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ITER: the first experimental fusion reactor

P.-H. Rebut, the ITER Joint Central Team

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Abstract

The International Thermonuclear Experimental Reactor (ITER) project is a multiphased project, at present proceeding under the auspices of the International Atomic Energy Agency according to the terms of a four-party agreement between the European Atomic Energy Community, the Government of Japan, the Government of the USA and the Government of Russia ("the parties"). The project is based on the tokamak, a Russian invention which has been brought to a high level of development and progress in all major fusion programs throughout the world.

The objective of ITER is to demonstrate the scientific and technological feasibility of fusion energy for commercial energy production and to test technologies for a demonstration fusion power plant. During the extended performance phase of ITER, it will demonstrate the characteristics of a fusion power plant, producing more than 1500 MW of fusion power.

The objective of the engineering design activity (EDA) phase is to produce a detailed, complete and fully integrated engineering design of ITER and all technical data necessary for the future decision on the construction of ITER.

The ITER device will be a major step from present fusion experiments and will encompass all the major elements required for a fusion reactor. It will also require the development and the implementation of major new components and technologies.

The inside surface of the plasma containment chamber will be designed to withstand temperature of up to 500 °C, although normal operating temperatures will be substantially lower. Materials will have to be carefully chosen to withstand these temperatures, and a high

neutron flux. In addition, other components of the device will be composed of state-of-the-art metal alloys, ceramics and composites, many of which are now in the early stage of development of testing.

The main systems of ITER are the superconducting magnet coils and their support, the vacuum vessel and the shield-blanket, the heating and fueling systems, the cryostat, the power supplies and the buildings.

During operation the ITER device will sustain a controlled fusion burn for periods of more than 1000 s. Numerous components, experimental packages and test modules will have to be remotely installed and removed from the ITER device in order to test materials properties, component characteristics and material lifetimes.

The status of the ITER design as of July 1994 is presented below.

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ITER: the first experimental fusion reactor

P.-H. Rebut (for the ITER Joint Central Team and Home Teams)

ITER San Diego Joint Work Site, La Jolla, CA 92037, USA

Abstract

The International Thermonuclear Experimental Reactor (ITER) Project is a multi-phased project, presently proceeding under the auspices of the International Atomic Energy Agency according to the terms of a four-party agreement between the European Atomic Energy Community, the Government of Japan, the Government of the United States, and the Government of the Russian Federation. The project is based on the tokamak, a Russian invention which has been brought to a high level of development and progress in all major fusion programs throughout the world. The objective of ITER is to demonstrate the scientific and technological feasibility of fusion energy for commercial energy production and to test the technologies for a demonstration fusion power plant. During extended performance operaton ITER will be capable of producing more than 1000 MW (electric) of fusion power, an amount of power that is comparable with one of today's electricity generating plants. The objective of the Engineering Design Activities (EDA) phase is to produce the detailed, complete, and fully integrated engineering design of the tokamak and all technical data necessary for the construction of ITER.

The ITER project will be a major step from present fusion experiments and will progress towards a fusion reactor. It will also require the development and implementation of major new components and technologies. The inside surfaces of the plasma containment chamber will be designed to withstand temperatures of up to nearly 500 °C, although normal operating temperatures will be substantially lower. Materials will have to be carefully chosen to withstand these temperatures and a high neutron flux. In addition, other components of the device will be composed of state-of-the-art metal alloys, ceramics and composites, many of which are now in the early stages of development and testing. The main systems of ITER are the superconducting magnet coils and their support, the vacuum vessel and the shield/blanket, the heating, fueling systems, the cryostat, the power source and the buildings. During operation the ITER device will sustain a controlled fusion burn for periods of greater than 1000 s. Numerous components, experimental packages, and test modules will have to be remotely installed and removed from the ITER device in order to test materials properties, component characteristics and material lifetimes.

This paper reviews the present status of the ITER design, its components and technologies.

1. Introduction

An outline design for ITER has been developed which satisfies the agreed detailed technical, cost and schedule objectives of ITER. The present status of the ITER design provides the basis for the continued engineering design work, for focusing ITER research and development, and for other related

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activities within the scope of the ITER EDA Agreement.

2. Programmatic and technical objectives

The overall objective of ITER, as defined in the ITER EDA Agreement [1], is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes. ITER will demonstrate controlled ignition and extended burn of deuterium–tritium plasmas, with steady-state operation as an ultimate goal, and technologies essential to a reactor in an integrated system, and will also perform integrated testing of high heat flux and nuclear components.

The main characteristics and parameters of the outline design for ITER follow from its agreed objectives. Two phases of operation are necessary: (1) the basic performance phase which focuses on ignition and associated physics and technological questions; and (2) the enhanced performance phase which is needed to achieve the objectives of the testing, primarily testing a prototype blanket for a demonstration reactor.

The ITER detailed technical objectives include [2]:

(i) provision of an inductive pulse flat-top capability, under ignited conditions, of approximately 1000 s. For testing particular blanket designs, pulses of approximately 2000 s are desirable;

(ii) carrying out of nuclear and high heat flux component testing at conditions relevant to a fusion power reactor. The average neutron wall loading should be about 1 MW m^{-2}; the machine should be designed to be capable of at least 1 MWa m^{-2} to carry out longer time integral and materials tests;

(iii) desirability of operating at higher flux and fluence levels. Within the engineering margins, the ITER designers should examine the implications and possibilities of exploiting a wider range of operational regimes. The design of permanent components of the machine should not preclude achieving fluence levels up to 3 MWa m^{-2};

(iv) in view of steady-state operation as an ultimate goal, current drive capability of the heating system required for ignition in the first phase of operation.

