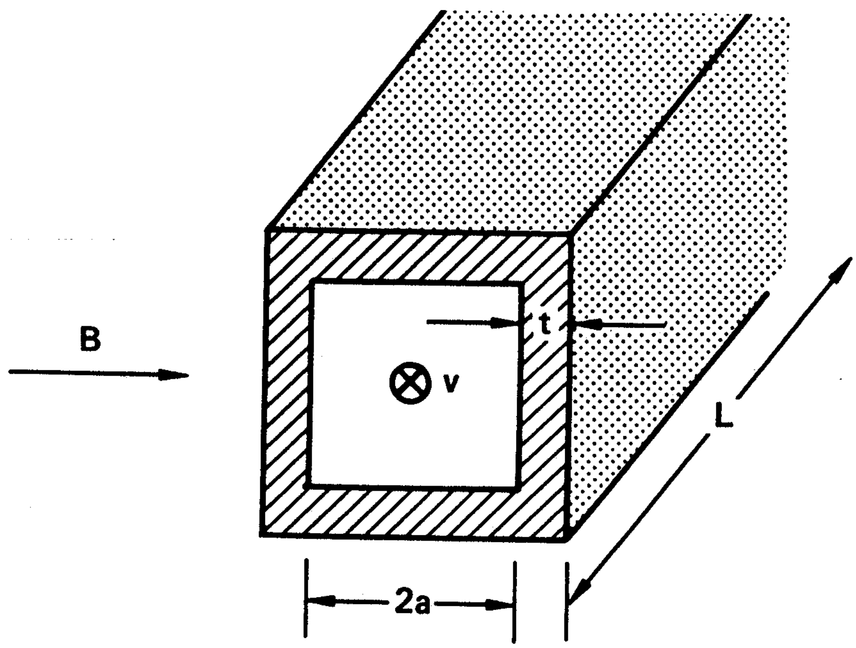
$$\Delta p \simeq \sigma_f v B^2 L \phi$$

$$\phi = \frac{\sigma_w t}{\sigma_f a}$$

- But the Pressure Stress is Relatively Insensitive to the Wall Thickness

$$\sigma = \frac{pa}{t} \sim \sigma_w v B^2 L$$

- The Maximum Allowable Pressure Stress Limits the Flow Velocity. This Conflicts with Heat Transfer Requirements.



UNCERTAINTIES IN MHD PRESSURE DROP

MHD Flow in Conducting Structures Requires the Simultaneous Solution of Electromagnetic and Fluid Flow Equations in Complex Geometrical Configurations

Uncertainties Arise From:

- Complex Three-Dimensional Flow Effects (Internal Channel Geometry)

  Bends, Contractions, Manifolding, etc.

- Complex Magnetic Field Effects

  Sensitivity to Direction of Field

  Field Gradients

- Complex Structure Geometry Effects (External Channel Geometry)

  Multiple Channel Effects

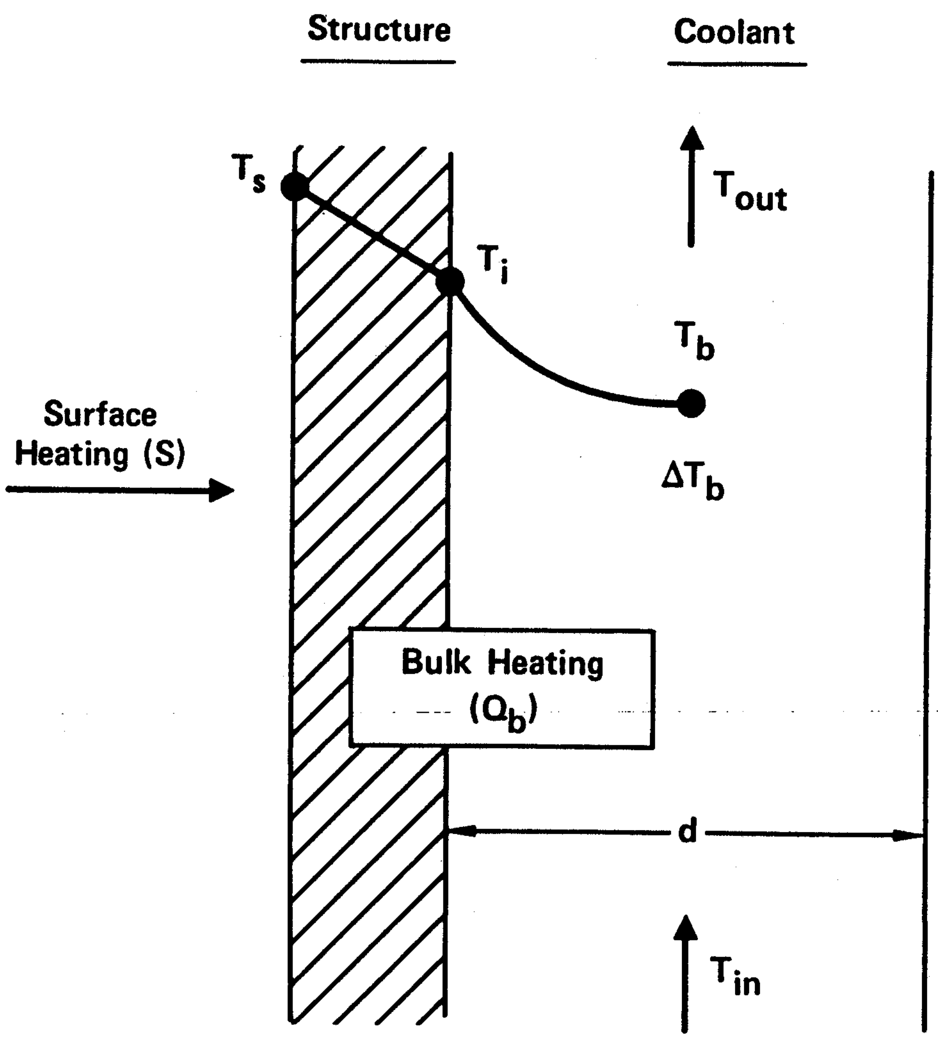
  Leakage Currents

HEAT TRANSFER REQUIREMENTS

The Minimum Inlet Temperature and Maximum Structure and Interface Temperatures Place Upper Limits on $\Delta T_b = T_{out} - T_{in}$

This Translates to a Lower Limit on Flow Velocity.

$$\rho \, c_p \, v \, \Delta T_b = \frac{L}{d} (S + Q_b)$$



$$T_s = T_{in} + \Delta T_b + \Delta T_{film} + \Delta T_s \leqslant T_s^{max}$$

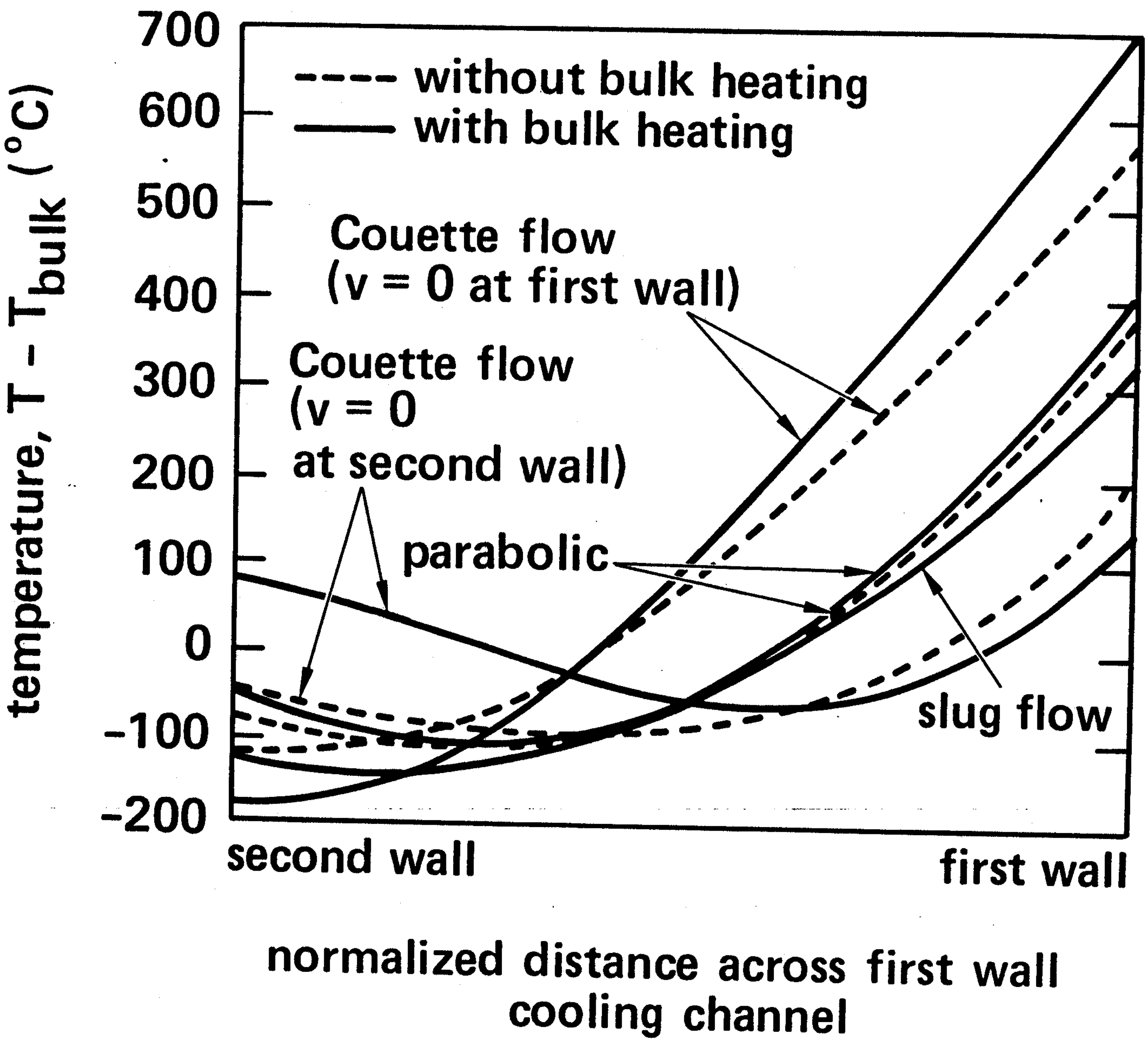
MHD FLUID FLOW PHENOMENA

The Magnetic Field Dominates the Velocity Profiles in a Liquid Metal Blanket, Resulting in

