FINESSE OVERVIEW

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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

FINESSE PRINCIPAL TECHNICAL TASKS

I. Identification of Issues

II. Quantifying Test Requirements
   - A. Survey of Testing Needs
   - B. Quantifying Test Requirements

III. Evaluation of Experience from Other Technologies
   - A. Fission
   - B. Aerospace

IV. Survey and Evaluation of Test Facilities
   - A. Non-Fusion Devices
   - B. Fusion Devices

V. Comparative Evaluation of Test Facilities, Scenarios

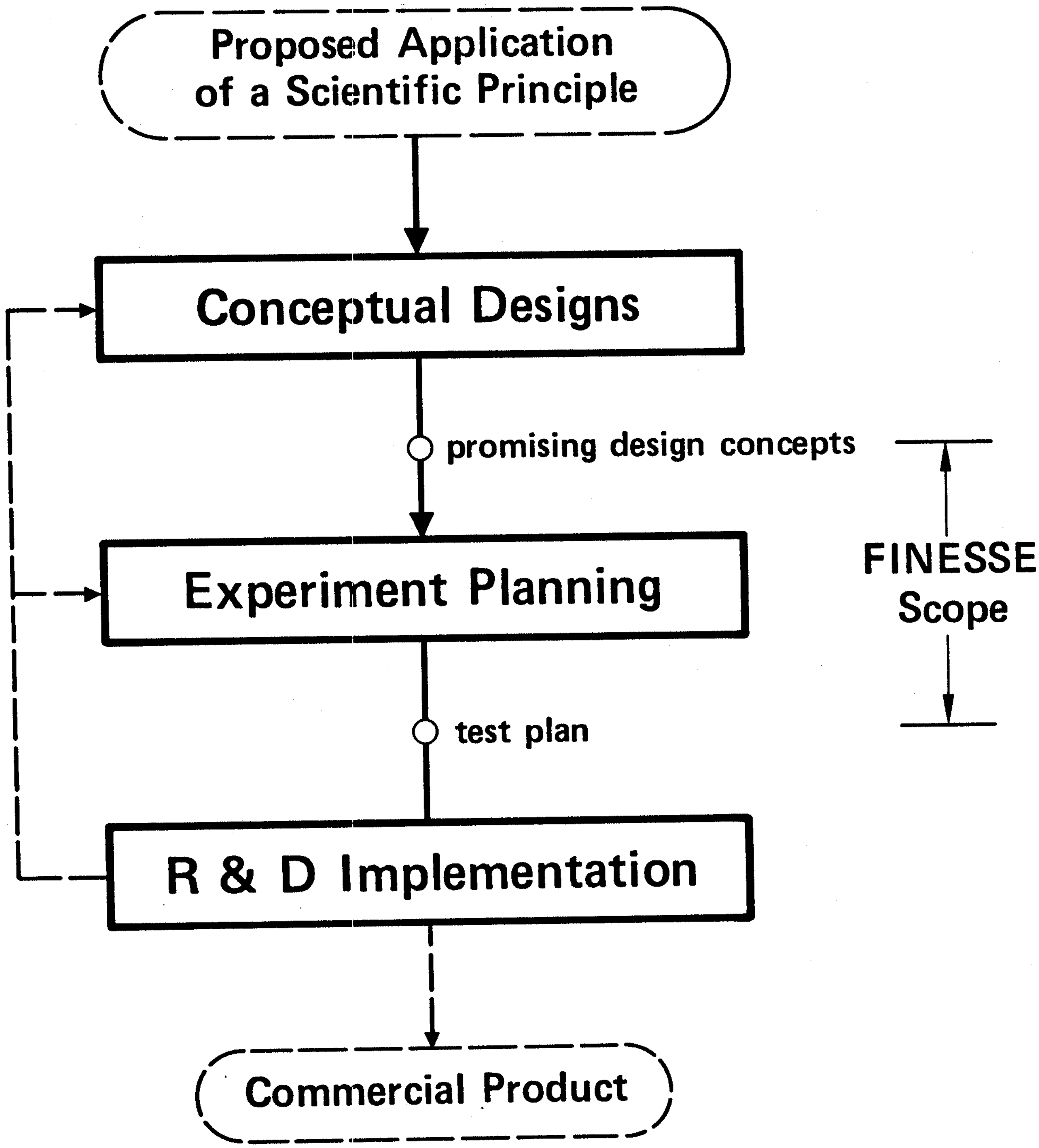
VI. Recommendations on Fusion Nuclear Technology Development Strategy

FINESSE is a technical study to provide information for effective planning of fusion nuclear technology experiments and facilities.

