Adequacy of R & D  
and Incremental Cost/Risk/Benefit 
For ITER Driver Blanket

ISCUS Subgroup 
Presented By 
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Topics

- General Design Features and Parameters
- Key Technical Issues
- Highlights of R & D
- Incremental Cost/Benefit/Risk
<table>
<thead>
<tr>
<th></th>
<th>PHYSICS PHASE</th>
<th>TECHNOLOGY PHASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fusion Power, MW</td>
<td>1100</td>
<td>860</td>
</tr>
<tr>
<td>Neutron Wall Load, MW/m²</td>
<td>(MIN/MAX)</td>
<td></td>
</tr>
<tr>
<td>Inboard</td>
<td>0.4/1.1</td>
<td>0.3/0.9</td>
</tr>
<tr>
<td>Outboard</td>
<td>0.8/1.5</td>
<td>0.6/1.2</td>
</tr>
<tr>
<td>DT Flat Burn Time, s</td>
<td>Up to 400</td>
<td>2300</td>
</tr>
<tr>
<td>Minimum Dwell Time, s</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Number of DT Pulses</td>
<td>$10^4$</td>
<td>$5 \times 10^4$</td>
</tr>
<tr>
<td>DT Fluence Goal, MWa/m²</td>
<td>0.05</td>
<td>3</td>
</tr>
<tr>
<td>Operating Temperature Limits, ºC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austenitic Steel (316)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structural Component</td>
<td>&lt;400</td>
<td></td>
</tr>
<tr>
<td>Short Term</td>
<td>&lt;800</td>
<td></td>
</tr>
<tr>
<td>Aqueous Interface</td>
<td>&lt;150</td>
<td></td>
</tr>
<tr>
<td>Ceramic Breeder Temperature Range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li₂O</td>
<td></td>
<td>370-1000*</td>
</tr>
<tr>
<td>LiAl₂O₂</td>
<td></td>
<td>450-900</td>
</tr>
<tr>
<td>Li₂ZrO₃</td>
<td></td>
<td>370-1000</td>
</tr>
<tr>
<td>Beryllium</td>
<td></td>
<td>&lt;600</td>
</tr>
</tbody>
</table>

* Special attention should be given to avoid mass transport above 800ºC.
# Tritium Breeding Blanket Design Specifications

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Option Blanket Structural Material</td>
<td>Ceramic Breeder</td>
</tr>
<tr>
<td>Coolant</td>
<td>Austenitic Steel (316)</td>
</tr>
<tr>
<td>Breeder Material</td>
<td>Water: 60-100°C, &lt;15 MPa</td>
</tr>
<tr>
<td>$^6\text{Li}$ Enrichment</td>
<td>$\text{Li}_2\text{O}$ or Ternary ($\text{LiAlO}_2$, $\text{Li}_2\text{ZrO}_3$)</td>
</tr>
<tr>
<td>Neutron Multiplier</td>
<td>50-95%</td>
</tr>
<tr>
<td>Breeder Configuration</td>
<td>Beryllium</td>
</tr>
<tr>
<td>Breeder and Multiplier Clad</td>
<td>Layered or Breeder-in-Tube</td>
</tr>
<tr>
<td>Breeder Temperature Control</td>
<td>Austenitic Steel (316)</td>
</tr>
<tr>
<td>Tritium Recovery Method</td>
<td>Gradient in Beryllium or Helium Gas Gap</td>
</tr>
<tr>
<td>Coolant Flow Direction</td>
<td>Continuous In-Situ Purge Gas: $\text{He} + (0.2-1%) \text{H}_2$</td>
</tr>
</tbody>
</table>

- **Inboard-First Wall Blanket**
- **Outboard-First Wall Blanket**

- Poloidal
- Poloidal or Toroidal
- Toroidal
- Toroidal or Poloidal
ITER TRITIUM BREEDING POTENTIAL

- Current Design Potential
  - The net tritium breeding ratio is in the range of 0.8 to 0.9 based on the following assumptions:
    - Reliable and safe blanket operation
    - No tritium breeding form the sixteen ports
    - No tritium breeding in the divertor zones
    - Limited inboard blanket thickness (about 10 cm)
    - Copper loops for the plasma operation
  - Higher net tritium breeding is attainable with design improvements.
Cost Issues and External Tritium Sources