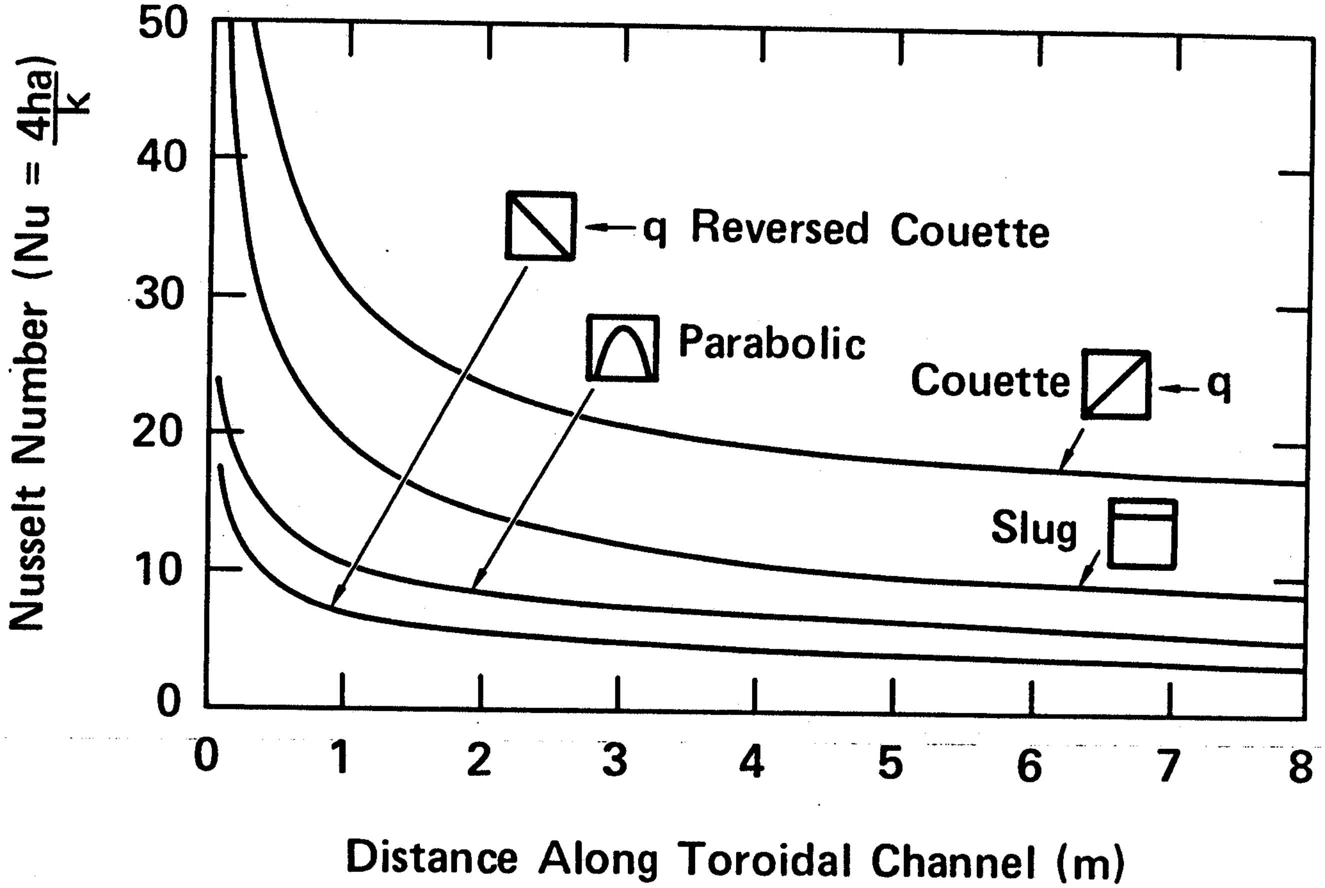
- Turbulence Supression
  - Long Entry Lengths for Heat and Mass Transfer
  - Reduced Heat and Mass Transfer in the Coolant
- Very Thin Boundary Layers
  - Enhanced Corrosion
- High Velocity Fluid Jets

The Uncertainties in MHD Fluid Flow Are Similar to Those for MHD Pressure Drop i.e., Geometric Complexities in Flow, Magnetic Field, and Structure Geometry

Temperature Profiles Depend Strongly on the Velocity Profile

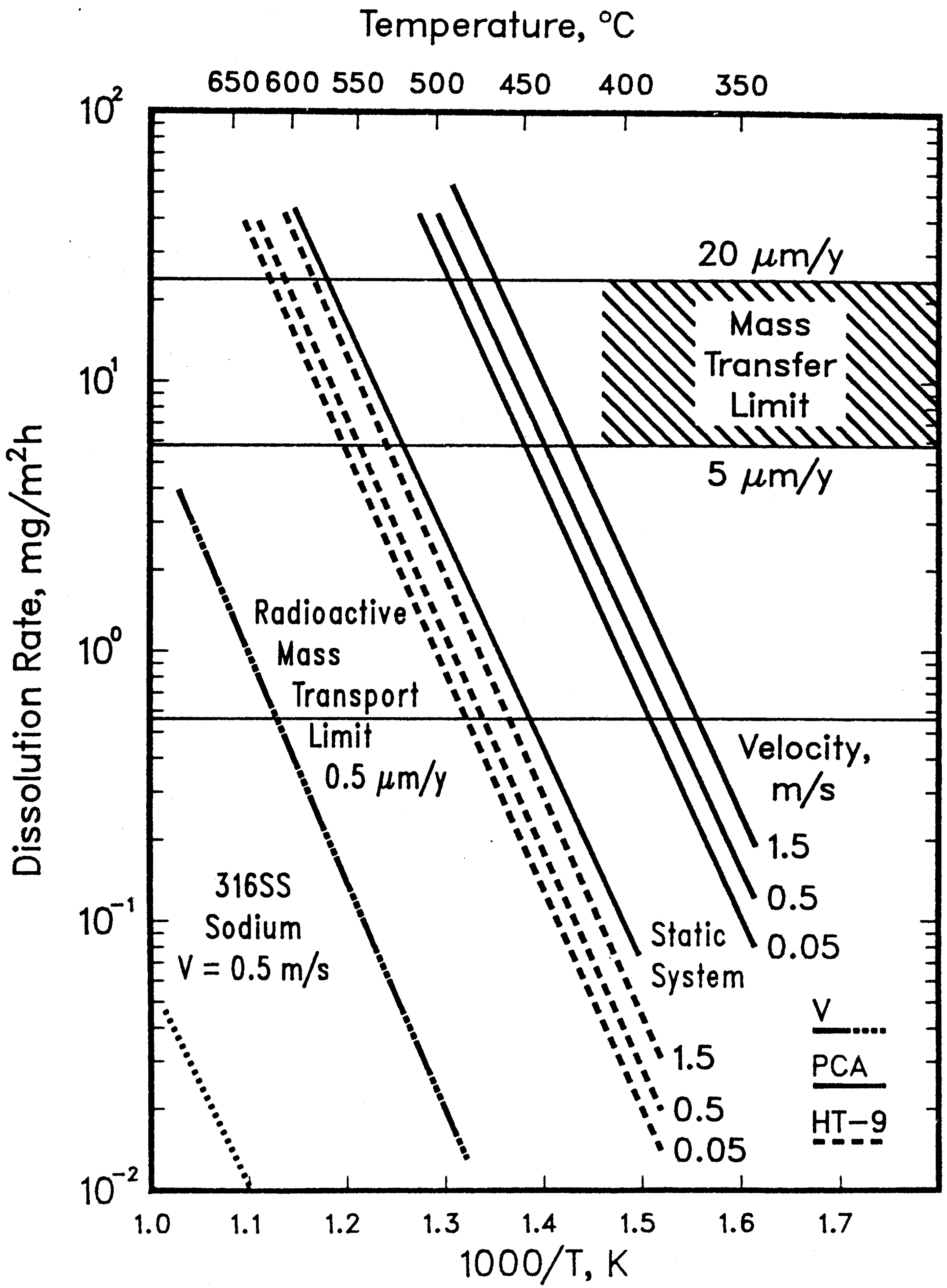


In Laminar Flow, the Heat Transfer Coefficient Depends on the Velocity Profile and Varies Throughout the Entire Blanket



LIQUID METAL CORROSION PHENOMENA

- Mass Transport in the Primary Coolant System
  - Plugging
  - Activated Material Transport
- Localized Wall Thinning
- Selective Dissolution (e.g. Ferrite Layer Formation in Stainless Steel)
- Embrittlement
  - Due to Liquid Metal (Especially LiPb)
  - Due to Impurities (Especially Vanadium)


Temperature, °C
650 600 550 500 450 400 350
Dissolution Rate, mg/m²h
10²
10¹
10⁰
10⁻¹
10⁻²
20 μm/y
Mass
Transfer
Limit
5 μm/y
Radioactive
Mass
Transport
Limit
0.5 μm/y
Velocity,
m/s
1.5
0.5
0.05
Static
System
316SS
Sodium
V = 0.5 m/s
1.5
0.5
0.05
V
PCA
HT-9
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7
1000/T, K

