ITER EDA DOCUMENTATION SERIES NO. 21

International Thermonuclear Experimental Reactor
(ITER)

Engineering Design Activities
(EDA)

FINAL REPORT

of the

ITER ENGINEERING DESIGN ACTIVITIES

Prepared by the ITER Council

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2001

FINAL REPORT OF THE ITER EDA
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ITER

FOREWORD

Development of nuclear fusion as a practical energy source could provide great benefits. This fact has been widely recognized and fusion research has enjoyed a high level of international co-operation. Since early in its history, the International Atomic Energy Agency has actively promoted the international exchange of fusion information.

In this context, the IAEA responded in 1986 to calls at summit level for expansion of international co-operation in fusion energy development. At the invitation of the Director General there was a series of meetings in Vienna during 1987, at which representatives of the world's four major fusion programmes developed a detailed proposal for co-operation on the International Thermonuclear Experimental Reactor (ITER) Conceptual Design Activities (CDA). The Director General then invited each interested Party to co-operate in the CDA in accordance with the Terms of Reference that had been worked out. All four Parties accepted this invitation.

The ITER CDA, under the auspices of the IAEA, began in April 1988 and were successfully completed in December 1990. The information produced within the CDA has been made available for the ITER Parties and IAEA Member States to use either in their own programmes or as part of an international collaboration.

After completing the CDA, the ITER Parties entered into a series of consultations on how ITER should proceed further, resulting in the signing of the ITER EDA (Engineering Design Activities) Agreement on July 21, 1992 in Washington by representatives of the four Parties. The Agreement entered into force upon signature of the Parties, with the EDA conducted under the auspices of the IAEA.

As the original six-year EDA Agreement approached a successful conclusion, the Parties entered into a series of consultations on how future steps could be taken toward decisions on construction. A provisional understanding was reached that the EDA Agreement should be extended by three years to enable the Parties to complete their preparations for possible construction decisions. By the time of the expiration of the original EDA Agreement, the EU, JA and RF Parties had agreed to extend the Agreement while the US Party, complying with Congressional views, did not participate beyond an orderly close out activity ending in September 1999. The extended EDA was successfully completed in July 2001.

As part of its support of ITER, the IAEA is pleased to publish the documents summarizing the results of the Engineering Design Activities. Together with the twenty previous volumes in the ITER EDA Documentation Series, on:

- ITER EDA Agreement and Protocol 1 (DS/1)
- Relevant Documents Initiating the EDA (DS/2)
- ITER Council Proceedings: 1992 (DS/3)
- ITER Council Proceedings: 1993 (DS/4)
- ITER EDA Agreement and Protocol 2 (DS/5)
- ITER Council Proceedings: 1994 (DS/6)
- Technical Basis for the ITER Interim Design Report,

Cost Review and Safety Analysis (DS/7)

- ITER Council Proceedings: 1995 (DS/8)
- ITER Interim Design Report Package and Relevant Documents (DS/9)
- ITER Interim Design Report Package Documents (DS/10)
- ITER Council Proceedings: 1996 (DS/11)
- ITER Council Proceedings:1997 (DS/12)
- Technical Basis for the ITER Detailed Design Report Cost Review and Safety Analysis (DDR) (DS/13)
- ITER Final Design Report, Cost Review and Safety Analysis (FDR) and Relevant Documents (DS/14)
- ITER Council Proceedings: 1998 (DS/15)
- Technical Basis for the ITER Final Design Report, Cost Review and Safety Analysis (FDR) (DS/16)
- ITER Council Proceedings: 1999 (DS/17)
- ITER-FEAT Outline Design Report (DS/18)
- Technical Basis for the ITER-FEAT Outline Design (DS/19)
- ITER Council Proceedings: 2000 (DS/20)

This volume represents essential information on the ITER EDA results.

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Preface

This is the Final Report by the ITER Council on work carried out under the terms of the Agreement among the European Atomic Energy Community, the Government of Japan, the Government of Russian Federation and the Government of the United States of America on Cooperation in the Engineering Design Activities (EDA) for the ITER. The ITER EDA were conducted under the auspices of the International Atomic Energy Agency (IAEA).

In accordance with Article 16 of the ITER EDA Agreement, this reports follows the approval by ITER Council of the Director's report on the ITER design.

