The Engineering Challenges of ITER

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Abstract. ITER for the first time brings together reactor-grade plasma and current technology, in an attempt to see how a viable energy source can be built. The main engineering challenge is to produce it on time and to budget, while maintaining some flexibility to respond to changes in understanding as the device operates. The current ITER design was completed in 2001, and a number of changes have been proposed since then. A design review process is therefore underway to address outstanding design issues, to identify any new ones, and to ensure that the schedule and objectives can be met. This involves the expertise of the International Team, along with experts of the Parties, and will focus initially on long lead items and related basic systems to provide a framework for later procurements.

The involvement of seven Parties providing most of the hardware in kind with many multi-Party procurements is in itself an engineering challenge, and the means of realising high quality coherent systems requires careful attention to the details of the manufacturing process, and clear documentation of the responsibilities of the individual actors in an agreement between them at the outset. The procedure for doing this is just being established.

1. Introduction

ITER is the most important step on the path to developing fusion energy using magnetic confinement. For the first time, reactor-grade plasma will be brought together with current technology to see whether a viable power source can be built. The ITER plasma is designed to deliver ten times more power than used to heat it. If ITER does not work, then this line of research will struggle to continue. If it does, then it is reasonably sure to be able to proceed to the commercialising steps that follow, with government and eventually with industrial risk capital. So it is very important that ITER be a financial as well as technical success, and that it sticks to its scheduled aims.

The main engineering challenge of ITER is therefore to produce it on time and within budget to have a timely decision on possible future energy sources and show the economic possibilities. On the way the aim will be to be flexible enough to take account of improved ways of implementing the design, or to take account of new plasma physics insights that have developed over recent years, if these can be accommodated within the schedule and cost, provided they give an appropriate benefit for the enhanced risk. For ITER, for the first time in fusion development, there will be the additional factor of maintaining the site license, which will have been given for the initial design, during essential changes that may be required during the construction. This requires the project to have a healthy relationship with the licensing authorities in the host country France, which will be especially valuable during the subsequent operation phase. During operation there will be the opportunity early on to make changes to in-vessel components and in the ports. Once the nuclear operation starts, about 5 years after construction ends, however, changes to the configuration will have to follow a more laborious process to satisfy the licensing authorities that agreed operating ranges are not being exceeded, so a lot needs to be accomplished in the early years of operation.

Since the ITER design was completed 5 years ago, to the extent that a cost estimate could be agreed on by the then Participants, there have been a number of design modifications with a view to making the design and the cost estimates more realistic in practice, or actually to cut costs. Naturally there have also been some research and technical developments during that period, which now might allow better design solutions to be implemented. Thus, before ITER construction can go ahead, and before the licensing documents can be finalised, it is essential to carry out a detailed design review to assess whether the solutions now proposed still are valid, and can be accomplished in the planned timescale. This process is just beginning now, and is expected to be completed by the end of 2006, with some knock-on actions inevitable in 2007. In particular it is important to ensure that the main tokamak building and pit, and the hot cells, have sufficient space to accommodate equipment and operations, as errors there cannot be corrected later, and are a major contributor to the use of project contingency funds. Being too cramped to move, or unduly delayed waiting for refurbishment facilities, will slow down the experimental programme, and ultimately the implementation of fusion power.