UNCERTAINTIES IN LIQUID METAL CORROSION

- New Materials

  The Basic Materials Interactions are Poorly Understood and Poorly Quantified

- Unique Environment

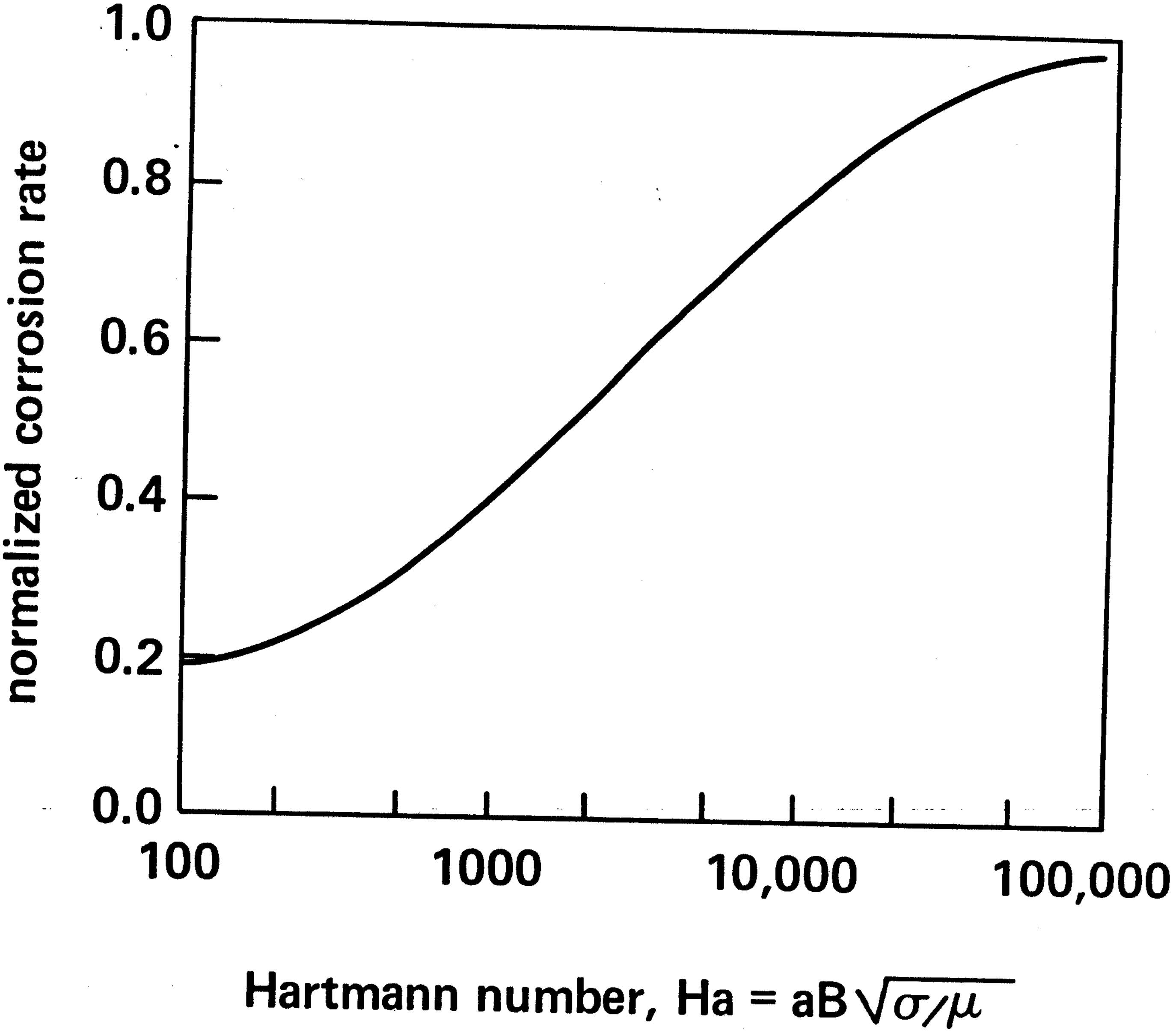
  MHD Effects (Coupled Heat, Mass, and Momentum Transport)

  Loop Effects

  Irradiation Effects

FINESSE

The Corrosion Rate is Strongly Influenced by MHD Velocity Profiles



FINESSE

DESIGN WINDOW ISSUES

Issue

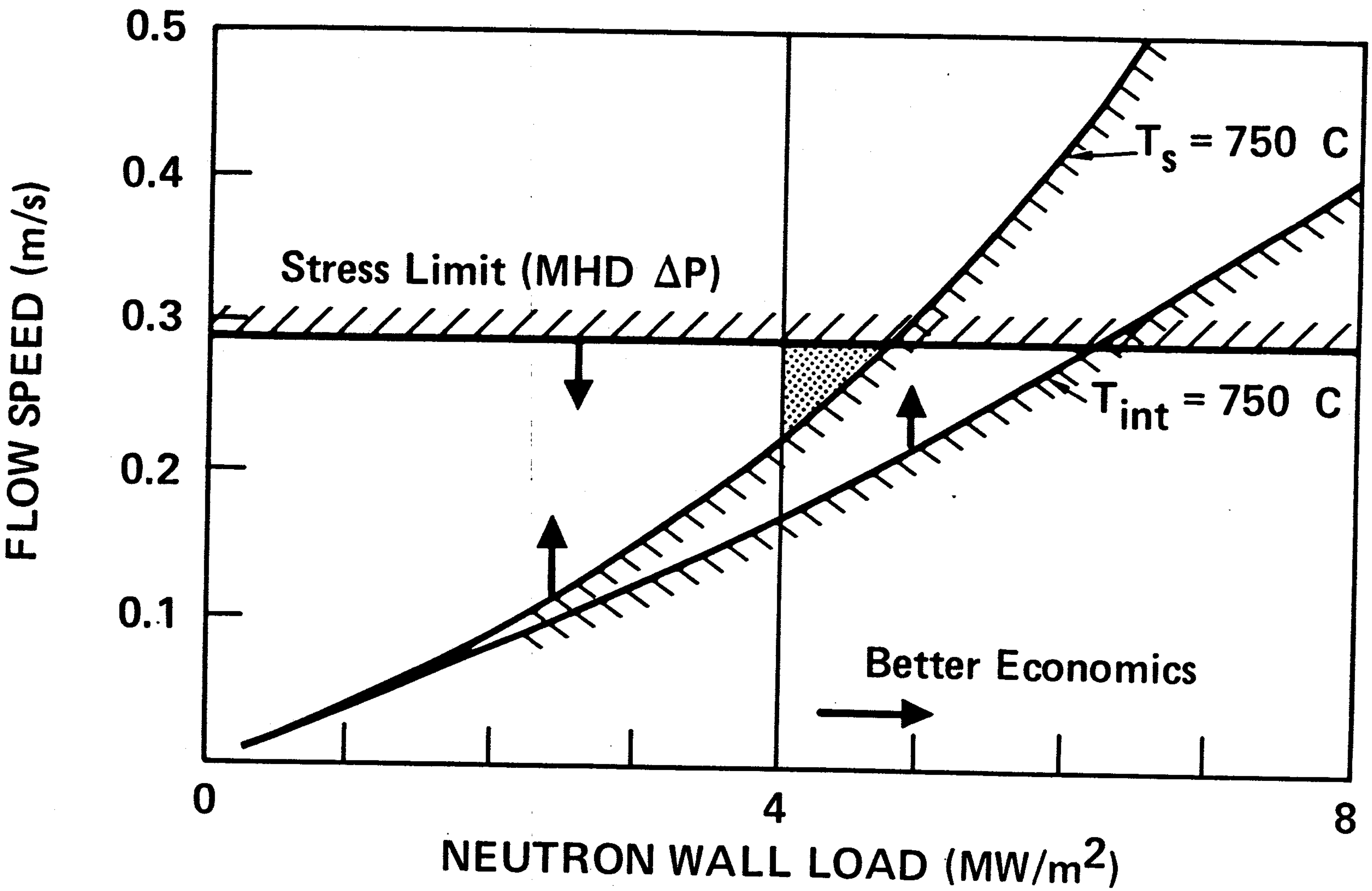
An Effect That Imposes a Limit on Design Window Represents an Issue