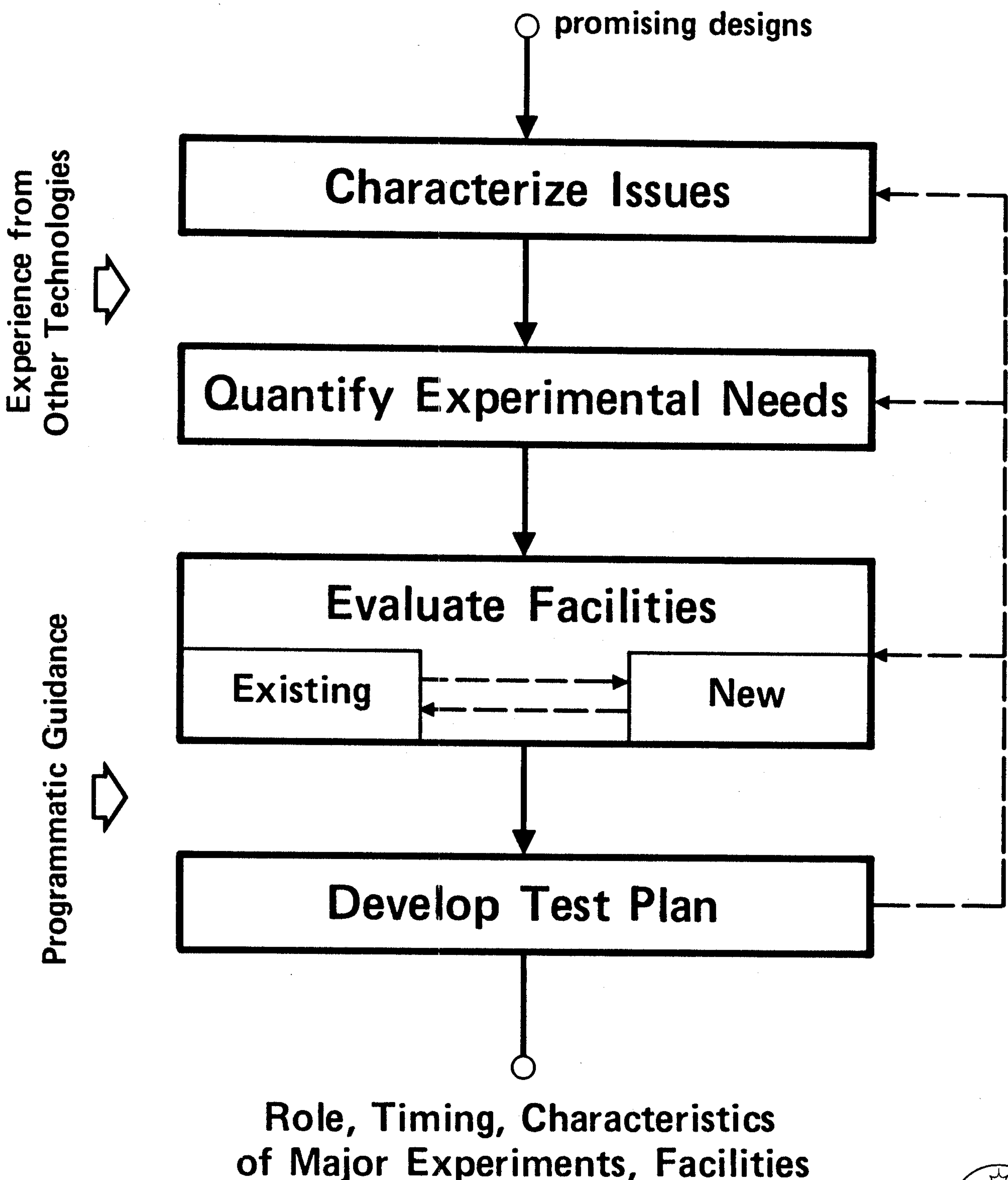
FINESSE PROCESS is an APPROACH For Experiment Planning

EXPERIMENT PLANNING

Is a Key Element of Technology Development



FINESSE PROCESS For Experiment Planning



Characterize Issues

- Assess Accuracy and Completeness of Existing Data and Models
- Analyze Scientific/Engineering Phenomena to Determine (Anticipate) Behavior, Interactions and Governing Parameters in Fusion Reactor Environment
- Evaluate Effect of Uncertainties on Design Performance
- Compare Tolerable and Estimated Uncertainties

△ Quantified Understanding of Important Issues, Interactions, Parameters . . .