1. Introduction

Thermonuclear fusion is one of the very few options, potentially acceptable from the environmental, safety and economic points of view, to provide energy over the long term for a growing world population. World-wide research efforts have brought the leading programmes to the threshold of conditions that might be expected in a fusion reactor. Together with advances in fusion science arising from a range of smaller experiments and the development of necessary fusion technologies, the fusion programme at the world level has now achieved a level of knowledge that allows to address, in the next step on the development path, the challenge of exploring the physics of a burning plasma in an experimental device that incorporates the key features of fusion technology in reactor-relevant conditions and thus to demonstrate the scientific and technological feasibility of fusion power for peaceful purposes. ITER was conceived to meet this objective.

The history of co-operation on ITER began in 1985 when government leaders in summit meetings called for more substantial international co-operation in order to increase the efficiency and minimize the cost of fusion power development. In response to the summit initiatives, experts from the then European Community, Japan, the then Soviet Union, and the United States, were invited by the Director-General of the IAEA to develop "Terms of Reference Concerning Conceptual Design Activities (CDA) for an International Thermonuclear Experimental Reactor". The CDA began in 1988 after the four Parties formally accepted the invitation from the Director-General to participate, in accordance with the terms of reference, under the auspices of the IAEA. The CDA were successfully completed in 1990.

After completing the CDA, the four Parties entered into negotiations on how ITER should proceed further, resulting in the ITER EDA Agreement [1] under the auspices of the IAEA. The Agreement was signed on July 21, 1992 in Washington by representatives of the four Parties and entered immediately into force. Joint work during the six years period originally set for the Agreement led, by July 1998 to the development of a design for ITER that was adjudged to fulfill the overall programmatic objective and the detailed technical objectives and cost target as originally set.

With the approaching end of the original period set for the EDA, the Parties negotiated an agreement extending the EDA period for three years which was signed by three Parties, Euratom, Japan and the Russian Federation. The USA agreed to participate for one additional year. At that time the Parties, recognising the possibility that they might be unable, for financial reasons, to proceed to the construction of the then foreseen device, adopted a less demanding set of detailed technical objectives [2] that would still meet the overall programmatic objectives but at a significantly reduced cost (about 50%). The EDA extension period was primarily devoted to developing a design under the revised technical objectives set in 1998, as well as completion of planned technology R&D projects. The results of these activities have been reflected in the report of the ITER design presented by the ITER Director and approved by the ITER Council [3].

The terms of the ITER EDA Agreement allowed for the participation of other countries in the joint work of the Parties. Accordingly, Canada participated in the EDA as an associate of Euratom and Kazakhstan participated through the Russian Federation.

2. ITER EDA Objectives

The purpose of the ITER Agreement is to produce a detailed, complete, and fully integrated engineering design of ITER and all technical data necessary for future decisions on the construction of ITER. Such design and technical data shall then be available for each of the Parties to use either as part of an international collaborative programme or in its domestic programme.

2.1 Programmatic Objectives

The overall programmatic objective of ITER is to demonstrate the scientific and technological feasibility of fusion power for peaceful purposes.

ITER would accomplish this objective by demonstrating controlled ignition and extended 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.

2.2 Technical objectives

Detailed technical objectives to determine the best practicable way to achieve the programme objectives were adopted in 1992 by the ITER Council and served as the focus for design work for the first six years of the EDA Agreement. In 1998 revised detailed objectives were adopted by reducing the size of device as well as the capital cost, while maintaining the programmatic objectives and by taking account of the progress in physics and technology R&D. Detailed technical objectives adopted by ITER Council in 1998 are summarized in Table 2-1.

Table 2-1 Summary of Detailed Technical Objectives

Plasma Performance: ● to achieve extended burn in inductively driven plasma operation with a ratio of fusion power to auxiliary power injected into the plasma $Q \geq 10$ with an inductive burn duration between 300 and 500 s, ● to aim at demonstrating steady state operation using non-inductive current drive with $Q \geq 5$, ● controlled ignition should not be precluded. **Engineering Performance and Testing:** ● demonstrate availability and integration of essential fusion technologies, ● test components for a future reactor, ● test tritium breeding module concepts; with a 14MeV neutron average power load on the first wall ≥ 0.5 MW/m^2 and fluence $0.3 \geq$ MWa/m^2, ● the option for later installation of a tritium breeding blanket on the outboard of the device should not be precluded. **Operation requirements:** ● the operation anticipated over an approximately 20 year period should address the issues of burning plasmas, steady-state operation and improved modes of confinement, and testing of blanket modules.

