ITER

ITER EDA DOCUMENTATION SERIES No. 20

International Thermonuclear Experimental Reactor
(ITER)

Engineering Design Activities
(EDA)

ITER
COUNCIL PROCEEDINGS: 2000

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2001

ITER COUNCIL PROCEEDINGS: 2000
IAEA, VIENNA, 2001
IAEA/ITER EDA/DS/20

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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.

As part of its support of ITER, the IAEA is pleased to publish the documents summarizing the results of the Engineering Design Activities.

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INTRODUCTION

No ITER Council Meetings were held in 2000. However, continuing the ITER EDA, two important Meetings took place during the year. These were the ITER Meetings held in Tokyo, 19-20 January, and in Moscow, 29-30 June.

The delegations of all three ITER Parties participating in the extended EDA (EU, Japan, Russian Federation), took part in the Meetings. The Parties' delegations to these meetings were headed by IC Members.

Both Meetings were exclusively devoted to the ITER EDA and their agendas covered all issues important for the ITER development. Because of the importance of the decisions taken at these two meetings, this publication comprises their documents.

Together with the nineteen 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)

this volume represents essential information on the evolution of the ITER EDA.

ITER Meeting, 19-20 January 2000, Tokyo

DOCUMENTS
OF THE
ITER MEETING

19-20 January 2000, Tokyo

RECORD OF THE ITER MEETING
Tokyo, 19-20 January 2000

1. The Meeting accepted participation as attached (**Attachment 1**).

2. The Meeting Agenda was adopted (**Attachment 2**).

3. The Meeting was pleased to note the letter from Minister Adamov inviting a start of Explorations and noted the actions and expectation by the Parties to complete positive response as soon as possible.

4. The meeting took note also of the interest expressed by Canada through the EU in offering to host ITER in Canada.

5. The Meeting took note of the positive situation in each of the Parties related to fusion development and ITER.

6. The Meeting took note of the Director's Status Report (**Attachment 3)** and expressed satisfaction at the progress of the joint technical work. The Meeting welcomed the continuing interactions with US physicists on generic tokamak physics issues. Delegations expressed views on the need to balance the staffing in the JCT for the benefit of the project. The Meeting understood that Parties will use best efforts to regularise the Joint Fund situation in a timely manner.

7. The Meeting accepted the Report and Advice from the MAC meetings in July and December 1999 (**Attachment 4 and 5**); the Meeting supported the procedure recommended by MAC to get Council approval/endorsement of applicable MAC recommendations.

8. The Meeting accepted the ITER-FEAT Outline Design Report (**Attachment 6)**, taking note of the TAC Report and recommendations (**Attachment 7)** and agreed to transmit the reports to the Parties for their consideration and domestic assessment.

9. In light of TAC recommendation 2 (2), the Meeting agreed that the Outline Design Report provides the basis for continuing design work by JCT and Home Teams.

10. Recognising the importance to optimise a single agreed design, the Meeting asked the Director and JCT to interact with the Parties during the course of their domestic assessments. The Parties should keep the Director informed of the findings of their domestic assessments with a view to optimising a design for approval, following TAC review, at the coming ITER Council Meeting, in the context of the planned Joint Assessment.

11. The Meeting agreed that the acronym FEAT should continue to be used provisionally and asked the CPs to consult further on appropriate nomenclature, taking into account professional PR advice, for future consideration by the IC.

12. The Meeting approved the designation of Professor Komarek as a new TAC Member for the EU in succession to Professor Troyon. The Meeting expressed its warmest appreciation to Professor Troyon for his contributions to ITER.

13. The Meeting endorsed revised Site Design Requirements and Site Design Assumptions (**Attachment 8**), recognising that the different Site Design Assumptions have differing importance which will be considered during the Explorations and Negotiations.

14. The Meeting noted the Tentative Sequence of Events 1999-2002 towards future decisions on ITER construction (**Attachment 9, not included in this publication**) (which includes in the EU section a major modification in the schedule for preparation of Framework Programme 6), and asked the CPs to keep the sequence up to date and regularly disseminated. The Meeting agreed to the Director's complementary Outline of Technical Activities (**Attachment 10).**

15. The Meeting endorsed for transmission to the Parties the Report of the ITER SWG-P2 on Joint Implementation of ITER (**Attachment 11**). The Meeting agreed that the SWG-P2 had accomplished the task entrusted to it and thanked the Co-Chairs and all participants for the successful efforts.

16. The Meeting heard the summary of inter-Party consultations on Explorations.

17. The Meeting agreed Further Tasks for MAC (**Attachment 12**).

18. The Meeting agreed Further Tasks for TAC (**Attachment 13).**

19. The Meeting agreed Further Tasks for CPs (**Attachment 14**).

20. Upon invitation by the RF Delegation, the Meeting agreed to have the next Council Meeting in Moscow on 30 June – 1 July. Upon invitation by the EU Delegation, the Meeting tentatively agreed to have the following Council Meeting in Toronto on 19-20 October, which will be confirmed at the Moscow Council Meeting.

21. The Meeting approved this Record.

ITER MEETING

LIST OF ATTENDEES

EU

Prof. J. Routti	IC Member
Dr. U. Finzi	IC Member
Prof. K. Pinkau	Expert, SWG Co-Chair
Prof. R. Toschi	Expert, HTL EU
Dr. E. Canobbio	Expert, CP EU
Dr. D. Dautovich	Expert
Mr. M. Bourene	Expert
Dr. S. Clement	Expert

JA

Mr. S. Nakazawa	IC Member
Dr. M. Yoshikawa	IC Co-Chair, MAC Chair
Mr. M. Nakamura	Expert
Mr. H. Oka	Expert
Dr. H. Kishimoto	Expert, SWG Co-Chair
Dr. T. Tsunematsu	Expert, HTL JA
Dr. H. Takatsu	Expert, CP JA

RF

Acad. E. Velikhov	IC Chair
Dr. Yu. Sokolov	IC Member
Dr. L. Golubchikov	Expert, CP RF
Mr. Yu. Konashkov	Expert
Mr. L. Sushin	Expert
Mr. S. Mari	Expert

ITER

Dr. R. Aymar	Director
Dr. Y. Shimomura	Deputy to the Director
Dr. M. Huguet	Deputy Director
Mr. M. Drew	PC w/D
Prof. M. Fujiwara	TAC Chair
Dr. V. Vlasenkov	IC Secretary

IAEA

Dr. D.D. Sood	IAEA Representative

ROM 19/01/00
Attachment 2

ITER MEETING

Tokyo, 19-20 January 2000

AGENDA

Meeting Opening
Meeting arrangements and attendance
Remarks by Parties' Delegations
Adoption of the Agenda

1. Director's Status Report
2. MAC Report and Advice
3. Report on Design Options
    - 3.1 Outline Design Report
    - 3.2 TAC Report
    - 3.3 Revised Site Requirements and Site Design Assumptions
4. Special Working Group (SWG-P2) Report
5. Contact Persons' (CP) Report on Tentative Sequence of Events, including Joint Assessment

Consultations on Explorations

6. Further Tasks
    - 6.1 MAC
    - 6.2 TAC
    - 6.3 CPs
7. Interparliamentary Meetings
8. Other Business
9. Next Meetings, Dates and Places
10. Approval of Record of the Meeting (ROM) and Minutes

ITER EDA STATUS REPORT

Report by the Director

1 This note summarises progress made in the ITER Engineering Design Activities in the period between the ITER Meeting in Grenoble (July 1999) and the end of 1999.

Overview

2 Design work continued to converge on the features of the specific design to be presented to the ITER Council in January 2000. As foreseen in Grenoble, a joint JCT/Home Team "Integration Task Force" was established and acted as the main vector for progress in this activity. Thanks to the constructive approach taken by the Task Force participants and intensive drafting efforts from the JCT, with Home Team assistance in many areas, the key Paper — "Technical Basis for the ITER-FEAT Outline Design" — was completed on time and circulated to TAC by 10 Dec, for review by TAC at its meeting in Naka on 20-22 December.

3 Progress has been made in regularising the design task allocation process for the EDA extension period; Comprehensive Task Agreements for Home Team design activities have been agreed, except for a small number of final task specifications, and are ready for review by MAC.

4 The Technology R&D programmes have continued to make progress as foreseen. US involvement in the Coil Testing programme has been clarified.

5 The formal procedures concerning the revalidation of the EDA Agreement in three Party configuration were finally initiated on 13 December. After the revalidation of the EDA, a number of pending formal issues — notably in relation to the Joint Fund and JCT secondments— can soon be resolved.

Joint Central Team and Support

6 The status of the Team in November 1999 is summarised in the Table on the next page. There has been a small increase in JCT staff on site in all categories. There are now three Canadians on the Team and two more RF Team Members are expected shortly. However some departures are expected in the near future not all of whom will be replaced on the Team.

7 Overall it appears clear that the JCT effort foreseen for the EDA extension period (396 PPY) will not be achieved. This shortfall increases the importance of continued efforts to integrate JCT and Home Team activities in efficient modes of joint work

Table 1: JCT - Status by Joint Work Site and Party at 22 Nov 1999

	Garching	Naka		Total
by Site	50[1]	54[1, 2]		104[1,2,]
	EU	JA	RF	
by Party	46[1,2]	33	25[2]	104[1,2]

1 includes three Canadians provided through the Canadian association with the EU Party.
2 two additional RF members are due to arrive as soon as visa formalities will be complete

8 Completion of the revalidation of the EDA Agreement will allow to formalise the extension of secondment agreements, where this action was previously being blocked.

Task Assignments

9 The status of task agreements was presented in detail in specific papers to the MAC. The overall position for Task assignments is as summarised in Table 2 below. The main figures reflect the contributions of the current EDA Parties only.

Table 2. Summary of Task Agreements (cumulative)

TA Status	**R&D** Number	**Design** Number
Task Agreements committed (EU,JA,RF)	**591**	**456**
Task Agreements completed or to be completed	478	424
Task Agreements on-going	113	32
US (to 7/99)	*173*	*162*

10 Table 3 overleaf summarises the cumulative total of task agreements to date including tasks approved from the MAC meeting in Garching but still to be concluded.

Table 3. Task Agreements Summary per Parties

Party	R&D (IUA)			Design
	TAs concluded	Remainder of MAC Garching	Sum	(PPY)
EU	210,040	23,970	234.010	220.63
Japan	215,585	9,155	224,740	206.78
Russia	93,263	5,600	98,863	163.00
US(to 7/99)	*108,023*	-	*108,023*	*170.71*
Total	626,911	38,725	665,636	761.12

Joint Fund

11 The current status of the ITER Joint Fund is summarised in Table 4 below which shows budget and actual contributions for 1998 and 1999.

Table 4 Status of the ITER Joint Fund 1998 - 1999

Party	1998 contributions outstanding	1999 Revised budget contributions	1999 Contributions made	1999 contributions outstanding
EU	0	$440,783	$625,000	-$184,217*
JA	$281,000	$440,783	$0	$440,783
RF	0	$440,783	$428,878	$11,905
Total	$281,000	$1,322,349	$1,053,878	$268,471

* the excess will be treated as a pre-payment towards the EU contribution to the 2000 budget

12 With the imminent completion of the EDA revalidation exercise procedure, it will soon be possible to formalise and implement the outstanding decisions based on MAC recommendations from the Meeting in Garching in July (MAC Garching R&A 3 and 4).

13 The first step is for the Council to approve by written procedure:

- the 1998 Joint Fund Accounts;
- the revised 1999 Joint fund Budget
- the proposed 2000 Joint Fund Budget.

Thereafter the Joint Fund Rules require that, following IC approval the Director must notify the IAEA of the Joint Fund budget decisions. The budgets are adopted upon IAEA's confirmation of receipt of the Director's notification, and the Director then issues the call for contributions. It is hoped that, with the co-operation of all concerned these actions may be completed by the end of 1999 or in early 2000 so as to resume a normal mode of Joint Fund operation without further delay.

14 The pattern of Joint Fund expenditures during 1999 has been affected by the general uncertainties, not least in regard to the timing of receipt of contributions. Nonetheless, the general features of spending follows the patterns outlined to the MAC meeting at Garching (July 1999), in particular:

- the US Agent has spent no further money following the closure of the San Diego Joint Work Site and transfer of project documents and equipment to Garching and Naka. The agent holds only a small residue (~$8000) of unspent money against 1998 budget appropriations, which will be returned to the IAEA in the context of the 1999 accounts exercise;
- the Agents at the two Joint Work Sites are making urgent improvements to information systems in those areas supported from the Joint Fund along the lines accepted in July 1999;
- after an interruption, the RF Agent is now supporting design support contracts, at around the rates foreseen. A list of 1999 contracts is attached;
- the reserve of unspent 1998 appropriations is being held back in order to offset contributions in 2000, as explained in July 1999.

ITER Physics

15 The Physics Basis document was published in December 1999 as a special edition of "Nuclear Fusion". More than 800 additional copies of the reprinted document have been ordered to allow wide dissemination throughout the Fusion Physics community. In addition, a special reprint of the overview chapter is being produced for more general circulation.

16 The seven ITER Physics Expert Groups, with their modified titles and charges, have resumed their activities with schedules under which each group has about two meetings per year, often in combination with one or more others.

17 Proposals adopted in Grenoble to permit interaction with US physicists on generic tokamak physics issues have been implemented. Under the agreed procedures, responsibility rests with the Party hosting an Expert Group Workshop to develop, in consultation with the Director and others, a draft programme for a pre-meeting on related generic issues and then to extend invitations to US participants. The co-operation of the host Parties and of the hosting institutions in these matters is greatly appreciated.

RF Design support contracts — 1999

Ref.No.	Title/Dates/Volume	Institute	Financial status
01-99	**Vacuum Vessel Equatorial and Upper Port Structures: Design and Analysis** Start - 1 July Interim Rep.- 30 Oct. Final Rep.- 30 Dec.	Efremov Institute	$7,500 2 Stages:$3,750 each
02-99	**Initial Electromagnetic Analysis of VV and Blanket for IAM** Start - 1 July Final - 30 October	Efremov Institute	$6,000 1 Stage
03-99	**Blanket Module and Attachment Analyse**s: 5 Tasks Start - 1 June Final Rep. - 31 Dec.	ENTEK	$28,500 1 Stage
04-99	**Divertor**: 3 Tasks Start - 1 July Prog. Rep. - 30 Sept. Final Rep.- 30 Dec.	Efremov Institute	$41,250 2 Stages: I-$16,000 II - $6,500+11,250&7,500
4A-99 St.1	**Divertor: Dust Assessment** Final for St.2 - 30 Dec.	Kurchatov Institute	$5,250 - Stage 1 $6,000 - Stage 2
4B-99	**Divertor: 3 Tasks** Start - September Final: An.Suppl. - July 2000 E-M Anal. - Nov.1999 Leak Det. - April 2000	Efremov Institute	$22,500 1 Task - $11,250 2 Task - $3,750 3 Task - $7,500
05-99	**Magnet: 8 Tasks** 1 Stage-1 Jan.-1 Jul.99 2 Stage-1 Jul.-31 Dec.99	Efremov Institute	$60,000 - 1 Stage $60,000 - 2 Stage
06-99	**3D Electromagnetic Analysis for RTO/RC-Iter** Start - 1 June Final - 30 Sept.	Efremov Institute	$10,500 1 Stage
07-99	**Power Supply Systems for RC-ITER** Start - 1 July Final - 30 Sept.	Efremov Institute	$6,000: 1 Stage COMPLETED
08-99	**Design Modifications to the Beamline Components for RTO/RC ITER** Start - 1 February Brief Prog. Rep. - May Final - 31 July	Kurchatov Institute	$7,500 1 Stage COMPLETED

ı8A-99	**Design for the Beamline Components for ITER-FEAT injectors** Start - 1 September Prog. Rep. - 31 Dec. Final - 31 March 2000	Kurchatov Institute	$7,500.00
09-99	**Cryoplant Analysis and Modeling** Start - 1 June Final - 30 August Final Rep. - 30 Dec.	Efremov Institute	$15,000 2 Stages: $7,500 each.
10-99	**VV Thermal Shield** Start - 1 July Final - 30 Dec.	Efremov Institute	$12,000 1 Stage
11-99 1st. St.	**Physics Design** Start - 1 January Prog. Rep - 31 March Final - 31 July	Kurchatov Institute	$35,000 2 Stages COMPLETED
11-99 2nd St.	**Physics Design** Start - 1 August Quart. Reports: 31 Oct. 99 31 Jan. 2000 30 Apr. 2000 Final: 31 July 2000	Kurchatov Institute	$60,000 1 Stage
12-99	**Diagnostic Design** Start - 1 April Prog. Rep. - 30 June Final - 30 Sept.	Kurchatov Institute	$30,000 COMPLETED
13-99	**Vacuum Vessel Coolant Circuit Design** Start - 26 August Prog. Rep. - 17 Oct. Draft Final Rep. - 26 Nov. Final Rep. - 31 Jan. 2000	Efremov Institute	$4,500
14-99	**Engineering Verification of the High Heat Flux Components for NB H&CD for RTO/RC ITER** Start - 1August Final - 31 December	Efremov Institute	$7,500 1 Stage
15-99	**Steady State Electrical Power Network** Start - 1 August Final - 31 December	VNIPIET	$6,000 in 2 Stages
			Total: $438,500.00

MAC Report and Advice

MAC Meeting
22/23 July 1999
Garching JWS

MAC Membership and Meeting Participation:

Participation was accepted as attached in the **MAC Garching July 1999 R&A Attachment 2** (Attachments not included)**.**

Agenda

The Agenda was adopted as attached in the **MAC Garching July 1999 R&A Attachment 1** as amended**.**

ITER EDA Status

MAC Garching July 1999, R&A-1:

a) MAC noted the Status Report presented by the Director set out in the **MAC Garching July 1999 R&A Attachment 3.**

b) Regarding US involvement in the test programmes of the CS model coil, divertor cassette and remote welder, MAC was informed that bi-lateral exchange programme arrangements have been made between the US and Japan. The conclusion of the draft minutes of the US-Japan Coordination Committee for Fusion Energy held on 17 May 1999, which was tabled at the meeting, is annexed.
MAC noted that the Japanese Party will be conducting the above test programmes under ITER Task Agreements to be concluded between the JA HTL and the Director in the framework of the ITER EDA Agreement and, therefore, that the relevant dispositions, terms and conditions of the ITER EDA Agreement relevant to such R&D work, in particular those concerning Information and Intellectual Property, will apply in full.

c) MAC commended the Concept Improvement Task Force for its successful joint work. All Parties recommended that task force activities should continue with the view of establishing clear understanding of the design integration among the JCT and HTs.

d) MAC noted that the document titled “Assessment and Executive Summary of the Technology R&D Task Agreements during 6 years periods, 1992-1998" was completed and distributed to the Parties. The table of contents for the document is attached in the **MAC Garching July 1999 R&A Attachment 4.**

Work Program

MAC Garching July 1999, R&A-2:

Task Agreements

a) MAC took note of the Task Agreements Status Summary and compiled list of Task Agreements per Party in the **MAC Garching July 1999 R&A Attachment 5.**

b) Concerning withdrawal of the US Party, MAC recognized that five technology R&D Task Agreements for US Party will be still going on likely until the end of 1999 US Fiscal Year. MAC noted that those Task Agreements are considered closed by 20 July 1999, assuming that the Final Reports of those tasks are to be submitted to the JCT and distributed to the other Parties when those works are completed.

c) MAC reviewed and supported the new six Design Task Agreements of which credit is more than 500 IUA or 2.5PPY as presented in Tables 1 and 2 in the **MAC Garching July 1999 R&A Attachment 6**. This review and support constitute Council approval according to the IC-5 ROD 4 (c) 9.

d) MAC took note of new six Technology R&D Task Agreements and two Design Task Agreements of which credit is not more than 500 IUA or 2.5PPY per task in Tables 3 and 4 in the **MAC Garching July 1999 R&A Attachment 6.**

e) MAC reviewed and supported the modifications of Task Agreements since MAC Cadarache March 1999 of which credit changes are more than 500 IUA or 2.5PPY, or more than 20% as presented in Tables 1 and 2 in the **MAC Garching July 1999 R&A Attachment 7**. This review and support constitute Council approval according to the IC-5 ROD 4 (c) 9.

f) MAC took note of the modifications of Task Agreements since MAC Cadarache March 1999 of which credit changes are not more than 500 IUA or 2.5 PPY, or 20% as set out in Tables 3 and 4 in the **MAC Garching July 1999 R&A Attachment 7** and no cancellation of Task Agreements.

Technology R&D Task Sharing Proposals for the Priority 2 Tasks

g) MAC reviewed and supported the Directorís updated proposal for Technology R&D Task sharing for the priority 2 in the Work Program during the ITER EDA extension period **(MAC Garching July 1999 R&A Attachment 8)**. This review and support constitutes Council approval according to the IC-5 ROD 4 (c) 9.

h) MAC supported the Directorís view of the need to develop NbTi conductor and to test an insert at the CS Model Coil Test Facility. The Parties will explore ways to establish adequate confidence that testing will be completed if the test programme extends beyond the EDA duration.

Guidelines for a planned allocation of Design Resources proposed by the HTLs for the EDA Extension Period

i) MAC noted the guidelines for a planned allocation of design resources for the EDA extension period **(MAC Garching July 1999 R&A Attachment 9).** MAC understood that a revised sharing will be presented after further discussion among the Director and Home Team Leaders to reach an efficient implementation scheme as soon as possible.

Consolidated Annual Accounts of the 1998 ITER Joint Fund

MAC Garching July 1999, R&A-3:

a) MAC reviewed consolidated accounts for the ITER Joint Fund Budget of 1998 as presented by the Director **(MAC Garching July 1999 R&A Attachment 10)** with supporting detailed information.

b) For the table of Flow of Funds Statement, the currency variations are an inevitable feature of cross-border financial transactions. To clarify the currency variations, MAC asked the Director to show the applied exchange rates in the table.

c) MAC noted that each Party, including US, has exercised appropriate oversight of the funds provided to the Joint Fund Agent in its territory.

d) On the basis of the information provided, MAC recommends ITER Council to approve the consolidated annual accounts of the ITER Joint Fund for 1998.

The ITER Joint Fund - Revised Budget for1999 and Budget for 2000

MAC Garching July 1999, R&A-4:

a) MAC reviewed the Director's proposals for the revised 1999 and the 2000 Joint Fund Budget and its allocation to Agents and main Budget Articles, together with additional supporting information.

b) MAC recommends the ITER Council to approve the revised Joint Fund Budget for 1999 **(MAC Garching July 1999 R&A Attachment 11)** and the Joint Fund Budget for 2000 as proposed by the Director **(MAC Garching July 1999 R&A Attachment 12)**.

Redistribution of assets from San Diego to Naka and Garching that were purchased by the Joint Fund

MAC Garching July 1999, R&A-5:

a) MAC noted that the redistribution of the assets from San Diego to Garching and Naka was made appropriately (the Table 4 of **MAC Garching July 1999 R&A Attachment 3).** MAC noted the US view on the disposition of Joint Fund assets as attached in the **MAC Garching July 1999 R&A Attachment 13.**

b) MAC noted that the Joint Fund Agents in EU and JA have taken over management responsibility of Joint Fund assets transferred from San Diego.

Information Technology needs at the ITER Joint Work Sites

MAC Garching July 1999, R&A-6:

a) MAC recommends ITER Council to endorse the Directorís proposal as set out in the **MAC Garching July 1999 R&A Attachment 14**, supporting the Directorís view of the importance of making the required resources available for speedy implementation before the end of 1999.

Review the Disposition of Commingled R&D Components involving the US Party

MAC Garching July 1999, R&A-7:

a) MAC accepted the report of the MAC-CPs to MAC regarding the dispositions applicable to the disposal of the Commingled R&D Components involving the US Party **(MAC Garching July 1999 R&A Attachment 15),** noted the information on the ownership and value (IUA) of the Commingled R&D Components **(MAC Garching July 1999 R&A Attachment 16),** and recommends to ITER Council to endorse the reportís proposals.

b) MAC expressed high appreciation of the work performed by Dr.Rager and MAC-CPs, supported by the JCT.

c) MAC noted the Directorís view of the importance of giving further consideration to point to 3. d). MAC supported the Directorís proposals that any item for which there is no expressed declaration (Point 7) should be held as is.

Review the Director’s Proposal for ITER Meetings

MAC Garching July 1999, R&A-8:

a) MAC reviewed and supported the schedule of Technical Meeting and Workshops as set out in the **MAC Garching July 1999 R&A Attachment 17**. In accordance with the IC-3 ROD 5.2, this review constitutes IC endorsement of the proposals for meetings.

b) MAC noted that proposals are being developed to permit continued interaction of Physics Expert Groups with US physicists under appropriate auspices. The mechanism or framework for the continued interaction with US physicists will be discussed in the PD's meeting in 28-29 July 1999.

Other Business

Future Meeting

MAC tentatively decided that the next MAC Meeting would be held in Naka on 17-18 December 1999.

MAC Report and Advice:

MAC approved the present MAC Garching July 1999 Report and Advice to the Council.

MAC Report and Advice

MAC Meeting
17 December 1999
Naka JWS

MAC Membership and Meeting Participation:

Participation was accepted as attached in the **MAC Naka December 1999 R&A Attachment 2** (Attachments not included)**.**

Agenda

The Agenda was adopted as attached in the **MAC Naka December 1999 R&A Attachment 1.**

ITER EDA Status

MAC Naka December 1999, R&A-1:

a) MAC noted the Status Report presented by the Director set out in the **MAC Naka December 1999 R&A Attachment 3** as amended.

b) MAC noted that the procedures concerning the revalidation of the ITER EDA Agreement in the three Party configuration were initiated on 13 December 1999 at IAEA.

c) MAC took note of the present situation of the ITER Joint Fund presented by the Director. The Director hoped that the outstanding decisions concerning the Joint Fund would allow approval of the 1999 Budget before the end of this year.

d) The approval by the ITER Council of the MAC recommendations from MAC Garching July 1999 (R&A 3 and 4) will be pursued by written procedure immediately after issues of the ITER legal framework are settled.

e) MAC noted that the name of the machine, ITER-FEAT, proposed by the SWG-P2 and to be proposed to the next Council meeting is used provisionally for the outline design.

Work Program

MAC Naka December 1999, R&A-2:

a) MAC took note of the Task Agreements Status Summary and compiled list of Task Agreements per Party in the **MAC Naka December 1999 R&A Attachment 4**.

b) MAC reviewed and supported the two new Design Task Agreements of which credit is more than 500 IUA or 2.5PPY as presented in Table 1 in the **MAC Naka December 1999 R&A Attachment 5**. This review and support constitute Council approval according to the IC-5 ROD 4 (c) 9.

c) MAC took note of seventeen new Design Task Agreements including VHTP for which credit is not more than 500 IUA or 2.5PPY per task in Table 2 in the **MAC Naka December 1999 R&A Attachment 5**.

d) MAC reviewed and supported the modifications of Task Agreements since MAC Garching July 1999 of which credit changes are more than 500 IUA or 2.5PPY, or more than 20% as presented in Table 1 and 2 in the **MAC Naka December 1999 R&A Attachment 6**. This review and support constitute Council approval according to the IC-5 ROD 4 (c) 9.

e) MAC took note of the modifications of Task Agreements since MAC Garching July 1999 of which credit changes are not more than 500 IUA or 2.5 PPY, or not more than 20% as set out in Table 3 in **the MAC Naka December 1999 R&A Attachment 6** and no cancellation of Task Agreements.

f) MAC reviewed and supported the Design Task sharing proposals among the three Parties for the 2000-01 Comprehensive Task Agreements as presented in the **MAC Naka December 1999 R&A Attachment 7**.

