

Progress Report for FY 1998

Nuclear Systems and Testing Program for ITER (DOE Grant No. DE-FG03-88ER52150)

DOE/ER/52150--T3

I. Progress Report for 1998

1.0 Summary

This progress report summarizes UCLA's FY 98 tasks identified under the US ITER Nuclear System and Testing Program. The effort during this performance period focused on a number of TBWG activities (including test module design and analysis) that were identified and agreed upon (in the presence of the ITER Director and Deputy Director) at TBWG-4. These include:

- a) DEMO test module design and performance analysis under pulsed operation
- b) Test program operation plan
- c) Test port design and analysis
- d) Decay heat calculations and safety analysis
- e) Further discussion among the parties to define collaboration on R&D for the test program as well as possible collaboration on the construction and operation of test articles.
- f) Remote handling and ancillary equipment
- g) Criteria for qualifying a blanket module or submodule for actual insertion and testing in ITER
- h) Definition of test module instrumentation and verification of capability to perform in the ITER fusion environment (magnetic field, radiation, heating, etc.)
- i) Analysis to show that the results to be obtained from the test modules as designed can be extrapolated to DEMO and reactor conditions (e.g. higher wall loads and the need to demonstrate tritium self-sufficiency)

The main achievements during this performance period include:

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- (1) updating and finalizing the US DDDs for the ITER Test Blanket Program to form part of the ITER Final Design Report(FDR). Specific revisions were in response to the minimal lithium volume test blanket design requirements and safety impact. The complete, revised US Test Blanket DDD entitled "DDD 5.6 H&I US Li/V and Helium-Cooled Solid Breeder Test Blanket Systems" was forwarded to the ITER JCT in May 1998. It includes a final revision of the general Test Blanket DDD Executive Summary.
- (2) evaluating the feasibility of the US test program, including instrumentation and the benefits of the ITER test program. Details of this assessment, including solid breeder and liquid breeder blanket test plans, are documented in UCLA-IFNT-13 (attached).

In addition, dose mapping calculations were performed for the ITER Building, including equipment and layout of coolant pipes/heat exchangers. A report on ITER Building dose calculations was sent to US ITER management and to the Garching Task Coordinator in April, 1998. The report entitled "Three-Dimensional Calculations of ITER Building Dose Rate Profiles and Assessment of Accessibility Inside the Building During Operation and After Shutdown of ITER" can be located through ITER Reference number of ITER Task S 62 TD 12, ID No: D325 ITER/US/98/S62TD12-D325 UCLA-FNT-100 UCLA-ENG-98-190

2.0 Detailed Description

The final US test blanket DDD was extensively revised during this performance period to incorporate all new interface design concepts and a new Li/V test module design (See Figure 1). The new lithium design was conceived during the TBWG-5 meeting to satisfy the ITER safety guidelines.

The need to provide a lithium-cooled blanket that is inherently safe in the predominately water-cooled ITER device demanded the reduction of the volume of lithium to less than 35 kg to ensure that hydrogen produced from lithium-water reaction is below 5 kg. This is accomplished by cooling only the first two blanket channels with lithium. These coolant channels are directly behind the test blanket first wall and the walls are constructed of a vanadium alloy. Because the amount of hydrogen generated would be insufficient to cause a

safety problem, the remainder of the test blanket module would basically function as a water-cooled shield. Water coolant is circulated in the steel shielding area behind the lithium coolant section. Correspondingly, the lithium-cooled first wall would immediately face the plasma to gain operational experience.

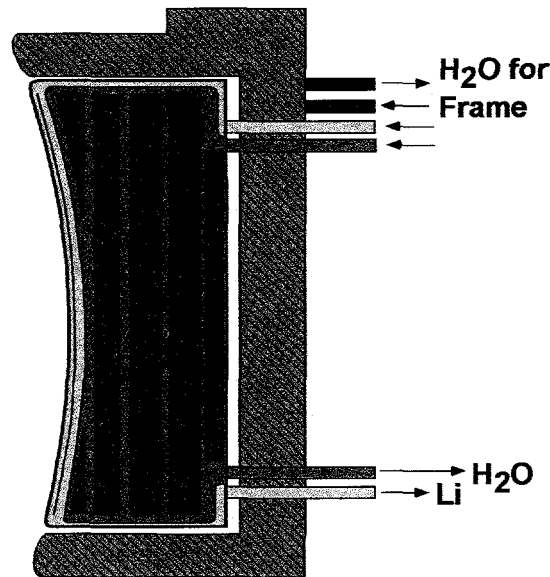


Figure 1 Lithium Blanket Test Module and Frame

Figure 2 illustrates a remote handling manipulator inside the vacuum vessel extension. The pipes and diagnostic cables have been removed, the sealed welds have been severed, and the retaining fasteners removed. The remote handling manipulator is about to remove the assembly from the port. The sketch illustrates a possible wheeled mechanism to facilitate load transfer from the vacuum vessel to the RH manipulator and reduce the static and rolling friction for test blanket assembly removal.

