FUSION BLANKET DESIGN ISSUES
AND EXPERIMENT PLANNING

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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/m²

- 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

<table>
<thead>
<tr>
<th></th>
<th>TOKAMAK</th>
<th>TMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor Design Basis</td>
<td>STARFIRE</td>
<td>MARS</td>
</tr>
<tr>
<td>Peak Magnetic Field, T</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Neutron Wall Load, MW/m²</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>First Wall Heat Flux, W/cm²</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>First Wall Erosion, mm/y</td>
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<td>0.1</td>
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</table>
## Candidate First-Wall/Blanket Materials

<table>
<thead>
<tr>
<th>Breeding Materials</th>
<th>Coolants</th>
<th>Structure</th>
<th>Neutron Multiplier</th>
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<tbody>
<tr>
<td>Liquid Metals</td>
<td>H$_2$O Li 17Li–83Pb He Salt</td>
<td>Austenitic Steel PCA Mn Steel$^A$</td>
<td>Be Pb</td>
</tr>
<tr>
<td>Li</td>
<td>Li 17Li–83Pb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17Li–83Pb</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceramics</td>
<td>Li$_2$O Li$_8$ZrO$_6$ LiAlO$_2$'</td>
<td>Ferritic Steel HT–9 Mod. Ferr. St.$^A$</td>
<td></td>
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<tr>
<td>Salt</td>
<td>FLIBE$^D$</td>
<td>Vanadium Alloy</td>
<td>V15Cr5Ti</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^A$Low-activation structural alloys. V15Cr5Ti is inherently low activation.

$^B$LiAlO$_2$ is representative of ceramics that include Li$_2$SiO$_3$, Li$_2$ZrO$_3$, etc.

$^C$Nitrate salt.

$^D$Fluoride salt.
BLANKET OPTIONS

LIQUID METALS

- Li
- Li
- Li
- Li, He
- LiPb, (He, H₂O, Na)
- LiPb
- LiPb
- H₂O
- ALTERNATE CONCEPT SCREENING
- X₂
- Y₂

SOLID BREEDERS

- Li₂O
- H₂O
- Li₂O
- He
- SX
- SX

TERNARY CERAMICS
- LiAl₂O₃, Li₂SiO₃
- Li₂ZrO₃, Li₂TiO₃

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

M = NEUTRON MULTIPLIER
- 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$_2$O/He/FS
- LiAlO$_2$/He/FS/Be
- LiAlO$_2$/H$_2$O/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

<table>
<thead>
<tr>
<th>Index Name</th>
<th>Weighting Value ($W_i$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Tritium Breeding and Inventory</td>
<td>25</td>
</tr>
<tr>
<td>2. Engineering Complexity and Fabrication</td>
<td>25</td>
</tr>
<tr>
<td>3. Maintenance and Repair</td>
<td>15</td>
</tr>
<tr>
<td>4. Resources</td>
<td>$5^\wedge$</td>
</tr>
<tr>
<td>5. Power Swings</td>
<td>10</td>
</tr>
<tr>
<td>6. Increased Capability</td>
<td>10</td>
</tr>
<tr>
<td>6.1 Increased Neutron Wall Loading</td>
<td>5</td>
</tr>
<tr>
<td>6.2 Higher Surface Heat Flux, Higher Erosion</td>
<td>5</td>
</tr>
<tr>
<td>7. Startup/Shutdown Requirements</td>
<td>10</td>
</tr>
</tbody>
</table>

$^\wedge$ Assumes go/no-go materials shortage does not exist.
### Safety Evaluation Indices

<table>
<thead>
<tr>
<th>Index Number</th>
<th>Index Name</th>
<th>Weighting Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Structure Source Term Characterization</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>Breeder/Multiplier Source Term Characterization</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Coolant Source Term Characterization</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Fault Tolerance to Breeder–Coolant Mixing</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Fault Tolerance to Cooling Transients</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>Fault Tolerance to External Forces</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Fault Tolerance to Near–Blanket Systems Interactions</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>Fault Tolerance of the Reactor Building to Blanket Transients</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>Normal Radioactive Effluents</td>
<td>20</td>
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<tr>
<td>10</td>
<td>Occupational Exposure</td>
<td>10</td>
</tr>
<tr>
<td>11</td>
<td>Waste Management</td>
<td>10</td>
</tr>
</tbody>
</table>
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 development.
    • Annual operating costs.
    • Facility requirements.