Review the Director's Proposal for ITER Meetings

MAC Naka December 1999, R&A-3:

a) MAC reviewed and supported the plan of Technical Meetings and Workshops as set out in the **MAC Naka December 1999 R&A Attachment 8.** In accordance with the IC-3 ROD 5.2, this review constitutes IC endorsement of the proposals for meetings.

b) MAC noted that as far as possible before each Expert Group Meeting an international pre-meeting on generic tokamak physics issues is proposed in order to favor continued interaction between the ITER Physics Expert Groups and US physicists.

Other Business

Situation of the approval of the previous MAC recommendations by written procedure

A letter which is to be sent from MAC to IC Chair to obtain IC approval/endorsement through written procedure has been prepared. The letter will be sent immediately after the completion of the EDA revalidation.

Future Meeting

MAC tentatively decided that the next MAC Meeting would be held in St. Petersburg on 6-7 or 17-18 July 2000.

MAC Report and Advice:

MAC approved the present MAC Naka December 1999 Report and Advice to the Council.

ROM 19/01/00
Attachment 6

ITER-FEAT Outline Design Report

ITER-FEAT — Outline Design Report
Report by the ITER Director

1.0 Background and Introduction

Six years of joint work under the ITER EDA agreement yielded, by July 1998, a mature design for ITER as presented in the ITER Final Design Report, Cost Review and Safety Analysis (FDR)[1] (the 1998 ITER design), supported by a body of scientific and technological data which both validated that design and established an extensive knowledge base for designs for a next step, reactor-oriented tokamak experiment. The 1998 ITER design fulfilled the overall programmatic objective of ITER - to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes - and complied with the detailed technical objectives and technical approaches, and cost target adopted by the ITER Parties at the start of the EDA.

When they accepted the FDR report, the ITER Parties, recognising the possibility that they might be unable, for financial reasons, to proceed to the construction of the then foreseen device, established a Special Working Group (SWG)[2], and charged it with two tasks:

- to *propose technical guidelines for possible changes to the detailed technical objectives and overall technical margins, with a view to establishing option(s) of minimum cost still satisfying the overall programmatic objective of the ITER EDA Agreement,* and
- to *provide information on broader concepts as a basis for its rationale for proposed guidelines, and articulate likely impacts on the development path towards fusion energy.*

In reporting on the first task, the SWG[3] proposed revised guidelines for Performance and Testing Requirements, Design Requirements, and Operation Requirements, noting that *"preliminary studies ... suggest that the direct capital costs of ITER can be reduced significantly by targeting the less demanding performance objectives recommended..."* and expressing the view that *"these less demanding performance objectives will satisfy the overall programmatic objectives of the ITER Agreement even though these performance objectives are necessarily less than those that could be achieved with the present* [1998] *design."* Consequently, the ITER Council adopted the recommended revised guidelines and asked the Director *"to continue efforts with high priority toward establishing, option(s) of minimum cost aimed at a target of approximately 50% of the direct capital cost of the present design with reduced detailed technical objectives, which would still satisfy the overall programmatic objective of ITER.*"[4].

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[1] ITER Final Design Report, Cost Review and Safety Analysis, IC-13 ROD Attachment 6

[2] IC-13 ROD Attachment 10

[3] ITER Special Working Group Report to the ITER Council on Task #1 Results, EIC-1 ROD Attachment 1

[4] EIC-1 ROD 3.1

In addressing the second task, the SWG reviewed and compared two possible strategies for meeting the programmatic objective of demonstrating the scientific and technological feasibility of fusion, based on:

- an ITER-like machine, capable of addressing both scientific and technological issues in an integrated fashion, and
- a number of complementary lower cost experiments each of which would specialise on scientific/technological issues.

With regard to the second strategy, the SWG[5] found that the complex non-linear interactions between α-particle heating, confinement barriers and pressure and current profile control, and their compatibility with a divertor can be addressed only in an integrated physics/technology step like an ITER-type experiment, capable of providing long burn in conditions in which α-particles are the dominant source of plasma heating. A satisfactory understanding of these physics/plasma/technology interactions is essential to any reactor-oriented fusion development programme. Moreover the SWG expressed the unanimous opinion that the world programme is *"scientifically and technically ready to take the important ITER step."*

Given the instruction to address revised technical guidelines from SWG Task 1 and against the programmatic background of the SWG Task 2 conclusions, the main features of ITER design activities since July 1998 has therefore been:

- the study of options for cost reductions against the new, reduced, technical objectives by reducing plasma performance and technical margins, using the advances in physics and technology understandings, and tools arising out of the ITER collaboration to date, and
- the studied convergence towards a specific single design, following newly adopted guidelines.

As a result, it is now possible to define the key elements of a device, referred to as ITER-FEAT. This report provides the results to date of the joint work in the form of an Outline Design Report on the ITER-FEAT design, which, subject to the views of ITER Council and of the Parties, will be the focus of further detailed design work and analysis in order to provide to the Parties a complete and fully integrated engineering design within the framework of the ITER EDA extension.

A companion paper[6] which documents the Technical Basis to this report was presented to the ITER Technical Advisory Committee for review at its meeting on 20-22 December 1999, in Naka.

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[5] SWG report to the ITER Council on Task #2 Result, ITER Meeting 10-3-1999 ROM Attachment 5

[6] Technical Basis for the ITER-FEAT Outline Design, Draft for TAC review, 12 December 1999

Plasma Performance

The device should:

- *achieve extended burn in inductively driven plasmas with the ratio of fusion power to auxiliary heating power of at least 10 for a range of operating scenarios and with a duration sufficient to achieve stationary conditions on the timescales characteristic of plasma processes.*
- *aim at demonstrating steady-state operation using non-inductive current drive with the ratio of fusion power to input power for current drive of at least 5.*

In addition, the possibility of controlled ignition should not be precluded.

Engineering Performance and Testing

The device should:

- *demonstrate the availability and integration of technologies essential for a fusion reactor (such as superconducting magnets and remote maintenance);*
- *test components for a future reactor (such as systems to exhaust power and particles from the plasma);*
- *Test tritium breeding module concepts that would lead in a future reactor to tritium self-sufficiency, the extraction of high grade heat, and electricity production.*

Design Requirements

- *Engineering choices and design solutions should be adopted which implement the above performance requirements and make maximum appropriate use of existing R&D database (technology and physics) developed for ITER.*
- *The choice of machine parameters should be consistent with margins that give confidence in achieving the required plasma and engineering performance in accordance with physics design rules documented and agreed upon by the ITER Physics Expert Groups.*
- *The design should be capable of supporting advanced modes of plasma operation under investigation in existing experiments, and should permit a wide operating parameter space to allow for optimising plasma performance.*
- *The design should be confirmed by the scientific and technological database available at the end of the EDA.*
- *In order to satisfy the above plasma performance requirements an inductive flat-top capability during burn of 300 to 500 s, under nominal operating conditions, should be provided.*
- *In order to limit the fatigue of components, operation should be limited to a few 10s of thousands of pulses*
- *In view of the goal of demonstrating steady-state operation using non-inductive current drive in reactor-relevant regimes, the machine design should be able to support equilibria with high bootstrap current fraction and plasma heating dominated by alpha particles.*
- *To carry out nuclear and high heat flux component testing relevant to a future fusion reactor, the engineering requirements are*

  Average neutron flux ≥ 0.5 MW/m^2

  Average neutron fluence ≥ 0.3 MWa/m^2
- *The option for later installation of a tritium breeding blanket on the outboard of the device should not be precluded.*
- *The engineering design choices should be made with the objective of achieving the minimum cost device that meets all the stated requirements.*

Operation Requirements

The operation should address the issues of burning plasma, steady state operation and improved modes of confinement, and testing of blanket modules.

- *Burning plasma experiments will address confinement, stability, exhaust of helium ash, and impurity control in plasmas dominated by alpha particle heating.*
- *Steady state experiments will address issues of non-inductive current drive and other means for profile and burn control and for achieving improved modes of confinement and stability.*
- *Operating modes should be determined having sufficient reliability for nuclear testing. Provision should be made for low-fluence functional tests of blanket modules to be conducted early in the experimental programme. Higher fluence nuclear tests will be mainly dedicated to DEMO-relevant blanket modules in the above flux and fluence conditions.*
- *In order to execute this program, the device is anticipated to operate over an approximately 20 year period. Planning for operation must provide for an adequate tritium supply. It is assumed that there will be an adequate supply from external sources throughout the operational life.*

2.0 Revised Objectives

The revised performance specifications adopted by the ITER Council which are set out in full in the above Table, require, in summary:

- to achieve extended burn in inductive operation with $Q \geq 10$, not precluding ignition, with an inductive burn duration between 300 and 500 s, a 14 MeV average neutron wall load ≥ 0.5 MW/m^2, and a fluence ≥ 0.3 MWa/m^2;
- to aim at demonstrating steady-state operation using non-inductive current drive with $Q \geq 5$;
- to use, as far as possible, technical solutions and concepts developed and qualified during the EDA;
- to target about 50% of the direct capital cost of the 1998 ITER design with particular attention devoted to cash flow.

3.0 The approach to an Outline Design

System Studies

As a first approach to identifying designs that might meet the revised objectives, system codes were used which summarise in quantitative form the inter-relationships among the main plasma parameters, physics design constraints and engineering features, and can be combined with costing algorithms.

Such an analysis combines a detailed plasma power balance and boundaries for the plasma operating window, providing the required range of Q for the DT burn, with engineering concepts and limits. Four key parameters — aspect ratio, peak toroidal field, elongation, and burn flux — are intimately linked, allowing options in the systems analysis to be characterised principally by the aspect ratio (A), in addition to the device size, given by the major radius (R). Access to the plasma (e.g. for heating systems) and allowable elongation (simultaneously constrained by plasma vertical position and shape control and by the necessary neutron shield thickness), are functions of aspect ratio.

On this basis the system studies indicated a domain of feasible design space, with aspect ratios in the range 2.5 to 3.5 and a major radius around 6 m, able to meet the reduced requirements, with a shallow cost minimum across the range. The shallowness of the cost curve and the inevitable approximate nature of the system studies made it clear that no particular choice can be made on the optimal aspect ratio based on estimated costs alone. In addition, there are other important aspects whose cost or performance impact may not be easily factored into a systems optimization.

Study of representative options

In order to provide a basis for rigorous exploration and quantification of the issues and costings, representative options that span an appropriate range of aspect ratio and magnetic field were selected for further elaboration and more comprehensive consideration, as reported to the ITER meeting in Cadarache, March 1999[7].

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[7] Study of Options for the Reduced Technical Objectives/Reduced Cost (RTO/RC) ITER, (ROM 1999-03-10 Attachment 8)

The development of specific representative options provided a more tangible appreciation of the key issues and a practical framework for the process of convergence was explored and clarified in a joint JCT/Home Team "Concept Improvement Task Force" constituted in April 1999, following the guiding principles:

- to preserve as far as possible physics performance and margins against the revised targets, and the scope for experimental flexibility, within the cost target and relevant engineering constraints;
- to exploit the recent advances in understanding of key physics and engineering issues to be drawn from the results of the ITER voluntary physics programme and the large technology R&D projects;
- to maintain the priority given to safety and environmental characteristics, using the principles, analyses and tools developed through ITER collaboration to date.

The Task Force recommendations, presented to the Programme Directors' Meeting in Grenoble (July 1999)[8], were instrumental in developing consensus on the criteria and rationale for the selection of major parameters and concepts as the precursor to converging and integrating the various considerations into a single coherent outline design.

Intensive joint work through a JCT/Home Teams "Integration Task Force", has led to a single configuration for the ITER-FEAT design which represents an appropriate balance of the key technical factors and the cost target and the use of the conservative option for the energy confinement scaling.

[8] Study of options for the RTO/RC ITER, Director's Progress Report, ITER Meeting, Grenoble July 1999.

4.0 ITER-FEAT Parameters and Design Overview

The main parameters and overall dimensions of the ITER-FEAT plasma are summarised in Table 4.1 below. The figures show parameters and dimensions for nominal operation; figures in brackets represent maximum values obtaining in specific limiting conditions, including, in some cases, additional capital expenditures:

Table 4.1 Main Parameters and dimensions of ITER-FEAT plasma

Total fusion power	500 MW *(700 MW)*
Q — fusion power/auxiliary heating power	10
Average neutron wall loading	0.57 MW/m^2 *(0.8 MW/m^2)*
Plasma inductive burn time	≥ 300 s.
Plasma major radius	6.2 m
Plasma minor radius	2.0 m
Plasma current (I_p)	15 MA *(17 MA)*
Vertical elongation @ 95% flux surface/separatrix	1.70/1.85
Triangularity @ 95% flux surface/separatrix	0.33/0.49
Safety factor @ 95% flux surface	3.0
Toroidal field @ 6.2 m radius	5.3 T
Plasma volume	837 m^3
Plasma surface	678 m^2
Installed auxiliary heating/current drive power	73 MW *(100 MW)*

The ITER-FEAT facility comprises the following systems:

- the tokamak itself, consisting of a vacuum vessel and its internal components, a blanket and divertor, and superconducting magnets and associated structure);
- a cryoplant and cryodistribution;
- a pulsed electrical power supply;
- a cryostat and its associated thermal shields;
- a fuelling and exhaust system including an exhaust tritium processing system;
- a cooling water system;
- a plasma measurement (diagnostic) system;
- a heating and current drive system and its electrical power supply;
- buildings and services;

The initial assembly of the tokamak and its remote maintenance are also important elements of the ITER-FEAT design.

A cross-section of the tokamak showing the vacuum vessel, its internal components and its ports, as well as some features of the magnet system and cryostat, is shown in Figure 4.1. Figure 4.2 shows an overall schematic of systems important for normal operation, and Figure 4.3 shows an indicative site layout for the entire ITER-FEAT facility.

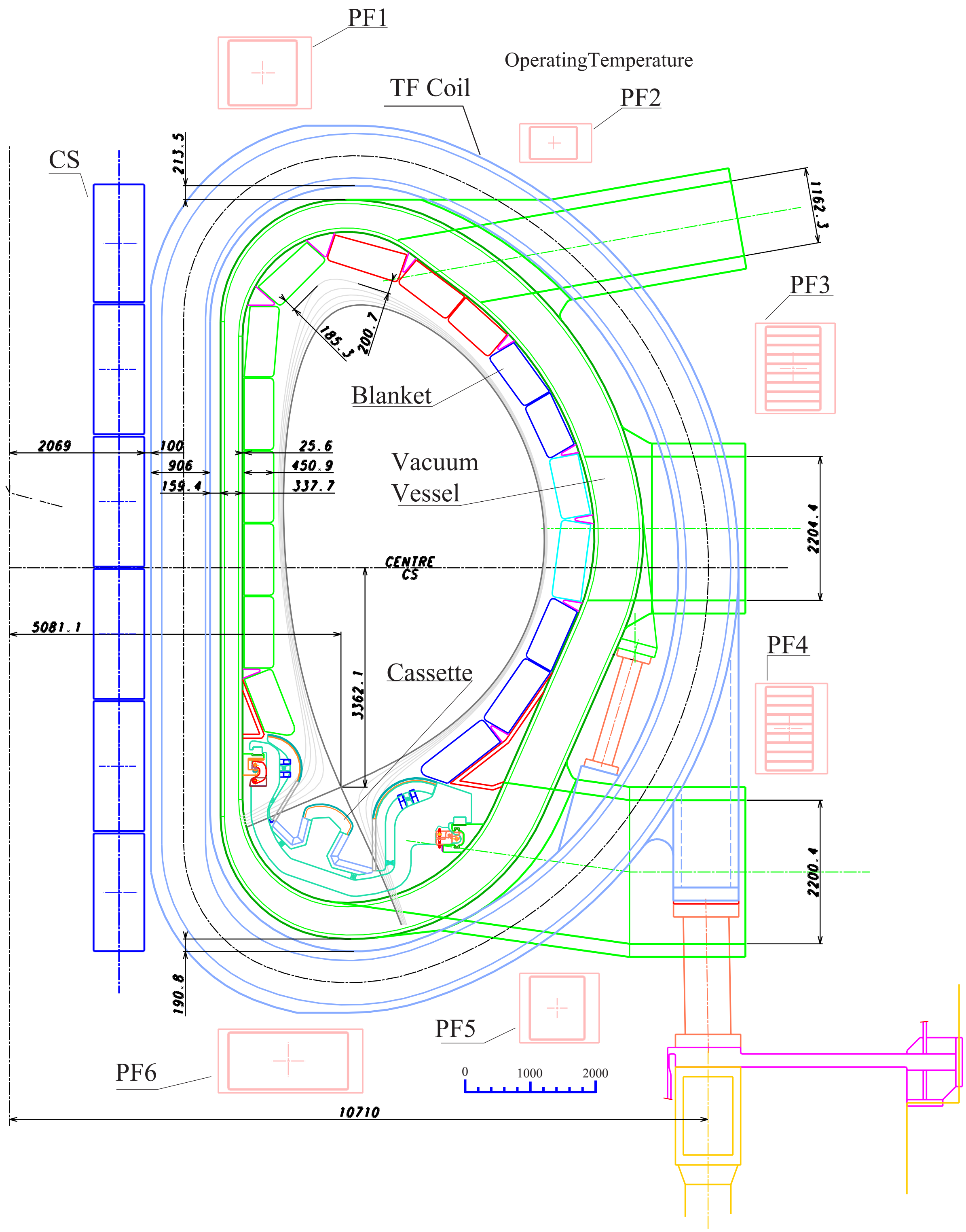

Figure 4.1 Cross-section of the ITER-FEAT tokamak

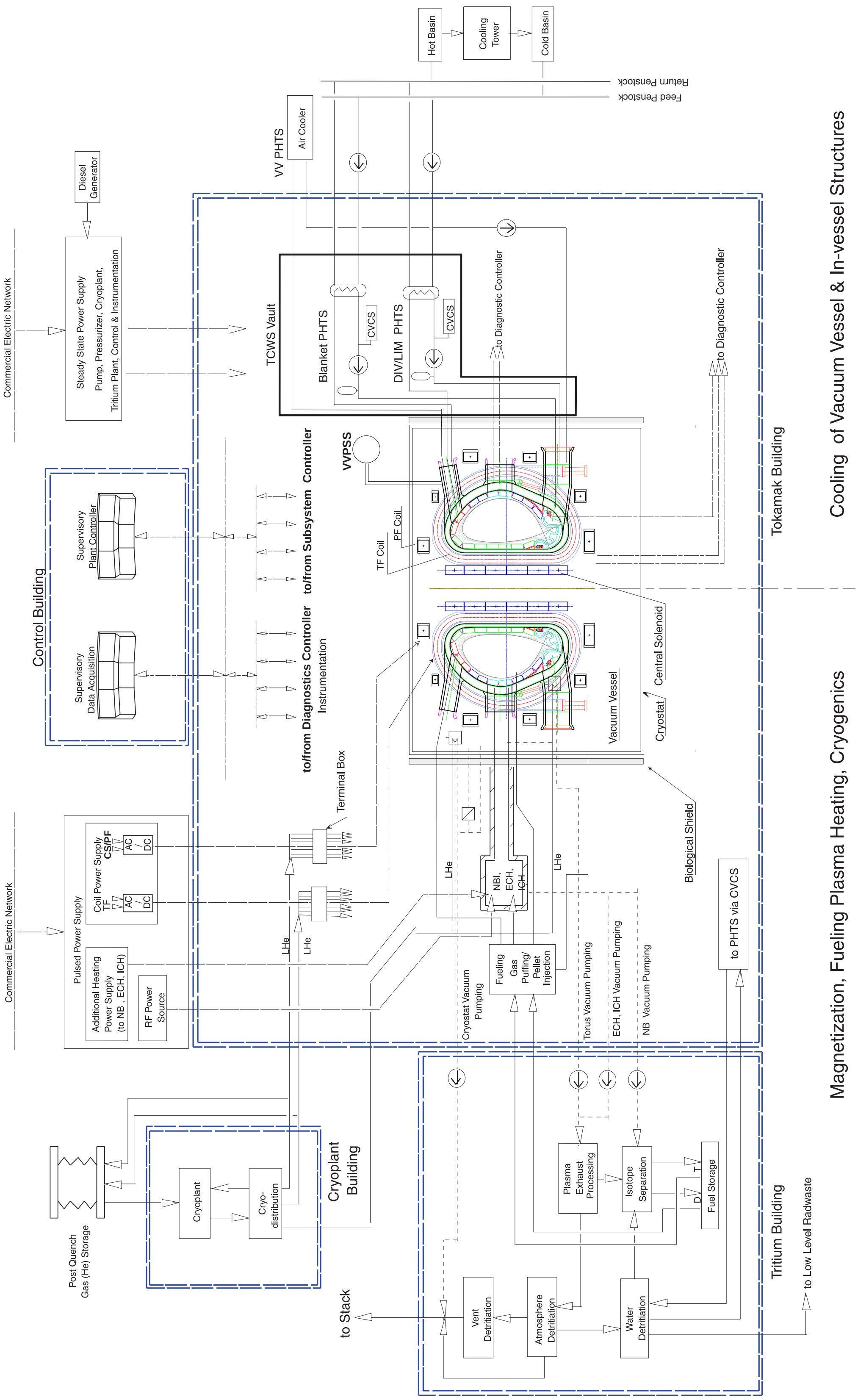

Figure 4.2 ITER-FEAT plant systems diagram

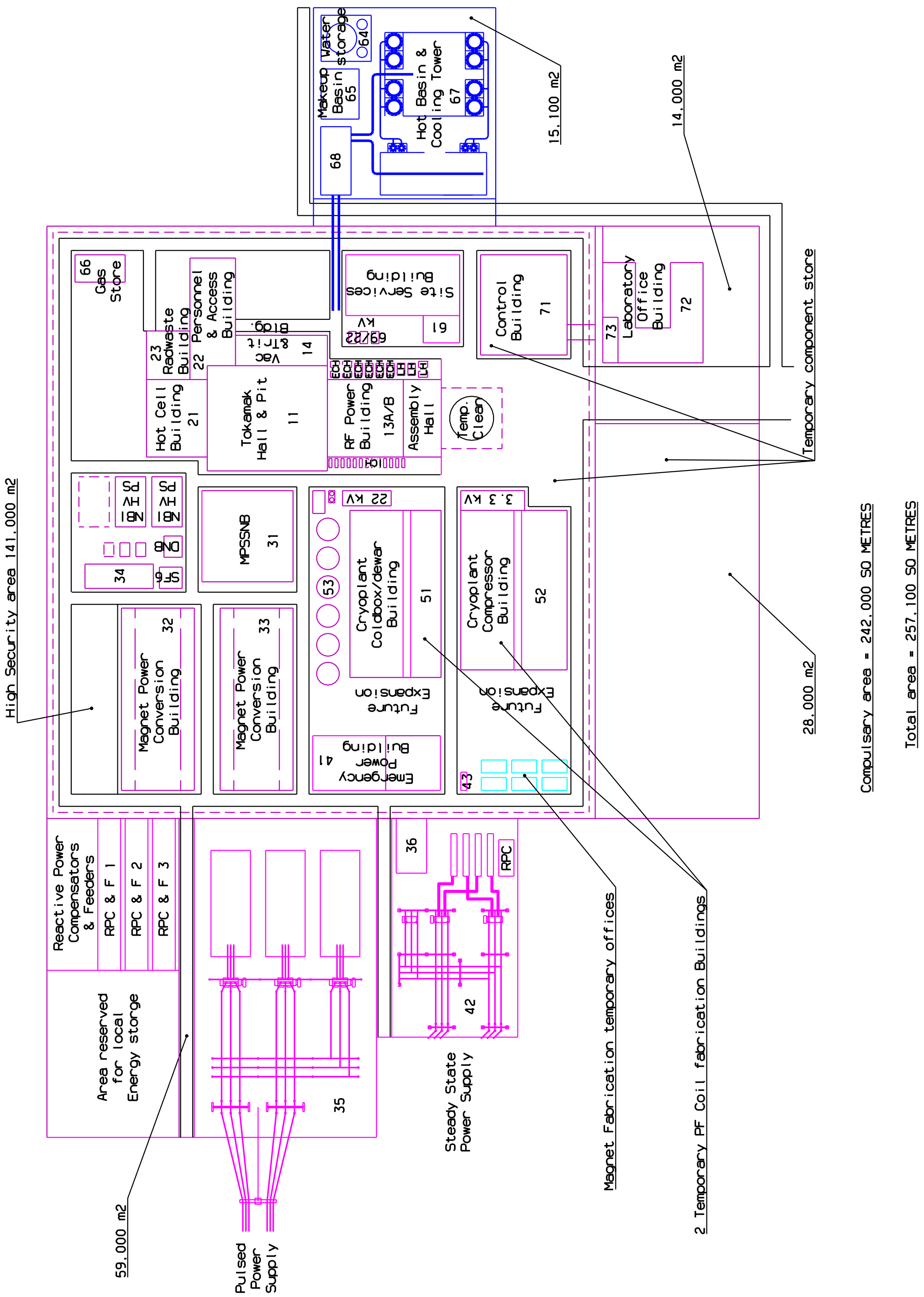

Figure 4.3 ITER-FEAT site and facilities layout

5.0 Physics basis and Plasma performance projections

Overview

The principal physics goals of ITER-FEAT are:

(i) to achieve extended burn in inductively driven plasmas with the ratio of fusion power to auxiliary heating power (Q) of at least 10 for a range of operating scenarios and with a duration sufficient to achieve stationary conditions on the timescales characteristic of plasma processes;

(ii) to aim at demonstrating steady-state operation using non-inductive current drive with a ratio of fusion power to input power for current drive of at least 5.

In addition, the possibility of higher Q operation will be explored if favourable confinement conditions can be achieved.

The reference operating scenario for ITER-FEAT inductive operation is the ELMy H-mode and the rules and methodologies for projection of plasma performance to the ITER scale are those established in the ITER Physics Basis (IPB)[9], which has been developed from broadly-based experimental and modelling activities within the magnetic fusion programmes of the ITER Parties.

The key physics issues relating to plasma performance in the ELMy H-mode regime are:

- the maintenance of H-mode quality confinement at sufficiently high density, achieving adequate plasma β to produce the requisite fusion power, and hence Q value;
- the provision of satisfactory power and particle exhaust to ensure acceptable levels of helium and plasma impurities;
- the evolution of plasma confinement phenomena scaling with size;
- efficient transfer of α-particle power to the thermal plasma while limiting anomalous α-particle losses, via TF ripple or collective instabilities, to prevent damage to the plasma-facing components.

At the same time, global magnetohydrodynamic (mhd) stability and plasma control capability must be such that the thermal and electromagnetic loads, as well as runaway electron currents, arising from disruptions are within acceptable bounds.

H-mode operation at high plasma density is favoured by the choice of a high plasma triangularity and the exploitation of high-field-side (‘inside’) fuel pellet launch, while the overall choice of design parameters allows considerable headroom for Q = 10 operation well below the Greenwald density. Plasma performance predictions show that Q = 10 operation can be achieved at modest values of β_N (~1.5). However, in the event that the β threshold for the onset of neoclassical tearing modes (NTMs) scales unfavourably with size to ITER-FEAT, stabilization of the modes by localized Electron Cyclotron Current Drive (ECCD) is foreseen.