3. Scope of the ITER Engineering Design Activities

The EDA Agreement called for the Parties to conduct jointly the following EDA:

(a) to establish the engineering design of ITER including

(i) a complete description of the device and its auxiliary systems and facilities,
(ii) detailed designs with specifications, calculations and drawings of the components of ITER with specific regard to their interfaces,
(iii) a planning schedule for the various stages of supply, construction, assembly, tests and commissioning of ITER together with a corresponding plan of human and financial resources requirements, and,

(iv) specifications allowing immediate calls for tender for the supply of items needed for the start-up of the construction of ITER if and when so decided;

(b) to establish the site requirements for ITER, and perform the necessary safety, environmental and economic analyses;

(c) to establish both the proposed programme and the cost, manpower and schedule estimates for the operation, exploitation and decommissioning of ITER;

(d) to carry out validating research and development work required for performing the activities described above, including development, manufacturing and testing of scalable models to ensure engineering feasibility; and,

(e) to develop proposals on approaches to joint implementation for decisions by the Parties on future construction, operation, exploitation and decommissioning of ITER.

4. Organization and Resources of the EDA

The EDA were directed and managed by the ITER Council (IC), responsible for overall direction of the EDA and exercising overall supervision of its execution, and the ITER Director, responsible for direction and coordination of the performance of technical activities which were shared among an international Joint Central Team and Home Teams in each of the Parties. The Technical Advisory Committee (TAC) and Management Advisory Committee (MAC) advised the IC on technical and on administrative matters, respectively. Joint Work Sites for the Joint Central Team were set up at three sites, San Diego (US), Garching (EU), and Naka (JA). Activities at the three sites were supported by the respective Parties. In December 1998, the San Diego site was closed following the decision of the USA to withdraw from the project.

The total resources for the conduct of the EDA activities are:

- Joint Central Team amounting to 999 PPY (Professional Person Year) with an additional contribution by the Visiting Home Team Personnel of 43 PPY.
- 531 Design Tasks curried out by the Home Teams amounting to 943 PPY equivalent.
- 815 Technology R&D Tasks carried out by the Home Teams amounting to 658 kIUA [1].
- Physics R&D carried out by the Parties on a voluntary basis using existing plasma devices.
- Joint Fund amounting to 14.56 M$US for the entire EDA period.

[1] One IUA is an ITER Unit of Account and is equal to 1000US$ of January 1989.

5. Engineering Design

The ITER design is based on scientific knowledge and extrapolations derived from the operation of world tokamaks over the past decades and on the technical know-how flowing from the fusion technology R&D programmes around the world. The design has been validated by wide-ranging physics and engineering work, including detailed analyses, specific experiments in existing fusion research facilities and dedicated technology developments and tests.

The main parameters and characteristics follow directly from the detailed objectives and cost target set in 1998. Safety and environmental characteristics reflect a consensus among the Parties on safety principles and design criteria for minimising the consequences of ITER operation for the environment and the results of analysis on all postulated events and their consequences.

ITER is a long pulse tokamak with elongated plasma shape and single null poloidal divertor. The nominal inductive operation produces a DT fusion power of 500 MW for a burn length of 400 s, with the injection of 50 MW of auxiliary power.

The major components of the tokamak are the superconducting toroidal and poloidal field coils which magnetically confine, shape and control the plasma inside a toroidal vacuum vessel. The magnet system comprises toroidal field coils, a central solenoid, external poloidal field coils, and correction coils. The toroidal field coil windings are enclosed in strong cases as well as the external poloidal field coils. The vacuum vessel is a double-walled structure. The magnet system together with the vacuum vessel and internals are supported by gravity supports.

Inside the vacuum vessel, the internal, replaceable components, including blanket modules, divertor cassettes, and port plugs such as the limiter, heating antennae, test blanket modules, and diagnostics modules, absorb the radiated heat as well as most of the neutrons from the plasma and protect the vessel and magnet coils from excessive nuclear radiation. The heat deposited in the internal components and in the vessel is rejected out of the vessel by means of the tokamak cooling water system.

The entire tokamak is enclosed in a cryostat, with thermal shields between the hot components and the cryogenically cooled magnets.

During plasma start-up, low-density gaseous fuel will be introduced into the vacuum vessel chamber by the gas injection system. The plasma will progress from a circular configuration to an elongated divertor configuration as the plasma current is ramped up. As the current develops (nominally up to 15 MA), subsequent plasma fuelling (gas or pellets) together with additional heating leads to a high energy gain burn and finally to a controlled burn with a fusion power of about 500 MW. With non-inductive current drive from the heating systems, the burn duration is envisaged to be extended up to 3000 s. In inductive scenarios, before the inductive flux available has been fully used, reducing the fuelling rate so as to slowly ramp-down the fusion power terminates the burn. This phase is followed by plasma current ramp-down and finally by plasma termination. The inductively driven pulse has a nominal burn duration of 400 s, with a pulse repetition period as short as 1800 s.

