2. The ITER project

2.1. Thermonuclear fusion

Thermonuclear fusion holds the promise of virtual endless energy supply. It is the energy producing process, which takes place continuously in the sun and the stars. In the core of the sun at temperatures of 10-15 million degrees Celsius and extreme gravitational pressure and density, hydrogen is converted to helium providing enough energy to sustain life on earth. For energy production on earth different less demanding fusion reactions are involved. The most suitable reaction occurs between the nuclei of the two heavy forms (isotopes) of hydrogen, deuterium (D) and tritium (T).

$$D + T \rightarrow He + n + 17.6\ MeV$$

Deuterium is widely available in water; tritium can be bred from lithium using the neutrons generated in the fusion reactions. Lithium, the lightest metal, is plentiful in the earth's crust.

At the high temperatures at which these fusion processes take place, ~100 million °C, the state of matter is that of a plasma, a fully ionised gas, in which the ions and electrons move freely. As charged particles, the ions and electrons are subject to magnetic forces. This provides an opportunity to contain the hot plasma. The most widely used and most successful magnetic configuration to confine the plasma and to obtain nuclear fusion in a controlled way uses a Russian concept, the tokamak.

2.2. Tokamak

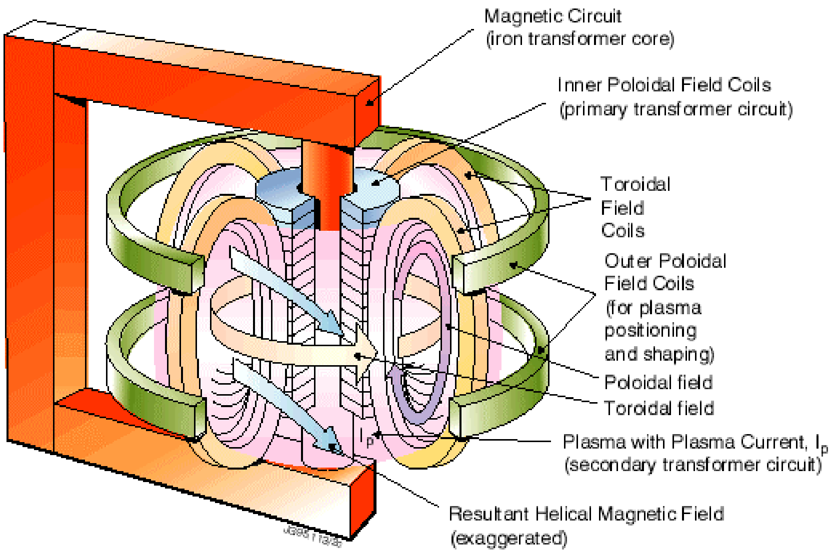

Figure 2.1: Schematic of a Tokamak

A tokamak has a doughnut shaped vacuum vessel (torus), which is surrounded by magnetic coils (see Figure 2.1). These coils generate a toroidal magnetic field. The plasma is formed inside the vacuum vessel when a current is induced in the toroidal direction using a transformer, in which the plasma acts as the secondary winding. The plasma particles move freely along the magnetic field lines in small gyrating orbits. This restricts their radial movement and provides particle confinement. The current is heating the plasma at the same time by ohmic dissipation. The plasma current also produces a poloidal component of the magnetic field, which together with the toroidal field results in a helical field line structure. A number of poloidal field coils are added to provide better control of plasma position and stability.

The Joint European Torus (JET) in Abingdon (UK) is the largest tokamak in the world (Figure 2.2). JET holds the world record in fusion power (16.1 MW) and is currently the only tokamak in the world that can operate with a deuterium – tritium mixture (see www.jet.efda.org/).

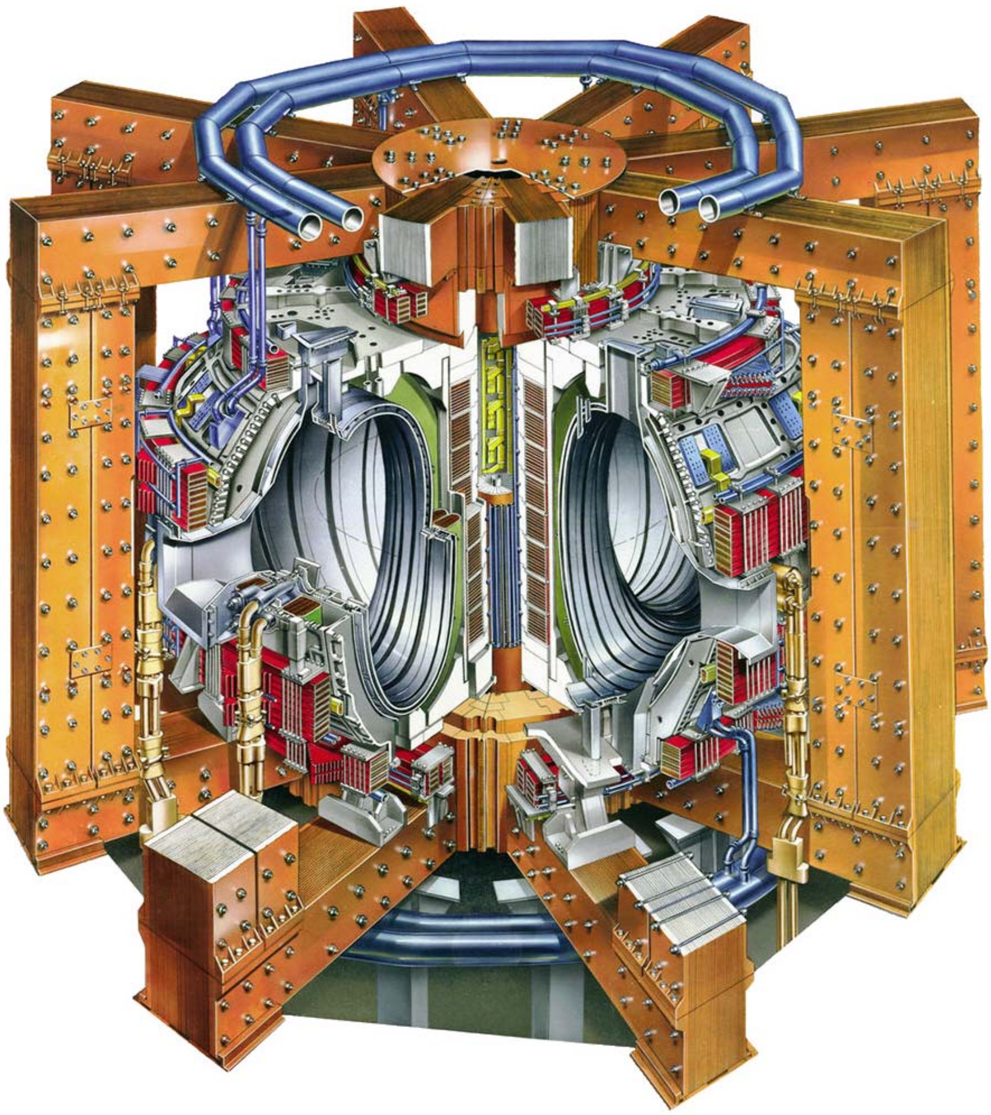

Figure 2.2: Cut through of the JET Tokamak

Tore Supra (Figure 2.3) in Cadarache (France) is a tokamak with a superconducting toroidal field configuration. It has already produced discharges of two minutes and will in the near future be capable to investigate the effects on wall materials under large sustained heat fluxes (see www-fusion-magnetique.cea.fr/).