Extensive divertor model validation and analysis activities performed so far during the EDA give confidence that the proposed divertor design allows adequate power dissipation in

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[9] ITER Physics Basis, ITER Physics Expert Groups et al, Nucl. Fusion, IAEA, Dec 1999

volume to be achieved, with peak time-averaged power loads below the acceptable level of 10 MWm^{-2}, and that the planned fuelling throughput of 200 Pam^3s^{-1} will limit the core helium concentration below 6%.

While the detailed evaluation of α-particle loss processes is still in progress, it is expected that the losses via TF ripple can be brought within acceptable limits by reducing the residual TF ripple level via ferromagnetic inserts. In many respects ITER-FEAT represents a key experimental step in the evaluation of α-particle losses due to collective effects at the reactor scale. Nevertheless, on the basis of studies carried out in support of the ITER FDR design, it appears unlikely that excitation of collective mhd instabilities, such as Alfvén eigenmodes, will limit plasma performance in ITER-FEAT inductive scenarios.

The development of plasma operation scenarios that exploit active profile control to access enhanced confinement regimes, which has occurred in the course of the EDA, has allowed greater emphasis to be placed on the use of such scenarios in ITER-FEAT. In particular, these regimes offer the prospect of establishing reactor-relevant steady-state operation in which a significant fraction of the plasma current is generated via the bootstrap effect. Flexibility in the ITER-FEAT design through plasma shaping, a mixture of heating and current drive systems, and mhd stability control techniques for NTMs and resistive wall modes (RWMs), favours the exploitation of plasma scenarios with either shallow monotonic or negative central shear. Although the precise conditions for the development of internal transport barriers (ITBs) are uncertain, the aim has been to provide ITER-FEAT with the necessary plasma control tools to facilitate access to such modes of operation. Moreover, sophisticated diagnostics of key profiles such as q, pressure, and rotation will be required to operate with a high level of reliability from the first phase of plasma experiments, and this has been acknowledged in assigning measurement priorities. The question of α-particle, losses via TF ripple losses or collective instabilities, is anticipated to be particularly acute in these regimes, and the design of the ferromagnetic inserts will reflect this consideration. Predictions of steady-state operation in ITER-FEAT, therefore, build upon these recent developments and reflect the expectation that considerable further progress can be achieved in the fusion programme in the future to resolve remaining uncertainties.

Physics Basis and Selection of Plasma Parameters

The reference plasma scenario for inductive Q = 10 operation, the ELMy H-mode, is a reproducible and robust mode of tokamak operation with a demonstrated long-pulse capability. The essential physics which enters into the prediction of plasma performance in ITER-FEAT derives from the two principal ELMy H-mode scalings, i.e. the H-mode power threshold scaling, which defines the lower boundary of the device operating window in terms of fusion power, and the energy confinement time scaling. The recommended form for the former scaling is,

$$P_{LH} = 2.84 M^{-1} B_T^{0.82} \bar{n}_e^{0.58} R^{1.00} a^{0.81} \qquad \text{(rms err. 0.268)}$$

in (MW, AMU, T, $10^{20}m^{-3}$, m), with M the effective isotopic mass of the plasma fuel. This scaling expression is based on the latest version of the threshold database (DB3) extended with results from recent dedicated H-mode threshold experiments in Alcator C-Mod and in JT-60U, the latter using the new ‘W’ shaped divertor. For ITER-like devices, this scaling yields an H-mode power threshold prediction which is approximately a factor of 2 lower than that predicted by an earlier version (IPB98(5)). There is, however, evidence from JET and

JT-60U that the heating power should be 1.3-1.5 times higher than the H-mode threshold to obtain a good H-mode confinement. Therefore, a boundary corresponding to $1.3P_{L\text{-}H}$ is also taken into account in the analysis of performance.

Thermal energy confinement in the type I ELMy H-mode is described by the IPB98(y,2) scaling,

$$\tau_{E,th}^{IPB98(y,2)} = 0.0562 I_p^{0.93} B_T^{0.15} P^{-0.69} n_e^{0.41} M^{0.19} R^{1.97} \varepsilon^{0.58} \kappa_x^{0.78} \qquad \text{(rms err. 0.145)}$$

where the units are (s, MA, T, MW, 10^{19}m^{-3}, AMU, m) and the elongation κ_a is defined as $\kappa_a = S_o/(\pi a^2)$ with S_o being the plasma cross-sectional area. A comparison of the H-mode thermal confinement times with the scaling for a subset of ELMy data in the ITER H-mode database is shown in Figure 5.1.

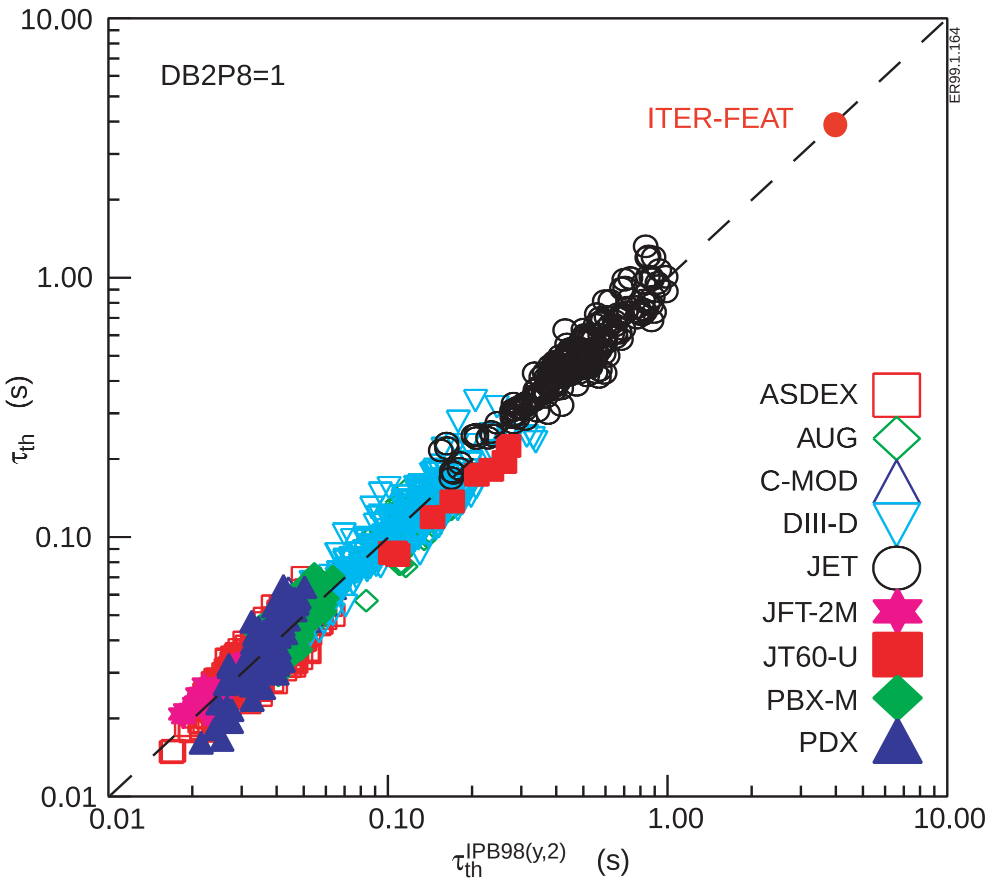


Figure 5.1 Comparison of ELMy H-mode thermal energy confinement times with the scaling expression IPB98(y,2) and scaling prediction for the energy confinement time in a nominal ITER-FEAT Q = 10 discharge.

IPB98(y,2) has been selected as a conservative option from among five empirical log-linear (power law) scaling expressions for the energy confinement time reviewed by the Physics Expert Group concerned. Other projections which include the (ohmic) H-mode data from small tokamaks predict ~ 20% higher confinement for an ITER-like machine.

• The principal mhd stability constraints which contribute to the definition of the device performance relate to the plasma current, elongation, plasma density, and plasma pressure.

1. There is now an extensive energy confinement database for plasmas with $q_{95} \sim 3$, and proven experience in operation with low disruption frequency. A quantitative analysis of disruption frequency on several tokamaks has shown that ITER's goal of achieving an initial disruption frequency of 10% has been attained in existing devices, with no specific problems due to proximity to $q_{95} = 3$. Although recent experiments found no significant degradation of confinement with decreasing q_{95} over the range $2.3 \leq q_{95} \leq 4$, selection of a lower q_{95} operating point would reduce performance margins (particularly for higher Q operation) and might also impair steady-state capability. Therefore, $q_{95} = 3$ has been retained as an acceptable compromise between good energy confinement and satisfactory mhd stability properties although flexibility to accommodate discharges with higher currents ($q_{95} \sim 2.7$) at reduced pulse length is under study.

2. Plasma shaping capability (elongation and triangularity) derives from a consideration of axisymmetric plasma stability and power required to maintain the plasma vertical position, equilibrium control including inner divertor leg length, limits to the acceptable vacuum vessel forces during a vertical displacement event, and the advantages in confinement which may accrue, both from a higher current capability and from direct dependencies of energy confinement on shaping parameters. The range of issues involved in determining the optimum shaping capability has motivated a reassessment of the shaping parameters for ITER-FEAT.

   An examination of the H-mode global confinement database confirms that the confinement times from JET and DIII-D are consistent with the IPB98(y,2) scaling up to the highest available values of κ_{95} (~ 1.8 at $q_{95} \leq 3.5$). Nonetheless, in view of studies that show difficulties in maintaining vertical position control within an acceptable range of PF circuit power and coil voltage if only the passive stabilisation of the vacuum vessel and the active stabilisation action of external poloidal field coils are employed, an elongation of $\kappa_{95} = 1.7$ ($\kappa_X \approx 1.84$) has been selected for the reference parameter.

   Although there is no explicit dependence of energy confinement time on triangularity, the high triangularity of the ITER-FEAT design ($\delta_{95} \approx 0.33$ or $\delta_x \approx 0.49$) reflects several potential advantages:

   - the current-carrying capability of the device, and hence confinement capability, is linked to triangularity through $q_{95;}$
   - recent results from JET, demonstrate that operation at higher triangularity allows high confinement to be maintained at densities close to the Greenwald value, a result which has been confirmed in ASDEX Upgrade.;
   - in steady-state scenarios, where the pressure and current profiles are closely linked, it has been predicted that the β-limit should benefit from higher triangularity.

   One possible disadvantage is that the type I ELM frequency is known to decrease with increasing triangularity (increasing edge shear) and the resultant increase in the amplitude of heat pulses which may be produced by lower frequency ELMs is likely to lead to increased erosion of the divertor target.

3. The choice of an aspect ratio of 3:1 is a compromise between the benefits of lower aspect ratio such as lower magnetic field values and a larger margin relative to the H-mode power threshold and those associated with higher ratios such as higher plasma

densities. Practical considerations of accessibility and of maintaining acceptable margins for equilibrium and vertical stability control, also figure in the judgement.

4. The $\beta^2 B^4$ dependence of fusion power motivates operation at the highest attainable β. However, in recent years, neoclassical tearing modes (NTMs) have been shown to limit the achievable β_N (= β(%)/[I_p(MA)/a(m)B(T)]) in ELMy H-mode plasmas to values below the ideal limit, $\beta_N \sim 3.5$, and this instability might occur in the ITER-FEAT target range of $\beta_N \sim 1.5$-2.5, leading to degradation of confinement (or disruptions). A stabilization technique for NTMs based on electron cyclotron current drive is, however, yielding promising results on present experiments and its application is foreseen in ITER-FEAT to allow control of such modes if necessary. Nevertheless, the assumption $\beta_N \leq 2.5$ has been taken as a pragmatic limit for calculations of the ITER-FEAT operating window.

5. Optimum use of the plasma pressure for fusion power production implies that densities in the vicinity of (and, in power plants, perhaps beyond) the Greenwald density ($\bar{n}_{GW}(10^{20}\,m^{-3}) = I_p(MA)/\pi a^2(m)$) be attained. Although it has traditionally been difficult to maintain H-mode confinement at densities close to the Greenwald value, experiments at higher triangularity have obtained H-mode quality confinement at 80% of the Greenwald density. In addition, experiments with inside pellet launch and recent experiments with pumping at both the inboard and outboard divertor strike points have sustained H-mode level confinement at densities beyond the Greenwald value. On the basis of these results, the conservative assumption $\bar{n}_e \leq n_{GW}$ is used to limit the density range foreseen for the ITER-FEAT reference regime. In addition, as is below, ITER-FEAT can achieve its mission of Q = 10 at a normalized density of $n/n_{GW} \sim 0.6$, and inside pellet launch will be available to facilitate high-density operation.

• Several other physics considerations constrain the operating window of the chosen device. In particular, it has been decided to retain a single-null diverted equilibrium, since the scaling of the H-mode threshold power is more favourable in single null, as opposed to double null, plasmas. Moreover, the difficulty of maintaining a double null equilibrium which is fully up-down symmetric with respect to power handling is likely to impose unrealistic requirements on the accuracy of plasma vertical position control.

• Scrape-off layer and divertor behaviour influences plasma performance in several ways, but the principal issues for ITER-FEAT performance projections are the peak power to the divertor target, plasma helium fraction, and core plasma impurity content. There is substantial experimental evidence that helium exhaust rates are determined by the divertor throughput, rather than by helium transport rates in the bulk plasma, and that $\tau^*_{He} / \tau_E \sim 5$ can be achieved under relevant plasma conditions with the projected throughput of 200 Pam^3s^{-1}. This would limit helium fractions in ITER-FEAT to acceptable levels, below 6%.

Domains of inductive operation

Based on the physics considerations and constraints outlined above, and with the major dimensionless geometrical parameters determined, it is possible to identify major radius and plasma current on the basis of the requirement that Q = 10 be achieved, that acceptable performance margins can be maintained, and that the projected cost of the device falls within the required range. Smaller devices are more attractive from the cost point of view, but provide smaller margins for Q = 10, lesser likelihood of accessing Q > 10 and less flexibility to explore varying modes of operation. Increasing the size increases the operational domain and the margins but at an inevitable increase in cost. The reference parameter set, having a plasma major radius of 6.2 m and plasma current of 15 MA, was selected as it offers a satisfactory margin for Q ≥ 10 operation, has adequate flexibility and its cost satisfies the target.

Table 5.1. Nominal parameters of ITER-FEAT in inductive operation

Parameter	Units	Reference Q = 10	High Q, high P_{fus}	Parameter	Units	Reference Q = 10	High Q, high P_{fus}
R/a	m/m	6.2 / 2.00	6.2 / 2.00	P_{aux}	MW	40	23
Volume	m^3	837	837	P_{ohm}	MW	1.3	1.7
Surface	m^2	678	678	P_{tot}	MW	123	144
Sep.length	m	18.4	18.4	P_{brem}	MW	21	29
$S_{cross-sect.}$	m^2	21.9	21.9	P_{syn}	MW	8	10
B_T	T	5.3	5.3	P_{line}	MW	19	20
I_p	MA	15.0	17.4	P_{rad}	MW	48	59
κ_x / δ_x		1.86 / 0.5	1.86 / 0.5	P_{fus}	MW	410	600
$\kappa_{95} / \delta_{95}$		1.7 / 0.35	1.7 / 0.35	P_{sep} / P_{LH}	MW/ MW	75/48	84/53
$l_i(3)$		0.86	0.78	Q		10	24
V_{loop}	mV	89	98	τ_E, s		3.7	4.1
q_{95}		3.0	2.7	W_{th}	MJ	325	408
β_N		1.77	1.93	W_{fast}	MJ	25	33
$<n_e>$	$10^{19}\,m^{-3}$	10.14	11.56	$H_{H-IPB98(y,2)}$		1.0	1.0
n/n_{GW}		0.85	0.84	τ_α^* / τ_E		5.0	5.0
$<T_i>$	keV	8.1	9.1	Z_{eff}		1.65	1.69
$<T_e>$	keV	8.9	9.9	$f_{He,axis}$	%	4.1	5.9
$<\beta_T>$	%	2.5	3.2	$f_{Be,axis}$	%	2.0	2.0
β_p		0.67	0.62	$f_{C,axis}$	%	0.0	0.0
P_α	MW	82	120	$f_{Ar,axis}$	%	0.12	0.11

Performance calculations using the agreed physics guidelines yield a substantial operating window for Q ≥ 10 inductive operation for the selected parameter set.

Parameters of two representative plasmas in ITER-FEAT are listed in Table 5.1 The first column shows a reference Q = 10 discharge with the nominal plasma current of 15 MA and a fusion power of 400 MW, while the second column tabulates parameters for a regime with higher current, I_p = 17.4 MA ($q_{95} \sim 2.6$), that has the potential for a higher Q of ~ 25 and higher fusion power of ~ 600 MW, although with potentially higher risk of plasma disruption. In these simulations, the total power exhausted to the divertor target is held below 30 MW.

To illustrate the range of performance which can be achieved in ITER-FEAT, Figures 5.2 and 5.3 show values of P_{fus} and Q as a function of the auxiliary heating power for discharges with I_p = 13.1, 15.1 and 17.4 MA in which an operating point having $H_{H-IPB9(y,2)} = 1$ and $n/n_{GW} = 0.85$ is selected. The minimum fusion power at 15.1 and 13.1 MA is limited by the L-H back transition, taken as $1.3 \times P_{LH}$. There is a strong increase in Q and P_{fus} with the plasma current and a strong increase in Q with reducing the auxiliary heating power. This emphasizes the fact that the operation space is multidimensional and that plasma parameters can be adjusted to optimize the fusion performance according to whether high Q or high fusion power (e.g. to maximize the neutron wall loading) is required.

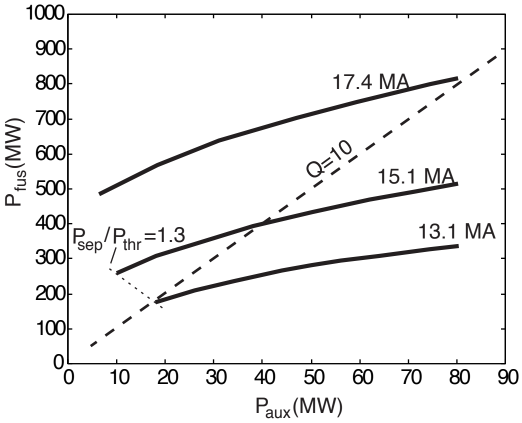


Figure 5.2 P_{fus} as a function of P_{aux} for I = 13.1, 15.1 and 17.4 MA at $H_{H\text{-}IPB9(y,2)}$ = 1 and n/n_{GW} = 0.85.

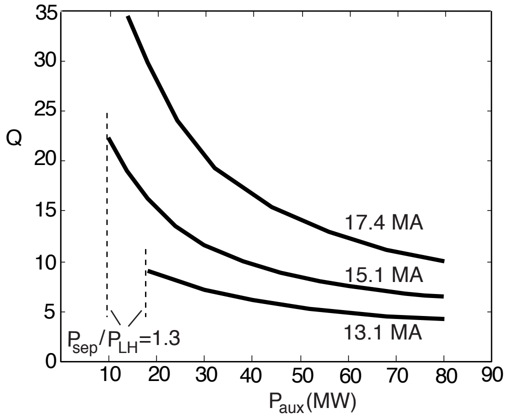


Figure 5.3 Q as a function of P_{aux} for I = 13.1, 15.1 and 17.4 MA at $H_{H\text{-}IPB9(y,2)}$ = 1 and n/n_{GW} = 0.85.

A more complete view of the range of plasma parameters at which Q = 10 operation is possible can be gained from an analysis of the operational domain in terms of fusion power and confinement enhancement factor, in which the various operational boundaries (P_{loss} = 1.3P_{LH}, n = n_{GW}, and β_N = 2.5) can also be traced, as shown in Figure 5.4 and Figure 5.5. Inside the indicated domain the Q = 10 is maintained, but the auxiliary power is adjusted together with the density.

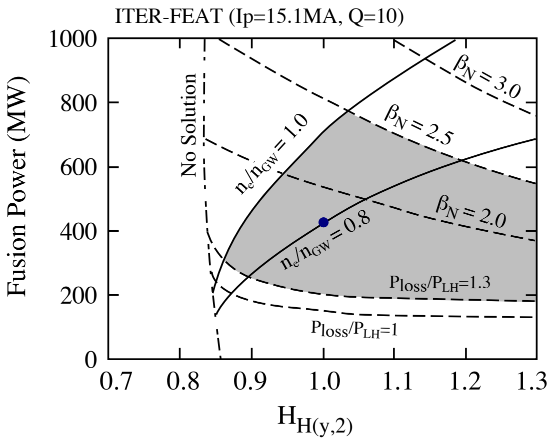


Figure 5.4. Q = 10 domain (shaded) for I_p = 15.1 MA (q_{95} = 3.0).

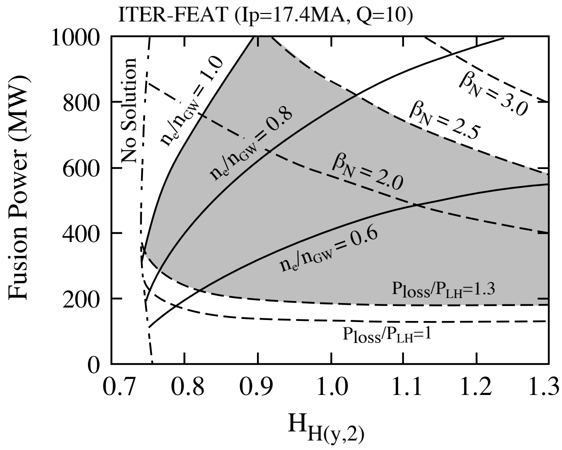


Figure 5.5 Q = 10 domain (shaded) for I_p = 17.4 MA (q_{95} = 2.6).

It is evident from the above, that:

- for operation at q_{95} = 3 the fusion output power from the ITER-FEAT design is in the region of 200-600 MW (at $H_{H(y,2)}$ = 1), corresponding to a mean separatrix neutron flux ('mean neutron wall loading') of 0.29-0.86 MWm^{-2}, so that the device retains a significant capability for technology studies, such as tests of tritium breeding blanket modules;
- the margin in H-mode threshold power (at $H_{H(y,2)}$ = 1) is significantly greater than the predicted uncertainty derived from the scaling;

- the device has a capability for Q = 10 operation at n/n_{GW} ~ 0.6 and β_N ~ 1.5 (when $H_{H(y,2)} = 1$).

The results also illustrate the flexibility of the design, its capacity for responding to factors which may degrade confinement while maintaining its goal of extended burn Q = 10 operation, and, by implication, its ability to explore higher Q operation as long as energy confinement times consistent with the confinement scaling are maintained.

For instance, Figures 5.6 (I_p = 15.1 MA) and 5.7 (I_p = 17.4 MA) illustrate the window for higher Q operation (Q = 50, representative of 'controlled ignition') in ITER-FEAT, showing that controlled ignition is not precluded: operation at a range of Q values is possible and values as high as 50 can be attained if $H_{98(y,2)}$ ~ 1.2 is achieved in a improved confinement mode, e.g. reversed shear or shallow shear mode with internal transport barrier, or high density operation can be extended beyond the Greenwald value, or operation at lower q_{95} (~ 2.6) can be sustained without confinement degradation.

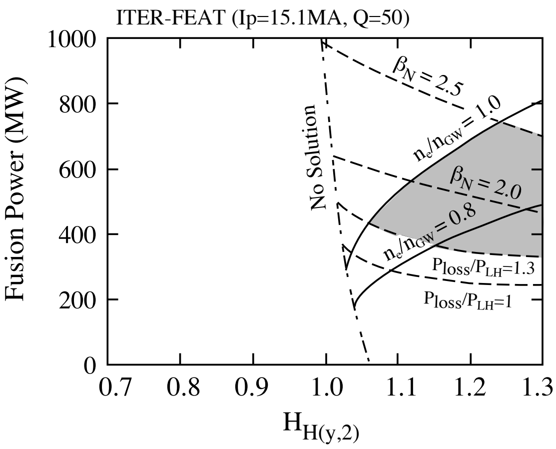


Figure 5.6. Q = 50 domain for I_p = 15.1 MA (q_{95} = 3.0).

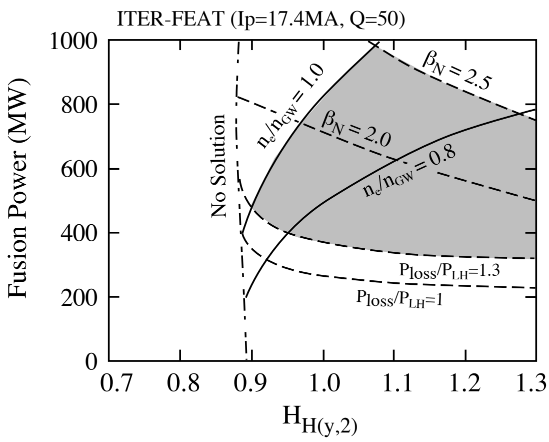


Figure 5.7. Q = 50 domain for I_p = 17.4 MA (q_{95} = 2.6).

Operating Flexibility

The design is capable not only of studying the standard operating regime, but also incorporates the flexibility and extended capability to achieve enhanced performance within the cost constraint. Several aspects of the design address the issue of pressing the boundaries of the operating domain and of accommodating uncertainties in physics predictions. For example, the inclusion of inside pellet launch opens the route towards operation at high density. Moreover, a variety of active feedback control techniques are provided for the stabilization of mhd instabilities. Active current profile control techniques could also provide an additional tool for the control of mhd activity. To extend the achievable range of Q values (and to counteract any unforeseen degradation of confinement), the possibility of operating the device with plasma currents up to ~ 17.4 MA (q_{95} ~ 2.6) is being explored, albeit at reduced pulse length (>100 s). Finally, the capability of operation at fusion powers up to 40% higher than the reference value (though under the assumption of no increase in total neutron fluence) is included in the design to enhance the possibility of ignited operation and to accommodate the possibility that higher β values than assumed are achieved.

Steady-state and hybrid operation

A complete scenario for steady-state operation with Q = 5 which treats energy confinement plasma profiles, current drive requirements, divertor performance and plasma equilibrium self-consistently, and which satisfies all relevant constraints is yet to be developed. In ITER it is likely that a variety of candidate steady-state modes of operation will be investigated and it is therefore essential that the requisite tools for the control of plasma geometry and profiles are available for on-axis and off-axis current drive capabilities to enable plasmas with shallow or reversed shear configurations to be sustained, in the latter regime simultaneously maintaining the central safety factor well above unity, while the minimum safety factor is held above two; a poloidal field system capable of controlling the more highly shaped plasmas characteristic of high-β_p operation; and methods to allow reliable long pulse operation at high-β, including techniques for the stabilization of neoclassical tearing modes and resistive wall modes.

The capability of the ITER-FEAT designs for steady-state operation with Q = 5 are being studied numerically using 0-dimensional analysis within the limitations of current assumptions. Two operational scenarios are under consideration for steady-state operation: high current (12 MA) with monotonic q or shallow shear, and modest current (8 MA) with negative shear. The high current steady-state operation requires all the current drive power (100 MW) available for ITER-FEAT, but the requirements on confinement ($H_H \sim 1.2$) and beta ($\beta_N \sim 3$) are modest. On the other hand, the low current steady-state operation requires more challenging values of confinement improvement $H_H \sim 1.5$ and beta ($\beta_N \sim$ 3.2-3.5). Performance predictions for this mode of operation are much less certain than for inductive operation and high current steady-state operation. In particular, the operating space is sensitive to assumptions about current drive efficiency and plasma profiles.