With regard to safety, the current design focuses on confinement as the overriding safety function, other functions being recognised as being required to protect confinement. Successive barriers are provided for tritium and activated dust. These include the vacuum vessel, active air conditioning systems, with de-tritiation and filtering capability in the building confinement. Effluents are filtered and detritiated in such a way that their release to the environment is as low as reasonably achievable.

The main parameters of ITER are shown in Table 5-1. Figure 5-1 shows a cutaway view of the ITER device inside the cryostat while Figure 5-2 shows a vertical cross section of the tokamak.

Table 5-1 Main Parameters of ITER

Total Fusion Power	500 MW *(700 MW)*
Q — fusion power/additional heating power	≥10
Average 14MeV neutron wall loading	≥0.5 MW/m^2
Plasma inductive burn time	≥ 400 s
Plasma major radius (R)	6.2 m
Plasma minor radius (a)	2.0 m
Plasma current (I_p)	15 MA *(17 MA)*
Toroidal field at 6.2 m radius (B_T)	5.3 T

Note: The machine is capable of plasma current up to 17 MA, with the parameters shown in parentheses, within some limitations on other parameters such as pulse length.

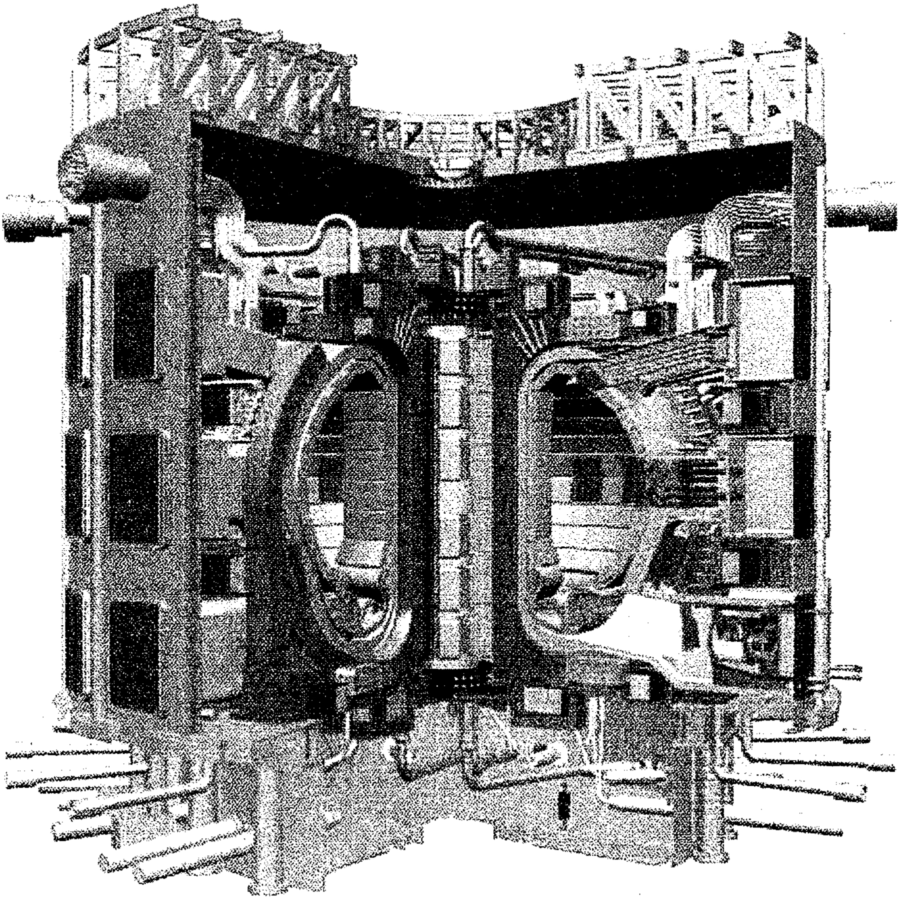

Figure 5-1 View of the ITER device inside the cryostat

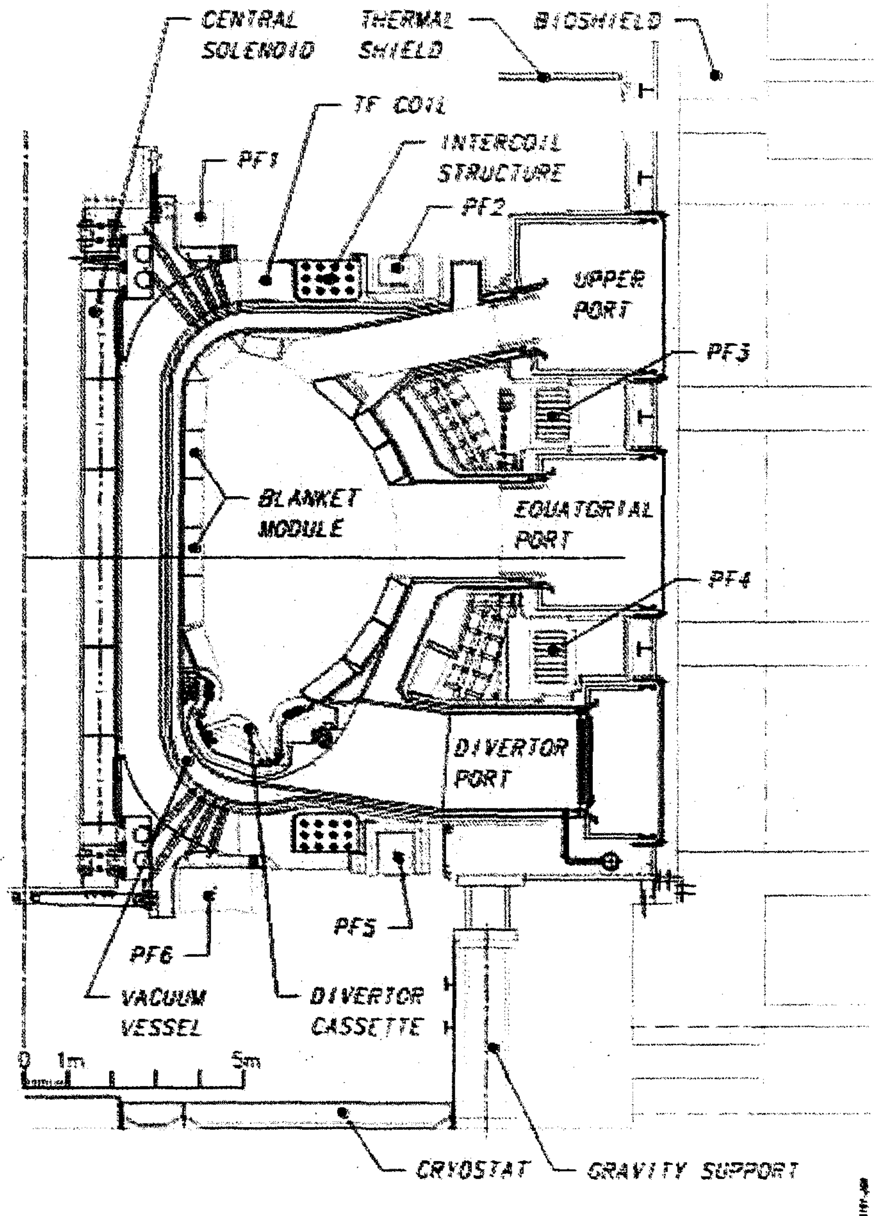

Figure 5-2 Tokamak cross section

6. Validating Research and Development

The overall design philosophy for ITER has been to use established approaches and to validate their application through wide-ranging physics and engineering work. This included detailed analyses, experiments in existing fusion research facilities, and dedicated