Technology Considerations in Major Next-Step Fusion Experiments

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The Logic for the Next Step Must Flow from What We Want to Achieve Over the Next Two Decades:

"Develop a VISION for an Attractive Product"

- Attributes of an Attractive Product:

  Economics
  Safety
  Environmental Impact

- Fusion will have Safety and Environmental Advantages

The Major Uncertainties and
the Grand Challenge are in

Economics

Developing A VISION for an Economically Competitive System Must Be:

A Joint Effort Between Physics AND Technology

- A Key Element in Technology is the "In-Vessel System," Particularly Power Extraction Technology

- This fact is obvious from examination of the most important figure of merit:

COST of Energy (cents/kwh) ≡ COE

Attractive Vision Requires JOINT Physics and Technology Efforts
(Power Extraction Technology is Critical)

Need High Power Density
- High-Performance Plasma
- Power Extraction Technology

Need Low Failure Rate

$$COE = \frac{C \cdot i + \text{replacement cost} + O\,\&\,M}{P_{fusion} \cdot \text{Availability} \cdot M \cdot \eta_{th}}$$

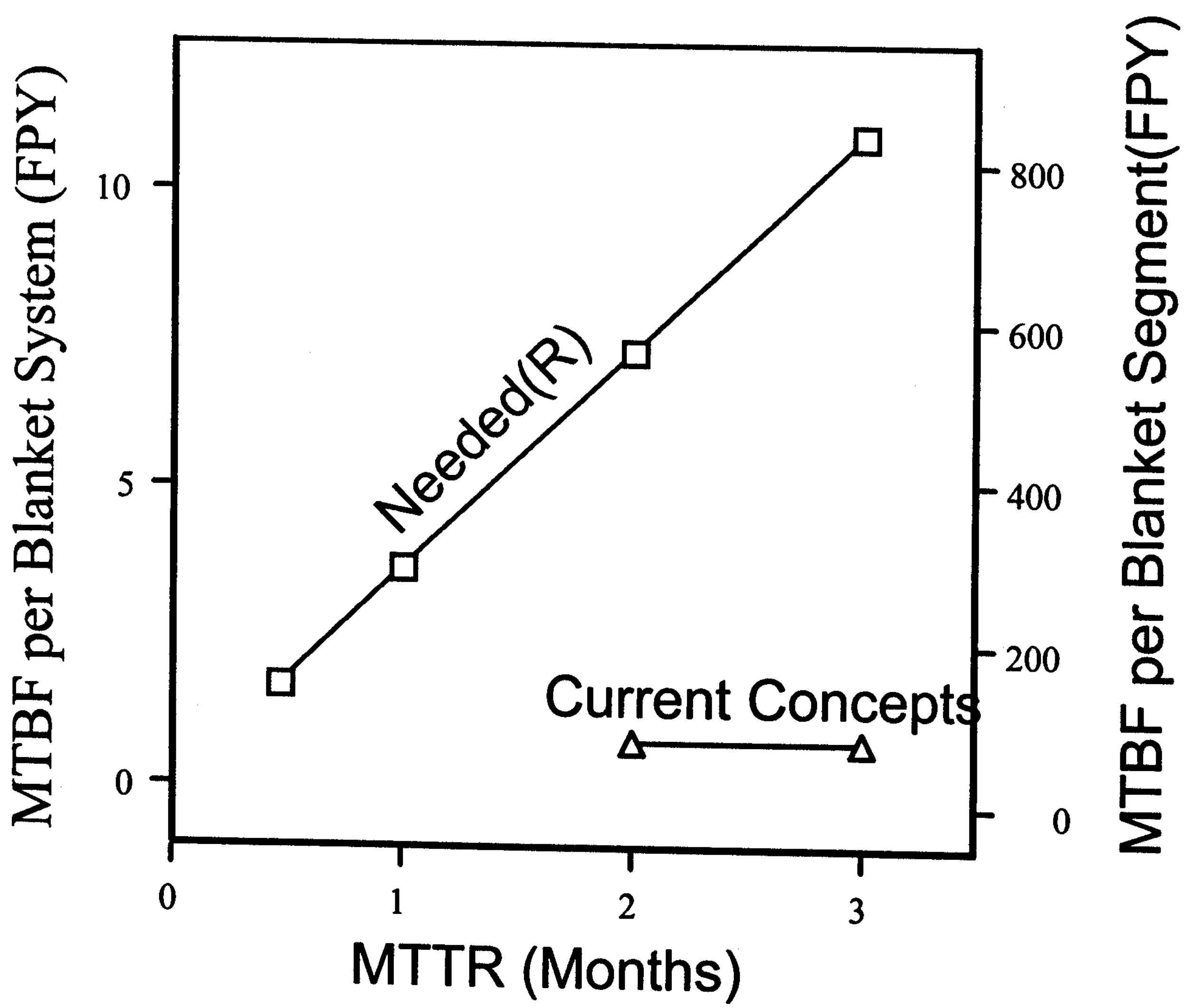
Energy Multiplication

Need High Temp. Energy Extraction

$$\frac{(1/\text{failure rate})}{1/\text{failure rate} + \text{replacement time}}$$

- **Need Low Failure Rate:**
  - Innovative Power Extraction Technology
- **Need Short Maintenance Time:**
  - Simple Configuration Confinement
  - Easier to Maintain In-Vessel Technology

Current FW/B Design Concepts are NOT Capable of Meeting the Challenging Reliability and Maintenance Requirements



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The Community is Making Progress Toward Identifying A VISION for an Attractive Product

- In Physics: Innovative Confinement Concept Initiative, Plasma Science, etc.

- In Technology: New Initiatives Such As APEX and ALPS

- APEX:

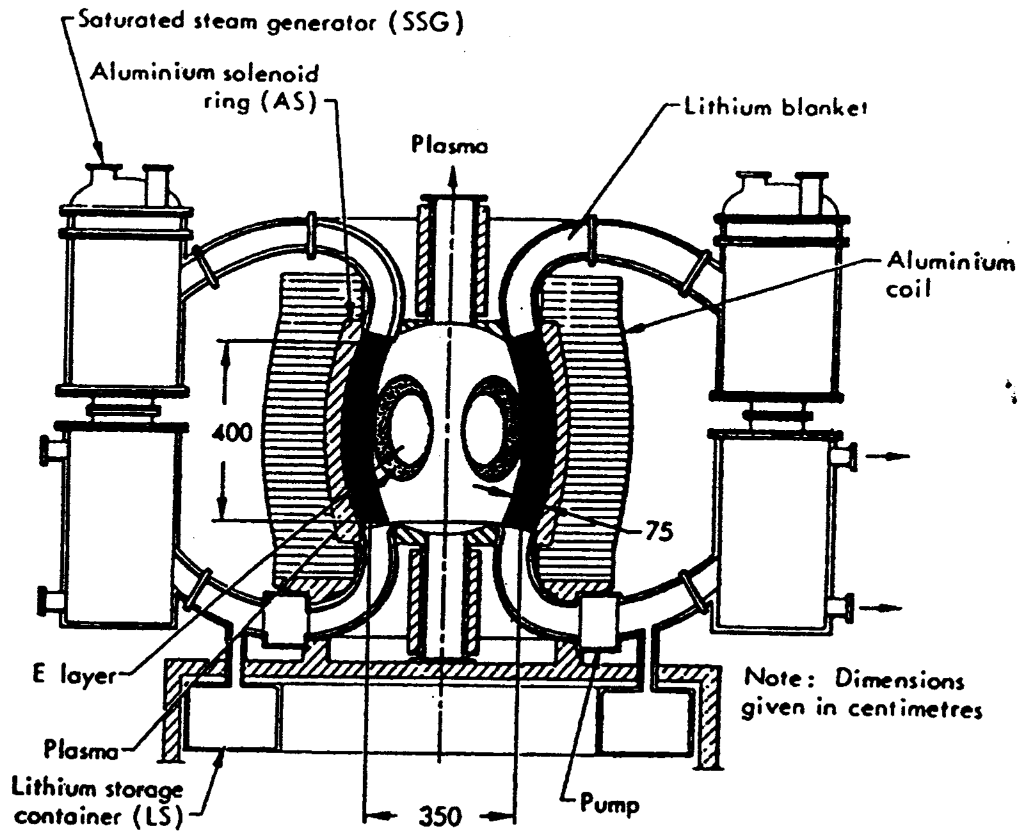
  Major Initiative to Identify <u>Revolutionary</u> Concepts for In-Vessel Components (Power Extraction Technology) that –