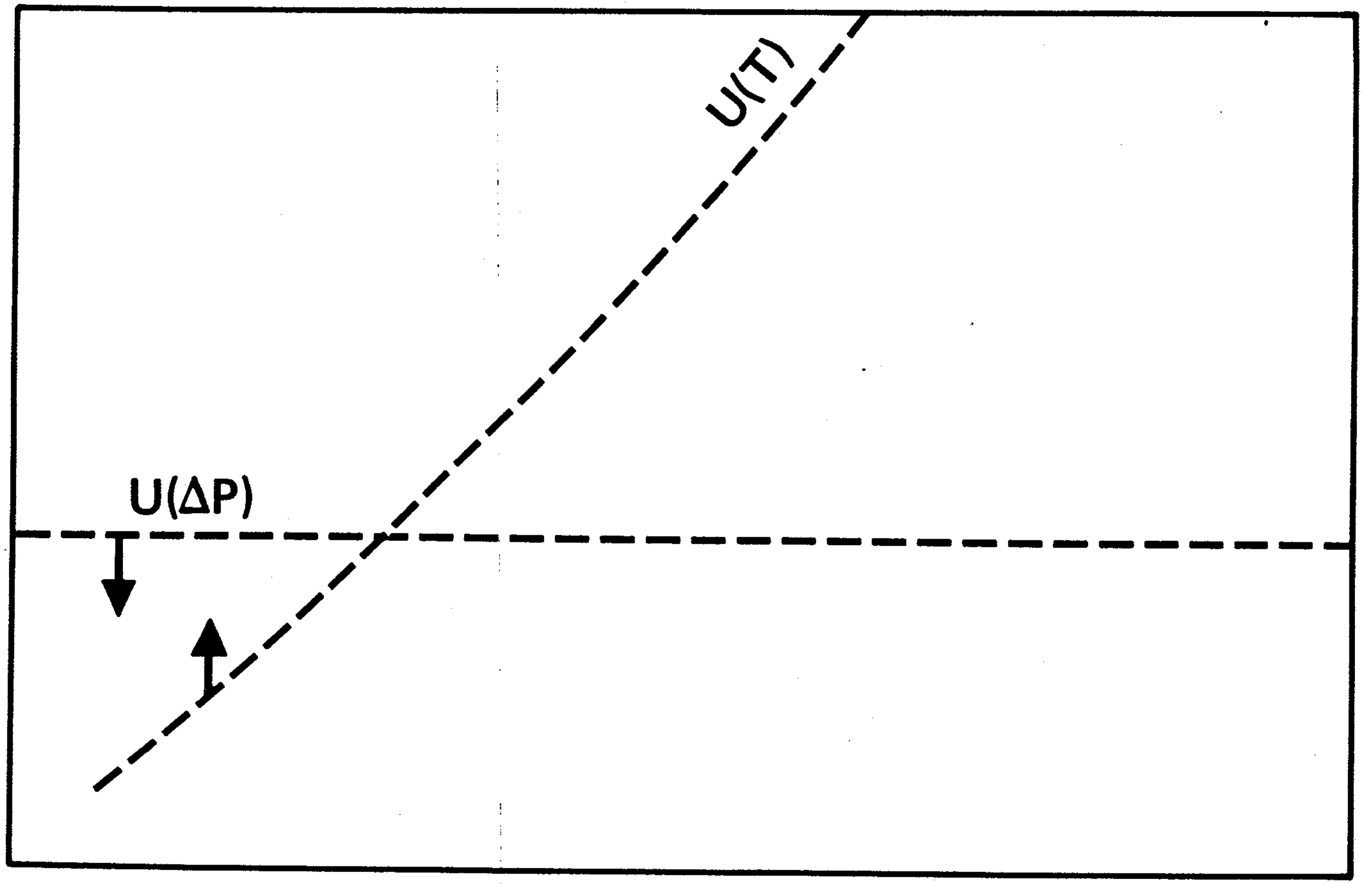
Important

If Uncertainty in Defining the Limit is Wider Than Design Window, the Issue is Important

FINESSE

Design Window Is Narrow For Best Liquid Metal Blanket (Li/V)

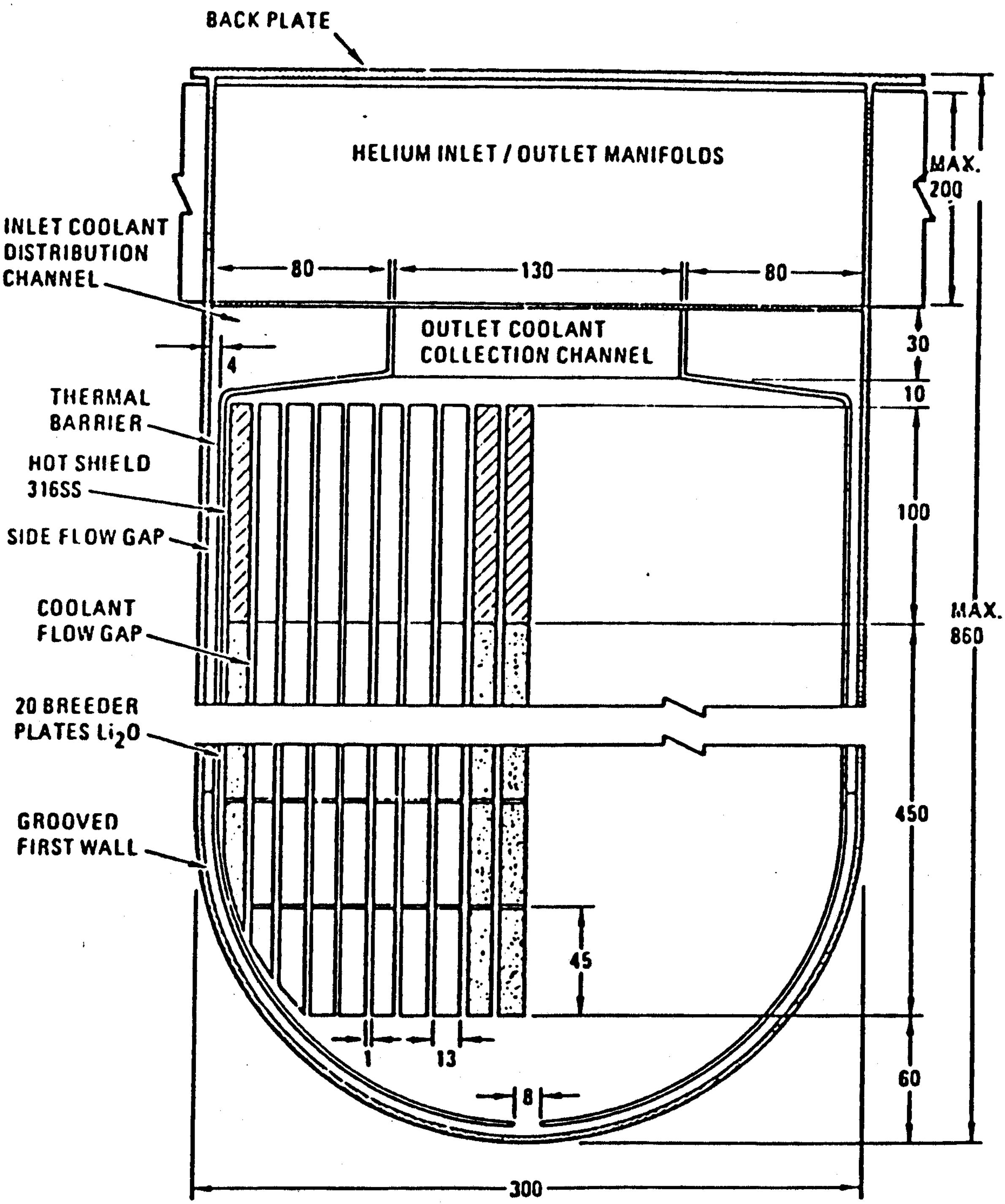




U(T): Any of:
T_s = 650 C
T_{int} = 550 C
h_m = 0.7h

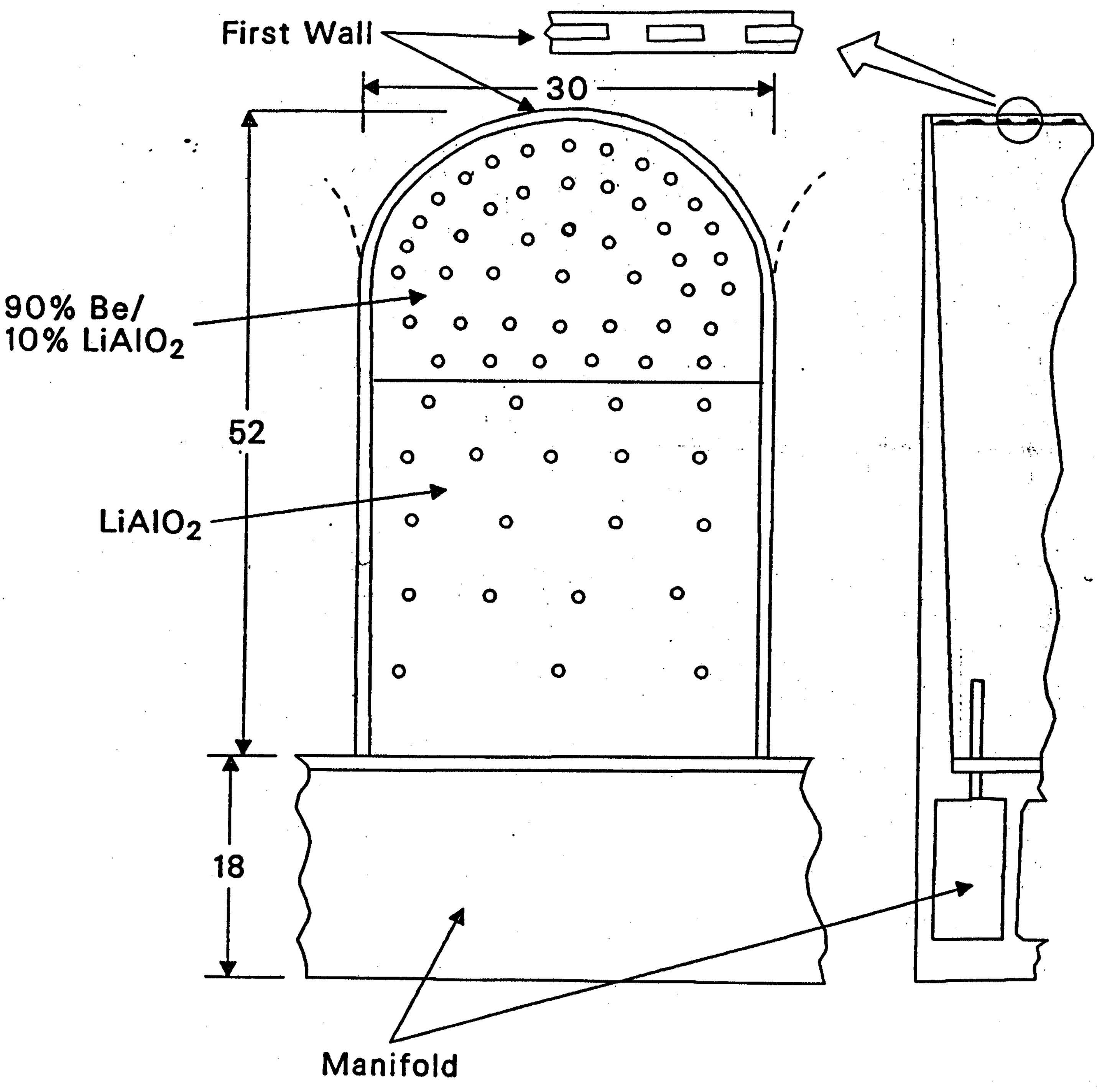
Uncertainties in MHD, Corrosion, Heat Transfer, Radiation Effects Represent Major Issues