* ITER Tritium Burn Rate

<table>
<thead>
<tr>
<th>PHASE</th>
<th>AVAILABILITY %</th>
<th>Burn Rate, Kg/y</th>
<th>Fluence, MWa/m²</th>
<th>Total Tritium Burned for Phase Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics</td>
<td>0.5</td>
<td>0.05</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Technology</td>
<td>10</td>
<td>6</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>18</td>
<td>3</td>
<td>180</td>
</tr>
</tbody>
</table>

*Tritium Cost Without Breeding

- Tritium unit cost is $29,000 per gram (DOE price as of 10/29/88).
- Tritium cost per phase

Physics: $0.23 Billion
Technology: $1.70 Billion for 1 MWa/m²
$5.20 Billion for 3 MWa/m²

(The physics phase cost includes 5 Kg tritium inventory cost in the different reactor components)
Cost Issues and External Tritium Sources (cont.)

* Tritium cost with breeding blanket for different tritium supply rates

<table>
<thead>
<tr>
<th>Supply Rate Kg/y</th>
<th>Required TBR</th>
<th>Total Tritium Purchased Kg</th>
<th>Total Cost of Tritium B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.94</td>
<td>36</td>
<td>1.04</td>
</tr>
<tr>
<td>2</td>
<td>0.84</td>
<td>52</td>
<td>1.51</td>
</tr>
<tr>
<td>3</td>
<td>0.74</td>
<td>68</td>
<td>1.97</td>
</tr>
<tr>
<td>4</td>
<td>0.64</td>
<td>84</td>
<td>2.44</td>
</tr>
</tbody>
</table>

* Assuming 20 Kg of tritium available at the start up and a total inventory of about 5 Kg in the different ITER systems.

Based on the know external tritium supplies of about 2 Kg/year and economic benefits a TBR > 0.8 is required for ITER.
Key Technical Issues

- Issues **Common** to Driver and Non-Driver Blankets
  - Radiation induced embrittlement of steel structure
  - Aqueous stress corrosion cracking
  - Cooling system reliability and chemistry control

- Issues **Unique** to Driver Blanket
  - Demonstration of breeder temperature control
  - Characterization of ceramic breeder performance
  - Integrated module tests
ITER Driver Blanket R & D

- A detailed list of R & D items was prepared by the ITER team with input from home teams

- The driver blanket R & D was reviewed in the US several times prior to the ISCUS Review

- The R & D list includes:
  - Issues to be addressed
  - Results to be achieved
  - Specifications
  - Milestones
  - Facility requirements
ITER Driver Blanket R & D

Main R & D Items

1. Blanket Material Development
   - Ceramic breeder performance
   - Beryllium multiplier performance
   - Insulator performance

2. Fabrication and Scalable Model Testing
   - Fabrication capability of materials
   - Fabrication capability of blanket modules
   - Integrated out-of-reactor tests
   - Integrated in-reactor tests

3. Blanket/Shield Neutronics
   - Bulk and penetration shielding
   - Radioactivity and afterheat
   - Tritium breeding
   - (Nuclear heating) [Missing from present plan]

4. Structural Material R & D
   - Austenitic steel
   - PFC structure
   - Advanced structure
Q: Will the R & D specified in the Iter Long Range Technology Plan plus the ongoing R & D base program provide by 1996 the data base for driver blanket technology that is adequate to support a construction decision for ITER?

A: Yes (with minor additions)
Question:

Should ITER have a breeding blanket?

Answer can be obtained through Cost/Benefit/Risk Analysis

Remarks

• Eliminating breeding material does not make the blanket disappear

• A non-breeding blanket will still have to remove the heat, will have coolant tubes, will have first wall, and non-breeding material such as steel

• Features of the blanket, particularly the amount of beryllium, and the TBR can be adjusted depending on the cost/benefit/risk analysis results
Breeding Vs. Non-Breeding Blanket

**Cost**

- Tritium
- Construction
- Incremental R & D

**Benefits**

- Tritium Requirements
- Data Base for DEMO

**Rists**

- Limitations on Machine Performance
- Reliability
- Safety
- Technical Issues
ITER Fluence?