The collaboration formed to build the ITER project is a powerful mix of many countries, cultures and institutions. With seven partners (China, Europe, India, Japan, Korea, Russian Federation and the US) lining up to accept the Joint Implementation Agreement, with their different strengths and specialities, and with common interests to develop the key technologies, the procurement process for many components is highly interdependent, and involved. In this first of a kind experiment of this scale to build a large facility, many road blocks are anticipated and new methods of project management will have to be applied to achieve the ultimate first plasma date in time and on budget. Since everybody's national prestige is associated with the success of the project, in the end this may not be so difficult. The general philosophy of design and construction in far away places and installation and commissioning in a central location is not new but it will be important for the ITER Staff and the Domestic Agencies to keep a close watch on suppliers to maintain the verified quality of prototypes into the production run. Experience in the large particle accelerator construction, other areas of science, as well as in industry, however, shows that with a cooperative atmosphere between different suppliers of similar components there are great benefits to be had when problems inevitably arise because access to a much larger pool of expertise is available. Provided problems are recognised early, and suitable information can be exchanged in time, or task forces set up to attack an identified problem, delays can be avoided if every partnering industry or institution is prepared to build these relationships and work together. With ITER, we are pushing the experience quite a bit wider, and will from time to time require cooperation between suppliers on a global scale, for the benefit of ITER. The future ITER Parties will foster this cooperative atmosphere, which will surely have beneficial spinoffs in other fields.

To be successful, the construction process in ITER will have to put emphasis on (1) integration between the design philosophies and design approaches in the different countries, (2) well defined handoff points, (3) integrated technical designs and schedules, and of course (4) a smooth transition into an operational facility – all of this while maintaining the overall project schedule and cost.

While it is too soon to state in detail any particular engineering challenges of ITER, especially as the design review is underway, this paper will elaborate on the above themes, highlighting where the experiences of the high energy physics field in the construction of large accelerators has an impact on ITER engineering, construction and operation.

2. Project Schedule and Work Programme

The ITER project schedule is shown in Fig. 1, leading up to first plasma by the end of 2016. The current focus of technical work in the project is therefore grouped around six main activities:

- Site adaptation to take into account site specific conditions and regulations, with a view to site preparation work starting at the beginning of 2007.

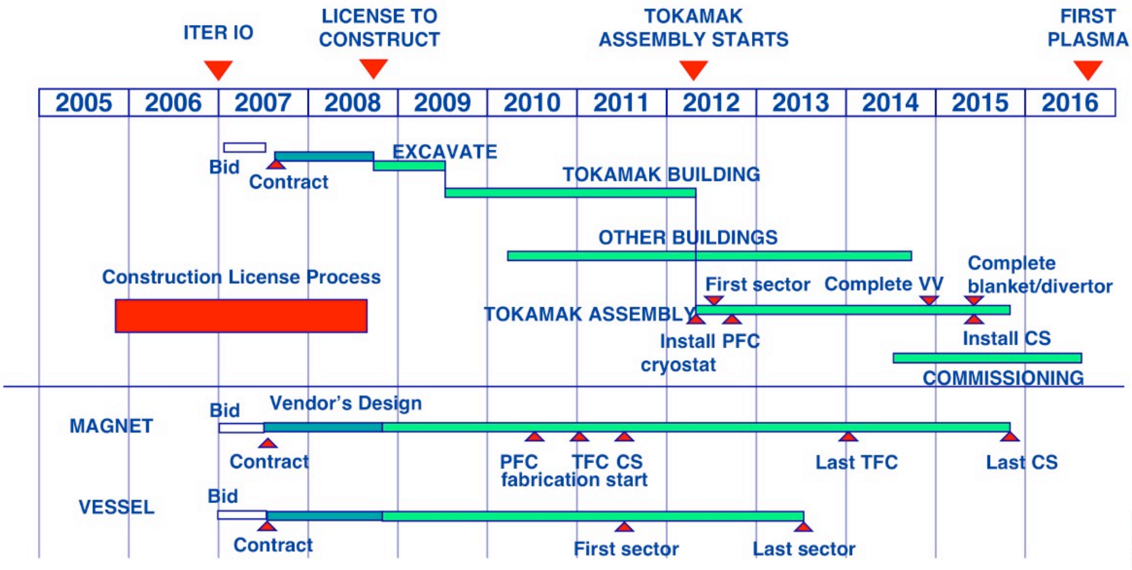

Fig. 4 ITER Project Schedule

- Preparation of the Preliminary Safety Report with a view to its submission and the license application by the end of 2007, and with a public enquiry in mid 2008, leading to the granting of a construction license before the end of 2008.
- Preparation for design review, in particular of urgent items in the last quarter of 2006.
- Finalisation of the technical specifications for superconducting coils, vacuum vessel and the tokamak building complex.
- Memoranda of Understanding for all procurement agreements need to be established to document the technical sharing of work.
- Development of a realistic resource-loaded schedule.