Further activities during this period of performance have been directed toward preparations for the TBWG meeting that was held in Moscow, Russian Federation on 2-3 July 1998. Main topics addressed during the meeting included the Parties' test plans, feasibility of the ITER Blanket Test Program and progress on the cooperative tasks on test blanket R&D.

A report entitled "Coordinated Blanket Test Program in ITER" developed by the Test Blanket Working Group in compliance with the ITER Council's Terms of Reference was addressed to the ITER and Parties' Program Directors on July 20, 1998. The US assessment of the benefit

and limitation of testing in ITER provided major input to the report. The primary benefit of using ITER for testing DEMO/Power plant-like blankets is that it provides the actual fusion environment, viz., neutron energy spectrum, chemical, electromagnetic, and thermal. The combined effects of magnetic fields, radiation, and thermally induced stresses on corrosion, mass transfer, and re-deposition can be evaluated. The initial fusion results of tritium generation, radiation effects, and tritium recovery, stability of breeding material and compatibility with the structure can be evaluated under prototypical conditions. Although the tritium production rates will be lower than anticipated for a DEMO, important information and experience will be generated. In addition, ITER testing will provide an important learning experience in replacement procedures for the blanket module in a DEMO or commercial power plant. The necessary steps, including cool down of the blanket and coolant drainage will be similar to those for a DEMO or commercial power plant. However, as a result of the limited fluence goal for ITER, the test program in ITER can only focus on the initial fusion break-in tests. The pulsed operation and low duty cycle characteristics of ITER limit the extent to which FNT testing data will be obtained during the BPP. Details of this assessment including solid breeder and liquid breeder blanket test plans are documented in UCLA-IFNT-13.

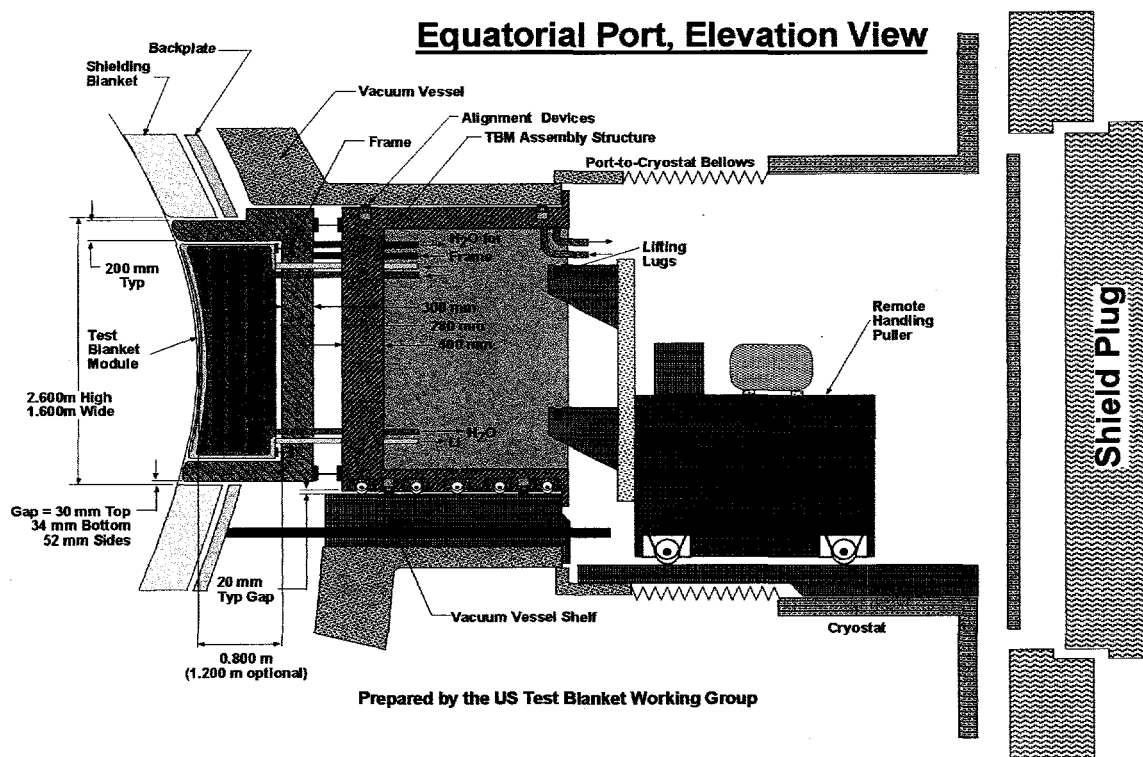


Figure 2 Test Blanket Assembly Being Removed By Remote Handling Equipment

3.0 Conclusion

The scope of US ITER test program activities in the future will be established once the direction of ITER becomes clear. However, it is believed that continued support of US TBWG activities is essential to continued access to other Parties' programs on blanket development.