In addition, the potential performance of hybrid modes of operation, in which a substantial fraction of the plasma current is driven by external heating and the bootstrap effect, leading to extension of the burn duration, is being evaluated as a promising route towards establishing true steady-state modes of operation. This form of operation would be well suited to systems engineering tests.

An operation space, in terms of fusion power versus confinement enhancement factor, and showing the transition from hybrid to true steady-state operation is illustrated in Figure 5.8 for I_p = 12 MA and P_{CD} = 100 MW. Contours of constant n/n_{GW} and β_N are indicated, as is the threshold for Q = 5 operation. It is assumed that the plasma minor radius is reduced by shifting the magnetic axis outward. For a given value of fusion power (and hence Q), as the confinement enhancement factor, $H_{IPB98(y,2)}$, increases (simultaneously decreasing plasma density and increasing β_N), the plasma loop voltage falls towards zero. For example, operation with V_{loop} = 0.02 V and I_p = 12 MA, which corresponds to a flat-top length of 2,500 s, is expected at $H_{IPB98(y,2)}$ = 1, Q = 5, n_e/n_{GW} = 0.7, and β_N = 2.5. True steady-state operation at Q = 5 can be achieved with $H_{IPB98(y,2)}$ = 1.2 and β_N = 2.8. This analysis indicates that a long pulse mode of operation is accessible in ITER-FEAT.

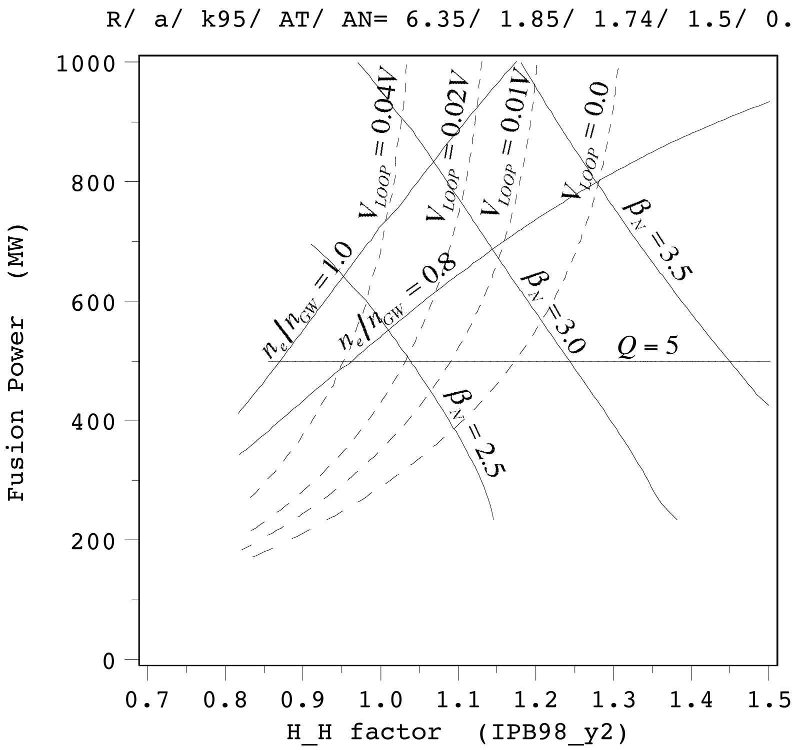


Figure 5.8 Operation space for ITER-FEAT for hybrid (long pulse) and steady-state operation. Here, I_p = 12 MA and P_{CD} = 100 MW.

Probabilistic Performance Analysis

As with any extrapolation from current experience to unprecedented domains, there are unavoidable ranges of uncertainty on either side of the performance projections for ITER.

To provide an evaluation of the probability of achieving a fusion gain of Q ≥ 10 in ITER-FEAT, an analysis based only on the estimated uncertainty in the form of the confinement scaling has been developed. This approach does not provide information on, for example, the probability of achieving a specified fluence, since many other factors influencing the average duty cycle and total operational time of the device must be considered.

It is assumed that the energy confinement time (or, in practice, the $H_{H(y,2)}$ factor) for a given set of plasma parameters can be described by a Gaussian distribution having a standard deviation of either 10% or 20% about the mean value. However, for similar discharge conditions, the distribution of $H_{H(y,2)}$ in the database has a smaller spread: for example, with $n_e/n_{GW} \geq 0.65$, $q_{95} \leq 3.5$, $P_{RAD}/P_{HEAT} \leq 0.5$ and $\kappa \geq 1.5$, the spread of $H_{H(y,2)}$ values in the database is only 5%. This illustrates the important point that only a fraction of the scatter in the experimental data is associated with irreproducibility in discharge conditions.

Using conservative operating conditions, it is possible to delineate operation domains for various values of auxiliary heating, which when integrated with the assumed probability density function for H_H, allows to quantify the probability that Q exceeds a given Q_0 value. Combining the analysis for the range of values generates a family of probability curves values that can be used to summarise the overall probability to achieve a target Q value. This analysis is illustrated in Figure 5.9 for the case of σ = 20%, and is summarised in Figures 5.10 and 5.11 for σ = 10% and 20%, and for values of plasma current at 15.1 MA and 17.4 MA respectively.

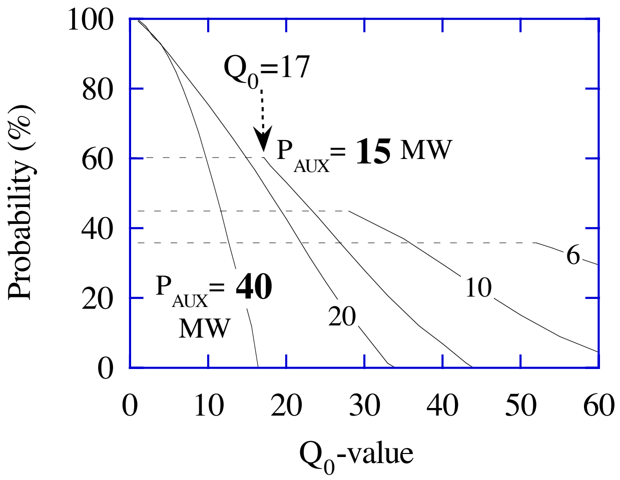


Figure 5.9 Probability of achieving $Q \geq Q_0$ in ELMy H-mode for a range of fixed heating powers, P_{AUX}, when σ = 20%. Here $n_e/n_{GW} \leq 0.85$ and $\beta_N \leq 2.5$. The flat part of each curve corresponds to $P_{loss} \leq P_{LH}$ (at P_{AUX} = 6, 10, 15 MW). In these cases the probability of $Q \geq Q_0$ is equal to that of $Q \geq Q_{MAX}$, where Q_{MAX} is the value which gives the maximum probability.

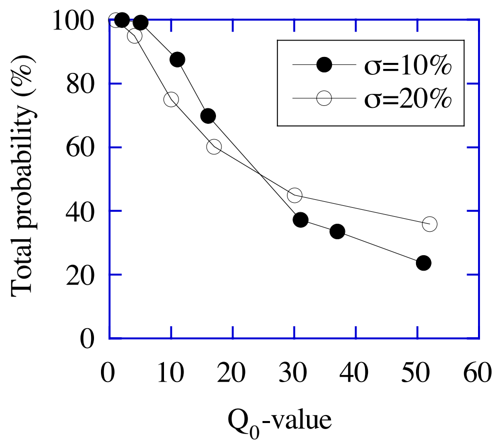


Figure 5.10. Probability of achieving $Q \geq Q_0$ in ELMy H-mode for σ = 10% and 20% with I_p = 15.1 MA, $n_e/n_{GW} \leq 0.85$ and $P_{loss} \geq P_{LH}$.

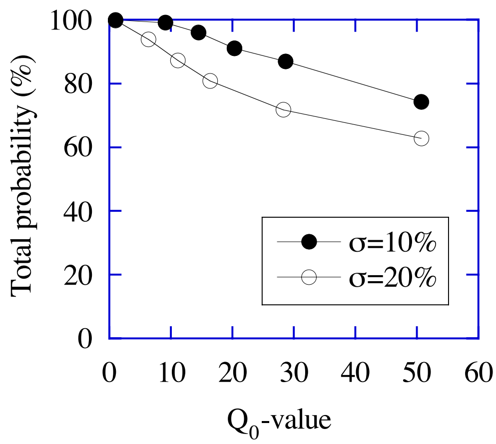


Figure 5.11 Probability of achieving $Q \geq Q_0$ in ELMy H-mode for σ = 10% and 20% with I_p = 17.4 MA, $n_e/n_{GW} \leq 0.85$ and $P_{loss} \geq P_{LH}$.

On this basis, the probability of achieving Q ≥ 10 in the ELMy H-mode regime is high. However, if for unexpected reasons Q ≥ 10 were not achieved under nominal operating conditions, there are, as noted previously, various options for increasing the probability of achieving the required Q. For example, raising the plasma current to 17.4 MA increases the probability of achieving Q ≥ 10 to ~ 90% and 100% if σ= 20% and 10% respectively. Another option is to increase the fuel throughput in the divertor beyond the reference value of 200 Pam^3s^{-1} to, say, 400 Pam^3s^{-1} (which can be maintained for 200 s), allowing the helium concentration to be reduced by 2% (incremental), which, in fusion performance terms, is equivalent to a 1 MA increase in plasma current. Furthermore, regimes with active profile control could allow enhanced confinement to be accessed in inductive operation.

The probability calculation outlined above is essentially a 'model' calculation, i.e. it represents a numerical result based on simple, well-defined assumptions. It does not, however, amount to a complete evaluation of the true probability of achieving $Q \geq 10$. In addition, it is a model calculation carried out in only one dimension of the multi-dimensional operating space which describes a burning plasma and it neither fully reflects the complexity of the behaviour close to operating limits, nor the degree to which experimental optimization of plasma parameters can improve plasma performance. In summary, the optimum operating point of a tokamak plasma consists neither of a random selection of parameters, nor a random response to the operating conditions selected, but corresponds, rather, to a well-defined and reproducible plasma state resulting from extensive experimental development.

Deterministic assessment of performance

As observed above, the uncertainty in extrapolation of the energy confinement time along the scaling law — expressed in a probability distribution of the scalar H_H around a mean value — includes, from a statistical analysis, the consequences on confinement performance from varying machine operating conditions, particularly when their non-dimensional plasma parameters approach their respective limits. As examples, the effect of magnetic shear (from δ,q,κ,A) on confinement in high density discharges, or the effect of saw teeth on low-edge-safety-factor discharges at higher elongation and triangularity are not obviously reflected in the scaling law.

To overcome some of these difficulties, a deterministic procedure has been established so as to define a more focussed experiment, similar in all non-dimensional parameters to a fully documented experiment available in the database from present machines.

- Each discharge from the database is used to size, by means of a system code (in accordance with ITER engineering criteria) a Q = 10 machine with the same geometry and parameter values for κ,δ,A,q_{95} and n/n_{GW} as in the experimental case.
- As a first step the extrapolation in the energy confinement time is performed using a ratio to the experimental value coming from the relative values of the parameters not kept constant as follows:

$$\frac{\tau_{E,Q10}}{\tau_{E,Ex}} = \left(\frac{P_{Q10}}{P_{Ex}}\right)^{\gamma_P} \cdot \left(\frac{B_{Q10}}{B_{Ex}}\right)^{\gamma_B} \cdot \left(\frac{R_{Q10}}{R_{Ex}}\right)^{\gamma_R} \cdot \left(\frac{M_{Q10}}{M_{Ex}}\right)^{\gamma_M}$$

  From the dimensionally correct IPB98(y,2) scaling law,

  $\gamma_P = -0.69$, $\gamma_B = 1.49$, $\gamma_R = 2.49$, $\gamma_M = 0.19$

  From the more than 1000 discharges in the ELMy H-mode database, only half of them turn out to extrapolate to a Q = 10 machine of major radius smaller than 8 m, 70 to a radius smaller than 6.2 m and only a few to radius smaller than 6 m, the smallest value being 5.6 m with $q_{95} = 3.0$.
- As a second step, a more general case is worth considering, which avoids completely the use of empirical scaling formula, the extrapolated device being sized to obtain a required fusion power (and not a Q value) from experimental discharges with the same parameter package as before and, in addition, a fixed value for β_N.

  In this case, Figure 5.12 shows the major radius versus the safety factor q_{95} for all machines extrapolated from experimental discharges and capable of 500 MW of fusion power. A good number of discharges can be extrapolated to 500 MW devices of radius between 6 and 6.2 m (although the relevant values of Q cannot be determined in this case).

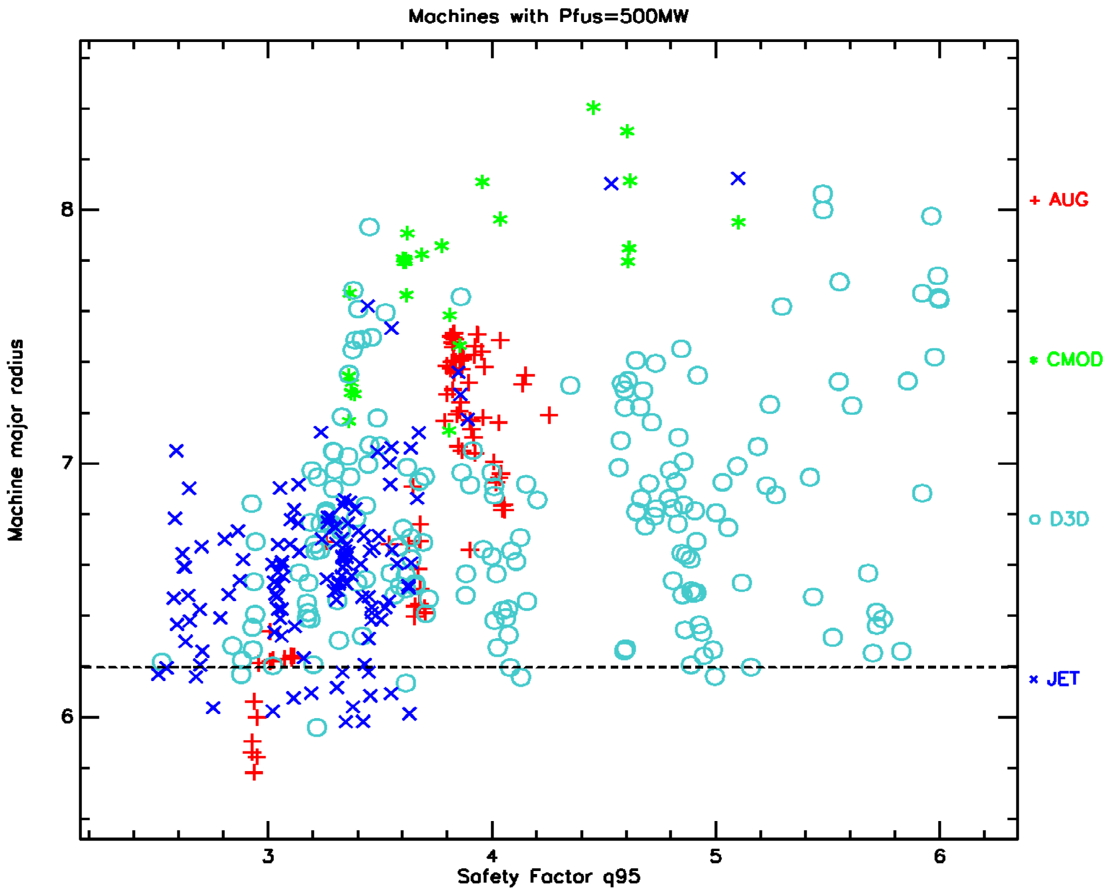


Figure 5.12 Major radius of 500 MW fusion power machines versus safety factor in the database under the assumption of constant beta

In summary, according to this deterministic approach to extrapolation using similar non-dimensional parameters from the documented experimental discharges in present machines (assuming continuity of variation with ρ* of the physical behaviour of plasma and of radial parameter profiles), the ITER-FEAT design parameters appear adequately chosen to achieve the performance goals, on the basis of extrapolation from many high performance ELMy H-mode discharges from JET, DIII-D and Asdex-U.

6.0 Design Features and Assessments

Summary of design features

Following the revised technical guidelines, the design of ITER-FEAT aims to use as far a possible technical solutions and concepts developed and qualified during the EDA so far. Nonetheless, changes in overall scale and in some physics requirements (e.g. more plasma shaping); the pressure to preserve the plasma performance capacity and flexibility, whilst approaching the 50% cost target ITER-FEAT have induced some significant changes in the design features from the 1998 ITER Design; in addition, the continuing flow of new data from the technology R&D projects have enabled changes in design criteria associated with a better knowledge of the available margins.

The main engineering features and materials in the design are summarised in Table 6.1 At this stage of the development of the design, not all components/subsystems are "frozen". Nevertheless, all systems which interfere with the global layout of the project have their parameters frozen. Inside some systems with no external influence more than one option is maintained pending further analysis, and, in general, detailed design work and optimisation will lead to limited modifications. As noted above, the proposed engineering design relies mainly on technical solutions which have been or are being qualified by the on-going R&D in the Parties' laboratories and industries. Most of the remaining issues are related to the choice of options which will provide the largest cost saving through improved and more efficient manufacturing processes.

Because of the unwillingness to compromise with physics extrapolation so as to provide enough margins in the physical parameters and physics-related systems e.g., plasma size, fuelling, and heating and current drive, a major focus of effort will be to press on the manufacturing processes (with their feedback on design) to approach as closely as possible the target of 50% saving in direct capital cost from the 1998 ITER design.

The following paragraphs summarise and assess the key features of the main the ITER-FEAT components and subsystems, and the overall plant systems integration and illustrate some of the issues and options remaining to be decided.

Magnets and structures

The superconducting magnet system which confines, shapes and controls the plasma inside a toroidal vacuum vessel comprises three main systems and their power supplies:

- 18 Toroidal Field (TF) coils which produce the confining/stabilizing toroidal field;
- 6 Poloidal Field (PF) coils which contribute to the plasma positioning and shaping; and
- a Central Solenoid (CS) coil which provides the main contribution to the induction of poloidal field current in the plasma.

Correction coils (including three sets located above, outboard of and below the TF coils) are also required to correct error fields that arise due to imperfections in the actual PF and TF coil configuration and to stabilize the plasma against resistive wall mode instabilities.

The magnet system weighs, in total, about 8,700 t — about one third of the weight of the 1998 design.

Table 6.1 Main engineering features of the ITER-FEAT systems

Superconducting toroidal field coils (18 coils)	
Superconductor	Nb3Sn in circular stainless steel (SS) jacket in grooved radial plates, or in square SS conductor
Structure	Pancake wound, in welded SS case wind, react and transfer technology
Superconducting Central Solenoid (CS)	
Superconductor	Nb3Sn in square Incoloy jacket, or in circular Ti/SS jacket inside SS U-channels
Structure	Pancake wound, 3 double or 1 hexa-pancake wind react and transfer technology
Superconducting poloidal field coils (PF1-6)	
Superconductor	NbTi in square SS conduit
Structure	Double pancakes
Vacuum Vessel (9 sectors)	
Structure	Double-wall welded ribbed shell, with internal shield plates and ferromagnetic inserts
Material	SS 316 LN structure, SS 304 with 2% boron shield, SS 430 inserts
First Wall/Blanket (429 modules)	(Initial DT Phase)
Structure	Single curvature faceted separate FW attached to shielding block which is fixed to vessel
Materials	Be armour, Cu-alloy heat sink, SS 316 LN structure
Divertor (54 cassettes)	
Configuration	single null, cast or welded plates, cassettes
Materials	W alloy and C plasma facing components Copper alloy heat sink, SS 316 LN structure
Cryostat	
Structure	Ribbed cylinder with flat ends
Maximum inner dimensions	28 m diameter, 24 m height
Material	SS 304L
Heat Transfer Systems (water-cooled)	
Heat released in the tokamak during nominal pulsed operation	750 MW at 3 and 4.2 MPa water pressure, ~ 120°C
Cryoplant	
Nominal average He refrig. /liquefac. rate for magnets & divertor cryopumps (4.5K)	55 kW/0.13 kg/s
Nominal cooling capacity of the thermal shields at 80K	660 kW
Additional Heating and Current Drive	
Total injected power	73 MW initially, 100 MW nominal maximum
Candidate systems	Electron Cyclotron, Ion Cyclotron, Lower Hybrid , Negative Ion Neutral Beam
Electrical Power Supply	
Pulsed Power supply from grid	
Total active/reactive power demand	500 MW/400 MVAr
Steady-State Power Supply from grid	
Total active/reactive power demand	110 MW/78 MVAr

The CS and TF coils use a conductor with a large number of Nb_3Sn strands (~ 1,000), whereas the remaining PF and correction coils use a similar conductor with NbTi strands. All coils are cooled by supercritical helium at ~ 4.5K. The TF coil case is the main structural component of the magnet system and the machine core. The PF coils and vacuum vessel are linked to the TF coils such that all interaction forces are resisted internally in the system thus eliminating the need for large external load transferring structures and the mechanical moments associated with such structures. The TF coil inboard legs are wedged all along their side walls in operation and they are all linked at their two ends to two strong coaxial rings which resist the local de-wedging of those legs under plane loads, a detrimental effect to resist against out of plane loads where these are at their maximum. At the outboard leg, the out-of-plane support is provided by intercoil structures integrated with the TF coil cases. Views of the TF coil case are shown in Figure 6.1.

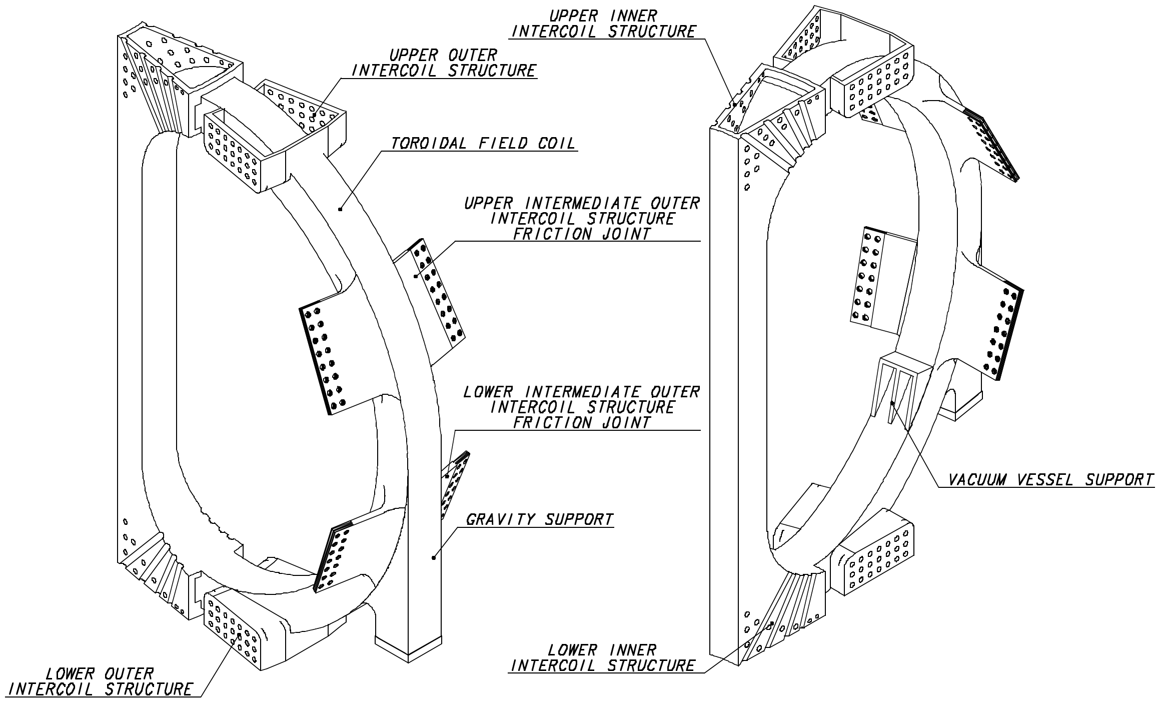


Figure 6.1 3-D views of the TF coil case

A power supply provides the DC coil currents to the different coils from the AC high voltage grid which supplies the ITER-FEAT site. The various coil electrical loads have different characteristics in terms of the currents, power, length of pulse, and so the coil power supply is made up of several subsystems. In addition, protective circuitry is provided to discharge the magnetic energy to external resistors in the possible event of superconducting coils quenching (rapid loss of superconductivity) under certain conditions.

Two options are still under investigation for the TF coil winding: one with a circular conductor embedded in radial plates and the other with a square conductor. The radial plate option has advantages in terms of the insulation reliability and fault detection capability, but suffers from cost and radial build penalties.

For the CS winding, there are two options to provide the structural material which is subject to fatigue due to the large number of pulses. The first one uses an Incoloy square jacket with a co-wound strip and the second one uses two, stainless steel, U-channels welded around a thin circular, jacket made of Incoloy or titanium. The selection of the option has some limited impact on the CS flux capability but the choice can be postponed until more R&D results are available.

External conditions (static and variable magnetic field, stress and strain levels, cooling etc.) to be met in operation by the TF and CS coil conductors will be simulated in the testing facility built for the CS model coil. Insert coils made of TF and CS conductors will be tested. Results will provide a measure of the margins available around the reference operating point. The model coil programme has also addressed and resolved a number of key manufacturing issues. Production of the CS and TF conductors at industrial scale has been achieved and the "wind react and transfer" process for the conductor has been qualified.

The TF coil case manufacturing issues are being addressed in an R&D programme which includes welding development and the production of large forged pieces and castings as required in the full size coil cases and outer intercoil structures. This development is expected to facilitate manufacture and reduce cost.

In total, the large effort in R&D provides confidence that the remaining issues for the magnet design are not ones of feasibility, but rather, issues which relate to options to reduce the capital cost and to fulfil new requirements for plasma operation (e.g., the segmented CS and wedged TF coils).

For the PF coils, R&D has been initiated to verify the performance of the NbTi conductors for the PF coils; this work has to include the manufacture of a coil with a full size conductor and the testing of this coil in pulsed conditions.

For the main components and subsystems for the magnet power supplies, including AC/DC conversion system, the reference designs are based on existing technology and products available in the world market, or on the progress that is expected to be achieved in the near future.

Cryoplant and Cryodistribution System

Liquid helium from a cryoplant is distributed by a cryodistribution system to auxiliary cold boxes feeding the magnet and other loads as well (e.g. cryopumps for the pumping of the vacuum vessel). Circulating pumps force the flow of supercritical helium through the load in each separate circuit, which exchanges heat with a helium bath, whose pressure (and thus temperature) are controlled by a cold compressor in the return path towards the cryoplant. The plant design has to reconcile the pulsed character of the heat deposited in the magnet coils and the cryopumps, with the steady operation of the cryorefrigerator, which handles only the average heat load.

Although the envisaged cryoplant is a very large and complex facility, the confidence of building such a plant with the required performance is very high since the cryorefrigerator and cryodistribution systems for large particle accelerators provide good bases that can be directly applied to the ITER-FEAT system design.

Cryostat and Thermal Shields

The whole tokamak (vacuum vessel, magnet and associated structures) is located within a single-walled cryostat and within the cryostat there are thermal shields at 80K to prevent the cold portions (~ 4K) from receiving heat from the "hotter" parts. Rectangular bellows made from elastomer are used to connect the interspace duct wall extensions of the VV ports with the cryostat port to compensate for differential movements.