BLANKET MODULE CROSS SECTION (AN EXAMPLE)



ALL DIMENSIONS IN mm

REFERENCE DESIGN CONFIGURATION FOR $LiAlO_2/H_2O/FS/Be$ CONCEPT - TOKAMAK



42

MAJOR ISSUES FOR SOLID BREEDER BLANKETS

- DT Fuel Self Sufficiency
- Tritium Recovery, Inventory
- Breeder Temperature Window and Control
- Irradiation Effects: Structure, Breeder, Multiplier
- Thermal/Mechanical Interaction:
  Breeder/Structure/Multiplier/Coolant
- Tritium Permeation (T_2, T_2O)
- Failure Modes

FINESSE

DT FUEL SELF SUFFICIENCY

- Critical Requirement for Renewable Energy Source
- Self-Sufficiency Condition:

  Achievable TBR > Required TBR

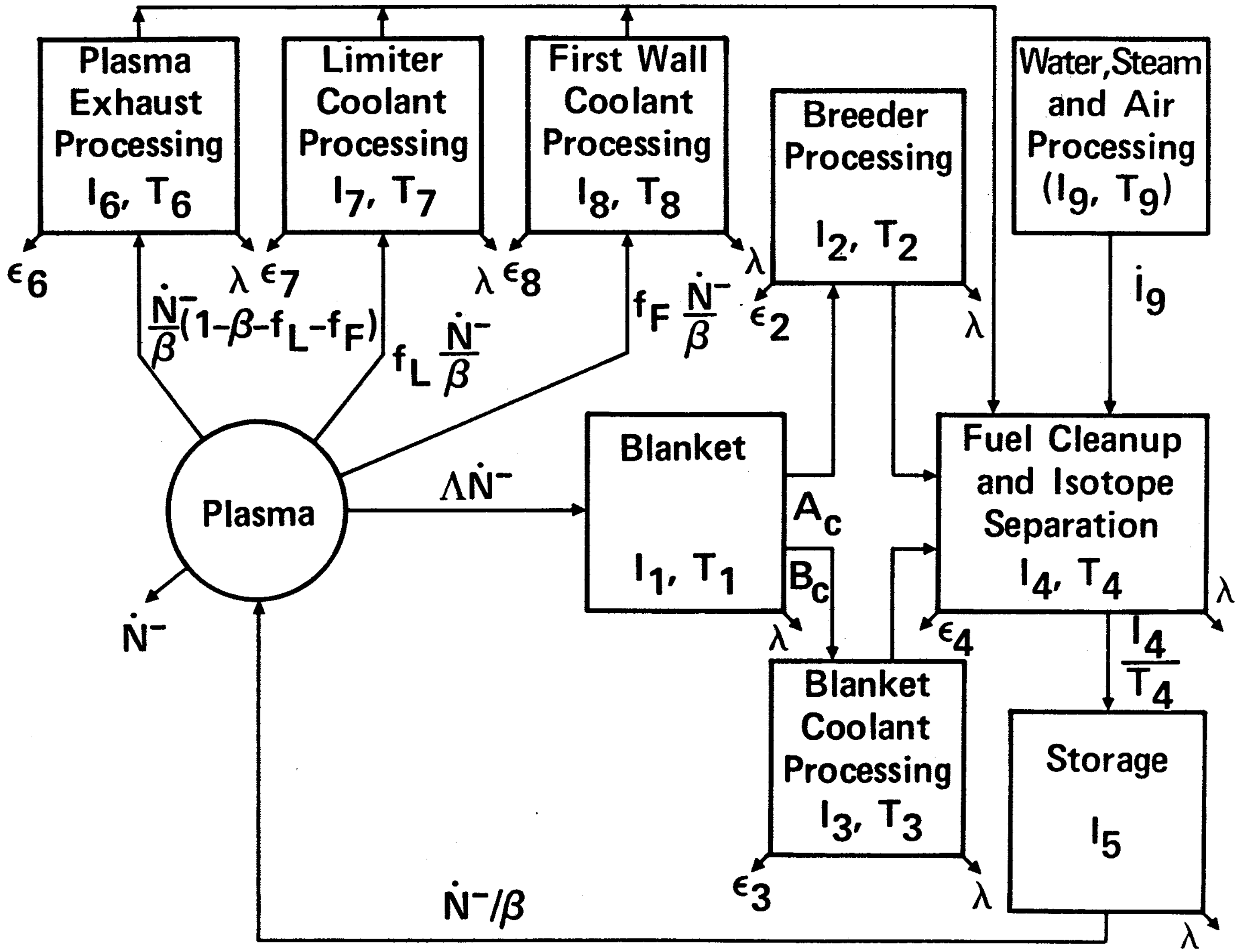
- Achievable TBR Analysis Shows:
  - TBR Strong Function of Reactor System, Blanket Concept
  - Best Blanket Concepts: TBR $\sim$1.05 - 1.2

    Present Uncertainties: $\sim$20%

- Required TBR Analysis Shows:
  - Strong Function of Several Physics, Engineering Parameters

FINESSE

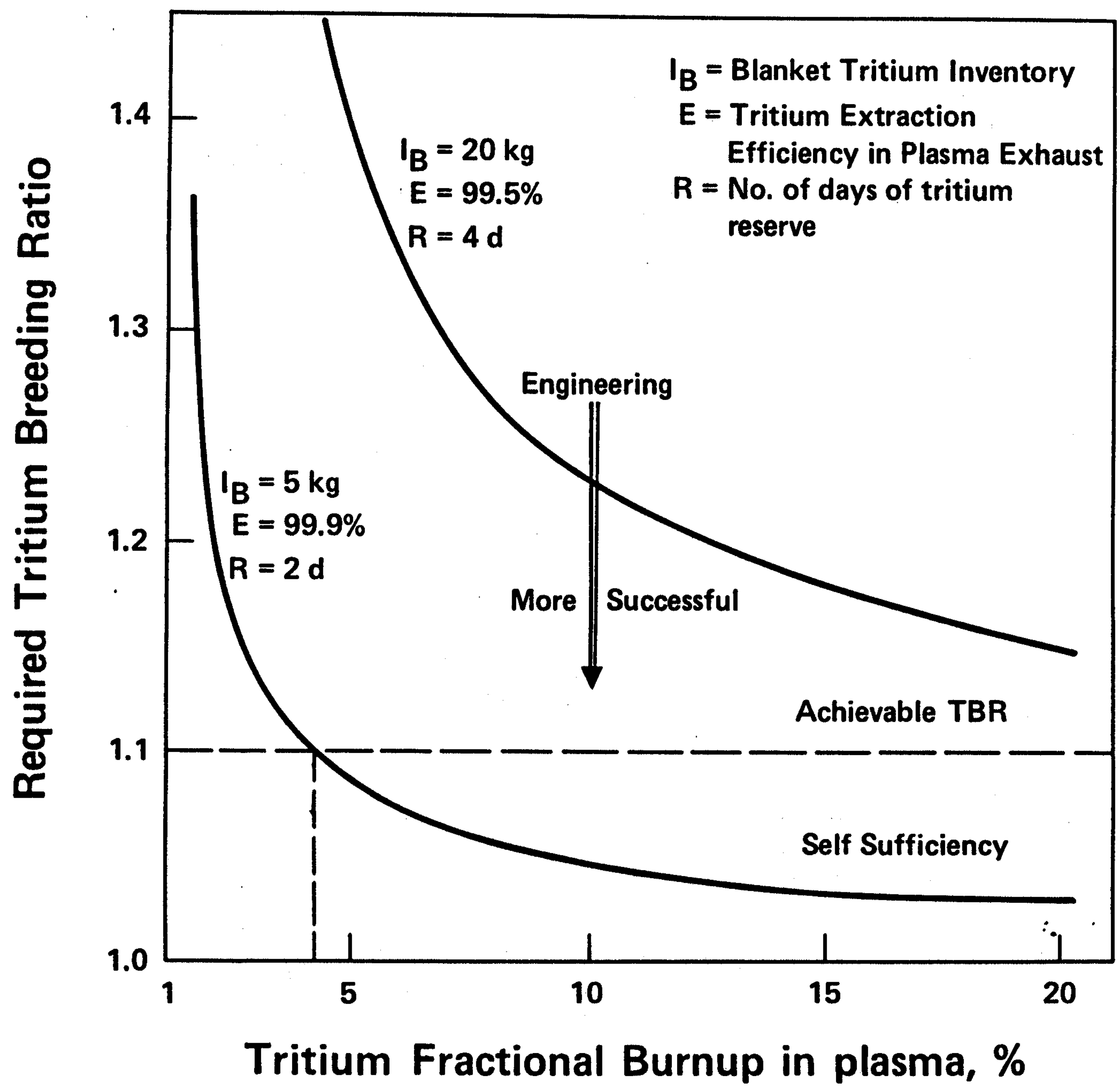
Schematic model of the fuel cycle for a DT fusion reactor used in the present work



ACHIEVABLE AND REQUIRED TRITIUM BREEDING RATIOS AND UNCERTAINTIES FOR LEADING BLANKETS IN TOKAMAKS

	Achievable Λ_a		Required Λ_r		
Concept	Λ_c	Δ_a	$1 + G_o$	Δ_g	$\varepsilon = \Lambda_a - \Lambda_r$
$LiAlO_2$/DS/HT9/Be	1.24	0.22	1.077	0.143	-0.20
LiPb/LiPb/V	1.30	0.24	1.072	0.142	-0.15
Li/Li/V	1.28	0.24	1.072	0.142	-0.17
Li_2O/He/HT9	1.11	0.21	1.077	0.143	-0.32
$LiAlO_2$/He/HT9/Be	1.04	0.19	1.077	0.143	-0.37
Li/He/HT9	1.16	0.22	1.072	0.142	-0.27
$LiAlO_2$/H_2O/HT9/Be	1.16	0.21	1.077	0.143	-0.27

