BLANKET MODULE TESTING IN TIBER II

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Abstract

The overall results of a multi-laboratory effort to develop blanket module test schedules and requirements for the ITER/TIBER reactor are summarized. The different blanket concepts that have been addressed are self-cooled liquid metal blankets, water-cooled blankets, helium-cooled blankets, self-cooled Flibe blankets, and water/Li-salt blankets. In each case, a specific blanket design was chosen as an example for a test module, and subsystem requirements were determined. A test matrix, based upon key issues for blanket operation, the required test environments and test times, and the ITER/TIBER operating schedule, was formulated for each blanket type.

Introduction

One of the primary objectives of ITER/TIBER is to provide the test environment for demonstrating the integrated performance of the most attractive blanket concepts. ITER/TIBER is the first device where all important parameters, including surface and bulk heating, 14 MeV neutron damage, and a high magnetic field, will be produced simultaneously. The ITER/TIBER design and operation are described in detail in Refs. 1. and 2. The design parameters of interest to blanket testing are listed in Table 1.

Table 1.
TIBER-II Design Parameters

Fusion Power	314 MW
Burn Time	> 1 week
Average Neutron Wall Loading	1.1 MW/m^2
Peak Neutron Wall Loading	1.9 MW/m^2
Fluence at Test Module	~ 4 $MW\text{-}yr/m^2$
Availability (final phase)	$\lesssim$30%
Tritium Consumption (final phase)	5.3 kg/yr
Surface Heat Flux	
First Wall (uniform)	0.25 MW/m^2
Divertor (peak)	3.5 MW/m^2
Test Area	
Wall Area	2 m (high) × 1.2 m
No. of Intercoil Spaces	8 (of 16)

The neutron wall loading and fluence to the test modules are 1.9 MW/m^2 and ~ 4 $MW\text{-}y/m^2$, respectively. There are a total of eight intercoil spaces available for test modules, with a first wall area of 2m (poloidal) x 1.2m (toroidal). Four to six of these modules would be dedicated to blanket tests. Figure 1 shows the cross-section of the ITER/TIBER reactor with the outboard test module.

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The total operating lifetime of ITER/TIBER is 12 years, which is divided into three phases. Phase I is a checkout phase, and Phase II is the major physics testing phase. Both phases would have a limited device availability of about 10%. Phase III is the extended nuclear testing phase, where the device would operate in the steady-state mode and availability would reach approximately 30%. Although the major blanket testing will take place in Phase III, some tests will also take place in Phases I and II.