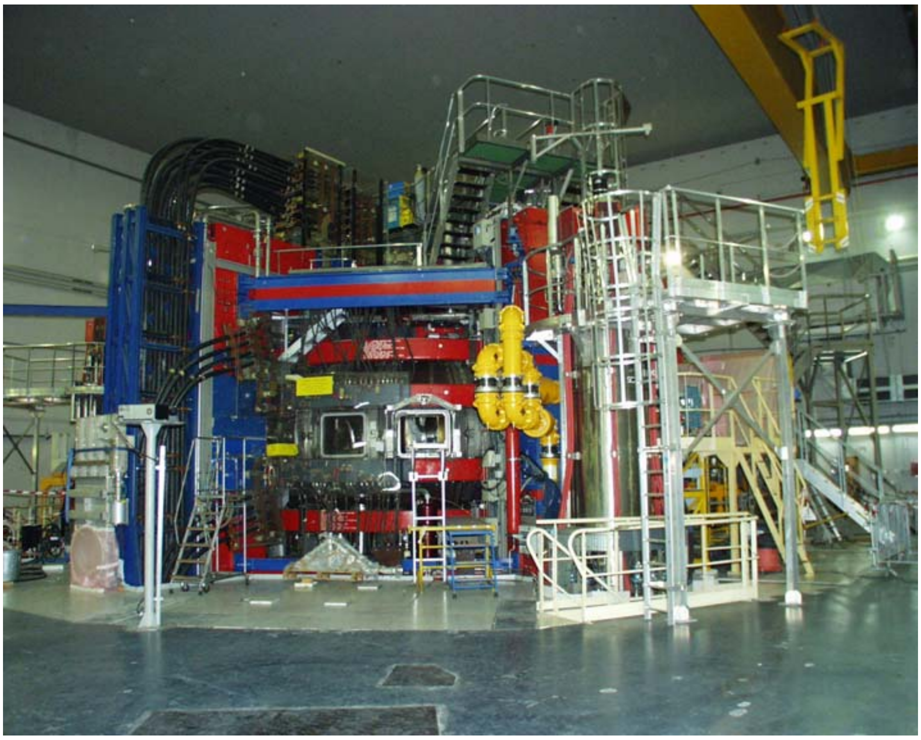

Figure 2.3: Photograph of Tore Supra

Europe has always organised and performed pioneering work in the operation of a number of complementary machines (see DG Research web site, describing the fusion programme at europa.eu.int/comm/research/fusion1). The following European tokamaks can be cited:

- ASDEX, then ASDEX Upgrade in Germany where the first H-mode was observed (www.ipp.mpg.de/de/pr/forschung/asdex/pr_for_asdex);
- TEXTOR in Germany (www.kfa-juelich.de/ipp/), focused in particular on plasma-wall interaction;
- Frascati Tokamak, then FTU, in Italy, tokamak with a high magnetic field and a large current density (www.frascati.enea.it/FTU/);
- DITE, Compass, in the United Kingdom (www.fusion.org.uk/), study of ELMs, control of plasma instabilities;
- START, MAST, in the United Kingdom (www.fusion.org.uk/), tokamak with a "spherical" configuration;
- Tokamak à Configuration Variable, in Switzerland (crppwww.epfl.ch/), enabling many plasma shaping.

Stellerators, which have a different magnetic configuration from tokamaks, are also studied, for example:

- W7-AS (www.ipp.mpg.de/de/for/projekte/w7as/for_proj_w7as), in Germany

- W7-X (www.ipp.mpg.de/de/for/projekte/w7x/for_proj_w7x), machine in construction in Germany
- Flexible Heliac TJII, in Spain (www-fusion.ciemat.es/)

Many other laboratories contribute to the fusion programme in theoretical, experimental or technology (Karlsruhe, where ITER toroidal field model coil is tested…). Figure 2.4 gives a complete overview of the Euratom coordinated fusion research.

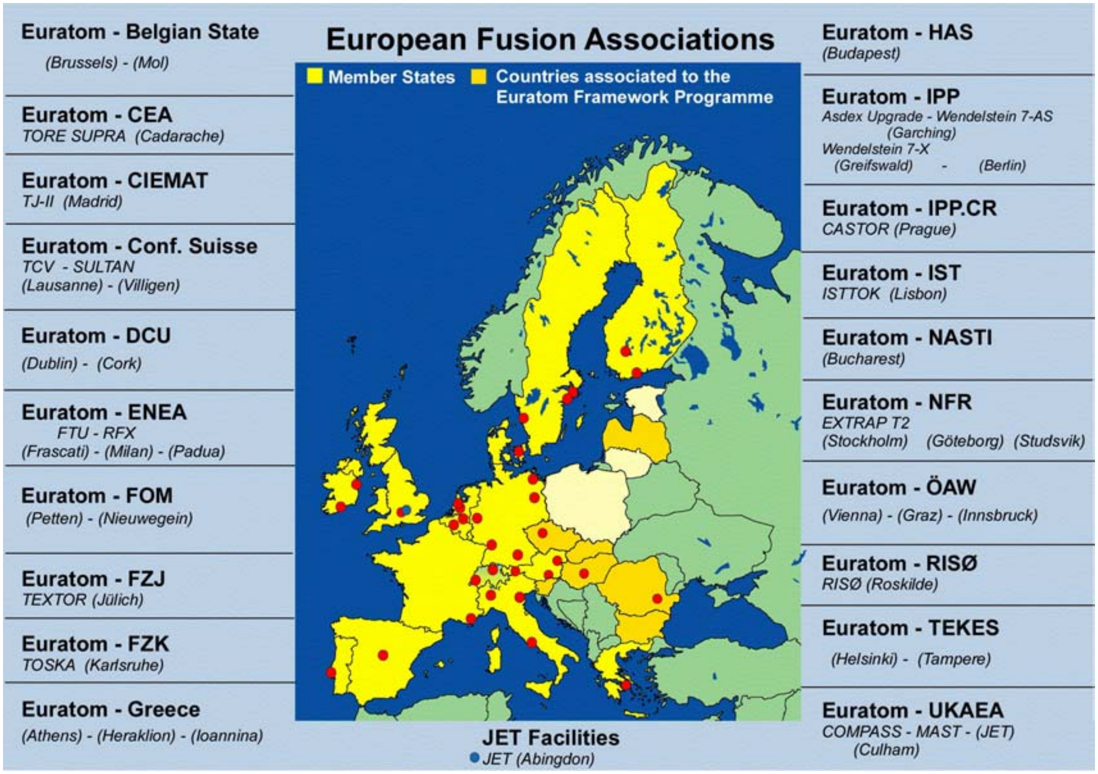

Figure 2.4: European Fusion Associations

The minimum size of a fusion reactor with the Tokamak configuration is set by the requirement that the plasma has to be big enough to confine the energy produced in the fusion reactions sufficiently to ignite – this is the condition when the energy produced by fusion is enough to keep the plasma at a temperature that enables to self sustain fusion reactions. Previous fusion experiments, in particular JET and similar projects in the United States and Japan, have taken fusion very close to this point and their results allow a very reliable extrapolation to the minimum size for a fusion reactor. It would have to be about three times the physical dimensions of JET with a plasma current of about 20 million Ampere (JET can reach about 7 MA). A reactor of this size would produce somewhat between one and two thousand megawatts of electricity – comparable to the biggest power stations that are presently in operation today.

On this basis the parameters of the Tokamak experiment to demonstrate plasma ignition and fusion power production, ITER, were deduced. Figure 2.5, based on worldwide database [1], shows ITER confinement time in comparison with existing machines and illustrates the confidence of the extrapolation.

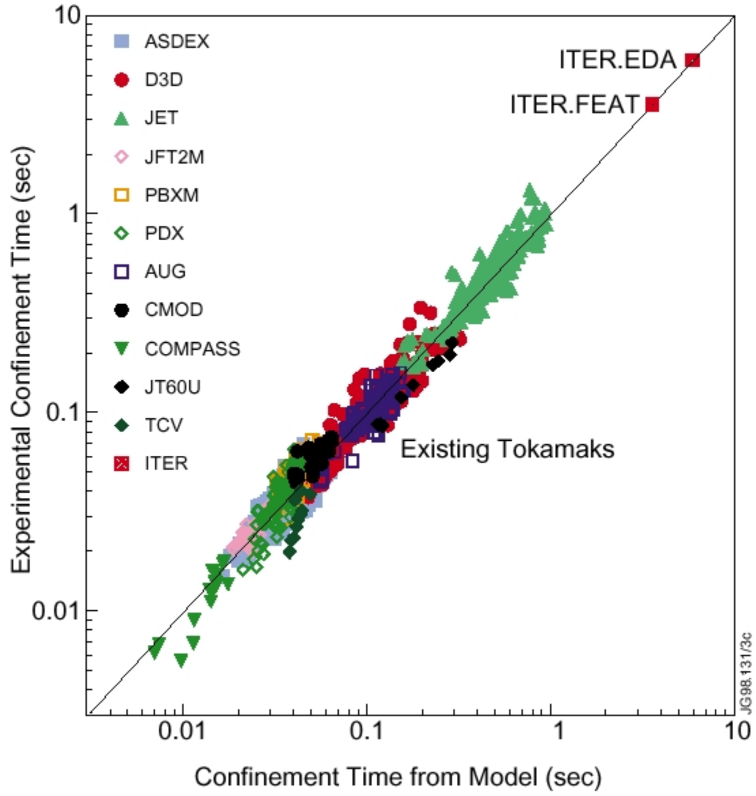

Figure 2.5: Experimental data from all the major tokamaks in the international fusion programme showing predicted confinement time versus measurements

However in order to keep the construction costs as low as possible, the new design for ITER has dimensions about 75 % of those of the previous design with a plasma current of about 15 million amperes. On the basis of present knowledge, this will not be quite big enough to reach ignition – the plasma heating systems will have to be left switched on all the time – but 50 MW of heating will generate about 500 MW of fusion power. In all other respects ITER will be a realistic test bed for a full size fusion reactor. There are also prospects that the reduced size ITER could get even closer to ignition if experiments to improve plasma confinement that are underway on JET and other tokamak experiments prove successful.

