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The status of the ITER design

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ABSTRACT

In parallel with a rapid build up to almost 300 people within the International Organization at Cadarache, the project team, including many from the member countries represented by their domestic agencies (DA), has concentrated its effort on an overall design review of ITER. An updated technical baseline was presented to council at the end of 2007. Several additional improvements were included during spring 2008 and it is probable that the results of the review will be accepted by council. As a result, the ITER design today provides a robust basis for a technical design that allows operation over a wide range of physical parameters, a design that can operate stably with high gain and can exploit the full scientific potential of the device. In the technical area, design changes have been integrated to improve performance, provide more robust subsystems and to minimize technical or operational risks. All of the adaptations required to support the licensing process as a nuclear facility in France have been made. In parallel major components are already under construction within the DAs. A full overview of the status of ITER design and construction, including the detailed discussion of the 2007 ITER baseline, is given. In addition, the construction status and the overall project review is presented.

1. Introduction

The signature of the ITER agreement on the 21 November 2006, marked the foundation of the ITER Organization (IO). In the ITER council meeting held immediately afterwards, the IO was asked to undertake a design review of ITER, recognizing the need to update the baseline for the construction project in line with the evolution of the project and R&D. Four main lines of activities were identified:

1. Perform a major review of the project technical scope to identify deficiencies, incorporate the resent results from fusion experience, identify the major technical risks and establish a new baseline for the technical scope.
2. Analyse and re-baseline the project schedule. Identify the critical activities for the completion of the project and launch the procurement activities of the long lead items, in particular the magnet conductors, the preparation of the site and the definition of the facilities for the fabrication of the coils.
3. Establish the project organization and build up the rules for effective management and coordination of the procurement activities with the domestic agencies.
4. Complete the licensing files, submit the application for the construction license and initiate discussions with the licensing authority.

The conclusions of the design review were presented in October 2007 and it was agreed that several issues should be addressed. The outcome of the process was the adaptation of the design to take into account the choice of Cadarache as the site, the implementation of French nuclear regulations and the identification by the Scientific and Technical Advisory Committee (STAC) of a number of technical issues which should be resolved.

ITER will be procured largely through in-kind contributions from the ITER members. The responsibility for the management of in-kind procurement activities is assigned by each member to entities called domestic agencies. During the same period that IO was established at the Cadarache site, the domestic agencies were set up.

Today the ITER site has been cleared and work has started on the basic infrastructure. Also, construction of a number of major components has started in the DAs.

2. Design review

When the IO was founded, over 200 issues relating to the design remained unresolved. At the same time, members of the fusion community and scientific organizations in the ITER member countries expressed concern over design solutions for many of the ITER components and their impact on either the performance of the

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Table 1
Major technical risks.

1	Vertical stability
2	Shape control/poloidal field coils
3	Optimization of flux consumption
4	ELM mitigation and/or control
5	Remote handling requirements integration
6	Maintainability of the blanket manifolds
7	Use of carbon in D-T phase—divertor armour strategy
8	Capability of upgrade (up to 17 MA discharge)
9	Coil fabrication (cold test)
10	Uncertainties on the loading condition for vacuum vessel/blanket
11	Blanket modules strategy
12	Hot cell design
13	Heating current drive strategy, diagnostics and research plan

device or its reliability. The reasons for these concerns were manifold, but a significant part was due to new physics results from existing experiments, indicating for example, higher sensitivity to magnetic ripple and the problem of edge localised mode (ELM) loads on the divertor and on the first wall. The main goal of the design review was therefore to examine the unresolved issues and to establish a new baseline design. This new baseline could then be used as input to the preliminary safety report which was due for submission to the French Nuclear Authorities at the end of 2007 [1].

The design review was performed by eight working groups which were chaired by scientists and engineers from outside of the ITER team with a co-chairman from the IO. The working groups had a total of approximately 150 members comprising leading experts drawn from the worldwide community. 80 professional person years (PPYs) were contributed from the ITER member countries in order to perform more complex studies, design analysis and design work to support the working groups.

At the beginning of 2007 a total of around 500 issues on the ITER design were registered in the database. These issues were reviewed and prioritised and effort was concentrated on the 13 areas of major technical risk (see Table 1) which had been given high priority—the issues which would have an impact on the long lead items (magnets, vacuum vessel, buildings and preliminary safety report).

The design review was very successful in tackling all high and medium priority issues and in producing practical and cost-conscious solutions. Thus, the new 2007 ITER baseline design was endorsed by the STAC as a good basis for starting construction.