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Quantify Experimental Needs

- Survey Needed Experiments
- Explore Engineering Scaling Options
  (Engineering Scaling is a Process to Develop Meaningful Tests at Experimental Conditions and Parameters Less Than Those in a Reactor)
- Evaluate Effects of Scaling on Usefulness of Experiments in Resolving Issues
- Develop Technical Test Criteria for Preserving Design-Relevant Behavior
- Identify Desired Experiments and Key Experimental Conditions

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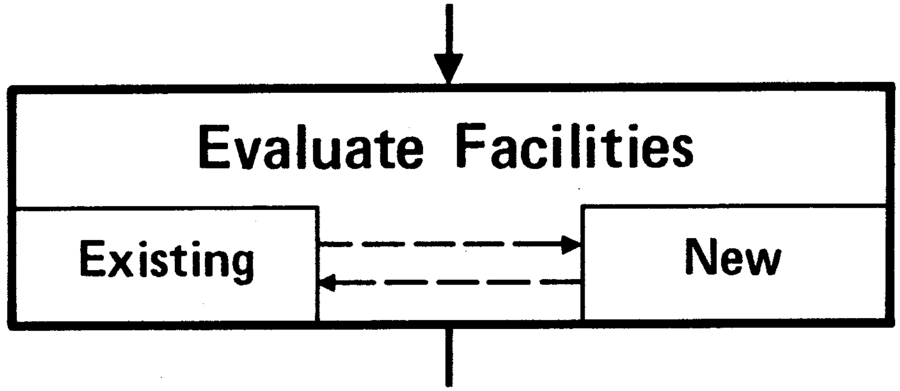

- o Survey (Availability)
- o Evaluate Capabalities and Limitations
- o Define Meaningful Experiments (Experiment Conceptual Design a Tool)
- o Estimate Costs
- o Explore Innovative Testing Ideas
- o Assess Feasibility of Obtaining Desired Information (e.g. I & C Limitations)
- o Develop Preliminary
  - Conceptual Designs of Facilities
  - Cost Estimates
- o Trade offs in Sequential and Parallel Experiments and Facilities
- o Define Major Facilities

Develop Test Plan

- Define Test Program Scenarios Based on
  - Promising Design Concepts
  - Importance of Issues
  - Desired Experiments
  - Possible Test Facilities
- Compare Risk, Usefulness and Cost of Test Program Scenarios

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FUSION NUCLEAR TECHNOLOGY ISSUES HAVE BEEN:

- Identified
- Characterized
- Prioritized

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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 ~1.05 - 1.2

    Present Uncertainties: ~20%

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

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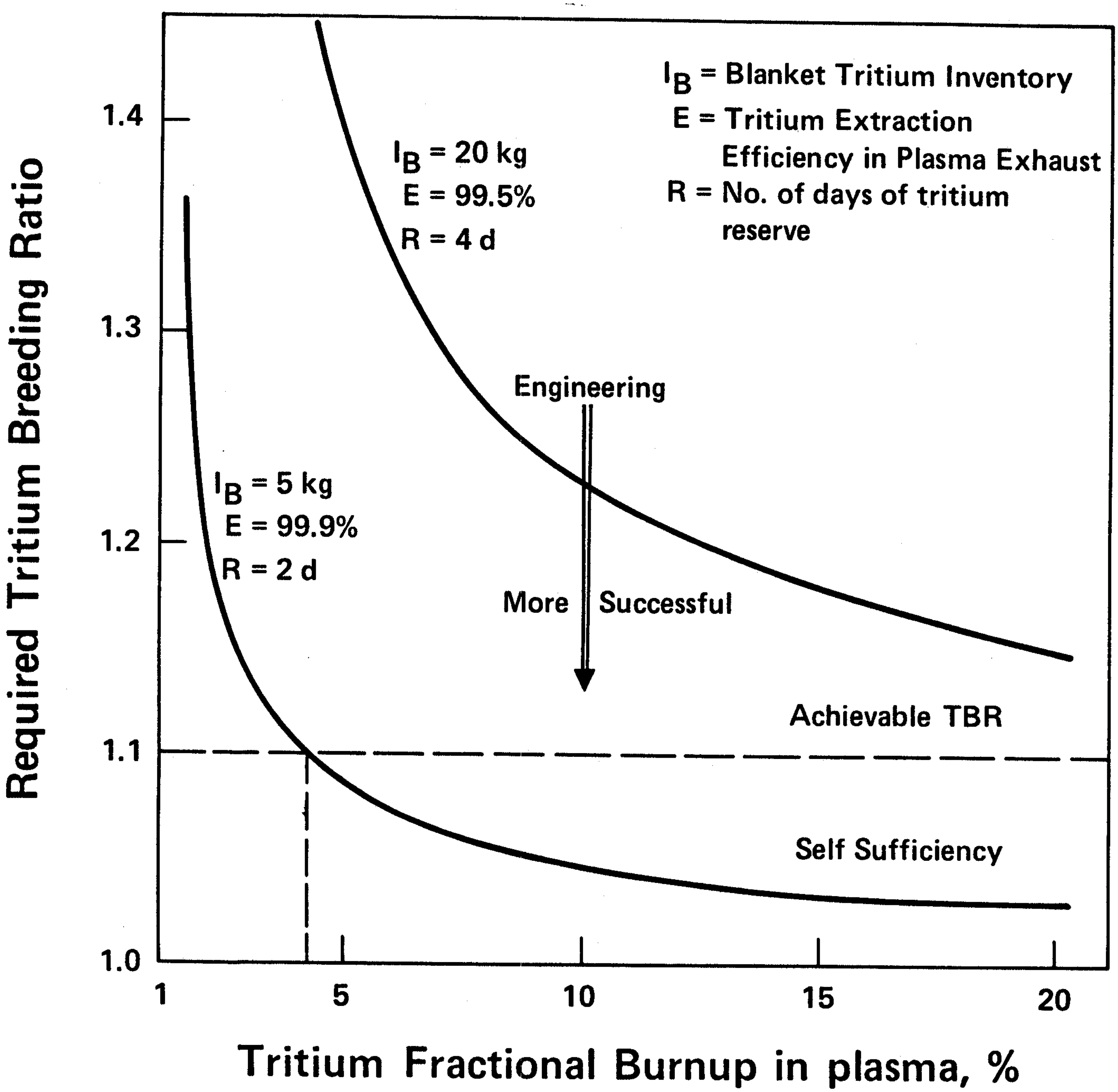
Attaining DT Fuel Self Sufficiency Requires Success in Physics and Engineering