technology developments including fabrication and test of full scale or scalable models of key components [4]. Unavoidable uncertainties remain in the extrapolation of performance from current experience to the ITER size and parameters; these can only be fully resolved through experiments at ITER scale.

On a voluntary basis, the Parties have conducted well-focused physics investigations that strengthen further the physics database, reduce the ranges of uncertainty in extrapolation and explore wider options for possible ITER operation. The ITER Physics R&D [5] has been carried out by seven Expert Groups, under the coordination of the ITER Physics Committee, as given in Table 6-1.

Table 6-1 Seven Expert Groups on ITER Physics R&D

1994 – 1999	1999 – 2001
Confinement and Transport Physics	Transport and Internal Barrier Physics
Confinement Database and Modeling	Confinement Database and Modeling
Edge Database and Modeling	Edge and Pedestal Physics
Scrape-Off Layer and Divertor Physics	Scrape-Off Layer and Divertor Physics
Disruptions, Equilibrium Control and MHD	MHD, Disruptions and Control
Fast Particles, Heating and Current Drive	Energetic Particles, Heating, and Steady State Operation
Diagnostics	Diagnostics

The design also addresses demanding technical challenges including:

- the unprecedented size of the superconducting magnets and structures,
- high neutron flux and high heat flux in the first wall,
- extremely high heat flux in the divertor,
- remote handling for maintenance and interventions in an activated tokamak structure,
- equipment unique to fusion reactors such as fuelling and pumping heating and current drive systems and diagnostics.