2.3. ITER

2.3.1. History

To understand the history of the ITER project, one has to go back to 1958. In Geneva that year, during the second international conference of the United Nations on the use of atomic energy for peaceful purposes, it was decided to declassify research into nuclear fusion by magnetic confinement, and international cooperation in this field was proposed. The European Community of that time, the Six, therefore included nuclear fusion in its research and development programme, with the collaboration of various laboratories. This was the starting point of the Euratom-CEA association for fusion in France.

The first ten years were naturally devoted to determining a suitable magnetic configuration. By 1968, in view of its performances, the tokamak configuration had shown itself to be the most promising. All the large fusion laboratories throughout the world started work in this direction. The beginning of the 70s thus saw the successive development, in France, of two machines based on this principle: TFR at Fontenay-aux-Roses and PETULA at Grenoble. Tokamaks were also built in all the major fusion laboratories in Europe, Japan, Russia and the USA.

A second generation of larger machines was built during the years '80s and many of them are still operational today. Apart from TFTR (USA, closed in 1997), it is worth mentioning JT-60 U (Japan), JET (Europe), the largest and most successful tokamak, and in Europe ASDEX-U, TORE SUPRA, FTU, COMPASS, and TEXTOR.

Current European research activities on fusion, co-ordinated by the Euratom programme are indicated in Figure 2.4.

The results were encouraging. Europe was already thinking ahead to the next generation tokamak aiming at ignition, NET. In November 1985, at the occasion of the Geneva summit conference, President Gorbachev suggested to Presidents Reagan and Mitterand [2] that the next machine be built in an international framework. As a consequence, the four great nations, the Soviet Union, the United States, Japan and the European Community decided to combine their efforts. Thus, under the auspices of the International Atomic Energy Agency (IAEA) the ITER project saw the light.

ITER first study phase, called the Conceptual Design Activities (CDA) started in April 1988 and was completed in December 1990. From its inception the ITER project was envisaged as the decisive step towards the realisation of fusion power. This was expressed in the Protocol of the next study phase – the Engineering design activities (EDA) signed in July 1992 – in which it is stated that: "*the overall programmatic objective of ITER, which shall guide the EDA, is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes. ITER would accomplish this objective by demonstrating controlled ignition and burn of deuterium-tritium plasmas, with steady-state as an ultimate goal, by demonstrating technologies essential to a reactor in an integrated system, and by performing integrated testing of the high-heat-flux and nuclear components required to utilize fusion energy for practical purposes.*" Within the EU and generally within the other parties, this objective has been taken to mean that ITER, together with some parallel activities in the field of materials development, would be the only step required to prepare for the construction of a demonstration power plant (DEMO).

In July 1998 the ITER design was completed, and prototypical models of the principal components had been manufactured and have since undergone testing, which is complete in some cases and is successfully ongoing in a few others. However the four parties prolonged the EDA phase and asked the project team to design a smaller machine, which would still fulfil the programmatic objective but would have reduced technical margins yielding a reduction to about half the original cost.

The ITER Council in Vienna in July 2001 accepted the Director's Final Report and concluded:

Upon completion of the ITER Engineering Design Activities, the ITER Council's final conclusions are as follows:

1. *The objectives of the ITER EDA Agreement have been fully met: the Parties have at their disposal a complete, detailed and mature design for ITER, with a supporting body of validating analysis and R&D and other technical information, which meets the detailed technical objectives and cost objectives set for it, including those relating to safety and environmental considerations.*

2. *The ITER co-operation has served to focus the fusion research efforts of the Parties to a common goal and has established a joint capability to undertake successfully tasks that might be beyond the financial or technical capacity of individual Parties.*

3. *ITER would enable, in a single device, full exploration of the physics issues as well as proof of principle and testing of key technological features of possible fusion power stations. It would provide the integration step necessary to establish scientific and technical feasibility of fusion as an energy source.*

In light of these conclusions, the ITER Council, recognising the social importance of the realization of fusion energy:

- *considers ITER as the essential tool to achieve this goal,*
- *affirms a shared single vision of ITER and of the means to realize it,*
- *considers that the fusion programme at the world level is now scientifically and technically ready to take the important ITER step, and*
- *reconfirms a common desire to promote construction of ITER through international co-operation.*

At a time of increasing global pressure on energy resources and global environmental concerns, the time is ripe to undertake the next step in the development of fusion energy. This will establish fusion as an option for large-scale energy supply with intrinsic safety and environmental benefits in the long term.

The ITER Council therefore recommends to the Parties to take the necessary steps to realise a Joint Implementation of ITER as the next step in the development of fusion as a source of energy for peaceful purposes.

2.3.2. ITER machine

ITER is an experimental fusion reactor based on the tokamak concept (Figure 2.6). The overall ITER plant comprises the tokamak, its auxiliaries and supporting plant facilities. In ITER sets of superconducting coils generate the magnetic configuration to confine and control the plasma in the vacuum vessel of the machine. They also induce an electrical current through it. Fusion power is produced by fusion reactions taking place in the plasma. Reaction rate is related to plasma temperature and density. To sustain the burn, the power associated with the helium nuclei generated in the reactions (20 % of the total fusion power) has to be sufficient to maintain plasma temperature at an adequate level.