Attaining DT Fuel Self Sufficiency Requires Success in Physics and Engineering



FINESSE

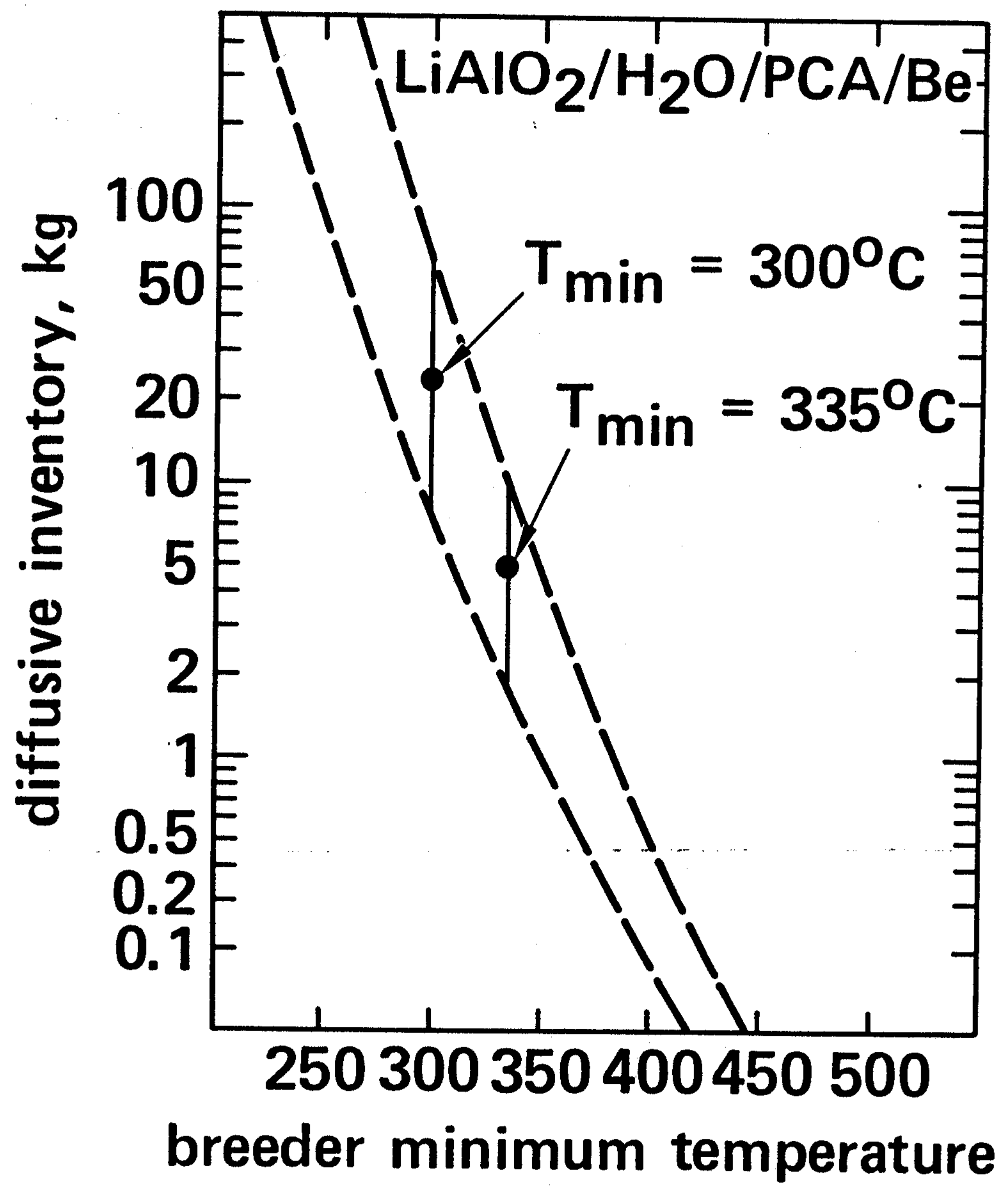
1.14

KEY CONCLUSIONS ON TRITIUM BREEDING

- Major uncertainties in attaining DT fuel self sufficiency include:
  - Plasma burnup fraction.
  - Required doubling time.
  - Tritium processing efficiency.

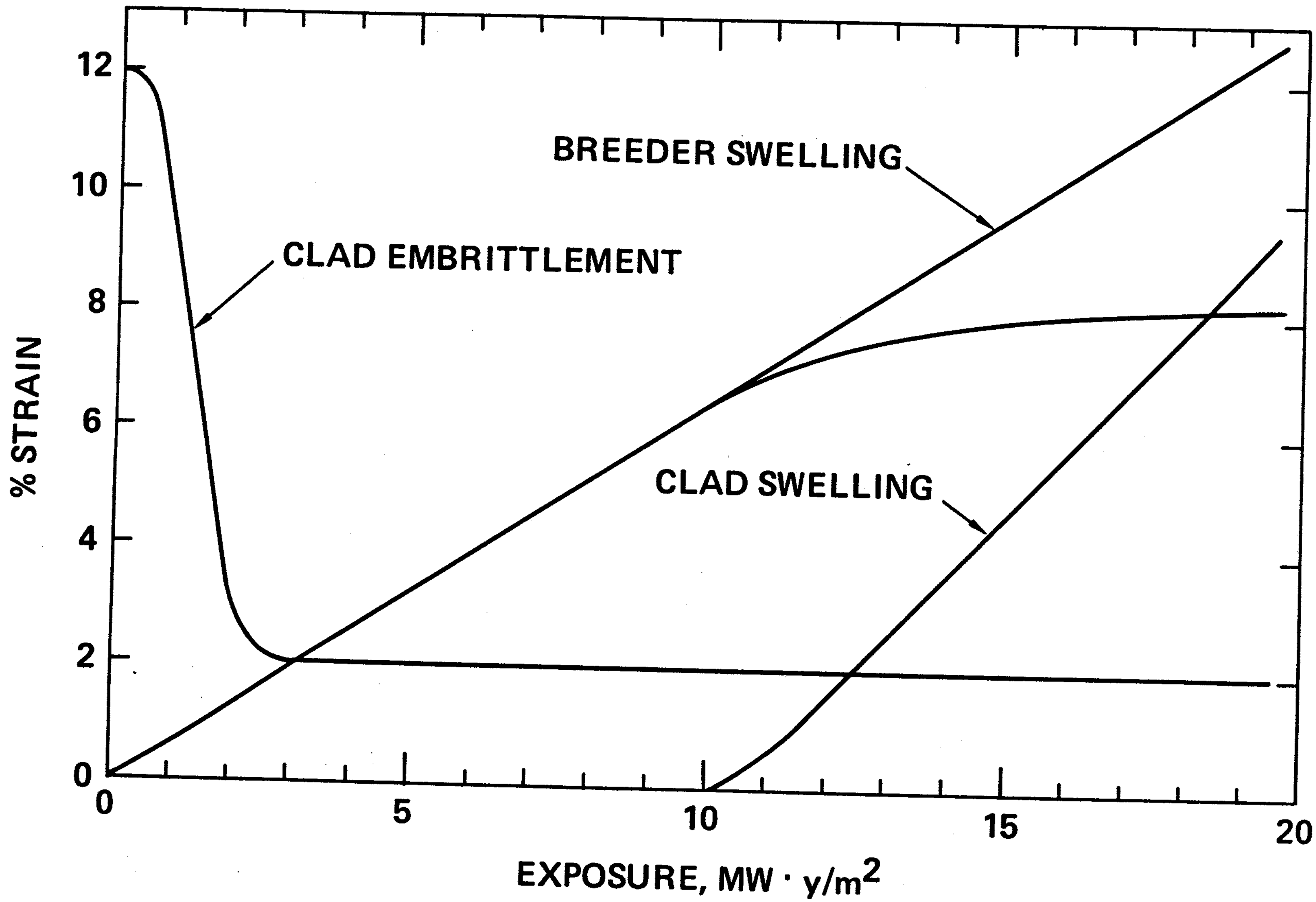
- Beryllium is the only reasonable neutron multiplier option.
  - Resources are probably adequate if reprocessing is acceptable.
  - Believe swelling can be accommodated.

Uncertainties in tritium diffusion rate and breeder temperature affect blanket inventory.



FINESSE

CLAD/BREEDER MECHANICAL INTERACTION
(ESTIMATES FOR Li_2O/HT-9/He)



FINESSE

MAJOR ISSUES FOR PLASMA INTERACTIVE COMPONENTS (First Wall, Limiter, Divertor, etc.)

- Erosion and Redeposition Mechanisms and Rates under Various Plasma Edge Conditions
- Thermomechanical Loading and Response
- Electromagnetic Loading and Response

FINESSE

MAJOR ISSUES FOR TRITIUM PROCESSING SYSTEM

- Plasma Exhaust Processing: Impurity Removal from Fuel
  - Extraction Efficiency
  - Reliability
- Coolant: Tritium Permeation and Processing
- Cryopumps Performance, Lifetime
- Reactor Room Air Detritiation Efficiency, Reliability
- Tritium Monitoring, Accountablility

FINESSE

MAJOR ISSUES FOR RADIATION SHIELDING:

- Accuracy of Prediction
- Data on Radiation Protection Requirements

MAJOR ISSUES FOR INSTRUMENTATION AND CONTROL

- Accuracy, Decalibration in Fusion Environment
- Lifetime under Irradiation

FINESSE

TYPES OF EXPERIMENTS (TESTS)