Major technology R&D projects therefore have been undertaken for the purpose of confirming performance and understanding operating margins. Assessment of results to date indicates, from an engineering and technology point of view, that the design is feasible, that it can be manufactured to specifications, and that it will be capable of meeting its operating objectives. In particular, seven large projects, undertaken jointly by the Parties have demonstrated the feasibility, performance, and maintainability of the main engineering components and systems of ITER. About three quarters of the R&D resource were concentrated to these seven projects as shown in Table 6-2.

In addition to the seven large R&D projects, development of components for fuelling, pumping, tritium processing, heating/current drive, power supplies, plasma diagnostics as well as safety related R&D have significantly progressed.

Table 6-2 ITER Technology R&D Areas and Resource Allocation

R&D Area	%
Magnets	27.9
Vacuum Vessel	5.3
Blanket and First Wall including Materials	16.3
Divertor & PFC including Materials	15.1
In-vessel Remote Handling	11.3
Subtotal	*75.9*
Fuelling & Pumping & Tritium System	5.3
Heating & Current Drive	7.9
Diagnostics	2.5
Safety Related R&D	3.4
Miscellaneous	5.0
Total	*100.0*

Note: Total resources: 658 kIUA.

7. Safety and Environmental Assessments

A central goal of ITER is to demonstrate the safety and environmental potential of fusion as an energy source.

A consensus across the Parties on safety principles and criteria for minimising the consequences to the public and the environment from ITER operations has been attained, based on internationally recognised safety criteria and radiological limits following ICRP and IAEA recommendations, and in particular on the concept of defense in depth and the As Low As Reasonably Achievable (ALARA) principle. Safety-related design requirements have been established and assessments have been or are being made to evaluate the success in meeting these requirements in the facility, system, and component design.

Comprehensive safety and environmental assessments of the ITER design and operation have been completed under generic site assumptions. The conclusion indicates that ITER will meet the objective of demonstrating the safety and environmental potential of fusion power.

The ITER Council considers that the safety assessments show that ITER can be constructed and operated without undue risk to health and safety and without significant environmental impact. The analyses and assessments completed with the involvement of experts from all Parties offer a well-developed technical basis for applications to the regulatory authorities of potential host countries for approval to construct and operate ITER.

8. Site Requirements

The ITER Council endorsed a set of ITER Site Requirements and Site Design Assumptions[6] The site requirements are firm in the sense that reasonable reconfiguration of the plant design will not result in a less demanding set of requirements. The requirements cover such matters as:

- land area and geotechnical characteristics,
- water supply and sanitary and industrial sewage capacity,
- heat sink capability,
- energy and electrical power capability for steady state loads,
- transport and shipping capacity.

The requirements have been set so as not to preclude the possibility of ITER construction in the territory of any of the ITER Parties.

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

Requirements for public safety and environmental considerations are, by their nature, site sensitive. Until a site is determined, the ITER plant design process works to a set of safety and environmental assumptions, which are expected to approximate the actual requirements.

The Site Design Assumptions have a wider and more detailed scope than the Site Requirements, and include additional considerations of infrastructure, external hazards and accident initiators and the regulatory environment. In general, the site design 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. Such modifications are expected to be feasible but they may have an impact on the cost estimate and the construction schedule.

9. Proposed Schedule and Estimates of Manpower and Cost

9.1 Proposed Schedule

The ITER project, after the signing of Joint Implementation Agreement will consist of three phases; construction phase, operation phase and decommissioning phase. It will take about ten years for construction including licensing procedure. Twenty years of ITER operation are envisaged to achieve the project goal. The decommissioning phase comprises, de-activation and clean-up, cooling-down, as well as dismantling and disposal.

Procurement, Construction/Assembly, and Commissioning

The overall schedule for procurement, construction/assembly, and commissioning that leads up to the first hydrogen plasma operation is shown in Figure 9-1. It represents a reference scenario developed on a number of assumptions. The actual schedule that can be realised will depend on the site specific licensing procedure, as well as the organization and arrangements under which ITER would be built.

Since the start of the actual construction on the site depends upon when the license to construct is issued by the regulatory authority, dates in the construction and commissioning plan are measured from the date at which the actual construction work for the tokamak buildings is started. The critical path of the plan starts with the regulatory licensing procedure and construction of the tokamak buildings and, in parallel, the manufacture of magnets and vacuum vessel. If the license process can be completed within 24 months, the construction period defined from the start of the regulatory process to first hydrogen plasma discharge is ten years.