3. Procurement Sharing

One of the main objectives of the Parties is to gain as much know-how out of ITER construction as possible, to put their industry into a good position when it ultimately comes to deployment of fusion power plants, and in the shorter term to involve them in the necessary cutting edge technologies. The sharing of the ITER procurements between the Parties, 90% of which they will provide "in kind", was therefore highly competitive. Nevertheless, it was possible to break up the work on a reasonable technical basis, as part of the negotiations. The technical splitting of procurements now has to be developed more carefully in detail, to ensure completeness of coverage, and safeguards have to be built in to the sharing to cover possible risks, such as the inability of a supplier in one Party to deliver in time sufficient high quality deliverables to meet the specifications.

The general procedure that has been developed for multiparty procurements envisages agreement of a Memorandum of Understanding (MoU) on each shared procurement defining the general approach on how the sharing amongst Parties could be optimised to simplify the interfaces, identify the clear responsibility, and minimize the project risks. The MoUs have to be developed as soon as possible in order to prepare technical specifications efficiently in the IO and responsible Parties' DAs. The MoUs will be reviewed by the ITER Leaders Meeting and then submitted for endorsement by the ITER Council, since there can be financial implications which have to be settled by balancing values of contributions across several procurement packages. Then for each Party involved, the specific technical deliverables, schedules and other conditions, including an earned value reporting system, will be set out in a Procurement Arrangement.

4. Relationship between IO and DAs

The general division of work between the international team and the Domestic Agencies (DAs) should govern the skill set that is being hired in both areas. While the international team is responsible for the design, the integration, installation and commissioning of the facility, staff in the Domestic Agencies will execute detailed design, procurement, vendor oversight, testing and delivery. In addition, with the enormous amount of expertise available in the Parties, much of the R&D that is still required as well as much of the knowledge necessary to finalize the design should come from there.

The relationship between the ITER Organisation and the industrial suppliers is unusual in ITER, due to the preponderance of in-kind supply, funded by the Parties inside or outside of their own territories, for value credit in the overall project as agreed in the ITER Technical Basis. Thus although the ITER Organisation has responsibility for the overall integration of ITER, and its safe and successful operation, the financial leverage in contract operation is with the DAs of the Parties, which fund the procurements. The DAs therefore should have procurement and technical expertise to follow the projects, and to be able to agree or negotiate with the IO about the financial implications of any changes that may occur.

From the IO side the relationship will normally be managed by a FTL (Field Team Leader) for each Party, who is part of the IO, but spends significant time in the DA and surveying progress in their suppliers. The FTL will:

- have delegated authority to agree to field changes within cost and schedule contingency up to an agreed upon amount;
- ensure all relevant documents are transmitted to the DA from the ITER Organisation;
- ensure consistency of procurement packages, designs prepared by the DA, and ITER specifications;
- use staff from the existing technical divisions in the IO, preferably those ultimately responsible for the installation, testing and operation of the component.

For its part, the DA will:

- deliver earned value, schedule and performance information to the FTL;
- provide the FTL and staff with an office.

The FTL submits earned value, schedule and performance information each month to the IO project office (PO), reports all other necessary and useful information to the PO or the leadership team, communicates any schedule variance, scope changes, scope variances or potential issues and, guided by the PO, develops a risk matrix in which potential threats are tracked. Estimates of potential cost or schedule variances are given to the PO as well as mitigation plans and strategies that the FTL develops in close collaboration with the DA.

With such a scheme, it should be possible to obtain early warning of problems, and to be able to compensate for them with minimum risk to the project costs and schedule deadlines.