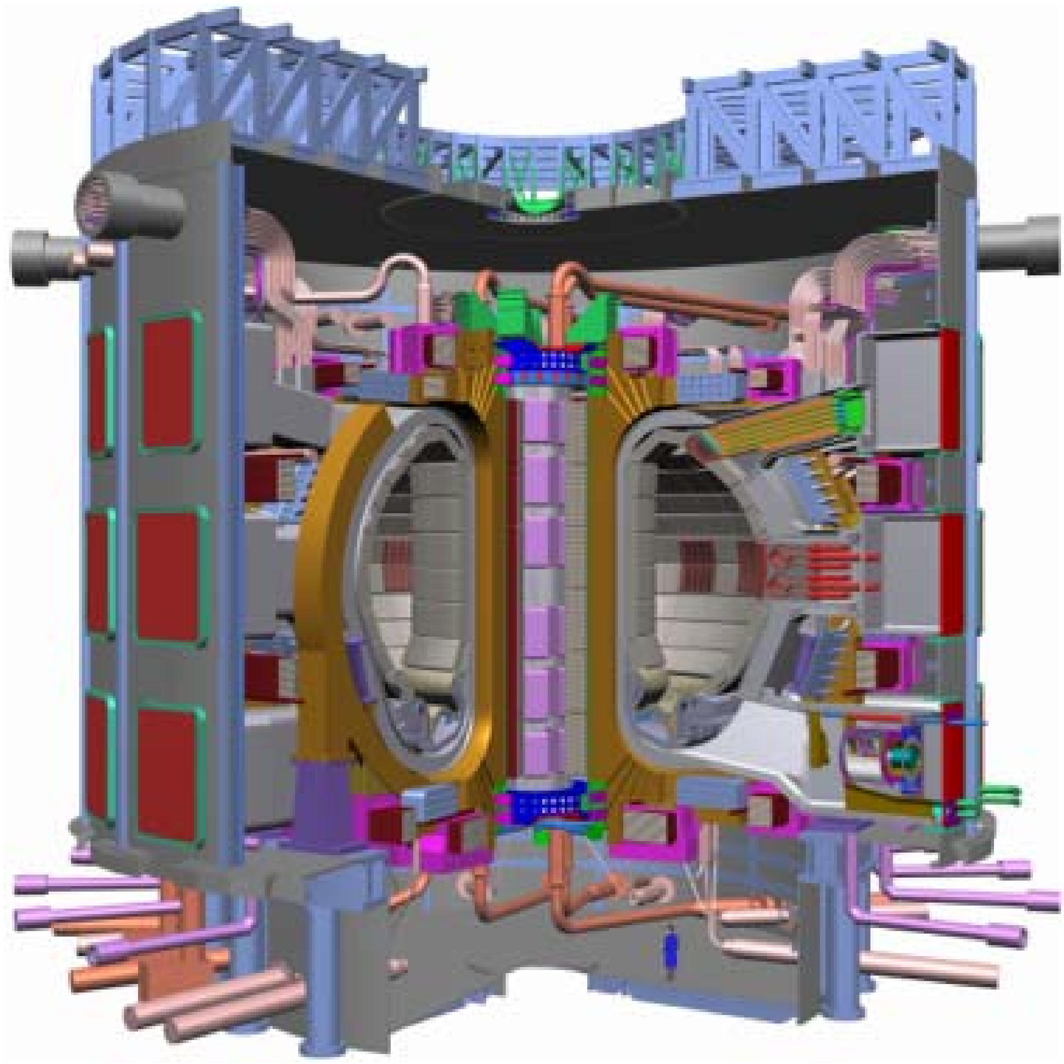

Figure 2.6: Cut of ITER Tokamak

To meet its objectives, ITER will be much bigger (twice linear dimensions) than the largest existing tokamak (JET) and its expected fusion performance will be many times greater, see Table 2.1. These extrapolations in size and physics performance provide the major challenges to the design of ITER. The design of the machine is such that it could be built on the territory of any of the Parties, with options to provide the capability for conducting experiments from remote centres throughout the participating countries.

Plasma Major Radius	R (m)	6.2
Plasma Minor Radius	A (m)	2
Toroidal Field on Axis	B_T (T)	5.3
Plasma Current	I_P (MA)	15
Fusion Power	P_{fusion} (MW)	410
Neutron Flux	$Flux_{Neutrons}$ (MW/m^2)	0.5
Power produced / Heating Power supplied	Q	10

Table 2.1: ITER Main Parameters

2.3.3. ITER organisation

The ITER project is a unique model for effective international collaboration in science and technology. The ITER Parties (European Union, Japan, Russian Federation) share the costs and benefits from the collaboration. Canada and Kazakhstan have also joined the project by associating respectively with Euratom and Russia. By pooling their resources and expertise and having access in common to all the information coming out of the work, the Parties realise much greater returns on their inputs to the project than they could do alone.

The ITER EDA has been conducted within the framework of an international agreement concluded under the auspices of the IAEA. The governments of the Parties are represented each by two members in the ITER Council whose seat is in Moscow. The ITER Council has responsibility for the overall direction of the EDA. It supervises its execution and reports to the Parties. The Council is assisted by Management and Technical Advisory Committees. Each Party delegates 3 members to the MAC, one of whom is the Home Team Leader. The MAC advises the Council on management and administrative matters, including finance, personnel and task assignment. The TAC, which advises the Council on technical matters, consists of up to four representatives per Party, acting in an individual capacity, chosen so that all the necessary areas of technical expertise are represented. The Council had the faculty to establish Special Working Groups or other ad hoc groups to undertake specific tasks.

The Director leads the Joint Central Team, which is located on the working sites at Garching and Naka. Until budget constraints forced the withdrawal of the US party, a third work site was maintained at San Diego. Each of the Parties maintains a Home Team, which performs specific design tasks and carries out validating R & D work. Each Home Team has a Leader who is responsible for the execution of these tasks. The Home Teams consist of a central technical-administrative organisation converting task agreements valued in "ITER credit" into contracts in real currency, and then placing these contracts in institutions and industry, which then also form part of the Home Team. The amount of credit each Party receives for the work is monitored to measure the contribution to the ITER design and R&D.

Following the end of the ITER EDA in July 2001, the project has entered an 18-month period of 'Co-ordinated Technical Activities', CTA, during which the principal role of the International Team will be the provision of information for the preparation of one or more site-specific design adaptations. This will be followed by the Construction, Operation, Exploitation and Decommissioning Activities (COEDA), planned to start in 2003. As these changes occur, a significantly different organisational structure will be required for the project. The central role will be taken by the 'ITER Legal Entity (ILE)', the remit and organisation of which will be formally defined by a new international agreement.

2.4. ITER schedule

The planning schedule for procurement, construction/assembly, commissioning and decommissioning depends on a number of assumptions. As the negotiations toward the joint implementation of ITER progress, decisions reached by the Parties may confirm or alter the assumptions that have led to its present status. The actual plan will therefore depend on the licensing procedure, as well as the organization and arrangements that will be put in place for the procurement/construction commissioning [3].

2.4.1. ITER construction

The ITER joint Implementation Agreement is expected to be signed during 2003 following formal negotiations. The ITER Legal Entity (ILE) will be established after ratification of the agreement within each Party. This organisation will start the formal regulatory procedure and procurement process for the long lead-time items. The regulatory approval process, however, will remain speculative until a site is formally selected. If the site proposals are received before or at a sufficiently early stage of negotiations, it will be possible to assess the time needed for licensing in the various possible host Parties and the effects on the overall schedule. Since the start of the actual construction on the site depends upon when the licence to construct is issued by the regulatory authority, dates in the construction and commissioning plan are, therefore, measured in months from a start date ("T = 0") defined as the date at which the actual construction work of excavation for the tokamak buildings is started.

Furthermore, the following assumptions pertain at t = 0.

- Informal dialogue with regulatory authorities should be established and should orient the technical preparation toward a licence application with a view to solving the major technical issues prior to the establishment of the ILE. Documents required for the formal regulatory process are assumed to be prepared before the ILE exists, so as to allow the ILE to begin the formal regulatory process immediately after its establishment or to benefit from an already launched process.
- Procurement specification of equipment/material for the longest lead-time items and critical buildings are assumed to be finalised during the co-ordinated technical activities (CTA).
- Procurement sharing is assumed to be agreed among the Parties during the CTA so as to permit the placing of all contracts at the appropriate time.
- The construction site work starts immediately at T = 0. It is assumed that site preparation has been started sufficiently early by the host Party so as not to place constraints on the start of construction.

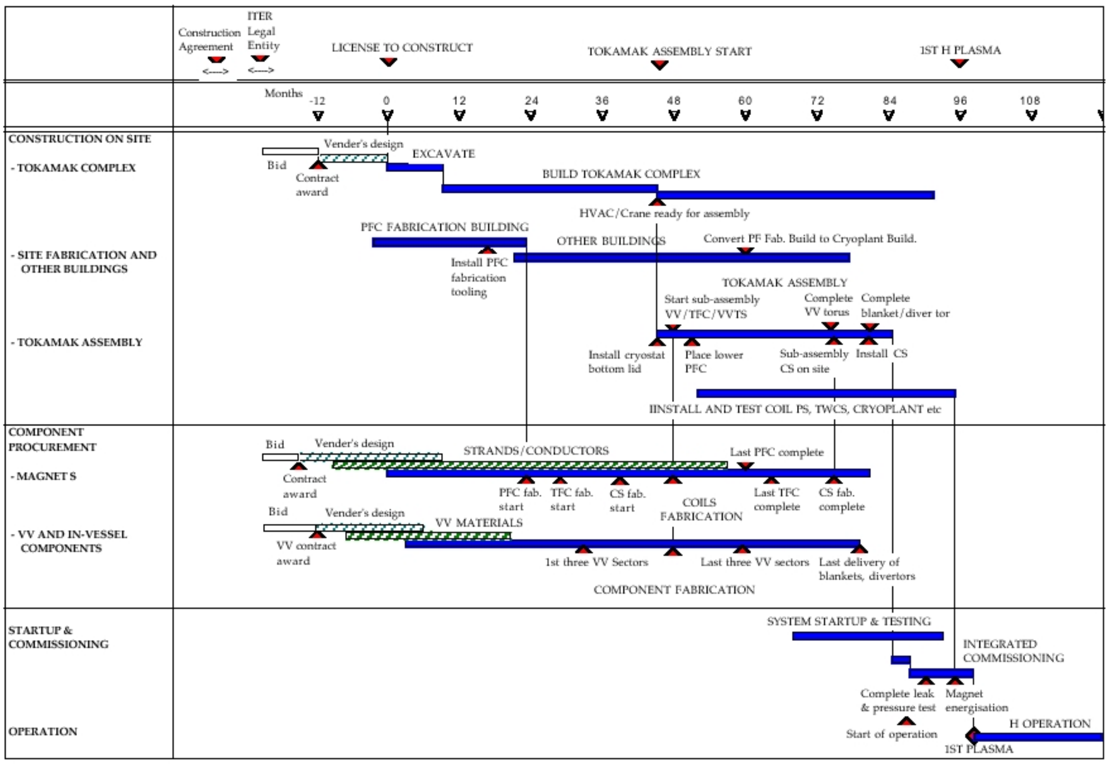

Figure 2.7: Overall Schedule up to First Plasma

See Chapter 6 for the European schedule. The overall schedule that leads up to the first hydrogen plasma operation is shown in Figure 2.7. It represents a reference scenario for the schedule of procurement, construction, assembly and commissioning of ITER. The detailed construction schedule is developed to correspond to each procurement package specified for the cost estimate. The schedule for each package includes procurement specification preparation, bid process, vendor's design (if appropriate), manufacturing (if appropriate), transport to site (if appropriate), installation and commissioning.

