ITER AND INTERNATIONAL SCIENTIFIC COLLABORATION*

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Abstract

After several years of conceptual and detailed design and difficult negotiations, ITER, the device designed to demonstrate the scientific and technical feasibility of nuclear fusion as a primary source of virtually inexaustible energy is approaching the start of the construction phase. Due to its size and cost and the involvement of virtually all the most developed countries, ITER will become a new reference standard for big science projects.

At present main activities underway are oriented towards (i) the consolidation of the design basis and the operation plans, (ii) the build-up of the team to oversee the construction, (iii) the preparation of the preliminary safety report to obtain the licence for construction, (iv) the finalisation of the agreement on cost and responsibilities sharing, (v) the site preparation and (vi) the preparation of the technical specifications for the procurement of the long lead items.

The paper describes the current status of the ITER Project, the technical and managerial challenges and discusses the organisational and sociological aspects related to its realisation.

INTRODUCTION

The ITER project will be one of the world's biggest scientific collaborations, involving countries representing over half the world's population. Its aim is to demonstrate that fusion, the physical reaction that occurs in the sun and stars, can be used to generate electric power.

Nuclear fusion occurs when the nuclei of light elements come together at very high temperature producing a nucleus of a heavier element, and releasing in the process a large amount of energy. Fusion on the long term offers several attractive features as a large-scale and long term energy source:

- its basic fuels are abundant and available everywhere: about 100 kg of deuterium and 3 tons of natural lithium are needed to operate for a whole year a 1 GW fusion plant generating about 7 billion kWh;
- no greenhouse gas emissions (to generate the same amount of energy with a coal fired plant one would release about 4 million tons of CO_2);
- no transportation of radio-active materials, as the tritium is produced and consumed on site;
- no possibility of "meltdown" or "runaway reactions", as a very small amount of fuel is in the chamber at any given moment and the reaction will stop in few seconds after the supply is interrupted;
- no long-lasting radioactive waste to be passed on to future generations, as the ashes of the fusion reaction are stable and activation comes only from the structural materials, which can be chosen to minimise waste..

The quest for fusion nuclear energy started in the 50s, after its enormous potential was demonstrated in military applications. Magnetic confinement and intertial confinement soon emerged as the only two viable approaches to obtain the conditions for nuclear fusion, the latter developed primarily in classifed, military-funded research, the former under international joint development because of its non military technology. The Tokamak, a magnetic configuration invented by Russian scientists in the 60s, was identified to be the most promising concept because of its advantage of a strong toroidal field for plasma (which still allows human access for modification or assessment),

The most advanced tokamaks such as TFTR [1] and JET [2], have already achieved the conditions for fusion reactions and generated fusion power, but only in ITER this will be done at a scale that will prove the scientific and techological feasibility of fusion as a energy source.

An agreement on the joint implementation of ITER construction, operation, and decommissioning has been initialled on May 24th, 2006 in Brussels by representatives of the People's Republic of China, Euratom, India, Japan, the Republic of Korea, the Russian Federation and the United States of America (the "ITER Parties"). The signature by the governments concerned is expected by the end of 2006, followed where needed by its ratification by the legislative bodies of the Parties.

ITER construction is due to start soon in Cadarache in the south of France, following the granting of the necessary authorisation by the French licensing authorities. The construction period is expected to take about 10 years, including licensing and the integrated commissioning of the facility [3]. The first plasma is expected by the end of 2016. After confirming the technical capability of the machine with hydrogen plasma, (which still allows human access for modification or assessment), deuterium and then tritium will be introduced, allowing ITER to reach full fusion power.

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THE ITER DESIGN

The programmatic objective of ITER "to demonstrate the scientific and technological feasibility of fusion power for peaceful purposes" is translated into a number of specific technical goals, all concerned with developing a viable fusion power reactor [4].