UCLA-IFNT-13

**Feasibility and Benefits of ITER
Blanket Test Program**

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Feasibility and Benefits of ITER Blanket Test Program

Version May, 1998

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1.0 Background Information

The ultimate goal of this testing is to evaluate and gain confidence in one or more breeding blanket concepts for electrical power generation in a DT fusion reactor. This is to be accomplished by installing and testing several test blanket modules in the ITER test ports provided specifically for this purpose. This ITER testing program is intended to lead to a single blanket design concept to be implemented in a demonstration power reactor. The demo power plant will prove the integrated operation of all necessary systems leading to an attractive, commercial electric generating fusion power plant.

The following steps must precede this level of testing in ITER: selection of materials, irradiation of materials in fission reactors, testing material or component applications, screening design approaches, conducting design trade studies, confirming component performance and reliability, validating remote handling equipment and procedures, and testing small system mockups. In attempting to understand the behavior of materials, components, and complete systems in a harsh environment of intense 14 MeV neutrons, high magnetic fields, and severe surface and volume heating; all available non-nuclear and fission testing have been employed to select materials and components and estimate performance in the DT fusion environment.

The ITER reactor will provide the first opportunity to test a complete first wall, blanket, and shield module in a true DT fusion environment. ITER will have a DT fusion plasma representative of a commercial fusion power plant plasma and will subject the test blanket module with a typical environment of 14 MeV neutrons, surface heat fluxes, electromagnetic loads, and charged particles. The 1000-second duration burn is sufficient to establish quasi-equilibrium conditions in most blanket functions.

Within this environment, the test blanket module must produce and recover tritium in quantities sufficient to demonstrate self-sufficiency, extract high-grade thermal energy from the blanket, and provide adequate shielding for the superconducting blankets and structures. The test blanket module must also accommodate the surface and volume heating effects, mechanical and electromagnetic loads, particle erosion, and 14 MeV neutron irradiation for the predicted module lifetime, without any unplanned performance degradation and loss of function.

Many different design approaches for fusion blankets (meant to include first walls, breeding blankets, support structures, cooling systems, neutron multipliers, and shielding systems) have been postulated over the past decades. In the US community, two distinct design approaches have been identified as best fitting the US plan leading to a commercially attractive power plant. These are the solid ceramic breeder, with a ferritic steel structure, and the liquid lithium breeder, with a vanadium alloy structure. Japan and the European Union has adopted the solid ceramic breeder with a ferritic steel structure as one of their principal blanket choices. The US is cooperating with other Parties in developing this approach. The US plan also includes the Li/V blanket approach, especially in selection and quantification of the vanadium structural alloys and the insulating coating to inhibit MHD pumping power losses. The Russian Federation is also interested in the Li/V blanket design approach and is cooperating with the US in this development effort.

1.1 Test Objectives

The goals of the blanket testing in the fusion environment is to test and develop blankets and to demonstrate the performance and availability levels required for an attractive fusion power plant. Previous study has shown that testing and development of the blanket component in fusion facilities proceed in three stages: 1) initial fusion break-in tests, 2) concept performance verification, and 3) component engineering development and reliability growth [4]. Given the limited fluence goal for ITER, the main objectives of blanket testing in ITER BPP is to perform the first stage of initial fusion break-in tests. It is expected that the test results would provide information for:

- initial indication of performance in the fusion environment
- calibration of non-fusion tests against performance in the fusion environment
- observation of effects of rapid changes in properties in early life
- initial check on codes and data

- test and development of experimental techniques and instrumentation
- selection of material combinations.

Initial Indication of Performance in the Fusion Environment

The test modules will be highly instrumented to provide extensive data on the operational performance. Both in-situ monitoring and post-test examination will be used to evaluate the blanket performance.

In-situ testing will focus on measurements of radioactive mass transfer in the coolant system and analysis of the tritium processing stream. Effects of the magnetic field and coolant flow characteristics on the corrosion products will be monitored. Tritium concentrations in the coolant will also be monitored and evaluated in terms of operational parameters such as temperature, operating scenario, and coolant flow characteristics. Of particular importance is the detection of tritium permeation in the secondary loop.

A major part of the test will be post-test destructive examination. Analyses of effects on all blanket elements will be performed. This includes breeder microstructure changes, interactions with the structure, and stability in the tritium processing fluid.

Calibration of Non-fusion Test Data Against Fusion Test Results

Testing in ITER will provide a means of confirming and calibrating the results from testing in non-fusion devices. Because the simulation (such as fission) facilities or test stands will be the primary means of testing to support the development of long-life blanket components, the correlation of results from ITER and the fission facilities is important. This correlation will be used to modify the test results for fission tests to enable the fission facilities test results to be used with confidence.

1.2 Stages of ITER Operation

The ITER operation would be divided into two phases: a Basic Performance Phase (BPP) and an Extended Performance Phase (EPP).