The design and size of the cryostat are within industrial experience. Provided R&D results confirm the suitability of the intended use of elastomer bellows and Ag-plating to large panels, there is no reason to doubt that the cryostat and thermal shields can be procured and assembled as intended. Should the R&D results be negative, alternative, back-up options are available.

Vacuum Vessel

The double-walled vacuum vessel is lined by modular removable components, including blanket modules composed of a separate first wall mounted on a shield block, divertor cassettes, and diagnostics sensors, as well as port plugs such as the limiter, heating antennae, and test blanket modules. All these removable components are mechanically attached to the VV. These vessel and internal components absorb most of the radiated heat from the plasma and protect the magnet coils from excessive nuclear radiation. This shielding is accomplished by a combination of steel and water, the latter providing the necessary removal of heat from absorbed neutrons. A tight fitting configuration of the VV aids the passive plasma vertical stability and ferromagnetic material in the VV localised under the TF coils reduces the TF ripple. The overall arrangement of one of the 9 vacuum vessel sectors is shown in Figures 6.2 and 6.3.

Integrated functionally with the VV is the vacuum vessel pressure suppression system (VVPSS). This system minimizes the peak pressure inside the vacuum vessel during an in-vessel LOCA by relieving the pressure, caused by the ingress of a water steam mixture from damaged water-cooled, in-vessel components, through rupture discs via pipework into a steam condenser tank.

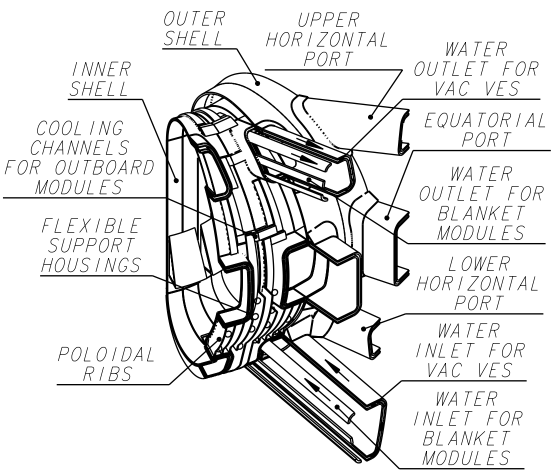


Figure 6.2
Vacuum Vessel overall arrangement

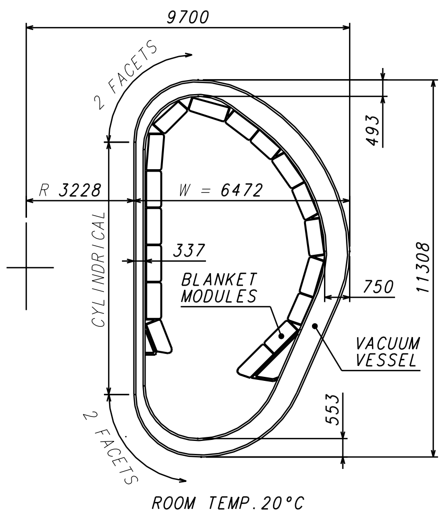


Figure 6.3
Vacuum Vessel cross-section

The manufacture of a full-scale sector of the 1998 ITER design gives a sound basis for the design of the present vessel. To reduce the VV fabrication cost, forging, powder HIPing and/or casting is being investigated for the large number of the housings in the VV for the blanket module support that have a relatively small and simple structure. The preliminary comparison of their fabrication costs with welded structures shows a cost benefit.

Blanket

The blanket system is made up of 429 modules, including those around the Neutral Beam injection lines. The initial blanket acts solely as a neutron shield and tritium breeding experiments are confined to the test blanket modules which can be inserted and withdrawn at radial equatorial ports. The blanket module design consists of a separate faceted first wall (FW) built with a Be armour and a water-cooled copper heat sink attached to a SS shielding block; this minimises radioactive waste and simplifies manufacture.

Two methods are being considered for FW attachment to the shield: a central mechanical attachment, which is bolted to a shield block at its rear side, or a system of bolts (accessed from the first wall) and small shear ribs, to support electro-mechanical loads and to prevent sliding due to thermal expansion.

Two options are being considered for blanket cooling: one with cooling channels integrated inside the vessel structure between the two walls, the other with channels mounted on the vessel in vacuum.

Overall, the manufacture and testing of blanket and FW mockups of the 1998 ITER design gives a sound basis for the present blanket design.

Divertor

The divertor exhausts the helium reaction product of the DT fusion reactions and limits the concentration of impurities (non-hydrogen isotopes) in the plasma by providing a region in which the magnetic field lines just outside the plasma boundary are "diverted" to meet a target plate at a small angle of incidence. Charged particles escaping from the confined plasma will flow to the target, but on the way will lose a large fraction of their energy by radiation and charge exchange with neutrals, thus limiting the power density on the target plate.

The divertor itself is made up of 54 cassettes. Figure 6.4 is a sketch in a poloidal cross-section of the diverted magnetic field and the divertor showing some features of the construction of a cassette, in particular the targets which are the surfaces subjected to the heat load from the diverted particles (peak heat fluxes are less than 20 MW/m^{2}).

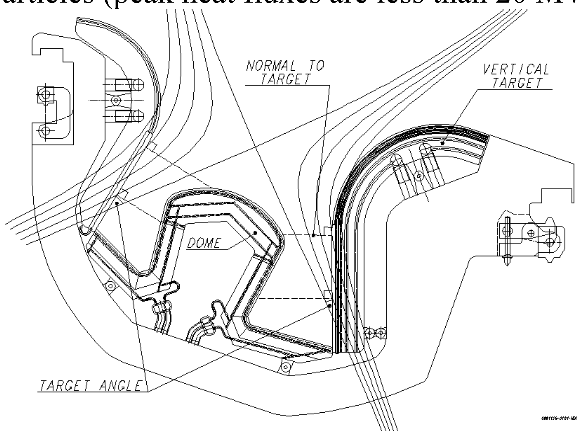


Figure 6.4 Divertor Plasma Facing Components Arrangement

The current design uses carbon at the vertical target strike points. Tungsten is being considered as a backup, and both materials have their advantages and disadvantages. The two options need continuous development so that the best judgement of the relative merits can be made by the time of procurement. Carbon has the best behaviour to withstand large power density pulses (ELMs, disruptions), but gives rise to tritiated dust. Procedures for the removal of tritium codeposited with carbon and tritiated dust from various components by a number of schemes are under consideration and need further development.

The development of carbon and tungsten armoured plasma facing components has advanced to a level capable of meeting the demanding requirements of the ITER-FEAT divertor for the average target heat load. The armour behaviour against large power density pulses could be the limiting factor. A successful R&D campaign has demonstrated that armoured components can routinely operate with heat loads of up to 20 MW/m^2 for carbon and > 10 MW/m^2 for tungsten, with a promise of also reaching 20 MW/m^2. A prototypical armoured vertical target, which is compatible with the ITER-FEAT divertor requirements, has been built and fully tested. Furthermore, successful operation in tokamaks, with the SOL partially attached to the divertor targets, has demonstrated that the average heat flux to the divertor can be reduced to a value where the armour life-time is adequate. This is the basis for confidence in the design.

Water Cooling system

The heat deposited in the vessel-internal components and the vessel is rejected to the environment via the tokamak cooling water system, which is designed to preclude releases of tritium and activated corrosion products to the environment. Some parts of these heat transfer systems are also used to bake and hence clean the plasma facing surfaces inside the vessel by releasing impurities.

In the worst situation, where all active cooling to in-vessel components is lost because of pipe breaks or power failure, natural convection in the vessel is able to exhaust their decay heat and keep components well below the temperature at which there is no significant chemical reaction between steam (air) and Be-dust.

The normal operation of active components of the water cooling system such as the main pumps, small pumps and motor-operated valves under the operational magnetic field must be guaranteed. The allowable strength of the magnetic field and the required shielding for each component is under study now.

The option of using sea/fresh water instead of forced flow cooling towers as the ultimate heat sink is being considered for a site-specific design. It may be that, in this case, an intermediate cooling water system may be required.

Whilst details of the different elements of the system have yet to be finalised, the general capacity of the main components in the water cooling system is within the industrial experiences (or industrial proven technology), therefore no problematic issues on the component design and manufacturing are expected

Fuel Cycle

The fuelling and pumping system also provides plasma density control. The tokamak fuelling system is capable of gas puffing, and pellet injection from the high field side, into the plasma. These gases are subsequently removed from the plasma together with the helium ash using the torus cryopumps, which exhaust to the tritium plant where impurities are removed from the hydrogen stream and the various isotopes of hydrogen are separated and stored. Tritiated impurities are processed to lower their tritium content enough to allow their release. The tritium plant also detritiates water, ventilation air and process fluids and solids.

Pellet launch is from the high field side of the tokamak to maximise pellet penetration for a given pellet speed, and fuelling efficiency. However, the pellet speeds required are somewhat beyond those currently achieved without pellet disintegration inside the curved guiding flight tube. Thus R&D is needed to improve the design and geometry of the flight tube.

Regarding the tritium plant, nearly all the separation systems have to be present by the start of DD operation since tritium will be generated during this phase of operation. However systems for water detritiation can be deferred to some extent until full DT operation; for how long needs further quantification.

Many subsystems in the ITER tritium plant are based on proven, industrial processes at relevant scale. In some instances the dynamic nature of ITER operation requires additional confirmation and this is targeted by R&D, e.g., on the isotope separation system and hydrogen storage beds.

Overall there is confidence, that, given the expected outcome of the R&D, the necessary subsystems can be designed, procured and operated as required.

Heating and Current Drive

The plasma heating systems must also have the ability to drive current in the plasma (current drive) to extend the tokamak plasma duration beyond the limitations imposed by the inductive current drive provided by the central solenoid. This lengthening of the tokamak pulse is an attempt to reach “steady-state” conditions where the current drive would be entirely non-inductive. The H&CD systems under consideration for ITER-FEAT are shown in Table 6.2 below:

Table 6.2 Heating and Current Drive Systems

	NB	EC (170 GHz)	ICRF (~ 50 MHz)	LH (5 GHz)
Power injected per unit equatorial port (MW)	16.5	20	20	20
Number of units for the first phase	2	1	1	0
Total power (MW) for the first phase	33	20	20	0
1) Each standard equatorial port can provide 20 MW of RF (EC or IC or LH) 2) The 20 MW of EC module power will be use either i) in 2 upper ports to control neoclassical tearing modes at the q = 3/2 and q = 2 magnetic surfaces, or ii) in one equatorial port for H&CD mainly in the plasma centre.				

Whilst the designs draw, in general, on existing operational systems, all the options require further R&D to validate the designs and to ensure the performance targets, in the conditions foreseen for ITER. If reasonable R&D programmes are maintained to address the various issues, there is confidence that a range of heating and current drive capacity capable of providing all the requested services can be made available.

Diagnostics

In order to understand the behaviour of the plasma in ITER-FEAT, a large number of special devices (diagnostics) will be applied to the tokamak to measure various properties of the confined plasma, the confining magnetic field and the fusion reaction products. Some of these diagnostics are not only required to evaluate the experiments but are required for machine protection (e.g. to avoid excessive heat loads on vessel-internal surfaces and the consequent damage), and for plasma control (e.g. magnetic field measurements which are required for the control of the plasma shape and position by the PF coils).

For magnetic diagnostics, the lifetime of the in-vessel coils and loops are the important issues. The results of the supporting radiation effects R&D indicate that the necessary lifetime can be achieved.

The ability of the neutron cameras to provide the total fusion power and the alpha particle source profile is directly linked to the available access. A wide angle of view is desirable in both the radial and vertical directions. A view through the intercoil structure for the vertical camera is being considered but the feasibility has yet to be established.

The optical/infrared systems view the plasma with a mirror, and a critical issue is the lifetime of this component. A solution for the mirrors is believed to exist for those systems which operate in the visible and infrared regions. Further work is required for diagnostics which require a relatively large solid angle of observation, for example, active charge exchange recombination spectroscopy and motional Stark effect.

Most of the measurements required for the machine protection and basic plasma control can be made using established techniques. In a few cases, however, novel approaches are required to take account of the expected operating conditions such as intense gamma background.

For sustained operation in high confinement modes, for example reverse shear, it is expected that the profiles of many parameters will have to be brought under active control. Measurements of most of the required profiles can be made but further work is required to confirm that the accuracies and resolutions that can be achieved will be sufficient.

Buildings and Services

The above systems are housed within buildings and structures along with plant services. Table 6.3 lists the main buildings and their footprints and other structures and areas which are required. Considerable effort has been made to make the best use of building space while providing an optimised layout for the required performance of the plant at a minimum cost. The tokamak and its closely associated systems are located mainly in the lower areas of the buildings as illustrated in Figure 6.5 which shows a section through the Tokamak building.

Table 6.3 Site Buildings, Structures and other areas

	Foot Print m^2
Tokamak Hall	5,482
Assembly Hall RF Heating Area in Assembly Hall (2,550 m^2)	3,825
Tritium, Hot Cell and Radwaste Buildings, Personnel and Access Control Structure	6,550
Power Supply Buildings	15,264
Cryoplant Buildings	13,950
Site Services,Control and Laboratory Office Buildings, etc	10,861
Building Totals	**55,932**
Power Supply Areas	59,282
Diesel Fuel, Cryo-Gas, Water and Gas storage, Makeup Basin	3,517
Hot Basin & Cooling Tower, Pumping Yard	9,674
Sub-Total Other Structures and Areas	**72,473**
Outdoor Storage /Expansion Areas	25,050
Parking Areas	31,410
Roadways	34,684
Sub-total Other outdoor areas	**91,144**
Grand Total	**219,549**

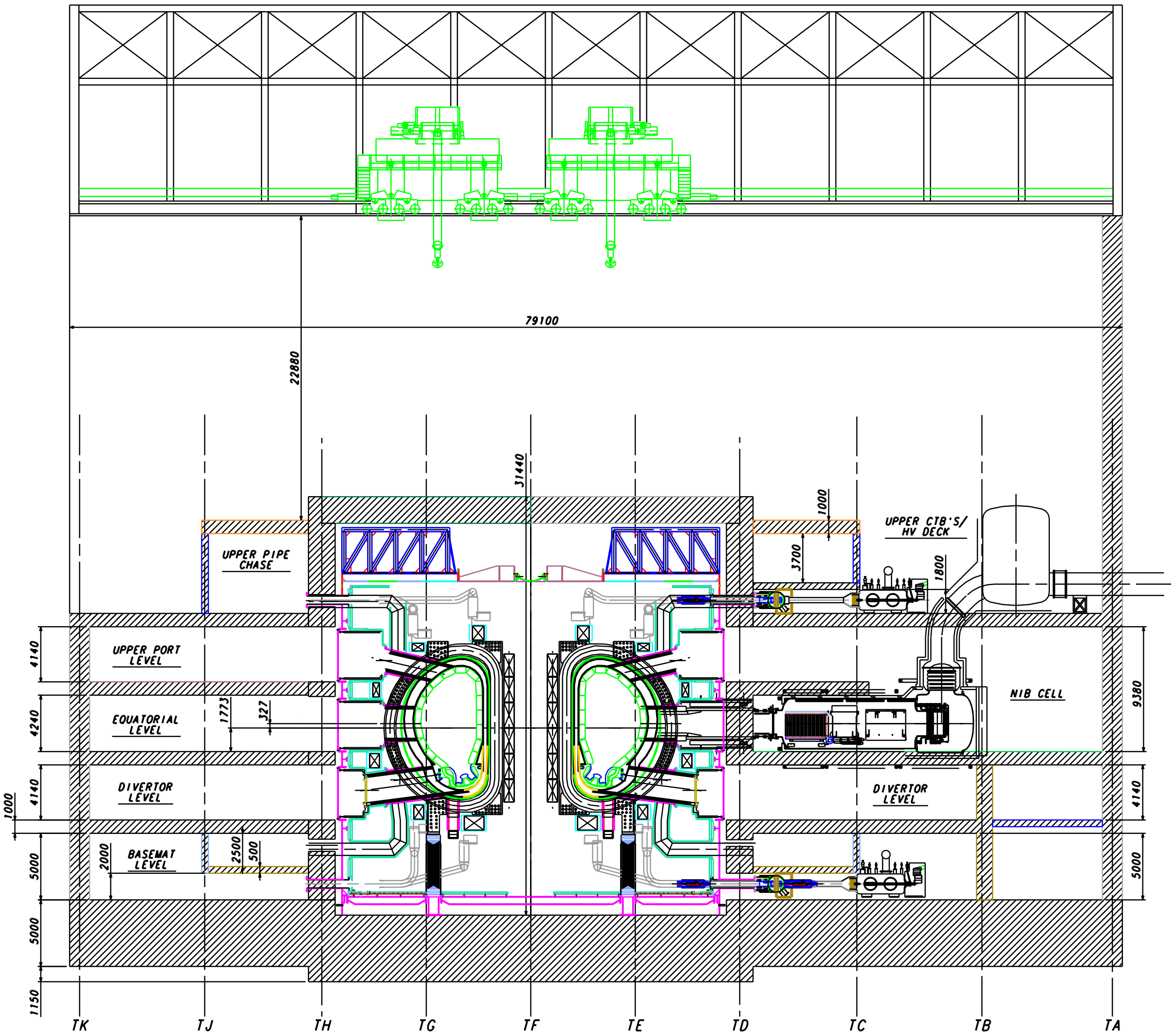


Figure 6.5 Tokamak building north-south section

Although the scale of the buildings and the components is towards the upper end of conventional building and construction experience, there is nothing about the buildings or structures that is outside the realm of current engineering and industrial practice. There are bigger structures, heavier equipment placed, and tighter tolerances used., but not so many all in a single project. Hence, it is an engineering challenge, but well within present engineering and construction capabilities.

Tokamak Maintenance

Because of the production of neutrons in plasmas of deuterium, and of deuterium and tritium, systems near the plasma will become radioactive and will require remote maintenance, with special remote handling equipment. The equipment involves an in-vessel transporter system for the removal and reinstallation of blanket modules, multifunction manipulators for divertor cassette removal, and specialised manipulators to handle vacuum vessel port plugs. Special casks, which dock horizontally to the access ports of the vacuum vessel, are designed to house such equipment and to transport radioactive items from the tokamak to the hot-cell where refurbishment or waste disposal operations can be carried out. Docking of these casks to the vessel and the hot cell flanges is tight, to avoid spreading of contamination. Hands-on assisted maintenance is used wherever justifiable.

A remote handling strategy for ITER has been confirmed by a comprehensive design and R&D programme which has successfully demonstrated that key maintenance operations like blanket and divertor replacement can be achieved using common remote handling technology. Several crucial issues like vacuum vessel remote cutting and re-welding, viewing, materials and components radiation hardness have been addressed and demonstrated. The above strategy is directly applicable to ITER-FEAT.

Some maintenance-related items still need to be addressed. In particular, the possibility of adopting a compact hot cell design based on the possibility to refurbish the divertor cassettes during the maintenance period is being assessed.

Overall, the development programme results so far obtained indicate that the remote maintenance strategy for ITER-FEAT is sound and sufficiently mature to support the ITER programme.

Tokamak Assembly

An outline procedure has been developed for the tokamak assembly, as the basis for determining the assembly schedule, manpower and tooling requirements and the associated cost.

The overall sequence is divided into the following six main sub-sections:

- lower cryostat activities, which cover activities from the initial assembly in this area up to the placement of the first TF/VV/VVTS sector;
- TF/VV/VVTS sub-assembly: Each sector includes a pair of TF coils, a 40˚ segment of the VV and three VVTS parts, an inboard 40° sector and two outboard, opposite hand 20° sectors.
- integrated TF/VV/VVTS assembly: The sequencing of the TF/VV/VVTS assembly in the cryostat;
- establish magnetic axis: survey procedures to establish the tokamak magnetic datum;
- ex-vessel activities: these activities occur in parallel with the in-vessel assembly procedures;
- in-vessel activities: further activities up to the preparation for commissioning.

A high level assembly plan has been established; details of many assembly activities, and related design of the assembly tooling now remain to be established. The need for a very accurate fit of the mating surfaces between adjacent TF coils may necessitate lengthy and precise matching operations, such as shimming, with a possible significant impact on the assembly schedule if the operations are to be carried out on the ITER site. Concepts and procedures for in-situ surveying and shimming have to be developed.

Plant control system

The integrated control and protection of the entire ITER plant will be achieved by the plant and plasma control system, and an independent interlock system.

The operation of the ITER plant is characterised by five major plant states as outlined below, in which many of the plant subsystems wait for commands before changing to another state, or some subsystems are undergoing maintenance or testing, or are in normal operation. The plant control system controls these states and the transitions between them, which occur through a sequence of steps.

The five defined plant operation states are:

- **Construction and Long-Term Maintenance State (LTM),** during which most of the tokamak subsystems which require maintenance will be shut down. Typical activities are large in-vessel and ex-vessel component replacement and maintenance.
- **Short-Term Maintenance State (STM),** for maintenance activities which typically last for 1 to 30 days. In this state, component maintenance and replacement will be carried out mainly outside of the vessel which remains under high vacuum conditions.
- **Test and Conditioning State (TCS)**, during which the tokamak systems are conditioned and heating and other ancillary systems might be tested; no in-vessel or major ex-vessel maintenance may be initiated.
- **Short-Term Standby State (STS),** which implies that the final preparation of each subsystem is completed and that the plant is ready for plasma operation.
- **Plasma Operation State (POS)**

The control system consists of a centrally-positioned supervisory control system (SCS) and subcontrol systems dedicated to each plant subsystem under the supervision of the SCS. Individual plant and diagnostic subsystems are directly controlled and monitored by their own dedicated intelligent control system. All systems use the same control method of conditional transitions between well-defined sequences of steps to be followed (i.e. SFC - Sequential Functional Control). The SCS controls the transition of the entire ITER plant from one operation state to another, and provides high level commands to plant subsystems, in order to achieve integrated control of the entire plant. The SCS also monitors the operation state of each plant subsystem to ensure it is operating within its proper operational envelope.

The interlock system monitors operational events of the plant, and performs preventive and protective actions to maintain the system components in a safe operating condition. The interlock system is also hierarchically structured and has individual interlock subsystems which are dedicated to each plant subsystem under the central supervisory interlock system.

The control system for ITER-FEAT follows well established principles of system control. Accordingly, no major problems are expected in implementing the design and it has been possible to draw significant conclusions for the safety of the plant, as summarised below.

7.0 Safety and environmental characteristics

Safety Objectives and Design Principles

A main goal of ITER is to demonstrate from the viewpoint of safety the attractiveness of fusion and thereby provide a good precedent for the safety of future fusion power reactors. However, it is necessary to account for the experimental nature of the ITER facility, the related design and material choices, and the fact that not all of them are suited for future fusion power reactors. To accomplish this, ITER safety needs to address the full range of hazards and minimise exposure to these, and to permit siting by any Party.

Detailed safety related principles and environmental criteria have been adopted based conservatively on internationally recognised safety criteria and radiological limits following ICRP and IAEA recommendations and, in particular the ALARA principle.

The following safety objectives are taken into account in setting the requirements that guide the design for ITER-FEAT:

- **General safety**: To protect individuals, society and the environment. To ensure in normal operation that exposure to hazards within the premises and exposure due to any release of hazardous material from the premises are controlled and kept below prescribed limits. To prevent accidents with high confidence, to ensure that the consequences of more frequent events, if any, are minor, and to ensure that the consequences of accidents are bounded and their likelihood is small.
- **No evacuation**: To demonstrate that the favourable safety characteristics of fusion and appropriate safety approaches limit the hazards from internal accidents such that there is, for some countries, technical justification for not needing evacuation of the public.
- **Waste reduction**: To reduce radioactive waste hazards and volumes.

The general principles outlined below both provide direction to guide the design, and provide for on-going, independent review and assessment to ensure the design will meet the safety objectives.

1) Deployment of fusion's safety characteristics

The safety approach is driven by a deployment of fusion's favourable safety characteristics to the maximum extent feasible. Relevant characteristics are:

- the fuel inventory in the plasma is always below 1 g
- plasma burn is terminated inherently when fuelling is stopped due to the limited confinement of the plasma energy and particles
- plasma burn is self-limiting with regard to power excursions
- plasma burn is passively terminated by the ingress of impurities under abnormal conditions (e.g. by evaporation or gas release or by coolant leakage)
- the energy and power densities are low
- the energy inventories are relatively low
- large heat transfer surfaces and big masses exist and are available as heat sinks
- confinement barriers exist and must be leak-tight for operational reasons.

2) Exploitation of the passive safety features

Passive safety, based on natural laws, properties of materials, and internally stored energy are used to help assure ultimate safety margins.

3) Incorporation of defence-in-depth

The ITER safety approach incorporates 'defence-in-depth', the recognised basis for safety technology. All activities are subject to overlapping levels of safety provisions so that a failure at one level would be compensated for by other provisions.

There are three sequential defence levels - 'prevention', 'protection', and 'mitigation'. Defence-in-depth, features at each of the three fundamental levels. All elements of defence in depth have to be available at all times during normal power operation and appropriate elements must be available when power is off (shutdown, maintenance, repair, decommissioning).

4) Provision for the experimental nature of ITER-FEAT

A robust safety envelope is provided to enable flexible experimental usage. Since ITER is the first experimental fusion device on a reactor scale, it will be equipped with a number of 'experimental components', in particular inside the vacuum vessel. In view of uncertain plasma physics and lack of operational experience, the experimental components are designed to allow for the expected loads from plasma transients so as to reduce the demands on systems which are required for safety. In particular, no safety function is assigned to experimental components.

Nevertheless, faults in experimental components that can affect safety are subject to safety assessments. On this basis, related measures will be incorporated in the design as appropriate.

The experimental programmes will be developed in such a way that design modifications will take account of experience from preceding operations and will stay within the safety envelope of the design.

Safety — Review and Assessment

Safety assessments covering normal operation, all categories of accidents, and waste management and disposal are an integral part of the design process, the results of which will be available to assist in the preparation of safety documentation for regulatory approval. The preliminary assessments of the ITER-FEAT design build on and develop further the detailed safety assessment of the 1998 ITER design.

Normal Operation

Effluents

Operational effluents are expected to be at a level which would cause public doses to the most exposed individual below 1% of the natural radiation background (postulating a typical 'generic' site).

Most releases are expected during maintenance operations. Presently available assessments suggest that the total tritium releases from the plant are about 0.25 g per year. In terms of doses, the releases of activation products are comparable to those of tritium.

Occupational Safety

Design criteria for personnel access have been established to ensure an acceptable level of occupational safety. Radiological hazards are being estimated by neutron activation analysis of components and structures, associated gamma transport calculations, and activated corrosion product build-up analysis, to assess against the design criteria. Non-radiological hazards (EM fields, beryllium, etc) are also being estimated. In addition to meeting the criteria for access, an iterative assessment process will be applied to operational and maintenance activities to reduce radiation exposure based on the ALARA principle.

Radioactive Waste
Activated and contaminated materials arise during the operational phases and remain after final shutdown. Not all these materials would need to go into a waste repository, rather after some decay time a significant fraction can be ‘cleared’, i.e. declared to be no longer radioactive waste. The related processes (e.g. as recommended by IAEA) range from ‘unconditional’ clearance to clearance ‘for recycling’.