- ITER should produce more power than it consumes. This is expressed in the value of Q, the amount of fusion power that is generated by the fusion reactions, divided by the amount of external heating power. A value of Q smaller than 1 means that more power is needed to heat the plasma than is generated by fusion. JET, presently the largest tokamak in the world, has reached Q=0.65, near the point of "break even" (Q=1). ITER has to be able to produce Q=10, or Q larger then 5 when pulses are stretched towards a steady state. The objective is reactor-relevant "burning plasma", where most of the plasma heating would come from the fusion reactions themselves.
- ITER must extend the pulse duration with profiles of plasma temperature, density, and current in near steady state, using non-inductive current drive which is almost essential for a power-generating reactor.
- ITER will implement and test the key technologies and processes needed for future fusion power plants - including superconducting magnets, components able to withstand high heat loads, and remote handling.
- ITER will test and develop concepts for breeding tritium from lithium-containing materials inside thermally efficient high temperature blankets surrounding the plasma.

By the end of 2020, ITER will demonstrate the extended burn of D-T plasma producing up to 700 MW of fusion power. This goal will be achieved in an inductively driven plasma or in an extended-pulse plasma.

As in all tokamak devices, in ITER magnetic confinement is achieved by the interaction between an externally imposed strong toroidal magnetic field and the poloidal magnetic field produced by current induced in the plasma by a magnetic flux swing generated by the central solenoid.

The plasma is contained in a high vacuum doughnut-shaped vacuum vessel (VV). Inside the vacuum vessel, the plasma-facing components intercept the plasma particles carrying 20% of the total fusion power + auxiliary heating, and a thick blanket absorbs the fusion reaction fast neutrons and reduces the radiation damage to the surrounding structures. In addition, diagnostics and additional heating systems are needed for the control, stabilisation and heating of the plasma.

Outside the vacuum chamber, 18 D-shaped Nb_3Sn superconducting magnets generate the toroidal field (with peak field at the conductor of 11.8.T), and a large central solenoid made of 6 separate segments provides the magnetic flux variation to induce the initial loop voltage to generate the plasma and to drive the toroidal plasma current. A set of 6 coils (the largest of which have a diameter of about 24 m) generate the poloidal fields to control the shape of the plasma and to generate the radial field to stabilise its vertical position. All magnets are made of superconducting materials and are surrounded by a large cylindrical cryostat. An actively-cooled silver-coated thermal shield at 80 K is used to reduce the radiation loads on the magnets.

Figure 1 shows a view through the ITER cryostat. The total tokamak assembly weighs about 23000 tonnes and contributes ~ 60 % of the total estimated cost of ITER.

Outside the cryostat wall, a concrete building provides the biological shielding and safety confinement functions. The tokamak buildings complex has a footprint of about 110 x 80 m and a height above ground of about 60 m. It