The ITER BPP is expected to last about 10 calendar years, and characterized by a typical operational availability profile illustrated in Table 2.3.2-1 GDRD[1,2]. This phase would include a 3-year period dedicated to the controlled ignition experiments, followed by an extended burn experiments period, a steady state operation experiments period, and finally

leading to a few thousand hours of full DT operation for blanket modules functional tests. The reference plasma burn time for blanket modules testing in this phase is about 1000 seconds, with a dwell time of 1200 seconds and a plasma duty cycle of ~ 45%. In addition, the machine operation would include 100% availability for continuous test campaigns of 3-6 days with the nominal pulse operation scenario.

The second phase, Enhanced Performance Phase, is also expected to last a decade, with emphasis placed on improving overall performance and carrying out a higher fluence component and materials testing programme. This phase would address high availability operation and advanced modes of plasma operation, and may address reactor-relevant blanket segment demonstration. Operation during this phase would include continuous testing campaigns lasting 1-2 weeks, and would accumulate a fluence of at least 1 MWa/m².

TABLE 2.3.2-1 (GDRD) ITER Operational Availability During BPP

	Year 1 to 3	Year 4 to 5	Year 6	Year 7 to 10
Availability (%)	-----	4	7	10*
Fluence (MW a/m ²)	-----	0.02	0.03	0.2
Average burn length (s)	-----	500	1000	1000
Number of pulses	3200	1600	1000	6000
Average repetition time (s)	-----	1700	2200	2200
* Including 100% availability for continuous test campaigns of 3-6 days with the nominal pulse operation scenario.				

1.3 Helium-Cooled Solid Breeder Test Plan

The neutron fluence of ~ 0.3 MWa/m² foreseen now for ITER BPP does not allow investigation of very slow processes such as corrosion or structural material swelling. However, the tests in ITER are necessary because they are the only ones which can be performed with the correct power and temperature distribution in the right neutron environment for large size test modules. Accordingly, the types of tests can be classified into the following categories:

- 1) environment characterization: Testing during the zero-activation plasma operation phase will be limited, however, the information concerning the ancillary equipment operation and mechanical behavior of the modules under various plasma operations can be examined. In addition, information about measuring techniques and instrumentation will be gained. Some limited testing is proposed during the extended burn and steady state experimental periods where the fluence is limited. During this period, environment characterization will be performed to the maximum extent possible. This includes measurements of tritium production, neutron spectrum, etc. in various locations in the test modules.
- 2) Fusion Break-in Tests-initial exploration of blanket performance: Tests will be performed during Year 7 to 10 of ITER BPP. The initial exploratory performance tests focus on an integrated test module assembly for the preferred blanket configuration, designed to operate at DEMO performance under ITER wall loading conditions. In the performance test, the basic characteristics of the blanket such as heat generation, thermal-hydraulics, tritium transport and control, and thermomechanical performance will be evaluated. Other test objectives are described in Section 1.1.

A summary of the test sequence for the US helium-cooled solid breeder test program is illustrated in Figure 1.3-1. As shown, there will be 2 poloidally-cooled oriented test modules inserted in the allocated test port during the first scheduled maintenance period of the first controlled ignition experiments period. As presently envisioned, there will be no scheduled removal for the US solid breeder test modules over the entire BPP. The only exceptions are: (1) in case of a test blanket module failure where the test blanket module has to be removed and replaced and (2) as required by the ITER machine.

The detailed test plan for the helium-cooled solid breeder blanket testing during the enhanced performance phase should be developed following a review of the testing results from the basic performance phase.

