IAEA-CN-53/F-II-3

ITER: TEST PROGRAMME*

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Abstract

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The ITER objectives described in the Terms of Reference state that ITER will provide the database "necessary for the design and construction of a demonstration fusion power plant". As part of the strategy to achieve these objectives, ITER has been designed to operate in two phases: the Physics Phase, which lasts for six years, and the Technology Testing Phase, which lasts for eight years. During the Technology Phase, submodules for the blanket and high heat flux and other nuclear components are inserted in especially designed test ports. Tests are provided for DEMO relevant design concepts as well as advanced reactor concepts. Besides providing the database for DEMO, these tests will provide powerful, albeit partial, demonstration of the ultimate potential of fusion reactor performance, safety and environmental attractiveness.

1. Introduction

As the first opportunity for fusion integrated testing, ITER will be utilized for a wide variety of tests requiring the complete fusion environment. Test information from ITER will be obtained by two means: 1) information from the operation of the components of the basic device including component-to-component interaction and overall system integration, and 2) a number of experiments on a number of nuclear components, including blanket test modules which will be introduced into ITER in specially designed ports. To date, the ITER test program effort has focused on the second part, i.e. especially designed experiments, for the nuclear components.

The objectives of the ITER test program are: 1) screening of concepts in tests which require the integrated fusion environment, 2) calibration of fusion integrated tests to results from non-fusion tests, 3) validation of candidate blanket concepts, and 4) testing of advanced concepts. The ITER objectives and characteristics contained in ANNEX I to the Terms of Reference state that ITER will provide the data base "necessary for the design and construction of a demonstration fusion power plant".

ITER has been designed to operate in two phases. The first phase, which lasts for 6 years, is devoted to machine checkout and physics testing with some limited technology tests. The second phase lasts for 8 years and is devoted primarily to technology testing. There are a number of especially designed ports on ITER that are allocated exclusively for technology testing, 3 ports during the physics phase and 5 ports during the technology phase. Considerations of limited space and time for testing in ITER dictated the development of a test plan that

* The activity of the International Thermonuclear Experimental Reactor (ITER) is conducted under the auspices of the International Atomic Energy Agency jointly by Euratom, Japan, the Union of Soviet Socialist Republics and the United States of America.

TABLE I. NUCLEAR TESTING REQUIREMENTS — RECOMMENDATIONS AND DESIGN VALUES

Device parameter	Recommendations: Minimum	Recommendations: Highly desirable	Reference ITER conceptual design (Technology Phase)
Average neutron wall load at the test module (MW/m^2)	≥ 1	2	1.34
Number of ports	5	7 (plus segment or sector)	5
Minimum port size (m^2)	2-3	segment or sector	3.74
Total test area (m^2)	10	20-30 (plus segment or sector)	18.7
Plasma burn time	≥ 1000 s	1-3 h (to steady state)	2290 s [a]
Dwell time (s)	[b]	≤ 20	300–400
Continuous test duration (weeks)	≥ 1	2	[c]
Continuous tests per year	2-3	5	[c]
Average availability (%)	10–15	25-30	18
Annual neutron fluence at the test module ($MW \cdot a/m^2$)	0.1	0.4	0.14
Total neutron fluence ($MW \cdot a/m^2$)			
at the test module	≥ 1	2–4	1.53
at the first wall	1.5–2	4-6	1.7

[a] Steady state option is being considered as an alternative.

[b] The minimum acceptable dwell time is highly dependent on the design concept and is difficult to specify. Further analysis in this area is recommended.

[c] Remains to be analysed for the conceptual design.

made maximum utilization of the facility. Some of the issues related to international collaboration on the test program have been successfully resolved through a combination of sharing time and space on ITER and collaboration on many of the tests.

2. Testing Requirements on ITER Parameters

Successful nuclear testing imposes important requirements on ITER major design parameters and engineering features. These requirements have been formulated based on results of technical analyses. Engineering scaling requirements are different for various issues, design concepts and the ultimate testing objectives. Table I summarizes the recommendations of the ITER testing group. Both minimum and highly desirable goals are provided. Analysis shows that device parameters below the minimum value in any category will seriously limit the usefulness of nuclear testing for important issues that particularly require testing in an integrated fusion environment. There is a high probability that results obtained with testing conditions below the "minimum" could not be extrapolated to reactor conditions. Conversely, the highly desirable range provides values above which there is reasonable confidence that results could be extrapolated to reactor conditions.

The fluence recommendation is based on a combination of the need to perform a sequence of concept performance tests, which take roughly 3-6 years at full power and high availability (~25%), resulting in 1-3 MW•a/m^2 of fluence, and the desire to perform concept verification tests, which require activation of fluence-related phenomena, resulting in 3-4 MW•a/m^2 of fluence. These fluences are based on the exposure at the location of the test articles. The actual machine fluence (at the first wall) is higher by a factor of 1.5 to 2 for several reasons. For example, the existence of plasma facing components, first wall and multiple-containment structures for some tests reduces the neutron flux at the test module. Also, the current testing strategy calls for extensive use of sequential testing in order to proceed from small size submodule performance tests to the larger and more integrated tests for concept verification.