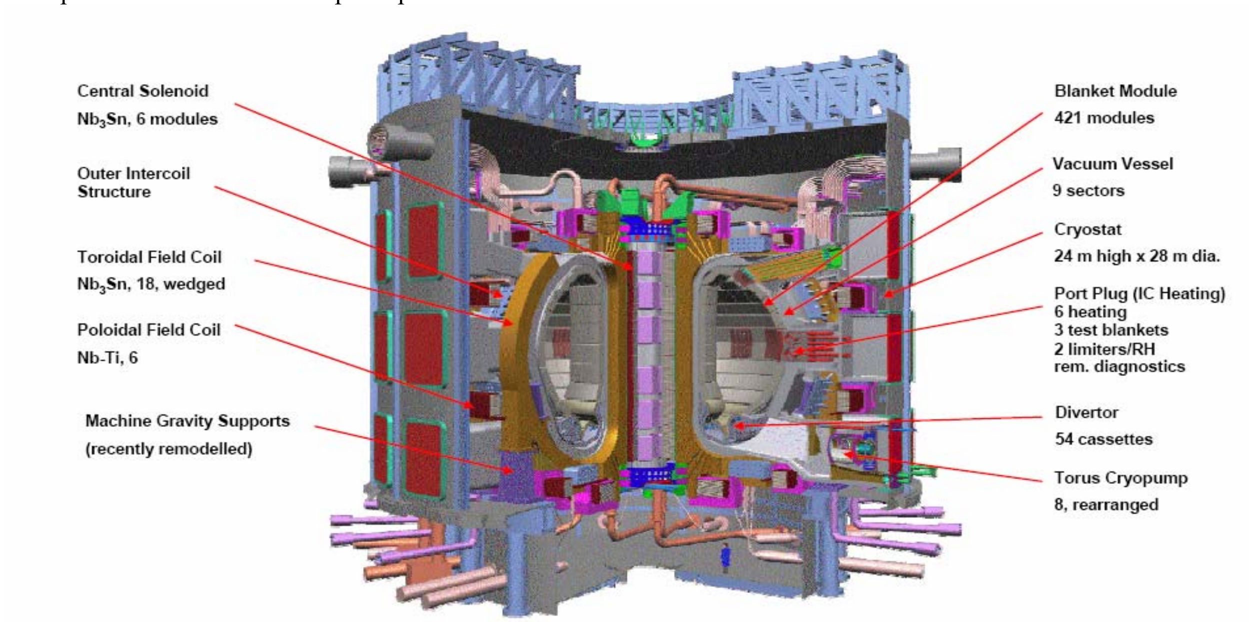

Figure 1: The ITER machine. The man in the bottom shows the scale.

will sit on a seismically-isolated concrete slab, and it is designed to resist the impact of a small airplane. Systems that are important for safe operation, such as the primary heat transfer system, the ventilation and atmosphere control, the vacuum and fuelling system, the machine diagnostics, and the safety and interlocks systems, are entirely contained in this complex. The remaining services, such as power supply transformers, cryogenic plant, power conversion for the magnets, pulsed power supply, the assembly hall, the hot cell for the maintenance and repair of activated component, the temporary storage for activated waste, the cooling station to dissipate heat, and the control building, occupy an area of about 40ha.

THE ITER ORGANISATION

ITER will present not only challenges in physics and technology but also in management [5].

Firstly, the project team needs to be pulled together from countries that are very much apart in cultural habits, as well as in time zones. The staffing regulations will apply for construction and operation of the experimental facility. Moreover, the construction team will have to rely heavily on the involvement of industrial suppliers of engineering and construction management services.

The management of ITER procurement foresees the existence of (see figure 2):

-a central project team;

-"field teams", which will monitor procurement quality - these together with the central project team will form the ITER Organisation (IO);

-"domestic agencies" (DAs), which will act as providers of goods and services to the IO on the basis of well defined specifications.

The second management challenge is associated with the relatively unconventional procurement system, which will be mostly "in kind". This means that at the signature of the agreement each Party will undertake the responsibility to procure its chosen components within the Party itself. The main reasons for selecting this type of procurement were:

a) to ensure that there will be appropriate involvement of the Parties in key fusion technology areas,
b) to ensure that the sharing of the burden will be independent on the purchasing powers in the different Parties. For this reason, the division of burden between Parties will be in percent of the value of the machine. A detailed evaluation, using uniform unit costs, was carried out to determine how the different parts of the machine contribute to its total value,
c) to automatically ensure the principle of fair return, whereby the money "given" to the project by a Party will automatically be spent in the Party itself.

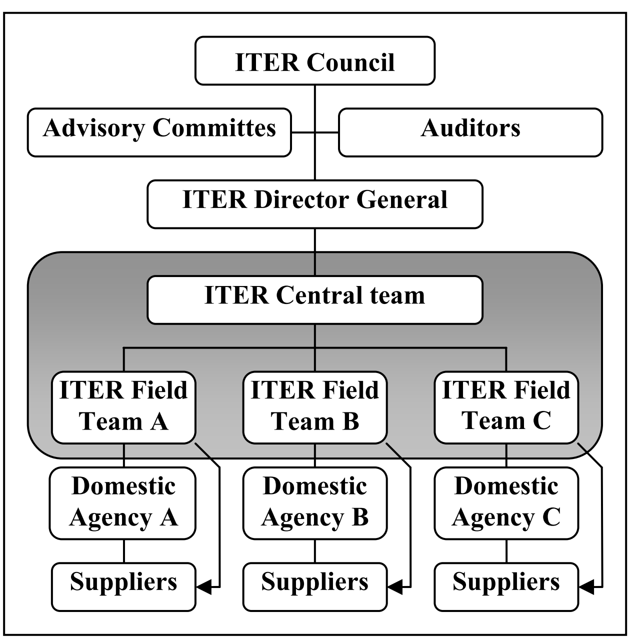

Figure 2: The ITER organisation

The actual sharing amongst the Parties foresees that the host, Europe, will bear 50% of the ITER value and that the other Parties will each bear 10%. Table 1 summarises the breakdown of the ITER procurement: the relative value of each system is indicated in % and the involvement of each party is indicated with an x. The last column indicates the part which is cash funded.