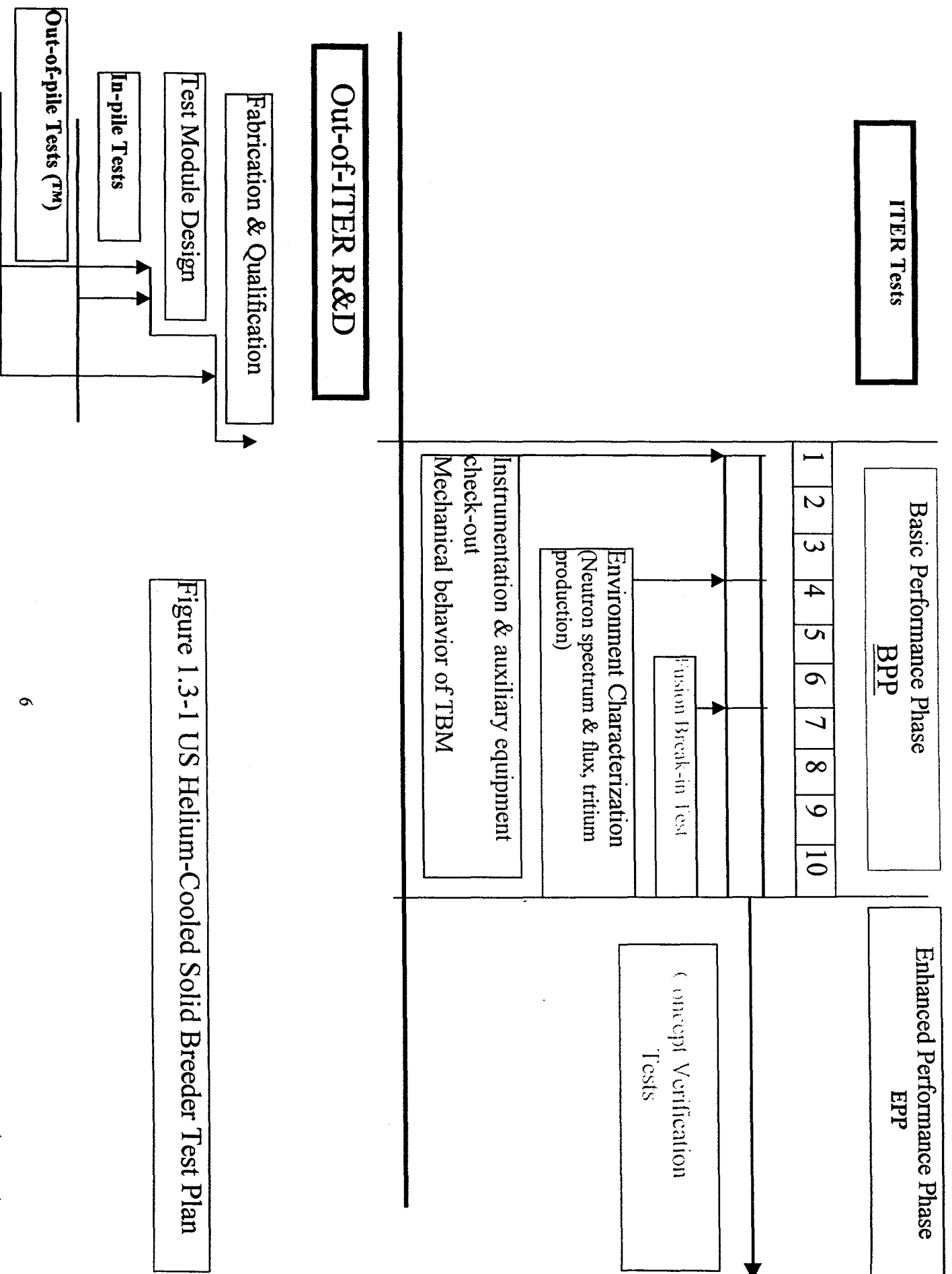


Figure 1.3-1 US Helium-Cooled Solid Breeder Test Plan

1.4 Li/V Test Plan

The primary function of testing a blanket testing module within ITER is to evaluate the functioning of the blanket testing module within proper radiation and MHD environment. Part of the MHD environment can be duplicated outside a fusion device. However, some of the MHD environment, such as disruption effect, will be difficult to duplicate. The radiation environment, including the flux, fluence and spectra effects, can only be observed within a fusion device such as ITER. However, it is much easier to perform an experiment outside of ITER, and should be carried out to assess integrated effects of various parameters. The mission of ITER testing is to confirm the conclusion from the out of reactor testing, and also evaluate these effects which can not be done outside ITER. Here, we summarize the more important tests which will be carried out within ITER:

1.4.1 Insulating coating testing

For a self-cooled liquid metal blanket to be creditable, an insulating coating has to be developed to reduce the effect of MHD pressure drop. This coating will be developed outside fusion environment. However, radiation damage, fatigue, disruption and corrosion all may have important effect to the integrity of the insulating coating. Also, the addition of impurities to maintain the coating may have effects on other subsystem, such as tritium recovery.

The candidates for the insulating coating for the Li/V blanket at this time are CaO and AlN. It is expected that full scale R/D program will be initiated in the US to qualify the usage of some of the materials for the ITER testing module.

The degradation of the insulating coating, if it occurs, will either increase the pressure drop across the testing module, which can be easily measured, or will change the flow distribution within the testing module, which can be measured by either measuring local temperature, or measuring local velocity. The identify of a insulating material, and obtain positive testing result within ITER, is a feasibility issue for a self-cooled liquid metal blanket.

An insulating coating is required to last the lifetime of the blanket. Therefore, self-healing characteristics is very important. Within the ITER device, start up and disruption may cause the coating to crack. The behavior of the coating after disruption, and the speed that it will recover, if it does, is very important experimental results for a self-cooled liquid metal blanket.

1.4.2 Material Testing

ITER is most likely the first device which will provide 14 MeV neutrons. Unfortunately, the fluence of the 14 MeV neutron is rather low, even at the end of EPP, to determine the end of life effect by the 14 MeV neutrons. However, valuable results can be obtained.

The most important results is to validate experimental results and code prediction based on fission irradiation and theory. The difference of material behavior, with different He/DPa ratio, up to a modest fluence, will provide us with more thorough understanding of material damage by neutrons.

Also, the first wall tritium permeation across V wall, with an insulating coating behind, provide important results to tritium permeation. The tritium concentration inside the first wall, and its impact on material properties, also will be measured. The tritium permeation and inventory may also have some impact to the performance of the insulating coating. The tritium permeation, if is high enough, will have effect on blanket tritium recovery system.