2.4.2. ITER operation

As an experimental device, ITER is required to be able to cope with various operation scenarios and configurations. Variants of the nominal scenario are therefore considered for extended duration plasma operation, and/or steady state modes with a lower plasma current operation, with H, D, DT (and He) plasmas, potential operating regimes for different confinement modes, and different fuelling and particle control modes. Flexible plasma control should allow the accommodation of "advanced" plasma operation based on active control of plasma profiles by current drive or other non-inductive means.

Four reference scenarios are identified for design purposes. Three alternative scenarios are specified for assessment purposes to investigate how plasma operations will be possible within the envelope of the machine operational capability assuming a reduction of other concurrent requirements (e.g. pulse length).

2.4.2.1. Scenarios foreseen during operation

Design scenarios

- **Inductive operation I**: P_{fus} = 500 MW, Q = 10, I_p = 15 MA, *with* plasma heating during current ramp-up. Q is the ratio between fusion power produced and heating power applied.
- **Inductive operation II**: P_{fus} = 400 MW, Q = 10, I_p = 15 MA, *without* heating during current ramp-up.
- **Hybrid operation** (i.e. plasma current driven simultaneously by inductive and non-inductive means) to produce longer duration pulsed plasmas.
- **Non-inductive operation type I**: weak negative shear (WNS) operation to explore the so-called advanced regimes.

Assessed scenarios

- Inductive operation III: P_{fus} =700 MW, I_p =17 MA, with heating during current ramp-up
- Non-inductive operation type II: strong negative shear (SNS) operation
- Non-inductive operation type III: weak positive shear (WPS) operation

2.4.2.2. Successive phases of operation

During its lifetime, ITER will be operated in successive phases.

H Phase

This is a non-nuclear phase using only hydrogen or helium plasmas, planned mainly for complete commissioning of the tokamak system in a non-nuclear environment where remote handling maintenance is not mandatory. The discharge scenario of the full DT phase reference operation can be developed or simulated in this phase. The peak heat flux onto the divertor target will be of the same order of magnitude as for the full DT phase. Characteristics of electromagnetic loads due to disruptions or vertical displacement events, and heat loads due to runaway electrons, will be basically the same as those of the DT phase.

Some important technical issues cannot be fully tested in this phase because of smaller plasma thermal energy content and lack of neutrons and energetic alpha particles. The actual length of the hydrogen operation phase will depend on the merit of this phase with regard to its impact on the later full DT operation, in particular on the ability to achieve good H mode confinement with a suitably high plasma density.

D Phase

The characteristics of deuterium plasma are very similar to those of DT plasma except for the amount of alpha heating. Therefore, the reference DT operational scenarios, i.e., high Q, inductive operation and non-inductive steady state operation, can be simulated further. Since some tritium will be generated in the plasma, fusion power production for short periods of time without fully implementing the cooling and tritium-recycle systems could therefore also be demonstrated. By using limited amounts of tritium in a deuterium plasma, the integrated nuclear commissioning of the device will be possible. In particular, the shielding performance will be tested.

DT Phases

During the first phase of DT operation the fusion power and burn pulse length will be gradually increased until the inductive operational goal is reached. Non-inductive, steady state operation will also be developed. DEMO reactor relevant test blanket modules will also be tested whenever significant neutron fluxes will be available, and a reference mode of operation for that testing will be established.

The second phase of full DT operation, beginning after a total of about ten years of previous operation, will emphasise improvement of the overall performance and the testing of components and materials with a higher neutron fluence. This phase will address the issues of higher availability and further improved modes of plasma operation. The implementation and the programme for this phase will be decided following a review of the results from the preceding three operational phases and an assessment of the merits and priorities of programmatic proposals.

A decision on incorporating in the vessel a tritium breeding blanket during the course of the second DT phase will be taken on the basis of the availability of this fuel from external sources, its relative cost, the results of breeder blanket module testing, and acquired experience with plasma and machine performance.

2.4.3. ITER decommissioning

It is assumed that the ITER organization at the end of operation will be responsible for starting the machine decommissioning through a de-activation period after which the facility will be handed over to a new organization inside the ITER host country.

During the first phase, the machine will, immediately after shutdown, be de-activated and cleaned by removing tritium from the in-vessel components and any removable dust. Also, any liquid used in the ITER machine systems will be removed (no component cooling will be further required) and processed to remove activation products prior to their disposal. De-activation will include the removal and safe disposal of all the in-vessel components and, possibly, the ex-vessel components. The main vacuum vessel may be prepared for dismantling by the cutting of the inner vessel wall. The ITER de-activation will also provide corrosion protection, for components that are vulnerable to corrosion during the storage and dismantling period, if such corrosion would lead to a spread of contamination, or present unacceptable hazards to the public or workers. These activities will be carried out by the ITER organization using the remote handling facilities and staff existing at the end of operation. At the end of phase 1, the ITER facility will be handed over to the organization inside the host country that will be responsible for the subsequent phase of decommissioning after a dormant period for radioactive decay.

2.5. ITER site requirements and assumptions

This list of requirements and assumptions was specified by ITER in October 1999 [4]. The version of the Plant Design Specification (PDS) published in July 2001 has the same list of requirements and assumptions [5].

2.5.1. Introduction

A set of site requirements that are compulsory for the ITER site has been defined, supplemented by design assumptions about the ITER site, which are used for design and cost estimates until the actual ITER site is known. Section 1 contains the principles for the development of the site requirements and site design assumptions. Section 2 contains the compulsory requirements, which are derived from the ITER design and the demands it makes on any site. Section 3 contains site design assumptions, which are characteristics of the site assumed to exist so that designers can design buildings, structures and equipment that are site sensitive.

Both the Site Requirements and the Site Design Assumptions are organized in the following categories:

- Land
- Heat Sink
- Energy and Electrical Power
- Transport and Shipping
- External Hazards and Accident Initiators
- Infrastructure
- Regulations and Decommissioning

Each of the categories is subdivided into related elements. Some of the categories are broadly defined. For instance, Infrastructure includes personnel, scientific and engineering resources, manufacturing capacity and materials for construction and operation. Requirements and assumptions for the various elements are justified in the **Bases** statements. These statements explain the rationale for their inclusion and provide a perspective in which they may be used.

2.5.2. Principles for site requirements and site design assumptions

The compulsory site requirements are based on the ITER site layout and plant design. These requirements are firm in the sense that reasonable reconfiguration of the plant design will not result in a less demanding set of requirements. Some of the site requirements are based in part on how the plant and some of its major components, such as the vacuum vessel and the magnet coils, will be fabricated and installed.

The assumptions that have been made to carry out the ITER design until a decision on localisation is reached are also addressed. These site design assumptions form some of the bases for the ITER construction cost estimate and schedule. The assumptions are not compulsory site requirements, but are guidelines for designers to follow until the actual site is known.

The requirements for public safety and environmental considerations are, by their nature, site sensitive. Also, the regulatory requirements for localisation, construction, operating and decommissioning ITER are likely to be somewhat different for each potential host country. Therefore, the Safety Contact Persons, designated by each potential Host Country, will help the Project Team to consider any particular requirements that localisation in their own country would impose. Until that time, the ITER plant will be designed to a set of safety and environmental assumptions contained in the ITER Plant Specifications, which are expected to approximate the actual requirements. Site sensitive considerations during operation such as the shipment of radioactive materials including tritium to the site, the temporary storage of wastes on the site, the shipment of wastes from the site and of the effluents from ITER during normal and off-normal operation, are addressed with the design analysis. Accordingly, a Generic Site Safety Report will be available as a firm basis on which the Site Safety Report will later be established to satisfy the licensing authorities of the Host Country.