5. Design Review

Today the different procurement packages are defined to a different extent, since the focus of the technical work since 2001 has been on the earliest procurements, and on those systems they interact most with, or those which are most influential on licensing. The scope of the ITER design remains sufficiently defined so that the value of each procurement can be estimated, and so that changes in the earliest procurements do not have to be made overlooking the implications in later procurements.

A design review process is just beginning driven by the International Team. This will be a continuous process over the next few years, focussing first on the earliest and most influential procurements to provide a frame for later ones. It is intended that the Parties will participate in the process through involvement of their experts on specific issues. Senior management decision making will be aided by a Technical Advisory Group (TAG, see below). The review is being driven by the Project Office, through the following (initial) Working Groups (WGs):

1. Design Requirements and Physics Objectives
2. Safety Issues and Licensing
3. Buildings, especially the Tokamak building
4. Magnet system
5. Vacuum Vessel and its interfaces
6. Neutral Beams
7. Tritium Plant

The first group will check whether the design requirements are consistent with the ITER objectives, and will need to have input from the ITPA to ensure this. The other groups will check that the design to be implemented conforms to its requirements.

The goal of the review is to resolve major open design questions in order to be able to prepare the procurement packages for the work breakdown structure (WBS) elements. Currently each problem requiring resolution before a procurement package can be written merits an “issue card”. At present there are over 200 issue cards, and the number is growing as new staff join the project and as previously sidelined procurements receive renewed attention. The issue cards are available in an online database accessible to the International and Participant Teams, and record not only the problem, but the actions underway to resolve them and the status of their resolution. These issues vary from the fundamental to the trivial, and therefore have differing degrees of influence on the Project’s risk of not reaching first plasma on time and on budget. The strategy for managing this risk at any time is documented in detail in the Project’s “Risk Management Strategy”, which is developed in conjunction with the procurement and construction schedules. This strategy therefore establishes the sequence and priority of the technical systems to be addressed, in conjunction with senior management. The issue cards and their rate of completion also provide a management tool to determine the progress and timely completion of the review.

The short-term aim is to establish a “Baseline Design 2007” where the changes to the 2001 design are either confirmed, modified or rejected and where existing design issues or the ones discovered by the WGs for the long lead items are to a large degree solved. Thus the working groups will not only compile a list of problems but also try to solve them. There will likely be a few (~ 2 to 3) design issues which are not solvable by the working groups either due to a lack of resources or due to a large impact on the cost and schedule. These will be presented to the ITER Council with the risk to the project if they are not resolved and the resources and time needed to resolve them. The WGs have to prepare this report and agree it with the PDDG and the PTs.

A. Main Review Elements

The charge of the ongoing design review has certain major elements:

- is the physics baseline established and documented well enough, and is the technical baseline consistent with it?

- is the manpower sufficient for this stage of the project and distributed appropriately?
- is the overall schedule consistent, sufficiently well established, and with enough contingency for this stage of the project?
- is the organization of ITER maturing and developing fast enough to be able to launch into construction when planned?
- which parts of the organization should be improved and how in order to support the construction project?
- is the civil construction on track for construction start in 2009?
- are the business systems in place to handle scope, schedule and cost of the ITER construction project?
- are the safety and civil construction aspects properly addressed for this stage of the project?
- where are the highest vulnerabilities?
- is the design review process appropriate to address all technical, scope, schedule and cost aspects of the project?
- how can it be improved?

B. Technical Advisory Group

The Technical Advisory Group (TAG) reports to the DG and PDDG. Members are appointed by the DG for a 3 year term with the possibility of a 3 year extension. Members are expected to accompany the design review process and the build up of the IO. Their advice will cover technical, managerial and organizational aspects to help the DG and PDDG to successfully manage the project. There will be about 12-15 members and they will be drawn from the international science community. Reports of the TAG will be made public. TAG recommendations will be tracked and reported on in subsequent reviews. The TAG is expected to meet at least twice per year.