1.4-3 Tritium breeding

One of the key function of a blanket is to breed sufficient tritium for D-T burning and for the start up of the next fusion power plant. For a lithium blanket, tritium breeding is usually not a feasibility issue, since lithium is the best breeding material available. However, tritium breeding still has to be assessed.

To assess tritium breeding ratio with a small testing module inside ITER is difficult. The neutron spectra, and the tritium production rate, is effected by the reflected neutron from the adjoining shield blanket. Therefore, it is difficult to assess the real tritium breeding with the tritium production rate measured within the testing module. On top of that, tritium will permeate both outward from, and inward to, the testing module. The real tritium production rate can not easily be obtained.

The only way to do this is to use both experimental results and calculation code. Numerical codes can be used and calibrated by the performance of the testing module. The same code will than be used to calculate for the entire reactor, with added confidence.

1.4-4 Tritium extraction and recovery

Tritium extraction and recovery can be demonstrated outside of fusion environment. The only issue associated with ITER is that the tritium recovery system has to account for all the impurities generated by radiolysis and/or corrosion. Therefore, the tritium recovery method, developed from the testing stand, will be added to the blanket system and its performance demonstrated.

1.4-5 MHD

MHD has important effects on both pressure drop and heat transfer. Although insulating coating will reduce the most important MHD pressure drop effect, there are still many MHD effects which are important and not well understood at this time.

The 3-D MHD effect can be important to pressure drop, heat transfer, and velocity distribution. However, this MHD effects can be tested and evaluated within a testing stand.

The most important MHD effects to be tested within ITER is to evaluate the pressure drop and flow distribution with an imperfect insulating coating. It is important to assess what will be the effect on heat transfer and velocity distribution when the insulating coating developing cracks, and how long will it take to recover.

1.4-6 Demonstration of electric power generation

To demonstrate electric power generation, the only requirement is that the coolant has a proper temperature range.

1.4-7 Code validation

One of the basic function of ITER testing is for code validation. Many numerical codes have been developed under fusion R/D. The testing results from the ITER testing module can be used to validate these codes. With this validation, there will be more confidence to use these codes for future application for demo or commercial power plants.

1.4-8 Long term reliability

Fusion blanket has to be operating reliably under some very severe conditions, including EM load, intense radiation damage, high tritium throughput, and high temperature. ITER is the only device which will provide all these conditions. Therefore, it is important to evaluate the testing blanket performance over an extended period of time to assess the long term reliability of the testing module. If failure occurs, it is important to assess the reason of the failure and to change the blanket design to accommodate the failure.

Also, the blanket replacement mechanism has to be tested. Although that the size and replacement scheme of the ITER testing module is very different from the demo or commercial power plant, this is the only real blanket device which we can performance the remote maintenance process. The steps needs to be taken, such as blanket cooling down and coolant drainage, will not be that different from the demo or commercial blanket. Therefore, this will provide an important learning experience toward to replacement of the blanket module in the demo.

The testing plan and testing schedule of the US Li/V blanket are shown on Figures 1.4-1 and 1.4-2.

Figure 1.4-1 US Test Plans for Lithium Blanket

1. Pre ITER tests used to validate materials, systems, and instrumentation

- Materials development and testing on vanadium structures and coatings
- Modeling and testing tritium extraction and handling systems
- Testing of MHD effects in dedicated facility
- 2. Initially testing will be in the DD operation during the BPP
 - Confirm optimum concentration of oxide for insulator formation and maintenance
 - Determine liquid metal velocity profile
 - Validate overall system performance
 - Validate maintenance equipment performance
- 3. Testing in Low Fluence DT operation in BPP
 - Confirm reliability of insulating coating
 - Confirm tritium recovery process
 - Confirm optimum operation conditions
- 4. Testing in BPP and EPP
 - Confirm overall system operation and performance
 - Investigate impact of neutron fluence on system performance
 - Accumulate reliability data
 - Determine MTBF and MTTR data

Figure 1.4-2 Lithium Breeder Test Plan vs. ITER Operational Plan

Operation year	1	2	3	4	5	6	7	8	9	10
ITER:				500	1000					
Average burn length (s)	-			500	1000		1000			
Number of pulses	3200			1600	1000		6000			
Average repetition time (s)	-			1700	2200		2200			
Total plasma operation time(h)	-			222	280		1670 ⁽¹⁾			
TBM:	Phase A			Phase B			Phase C			
Performed tests										
Testing operation time:										
	Confirm Li chemistry Measure Li velocity Maintenance testing			Coating reliability Tritium recovery Optimize operation condition			Confirm system operation and performance Effect of fluence Reliability data			
	-			≈ 300h			≈ 800h			

(1) Including 50% availability for continuous test campaigns of 3-6 days with nominal pulse operation scenario [2.1.1.7-1].

(2) According to the results of the screening tests.

Reference- Fax of Dr. Parker of 14 October 1997 to the TBWG-members.