The decommissioning phase of the ITER plant deserves special attention. In the absence of firm guidance and without prejudice to future negotiations of the Parties, it is assumed that the organisation in charge of operating ITER will have a final responsibility to "deactivate" the plant. In this context, "deactivation" is the first phase of decommissioning and includes all actions to shut down the ITER plant and place it in a safe, stable condition. The dismantling phase of decommissioning, which might take place decades after the "deactivation" phase, is assumed to become the responsibility of a new organisation within the host country. A technical report on the strategy of deactivation and dismantling will be included inside the design report documentation.

In conclusion the site design assumptions are very important, because without them progress is very limited for the site sensitive design of buildings, power supplies, site layout and safety/environmental studies. These assumptions were selected so that the design would not be significantly invalidated by actual site deviations from the assumptions. Deviations from the site design assumptions by the actual ITER site may require design and/or construction modifications, but these modifications are expected to be feasible. The modifications may determine the need for a revision of the cost estimate and construction schedule.

2.5.3. Site requirements

A. Land

1. Land area **(SR.A1)**

Requirement: The ITER site shall be up to 40 hectares in area enclosed within a perimeter. All structures and improvements within the perimeter are the responsibility of the ITER project. Land within the perimeter must be committed to ITER use for a period of at least 30 years.

Bases: The minimum area for the ITER site is predicted on the basis of providing sufficient area for the buildings, structures and equipment with allowances for expansion of certain buildings if required for an extension of the ITER programme.

The time period is specified to cover the construction (~10 years) and operations (~20 years) phases. Beyond that, the requirements for any decommissioning will be the responsibility of the Host Country.

2. Geotechnical Characteristics **(SR.A2)**

Requirement: The ITER Site shall have foundation soil-bearing capacity adequate for building loads of at least 25 t/m² at locations where buildings are to be built. Nevertheless, it is expected that it will be possible to provide at the specific location of the Tokamak Building means to support the average load of 65 t/m² at a depth of 25 m. The soil (to a depth of 25 m) shall not have unstable surrounding ground features. The building sites shall not be susceptible to significant subsidence and differential settlement.

Bases: The ITER Tokamak is composed of large, massive components that must ultimately be supported by the basemat of the structures that house them. Therefore soil-bearing capacity and stability under loads are critical requirements for an acceptable site. The Tokamak Building is composed of three independent halls on separate basemats, but served by the same set of large, overhead bridge cranes. Crane operation would be adversely affected by significant subsidence and differential settlement.

3. Water Supply **(SR.A3)**

Requirement: The ITER site host shall provide a continuous fresh water supply of 0.2 m^3/minute average and 3 m^3/minute peak consumption rates. The average daily consumption is estimated to be about 200 m^3. This water supply shall require no treatment or processing for uses such as potable water and water makeup to the plant de-mineralised water system and other systems with low losses.

Bases: The ITER plant and its support facilities will require a reliable source of high quality water. The peak rate of 3 m^3/minute is specified to deal with conditions such as leakage or fires. This water supply is not used for the cooling towers or other uses which may be satisfied by lower quality, "raw" water.

4. Sanitary and Industrial Sewage **(SR.A4)**

Requirement: The ITER site host shall provide sanitary waste capacity for a peak ITER site population of 1000. The host shall also provide industrial sewage capacity for an average of 200 m^3/day.

Bases: The ITER project will provide sewer lines to the site perimeter for connection to the sewer service provided by the host. The peak industrial sewage rate is expected to be adequate to deal with conditions such as leaks and drainage of industrial sewage stored in tanks until it can be analysed for release. Rainwater runoff is not included in industrial sewage.

B. Heat Sink **(SR.B)**

Requirement: The ITER Site shall have the capability to dissipate, on average, 450 MW (thermal) energy to the environment.

Bases: ITER and its associated equipment may develop heat loads as high as 1200 MW (thermal) for pulse periods of the order of 500 s. The capability to dissipate 1200 MW should be possible for steady-state operation, which is assumed to be continuous full power for one hour.

Duty Cycle requirements for the heat sink at peak loads will not exceed 30 %. The average heat load would be no more than 450 MW for periods of 3 to 6 days.

***C. Energy and Electrical Power* (SR.C)**

ITER Plant Steady State Electrical Loads

Requirement: The ITER Site shall have the capability to draw from the grid 120 MW of continuous electrical power. Power should not be interrupted because of connection maintenance. At least two connections should be provided from the supply grid to the site.

Bases: The ITER Plant has a number of systems, which require a steady-state supply of electrical power to operate the plant. It is not acceptable to interrupt this power supply for the maintenance of transmission lines, therefore the offsite transmission lines must be arranged such that scheduled line maintenance will not cause interruption of service. This requirement is based on the operational needs of the ITER Plant.

Maintenance loads are considerably lower than the peak value because heavy loads such as the tokamak heat transfer and heat rejection systems will operate only during preparations for and actual pulsed operation of the tokamak.

D. Transport and Shipping

1. Maximum size of Components to be shipped **(SR.D1)**

Requirement: The ITER Site shall be capable of receiving shipments for components having maximum dimensions (not simultaneously) of about:

- Width 9 m
- Height 8 m
- Length 15 m

Bases: In order to fabricate the maximum number of components, such as magnet coils and large transformers, off site, the ITER site must have the capability of receiving large shipments. For the reference case, it is assumed that only the Poloidal Field Coils will be manufactured on site, unless the possibility of transporting and shipping these large coils is proven feasible. For the same reason, it is also assumed that the CS will be assembled on site from six modules, unless it proves feasible that the assembly may be supplied as one large and complete unit. The cryostat will be assembled on site from smaller delivered parts. The width is the most critical maximum dimension and it is set by the Toroidal Field Coils, which are about 9 m wide. The height is the next most critical dimension, which is set by the 40° Vacuum Vessel Sector. A length of 15 m is required for the TF coils. The following table shows the largest (~100 t or more) ITER components to be shipped:

Component	Pkgs	Width (m)	Length (m)	Height (m)	Weight (t)
TF Coils	18	9	14.3	3.8	280
VV 40° sector	9	8	12	8	575
CS Modules	6	4.2	4.2	1.9	100
Large HV transformer	3	4	12	5	250
Crane Trolley Structure[2]	2	(14)	(18)	(6)	(600)

PF1	1	9.5	9.5	2.4	200
PF2	1	18.5	18.5	1.9	200
PF3	1	25.5	25.5	1.2	300
PF4	1	26.0	26.0	1.2	450
PF5	1	18.2	18.2	2.4	350
PF6	1	10.8	10.8	2.4	300
CS Assembly	1	4.2	18.8	4.2	850

Note that transportation and shipping of the PF Coils and of the CS Assembly are not requirements, but could be considered an advantage. Note too, that the PF Coils dimensions are for the coil and connection box envelope, and that for each coil there are vertical protrusions of ~1.5-1.8 m for the terminals.

2. Maximum Weight of shipments **(SR.D2)**

Requirement: The ITER Site shall be capable of receiving about a dozen components (packages) having a maximum weight of 600 t and approximately 100 packages with weight between 100 and 600 t each.

Bases: In order to fabricate the maximum number of components, including magnet coils, off site, the ITER site must have the capability of receiving very heavy shipments. The single heaviest component (Vacuum Vessel Sector) is not expected to exceed 600 t. All other components are expected to weigh less.

E. External Hazards and Accident Initiators

No compulsory requirements

F. Infrastructure

No compulsory requirements

***G. Regulations and Decommissioning* (SR.G)**

[2] Crane dimensions and weight are preliminary estimates

Details of the regulatory framework for ITER will depend on the Host Country. At a minimum, the Host's regulatory system must provide a practicable licensing framework to permit ITER to be built and to operate, taking into account, in particular, the following off-site matters:

1. The transport of kilograms of tritium during the course of ITER operations;

2. The acceptance and safe storage of activated material in the order of thousands of tonnes, arising from operation and decommissioning.

The agreement with the Host should provide for the issue of the liability for matters beyond the capacity of the project that may arise from ITER construction, operation and decommissioning.