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

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

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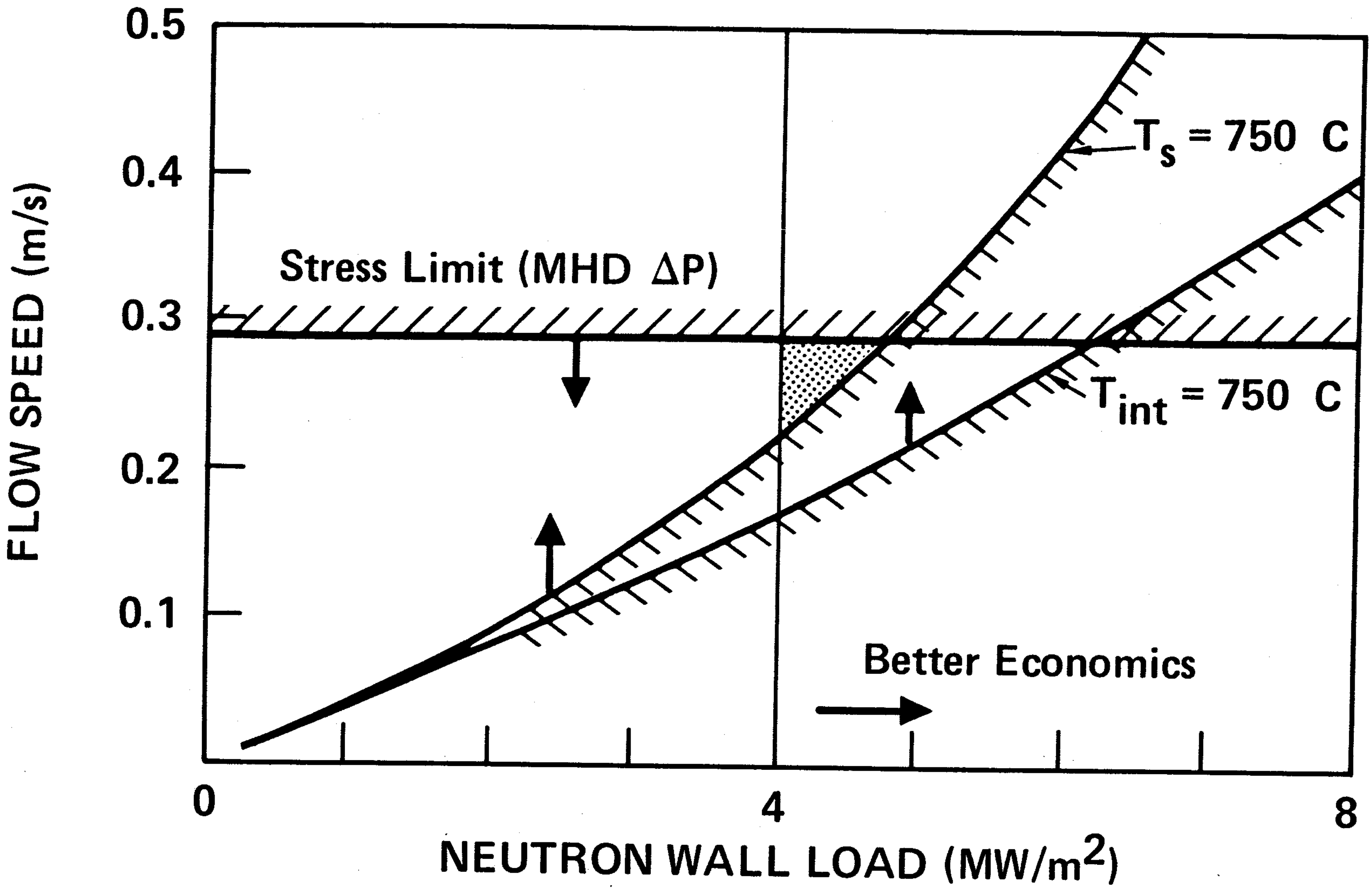
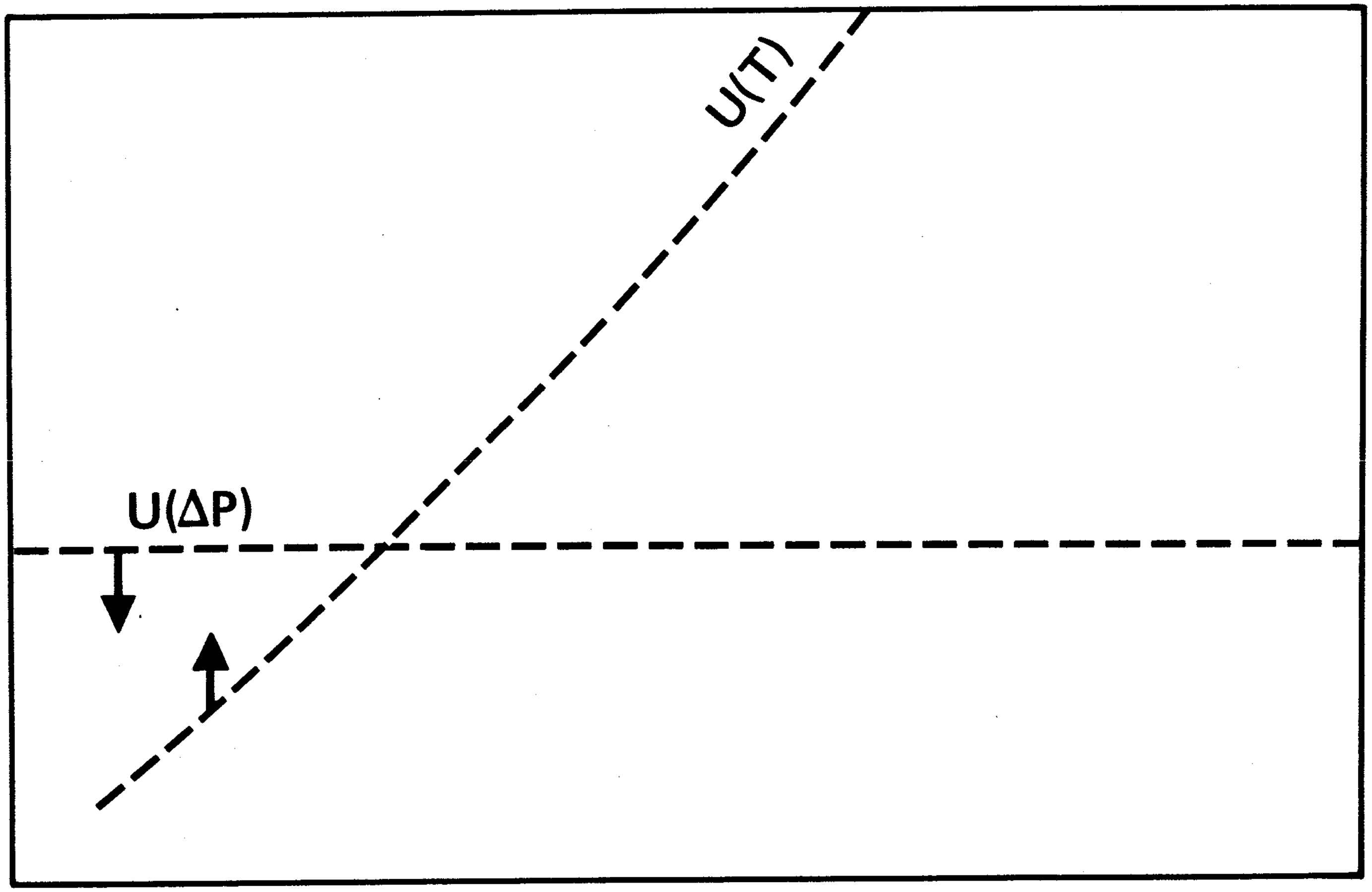
Design Window Is Narrow For Best Liquid Metal Blanket (Li/V)





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

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

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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

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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

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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

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

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IMPLICATIONS OF FUSION NUCLEAR ISSUES