2. Feasibility and Benefits of Blanket Test Program

2.1 Test Approach and Feasibility

The test approach adopted by the US and the other international parties is to design one or more complete test blanket modules (TBM) to be installed and operated in the ITER horizontal test ports for an extended period of time. It is felt that sufficient technical data will be available at the time of test initiation to ensure a high level of confidence that the TBM will operate as predicted, with no adverse impact to the operation of ITER, and will provide the necessary data to select and refine the blanket design approach. This success-oriented approach offers the least cost to achieve the maximum benefits in the shortest test time. If any anomalies or deficiencies are observed, there will be ample time to make corrections and continue the test program.

As noted in the Background Section, there have been and will continue to be supportive and collaborative research, development, and testing activities associated with the test blanket materials, components, and subsystems. After the designs of the TBMs have been finalized, small test mockups of the modules will be constructed to affirm the overall design fabricability, performance, and operability. The operational interfaces with the instrumentation and control, heat transfer and transport, tritium removal, structural supports, and remote maintenance will be verified with working mockups or operational subsystems. The plan is to install the test blanket module and its associated subsystems in the ITER device as soon as possible, even in the early checkout phase of ITER before plasma initiation. This will allow early correction of any deficiencies or incompatibilities associated with the test module with little or no impact on the ITER schedule. Simple shielding modules are being developed by ITER to be used in place of the test blanket modules should the test modules be removed for any reason.

TBM testing in the early phases of ITER will correspond to the system checkout to verify proper functioning of all subsystems, especially to verify that all instrumentation is working correctly. As ITER is checked out and incrementally brought to full operational status, the TBM will also be determined if it is ready to perform its testing mission and operational mission as one of the critical elements of the ITER program. During the early operational period, the fusion environment will be characterized and the response of the TBM elements and subsystems will be determined. As the plasma is converted from the DD phase to the DT phase, again the environment and the TBM elements and subsystem responses will be analyzed and recorded.

The main objective of the blanket testing in ITER will be to obtain the necessary test data to confirm the blanket operational performance. The supporting data will fall into five general categories: structural, thermal, tritium breeding, shielding, and

lifetime/reliability/maintainability. Table 2.1-1 presents more detail on the characteristics measured in each of these general testing areas.

Table 2.1-1 Main Testing Parameters

Structural Performance

Swelling, deformation, loss of strength, loss of ductility, cracking (*structure, solid breeder*)

Erosion (*first wall, coolant channels*)

Thermal Performance

Changes in thermo-physical properties

Removal of surface and volumetric heat flux

Temperatures of all internal components

Coolant flow rate, pressure, pumping power, and heat transfer to intermediate heat exchanger

Integrity and performance of liquid metal coating

Tritium Breeding Performance

Generation of tritium

Extraction and transport of bred tritium

Total tritium inventory

Shielding Performance

Breeding and lithium burnup effects

Bulk shielding effectiveness

Neutron streaming

Lifetime, Reliability, and Maintainability Performance

Determination/validation of life-limiting factors, including degraded performance

Determination of component/system reliability factors (MTBF)

Confirmation of maintenance approaches and equipment (MTTR)

In situ data will be gathered with a variety of instruments placed within the module or on the supporting subsystems. Some of the data will then be deduced from observed data. The remaining data will be obtained when the module is removed from the test port and dismantled to determine the physical changes that occurred during the testing.

Limited indications of structural performance may be obtained during operation, which is probably adequate with the given design safety factor. An excellent indication of overall blanket thermal performance and first wall surface temperatures may be obtained real-

time. Gross pumping power data can be obtained along with some indications of flow velocities and local pressures. Bulk tritium generation can be deduced from transported tritium, but retained tritium inventories in the module materials will have to be estimated until detailed tests of blanket material can be conducted. Extraction efficiency can be tracked real-time to help define system capabilities. Local and overall shielding can be obtained real-time as well as integrated, long-term effects. Lithium burnup fractions can be inferred, but confirmation will not be obtained until the module is disassembled. Some indication of blanket lifetime and reliability data can be obtained real-time but the better data will not be obtained until the end of the project. Even then, the lifetime and reliability data may be inconclusive due to the limited database. The maintainability data can be obtained from the maintenance operations, but that data may not be representative of the demo or commercial application. So it is judged to be feasible to obtain necessary and valuable information in the ITER test blanket program. There may be other methods that would result in more or higher fidelity data, but not within the cost and schedule constraints.

2.2 Benefits and Limitations of Using ITER for Blanket Testing

The primary benefit of using ITER for testing DEMO/Power Plant-like blankets is that it provides the actual fusion environment, viz., neutron energy spectrum, chemical, electromagnetic, and thermal. The combined effects of magnetic fields, radiation and thermally induced stresses on corrosion, mass transfer, and redeposition can be evaluated. Thermal and stress transients caused by disruptions can also be analyzed. The initial fusion results of tritium generation, radiation effects, and tritium recovery, stability of breeding material and compatibility with the structure can be evaluated under prototypical conditions. Although the tritium production rates will be lower than anticipated for the DEMO, important information and experience will be generated.