A provisional waste characterisation assessment for the ITER-FEAT has been performed although a detailed study cannot be done until the design is finalised (or nearly so). A scaling approach based on the detailed assessment of the 1998 ITER design indicates that the amounts of radioactive material falls by about a half.

Possible accident conditions
In case of accident, ITER-FEAT protects personnel and the public using radioactivity confinement. Sources of tritium or activated materials that occur within the vacuum vessel, in the tokamak cooling water system, in the fuel cycle and within the hot cell, are housed behind multiple physical and functional barriers, which protect against the spread and release of hazardous materials. The primary confinement barrier is designed to have high reliability to prevent releases. A secondary barrier is provided close to the primary one to limit the spread of contamination and protect personnel from leaks. Exhaust from rooms that can be contaminated is treated by filters and/or detritiation systems, and monitored.

Possible Loss of Coolant Accidents (LOCAs) are accommodated in the design by means of the vacuum vessel pressure suppression system, the various confinement structures, and the detriation and filtering systems, with the result that the assessed consequences of possible LOCAs are commensurate with the conservative ITER release guidance.

Decay heat densities in ITER-FEAT are so small that no emergency cooling of the in-vessel components is needed. The vacuum vessel cooling system has the capability to passively remove all decay heat via natural circulation. Maximum temperatures of the in-vessel components during accidents are below 330°C with vacuum vessel cooling only. These temperatures are sufficient to radiate the power from the in-vessel components to the vacuum vessel which transports the power to the ultimate heat sink. No significant chemical reactions occur between steam/air and Be-dust at these temperatures. Venting of the cryostat and air convection at the outer cryostat surface limit the maximum temperatures of the in-vessel components to about 350°C without any cooling of the vacuum vessel.

Safety – Conclusions
In recognition of the central importance of the safety and environmental aspects of ITER-FEAT, a rigorous approach is being pursued, by establishing firm and widely recognised safety principles and criteria for the design process against which then to assess the ongoing design work. Building on the comprehensive and detailed safety and environmental analysis undertaken for the 1998 design, the preliminary assessments of ITER-FEAT tends to confirm that the design will meet the project safety objectives and will have, in many respects a reduced overall safety and environmental impact.

8.0 Costs and Schedule

Indicative Cost Estimates

A valid cost estimate of ITER-FEAT will be obtained only after the engineering details have been worked out to provide specifications for an industrial cost analysis to be undertaken by firms of the Parties in the second half of 2000. Pending such analysis, only a rescaling from the costs of the 1998 ITER design can be done as outlined below. However, this simple scaling cannot take into account the improvements in the design and in the industrial fabrication process expected as a result of current design work and supporting analysis and R&D.

For this initial indicative exercise, the 1998 ITER design cost basis was used as fully as possible, retaining the detailed system cost structures developed for that design, with cost scaling being done, as far as reasonable, at the component levels.

All costs are again expressed in the ITER Unit of Account (IUA) defined as $1000 US in January 1989. The relationship between the IUA and the ITER Parties' currencies in January 1989, and the internal escalation factors to early 1999 are shown in Table 8.1.

Table 8.1 Currency parities in January 1989 and escalation factors to Jan 1999

	IUA	US $	ECU (Euro)	¥
Jan 1989 exchange rates	1	1000	875.8	127,510
Internal escalation factors	1	1.35	1.4	1.14

In the many cases where the ITER-FEAT systems have retained their basic design features from the 1998 ITER design, cost can be simply scaled down within an unchanged cost structure. For each system the major cost drivers are identified to recalculate the component materials costs, the tooling, the fabrication, assembly, testing and shipping costs.

The amount of materials is typically associated with the number of components and characteristic size or weight. The tooling cost drivers are selected depending on the specific technological procedures used for each system; often these drivers are used with power scaling factors less than 1, typically 0.7. A similar approach is used for recalculating the labour costs associated with fabrication, assembly, testing and shipping.

Some new design options require the adjustment of the previous cost structure and identification of additional cost drivers. Such changes have to be applied, e.g., to the multi-sectional central solenoid, and the vacuum vessel with added back plate functions following elimination of the backplate etc.

The results of this initial scoping for direct capital costs are summarised in Table 8.2 below. The figures show estimates for total system costs; the impact of deferring certain of the costs have yet to be quantified.

Table 8.2 Indicative cost breakdown for ITER-FEAT

Components/systems	Indicative Cost (kIUA)	% of Total
Magnet Systems	880	27
Vacuum Vessel, Blanket & Divertor	507	16
Power Supplies	224	7
Diagnostics	215	6
Other Main Tokamak Systems	664	21
Heating Systems (73 MW total)	229	7
Buildings, Site Facilities and Balance of Plant	503	16
Total Direct Capital Costs	**3,222**	**100**

Compared to the cost estimate of the 1998 design, the largest cost savings occur for the Magnet systems and tokamak buildings, where reductions of more than one half are indicated. Cost savings approaching 50% can also be expected for other size-dominated systems such as the Vacuum vessel/Blanket, Divertor, Pulsed Power supply, etc. Lesser savings are indicated for function-dominated systems such as balance of plant and even less for auxiliaries such as fuelling, pumping, tritium plant, cryoplant, remote handling and assembly. No savings are indicated for the diagnostics and CODAC systems.

The net result indicates an overall reduction to about 56% of the estimated direct capital costs of the 1998 design. The scope to approach closer to 50% will be better understood only after the further detailed design and analysis needed to optimise choices and after the Parties' industries will have had the opportunity to study and estimate procurement packages which incorporate expected improvements in design and fabrication process. These are now the most important areas of activity for reducing capital costs further towards the target.

Operating costs depend highly on the cost of electricity (assumed at an average cost of 0.05 IUA/MWh), the salaries of the 200 professionals and 400 support personnel, the cost of the divertor high heat flux component replacements and general maintenance expenses, most of which may vary quite substantially amongst the potential host sites for ITER. Simple scalings from the operating cost estimates for the 1998 ITER design suggest an indicative annual figure of about 180 kIUA over the first ten years of ITER operation — a saving of almost 50%.

The main driver for decommissioning costs included in this estimate is the amount of work necessary to de-activate the machine at the end of the plant operation, remove all in-vessel components and then, after activity decay, finally remove the ex-vessel components and dismantle the vacuum vessel. The required manpower for these operations is scaled according to the size and number of sections of the vacuum vessel, assuming a constant cost for additional equipment envisaged in the 1998 ITER design. The costs of transportation and long term storage of the activated material is not taken into account. On this basis a cost of about 170 kIUA for the assumed decommissioning is indicated - a saving of about 45%.

Schedules

The overall project plan is composed of an eight years construction phase including the commissioning necessary for the first hydrogen plasma discharge, followed by approximately

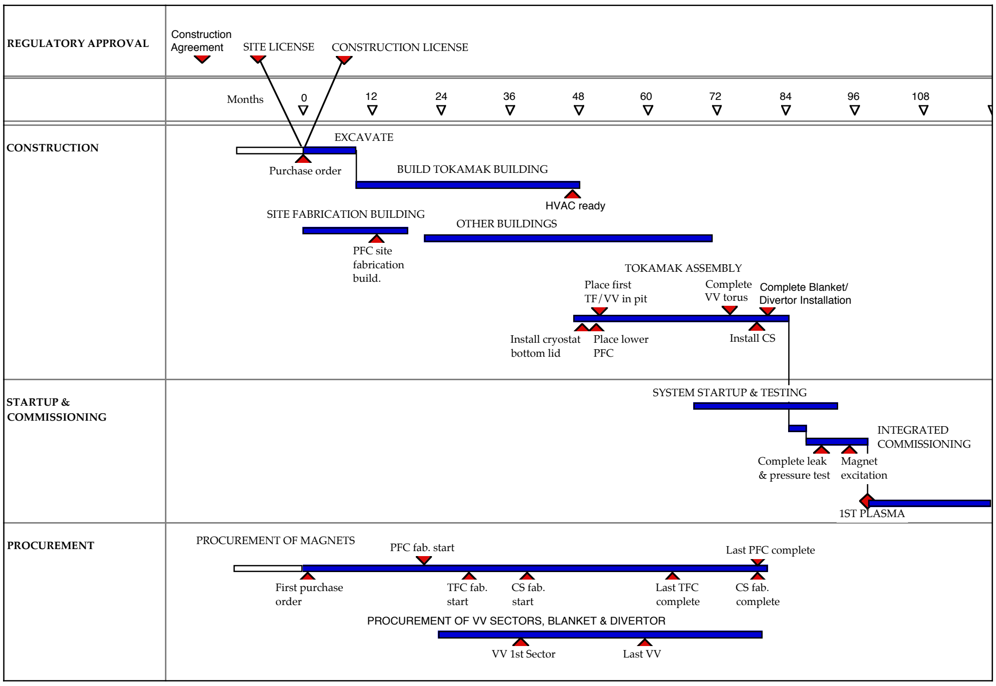
20 years of machine operation. For illustrative purposes this is divided into four phases: two and half years of hydrogen plasma operation, one and a half years of D operation, 3 years of DT operation to low fluence, and for the remaining time a higher fluence DT operation phase. There may be a one to two year machine modification phase before starting the second DT phase in which the outboard shield blanket can be replaced with a breeding blanket. A three year de-activation phase follows after twenty years of operation. The ITER organization has responsibility up to the end of this phase for the ITER facility, which is then handed over to an organization inside the Host Party for dismantling and disposal processes. Figure 8.1 shows the construction planning and figure 8.2 shows the planning for the first ten years of operation.

Construction Schedule

On the assumption that an appropriate amount of technical work has been completed and that an appropriate ITER organisation comes into operation when an agreement to construct ITER is signed, the start of the actual construction on the site depends upon when a site license or construction license is issued by the regulatory authority of the Host Party. Therefore, the dates in the construction schedule are measured in months from a start date ("T = 0") defined as the date at which the actual construction work of excavation for the tokamak building is started, immediately after the site license or construction license is issued. Documents required for the formal regulatory process are prepared by the Host Party to allow the regulatory process to start immediately after the signing of the Construction Agreement and to provide a licence after 12-24 months.

As previously, the construction plan is based on "just in time" delivery; the construction planning therefore depends strongly on timely preparations and efficient processing of contracts especially for the long lead-time items and for the critical buildings. A prompt start to the Tokamak Building and to the PF fabrication building (which will later be converted to the two cryoplant buildings) are the first steps to the critical path. This presumes that any necessary site preparations will have been completed by the Host before T = 0. The procurement schedules for the superconductor strand, for the TF coils are also critical early actions and it is important to ensure completion of the necessary preparations to launch these procurements.

Fig 8.1 Construction schedule for ITER-FEAT



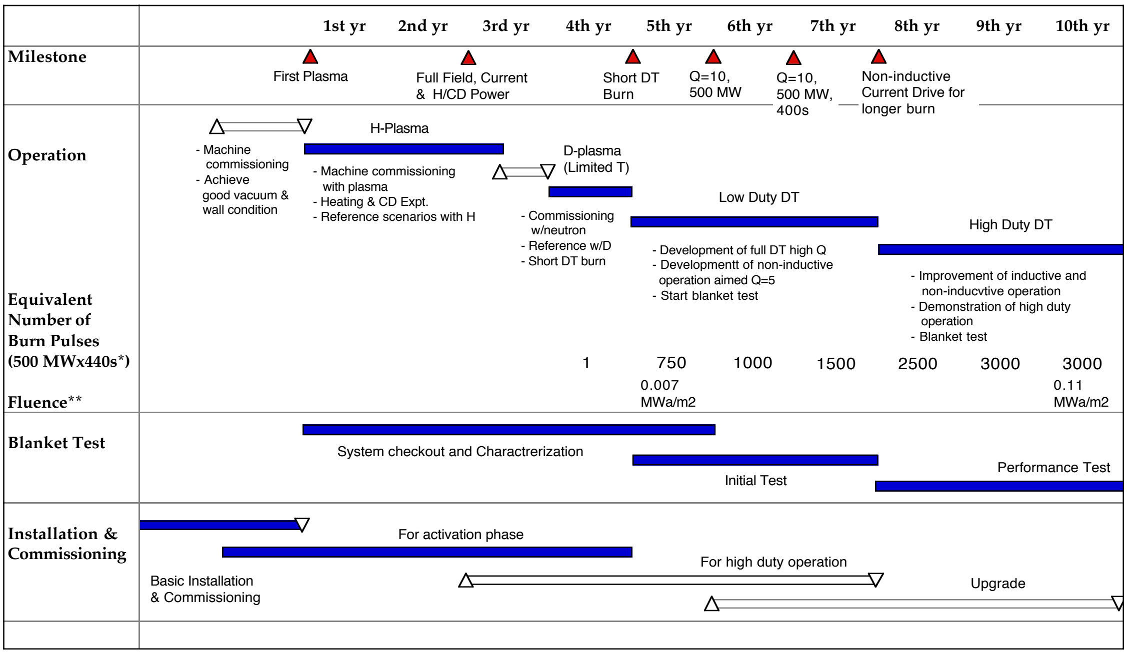
Operation Plans

Operation starts from the first plasma with hydrogen. The ITER machine will be fully commissioned and operated at full plasma current and the full heating power with H plasma discharges. At this time, operating with D plasma discharges with limited tritium, will allow all components and processes to be commissioned ready to work with tritium and with neutron irradiation, before the full deuterium-tritium operation starts to develop high-Q inductive, non-inductive and highly reliable operations suitable for blanket testing.

Hydrogen Phase (H-Phase)

In this first phase of operation (H-phase), no fusion reactions occur, and ITER in-vessel components are not activated and are not contaminated by tritium. ITER will be commissioned with tokamak discharges with the same electromagnetic characteristics as during active operation. By the end of this phase, the nominal plasma current will have been achieved at the maximum toroidal magnetic field and about 70 MW of external heating power with a flat-top duration of about one hundred seconds. The plasma scenario and its control in normal and off-normal conditions will have been established. The heat flux on the limiter and the peak heat flux on the divertor target will be in the same range of average values as for the reference operation for the DT-phase. Depending on plasma confinement characteristics with hydrogen (achievement of good H-mode at large enough densities), many features of the future operation of DT can be explored. Therefore the duration of this period may be lengthened if optimistic results are achieved.

Fig 8.2 Schedule for the first ten years of ITER-FEAT operation



* The burn time of 400 sec includes 400 sec flat top and equivalent time which additional flux is counted during ramp-up and ramp-down.
** Fluence at outboard midplane (Neutron wall load is 0.57 MW/m2 in average, 0.65MW/m2 at outboard and 0.41 MW/m2 at in board.)

Deuterium Phase with Limited Tritium Use (D-Phase)

The main purpose of this phase is to assess the mass scalings of performance, by comparison with H operation, and more accurately predict performance with DT, taking any necessary steps to correct or improve plasma control in preparation for full DT operation. By using limited amounts of tritium in a deuterium plasma, the integrated ITER system can be commissioned, especially with regard to shielding performance, including:

- "nuclear commissioning" of the machine with D/(T) plasma, including check and calibration of nuclear diagnostics, shielding test and radiation monitoring;
- research confirming operation with D/(T) plasma, albeit for short pulses;

Characteristics of D plasma behaviour are expected to be very similar to that of DT even if the alpha heating power is much less than the external heating power. Therefore, the reference plasma operational scenario including L-mode to H-mode transition, very short burn, demonstration of ELMy H-mode for a long period and plasma termination may be confirmed in this phase. The tritium balance can also be studied, and no vacuum vent is planned.

Deuterium-tritium plasma phases (DT-Phases)

Initially, physics studies will be done gradually by increasing and optimising the plasma operation space especially by developing reference scenarios for inductive and non-inductive operations. After developing reliable operation scenarios, series of pulses repeated continuously for a few days are planned mainly for engineering tests particularly relevant to breeding blanket test modules. The fluence at the end of this ~ 6 year phase will be typically ~ 0.1 $MWam^{-2}$.

A detailed operational plan for a second DT phase beyond the first ten years of operation has not been developed because it will depend on the plasma performance and operating experience obtained thus far. However, it is foreseen that there will be more emphasis on optimization of performances and reliable operation to produce higher neutron fluxes and fluence, using the most promising operational modes developed in the previous phases. The average neutron fluence on the first wall is planned to reach at least 0.3 $MWam^{-2}$ at the end of the 20-year operation program.

Tritium Supply

During the first ten years of ITER operation, the equivalent total burn duration at 500 MW is planned to be about 0.15 years or the total equivalent number of pulses is 11,800 at 500 MW. The net consumption of tritium with 500 MW and 400 s burn is about 0.4 g. including heating-up and cool-down phases, and the total consumption during the first ten years are about 5 kg. To achieve the reference average neutron fluence on the first wall of 0.3 MWa/m^2, a total net burn duration of 0.53 years at 500 MW of fusion power is needed, and about an additional 10 kg will be consumed. This tritium can be supplied by external sources.

Tritium Breeding Blanket Test Programme

ITER should "test tritium breeding blanket concepts that would lead in a future fusion reactor to tritium self-sufficiency, the extraction of high-grade heat, and electricity generation." To achieve this testing the ITER Parties will provide specific modules of their own design to be introduced in a few ITER equatorial ports. A common test blanket programme will be established. with the following main objectives:

1) to demonstrate tritium breeding performance and verify on-line tritium recovery and control systems;
2) to demonstrate high-grade heat extraction suitable for electricity generation;
3) to validate and calibrate the design tools and the database used in the blanket design process including neutronics, electromagnetic, heat transfer, and hydraulics;
4) to demonstrate the integral performance of blanket systems under different loading conditions;
5) to observe possible irradiation effects on the performance of the blanket modules.

Decommissioning Plan

It is assumed that the ITER organisation at the end of operation will be responsible for starting the machine decommissioning through a deactivation period after which the facility will be handed over to an organisation inside the ITER Host Country. The decommissioning plan is based on a logic of resources and equipment usage optimisation and takes into account the statutory Occupational Radiological Exposure (ORE) limits. The plan provides a framework within which the organisation that takes over responsibility for decommissioning can decide when and how to implement the ITER facility dismantling, depending on the financial, schedule, resources and/or any other priorities applicable at the time. Flexibility is provided by the use of two separate phases. Each phase duration and activity can be modified (to a certain extent) to accommodate the organisation requirements and constraints.

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 (assuming that no components cooling will be further required) and processed to remove the 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. ITER de-activation will also 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. These activities, part of phase 1 of the decommissioning schedule, will be carried out by the ITER organization using the remote handling facilities and staff existing at the end of the project. 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 of some decades for radioactive decay after which final dismantling and disposal could proceed.

Conclusions

1 The ITER-FEAT outline design meets the requirements set at the ITER Meeting in Cadarache, March 1999. It facilitates the exploration of a domain of inductive operation around $Q \geq 10$, in which isotropic α-particles are the dominant source of plasma heating and the main determinant of plasma behaviour. It could be used, with appropriate enhancements to the heating and current drive systems, to approach steady-state operation with $Q \geq 5$.

2 The design point for ITER-FEAT results from systems analysis and intensive joint assessments by Task Forces involving all the Parties. It represents an agreed appropriate compromise among the many interacting scientific, technical and cost constraints and objectives, recognising the importance of providing robustness to the unavoidable uncertainties of the plasma performance projections and of the need to offer capacity to exploit new physics results and understandings. The performance projections are based on a conservative choice of scaling extrapolation. Tools have been identified to allow the boundaries of the operating domain to be expanded and to mitigate possible problems should actual performance prove to lie in the adverse regions of the uncertainty ranges.

3 The parameter set and size appear to be sound even though the margins against uncertainty of the confinement extrapolation are not so large as first envisaged. It would be imprudent to compress or constrain the design further in the hope of achieving further cost savings.

4 Thus, in meeting the ITER mission to demonstrate the scientific feasibility of fusion energy, the conditions of plasma operation in ITER-FEAT will make technological demands that necessarily integrate and demonstrate key technologies for fusion energy - notably super-conducting magnet coils, fusion fuel cycle operation, accommodation of heat flux and neutron flux and fluences and the application of remote handling and maintenance technologies. ITER-FEAT will have the capacity to test principles and concepts for other fusion technologies such as breeding blanket modules.

5 The engineering features of the design rest on the approaches and solutions developed and qualified for the 1998 ITER design. The continuing flow of results from the large technology R&D projects provide a basis for confidence in the feasibility, performance and operating margins for the various systems.

6 The initial cost scoping exercise, based mainly on simple scaling from the industrial cost studies of the 1998 ITER Final Design Report, indicates a total capital cost estimated at about 56% that of the 1998 design and provides mainly the relative cost of the different systems as a percentage of the total. Indicative estimates of operating costs are about 51% those estimated for the 1998 design. A proper cost estimate of ITER-FEAT will be obtainable only after a new round of industrial estimates of procurement packages based on detailed design of components and systems. Such studies will be able to quantify the opportunities for re-optimising the manufacturing around the new design and for taking full benefit of the results emerging from the large technology R&D programmes. Thus, there appears to be scope for further reductions in total capital cost.

7 Analysis to date indicates that the favourable overall assessment of the safety and environmental characteristics of the 1998 ITER design applies also to the ITER-FEAT outline design; the analysis is being further refined around the specifics of the design and planned operations. The safety principles and criteria for ITER safety are being further developed with the aim of developing a consensus among the Parties in this area with their regulatory authorities before the case will be presented to the Host Authority.

8 Subject to the views of the ITER Council and of the Parties on the content of the present report and its supporting technical information, the project is in a position now to proceed to detailed design of the ITER-FEAT systems, to resolve the remaining open design issues, to prepare the inputs for industrial cost estimates, and to extend the safety and environmental assessments with the view to providing by the end of the ITER EDA extension, a sufficient technical basis for a possible decision by the Parties to proceed to joint construction and operation of ITER-FEAT.

ROM 19/01//00
Attachment 7

TECHNICAL ADVISORY COMMITTEE MEETING

20-22 December 1999
ITER Naka Joint Work Site

MINUTES

The ITER Technical Advisory Committee (TAC) was held on December 20-22, 1999 at the Naka Joint Work Site (JWS), Japan. The objective of the meeting was to review the document "Technical Basis for the ITER-FEAT Outline Design (ODR)" issued by the Director on 10 December, 1999. It is also aimed to provide the 16th ITER Meeting scheduled on January 19-20, 2000 in Tokyo with a technical assessment of the ODR and recommendations for the optimization of the anticipated plasma performance and engineering design, based on the guidelines approved by the Council in June 1998 and recommendations of the last TAC meeting.

A list of TAC participants is shown in Attachment 1. The Director summarized the conclusions of the meetings held after the last TAC, as a background, and also made an overview talk on the descriptions of ODR.

1. Introduction

The Chair welcomed the TAC members, ITER Directors, Home Team Leaders and experts from the co-operating countries, as well as the members of the Joint Central team (JCT). The Chair made a remark that TAC should conduct as detailed technical discussions as possible, where it can become critical to the detailed engineering design, even if ODR is an outline in its nature, and called for vigorous discussions to produce significant output of the meeting. The Chair also acknowledged the administrative staffs at Naka for their hospitality and efforts in arranging and hosting the meeting.

The Chair also stated that the draft agenda for this TAC meeting was formulated consulting with the Director, considering the discussions at the ITER Meeting held in Cadarache in March 1999. The agenda was adopted and given in Attachment 2.

2. Charges to TAC

The last ITER Meeting held in Cadarache in March 1999 asked TAC to conduct a thorough review of the document "Technical Basis for the ITER-FEAT Outline Design."

3. Technical review of the "Technical Basis for the ITER-FEAT Outline Design."

The TAC meeting was dedicated solely to the technical review of the above document "Technical Basis for the ITER-FEAT Outline Design."

The meeting consisted of eleven presentations from the JCT members, covering all the aspects of the ITER-FEAT design, including the safety considerations and plant facilities. The presentations were made on the first day of the meeting. After detailed discussions on the second day in two separate groups viz., one for plasma performance and control including diagnostics and the other for magnets, in-vessel components, plant facilities, assembly / maintenance and safety, the preparation of a draft report and its review was performed on the third day. Here, it was considered essential to discuss the safety issues in a single group. The report is appended in Attachment 3.

4. Approval of the minutes

All the participants adopted the aforementioned report in Attachment 3, to which minor modifications limited to the wordings are anticipated after the meeting.

5. Future meetings

The Chair personally thanked all the members of TAC for their hard work during, and in preparation for, the TAC meeting. He also expressed his desire that the TAC contribution would expedite the ITER-FEAT program.

A discussion also took place on the possibility that a TAC meeting could be organized to look into the progress and define the R&D issues of ITER-FEAT, in which engineering options are intended to converge, on either July 10-13 or 19-22, 2000 in St. Petersburg.

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Attachment 2

AGENDA

December 20

09h00 - 09h15	Welcome and Opening Addresses	Chair
09h15 - 09h30	Adoption of Agenda and Meeting Organization	Chair
09h30 - 09h45	Announcement of Logistics	Secretary
09h45 - 10h15	Introduction (Charges to TAC)	Chair
10h15 - 11h15	Brief Summary of the Meetings held since the last TAC meeting and Overview of the Descriptions in the Outline Design Report	Director
11h15 - 11h30	Break	
	Presentations from the JCT	
11h30 - 12h30	Plasma Performance assessment (including Heating and Current Drive)	Y. Shimomura
	Overall Operational conditions	V. Mukhovatov
12h30 - 13h30	Lunch and Group Photo	
13h30 - 13h45	Plasma boundary conditions and Divertor Operations	M. Shimada
13h45- 14h15	Magnet System (including cryogenics and power supply)	M. Huguet
14h15- 14h30	Plasma Shape Control/Vertical Stability	P. Mondino
14h30 - 15h00	Vacuum Vessel and Divertor	K. Ioki
15h00- 15h15	Blanket System	F. Elio
15h15 – 15h45	Plant facilities	R. Hemmings
15h45 - 16h00	Break	
16h00- 16h15	Diagnostics	A. Costley
16h15- 16h35	Assembly and Maintenance	R. Haange
16h35 – 17h00	Safety	C. Gordon
17h00 - 17h30	Executive Session of TAC, in order to define questions/concerns from TAC Members on Key issues which should be more documented by JCT and to organize Subgroups for the next day	

December 21

09h00 - 12h30	Discussion in parallel Subgroups with, if needed, an appropriate additional information from JCT presenters • Group A (Plasma Performance and Control, Diagnostics) • Group B (Magnet and In-vessel components, Heating / CD, Plant Facilities, Assembly / Maintenance, Safety)
12h30 - 13h30	Lunch
13h30-15h30	Continued Discussion in parallel Subgroups, if necessary
15h30-17h30	TAC Executive Session: Status report from Sub-Groups, and how to integrate their findings in a global TAC Report
18h30 - 20h30	Reception

December 22

09h00 - 12h30	Draft writing in TAC Subgroups or/and Plenary Session	
12h30 - 13h30	Lunch	
13h30 - 16h00	General Assessment, Findings and Recommendations	Chair
16h00 - 17h00	Discussion on the Draft Minutes and Summary	
17h00 - 17h15	Future Meetings	Chair
17h15 - 17h30	Procedure and Schedule of finalizing the Minutes	Secretary
17h30	Closing Remarks and Adjourn	Chair

ITER TECHNICAL ADVISORY COMMITTEE
20-22 December, 1999
ITER Naka Joint Work Site, Japan

REPORT OF THE TAC MEETING

1. Introduction and background

In response to the TAC recommendations made in February 1999, which, in view of the many possibilities for parameter sets, urged the ITER Council to take appropriate action with the aim of converging towards a single design option, the Director set up a task force to discuss the principal plasma parameters intensively. As a consequence, an IAM-type ITER, which places greater emphasis on the steady-state performance, was recommended by the task force report in July, 1999.

