FINESSE OVERVIEW

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FINESSE

A STUDY OF THE ISSUES, PHENOMENA AND EXPERIMENTAL FACILITIES 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

- Proposed Application of a Scientific Principle
  - Conceptual Designs
    - promising design concepts
  - Experiment Planning
    - test plan
  - R & D Implementation
    - Commercial Product

FINESSE Scope
FINESSE PROCESS For Experiment Planning

- Characterize Issues
- Quantify Experimental Needs
- Evaluate Facilities
- Develop Test Plan

Role, Timing, Characteristics of Major Experiments, Facilities
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 . . .
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
Evaluate Facilities

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

- Identified
- Characterized
- Prioritized
DT FUEL SELF SUFFICIENCY

- Critical Requirement for Renewable Energy Source

- Self-Sufficiency Condition:
  \[
  \text{Achievable TBR} \succ \text{Required TBR}
  \]

- 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
Attaining DT Fuel Self Sufficiency Requires Success in Physics and Engineering

\[ I_B = \text{Blanket Tritium Inventory} \]
\[ E = \text{Tritium Extraction Efficiency in Plasma Exhaust} \]
\[ R = \text{No. of days of tritium reserve} \]

**Case 1:**
- \( I_B = 20 \text{ kg} \)
- \( E = 99.5\% \)
- \( R = 4 \text{ d} \)

**Case 2:**
- \( I_B = 5 \text{ kg} \)
- \( E = 99.9\% \)
- \( R = 2 \text{ d} \)

- More Successful
- Engineering

Achievable TBR

Self Sufficiency

Tritium Fractional Burnup in plasma, %
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
Design Window Is Narrow For Best Liquid Metal Blanket (Li/V)

FLOW SPEED (m/s)

0.5

0.4

0.3

0.2

0.1

NEUTRON WALL LOAD (MW/m²)

0

4

8

Stress Limit (MHD ΔP)

T_s = 750°C

T_int = 750°C

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

$U(T)$: Any of:

$T_s = 650 \, \text{C}$

$T_{int} = 550 \, \text{C}$

$h_m = 0.7h$
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
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 (T₂, T₂O)
• Failure Modes
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
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
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
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
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
Liquid Metal Blanket MHD Experiments Needs

- Reactor
- Turbulence
- Experimentally Relevant
- Inertial
- ANL 1986
- Holroyd
- Loeffler

Ha (~ Magnetic Field · Dimensions)

Re (~ Speed · Dimensions)
MANY LIQUID METAL BLANKET ISSUES CAN BE ADDRESSED BY THREE FACILITIES

<table>
<thead>
<tr>
<th>Testing Condition</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Momentum Transfer</td>
<td>Heat Transfer</td>
<td>Mass Transfer</td>
</tr>
<tr>
<td>Velocity Profile</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Geometry</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Temperature Gradient</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Temperature Level</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Material</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Time</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Impurity Level</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Outside B Field</td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

$x = $ Important

$- = $ Not Important
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
NEUTRON—PRODUCING FACILITIES

- Accelerator—Based "Point" Sources
- Fission Reactors
- Fusion Devices
## POINT NEUTRON SOURCES CAPABILITIES

<table>
<thead>
<tr>
<th>Facility</th>
<th>Status</th>
<th>Peak Flux* n/cm² s</th>
<th>Testing Volume cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTNS-II</td>
<td>In Use</td>
<td>$5 \times 10^{12}$</td>
<td>0.1</td>
</tr>
<tr>
<td>LAMPF A-6</td>
<td>Operational</td>
<td>$1 \times 10^{13}$</td>
<td>20000</td>
</tr>
<tr>
<td>FMIT</td>
<td>Design Completed Project Deferred</td>
<td>$1 \times 10^{15}$</td>
<td>10</td>
</tr>
</tbody>
</table>

*Fusion First Wall Flux at 5 MW/m²:
$2 \times 10^{15}$ n/cm² s
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)
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
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
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
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 m²
## FUSION NUCLEAR TECHNOLOGY TESTING REQUIREMENTS ON FUSION FACILITY PARAMETERS

<table>
<thead>
<tr>
<th>Fusion Device Parameter</th>
<th>Minimum</th>
<th>Substantial Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron Wall Load, MW/m²</td>
<td>1</td>
<td>2 - 3</td>
</tr>
<tr>
<td>Surface Heat Load, MW/m²</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Plasma Burn Time, s</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>Plasma Dwell Time, s</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Magnetic Field, T</td>
<td>1</td>
<td>2 - 3</td>
</tr>
<tr>
<td>Continuous Operating Time</td>
<td>Days</td>
<td>Weeks</td>
</tr>
<tr>
<td>Availability, %</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>Fluence, MW · y/m²</td>
<td>1 - 2</td>
<td>2 - 6</td>
</tr>
<tr>
<td>Test Port Size, m² x m</td>
<td>0.5 x 0.3</td>
<td>1 x 0.5</td>
</tr>
<tr>
<td>Total Test Area, m²</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>
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: $\sim 0.2$ kg

2. Fusion Nuclear Testing Requires:
   Fusion Power: $\sim 20$ MW
   Total DT Burn Time: Several Years
   Tritium Consumption: $\sim 5$ kg

3. Combining 1 and 2 in One Device Requires:
   Tritium Consumption: $\sim 200$ kg
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 if 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)
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 m²
  2 – 10 MW · y/m²

• Several Ideas for FERF Evaluated
  Potential Problems Include:
  • Physics Feasibility
  • Engineering Feasibility
  • Cost
  • Timing
Obtaining Availability and Fluence Data For Blanket Is Most Difficult
# Role of Facilities For Fusion Nuclear Technology

<table>
<thead>
<tr>
<th>Purpose of Test</th>
<th>Basic Tests</th>
<th>Single, Multiple Interaction</th>
<th>Integrated</th>
<th>Component</th>
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</thead>
<tbody>
<tr>
<td>Non-Neutron Test Stands</td>
<td>Property Measurement</td>
<td>Phenomena Exploration</td>
<td></td>
<td>PITF</td>
</tr>
<tr>
<td>Point Neutron Sources</td>
<td></td>
<td></td>
<td></td>
<td>MSB</td>
</tr>
<tr>
<td>Fission Reactors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fusion Test Device (FERF)</td>
<td></td>
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<td></td>
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<tr>
<td>ETR/DEMO</td>
<td></td>
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</table>

The diagram shows the relationship between the various types of test facilities and their corresponding components.
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
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
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)
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
DETAILS OF FINESSE RESULTS ARE DOCUMENTED IN THE FOLLOWING REPORTS:


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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