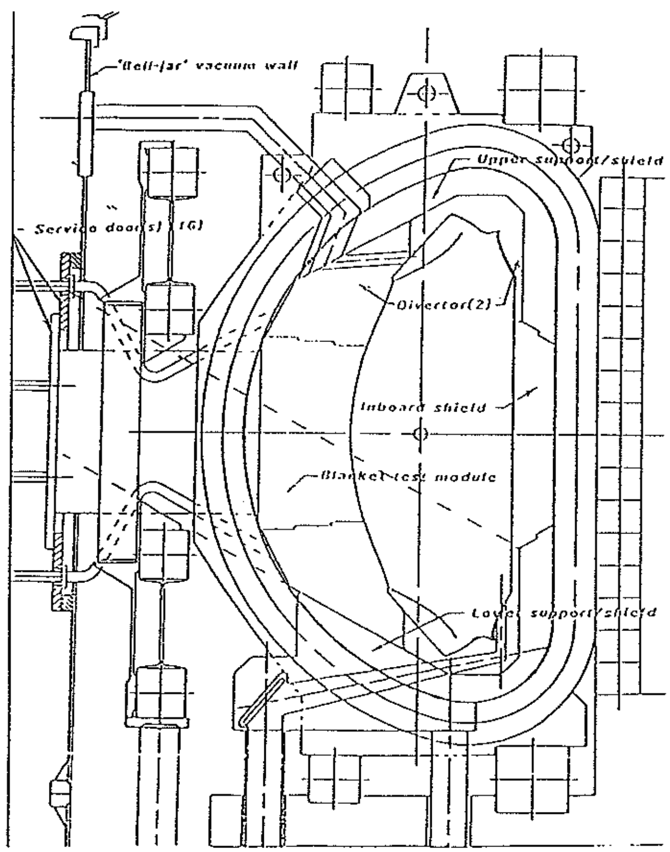

Fig. 1. Cross-Section VIEW of TIBER Showing a Blanket Test Module

Testing programs and schedules have been developed for several blanket types. The test programs have been divided by the type of coolant used in the module since the subsystem needs depend most heavily upon the coolant. The different blanket concepts that have been addressed are self-cooled liquid metal blankets, water-cooled blankets, helium-cooled blankets, self-cooled Flibe blankets, and water/Li-salt blankets. The overall approach in this study consists of identifying; 1) the key issues to be addressed in blanket development, 2) the leading design concepts, 3) the desired operating environment, 4) the types of tests to be conducted in TIBER, 5) module and subsystem designs, and 6) test schedules for each blanket concept. Additional details concerning blanket testing are given in Ref. 3.

Approach to Test Planning

In developing the test programs for blanket modules, several assumptions have been made covering the level of technology development prior to and during testing in TIBER. First, it has been assumed that blanket technology will be aggressively developed in non-fusion facilities. This means that to the extent possible, all key issues will be resolved, and engineering models and codes will be developed to the point where there is a high degree of confidence in the design and operation of the test modules. This degree of development is necessary to insure that no unexpected defects are present in the blanket modules which might jeopardize the operation of the entire ITER device. Second, it has been assumed that the large number of blanket designs present today will be culled down to a relatively small number of candidates. During the course of non-fusion testing some concepts will prove to be more attractive than others, and the tests in ITER/TIBER will be focused in the most attractive designs. Finally, certain tests where there is a high risk of failure will be performed outside of ITER/TIBER. Such tests include severe transient tests and tests which explore the ultimate performance limits of the blankets.

Blanket tests are designed to provide two basic types of information. The test results would be used to confirm the predicted behavioral response of the module and to build an engineering data base. The test types are divided into the major categories of predictive capability, engineering performance, and engineering reliability. A summary of the test types is presented in Table 2.

Table 2. Types of Tests for Blanket Modules

Test Type	Items Measured	Measurement Type
Predictive Capability	Neutron Flux/Energy	In-Module
	Temperature Profiles	In-Module
	Stress Profiles	In-Module
	MHD Velocity Profiles	In-Module
	Corrosion Loss Rates	Post-Operation
	Gap Conductance	In-Module
	Tritium Concentration Profiles	In-Module Out-of Module
Engineering Performance	Pressure Drop	Out-of-Module
	Thermal-Hydraulic Performance	Out-of-Module
	Overall Tritium Breeding	Out-of-Module
	Overall Tritium Loss Rate/ Inventory	Out-of-Module
	Shielding Efficiency	Out-of-Module
	Tritium Release Rate	Out-of-Module
	Coolant Impurity Levels	Out-of-Module
Engineering Reliability	Short Term Failure Modes	Post-Operation
	Determination of Design Flaws	In-Module
	Remote Maintenance Operations	Out-of-Module
	Long Term Failure Modes	Post-Operation
	Long Term Reliability	Out-of-Module
	Mass Transfer Effects	Out-of-Module
	Post-Test Examinations	Post-Operation

The predictive capability tests would be conducted to confirm and benchmark engineering codes developed prior to blanket module testing. Tests that fit into this category include the measurement of temperature profiles, tritium concentration profiles, and stress profiles. The measurements are usually made in-module during reactor operation, and the tests are usually short term. The need for in-module measurements means that there will be special instrumentation requirements, since any instrumentation placed in the module must operate in a severe thermal, neutron, and chemical environment, and must also be small enough to not interfere with the normal performance of the module. Clearly, instrumentation development will be a high priority for predictive behavior tests, since ultimately the specific tests which are possible will depend upon the availability of suitable instrumentation.

Engineering performance tests are those where specific gross performance characteristics of the blanket module are measured. Items of interest include overall coolant pressure drop, average increase in coolant outlet temperature, overall tritium breeding ratio, and shielding efficiency. Since these measurements would be made largely out-of-module, the instrumentation needs are less severe than those for predictive behavior tests. In most cases, the test times are a short to moderate length (minutes to days).

Engineering reliability tests are conducted to establish the data base necessary to determine the long range potential of various blanket concepts. The tests in this area focus on the lifetime and possible failure modes of the modules, and therefore tend to be long term (years). The tests include the determination of design flaws, identification of failure modes, and long term reliability. In contrast to the test described above, much of the information on engineering reliability comes from post-test examinations of the modules. The information obtained from post-test examinations would be combined with information on the module operating history to assess long term operating potential of different types of blankets.