- Question is crucial to Breeding Vs. Non-Breeding blanket question.

- Answer (from previous ISCUS presentation, ITER report and numerous other presentations and reports)

  Strongly Recommended: 3MW.y/m²
  Minimum: 1MW.y/m²
### Incremental Cost Associated with the Breeding Blanket

**ITER R&D Blanket Cost**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Total Blanket R&amp;D Cost</th>
<th>Breeding R&amp;D Cost</th>
<th>Non Breeding R&amp;D Cost</th>
<th>DEMO Relevant R&amp;D Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver Blanket Materials Development</td>
<td>19</td>
<td>14</td>
<td>5</td>
<td>19</td>
</tr>
<tr>
<td>Fabrication and Module Testing</td>
<td>57</td>
<td>20</td>
<td>37</td>
<td>57</td>
</tr>
<tr>
<td>Alternate Driver Blanket</td>
<td>25</td>
<td>25</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Blanket &amp; Shield Neutronics</td>
<td>10</td>
<td>3</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Test Module Interfaces</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>TOTALS</td>
<td>121</td>
<td>62</td>
<td>59</td>
<td>116</td>
</tr>
<tr>
<td>FW/BL Structure</td>
<td>25</td>
<td>0</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>
**Incremental Cost Associated with the Breeding Blanket (cont.)**

- Beryllium dominates the blanket cost.
  - Be unit cost (65-85% dense cold-pressed) is $600/Kg.
  - Be inventory 206 MT.
  - Total Be cost is about $124M.

- The cost of the blanket tritium recovery system is very small relative to the total cost of the fuel cycle system.

- The incremental R&D cost for the driver blanket is about $62M, which is about 7% of the total long-term R&D cost for ITER.

- Essentially all of the Breeding Blanket R&D is demo relevant.
**Benefits of Breeding Blanket for ITER**

- Substantial benefits in addition to the economics of tritium production are gained from a breeding blanket for ITER.

- Ceramic breeder materials performance under reactor relevant conditions (temperature, burnup rate, purge gas conditions, etc.)
  - Radiation effects
  - Thermo-mechanical performance
  - Tritium retention
  - Neutronics performance

- Beryllium Performance
  - Tritium retention
  - Irradiation induced swelling/creep
  - Mechanical performance

- Tritium Recovery System
  - Tritium transport
  - Cyclic effects
  - Tritium/impurities release from beryllium

- Engineering Benefits
  - Materials and blanket fabrication methods
  - Reliability data base from blanket operation
  - Blanket auxiliary systems (manifolds, maintenance systems, etc.) performance


**Benefits of Breeding Blanket for ITER (cont.)**

- Demonstration of blanket performance for extended operation is essential for commitment to a DEMO.

- Safety Benefits
  - Reducing tritium transportation shipments
  - Reduced tritium inventory on site
  - Reduced decay heat relative to non-breeding blanket

- Radioactive Waste Generation
  - Reduced activation and biological hazard potential relative to non-breeding blanket

- Tritium Requirements
  - Tritium resources will not limit ITER availability
Risks of Breeding Blanket for ITER

Reliability/Availability

• Blanket risk is much lower than for PFC
• First Wall failure rate much higher than for the blanket: Same for breeding and non-breeding
• Most failures in the blanket are associated with the structure and coolant: Same for breeding and non-breeding

Safety

• Additional tritium inventory in the blanket is small compared to total inventory in the system and is not "vulnerable"
• Reduced tritium inventory on site
• Reduced tritium transportation problems
• Breeder/coolant interaction can be controlled

Technical Issues

• Many are common to breeding and non-breeding
• Breeding blanket issues can be adequately addressed through the identified ITER R & D
Breeding Blanket is strongly recommended (necessary) for ITER to meet its objectives at lower cost, higher benefit with an increment or reduction in risk that is small