According to the decision taken at the ITER Meeting held in Cadarache in March 1999, the TAC is charged to conduct a detailed review of the document "Technical Basis for the ITER-FEAT Outline Design (ODR)," issued by the Director on December 10, 1999. Therefore, the TAC is requested to assess the appropriateness of the proposed plasma parameters and to review the engineering issues, which would have to be consistent with the chosen plasma parameters, in order to provide technical advice to the ITER Council.

Thirty-seven attendants, including nine TAC members, ten invited TAC experts and two Home Team Leaders participated in the review. The Joint Central Team staffs gave a total of eleven presentations, related to the description of the above document.

2. Overall assessment and key recommendations from TAC

(1) TAC appreciates that the convergence of the device parameters from IAM and LAM has been successfully achieved. The ITER-FEAT parameters are consistent with the recommendations of the last TAC meeting. In addition, TAC hereby greatly acknowledges the dedicated effort and the intensive design work made by the Director, JCT and Home Team members, since February 1999.

(2) TAC fully endorses the Outline Design Report and notes the progress made in reducing the remaining physics uncertainties and in achieving the objectives within the cost constraints. TAC finds that the ODR meets, in general, the detailed technical objectives provided by the SWG and endorsed by IC in 1998, and provides a sound basis for further detailed design.

(3) The TAC considers that the profile sensitivity of all the scenarios including the pedestal size should be studied to understand the variations in operating domains and the influence on achieving the objectives. Due consideration of the

plasma performance degradation near the operating boundaries (n / n_{GW}, P_{LH}, etc.), the compatibility with successful divertor operation should be analysed.

(4) The divertor is a critical component of the device. Issues related to the scaling of the SOL width and to the lifetime of the target due to ELMs are recognized. The scaling of the basic assumptions made in modeling should be validated on a range of experimental devices and the implications for the divertor design and the compatibility with the various operating scenarios should be evaluated. In TAC's view, R&D's on ELM control methods should also be vigorously pursued.
(5) In relation to the magnets, TAC recommends that R&D work on NbTi strand should be continued, and manufacturing capability of the NbTi and Nb_3Sn strands should be assessed together with the cost estimates that meet the reference specifications. In addition, the assessment of SS316LN, titanium and Incoloy as candidate jacket materials for the CS conductor should be finalized, including the use of titanium in the TF insert coil. The TFC design with radial plates seems feasible. However, it is necessary to continue the extended analysis of both the radial plate and square conductor options. TAC also recommends to finalize the blanket cooling design.
(6) It has been noted that ODR includes a limited number of design options for some components. The JCT is encouraged to pursue the design selection with emphasis on improving the options presented, in close collaboration with the HT's.
(7) TAC recommends that comprehensive and integrated safety assessments should be conducted in future to be consistent with the detailed design work, with particular attention paid to the licensability of ITER/FEAT. Further refinement on the estimation of the source terms arising from the radioactive inventory is to be encouraged in order to characterize the nuclear aspects of ITER and improve the safety and licensing process in the Parties.
(8) The present outline design of ITER-FEAT was intended to establish the technical feasibility of the device but, at present, not necessarily at the minimum cost. The current cost estimate discussed in ODR is 56% of FDR. TAC recommends that every effort should be made to reduce the cost further down to ~ 50%, including improvements in component design, manufacturing methods, and their integration in the system design in accordance with the operational requirements. However, TAC recommends that the moves towards cost reduction should not jeopardize the feasibility and necessary engineering margins for ITER-FEAT.
(9) TAC understands that the site requirements described in ODR are technically relevant to the specific design option given in ODR.

3. Assessment and recommendations on plasma performance including heating & CD, plasma control and diagnostics

3.1 Introduction

The ITER Director and JCT presented the outline design for ITER-FEAT which meets the objectives set out in SWG1, namely to achieve extended burn in inductive operation with Q>10, not precluding ignition, with a burn duration of 300 to 500 s, and the demonstration of steady-state operation using non-inductive current drive with Q>5. This followed the study of options by the JCT and Home Teams with the guidelines of preserving margins against the revised targets and the scope for flexibility within the cost target but exploiting advances in physics understanding, resulting in convergence to a single coherent outline design.

The resultant key parameters of size, aspect ratio, elongation, triangularity and safety factor were set by:

- size (R = 6.2m, a = 2 m), a balance between prudence in the confinement scaling laws resulting from the international machine database to provide adequate margin to achieve the performance objectives on the one hand and cost on the other;
- aspect ratio (A = 3.1), a balance between accessibility for heating and current drive lower power threshold and achieving substantial bootstrap current fraction and high density;
- elongation (κ_{95} = 1.70 using external coils), as high as possible compatible with adequate stability margin and control capability to sudden changes in plasma parameters;
- triangularity (δ_{95} = 0.33), as high as possible but compatible with the divertor configuration;
- safety factor, a prudent value of around 3 so as not to increase the probability of disruptions or instabilities and be well within the confinement database.

3.2 Reference scenario (Q > 10)

At 15 MA using a conservative variant of the multi-machine thermal confinement scaling gives a 10% confinement margin to achieve Q = 10 (20% with a more optimistic variant which includes ohmic H mode data from smaller devices) with a reference operating point ($H_H = 1$) of $\beta_N = 1.8$, density normalized to the Greenwald value of 0.8 and a transported power that exceeds the new L to H power threshold (which has reduced uncertainty) by more than a factor of two. At 17.4 MA ($q_{95} = 2.6$) this margin increases to 25%. A gas throughput of 200 Pam^3/s in the divertor is sufficient to keep the helium concentration below 6% which together with impurity concentration of Be and C are included in the power balance.

3.3 High Energy Gain (Q ~ 50)

At 17MA there is a 10% confinement margin to achieve high energy gain (ignition) and an operating point with $n / n_{GW} \sim 0.8$, $\beta_N \sim 1.5$, $P_{LOSS} / P_{LH} \sim 2$. The engineering feasibility of operation at 17 MA should be confirmed (see section 4).

3.4 Long pulse operation

The performance of hybrid modes of operation, in which a substantial fraction of the plasma current is driven by external heating and the bootstrap effect leads to a substantial extension of the burn duration and is a promising route towards steady state operation. At 12 MA pulse lengths of 1000-2000 s are possible with Q = 5, some confinement margin and modest densities and β_N values, well within existing database.

3.5 Steady-state operation

There are two approaches in achieving the aim of steady-state operation with Q > 5, high-current (12 MA) with monotonic q profile and modest current with negative shear. The high-current case requires high current-drive power with high efficiency with the modest bootstrap fraction but modest confinement enhancement (20%) and β_N (~ 2.8) below that where control of the resistive wall mode is required. The second approach is much more challenging (requiring a 50% confinement enhancement) but is strategically important for steady-state operation in DEMO. It is encouraging to note that JT-60U has achieved near full current drive for several seconds with high bootstrap fraction with off-axis neutral beam current drive in a reversed shear configuration with the requisite enhancement of confinement. We believe the outline design has the flexibility to investigate this mode of operation with shifting the magnetic axis outwards, providing for several current drive schemes to drive current at different radii as well as coils for feedback control of the resistive wall mode. We believe it is important to study the non-linear interplay between transport and transport barriers, stability and different current drive schemes driving current at different radii to understand the necessary diagnostics feedback requirements and the required balance between the different current drive methods in an alpha-heated plasma.

Recommendation

TAC recommends that a coordinated effort is required in present experiments, related to the approach to the steady-state modes of operations together with feedback control experiments on the resistive wall mode.

3.6 Improved performance predictions

Some consideration of profile sensitivity has been made indicating an improved operating domain from broader temperature profiles. The performance would improve for more peaked density profiles which may now be realizable as a result of the success of high field side pellet refueling. It was pleasing to note the development of two new approaches to assess the performance of ITER-FEAT, one a probabilistic assessment and the other a deterministic scheme.

It is also important to recognize that the performance predictions and confidence in these can be further enhanced through the more generic knowledge gained through the operation of other types of magnetic confinement facilities with respect to their confinement, divertor operation, fast particle behavior, etc.

Recommendations

- TAC considers that the profile sensitivity, including the influence of pedestal size, of all the scenarios should be studied using 1.5D modeling to understand the variations in operating domains and the influence on achieving the objectives. Due consideration of the performance degradation near operating boundaries (n / n_{GW}, P_{LH}, etc..) and the compatibility with successful divertor operation should be analyzed.
- The TAC was pleased to note a new approach to predicting the size of ITER-FEAT and the power production to achieve its objectives using the machine data-base and a number of dimensionless quantities, not using empirical confinement scaling. This adds confidence that the ITER-FEAT parameters are appropriate and we recommend the further development of this approach.
- Continued deployment of the dimensionless parameters approach to confinement scaling, particularly the different scalings of the core and edge plasmas and the further development of physics based codes even though they are not yet accurate enough to provide the principal basis for extrapolation to ITER-FEAT is required. They do permit the possibility of ascertaining if there could be underlying changes in the physics behavior of dominant alpha particles heated plasmas.

3.7 Neoclassical tearing modes

For the reference inductive operating scenario, the ideal β-limit is well above the nominal β_N of 2. However, it is known that in existing experiments β_N can be limited by neoclassical tearing modes (NTM) in the range $1.5 \leq \beta_N \leq 2.5$, corresponding to the projected Q = 10 operating window at 15.1 MA. Moreover, the threshold β_N for NTM onset is observed to reduce with decreasing ρ^*. Although some theoretical uncertainties remain, in particular in relation to the scaling of the seed island size, it is possible that NTMs triggered by sawteeth or ELMs will limit the achievable β-value in ITER-FEAT. Recent results from JET indicate, in addition, that the threshold β_N for the growth of NTMs decreases as q_{95} falls below the ITER-FEAT reference value of 3, suggesting that the potential 17.4 MA inductive operating scenario might be more susceptible.

Experiments in ASDEX-U with ECCD and in COMPASS-D with LHCD have confirmed the theoretical expectation that NTMs can be stabilized by localized non-inductive current drive. Predictions for ITER-FEAT indicate that 3/2 and 2/1 NTMs could be stabilized by ECCD powers in the range 10-30 MW. The ITER-FEAT outline design incorporates a proposal for two ECRF systems operating at 170GHz, one having a toroidal steering capability, the other a poloidal steering capability, which should allow two NTMs to be stabilized simultaneously. In addition, the proposed capability for sawtooth period control via localized ICCD or ECCD at q = 1 should contribute to the avoidance of NTMs by reducing the likelihood that sawteeth generate suitable seed islands.

In order to provide a more robust basis for the prediction of NTM onset conditions and stabilization requirements, further experimental and theoretical developments would be desirable to improve the predictive capability with respect to minimum seed island size, the scaling of the critical β_N for NTM onset with ρ^*, the influence of plasma shaping and energetic particles on NTM stability, and to clarify the conditions for the simultaneous stabilization of two or more NTMs. Further analysis is required to identify the sensitivity of stabilization power to temperature profiles and to establish the range of steering angles for the ECRF system.

3.8 Resistive Wall Modes

Long-pulse inductive ("hybrid") or steady-state operation in ITER-FEAT will likely require $\beta_N \sim 3$, or greater. For certain candidate regimes e.g., those having reversed central shear, the broad current profile (low l_i) can lead to the growth of a resistive wall mode (RWM), as the required β_N value exceeds the β-limit for the n = 1 external kink mode with the wall at infinity. Improved experimental and theoretical understanding of RWMs shows that plasma rotation merely slows the growth of the modes, and that stabilization will require active feedback control via a system of external coils. Such a system, having the flexibility to correct error fields as well as to suppress RWMs, is foreseen in the ITER-FEAT outline design. Further studies in existing experiments are desirable to confirm the stabilization requirements in terms of the mode number, coil geometry and power requirements. A more extensive study is required for the range of plasmas expected in ITER-FEAT non-inductive scenarios to identify conditions under which RWMs are expected and to predict the geometry and power requirements for RWM suppression. This should be used to confirm the adequacy of the proposed magnetic diagnostics and to provide a basis for the design of the ITER-FEAT RWM control/error field correction coil set.

3.9 Fuelling and density limits

ITER-FEAT requires, for the nominal Q = 10 and 400 MW operation, an averaged density of 1×10^{20} m^{-3}, assuming a conservative flat density profile. The density normalized to the Greenwald value is $n / n_{GW} \sim 0.85$. At higher current of 17.4 MA the device also has a capability for Q = 10 operation at $n / n_{GW} \sim 0.6$, albeit with shorter burn duration though still in excess of 100 s. These results illustrate the flexibility of the design for responding to confinement degradation observed experimentally at high density near the Greenwald value.

The experimental basis for fuelling and operating large devices near the required n / n_{GW} value whilst maintaining H-mode confinement has continued to improve significantly compared with the FDR situation. For example, $n / n_{GW} \leq 1.6$ has been achieved with HFS pellet injection on JET. Energy confinement degradation is still observed but occurs at higher density than with gas fuelling and the degradation at $n / n_{GW} \sim 0.85$ is of the order of 10%. Moderately peaked profiles are generated. Plasma triangularity is also helpful to maintain H-mode confinement at higher density.

Recommendation

- ITER-FEAT has adequate margins with respect to the density required to reach its objective. R&D on pellet injection or possibly collimated high velocity gas fuelling from the HFS has the potential to further increase the operation domain.

3.10 Divertor performance and ELM control

The overall aim of the power and particle control systems is to limit the peak power loading on the divertor target to less than $10 MWm^{-2}$, to maintain an edge helium concentration of less than 6% and to limit the core plasma Z_{eff} below 1.8.

Results of divertor modeling from ITER design variants indicate that the device can stay within the target power loading limit for a range of upstream separatrix density, 3.3 to 3.8×10^{19} m^{-3} with adequate fuelling throughput. In such a range, the upstream helium concentration is reduced to 3%.

Several tokamaks have confirmed that it is possible to exhaust helium at the required rate in ELMy H-modes. However such a demonstration is lacking for steady state scenarios with an internal transport barrier.

The physics of radiation, flow and detachment in the divertor channels observed in experiments is well described by modeling. However, the models rely on a basic assumption on the perpendicular transport, which needs to be validated by the scaling experiments. The very small energy scrape-off length observed in JET standard ELMy H-modes suggests that the SOL width does not increase with machine size.

The edge relaxations (ELMs) in the reference plasma regime for inductive operation are expected to produce pulsed energy deposition which may exceed the limiting value for vaporization of the graphite target plate. Reduction of ELM amplitude is required to increase the longevity of the target plates whilst avoiding the resultant loss of plasma confinement which is commonly observed. Some degree of success has been obtained experimentally by fuelling, shaping or choice of the heating method.

Recommendation

- The divertor is a critical component of the device. Issues related to the scaling of the SOL width and to the life-time of the target due to ELMs are recognized. TAC recommends to validate the scaling of the basic assumptions made in modeling on a range of experimental devices and to consider the implications for the divertor design and the compatibility with the various operating scenarios. R&D on ELM control methods should be vigorously pursued.

3.11 Disruptions and vertical displacement events

The heat loads and electromechanical forces on the vessel structures and the potential for high currents of runaway electrons impose significant design constraints. Potential avoidance and mitigation techniques need to be further developed on existing experiments to evaluate their potential for application on ITER. There is an indication from the halo current database on halo current fraction and toroidal peaking factor that there is a favourable size scaling, but this needs to be further quantified. ITER-FEAT is sensitive to runaway electron formation and there is a need to compare modelling with experiment, in particular JT60-U, taking into account magnetic fluctuations and synchrotron radiation, which could reduce the impact of run away electrons.

3.12 PF configuration and control

The PF system consists of a segmented central solenoid and six nearly symmetric up/down poloidal field coils permitting significant plasma shaping capability for high elongation and triangularity.

About 30 Wb of flux are available for driven burn for the reference scenario of 15 MA permitting a pulse length of 400 / 500 s. For the high current scenario (17 MA), this falls to 11Wb and the pulse length exceeds 100 s. This could be extended by the profile control in the current rise phase.

A detailed study of the vertical stability margin of the reference scenario has been made for both the external and internal coils. The vertical position control capability using external coils at $\kappa_{95} = 1.70$ is good throughout the pulse, provided that the self-inductance does not become too large at the start of the flat top nor during the current decay. This can be avoided by profile control and/or reducing the elongation. Abrupt decreases of inductance by 12% and β by 25% can be accommodated within the power supply capabilities and with small movements in the vertical direction as a result of the nearly symmetric up / down poloidal field coils system, which significantly reduce the power for vertical stabilisation. In this respect, the toroidally continuous rings, which support the blanket modules close to the divertor, play an important stabilising role. Somewhat higher elongation can be achieved with internal coils but with reduced stability margin and more sensitivity to configuration changes such as minor disruptions together with increased engineering complexity. A pulse length capability of up to 2000 s, representing a few full radius field diffusion times, is possible (limited by the water cooling system, cryoplant and tritium plant to constrain cost) with the ability of the control system to deal with many 10's of disturbances.

3.13 Heating and Current drive

The ODR retains the option for Heating systems (ECRH, ICRH, LHCD and NBI) fulfilling multiple functions including core ion and electron heating, on-axis and off-axis current drive and stabilization of MHD modes. In the first phase of operation, 33 MW is planned for NBH / CD and 20 MW each for IC and EC systems (73 MW of total power). The level of power could be subsequently increased to a total of around 100 MW and could include 20 MW of LH.

The new off-axis CD capability with NBI is obtained by adjustment of the neutral beam injection angle.

The RF launcher assemblies are designed as interchangeable horizontal plugs with the same nominal power per port (20 MW) cantilevered at the port closure plate. The EC beams can also be injected from an upper port for off-axis CD mainly for NTM stabilization. Toroidal EC beam steering is provided in the equatorial port EC launcher and poloidal steering is planned on the upper port. The IC coupler consists of a low voltage array of 4 x 2 elements fed by 8 coaxial transmission lines.

Recommendation

TAC notes that the heating and current drive systems have a substantially increased importance compared to the FDR design. The TAC welcomes the additional flexibility now included. Clearly R & D is required to confirm the specifications required from each system i.e., gyrotron and EC windows, NB sources at 1 MeV and IC and LH coupling in plasmas with narrow scrape-off layers.

3.14 Diagnostics

The proposed diagnostics for ITER-FEAT are categorized into 3 classes: protection and basic control, advanced control, evaluation and physics. A "start-up set" has been identified to guarantee initial plasma operation and to permit diagnostics which are not essential for the initial phase to benefit from continuing developments in the Parties' programs. The design for the majority of diagnostics can be transferred from ITER FDR to ITER-FEAT with minor modifications and, indeed, some diagnostics, such as the measurement of the core n_D/n_T ratio, benefit from the reduced dimensions of ITER-FEAT. A new arrangement is required for the vertical neutron camera, since the top vertical ports have been re-oriented in ITER-FEAT, but the proposed modification, using discrete lines of sight through the vacuum vessel, may be feasible. Progress was reported in the R&D program on plasma facing mirrors which gives confidence that an acceptable solution has been found for the majority of affected diagnostics, though further R&D is required for the large aperture mirror for MSE. Particular consideration should be given to factors (e.g., RIEMF) influencing the reliability of the magnetic measurements for equilibrium control in long pulse operation.

The increased emphasis on control of MHD instabilities and on the exploitation of plasma scenarios which exploit current profile control places greater weight on relevant diagnostic schemes in ITER-FEAT. Diagnostics measuring the position and amplitude of NTMs, growth of RWMs and the evolution of current (and safety factor) profile will need to be incorporated into the active feedback control loops in a manner already anticipated in the ITER FDR design for bolometric measurements of core and divertor radiation. Further studies are indispensable in these areas to confirm the feasibility of diagnosing the relevant plasma parameters with adequate space and time resolution, but the determination of the current/safety factor profile appears somewhat challenging. Particular emphasis should be given to the development of the relevant diagnostics and to the demonstration of the necessary measurement and feedback control capabilities in the Parties' programs. Similarly, the development of an adequate diagnostic capability for the energetic particle populations (alphas and beam-injected ions) should be given priority in R&D activities.

3.15 Overall recommendation

TAC fully endorses the Outline Design Report and notes the progress made in reducing the remaining physics uncertainties and in achieving the objectives within the cost constraints.

4. Assessment and recommendations on magnets, in-vessel components, plant facilities, assembly / maintenance and safety issues

4.1 Introduction

Aiming at realization of highly elongated plasmas required to satisfy the SWG guideline, the outline design of the engineering devices has been presented with a maximum use of the technology developed throughout the ITER-EDA R&D program.

The basic approach of the engineering design is directed to control the elongated plasma by adopting the design concepts such as segmented CS, wedged TF and symmetry PF coils for shape and position control, assisted with passive stabilizer.

In addition, much efforts have been made to reduce the machine cost, typically by adopting concepts, such as a separable FW, which enhances attractiveness in terms of safety by minimizing the waste production.

A new VV support is also introduced to minimize displacement of the VV port. It is noted that the fundamental tokamak design is derived from the reference parameter set, and further study will be pursued to confirm the design robustness and to clarify the operational flexibility for a high Q operation in higher plasma current regime.

Studies of the 17 MA hybrid and steady-state scenarios remain to be carried out but no substantial problems are anticipated.

4.2 Magnets

The conductors for the TF and CS coils have been designed according to the design criteria that have been defined during the periods of the EDA and EDA extension, based on R&D results available from component testing, particularly that associated with the model coil program.

There are two options to provide the structural material within the CS winding. The first one uses an Incoloy square jacket with a co-wound strip and the second one uses two SS U-channels welded around a thin Ti circular jacket.

Two options of the TF coil winding are still under investigation: one with a circular conductor embedded in radial plates and the other with a square conductor.

The key structural issue remains the out-of-plane supports of the TF coils at the inboard curved region in the vicinity of the divertor. Various design concepts have been analyzed, but final design has not yet been established.

Recommendations

- Continue R&D on NbTi strand in order to guarantee the achievement of properties in accordance with the specification. It is also necessary to assess the readiness of the industries to manufacture the NbTi and Nb_3Sn strands in accordance with the specifications and to obtain the cost estimations that meet the reference specifications. The TF insert coil to be built by Russian Federation will use a Nb_3Sn conductor with a thin circular titanium jacket. TAC recommends this development of a titanium jacketed conductor as one of the CS conductor options.
- Finalize the assessment of SS316LN, titanium and Incoloy as candidate jacket materials for the CS conductor.
- Although the TF coil option with radial plate is feasible, it is necessary to continue the analysis of both the radial plate and square conductor options.

4.3 Vessel and In-Vessel Components

The double wall VV concept of FDR has been retained, as well as the concepts for the in-vessel components. The main changes are the elimination of the back-plate, the adoption of a separate first wall and a new vessel supporting system.

In relation to the rationale for the plasma facing materials, the Director stated that the choice of PFC materials indicated in the ODR is under review. The ODR proposal was described as corresponding to the best knowledge considering the operating plasma scenarios proposed. It was also stated that the Director would continue to investigate the impact of TF fast discharge on the machine size and cost. In addition, the filler shield integration in the blanket modules needs to be further developed.

Recommendation

It is recognized that the final decision on PFC design can be taken at a later stage in construction. The JCT in collaboration with HT's should encourage the development of plasma-wall interaction modeling and validation in present experiments to support evolving PFC engineering design. The integration of the blanket cooling design should also be pursued.

4.4 Facilities, Assembly and Maintenance

Since the "Study of options for RTO/RC-ITER" report reviewed in February, there has been no major change in the dimensions of the major tokamak components. The machine concept is similar to IAM. Some design changes have been conducted to meet the plasma operation requirements and to achieve further cost reduction. These changes, in particular on the support structures of the TF coil, CS coil and VV, are still at the conceptual level.

The inboard leg of the TF coils should be fully wedged to mechanically sustain the toroidal compression force during the operation. In order to realize this concept, further detailed analyses including fabrication and assembly tolerances should be performed for the next step of the design phase.

In the ITER-FEAT design, the space for assembling, inspection, and repair of the VV support structure seems to be small. Since the VV is the first confinement barrier to tritium, its support structure should be highly reliable. Also from the engineering point of view, structural integrity of the VV design in the port region, stress evaluation of the attachments between VV and magnet, and the relative displacement should be assessed.

In accordance with remote handling requirements, more optimization of equipment in the Hot Cell building will be needed, and the radioactive waste including the liquid waste arising there should be evaluated.

In the ODR, only a conceptual machine layout is presented. The available space for transportation of casks seems to be very tight, which requires careful consideration.

4.5 Safety

At the previous TAC meeting held in February 1999, the study of option report for RC/ITER confirmed the safety and environmental attractiveness of ITER with some improvements compared to the FDR. The same position is maintained in the ODR.

The safety design specification remains the same as in the RC/ITER document. It implies that the safety level in particular in relation to the tritium inventory and the activated materials in the system are the same.

Recommendations

- Comprehensive and integrated safety assessments need be conducted in future to be consistent with the detailed design work. Attention should be paid to licensability of ITER/FEAT. In addition, a concerted effort is expected to overcome certain disadvantages resulting from the elimination of the backplate, such as possible cross contamination of the coolant, complexity of the cooling system, related to the probability of abnormal occurrences.
- Further refinement of the estimation of source terms based on the current design is encouraged, in order to improve the safety and licensing process.

APPENDIX

LIST OF THE TAC MEMBERS PRESENT
AND IN AGREEMENT WITH THIS REPORT

Prof. M. Fujiwara (Chair)
Prof. S.-I. Itoh
Dr. K. Soda
Prof. S. Tanaka

Dr. J. Jacquinot
Dr. D. Robinson

Prof. V.G. Kuchinski
Prof. A.K. Shikov
Prof. V.P. Smirnov

ITER-FEAT
Site Requirements and Site Design Assumptions

Proposal by the Director

1 Site Design Requirements and Site Design Assumptions for ITER were approved as part of the ITER Interim Design Package (IC-8 ROD Attachment 4) by the ITER Council in summer 1995 (IC-8 ROD 2) following the recommendations of the Special Review Group.

2 With the changes to detailed technical objectives, now reflected in the ITER FEAT outline design, it has been necessary also to revisit the earlier set of requirements and assumptions in order to make adjustments in light of the new characteristics of ITER-FEAT. These changes, which have been discussed informally with Home Teams, are reflected in the attached document, which follows, the structure and scope of the original as approved by the Parties in 1995.

Recommendation

The ITER Council is invited to endorse the Site Requirements and Site Design Assumptions for ITER-FEAT as set out in the attached document.

ITER FEAT
Site Requirements & Site Design Assumptions

Introduction

The objective of this document is to define a set of requirements that are compulsory for the ITER site, supplemented by assumptions about the ITER site which are used for design and cost estimates until the actual ITER site is known. Part I of this document contains the principles for the development of the site requirements and site design assumptions. Part II of this document contains the compulsory requirements which are derived from the ITER design and the demands it makes on any site. Part III of this document 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
- Transportation 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.

I. Principles for Site Requirements and Site Design Assumptions

1. 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 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.

2. This document also addresses the assumptions that have been made to carry out the ITER design until a decision on siting is reached. 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.

3. The requirements for public safety and environmental considerations are, by their nature, site sensitive. Also, the regulatory requirements for siting, constructing, 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 siting 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 shipment of radioactive materials including tritium to the site, temporary storage of wastes on the site, shipment of wastes from the site and effluents from ITER during normal and off-normal operation are addressed with the design analysis. Accordingly, a Generic Site Safety Report ("Non-Site-Specific 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.