Besides blanket module tests, sub-module and element tests would be conducted. The purpose of these tests would be to explore areas which are difficult or not possible to perform with module tests. An example of an element test is material specimen irradiation. The materials irradiated would be the same as those used in the blanket module, and the element tests would provide a means of monitoring the irradiation-induced property changes in the module. Specimens could be removed at frequent intervals, and property measurements would then be performed in hot-cells. An example of a sub-module test is coolant corrosion and mass transfer. Sub-module tests are likely to be easier to control and could be conducted for a longer period of time compared with full module tests.

The specific tests for blankets follow from the key issues which must be resolved before a blanket concept can be qualified for commercial application. The key issues for blankets have been previously identified through the FINESSE, BCSS, and TPA studies[4,5,6]. The major issues are:

(1) Tritium Breeding-Self Sufficiency,
(2) Tritium Inventory, Transport, and Recovery,
(3) Tritium Permeation and Release,
(4) Corrosion/Compatibility and Mass Transfer,
(5) Thermomechanical Behavior,
(6) Liquid Metal MHD Effects,
(7) Structural Response and Component Lifetime.

The relative emphasis of different issues depends upon the specific blanket concept. The test times will depend on a number of considerations including the specific blanket concept, the times required for the relevant phenomena to reach steady state, and the times needed to reach goal fluences.