2.5.4. Site design assumptions

The following assumptions have been made concerning the ITER site. These site design assumptions are uniformly applied to all design work until the actual ITER site is selected.

A. Land

1. Land Area **(SA.A1)**

Assumption: During the construction it will be necessary to have temporary use of an additional 30 hectares of land adjacent to or reasonably close to the compulsory land area. It is assumed this land is available for construction laydown, field engineering, pre-assembly, concrete batch plant, excavation spoils and other construction activities.

During operating phases, this land should be available for interim waste storage, heavy equipment storage and activities related to the maintenance or improvement of the ITER plant.

Bases: The assumptions made for the cost and schedule estimates are based on construction experience that uses an additional area of 25 hectares. Only a very limited amount of vehicle parking space (5 hectares) is allocated to the compulsory area, whereas a similar amount will be required to satisfy temporary needs during construction.

2. Topography **(SA.A2)**

Assumption: The ITER site is assumed to be a topographically "balanced" site. This means that the volumes of soil cuts and fills are approximately equal over the compulsory land area in Requirement A.1. The maximum elevation change for the "balanced" site is less than 10 m about the mean elevation over the land area in the compulsory requirement.

3. Geotechnical Characteristics **(SA.A3)**

Assumption: The soil surface layer at the ITER Site is thick enough not to require removal of underlying hard rock, if present, for building excavations, except in the area under the Tokamak Building itself, at an excavation of about 25 m.

4. Hydrological Characteristics **(SA.A4)**

Assumption: Ground water is assumed to be present at 10 m below nominal grade, well above the tokamak building embedment of up to 25 m below nominal grade. This assumption will require engineered ground water control during the construction of the tokamak building pit.

5. Seismic Characteristics **(SA.A5)**

Assumption: Using the IAEA seismic classification levels of SL-2, SL-1, and SL-0 and the assumed seismic hazard curves, the following seismic specifications are derived:

IAEA level	Return Period (years)	Peak Ground Acc.[3]
SL-2 50% tile	10^4	0.2
SL-1 50% tile	10^2	0.05
SL-0	short[4]	0.05

Bases: Safety assessments of external accident initiators for facilities, particularly when framed in a probabilistic risk approach, may be dominated by seismic events. Assumed seismic hazard curves are used in a probabilistic approach which is consistent with IAEA recommendations for classification as a function of return period. The selection of the assumed seismic hazard curve is relevant to regions of low to moderate seismic activity. Prior to site selection, specification of the peak horizontal and vertical ground acceleration provide the ITER designers guidelines according to the methodology to be used for seismic analysis, which will rely on a specified Ground Motion Design Response Spectrum and a superposition of modal responses of the structures (according to NRC recommendations). After site selection the actual seismic specifications will be used to adjust the design, in particular by adding seismic isolation, if necessary.

6. Meteorological Characteristics **(SA.A6)**

Assumption: A general set of meteorological conditions are assumed for design of buildings, civil structures and outdoor equipment, as follows:

[3] Peak Ground Acceleration is for both horizontal and vertical components in units of the gravitational acceleration, g

[4] The seismic specifications are not derived probabilistically – local (uniform) building codes are applied to this class. A peak value of 0.05 g is assumed equal to the SL-1 peak value

- Maximum Steady, Horizontal Wind ≤ 140 km/h (at 10 m elevation)
- Maximum Air Temperature ≤ 35 °C (24 hr average ≤ 30 °C)
- Minimum Air Temperature ≥ -25 °C (24 hr average ≥ -15 °C)
- Maximum Rel. Humidity (24 hr average) ≤ 95 % (corresponding vapour pressure ≤ 22 mbar)
- Maximum Rel. Humidity (30 day average) ≤ 90 % (corresponding vapour pressure ≤ 18 mbar)
- Barometric Pressure: Sea Level to 500 m
- Maximum Snow Load: 150 kg/m²
- Maximum Icing: 10 mm
- Maximum 24 hr Rainfall: 20 cm
- Maximum 1 hr Rainfall: 5 cm
- Heavy Air Pollution (Level 3 according to IEC 71-2[5])

Bases: The assumed meteorological data are used as design inputs. These data do not comprise a complete set, but rather the extremes, which are likely to define structural or equipment limits. If intermediate meteorological data are required, the designer estimates these data based on the extremes listed above. Steady winds apply a static load on all buildings and outdoor equipment.

***B. Heat Sink: Water Supply for the Heat Rejection System* (SA.B)**

Assumption: The JCT has selected forced draft (mechanical) cooling towers as a design solution until the ITER site is selected. At 30 % pulse duty cycle (450 MW average heat rejection) the total fresh ("raw") water requirement is about 16 m³/minute. This water makes up evaporative losses and provides replacement for blow down used to reduce the accumulation of dissolved and particulate contaminants in the circulating water system. During periods of no pulsing the water requirement would drop to about 5 m³/minute. Each blow down action will lead to a peak industrial sewage rate of 3000 m³/day.

Bases: The actual ITER Site could use a number of different methods to provide the heat sink for ITER, but for the purposes of the site non-specific design, the induced draft (mechanical) cooling towers have been assumed. These cooling towers require significant quantities of fresh water ("raw") for their operation. For 450 MW average dissipation, approximately 16 m³/minute of the water is lost by evaporation and drift of water droplets entrained in the air plume, and by blow down. This water also supplies make up to the storage tanks for the fire protection system after the initial water inventory is depleted. Cooling towers may not be suitable for an ITER site on a seacoast or near a large, cool body of fresh water. Therefore open cycle cooling will be considered as a design option.

C. Energy and Electrical Power

1. Electrical Power Reliability during Operation **(SA.C1)**

[5] Insulation Co-ordination part 2 Application guide, Provisional Scale of Natural Pollution Levels

Assumption: The grid supply to the Steady State and to the Pulsed switchyards is assumed to have the following characteristics with respect to reliability:

Single Phase Faults	a few tens/year 80%: t < 1 s a few / year 20%: 1 s < t < 5 min where t = duration of fault
Three Phase Faults	a few/year

Bases: ITER power supplies have a direct bearing on equipment availability, which is required for tokamak operation. If operation of support systems such as the cryoplant, TF coil supplies and other key equipment are interrupted by frequent or extended power outages, the time required to recover to normal operating conditions is so lengthy that availability goals for the tokamak may not be achieved. Emergency power supplies are based on these power reliability and operational assumptions.

2. *ITER Plant Pulsed Electrical Supply* **(SA.C2)**

Assumption: A high voltage line supplies the ITER "pulsed loads". The following table shows the "pulsed load" parameters for the ITER Site:

Characteristic	Values
Peak Active Power[6, 7]	500 MW
Peak Reactive Power	400 Mvar
Power Derivative[7]	200 MW/s
Power Steps[7]	60 MW
Fault Level	10–25 GVA
Pulse Repetition time	1800 s
Pulsed Power Duration[8]	1000 s

Bases: The peak active power, the peak reactive power and the power steps quoted above are evaluated from scenarios under study. Occasional power steps are present in the power waveform. The supply line for pulsed operation will demand a very "stiff" node on the grid to meet the assumption.

D. Transport and Shipping

[6] From which up to 400 MW is a quasi-steady-state load during the sustained burn phase, while the remaining 80 to 120 MW has essentially pulse character for plasma shape control with maximum pulse duration of 5 to 10 s and energy content in the range of 250 to 500 MJ.
[7] These power parameters are to be considered both positive and negative. Positive refers to power from the grid, while negative refers to power to the grid. Power variations will remain within the limits given above for the maximum power and for the power derivatives.
[8] The capability to increase the pulse power duration to 3600 s is also assumed, in which case the repetition time would increase accordingly to maintain the same duty factor.

Bases: Several modes of transport and shipping are assumed for ITER because the diversity of these modes provides protection against disruptions for timely delivery of materials and equipment needed by the project. The assumptions for transport and shipping are based on some general considerations, which are common for all modes.

When the assumptions describe the site as having "access" to a mode of transport or shipping, it means that the site is not so far away from the transport that the assumed mode would be impractical. Air transport is a good example, because if the airport is not within reasonable commuting time, the time advantage of this mode would be lost (i.e. it would become impractical).

1. Highway Transport **(SA.D1)**

Assumption: The ITER Site is accessible by a major highway, which connects to major ports of entry and other centres of commerce.