\[ \text{RDFM} = f(\text{RDR}) + f(\text{RDI}) \]  
(Equal weighting)
### Tokamak Blanket Ranking

<table>
<thead>
<tr>
<th></th>
<th>Engineering</th>
<th>Economics</th>
<th>Safety</th>
<th>R&amp; D</th>
<th>Overall c</th>
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</thead>
<tbody>
<tr>
<td>Li/Li/V</td>
<td>1.000 (1)</td>
<td>.85 a</td>
<td>.998 b</td>
<td>.886 (2)</td>
<td>1.000 (1)</td>
</tr>
<tr>
<td>Li/Li/FS</td>
<td>.750 (3)</td>
<td>.73 (7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LiPb/LiPb/V</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li/He/FS</td>
<td>.719 (4)</td>
<td>.79 (5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li₂O/He/FS</td>
<td>.611 (7)</td>
<td>.79 (5)</td>
<td>1.000 (1)</td>
<td>.840 (3)</td>
<td>.878 (2)</td>
</tr>
<tr>
<td>LiAlO₂/He/FS/Be</td>
<td>.682 (5)</td>
<td>1.00 (1)</td>
<td>.597 (6)</td>
<td>.723 (6)</td>
<td>.805 (7)</td>
</tr>
<tr>
<td>LiAlO₂/H₂O/FS/Be</td>
<td>.849 (2)</td>
<td>.98 (2)</td>
<td>.515 (7)</td>
<td>.692 (7)</td>
<td>.831 (4)</td>
</tr>
<tr>
<td>LiAlO₂/NS/FS/Be</td>
<td>.658 (6)</td>
<td>.84 (4)</td>
<td>.807 (5)</td>
<td>.824 (4)</td>
<td>.809 (5)</td>
</tr>
</tbody>
</table>

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 vanadium 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$_2$O/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$_2$O 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$_2$O). 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$_2$O 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

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**How Do We Plan
An Effective Experimental Program?**
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
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 PROCESS For Experiment Planning

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

Role, Timing, Characteristics of Major Experiments, Facilities
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
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
MHD PRESSURE DROP

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

\[ \Delta p \approx \sigma_f v B^2 L \phi \]
\[ \phi = \frac{\sigma_{wt}}{\sigma_{fa}} \]

- 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.

$$\rho \ c_p \ v \ \Delta T_b = \frac{1}{d} \ (S + Q_b)$$

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

- without bulk heating
- with bulk heating

Couette flow (v = 0 at first wall)
Couette flow (v = 0 at second wall)
parabolic
slug flow

normalized distance across first wall cooling channel
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)
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
The Corrosion Rate is Strongly Influenced by MHD Velocity Profiles

Hartmann number, $Ha = aB \sqrt{\sigma/\mu}$
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)

![Graph showing flow speed vs. neutron wall load](image)

- Stress Limit (MHD ΔP)
- $T_s = 750 \, ^\circ C$
- $T_{int} = 750 \, ^\circ C$
- Better Economics
Uncertainties in MHD, Corrosion, Heat Transfer, Radiation Effects Represent Major Issues
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 ($T_2, T_{20}$)
- Failure Modes
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 \approx 1.05 - 1.2
    Present Uncertainties: \approx 20%