C. Current Work

The current technical work in the ITER project team to prepare and support this design review is therefore orientated towards:

- identifying all systems that are not designed yet or are still in the conceptual stage;
- starting from the technical basis [1], identifying all systems that have integration or technical issues which need to or should be resolved before a procurement specification can be assembled, documenting the issues, and planning a path forward for resolution;
- identifying areas, concepts and technical designs where recent R&D results indicate a possible performance problem or unacceptably high manufacturing cost, documenting issues, and planning a path for resolution.
- identifying areas, concepts and technical designs in which recent R&D results would benefit the design, schedule or cost;
- prioritising open issues with respect to their scope, schedule and cost impact, and identifying and implementing solutions in priority order.

A risk assessment document will be provided that will guide the design review in terms of scope, schedule and cost, and a priority number will be assigned.

D. Constrained Change

In carrying out the design review, or generally finalising the design of specific procurements, or considering proposals for change in the design, since the overall ITER budget is fixed, changes which lead to cost increases, work or designs identified as not finished, or any other task that requires budget and was not foreseen before, needs to be offset against savings elsewhere. Each proposal for change therefore has to quantify the monetary, scope or schedule impact of the change, as well as the man-hours needed for integration and who is supposed to provide them, clarify the impact on other WBS elements as precisely as possible, and clarify whether the cost increase is a result of changes/conditions imposed by a Party. Any design change proposal has to be accompanied by proposed offsets in kind to keep the total project cost constant, proposed offsets in terms of scope (scope increase in one WBS versus scope decrease in another), and/or proposed offset possibly using additional Parties' contributions within their agreed commitments. If caused by limitations from a particular Party, how additional costs can be covered needs to be discussed with that Party and any others affected.

6. Engineering Challenges

Pending the above design review, it is too soon today to identify with confidence the critical technical issues that will have to be raised to the ITER Council level because of their fundamental impact on the planned objectives, budget or schedule of ITER.
Currently some items are causing concern.

- The performance of the magnet conductor, where results of recent testing on higher critical current strand shows no increase in temperature stability margin when wound into a conductor [2]. The experts are still discussing how best to resolve this issue, but this may be resolved by utilising the conductor previously tested during the EDA, and improving and testing a further optimised configuration. Clearly an accelerated programme of R&D on this topic will be needed, given the position of magnet procurement on the project's critical path.
- The use of the reference combination of beryllium first wall, and tungsten-coated divertor with carbon target plates, in the light of increasingly encouraging results with a full coating of tungsten [3]. The use of mixed materials including carbon brings with it operational problems of ensuring significant quantities of buried tritium cannot be released in an accident. An R&D programme would need to be carried out to ensure the quantity of tritium in the machine can be controlled, measured, and removed. As long as core plasma poisoning with tungsten impurities does not turn out to be a severe problem, use of tungsten coating everywhere looks to be a better reference option today.

With the realisation that ITER will now actually be built, it is no longer possible to avoid concerns in the design that have not been resolved during the intermediate technical work during the negotiations. Problems that remain now need to be solved quickly, or alternative solutions adopted which may not be the most elegant, but will nevertheless work reliably. The key engineering challenge is to recognise these items, and put the limited resources onto their resolution with the minimum of delay.

7. Conclusions

A design review is about to begin which will strengthen the technical and financial commitment of all stakeholders, DAs and project team members. This will be wide ranging but will initially focus on long lead items which will provide the frame for later procurements. The challenges in realising ITER appear to be hard but manageable, and with the support of the fusion community can be overcome.

Acknowledgement

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8. References

[1] ITER Technical Basis, ITER EDA Documentation Series No 24, IAEA Vienna, 2002

[2] D. Ciazynski, "Review of Nb_3Sn Conductors for ITER", Proc. 24th Symposium on Fusion Technology, Warsaw, Poland, September 2006, in publication

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