Sufficiently large test volumes for evaluating blanket integrated performance is another unique testing capability of ITER as compared to that of non-fusion test facilities.

Table 2.2-1 summarizes the major R&D tasks to be accomplished prior to DEMO: 1) plasma performance, 2) system integration, 3) plasma support systems, and 4) materials and FNT components performance and reliability and change out cycle. ITER as designed in EDA [2] will accomplish tasks 1, 2 and 3 with the possible exception of non-inductive current drive and steady state plasma operation. Task 4 will not be addressed adequately

in ITER. The primary reasons ITER can not satisfy the FNT fusion testing and development requirements are:

1. Pulsed operation with low duty cycle
2. Low device availability
3. Low fluence
4. Short continuous operating time
5. Small number of blanket test ports

The pulsed operation of the ITER will have a major impact on the performance of the blanket test modules. Extrapolation of results obtained under the pulsed burn conditions to a steady state operating scenario will be difficult. The pulsed operation is generally considered to be more severe, particularly in terms of thermomechanical response. An important result will be the potential for detecting premature failures that can be avoided by improved design.

The neutron fluence at the first wall of ITER is $0.3 \text{ MW}\cdot\text{y}/\text{m}^2$ during 10 years of a Basic Performance Phase (BPP) and $1 \text{ MW}\cdot\text{y}/\text{m}^2$ during an additional 10 year Extended Performance Phase (EPP). This overall testing fluence of $1.3 \text{ MW}\cdot\text{y}/\text{m}^2$ is inadequate to generate a sufficient database for construction of high reliable FNT components[4]. In addition, FNT testing requires many (~100) periods of Continuous Operation Time (COT), i.e. at 100% availability, each period is 1-2 weeks.

Table 2.2-1 Major R&D Tasks To Be Accomplished Prior to DEMO

1) Plasma <ul style="list-style-type: none">- Confinement- Impurity control and exhaust (divertor)- Disruption control- Current drive
2) System Integration
3) Plasma Support Systems <ul style="list-style-type: none">- Magnets- Heating
4) Fusion Nuclear Technology Components and Materials [Blanket, First Wall, High Performance Divertors] <ul style="list-style-type: none">- Materials combination selection- Performance verification and concept validation- Show that the fuel cycle can be closed- Failure modes and effects- Remote maintenance demonstration- Reliability growth- Component lifetime- Mean time to recover from failure

Technical Limitations of ITER Testing

One of the important requirements set by industry and utility for power plant is demonstration of high availability in which is given by:

$$\text{Reactor Availability} = AR = \frac{1}{1 + \sum_i (\text{outage risk})_i}$$

where i represents a reactor component, and the outage risk is defined as

$$\begin{aligned}\text{outage risk}_i &= \text{MTTR}_i \times \text{failure rate}_i \\ &= \text{MTTR}_i / \text{MTBF}_i\end{aligned}$$

where MTTR_i is the mean down time to recover from a failure in component i and MTBF_i is the mean time between failures for component i .

To achieve a low outage rate operation requires that a high reliability of component system and good accessibility for maintenance and repair (low failure rate and mean time to repair) be achieved. While the mean time to repair (MTTR) is determined by whether the reactor design configuration characteristics can be maintained in accordance with prescribed procedures and resources, a low component failure rate necessitates the need of a long mean time between failure (MTBF). MTBF and MTTR are the parameters which directly affect the percentage of time that a system is available for use.

The reliability level of components is established at the design phase, and subsequent testing and production will not raise the reliability without a basic design change/modification or improvement. The way to measure component reliability is to test completed products under conditions that simulate real life. Unproven component reliabilities can be estimated from the proven reliabilities of components of similar design and application, if such design and applications exist. However, high confidence in component performance in entirely new applications, such as fusion, can be obtained only from testing in relevant environments. One simply cannot assess reliability without data, and of course, the more data available, the more confidence one will have in the estimated reliability level.

Two approaches were adopted to quantify the testing benefits of a test facility [4]:

Approach I: Calculate the blanket system availability and the corresponding reactor availability achievable with 80% confidence.

Approach II: Calculate the confidence level in achieving the blanket system and reactor availability goals

The results based on the Poisson model indicated that:

(1) testing in the ITER could only confirm with 80% confidence level for achievement of a reactor availability of $\sim 7.1\%$ for meant time to repair (MTTR) = 1 week at the end of EPP fluence. This reduces to about 1.8% if MTTR equals to 1 month .

(2) no appreciable level of confidence ($< 1\%$) that the next-step fusion device such as DEMO will achieve availability goal of 60% with information provided by ITER testing.

Other assumptions made in the analysis included 12 test modules, 1 failure during the test and an experience factor of 0.8

In summary, ITER blanket testing will provide experience and knowledge base for DEMO blanket development. The fluence level as presently envisioned is barely sufficient for the FNT testing stages of initial fusion "break-in" and concept verification; and does not provide any real component reliability growth and demonstration testing.

References

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4. M. Abdou et al., Phase I Report of the IEA Study on High Volume Plasma-Based Neutron Source, December, 1994