  1) Can Handle Much Higher Wall Loads (> 10 MW/m^2)
  2) Have Low Failure Rates
  3) Have Faster Maintenance
  4) Have Simpler Technological and Material Requirements

Example of APEX Efforts
Explore LIQUID WALLS/Blankets

Advantages

- Allows Very High Wall Loadings, Makes High Power Density Systems Attainable
- Eliminates Many of the Material Radiation Damage Problems
- Low Failure Rate
- Much Easier Maintainability
  - ➢ All Liquids Inside the Vacuum Vessel



The Immaculate' Astron, Field Reversed Configuration
(Christofilos, J. Fus. Energy **8**, 1989)

Summary of Key Issues for "In-Vessel" Components

1. D-T fuel cycle **self sufficiency**
2. **Thermomechanical** loadings and response of blanket components under normal and off-normal operation
3. Materials **compatibility**
4. Identification and characterization of **failure modes, effects, and rates**
5. Effect of imperfections in electric (MHD) **insulators** in self cooled liquid metal blanket under thermal/mechanical/electrical/nuclear loading
6. **Tritium inventory** and recovery in the solid breeder under actual operating conditions
7. **Tritium permeation** and inventory in the structure
8. Radiation Shielding: accuracy of prediction and quantification of radiation production requirements
9. Plasma-facing component thermomechanical response and lifetime
10. **Lifetime** of first wall and blanket components
11. Remote maintenance with acceptable machine shutdown time.

IEA Study Summary

FNT Requirements on Major Parameters for Testing in Fusion Facilities, with Emphasis on Testing Needs to Construct DEMO Blanket

Parameter	Value
Neutron Wall Load, MW/m^2	1-2
Plasma Mode of Operation	Steady State
Minimum Continuous Operating Time, Weeks	1-2
Neutron Fluence ($MW{\bullet}y/m^2$) at Test Module	
Stage I: Initial Fusion "Break-in"	0.3
Stage II: Concept Performance Verification	1-3
Stage III: Component Engineering Development and Reliability Growth	4-6
Total Neutron Fluence for Test Device, $MW{\bullet}y/m^2$	>6
Total Test Area, m^2	>10

Figure 3. Stages of fusion nuclear testing in fusion facilities

	Fusion "Break-in"	Concept Performance Verification	Component Engineering Development & Reliability Growth	DEMO
Stage:	**I**	**II**	**III**	
Required Fluence ($MW-y/m^2$)	**~0.3**	**1 – 3**	**>4 – 6**	
Size of Test Article	**Sub–modules**	**Modules**	**Modules/Sectors**	
	■ Initial exploration of performance in a fusion environment ■ Calibrate non–fusion tests ■ Effects of rapid changes in properties in early life ■ Initial check of codes and data ■ Develop experimental techniques and test instrumentation ■ Narrow material combination and design concepts ■ 10–20 test campaigns, each is 1–2 weeks	■ Verify performance beyond beginning of life and until changes in properties become small (changes in structure mechanical properties are substantial up to about 1–2 $MW{\cdot}y/m^2$) ■ Data on initial failure modes and effects ■ Establish engineering feasibility of blankets (10 to 20% of lifetime) ■ Select 2 or 3 concepts for further development	■ Identify failure modes and effects ■ Iterative design/test/fix programs aimed at improving reliability and safety ■ Failure rate data: Develop a data base sufficient to predict mean–time–between–failure with sufficient confidence ■ Obtain data to predict mean–time–to–replace (MTTR) for both planned outage and random failure ■ Develop a data base to predict overall availability of FNT components in DEMO	

Recommendations (From Technology Viewpoint)

1) Encourage Exploration of Innovative Engineering Concepts that can Dramatically Improve the Vision for an Attractive Product
   - Enhance Coupling Between Confinement Innovation and Engineering Innovation Efforts

     [We Can Do it Together]

2) Incorporate Technology Testing, Particularly Power Extraction Technology, as a Key Element in the Mission for Next Step Device (e.g. in cost-reduced ITER)

3) We must realize that several (more than one) fusion facilities are required to develop the knowledge base.

ITER must be complemented by other facilities (e.g. VNS and others)