3 copies

Remarks on Nuclear Testing

Mohamed A. Abdou

1. General Observations
2. Technical Requirements
3. Suggested New Addition

Presented to SWG Briefing/ISCUS Meeting,
General Atomics, San Diego, March 18, 1998

General Observations

1. The Nuclear Testing Mission in ITER EDA did not cause any significant increase in the cost of the device. The design was dictated by physics (ignition) requirements. Test modules were accommodated in test ports, i.e. simply "utilizing the device".

2. There will always be some USEFUL Nuclear Tests to do in any D-T Burning Device. It is inconceivable (at least to me) that a DT burning device would be built without some sort of Nuclear Testing Mission.

3. The Issue is:

   How hard should the ITER Design be driven by the nuclear testing mission? Should ITER do it all?

   - We will make suggestions later

Nuclear Testing Requirements

A. Tests that depend on device parameters

Wall load
Fluence
Burn time, dwell time
Test area
Etc.

– These are well documented in literature

e.g. Abdou, Fusion Engineering and Design, 27, pages 111-153 (1995)
Abdou et al, Fusion Technology, 29, pages 1-58 (January 1996)

B. Other Engineering Tests

These are relatively new based on better understanding of the "in-vessel" issues.

Table 16. 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 ($MW \cdot y/m^2$) 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, $MW \cdot y/m^2$	>6
Total Test Area, m^2	>10
Magnetic Field Strength, T	>2

* if steady state is unattainable, the alternative is long plasma burn with plasma duty cycle > 80%.

A

Neutron Wall Load

Considerations

1) Engineering Scaling

2) Trade-offs between device availability and wall load for a given testing fluence and testing time

Engineering Scaling

- Test modules are designed to "act like" rather than "look like" a DEMO or a reactor module.
  - for example, maintaining average temperature is easy by varying coolant speed and flow rate. On the other hand, temperature gradients are dependent on bulk heating/wall load. Changing dimensions can preserve overall ΔT "across". But there are limits on changing dimensions in order not to alter or lose certain phenomena and effects.
    Same for stresses, etc.

An approximate rule: The confidence in extrapolation of results drops sharply for a scaling factor of more than 2-3 in neutron wall load

- However, one can argue that tests at any wall load are very important if the alternative is to have nothing.

Trade-offs between Wall Load, Availability and Time to Achieve a Given Fluence

Fluence = $P_n A_d t_d$

Assume 12 calendar years

Neutron Wall Load MW/m^2	Availability %			
	6 MW•y/m2	3	1	0.3
0.5	100	50	16.7	5
1.0	50	25	8.3	2.5
1.5	33	16.5	5.5	1.6
2.0	25	12.5	4.2	1.3

Fluence Requirements

Fluence requirements for FNT were developed by considering the following factors.

1. Time required to perform basic and multiple-effect experiments to observe groups of phenomena and to resolve technical issues associated with particular aspects of the blanket design. e.g. tritium release in solid breeders and thermo-mechanical interactions.

2. Time required to observe integrated behavior past the beginning of life (BOL) and during periods of significant radiation-induced changes in material properties and component behavior.

3. Time required to obtain data on key issues related to long-term component and system behavior such as corrosion and mass transfer, chemical interactions, stress relaxation, breeder burnup and tritium buildup, and containment.

4. Time required to obtain data on failure modes, effects, and rates.

5. Time required to perform the three stages of initial fusion break-in, concept verification, and component engineering development and reliability growth tests. The reliability growth testing phase is the most demanding on fluence requirements.

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/m²)	~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·y/m²) ▪ 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	

Suggestion for Adding to the ITER Mission "Engineering-Reality Check"

- We learned the last few years that failure rates and maintainability are very critical
  - Potential "Show Stoppers" for commercial fusion
  - May hinder progress in building powerful DT burning experimental facilities

- Suggestion

  Require that ITER in-vessel system be designed such that:
  1) mean-time-between-failures is one month (or longer) of continuous operation
  2) Recovery from a failure (normally replacement of a module) in the in-vessel components can be accomplished within two months or less.