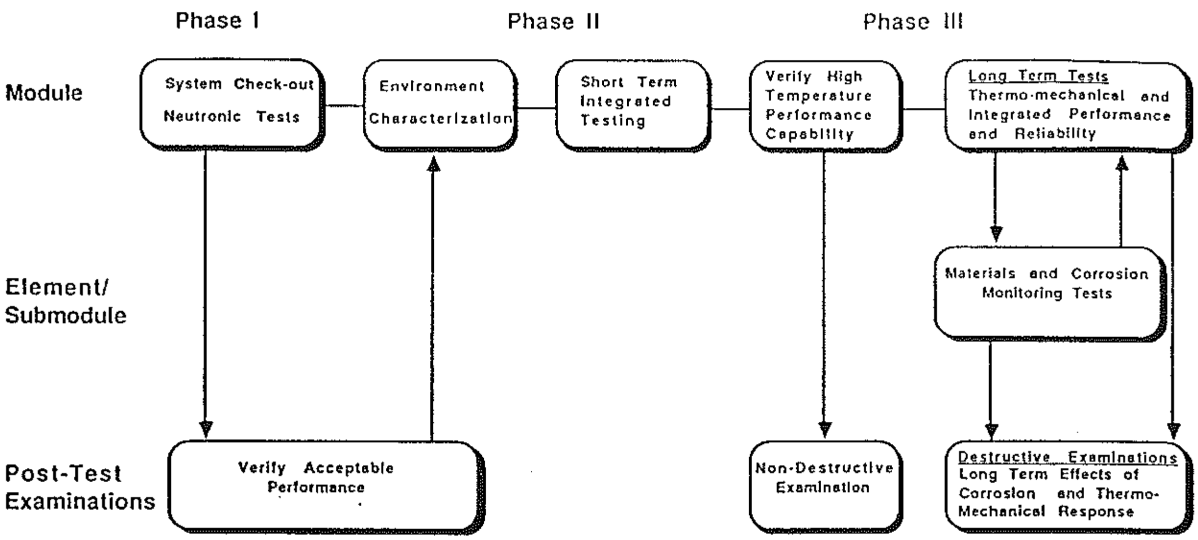

Fig. 2. Overall Test Schedule for Blanket Modules

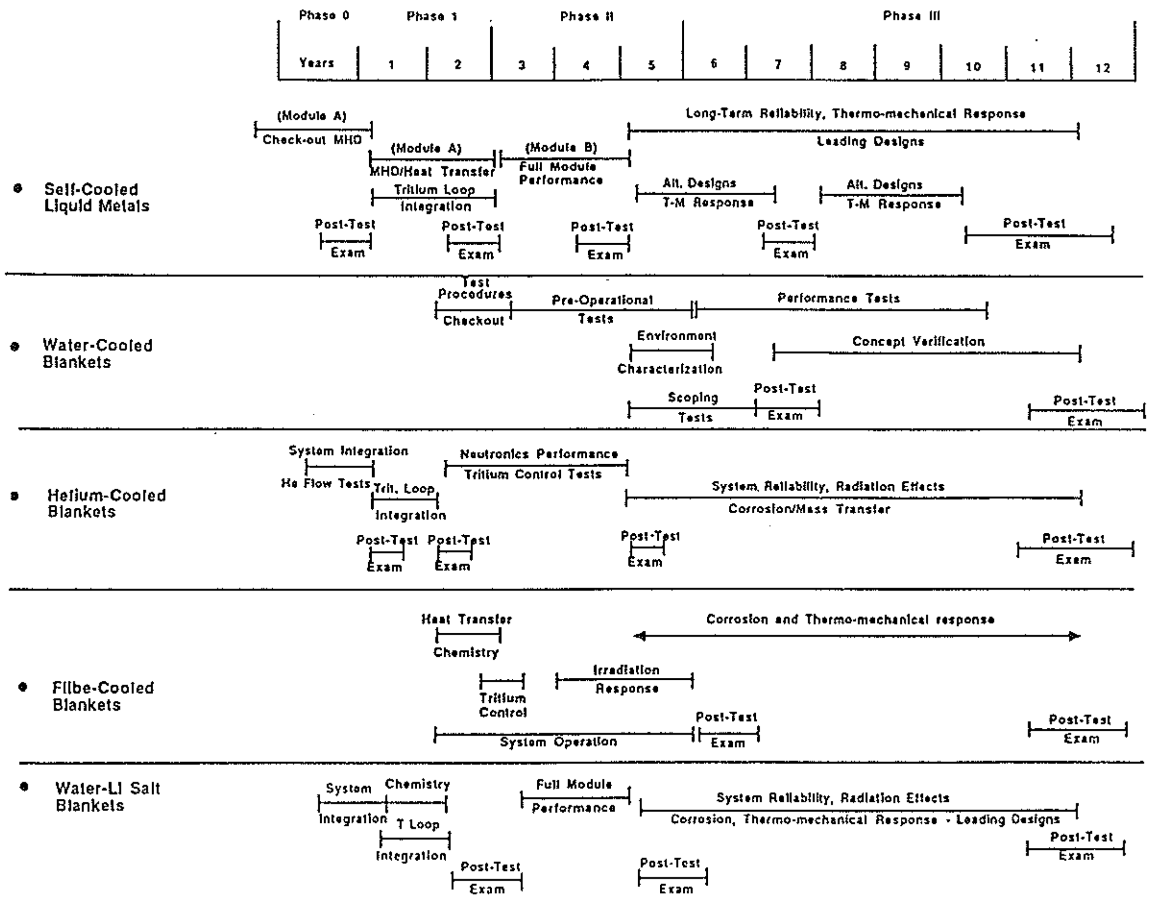

Fig. 3. Test Schedule for Specific Blanket Modules

Test Schedule

The ITER/TIBER operating schedule and the blanket test requirements have been integrated together to generate an overall test schedule, which is shown in Fig. 2. In general, testing would begin as early as Phase I. The types of tests performed in this phase would be limited to system check-out tests and short term tests which can be accommodated with low availability, pulsed operation. Possible short term tests include neutronics, MHD effects on liquid metals, and thermal hydraulics performance. During these tests, the modules would likely operate in a low performance mode to minimize the possibility of failure. The early tests would provide initial data on the performance characteristics of the modules as well as confirm the predictive capability of engineering design codes.

During Phase II and into Phase III, the integrated performance of the blanket modules would be tested up to their nominal operating parameters. The burn times of ITER/TIBER should be long enough for the blanket to reach steady state conditions. Each aspect of blanket behavior can be characterized by a response time to achieve steady state conditions. This time ranges from seconds for first wall temperature response to weeks for tritium buildup and release in solid breeders. In order to achieve meaningful test results and compare performance of the different blanket types, the burn time should be no less than 1000 s and preferably steady state (> one week) during this phase of testing. Following these initial high performance tests, the blanket modules would be examined to determine their integrity.

The extended period tests would be conducted during Phase III, and they would address important engineering considerations such as long term reliability, corrosion, thermomechanical response, and irradiation response. When the test series is complete, the test modules would be removed and brought to the hot cells for non-destructive and destructive examinations. The results of the on-line tests plus the results of the post-test examinations in the hot cells would then form the basis for assessing the overall performance of the various blanket types.