3. Design review follow-up

After the presentation of the design review to the council, STAC and Management Advisory Committee (MAC), a number of significant changes were introduced to the project.

3.1. Vertical stability and mitigation of edge localised modes

A review of experiments on present devices has led to the recommendation to increase the performance of the ITER vertical stabilization (VS) system [2]. In particular it was noted, that in the current ramp-up and flat-top of the 15 MA, $Q = 10$ reference scenario, the internal inductance, ℓ_i (3), can reach values as low as ℓ_i (3) = 0.6 and during the current decay ℓ_i (3) can rise to higher values than previously foreseen. In this phase adjustments (e.g. reducing elongation) will be required to maintain acceptable vertical stability. It was recommended to adopt the parameter $\Delta Z_{max}/a$ (where ΔZ_{max} indicates the maximum "sudden" vertical displacement of the plasma that can be recovered and a is the plasma minor radius) as an appropriate figure of merit for the characterizing the effectiveness of vertical stabilization. It was also recommended that the vertical stabilization system should be able to achieve reliable vertical stabilization for values of $\Delta Z_{max}/a$ of at least 0.05, as in many present devices.

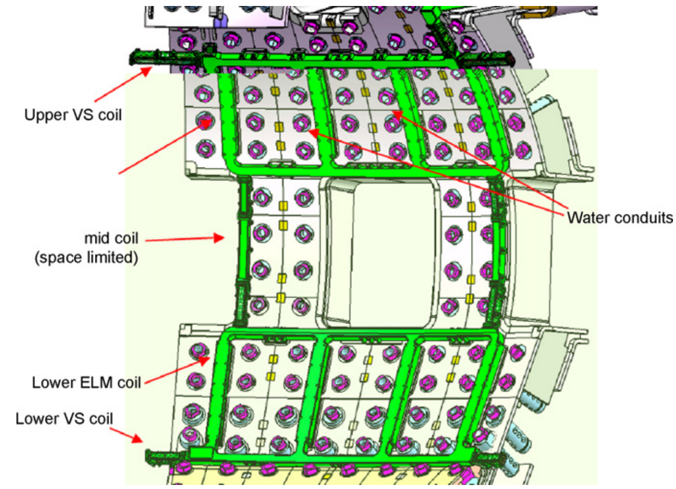

Fig. 1. Layout of proposed ELM mitigation and vertical stabilization coils on one sector of ITER vacuum vessel outboard wall.

Three approaches for the improvement of vertical stabilization have been studied [3]:

(a) Improving the passive stability by either forming toroidally conducting rows of blanket modules, or adding thin (1–2 mm) toroidal rings of copper to the vacuum vessel wall; although some improvement in the vertical stabilization capability was obtained, disadvantages were also identified which resulted in a decision not to pursue this option.
(b) Improving the characteristics of the present vertical stabilization system by increasing the applied voltage in the existing circuit (VS1 consisting of poloidal field (PF) circuits PF2, PF3, PF4 and PF5) from ±6 kV to ±9 kV and adding a second stabilization circuit (VS2) to the CS2U and CS2L modules of the central solenoid which would operate at ±6 kV; this did not yield a sufficient improvement in vertical stabilization capability, but it is, nevertheless, retained as a back-up option.
(c) Developing a new set of in-vessel coils, with an appropriate power supply and connections, to produce an additional radial field on a significantly shorter timescale than the existing external vertical stabilization circuit is capable of; analysis has shown that the required level of vertical stabilization can be achieved with acceptable requirements on coil current and voltage—this option will therefore be pursued as the principal approach to the resolution of this issue (see Fig. 1).

Edge localised modes are magnetohydrodynamic (MHD) instabilities that destroy the magnetic confinement near the plasma boundary. The onset of large ELMs is driven by the large pressure gradients and current densities associated with the reduced thermal energy transport in the high-confinement plasma mode (H-mode) which is essential to achieve ITER high gain operation ($Q > 10$). The scientific community has found increasing evidence that ELMs are potentially more damaging than originally thought [4]. A reduction by about a factor of 40 in the energy deposition by the ELMs is required in order to minimize the risk. Port plug mounted coils proposed during the design review appear incapable of mitigating such events with acceptable impact on plasma performance.

However, with joint efforts by the international fusion community, the domestic agencies and the IOs scientific and engineering resources, this effect was analyzed in much more detail and a satisfactory solution was found. From five different options, which were