- **BASIC Tests**

  Basic Property Measurements

- **SEPARATE EFFECT Tests**

  Explore Simple Phenomena

- **MULTIPLE EFFECT/INTERACTION Tests**

  Explore Complex Phenomena

  Multiple Environmental Conditions

  Multiple Interactions among Physical Elements

- **INTEGRATED Tests**

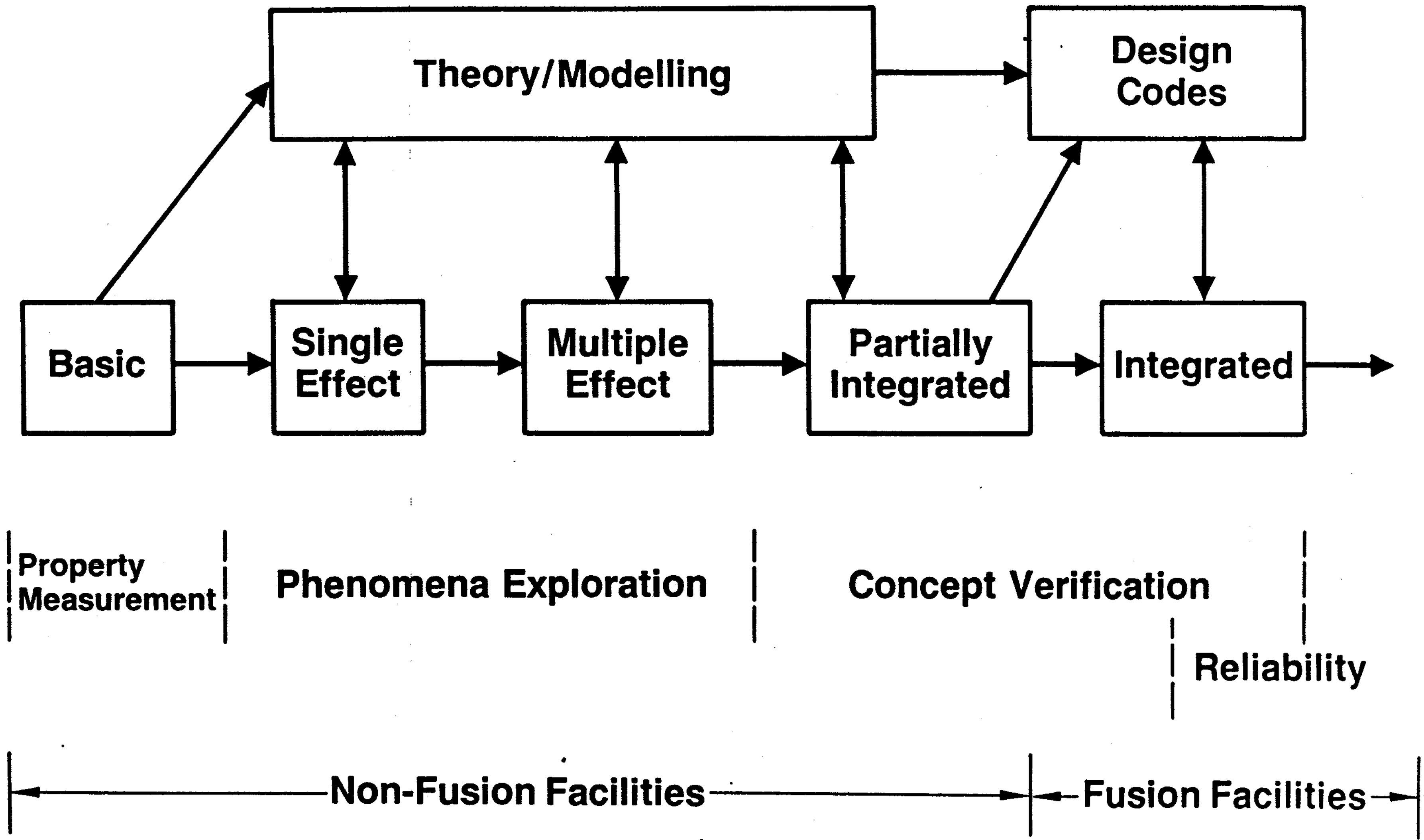
  Concept Verification, Engineering Data

  All Environmental Conditions, Physical Elements

- **COMPONENT Tests**

  Full-Size Component under Prototypical Conditions

FINESSE


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

FACILITIES FOR NUCLEAR EXPERIMENTS

- Non-Neutron Test Stands
- Neutron-Producing Facilities:
  - Point Neutron Sources
  - Fission Reactors
  - Fusion Devices

NON-NEUTRON TEST STANDS

- Can Play an Important Role:
  - Particularly for Fluid Flow/ Electromagnetic Issues
  - When Radiation Effects and Extensive Bulk Heating are Not Dominant Issues
- More Useful for Liquid Metal Blankets;

  Limited Value for Solid Breeder Blankets
- New Facilities are Required

FINESSE

POINT NEUTRON SOURCES CAPABILITIES

Facility	Status	Peak Flux* $n/cm^2 \cdot s$	Testing Volume cm^3
RTNS–II	In Use	5×10^{12}	0.1
LAMPF A–6	Operational	1×10^{13}	20000
FMIT	Design Completed Project Deferred	1×10^{15}	10

*Fusion First Wall Flux at 5 MW/m^2:
2×10^{15} $n/cm^2 \cdot s$

FINESSE

POINT NEUTRON SOURCES CONCLUSIONS

- Existing Sources Very Limited in Flux and Volume
  - Best Suited for:

    Neutronics Studies

    Limited Miniature Specimen Irradiation
- FMIT Can Provide High Fluence
  - Fission Reactor Testing Still Required
  - Fusion Reactor Testing Still Required

FISSION REACTOR UTILIZATION

Incentive for Use

Only Source Available Now to Provide:

- "Bulk Heating" in Significant Volume (Unit Cell) Experiments
- Significant Fluence

Limitations

- Different Spectrum
- Limitations on Simulating Fusion Environment (Electromagnetics, Surface Heat Flux, etc.)
- Limits on Temperature
- Small Test Size (<15 cm)