- Fusion Environment is Unique
- New Phenomena Expected Due to Interactions:
  - Environmental Conditions
    Neutrons, Magnetic Field, Heating, Tritium, etc.
  - Subsystems and Components
- New Phenomena Result in Critical Issues:
  - Feasibility
  - Attractiveness
- Need New Knowledge
  - Carefully Planned Experiments

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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

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FACILITIES FOR NUCLEAR EXPERIMENTS

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

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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

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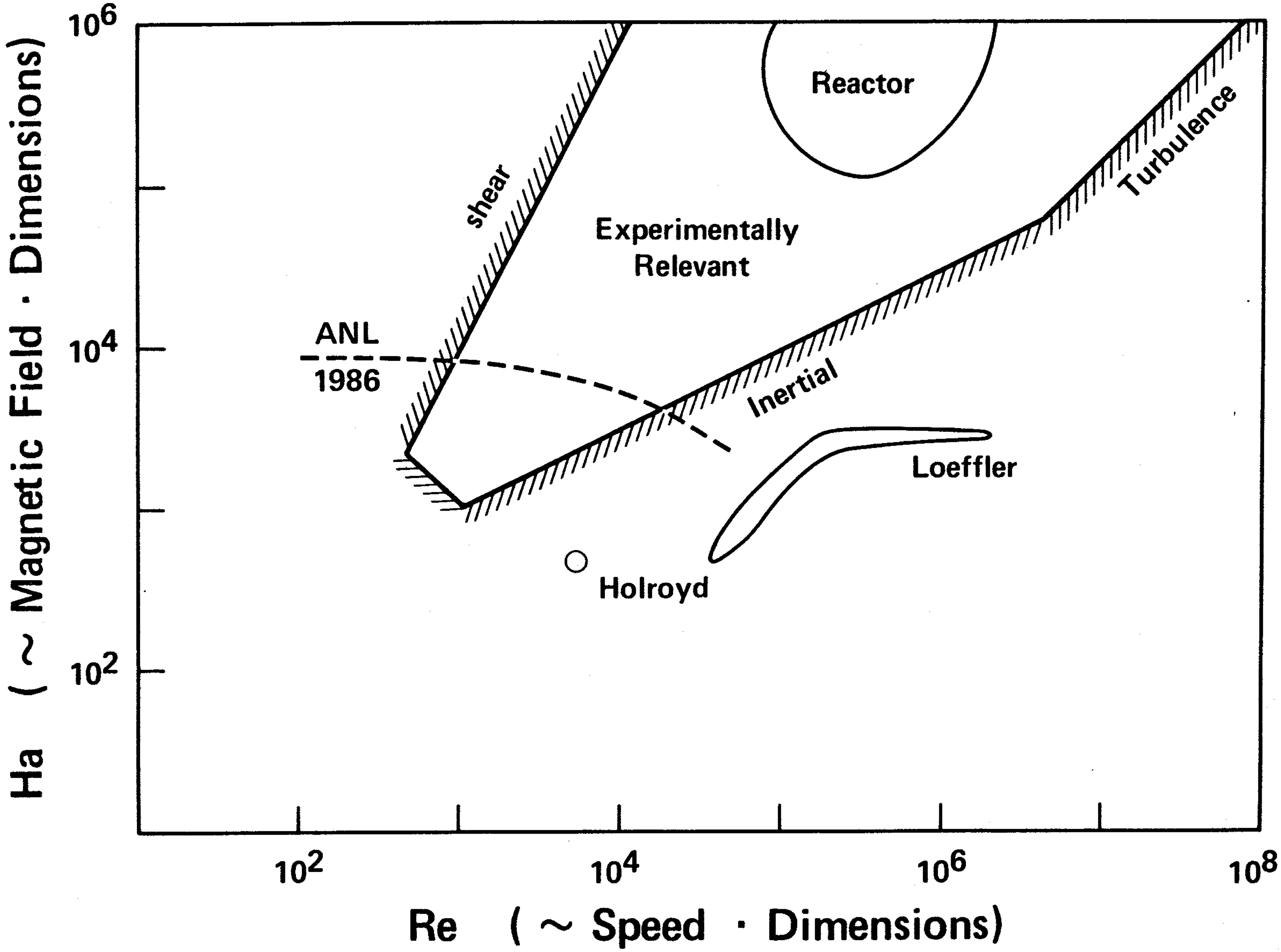
Liquid Metal Blanket MHD Experiments Needs