Steady state operation is a highly desirable goal for ITER during the technology phase as pulsing has many negative effects on the results and value of nuclear testing. If pulsing is unavoidable, then long burn times in the range of 1-3 hours are highly recommended because many nuclear processes have long time constants. There are many phenomena that have very short time constants. For example, the temperature, which has major influence on nuclear effects, changes rapidly within a few seconds. Thus, for many nuclear processes, it takes a long time (hours to days) to reach equilibrium but only a short time (seconds) to ruin it. From the nuclear testing standpoint, the dwell time should be <20 s. Since this is not practically achievable, the ITER testing group has recommended that obtaining a short dwell time be a high priority goal. The absolute minimum below which the value of the test diminishes is dependent on the design concept, but for many concepts is in the range of 100-200 s.

The nuclear testing requirements have substantially influenced the selection of ITER design parameters and engineering features. Also shown in Table I are the parameters for the present reference ITER design. ITER presently meets most of the nuclear testing requirements except in some cases where further work is required.

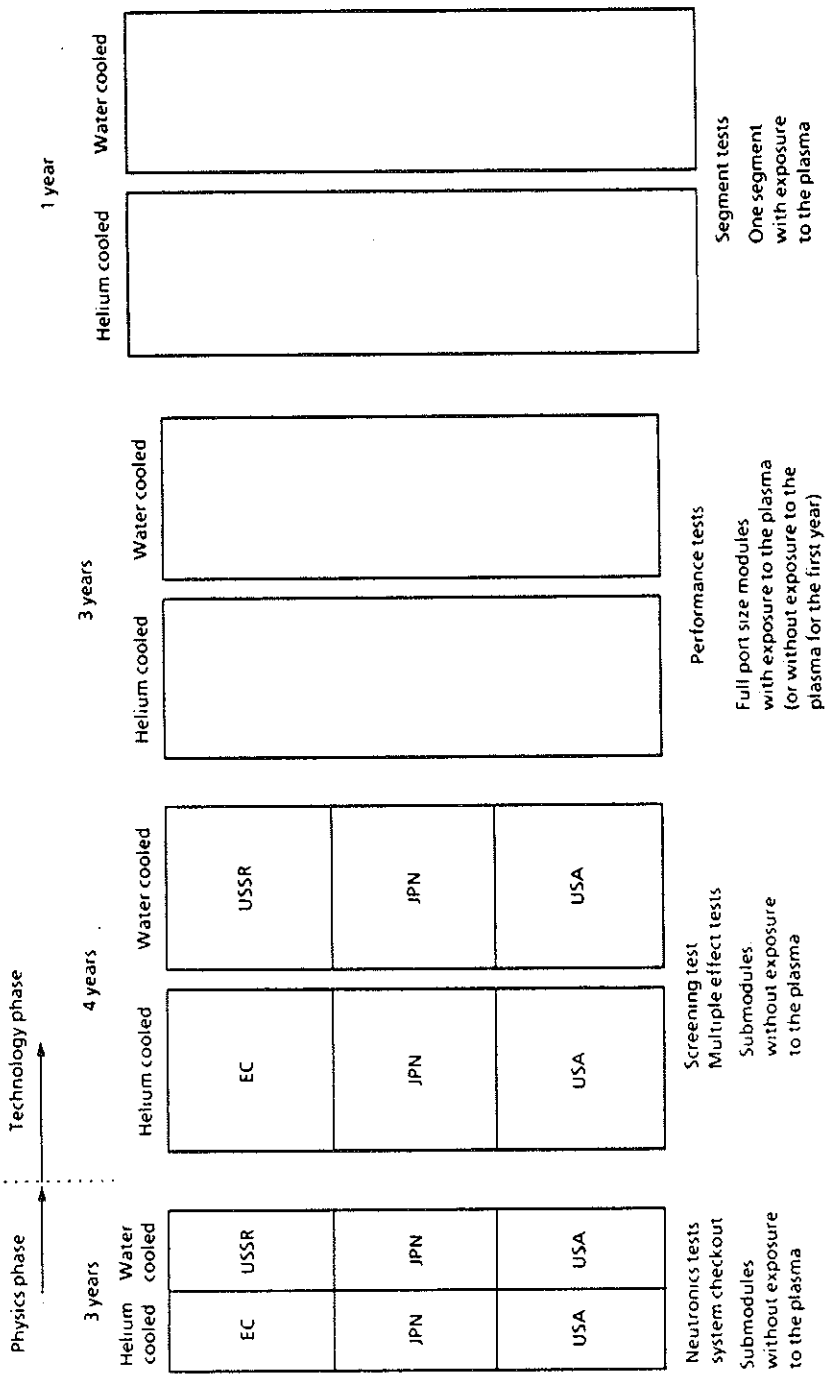

FIG. 1. Test port allocation to helium and water cooled solid breeder blankets.