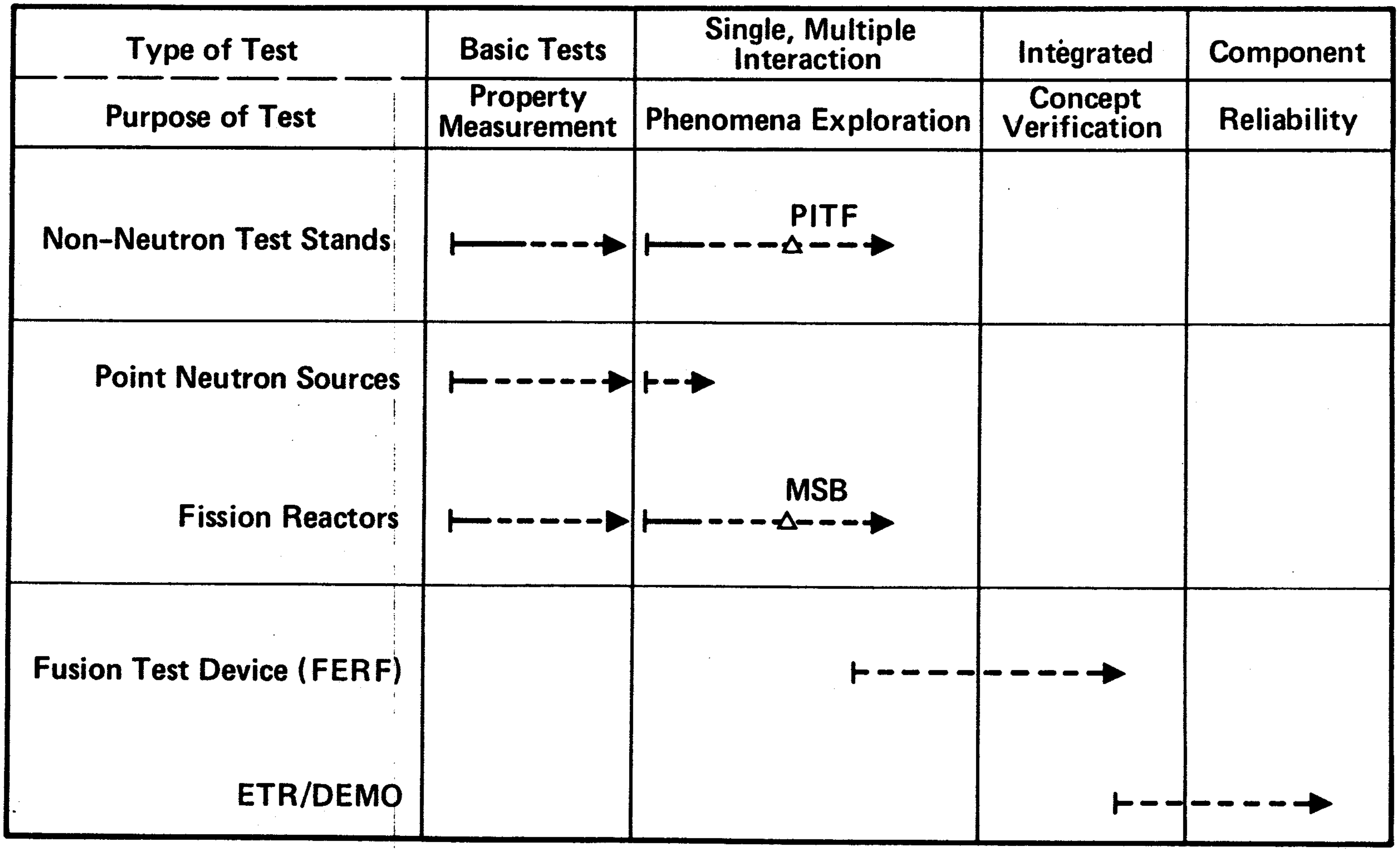
FINESSE

FISSION REACTOR UTILIZATION

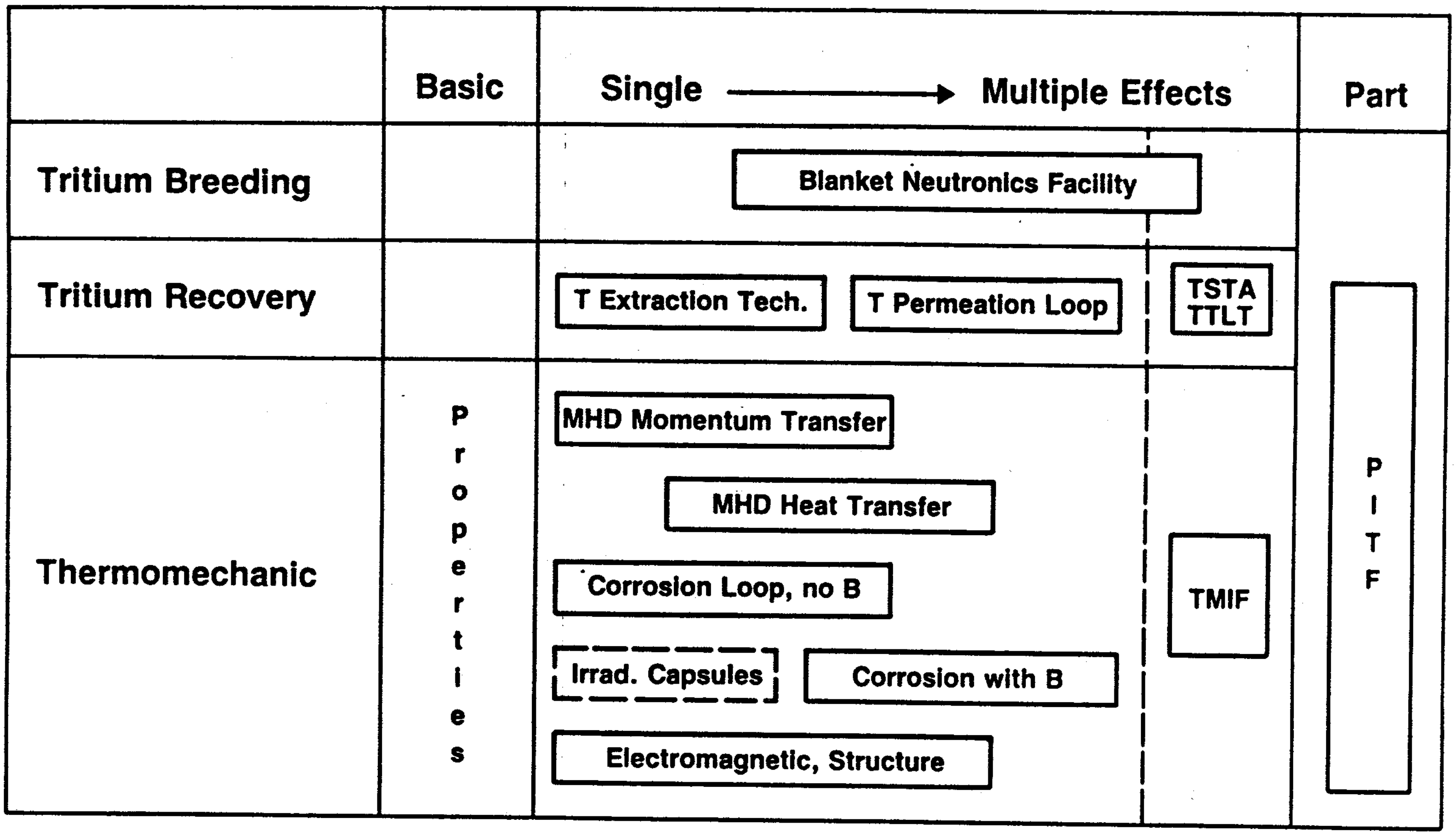
- Fission Reactors Can, Should Be Used to Address Many Important FNT Issues
- Suitable, Necessary for Solid Breeders
- Not as Useful for Liquid Metals
- Characteristics and Timing of Major Solid Breeder Experiments in Fission Reactors Are Being Developed

FINESSE

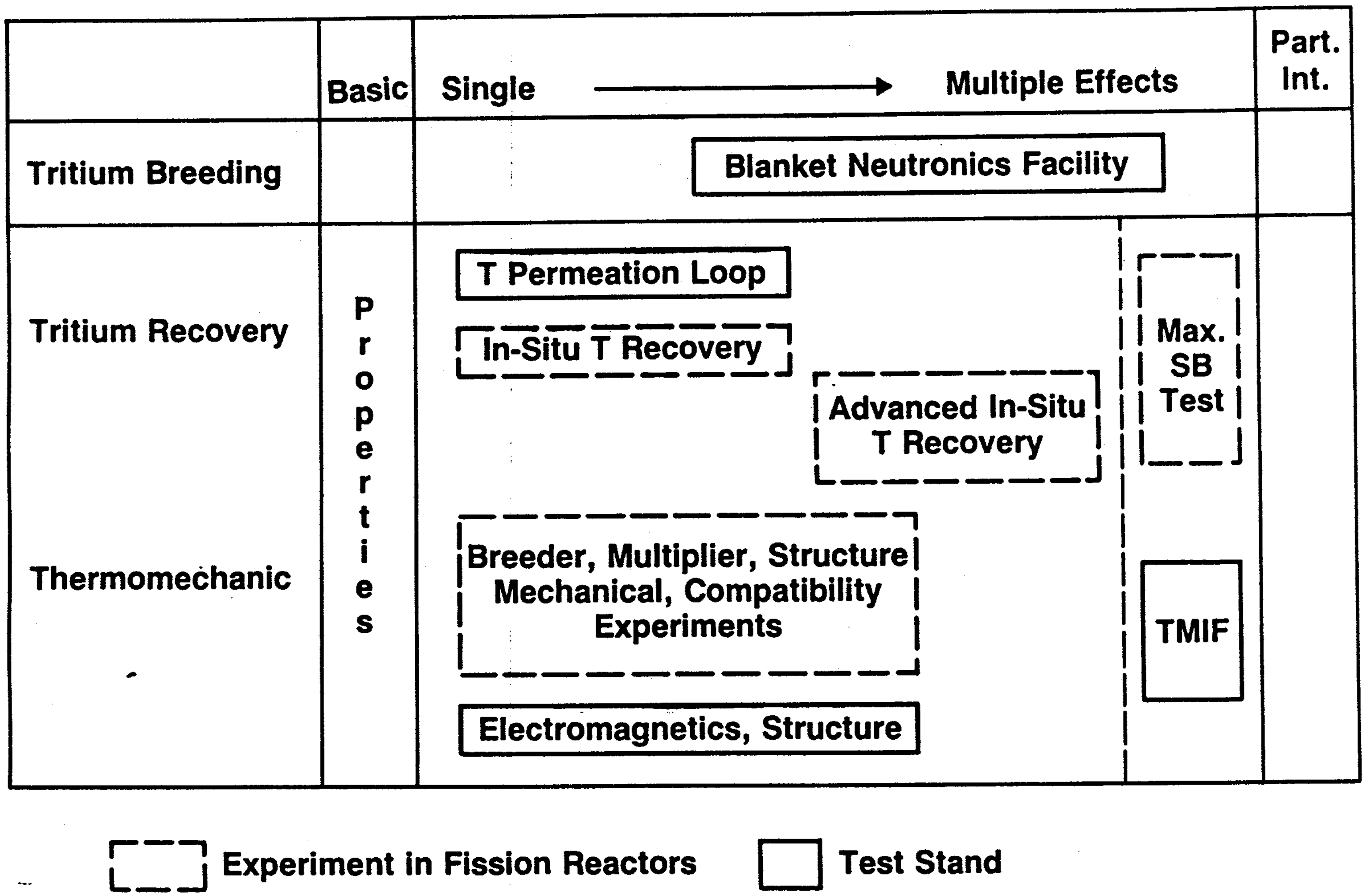
Role of Facilities For Fusion Nuclear Technology



Liquid Metal Blanket Experiments, Facilities



Solid Breeder Blanket Experiments, Facilities



SUMMARY OBSERVATIONS

- Fusion Nuclear Technology Poses Critical Issues:

  Feasibility

  Attractiveness (Safety, Economics)

- Resolving These Issues Requires:

  New Knowledge

  Experiments, Theory

- Will Involve High Cost, Long Lead Time

- A Technical Process of Studying Issues, Quantifying Testing Needs and Evaluating Experimental Facilities is Very Useful in Providing Decision Makers with Technical Input for Effective R & D Planning

FINESSE

SUMMARY OBSERVATIONS (CONTINUED)

- From Now to 1990's (or until a DT Fusion Device Becomes Available), Testing is Possible Only in Non–Fusion Facilities:

  Non–Neutron Test Stands

  Fission Reactors

  Point Neutron Sources

- Non–Fusion Facilities Can Address Many of Fusion Nuclear Technology Issues

- A Number of Non–Neutron Test Stands Can Be Constructed at a Reasonable Cost to Address Many FNT Issues, e.g., Liquid Metal Blanket Issues

- Many Important Experiments Can Be Performed in Fission Reactors, e.g., Unit Cell for Solid Breeders

FINESSE

SUMMARY OBSERVATIONS (CONTINUED)

- First Generation DT Fusion Devices, When They Become Available, Will Provide the Earliest Opportunity for FNT Integrated Tests
    - Critical for Concept Verification
- Effective FNT Integrated Tests Impose Quantifiable Requirements on Fusion Device Parameters (e.g., Wall Load, Plasma Burn Time)
- FNT Testing Needs Can Be Satisfied with Relatively Low Fusion Power (< 50 MW), But Requires Relatively Long Testing Time (Several Years)

FINESSE

SUMMARY OBSERVATIONS (CONTINUED)

Number of Blanket Options (Breeder/Coolant/Structure/Multiplier) Greatly Affects R & D Cost

- However, Present Uncertainties with All Options Appear Too Large to Permit Selection of Only One Option
- More Experimental Data Will Permit Reducing Number of Options
- The Degree of Risk in Selecting One Option Prior to Testing in Fusion Devices Will Become Clearer after Obtaining More Data from Testing in Non–Fusion Facilities

FINESSE

In Summary

- Fusion Nuclear Technology Is Very Important
- Much Work Needs To Be Done
- International Cooperation Can Play a Key Role
- FINESSE Welcomes Working with ALL to:
  - Define FNT R&D Needs
  - Define Technical Areas of Common Interest