MANY LIQUID METAL BLANKET ISSUES CAN BE ADDRESSED BY THREE FACILITIES

Testing Condition	1 Momentum Transfer	2 Heat Transfer	3 Mass Transfer
Velocity Profile	x	x	x
Magnetic Field	x	x	x
Geometry	x	x	x
Temperature Gradient	–	x	x
Temperature Level	–	–	x
Material	–	–	x
Time	–	–	x
Impurity Level	–	–	x
Outside B Field	–	–	x

x = Important

– = Not Important

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NEUTRONS ARE NECESSARY FOR MANY KEY EXPERIMENTS

- A Key Element of the Fusion Environment
  - Produce Large Single and Interactive Effects/Changes
  - Cause Numerous Critical Feasibility Issues
- Only Practical Method to Provide in Experiments:
  - Bulk Heating
  - Radiation Effects
  - Specific Reactions

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NEUTRON–PRODUCING FACILITIES

- Accelerator–Based "Point" Sources
- Fission Reactors
- Fusion Devices

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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} $n/cm^2 \cdot s$

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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

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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)

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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

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TESTING IN FUSION DEVICES

Purpose of FINESSE Effort

- Understand Role of Fusion Devices
- Quantify Requirements of Nuclear Testing on Parameters and Features of Fusion Testing Devices

  e.g., Wall Load, Fluence, Test Area

  Develop Engineering Scaling

  Effort Generic to All Device Types
- Understand Impact of Nuclear Testing on Cost, Performance (e.g., availability) of Various Types of Fusion Devices

  e.g., On Combined Physics/Technology Facility

  On Technology-Dedicated Device

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ROLE OF FUSION DEVICES FOR NUCLEAR TESTING

- Confirm Data from Non-Fusion Facilities
- Complete Exploration of Phenomena
- Integrated Tests
  - Concept Verification
  - Engineering Data
- In the Long Term:
  - Component Development
  - Reliability Data

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SPECIFIC FEATURES OF FUSION TEST DEVICES NOT AVAILABLE IN NON–FUSION FACILITIES

1. Simulation of All Environmental Conditions
   - Neutrons
   - Plasma Particles
   - Vacuum
   - Electromagnetics
   - Tritium

2. Correct Neutron Spectrum

3. Large Volume of Test Element/Module

   Some Test Require ~1 m x 1 m x 0.5 m

4. Large Total Volume, Surface Area of Test Matrix

   Needed: $>5\ m^2$

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FUSION NUCLEAR TECHNOLOGY TESTING REQUIREMENTS ON FUSION FACILITY PARAMETERS

Fusion Device Parameter	Minimum	Substantial Benefits
Neutron Wall Load, MW/m^2	1	2 - 3
Surface Heat Load, MW/m^2	0.2	0.5
Plasma Burn Time, s	500	1000
Plasma Dwell Time, s	100	
Magnetic Field, T	1	2 - 3
Continuous Operating Time	Days	Weeks
Availability, %	20	50
Fluence, $MW \cdot y/m^2$	1 - 2	2 - 6
Test Port Size, $m^2 \times m$	0.5 x 0.3	1 x 0.5
Total Test Area, m^2	5	10

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OBSERVATIONS ON TRITIUM CONSUMPTION IN FUSION DEVICES

1. Tokamak Ignition Requires:

Fusion Power:	200-500 MW
Total DT Burn Time:	$\sim 2 \times 10^5$ s
Tritium Consumption:	~0.2 kg

2. Fusion Nuclear Testing Requires:

Fusion Power:	~20 MW
Total DT Burn Time:	Several Years
Tritium Consumption:	~5 kg

3. Combining 1 and 2 in One Device Requires:

Tritium Consumption: ~200 kg

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OBSERVATIONS ON NUCLEAR TESTING IN FUSION DEVICES

- Relatively Long Time (Several Years) Needed for Nuclear Testing Introduces Tritium Supply Problems in First Generation DT Facilities <u>if</u> Facility Fusion Power is Large (Hundreds of Megawatts)

- A Near Full–Scale Tritium Breeding Blanket in a Fusion Device Without Prior Fusion Testing Introduces Important Issues (e.g., Reliability, Cost)

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OBSERVATIONS ON NUCLEAR TESTING IN FUSION DEVICES

- Cost of Providing Fusion Testing for Nuclear Technology Can Be Substantially Reduced if a Low Fusion Power Device Option Can Be Developed, e.g.,

  FERF: Fusion Engineering Research Facility

  20 – 50 MW

  5 – 10 m^2

  2 – 10 MW · y/m^2

- Several Ideas for FERF Evaluated

  Potential Problems Include:

  - Physics Feasibility
  - Engineering Feasibility
  - Cost
  - Timing

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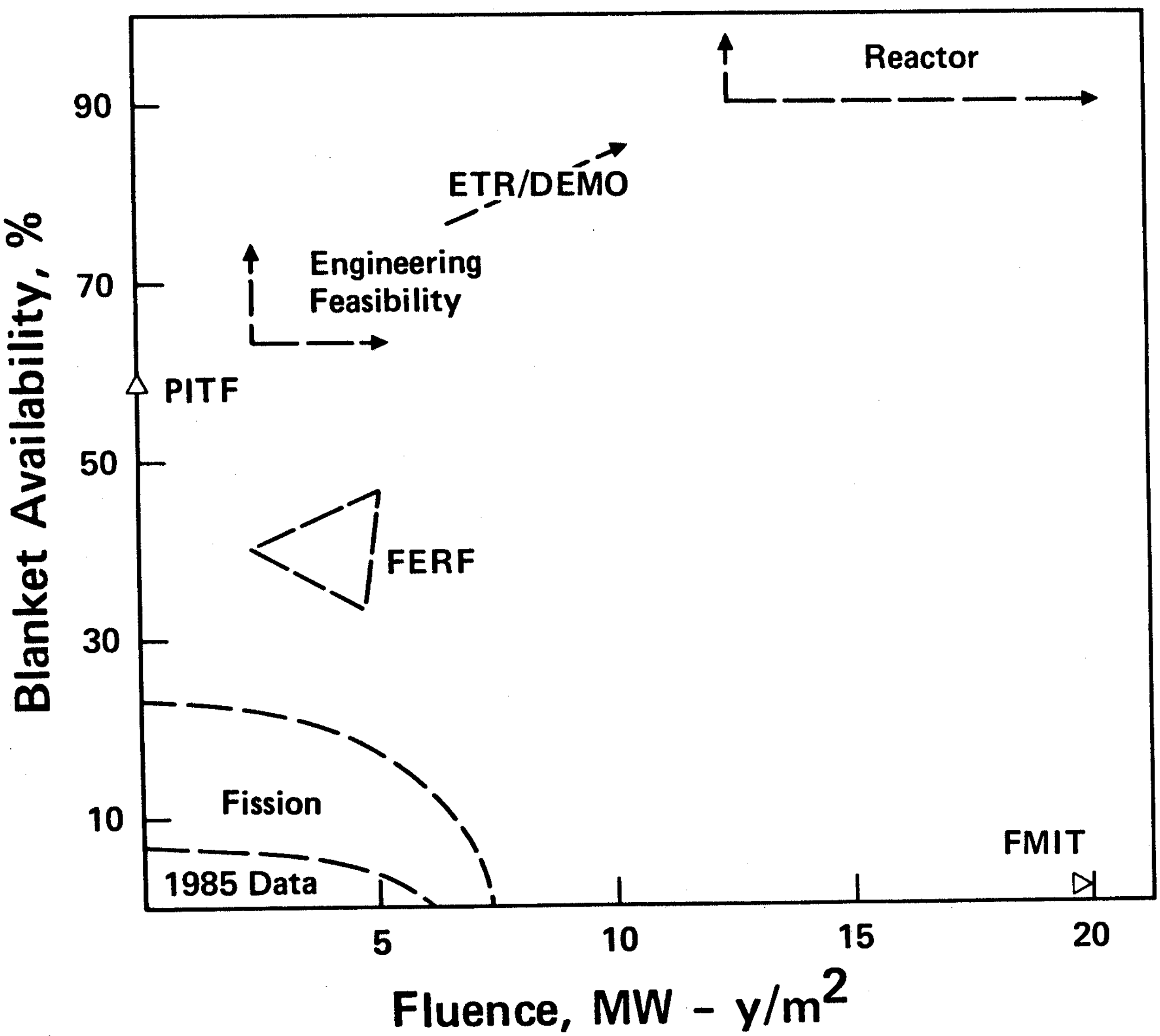
Obtaining Availability and Fluence Data For Blanket Is Most Difficult



Role of Facilities For Fusion Nuclear Technology

Type of Test / Purpose of Test	Basic Tests / Property Measurement	Single, Multiple Interaction / Phenomena Exploration	Integrated / Concept Verification	Component / Reliability
Non-Neutron Test Stands		PITF		
Point Neutron Sources				
Fission Reactors		MSB		
Fusion Test Device (FERF)				
ETR/DEMO				

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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

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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

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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)

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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

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DETAILS OF FINESSE RESULTS ARE DOCUMENTED IN THE FOLLOWING REPORTS:

1. "FINESSE: A Study of the Issues, Experiments and Facilities for Fusion Nuclear Technology Research and Development (Interim Report)," University of California, Los Angeles, PPG-821, also UCLA-ENG-84-30 (October, 1984).

2. Numerous Papers in the 6th Topical Meeting on the Technology of Fusion Energy, San Francisco (March, 1985).

3. FINESSE Final Report to be Issued (November, 1985).

Note:

If you wish to receive a copy of FINESSE Interim Report, please leave your name and address in the secretarial office.

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