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

<table>
<thead>
<tr>
<th>Concept</th>
<th>Achievable $\Lambda_a$</th>
<th>Required $\Lambda_r$</th>
<th>$1 + G_o$</th>
<th>$\Delta_g$</th>
<th>$\epsilon = \Lambda_a - \Lambda_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiAlO$_2$/DS/HT9/Be</td>
<td>1.24</td>
<td>0.22</td>
<td>1.077</td>
<td>0.143</td>
<td>-0.20</td>
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<tr>
<td>LiPb/LiPb/V</td>
<td>1.30</td>
<td>0.24</td>
<td>1.072</td>
<td>0.142</td>
<td>-0.15</td>
</tr>
<tr>
<td>Li/Li/V</td>
<td>1.28</td>
<td>0.24</td>
<td>1.072</td>
<td>0.142</td>
<td>-0.17</td>
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<tr>
<td>Li$_2$O/He/HT9</td>
<td>1.11</td>
<td>0.21</td>
<td>1.077</td>
<td>0.143</td>
<td>-0.32</td>
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<td>0.19</td>
<td>1.077</td>
<td>0.143</td>
<td>-0.37</td>
</tr>
<tr>
<td>Li/He/HT9</td>
<td>1.16</td>
<td>0.22</td>
<td>1.072</td>
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</tr>
</tbody>
</table>
Attaining DT Fuel Self Sufficiency Requires Success in Physics and Engineering

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

Required Tritium Breeding Ratio

\[ \text{I}_B = 20 \text{ kg} \]
\[ E = 99.5\% \]
\[ R = 4 \text{ d} \]

\[ \text{I}_B = 5 \text{ kg} \]
\[ E = 99.9\% \]
\[ R = 2 \text{ d} \]

Achievable TBR

Self Sufficiency

Engineering

More Successful

Tritium Fractional Burnup in plasma, \%
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.

![Graph showing LiAlO₂/H₂O/PCA/Be with points at T_min = 300°C and T_min = 335°C.]

- **breeder minimum temperature**
- **diffusive inventory, kg**
CLAD/BREEDER MECHANICAL INTERACTION
(ESTIMATES FOR Li$_2$O/HT-9/He)

% STRAIN

BREEDER SWELLING

CLAD EMBRITTLEMENT

CLAD SWELLING

EXPOSURE, MW \cdot y/m^2
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, Accountability
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
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
# 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
# Role of Facilities For Fusion Nuclear Technology

<table>
<thead>
<tr>
<th>Type of Test</th>
<th>Basic Tests</th>
<th>Single, Multiple Interaction</th>
<th>Integrated</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose of Test</td>
<td></td>
<td></td>
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<tr>
<td>Non-Neutron Test Stands</td>
<td></td>
<td>Phenomena Exploration</td>
<td>Concept Verification</td>
<td>Reliability</td>
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<tr>
<td>Point Neutron Sources</td>
<td></td>
<td></td>
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<tr>
<td>Fission Reactors</td>
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<tr>
<td>Fusion Test Device (FERF)</td>
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<tr>
<td>ETR/DEMO</td>
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</table>
# Liquid Metal Blanket Experiments, Facilities

<table>
<thead>
<tr>
<th>Basic</th>
<th>Single</th>
<th>Multiple Effects</th>
<th>Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tritium Breeding</td>
<td></td>
<td>Blanket Neutronics Facility</td>
<td></td>
</tr>
<tr>
<td>Tritium Recovery</td>
<td>T Extraction Tech.</td>
<td>T Permeation Loop</td>
<td>TSTA TTLT</td>
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<tr>
<td>Thermomechanic</td>
<td>MHD Momentum Transfer</td>
<td>MHD Heat Transfer</td>
<td>TMIF</td>
</tr>
<tr>
<td></td>
<td>Corrosion Loop, no B</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrad. Capsules</td>
<td>Corrosion with B</td>
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<tr>
<td></td>
<td>Electromagnetic, Structure</td>
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</tbody>
</table>
## Solid Breeder Blanket Experiments, Facilities

<table>
<thead>
<tr>
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<th>Part. Int.</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>In-Situ T Recovery</td>
<td>Max. SB Test</td>
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<tr>
<td>Thermomechanic</td>
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<td>Advanced In-Situ T Recovery</td>
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<td>Breeder, Multiplier, Structure Mechanical, Compatibility Experiments</td>
<td>TMIF</td>
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<tr>
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<td></td>
<td>Electromagnetics, Structure</td>
<td></td>
</tr>
</tbody>
</table>

- Experiment in Fission Reactors
- Test Stand
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
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
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