In parallel with the module tests, irradiation surveillance tests using elements would be conducted. Material samples would be removed at frequent intervals to determine their properties. The tests would include mechanical property and microstructural characterizations, and they would provide a means for tracking the changes in properties of the blanket module. Sub-module tests would also be conducted to examine the corrosion/mass transfer characteristics of the coolants. Small samples would be removed from time to time to measure corrosion loss and creep strain. These tests could be run for the entire life of the reactor, thus allowing extrapolation of the results from the module. A variety of element and submodule tests can be run for the different concepts of blankets.

Test Considerations for Specific Blanket Types

Individual blanket types have test requirements which result in somewhat different test schedules as shown in Fig. 3. The greatest differences occur between liquid coolant/breeder systems and solid breeder systems. The differences in test schedules are a consequence of the differences in test emphasis and the differences in response times for various phenomena. For example, MHD effects are considered to be of paramount importance in liquid metal systems. Since only the presence of the magnetic field is required to perform tests of liquid metal flow profiles, these tests can begin early in Phase I. In contrast, testing of tritium buildup and release in solid breeders requires steady state reactor operation and relatively high availability. Therefore, most of the tests on solid breeder blankets will not take place until Phase III. Liquid breeder/coolants generally require less time to reach steady state tritium inventories and do not have the same requirements on burn time and availability.

An important question addressed for the different blanket designs is the level to which a blanket module can simulate the behavior of a full coverage blanket system. A complete simulation is, of course, not possible in ITER/TIBER since it operates at a lower neutron wall loading and availability than a commercial reactor. However, it is desirable to test the blankets in configurations where all important phenomena can be observed in operating regimes that extrapolate to commercial systems. In most cases, the modules in ITER/TIBER appear to meet these requirements.[3] Specifically, thermal hydraulics, tritium release, and MHD effects are simulated reasonably well. On the other hand, thermo-mechanical response represents a complex interaction of many phenomena including thermal stress, primary stress, neutron wall load and fluence, and blanket design and geometry. In general, blanket systems which have extended poloidal or toroidal coolant paths (>2m) will be more difficult to simulate in a module. Additional effort is required to completely resolve this issue.

Safety concerns for testing are different for liquid metal and solid breeder systems. The greatest concern involves the possible use of liquid lithium in a reactor where water coolant is present. Special attention has been given to the liquid metal test modules to enhance the safety of this system. First, the total volume of liquid metal in the reactor hall has been reduced to < $1m^3$. Next multiple barriers are provided wherever there is a possibility of Li/water/air accidents. The Li dump tanks are located below the blanket subsystems so that all lithium would drain out of the blanket module in case of an accident. Finally, the use of an inert gas or dry nitrogen is recommended in the reactor hall to eliminate Li/air contact.

Conclusions

ITER/TIBER is an attractive facility for testing blankets. It provides a high wall loading, availability, and fluence which is needed for thorough assessments of different blanket types. It is also scheduled to operate in the steady state mode which is important for achieving steady state response conditions in the blanket modules.

An assessment of test types and schedules for a number of different blankets indicates that it is possible to conduct a comprehensive series of tests within the framework of the ITER/TIBER operating schedule. The size of the test modules (2m x 1.2m) is generally adequate for realistic simulation of full coverage blankets.

References

[1] C. Henning, B. G. Logan, "Overview of the TIBER II Final Design Report," this conference.

[2] R. Devoto, M. Fenstermacher, B. G. Logan, "TIBER II Baseline Operation," this conference.

[3] C. C. Baker, et. al, "TIBER II/ETR Nuclear Performance Analysis Report," Argonne National Laboratory Report, ANL/FPP-87-3, September, 1987.

[4] "Technical Issues and Requirements of Experiments and Facilities for Fusion Nuclear Technology:FINESSE Phase 1 Report," UCLA Report UCLA-ENG-85-39 (1985). "Modelling, Analysis, and Experiments for Fusion Nuclear Technology: FNT Progress Report: Modelling and FINESSE," UCLA Report, UCLA-ENG-86-44 (1987).

[5] "Blanket Comparison and Selection Study: Final Report,"Argonne National Laboratory Report, ANL/FPP-84-1 (1984).

[6] "Technical Planning Activity: Final Report,"Argonne National Laboratory Report, ANL/FPP/87-1 (1987).