MANAGERIAL AND SOCIAL ISSUES

The scientific community has seen in the past years an increasing number of large science projects which are managed through some form of collaborations among different institutions and sometimes across national borders (e.g the LHC at CERN [6] and SNS[7]). The main advantages of these collaborations are that they can face the increasing cost of big science, and they bring together the mix of scientific, technical and industrial

Table 1: Breakdown of the ITER procurement
Column F stands for cash funded

	%	CN	EU	IN	JA	KO	RF	US	F
TF conductor	7	x	x		x	x	x	x	
PF conductor	5	x	x				x		
Magnet	14	x	x		x		x	x	
Building	13		x						
Vessel	8		x	x		x	x		
In-vessel	8	x	x		x	x	x	x	x
Addit. heating	8		x	x	x		x	x	
Power supply	7	x	x			x	x	x	
Diagnostics	5	x	x	x	x	x	x	x	x
Cooling	5			x				x	x
Maint.equipment	4	x	x		x				x
Cryostat	3			x					
Assembly (tools and operations)	3					x			x
Tritium	3		x			x		x	x
Cryoplant	3		x	x					x
Data acquisition	2								x
Thermal shield	1					x			
Vacuum	1	x	x					x	x

skills needed for the design and construction work. Also, they facilitate the access of scientists to existing facilities.

How this collaborative approach will be exploited to face the challenges of the project is discussed below.

Role of the IO and DAs

In ITER, special technical challenges derive from the highly integrated design of the tokamak assembly (with many interfaces among different systems and procurement packages), from the large number of systems required for its functioning (which implies diversified skills and actors) and from the extensive use of innovative technologies. As indicated above, the procurement of this integrated device is divided among the seven Parties (and a larger number of fusion laboratories and industries) with the risk that the responsibility for the overall project success could be overweighed by the contractual responsibility of each Party to deliver specific items of equipment.

Within each Party, a clear separation exists between its role of supplier of individual items (the DAs) and its role of stakeholder responsible for the overall success of the project.

Also, the boundaries between the responsibilities of the IO and those of the Parties are clearly defined. The IO will focus on integration activities, on the management of the on-site installation, and on the direct procurement of the parts where the knowledge resides in the IO. The DAs will manage the procurement contracts.

Key responsibilities of the IO are the definition of requirements, the identification and monitoring of the interfaces, and configuration and documents control. The IO develops the Plant Breakdown Structure, that identifies each parts of the plant, and the Work Breakdown Structure, that describes all activities required to achieve the final objective. The IO maintains the centralised overall project schedule by integrating the detailed procurement schedules of each Party, implements the rules for the safety on-site during construction and operations, and manages the machine assembly. It is in charge of the procurement of the data acquisition and control systems, and is directly responsible for the interfaces with the licensing authority,

The DAs have to conform to the overall ITER quality plan developed by the IO but are largely independent in adopting national practices and rules. The DAs are responsible to inform the IO of problems and delays during the procurement and to collaborate on their solution.

For both the IO and DAs the current priorities are the build-up of the respective teams, ensuring that the staff and knowledge in the existing teams are transferred smoothly to the new organisations, and the preparation for the start of the procurement.

To reduce the risks and minimise the problems at interfaces, a top-to-bottom process has been initiated to identify the outstanding design issues. The consequences of these issues on design, performance, cost and schedule, and the required corrective actions, will be assessed in a project design review. This will be carried out as joint activity involving all Parties, and will aim at the overall minimization of the risk for the project as a whole. The objective is to achieve a common understanding of the full scope of ITER and of the deliverables of each Party and to develop an integrated schedule based on a commonly accepted design.

Detailed design activities will continue during the procurement phase and will be distributed across distant work sites, fusion laboratories and industries. The ITER staff has acquired a considerable experience in the management of distributed design work and collaboration with external institutions. The tools and procedures to manage this “concurrent engineering” have been tested and deployed, benefiting also from the experience of industries (such as the aeronautic industry) where this has become common practice. For the successful management of this form of collaboration, each participant has to develop a clear understanding of its role and of its interfaces, and must equip itself with the necessary tools based on the specifications provided by the IO.