3. Test Program

International collaboration on the test program on ITER is necessary as there is neither sufficient space nor time to serve the needs of four independent, national programs. A scheme has been developed for sharing space and time on the device among the parties.

The numbers of ports available for testing in ITER are 3 during the physics phase and 5 during the technology phase, each port is $3m^2$ at the first wall. The allocation of the 3 ports during the physics phase is as follows: one port for neutronics tests (including possible sharing with some materials tests), one port for liquid metal blankets (both self cooled and separately cooled), and the third port for all types of solid breeder blankets (gas cooled and water cooled).

During the technology phase the 5 ports are allocated as follows: 1) one port for solid breeders, gas cooled, 2) one port for solid breeders, water cooled, 3) one port for self cooled liquid metals, 4) one port for separately cooled liquid metals, and 5) one port for material and other types of tests.

The details of the test program have been developed to maximize the utilization of ITER and to best serve the testing needs of various countries subject to ITER constraints on available testing space and time. An example is offered by the test plan developed for solid breeder blankets discussed below.

The test program in ITER for the solid breeder blanket foresees that initially there will be 3 concepts for each coolant. Namely, 3 concepts with Europe, Japan and USA lead with the helium cooling and 3 concepts with Japan, USA and USSR lead with water cooling. The test program will be implemented as follows:

1. During the Physics Phase, a horizontal port will be allocated to the solid breeder blanket. The purpose of the tests in this phase is to characterize the neutronic environment, to check out blanket systems, and to check out instrumentation.
2. During the Technology Phase, two horizontal ports will be allocated to the solid breeder blanket: one for designs with gas cooling and one for designs with water cooling.
3. During the first three years of the Technology Phase, three submodules will be tested in each of the two ports available. In the port for gas-cooled designs, the EC, Japan and the US shall have the lead on the design, construction and operation of one of the three modules, respectively. The port for water-cooled design is partitioned in exactly the same way. The lead for submodule design, construction and operation shall be taken by Japan, the US and the USSR.
4. During the following three years of the Technology Phase, a single module of the chosen concept with helium and water cooling shall be tested in each of the two ports. Failing to achieve agreement on a single reference solution, the three single modules for the three different concepts will be tested successively for a period of one year each.
5. The tests of the submodules will be performed behind a first wall similar to the driver blanket first wall. In case of a single reference blanket, the blanket module will be tested for the first year behind a driver blanket-type first wall and with its own first wall facing the plasma for the two remaining years.
6. For various designs it may be necessary to perform tests with complete segments or even sectors during the final period of the Technology Phase and during a possible extended phase operation. The test sequence and the

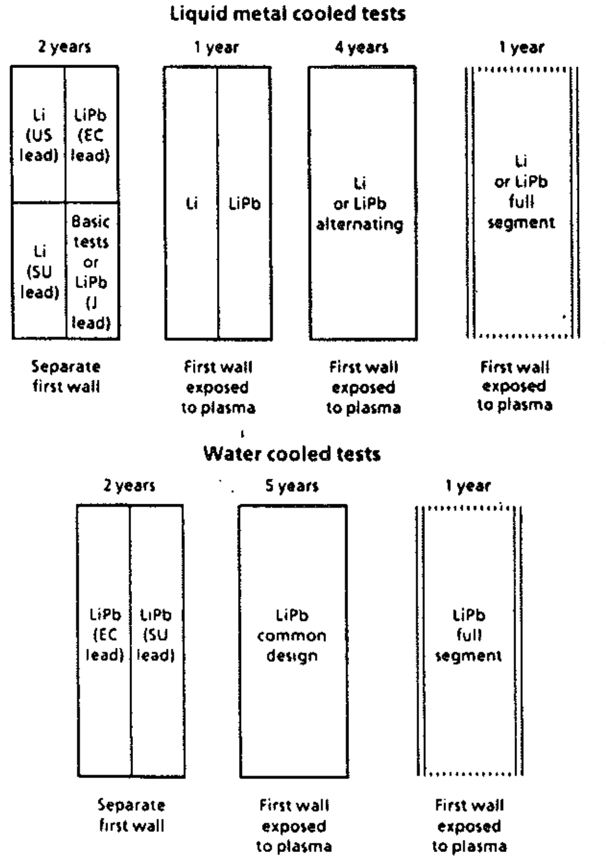

FIG. 2. Test sequence for liquid metal blankets.

highlights of the solid breeder blanket test program discussed above are illustrated in Fig. 1. Similar details have been developed for liquid metal blanket concepts and are illustrated in Fig. 2.

4. Ancillary Equipment Configuration and Maintenance

For each test in ITER a specific set of external equipment must be provided in the ITER plant, with supply lines to the test location. Examples of such equipment are: 1) heat rejection systems, 2) tritium recovery systems, 3) chemical (impurity) control systems, 4) coolant and purge fluid storage, 5) hot cells and post irradiation examination rooms, and 6) control and data acquisition systems. The ancillary equipment requirements for the ITER test program are extensive and they impose important requirements on the configuration and maintenance schemes for ITER.