2. Air Transport **(SA.D2)**

Assumption: The ITER Site is located within reasonable commuting time from an airport with connections to international air service.

3. Rail and Waterway Transport **(SA.D3)**

Assumption: It is assumed the ITER site will have rail and waterway access. The railway is assumed to connect to major manufacturing centres and ports of entry.

E. External Hazards and Accident Initiators

1. External Hazards **(SA.E1)**

Assumption: It is assumed the ITER Site is not subject to significant industrial and other man-made hazards.

Bases: External hazards, if present at the ITER site, must be recognised in safety, operational and environmental analyses. If these hazards present a significant risk, mitigating actions must be taken to ensure acceptable levels of public safety and financial risk.

2. External (Natural) Accident Initiators **(SA.E2)**

Assumption: It is assumed the ITER Site is not subject to horizontal winds greater than 140 km/hr (at an elevation of 10 m) or tornadic winds greater than 200 km/hr. The ITER Site is not subject to flooding from streams, rivers, sea water inundation, or sudden runoff from heavy rainfall or snow/ice melting (flash flood). All other external accident initiators except seismic events are assumed below regulatory consideration.

Bases: The wind speeds specified in this requirement are typical of a low to moderate risk site. Tornadic winds apply dynamic loads of short duration to buildings and outdoor equipment by propelling objects at high speeds creating an impact instead of a steady load. The design engineer uses the tornadic wind speed in modelling a design basis projectile, which is assumed to be propelled by the tornado. This design basis is important for buildings and structures that must contain hazardous or radioactive materials or must protect equipment with a critical safety function.

ITER is an electrically intensive plant, which would complicate recovery from flooded conditions. This assumption does not address heavy rainfall or water accumulation that can be diverted by typical storm water mitigation systems. For the purposes of this assumption, accidents involving fire, flooding and other initiators originating within the ITER plant or its support facilities are not considered external accident initiators.

F. Infrastructure

Bases: The ITER Project is sufficiently large and extended in duration that infrastructure will have a significant impact on the outcome. Industrial, workforce and socio-economic infrastructure assumptions are not quantitatively stated because there are a variety of ways these needs can be met. The assumptions are fulfilled if the actual ITER site and its surrounding region already meets the infrastructure needs for a plant with similar technical, material and schedule needs as ITER requires.

1. Industrial **(SA.F1)**

Assumption: It is assumed the ITER Site has access to the industrial infrastructure that would typically be required to build and operate a large, complex industrial plant. Industrial infrastructure includes scientific and engineering resources, manufacturing capacity and materials for construction. It is assumed the ITER Site location does not adversely impact the construction cost and time period nor does it slow down operation. The following are examples of the specific infrastructure items assumed to be available in the region of the site:

- Unskilled and skilled construction labour
- Facilities or space for temporary construction labour
- Fire Protection Station to supplement on-site fire brigade
- Medical facilities for emergency and health care
- Contractors for site engineering and scientific services
- Bulk concrete materials (cement, sand, aggregate)
- Bulk steel (rebar, beams, trusses)
- Materials for concrete forms
- Construction heavy equipment
- Off-site hazardous waste storage and disposal facilities
- Industrial solid waste disposal facilities
- Off-site laboratories for non-radioactive sample analysis

Bases: Efficiency during construction and operation of a large, complex industrial facility varies significantly depending on the relative accessibility of industrial infrastructure. Accessibility to infrastructure can be demonstrated by comparable plants operating in the general region of the site.

2. Workforce **(SA.F2)**

Assumption: It is assumed that a competent operating and scientific workforce for the ITER Plant can be recruited from neighbouring communities or the workforce can be recruited elsewhere and relocated to the neighbouring communities.

It is also assumed that ITER has the capability for conducting experiments from remote locations elsewhere in the world. These remote locations would enable "real-time" interaction in the conduct of the experiments, while retaining machine control and safety responsibilities at the ITER Site Control Facility.

Bases: The workforce to operate, maintain and support ITER will require several hundred workers. The scientific workforce to conduct the ITER experimental program will also require several hundred scientists and engineers. The assumption that these workers and scientist/engineers come from neighbouring communities is consistent with the site layout plans, which have no provisions for on-site dormitories or other housing for plant personnel.

A significant scientific workforce must be located at the ITER Site as indicated in the Assumptions. However, this staff can be greatly augmented and the experimental value of ITER can be significantly enhanced if remote experimental capability is provided. The result of the remote experiment is that scientific staffs around the world could participate in the scientific exploitation of ITER without the necessity of relocation to the ITER Site. Remote experimental capability is judged to be feasible by the time of ITER operation because of advances in the speed and volume of electronic data transfers that are foreseen in the near future.

3. Socio-economic Infrastructure **(SA.F3)**

Assumption: The ITER Site is assumed to have neighbouring communities, which provide socio-economic infrastructure. Neighbouring communities are assumed to be not greater than 50 km from the site, or one hour travel. Examples of socio-economic infrastructure are described in the following list:

- Dwellings (Homes, Apartments, Dormitories)
- International Schools from Kindergarten to Secondary School
- Hospitals and Clinics
- Job Opportunities for Spouses and other Relatives of ITER workers
- Cultural life in a cosmopolitan environment

Bases: Over the life of the ITER plant, thousands of workers, scientists, engineers and their families will relocate temporarily or permanently to the communities surrounding the ITER site. These people could comprise all the nationalities represented by the Parties. This "world" community will present special challenges and opportunities to the host site communities.

To attract a competent international workforce, international schools should be provided. Teaching should be partially in the mother tongue following programmes, which are compatible with schools in each student's country of origin. All parties should assist with the international schools serving these students.

The list of examples is not intended to be complete but it does illustrate the features considered most important. The assumed 50 km distance should maintain reasonable commuting times less than one hour for workers and their relatives.

G. Regulations and Decommissioning

1. General Decommissioning **(SA.G1)**

Assumption: During the first phase of decommissioning, the ITER operations organization places the plant in a safe, stable condition. Dismantling may take place decades after the "deactivation" phase. Dismantling of ITER is assumed to be the responsibility of a new organization within the host country. The ITER operations organization will provide the new organization all records, "as-built prints", information and equipment pertinent to decommissioning. Plant characterization will also be provided for dismantling purposes after "deactivation".

Bases: Experience and international guidelines (IAEA Safety Series No. 74, 1986, "Safety in Decommissioning of Research Reactors") stress the importance of good record keeping by the operations organization as a key to decommissioning success.

2. ITER Plant "Deactivation" Scope of Work **(SA.G2)**

Assumption: The ITER operations organization will develop a plan to put the plant in a safe, stable condition while it awaits dismantling.

Residual tritium present at the end of ITER operations will be stabilised or recovered to secure storage and/or shipping containers. Residual mobile activation products and hazardous materials present at the end of ITER operations will be stabilised or recovered to secure storage and/or shipping containers such that they can be shipped to a repository as soon as practical.

ITER deactivation will include the removal of in-vessel components and their packaging in view of long-term storage. This removal from the vacuum vessel will be done by personnel and remote handling tools, trained for maintenance during the previous normal operation.

Liquids used in ITER systems may contain activation products, which must be removed before they can be released to the environment or solidified as waste. It is assumed that all liquids will be rendered to a safe, stable form during the "deactivation" phase, and afterwards no more cooling will be necessary.

ITER "deactivation" will provide corrosion protection for components, which are vulnerable to corrosion during the storage and dismantling period, if such corrosion would lead to spread of contamination or present unacceptable hazards to the public or workers.

Bases: It is recommended (IAEA Safety Series No. 74, 1986) that all radioactive materials be rendered into a safe and stable condition as soon as practical after the cessation of operations.

***H. Construction Phase* (SA.H)**

General requirements for the construction phase (except land) are very dependent on local practice. However, water, sewage and power supplies need to be provided at the site for a construction workforce of up to 3000 people.

References

[1] "ITER Physics Basis", Nuclear fusion, vol. 39, n°12 (1999), pp. 2137-2638

[2] IAEA Bulletin 374, T J Dolan, D P Jackson, B A Kouvshinnikov, D L Banner, "Global co-operation in nuclear fusion: Record of steady progress"

[3] Extracts from "Summary of the ITER Final Design Report", May 2001, section 8

[4] ITER Site Requirements and ITER Site Design Assumptions, N CL RI 3 99-10-19 W 0.2

[5] Plant Design Specification, chapter 4, G A0 SP 2 01-06-01 R 2.0