ITER is therefore a full ignition, high power tokamak producing a nominal fusion power of 1.5 GW for about 1000 s. In that sense, ITER is truly a fusion experimental reactor. The outline design incorporates safety and technical margins consistent with this major step in fusion power development.

Table 1
Principal parameters of the ITER outline design

Fusion power (nominal)	1.5 GW
Burn time (nominal)	1000 s
Plasma current	24 MA
Major radius (nominal)	8.1 m
Plasma minor radius (maximum)	3.0 m
Elongation	1.55 m
Divertor configuration	Single null
Toroidal field (at nominal major radius)	5.7 T
Toroidal field ripple at plasma edge (maximum)	±2%

3. Main elements of the outline design

3.1. Principal parameters

The principal parameters of the outline design for ITER are listed in Table 1.

The main features of the outline design are shown in cross-section in Fig. 1. The ITER objectives are ambitious, but must be viewed in the context of the overall ITER project when operation starts about 12 years from now. Therefore, the performance is what may reasonably be expected in the field of fusion research at that time. These objectives extrapolate from results of equivalent break-even conditions presently achieved in the largest operating tokamaks [3–5], JET [6] and TFTR [7]. These tokamak experiments, the first to use a deuterium–tritium fuel mixture, have generating multi-megawatt peak fusion powers in high power pulses. However, these conditions have only been achieved transiently [6] with MHD instabilities (such as giant sawteeth, which induce disruptions, and vertical instabilities) and impurity influxes still limiting better performance and steady-state operation required for a reactor.

In addition to being a major plasma experiment, ITER is a thermonuclear experiment. To ensure safe operation, a very high level of quality and reliability must be achieved in the design of all components.

4. ITER design guiding principles

The guiding principles followed in the EDA are: (i) to minimize the number of components; (ii) to simplify each component design; (iii) to reduce the path length of forces; (iv) to increase the reliability of key systems;

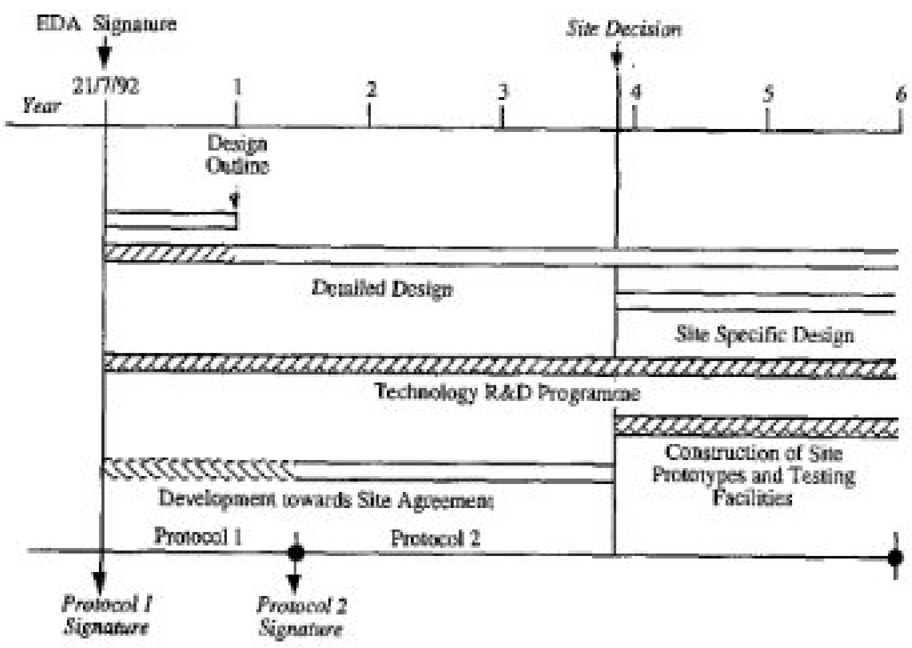

Fig. 12. ITER EDA planning schedule.

To maintain the EDA schedule indicated in Fig. 12 and to fulfill the objective of the EDA within the duration foreseen, the siting issue needs to be completed by the end of the fourth year of the EDA.

18. Conclusions

The present ITER design forms the basis on which the ITER device can be detailed. It integrates the different ITER issues into a coherent and cost-effective design, which minimizes mechanical and electrical stress and ensures reliability. With this design, the ITER objectives can be fulfilled.

Physics predictions show that ITER incorporates only a minimum margin for ignition. The objective of a neutron wall loading of only about 1 MW m^{-2} corresponding to the nominal fusion power of 1.5 GW is fulfilled. The present reference design of the shield/blanket also satisfies the safety requirements during both normal and abnormal operations, including thermal shock resulting from a disruption at the β-limit. These parameters are similar to a power reactor, even at a very early experimental stage.

Design and performance margins will allow compensation for adverse effects of uncertainties in the physics and the engineering. The fulfillment by ITER of the objectives is vital to the development of fusion as a source of commercial fusion energy. This apparatus cannot fail in its first mission to demonstrate "controlled ignition and extended burn of deuterium-tritium plasmas", without jeopardizing the whole fusion program.

In the period leading to the ITER construction some important issues must be resolved. The divertor concept achieving power exhaust and impurity control must be tested in a test bed, and in devices similar to ITER. A vigorous R&D program must be implemented which is focused on ITER requirements including, in particular, the development of magnets as well as materials for the first wall and the divertor.

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