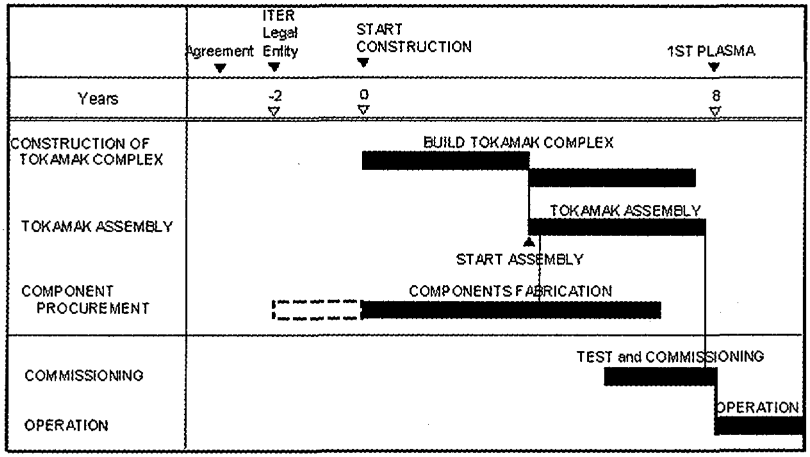

Figure 9-1 Overall ITER Construction Schedule

Operation and Exploitation

After completion of assembly, and following individual sub-system tests, there will be the need, for about one year, for adequate testing of controls and interfaces between subsystems. Thereafter, plan for operations foresees initial phases of hydrogen and deuterium operation in order fully to commission and characterise the machine and to simulate operations in anticipation of the nuclear conditions of full deuterium and tritium (DT) operation.

Two main phases of DT operation are then foreseen. During the first phase, 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. Reactor relevant blanket modules will also be tested whenever significant neutron fluxes will be available.

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 on the basis of the results from the preceding operational phases and an assessment of the merits and priorities of programmatic proposals.

Decommissioning

Two separate phases are considered for decommissioning. During the first phase, the machine will, immediately after shutdown, be de-activated and cleaned by removing tritium and activated dust from the vacuum vessel. In-vessel components will also be removed from the vessel and prepared for long term storage according to applicable regulations. These activities will be carried out over a period of about five years using the remote handling facilities and staff in place at the end of operation. After the first phase, the plan foresees a period for radioactive decay before a final dismantling and disposal over a period of about six years.

9.2 Estimated Manpower

The estimate of manpower required for the operation, exploitation and decommissioning of ITER will depend, inter alia, on the organisational structure established for implementing ITER. It has been assumed that an international ITER Project entity will be established with its staff to take responsibility for jointly implementing ITER on behalf of the Parties. There would then be a site-based international team complemented by staff located in each of the Parties who would be responsible to manage and follow the technical content of the procurements provided by the Party. Each would also establish appropriate domestic arrangements to manage the financial and legal aspects of its contributions.

On this basis, the global man-years of the international ITER entity during the construction phase amount to 1800 PPY for professionals and 2760 PPY for support personnel.

Manpower estimates of permanent staff on site during the operation phase indicate an average level of 200 professionals and 400 support staff (clerical, technicians and CAD operators). These staff are expected to operate and maintain the facility, and support the experimental programme. In addition it is expected that the Parties will send visitors to the site to conduct specific experiments on ITER. No estimates have been made of the additional numbers concerned in this way in the experimental exploitation of ITER.

9.3 Cost Estimates

Construction Costs

In order to isolate the cost estimating process from fluctuating economic factors such as variations in exchange rates and domestic inflation rates, cost figures for ITER are expressed in terms of a normalised "ITER Unit of Account (IUA)", where 1IUA is defined as the equivalent purchasing power of US$1000 in January 1989. The conversion factor of 1 IUA to each currency in 2000 is: 1 IUA= 1.39 kUS$, 1.28 kEuro, 148 kYen, and 39.5 kRouble.

In order to provide data for the cost estimates on as realistic a basis as possible, the cost structure of ITER was broken down into 85 "procurement packages" each at a level representing a plausible procurement contract, which were then presented to the Parties industries and large laboratories with relevant for detailed quantified studies. The results of these studies constitute a broadly-based comprehensive database for cost analysis, comparison and evaluation.

The evaluated cost estimate for ITER construction is presented in Table 9-1. The total direct capital cost of ITER amounts to 2,755 kIUA. In addition the cost of spares and items needed only a few years after start of operation (for full DT operation) amounts to 258 kIUA.