Relationship with the Suppliers

During the past years a number of large R&D projects have been completed to reduce the risks in the fabrication of the most critical components of the tokamak and to demonstrate the feasibility of the proposed maintenance approach. Critical fabrication techniques were developed and tested [8]. The results were analysed and used in the design. However, with the procurement spread across the globe, many vendors still need to demonstrate their capability to meet the ITER requirements. For an effective manufacturing risk reduction, the use of procurement staged contracts is foreseen, where the full fabrication contract is awarded only after the supplier performance has been assured.

On the positive side, the participation of many countries increases the number of vendors and the possibility to transfer fabrication contracts when the performance is inadequate, and will lead to an effective risk reduction.

During the construction phase the IO management will exercise a tight control to limit the scope and number of design changes. These tend to have a knock-on effect and increase the difficulties to maintain coherence across the project. However, changes caused by difficulties in fabrication, installation or assembly of the components, delays or regulatory issues, cannot be avoided in a project of this type. The IO has developed a procedure for the tracking, processing and record of design changes. This procedure needs to be extended to involve the DAs in the assessment and management of the associated cost and schedule implications. However, it is important that the IO retains the capability to dynamically manage the procurement of various systems which are closely interfaced and which may undergo these design changes. This may require the re-allocation of procurement contracts from one party to another and a re-discussion of the cost sharing.

The staff in the IO will be limited in size and some of the skills needed for the detailed phase of the work will be in the parties or industries. Thus, the use of "built-to-print" procurement contracts is limited to those systems where the knowledge is mostly concentrated in the IO. For the other cases, the procurement will be based on functional specifications. In these cases, the preferred procurement scheme is to use staged contracts in which the initial phase will be the development of the detailed design and the technical specifications, followed by the award of the manufacturing contracts.

Participation of the Scientific Community

During Engineering Design Activities (1992-2001) the participation of the fusion community was organised through a number of experts groups including ITER designers and fusion scientists. They were charged to support the design team in the choice of the project's goals, coordinating the efforts of existing experiments, and providing independent peer reviews.

During the construction and commissioning phase of ITER, the involvement of the fusion community will be needed to resolve the scientific challenges related to the selection of the operation parameters and to the prediction of new physics phenomena that can be studied experimentally only in ITER itself.

Considering the strong interplay between the technological limits and the plasma performance, this collaboration will benefit both the IO and the fusion laboratories. The existing links must be maintained and strengthened: the IO will focus on the engineering aspects while the scientific work in support of it and the training of the machine operators will be mostly responsibilities of the fusion laboratories.

Social and Cultural Aspects

Several studies have already indicated that social aspects and differences in national culture may complicate collaboration in large technological projects [9].

A case study was conducted recently on ITER and its European predecessor JET[10]. The authors identified a number of management issues (such as the degree of centralisation in the management structure, the attitude towards geographic distribution of the work, the long term budgetary commitment, the importance given to family and education issues or pay equity) which are impacted by differences in the national cultures. The paper succesfully related the cultural differences among the countries participating to the ITER negotiation with the positions they took on subjects such as the funding of the project, the centralisation of the design activities, the preferences given to different schemes of IO organisation structure and staffing regulations .

Although the conclusions of these types of studies are too generic to serve as useful management tools, they may serve to increase the awareness that these aspects may play an important role in the daily management of the project. However, people involved in large projects can recognise that the common scientific culture and the participation in a challenging undertaking contribute to the elimination of cultural barriers and simplify the management process.

SUMMARY

ITER is the culmination of 50 years of research in fusion and, after the initialisation of the agreement last month in Brussels, has moved into the construction phase.

This paper has described the technical, managerial and social challenges that remain to be solved to meet the tight budget and schedule and discussed how the management structure and the international collaboration can be used to provide the needed resources and skills.

The management of a collaboration at this scale is in itself a challenge, but the sharing of a common goal in a mission-oriented organization with very large personal commitment will foster the ITER ethos as a glue to keep the Team focussed and will be the key for the success of the project.

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