Site-specific adaptations of the design may induce changes in the cost of some systems. Similarly, the present design is consistent with codes and standards, which have been defined inside the project. These rules are coherent but are not identical to those of any specific Party, even if they do not contradict them. Regulatory bodies from the host country may request application of different and specific design rules or quality assurance measures. This may also induce cost variations.

Based on the estimated manpower as described above, and assuming the annual cost of one professional and one support staff member to be 150 IUA and 75 IUA respectively, the global cost estimate for the professional and support personnel in the ITER team amounts to 477 kIUA for ten years until the start of ITER operation

In addition to personnel costs, some R&D during construction will still be necessary. For instance, R&D for all heating and current drive methods is required with high priority. Although the EDA has provided the principle qualification of design solutions to be implemented in ITER, during the manufacturing of components, proposed process improvements and design changes or unexpected difficulties could require new tests. It is therefore prudent to expect a spending in R&D of 60-80 kIUA during ITER construction.

Manpower costs of permanent staff on site based on the manpower estimates of an average level of 200 professionals and 400 support staff (clerical, technicians and CAD), amount to about 60 kIUA/year. The costs of Parties' staff visiting the project for specific experiments are assumed to be borne by the Parties concerned.

In addition to personnel costs, 30 kIUA is estimated for the energy consumption, 8 kIUA for the tritium purchase and 90 kIUA for spare parts, maintenance and improvements, i.e. a total average per year of 188 kIUA.

Table 9-1 Summary ITER Direct Capital Cost Estimates

	Direct Capital Cost (kIUA)	Percentage of Total
Machine Core		
Magnet Systems	762.1	28%
Vacuum Vessel	230.0	8%
Blanket and Divertor	241.2	9%
Other Machine Core	231.5	8%
Machine Core, subtotal	**1464.8**	**53%**
Auxiliaries		
Buildings	380.3	14%
Power Supplies & Distribution	214.7	8%
Cryoplant and Cooling Water System	131.5	5%
Other Auxiliary Systems	189.7	7%
Auxiliaries, subtotal	**916.2**	**33%**
Heating and Current Drive	**205.7**	**7%**
Diagnostics, Control and Data Acquisition	**168.0**	**6%**
Grand Total	**2754.7**	**100%**

Decommissioning Costs

Because of the remote maintenance implemented during operation, the ITER facility will offer most of the tools, procedures, and trained staff, to accomplish the decommissioning operations. This capacity is an essential element in keeping down the estimated cost of decommission. Moreover the estimate is based on the requirements for the dismantling of the main activated parts of the ITER facility only. The non-active parts are not considered, because their residual values are probably higher than their dismantling costs.

Other costs (dependent on the Host country) are not included in the present estimate:

- radwaste disposal,
- components and facilities salvage value after dismantling where applicable,
- non-active parts dismantling and salvage value,
- site restoration.

Under the assumptions and limitations listed above, the estimated cost for decommissioning amounts to 250 kIUA for manpower costs and 85 kIUA for possible hardware costs.

Summary

For reference, a summary of the cost estimates for all phases of ITER plant life is set out in Table 9-2.

Table 9-2 Summary of ITER Cost Estimates

	Cost (kIUA)
Construction costs	
Direct capital cost	2755
Management and support	477
R&D during construction	60-80
Operation costs (average/year)	
Permanent personnel	60
Energy	≃ 30
Fuel	≃ 8
Maintenance/improvements	~ 90
Total	188
Decommissioning cost	335

10. Proposals on Approaches to Joint Implementation

A Special Working Group in terms of the EDA Agreement Protocol 2 was set up by the ITER Council in order to develop proposals on approaches to joint implementation for decisions by the Parties on future construction, operation, exploitation and decommissioning of ITER.

The central feature of the proposals is the conclusion of an International Agreement on Joint Implementation of ITER under which the Parties involved would jointly establish and support an ITER legal entity (ILE) which would have the charge, the structure, the authority, and means to implement the project on behalf of the Parties.

The terms of the International Agreement would establish the Parties' political commitment to realising the aims of the project and provide the means, both directly and through subsidiary instruments, necessary to enable ITER to come to fruition. To this end the Agreement and its related instruments would address, inter alia:

- the organisational and managerial structure, including the means by which the Parties exercise the governance and share overall responsibility for the Project
- the place of the ITER site and relations of the project with the host authorities
- the distribution among the Parties of responsibilities for cost sharing and technical contributions to the Project.

Following successful conclusion of the work of the Special Working Group [7], the three current ITER EDA Parties (Euratom, Japan and the Russian Federation) conducted during 2000 non-committal, pre-negotiation discussions, to prepare for negotiations concerning joint implementation of ITER.

11. Conclusions

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.

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