4. 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 organization 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 organization within the host country. A technical report on the strategy of deactivation and dismantling will be described inside the design report documentation.

5. In conclusion, the site design assumptions are very important, because without them progress is very limited for site sensitive designs 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 revise the cost estimate and the construction schedule.

II Site Requirements

A. Land

1. Land Area

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 predicated on sufficient area for the buildings, structures and equipment with allowances for expansion of certain buildings if required for 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*

Requirement The ITER Site shall have foundation soil bearing capacity adequate for building loads of at least 25 t/m^2 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 65t/m^2 at a depth of 25m. 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*

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*

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 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 analyzed for release. Rainwater runoff is not included in industrial sewage.

B. Heat Sink

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

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 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 Component to be shipped*

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 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:

Largest ITER Components to be Shipped

Component	**Pkgs**	**Width (m)**	**Length (m)**	**Height (m)**	Weight (T) **Each Pkg**
TF Coils	18	9	14.3	3.8	280
Vac. Vessel 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	(14)	(18)	(6)	(600)

* Crane dimensions and weight are preliminary estimates.

PF Coils and CS Assembly**

Component	**Pkgs**	**Width (m)**	**Length (m)**	**Height (m)**	Weight (T) **Each Pkg**
PF-1	1	9.5	9.5	2.4	200
PF-2	1	18.5	18.5	1.9	200
PF-3	1	25.5	25.5	1.2	300
PF-4	1	26.0	26.0	1.2	450
PF-5	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 Coil 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*

Requirement The ITER Site shall be capable of receiving about a dozen of 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 tonnes. All other components are expected to weigh less.

E. External Hazards and Accident Initiators

No Compulsory Requirements.

F. Infrastructure

No Compulsory Requirements

G. Regulatory and Decommissioning

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 mattters:

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.

III 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

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 maintenance or improvement of the ITER Plant.

Bases The assumptions made for the cost and schedule estimates are based on construction experience which 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 similar amount will be required to satisfy temporary needs during construction.

2. Topography

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

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

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

Assumption The ITER seismic design specifications for the applicable Safety Importance Class (SIC) are based on an assumed seismic hazard curve. 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:

SIC	IAEA level	Return Period (years)	Peak** Ground Acc.
1*	SL-2S 85% tile	10^4	0.4
2,3	SL-2 50% tile	10^4	0.2
3	SL-1 50% tile	10^2	0.05
4***	SL-0	short	0.05

* No ITER components in this class

** Peak Ground Acceleration is for both horizontal and vertical components in units of the gravitational acceleration, g.

*** SIC 4 components, the seismic specifications are not derived probabilistically - local (uniform) building codes are applied to this class. A peak value of 0.05g is assumed equal to the SL-1 peak value.

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

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

- 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/m^2
- 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)

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. Water supply and industrial sewage for Heat rejection system

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 m^3/minute. This water makes up evaporative losses and provides replacement for blowdown 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 m^3/minute. Each blowdown action will lead to a peak industrial sewage rate of 3000 m^3/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 m^3/minute of the water is lost by evaporation and drift of water droplets entrained in the air plume, and by blowdown. 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

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

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*	500 MW #
Peak Reactive Power	400 MVAr
Power Derivative*	200 MW/s
Power Steps*	60 MW
Fault Level	10-25 GVA
Pulse Repetition time	1800 s
Pulsed Power Duration**	1000 s

from which up to 400 MW is a quasi steady state load during the sustained burn phase, while the remaining 80 – 120 MW has essentially pulse character for plasma shape control with a maximum pulse duration of 5 – 10 s and an energy content in the range of 250 – 500 MJ.

* 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.

** 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 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

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

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

2. Air Transport

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

3. Rail and Waterway Transport

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

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

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 modeling 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 socioeconomic 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

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 labor
- Facilities or space for temporary construction labor
- 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

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. Socioeconomic Infrastructure

Assumption The ITER Site is assumed to have neighbouring communities which provide socioeconomic infrastructure. Neighbouring communities are assumed to be not greater than 50 km from the site, or one hour travel. Examples of socioeconomic 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. Regulatory and Decommissioning

1. General Decommissioning

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

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

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.

ROM 19/01/00
Attachment 10

Tentative Sequence of Technical Activities for 2000-2001

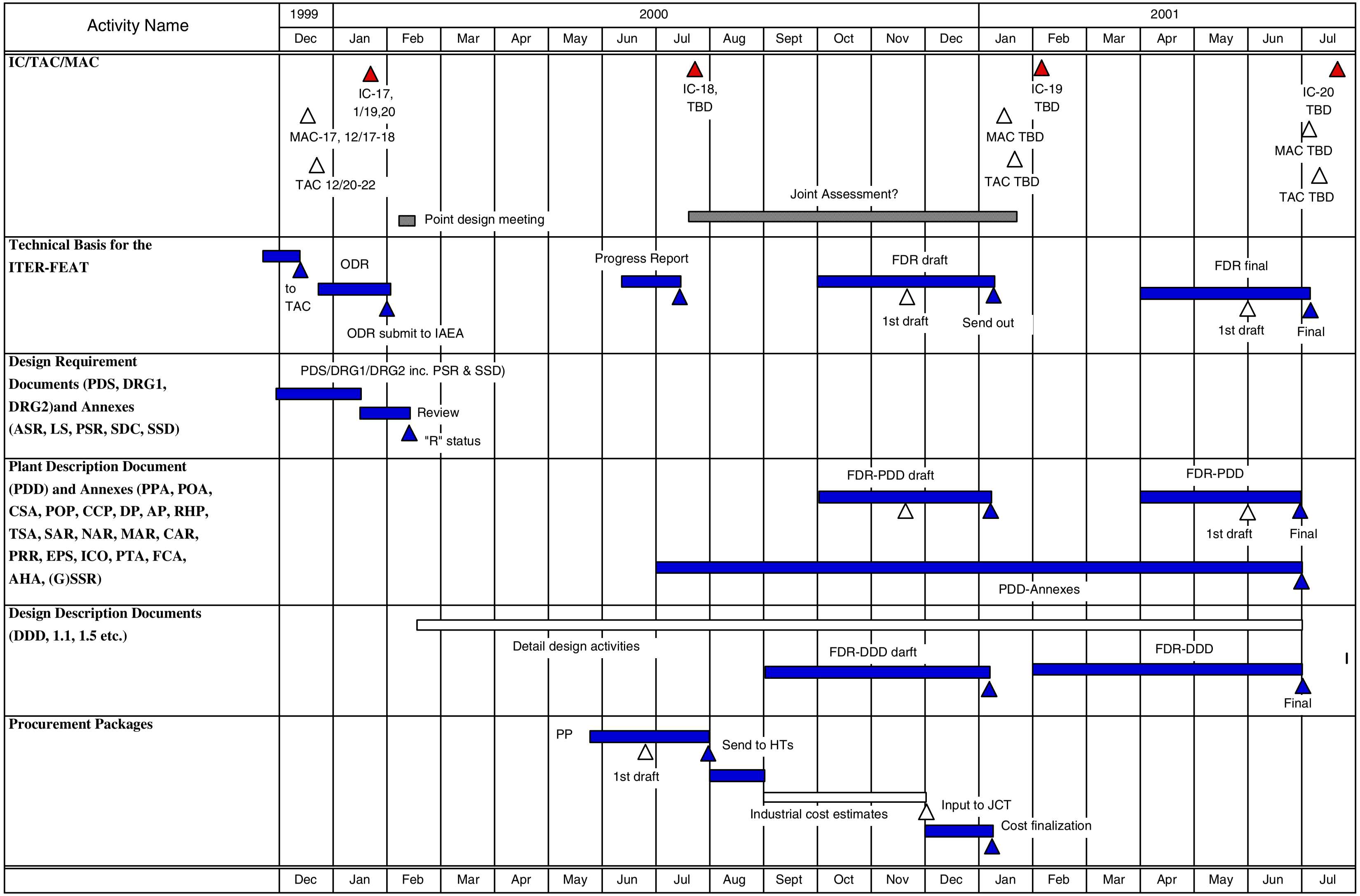
Information from the Director

The attached document (already shown informally to MAC and TAC) is provided as input to the Council's discussion of the TSOE. It shows how the technical work can be best planned to complement the key actions in the Parties' agendas for Explorations/Negotiations etc.

The main objective, from a technical perspective, is to provide as soon as possible for use by the Parties the main procurement packages and the updated industrial cost estimates, that will be essential inputs for the Parties at a start of negotiations. This will be the main priority for design work, with the aim to have a "Draft FDR" containing such information ready around the end of 2000 - the earliest date by which it is reasonable to expect to see reliable cost estimates.

Against this background, and considering the elapsed time, there is little merit in generating a full "DDR" for summer 2000. Rather it is better to provide a progress report which will briefly summarise the choices made for the few remaining design options, while concentrating JCT and Home Team designers' efforts on the key task of preparing the packages for costing and pursuing the costing exercises with their industrial experts.

It is to be noted that the "IC" and related TAC and MAC dates are only our working assumptions. It is presumed that the actual IC timetable will be set according to the strategic demands of the Parties - possibly co-ordinated with the planned timetable(s) for Explorations/Negotiations.



Activity Name
1999
2000
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Apr
May
Jun
Jul
IC/TAC/MAC
IC-17, 1/19,20
MAC-17, 12/17-18
TAC 12/20-22
IC-18, TBD
IC-19 TBD
MAC TBD
TAC TBD
IC-20 TBD
MAC TBD
TAC TBD
Point design meeting
Joint Assessment?
Technical Basis for the ITER-FEAT
to TAC
ODR
ODR submit to IAEA
Progress Report
FDR draft
1st draft
Send out
FDR final
1st draft
Final
Design Requirement Documents (PDS, DRG1, DRG2)and Annexes (ASR, LS, PSR, SDC, SSD)
PDS/DRG1/DRG2 inc. PSR & SSD)
Review
"R" status
Plant Description Document (PDD) and Annexes (PPA, POA, CSA, POP, CCP, DP, AP, RHP, TSA, SAR, NAR, MAR, CAR, PRR, EPS, ICO, PTA, FCA, AHA, (G)SSR)
FDR-PDD draft
FDR-PDD
1st draft
Final
PDD-Annexes
Design Description Documents (DDD, 1.1, 1.5 etc.)
Detail design activities
FDR-DDD darft
FDR-DDD
Final
Procurement Packages
PP
1st draft
Send to HTs
Industrial cost estimates
Input to JCT
Cost finalization

Report of the ITER SWG-P2 to the ITER Council on Joint Implementation of ITER[1]

1. Introduction

(1) The next major step along the path to establishing fusion as an energy source is to construct and operate a fusion device, the overall programmatic objective of which is to demonstrate the scientific and technological feasibility of fusion power for peaceful purposes. Recent work undertaken in the international collaborative frame of the ITER Engineering Design Activities (EDA) Agreement has established the technical basis for taking such a step in a facility that will integrate key scientific and engineering features of fusion energy systems, and the SWG report of 30 January 1999 has reached the conclusion that *"the world program is scientifically and technically ready to take the important ITER step"*.

(2) This present report is intended to serve as a non-binding basis for the start of Explorations.

2. Joint Implementation

(1) The technical challenge of realizing ITER and its estimated cost and duration make ITER one of the most significant single civil R&D projects in the world, and calls for a pooling of technical expertise and sharing of resources world-wide.

(2) Taking into account the genesis of ITER as an initiative at summit level (in 1985 and 1986 and at the Birmingham G8 meeting, May 1998), the international nature of both the energy/environment problem and the fusion research effort so far, and the success of international collaboration on ITER phases of "Conceptual Design Activities" (CDA) and the ongoing EDA, the SWG-P2 recommends and has entirely focused on *joint implementation* of the Construction, Operation, Exploitation and Decommissioning Activities (COEDA) of ITER, which is expected to involve a balance of cost-sharing and status in governance, and a fair return in benefits.

(3) Accordingly, the EDA Parties, namely EU (with Canada as associate), Japan, and Russian Federation (with Kazakhstan as associate), should prepare for the establishment of an ITER collaboration by an international agreement which must meet the challenges of the project and ensure the degree of stability and the distributions of benefits, cost, and governance necessary for a project of this scale.

3. Benefits

(1) The Parties will share scientific and technological benefits from the construction, operation and exploitation of ITER. The scientific output of ITER will be open equally to all Parties and they will jointly develop an understanding of fusion science and technology, including industrial know-how and spin-off in meeting ITER's overall programmatic objective. By participating in a joint implementation of ITER, each Party will make optimum use of past

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[1] The current SWG-P2 Task was defined at the ITER meeting in Cadarache in March 1999 (ROM 99-03-10, 6.3). This report follows on from the SWG-P2 report on its Task # 1, which was approved by ITER Council in July 1996 (IC-10 ROD Attachment 10).

investments in fusion and will incur lower costs relative to those of undertaking ITER in a solely domestic programme.

(2) The Host Party obtains the prestige of having been chosen to host an international project of highest quality and visibility. This report does not address the issues of possible general economic benefits from a participation as Host or otherwise in the implementation of ITER.

(3) The terms of the collaboration must ensure that fair returns accrue to the Parties with respect to successful scientific and technical proposals, experimental opportunities, and industrial contracts.

4. Contributions

(1) To maintain the international character of the project and to reflect the common interest and shared responsibility to pursue jointly the programmatic objectives, each Party should make a significant contribution to the total cost of the project needed in construction, operation and decommissioning phases. The common area of construction[2], which is estimated at about three quarters of the total capital cost, should be shared among the Parties in a way which is as balanced as possible.

(2) The Host Party should bear the remainder of the capital cost which includes the construction of buildings and infrastructure, as defined in the approved design, and machine assembly. In addition, site preparations to satisfy the "ITER Site Requirements" will be undertaken, in principle, by the Host at its cost.

(3) The Host Party will also be expected to accept special responsibilities to ensure that the project will come to fruition, including the provision of the necessary legal framework for licensing and management of a due process for decommissioning and preparing an appropriate socio-cultural infrastructure, such as construction and maintenance of facilities for schooling. The non-Host Parties should also provide due contributions such as services for education system based on the Parties' needs.

(4) The annual operation costs (staff, system maintenance and repair, enhancements and electricity etc), assumed as 6-7% of the construction cost, should be shared among the Parties in ways compatible with the sharing of the construction cost.

(5) The sum of the contributions from each Party foreseen at the time of adoption of the international agreement must cover 100% of the estimated total resources needed throughout the project.

(6) The international agreement should define the total amount of the estimated costs for the ITER project expressed in a new unit based on the currency chosen for the ILE in the agreement, and distribution of contributions among the Parties.

5. Legal Framework

(1) The decision to construct ITER should be taken, together with the setting in motion of joint implementation, by means of an international agreement, signed and ratified, accepted or

[2] defined as items that could be produced in any of the Parties and transported to the site.

approved in accordance with the due process of each Party to secure the highest level of political commitment and stability for the implementation of the project.

(2) The international agreement should provide for the establishment of an ITER legal entity (ILE) to be jointly set up and supported by the Parties, with the responsibility to implement ITER. The ILE must have the charge, the structure, the authority and means to implement the project for the Parties. While the ILE will have to comply with the applicable laws and regulations of the Host, the need for the institutional independence of the ILE from the Host authorities is recognised.

(3) Subsidiary statutes or protocols implementing the ILE should provide the instruments for the normal exercise of management responsibility. They must allow for the flexibility that will be necessary to bring the ITER project to fruition over the several decades of the project. Thus, the distribution of terms and conditions between the international agreement and the statutes/protocols requires careful consideration.

(4) The provision of the site and local technical support by the Host Party should be the subject of a site support arrangement between the ILE and the Host.

(5) Within the legal framework, there should be two organs of project management:

- a Council, composed of Parties' designated representatives which will be responsible for the promotion and overall direction of the project, and will exercise overall supervision of its execution; and
- a Director-General, who will be the chief executive officer and the legal representative of the ILE, and who will be responsible to the Council for the execution of the project.

(6) Members of the Council will also bear the responsibility, in their domestic systems, to promote and protect the interests of the project and to sustain support throughout its entire duration.

(7) The Director-General must be vested with the managerial powers to lead ITER towards success. He will be assisted by an ILE staff over whom he should have sole managerial authority. He should be responsible for all the technical aspects of the project's execution, for compliance with the Host's regulatory requirements for worker and public safety, and for the protection of the environment.

(8) The balance of the Parties' status in the governance of the Project will be set primarily by the allocation of voting weights in the Council's decision-making process which should take into account the following:

1. decisions requiring consensus;

2. decisions requiring Host Party concurrence; and

3. decisions reached by voting, where the Parties' votes are weighted in relation to their contributions, while no issues may be decided solely by a single Party.

(9) The decision-making process for the scientific programme, which will be based primarily on scientific arguments, should also contain an element to reflect the contributions of each Party.

(10) The international agreement may lead to the ILE being established either under international law or under the domestic (civil or public) law of the Host.

(11) The issues of privileges and immunities and other facilitations to be accorded by the Parties are to be discussed in the Explorations/Negotiations, the results of which will be reflected in the international agreement or subsidiary instruments.

6 Siting, Licencing and Decommissioning

6.1 Siting

(1) The Parties wishing to host the ITER facility should make a formal single specific site offer before or at a sufficiently early stage of Negotiations which should confirm the readiness to satisfy the ITER Site Requirements and the extent to which the Site Design Assumptions are met, based on the document approved by the ITER Council.

(2) By this time each such Party should have in place the procedures to follow in order to licence construction and operation of the facility and should produce a statement through the appropriate regulatory authority that indicates that no major impediments to licencing ITER are foreseen.

6.2 Licensing

(1) An early, informal dialogue with regulatory authorities should be established with the aim of developing common views among the Parties on the principles and criteria for ITER safety, also because of its possible impact on licensing of future fusion energy facilities.

(2) This dialogue should orient efficiently the technical preparations for license applications with a view to solving the major technical issues before adoption of the international agreement.

(3) Therefore, at that time, the Parties should have confirmation that ITER can be licenced in the Host country (and that the licencing process would not be unduly vulnerable to challenge). The international agreement should make special provisions to deal with possible consequences of the licencing process.

6.3 Decommissioning

(1) With respect to decommissioning, only de-activation[3] should be within the responsibility of the ILE. Responsibility for carrying out the remaining decommissioning steps should rest with the Host Party.

(2) In accordance with normal practice, financial provisions for decommissioning and long term storage and disposal of activated materials which belong to the ILE should be made jointly by the Parties through a fund to be established under the international agreement and

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[3]"De-activation" covers actions to put the plant into a safe, stable condition while it awaits dismantling, and includes removal/stabilisation of tritium and residual mobile activation products, removal and packaging of in--vessel components, rendering of all liquid to safe, stable form and protection for components vulnerable to corrosion during the storage/dismantling process.

built up during operations and safeguarded for this purpose. Any guarantees demanded as part of the licensing process should be the responsibility of the Host Party.

(3) The SWG-P2 points out that components introduced into the ITER facility by a Party and still under the ownership of that Party at the time of decommissioning shall, in principle, be brought back by the concerned Party at its own cost to its home territory. However, at that time, each Party may choose to give up and transfer the ownership over the introduced components to the ILE by agreement. The terms and conditions under which the ILE accepts such components should be defined during the Explorations/Negotiations leading to the international agreement.

7. Procurement

(1) From the perspective of successful project management, the procurement process should primarily focus on technical performance, quality, schedule and cost, and should provide the opportunity for the ILE to directly exercise technical oversight of the procurement process and performance of engineering and manufacture.

(2) Within the above provision, components/systems and services for ITER could be procured in one of two ways according to each Party's preference, either as contributions in kind procured and supplied by specified Parties for a pre-determined credit value or procured directly by the ILE using funds contributed by the Parties to its budget ("funded"). A Party providing an in kind contribution bears the risk of having to provide additional resources because of unforeseen conditions encountered by that Party. The need for any additional resources arising from new requirements from the ILE should however be considered as change requiring reassessment of the credit value and other factors. With funded activities, such risks should lie with the ILE but this risk should be shared with the interested Party(ies) according to any conditions attached to the funding.

(3) On the basis of data from the EDA, all Parties should, as soon as possible, be addressing jointly the issues of the overall percentage shares of contributions and of an initial allocation to each Party of procurements. These shares of contributions should be set out in writing at the time of the adoption of the text of the international agreement.

(4) At least some part of each Party's contributions should be provided in funds in order to ensure efficient work in systems integration.

(5) Whatever the mode of procurement, the Director-General, assisted by the project team should be centrally involved in all technical aspects of the process. For example, the project team could be composed of a central team based at the ITER Site and centers, in each of the Parties who, would directly exercise technical oversight of the procurement of items from within each Party. In turn the Parties should designate domestic agencies who would be responsible for the supply of contributions-in-kind and could support administrative aspects of the funded procurements.

8. Staffing

(1) Staffing arrangements should reflect the need to encourage mobility between the project and the rest of the Parties' programmes.

(2) The ITER staff should consist of ILE employees (if so decided), staff seconded from the Parties and contract personnel, all of whom shall report to the Director-General.

(3) The ITER staff complement should be kept to a minimum necessitated by the project implementation and appointed for limited durations. Rules for appointment, term of service etc. shall be set by the Council.

(4) For the purpose of ensuring wide scientific participation in the Project and of training future generations of fusion researchers, participation of other qualified personnel such as from universities and other institutions will be encouraged under rules to be established by the Council.

9. Finance and Accounting

(1) Financial regulations and implementing measures governing the contribution, use and accounting of ILE funds and procurements in kind should be adopted at the outset of the Project. The financial regulations should include provisions for audit consistent with each Party's fiduciary requirements.

(2) Contributions in kind will be supplied under the normal budgetary and financial rules of the contributing Party subject to any special conditions arising from the international agreement or ILE Statutes/Protocols. The audit requirements in this case will be those normally applied in the Party concerned.

10. Intellectual Property Rights

(1) Intellectual Property Rights (IPR) are part of the benefits. The Parties should designate IPR specialists to jointly develop acceptable IPR provisions for ITER referring to the general principles established for the ITER EDA.

(2) Possible guidelines for consideration/development by the IPR specialists could be as follows:

- As a legal entity the ILE should have the capacity to own intellectual property and should do so under the terms to be established in an IPR annex to the Statutes.

- In accordance with ITER's programmatic objectives, the intellectual property (IP) regime should favour a liberal dissemination of information consistent with the ITER IP terms and conditions. Subject to the other ITER IP provisions already agreed, the scientific results derived from ITER operations should be widely and freely accessible among the Parties for the purposes of fusion R&D for peaceful uses.

- The technology know-how derived from the construction, operation and decommissioning of ITER should also be shared among the Parties for the purposes of fusion R&D for peaceful uses. But there will be safeguards to protect pre-existing business confidential information and to protect the rights of Parties making contributions-in-kind for the commercial exploitation outside the domain of fusion R&D of intellectual property generated in producing the contribution.

11. Participation and Accession[4]

(1) The Parties to the international agreement should be the present EDA participants.

(2) Expressions of interest during the Explorations/Negotiations phase from other possible participants in joining from the start of the agreement should be treated on a case-by-case basis, taking account, inter alia, of the progress towards convergence achieved among the current participants.

(3) The international agreement should allow for possible third parties to join the Project after adoption of the agreement. Any such requests should be decided by unanimity among the Parties. The international agreement should provide both for full accession of new Parties, under terms such as a significant contribution and commitments, and for other forms of participation such as possible "associate" membership for which lesser conditions of participation and status in the collaboration should be agreed.

12 Conclusion

In the process and at the conclusion of its discussions, all delegations of the SWG-P2 have agreed that they:

- share a single vision of the ITER goal and of the means to realize it;
- recognize the technical and social import of ITER for the realization of fusion energy;
- reconfirm the common desire to promote construction of ITER through international co-operation; and
- recognize that the time is now ripe for initiating international efforts with governmental involvement with the aim to establish a firm international legal framework for joint implementation of the ITER project.

The SWG therefore proposes to the ITER Council, according to the terms of the present report, to recommend to the Parties to start Explorations[5] in early 2000 among the interested parties with the view to reaching, at the time of the Joint Assessment foreseen for summer 2000, a common understanding on the necessary steps for a future decision on the Construction, Operation, Exploitation and Decommissioning of ITER.

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[4] Terms for possible withdrawal from the participation should be set so as to protect the mutual interests of the project and the remaining Parties, especially during the construction phase.

[5] Suggested Milestones are:

Start of Explorations	early 2000
Interim position	at the time of the Joint Assessment
End of Explorations	by end of 2000
Start of Negotiations	by July 2001

LIST OF PARTICIPANTS FOR SWG-P2

European Union:

Dr. E. Canobbio	Delegation Head
Dr. J. Pamela	Member
Prof. K. Pinkau	SWG-P2 Co-Chair
Prof. R. Toschi,	Member, EU HTL
Prof. J.-P. Watteau	Expert
Dr. D. Dautovich	Expert
Dr. J. Grunwald	Expert

Japan:

Mr. H. Nakamura	Delegation Head until July '99
Mr. M. Nakamura	Delegation Head as of July '99
Dr. H. Kishimoto	SWG-P2 Co-Chair
Dr. H. Takatsu	Member, JA CP
Mr. Kaz. Kurihara	Member
Mr. Z. Naganuma	Expert
Dr. T. Tsunematsu	Expert, JA HTL
Mr. S. Hino	Expert
Mr. Y. Tajima	Expert
Dr. Ken. Kurihara	Expert
Mr. M. Murasawa	Expert
Mr. S. Yoshinari	Expert

Russian Federation:

Dr. V.M. Korzhavin	Delegation Head
Dr. O.G. Filatov	Member, RF HTL
Dr. Yu.I. Konashkov	Member
Dr. A.V. Ubeev	Member
Mr. K. K. Chernov	Expert
Dr. V.D. Fomenko	Expert
Dr. L. G. Golubchikov	Expert

ITER:

Dr. R. Aymar	ITER Director

JCT:

Dr. Y. Shimomura	Deputy to the Director
Mr. M. Drew	Secretary to the SWG

MAC Further Tasks

1. Review Work Program
   - Proposals by the Director for Task Agreement for tasks costing more than 500 IUA, if any;

2. Review Joint Fund
   - Consolidated Annual Accounts of the 1999 ITER Joint Fund;
   - Proposals by the Director for the revised 2000 Joint Fund Budget;
   - Proposals by the Director for the 2001 Joint Fund Budget.

3. Review proposals by the Director for ITER Meetings

4. Other Business
   - Initial discussion on the disposition after July 2001 of R&D hardware and facilities built during the EDA.

TAC Further Tasks

Review of the converged engineering design and of the possible new R&D needs

CPs' Further Tasks

1. Facilitate start of Explorations.
2. Update and disseminate Tentative Sequence of Events.
3. Consider ITER nomenclature.
4. Consider possible revisions to the ITER logo and standard project stationery
5. Co-ordinate planning for inter-Parliamentary actions.

ITER Meeting, 29-30 June 2000, Moscow

DOCUMENTS OF THE ITER MEETING

29-30 June 2000, Moscow

RECORD OF THE ITER MEETING

Moscow, 29-30 June 2000

1.1 The Meeting accepted participation as attached (Attachment 1). The Meeting was informed about the nomination of a new Council Member from JA, Mr. Motohide Konaka. The Meeting expressed its thanks to Mr. S. Nakazawa for his valuable contributions to ITER during his term as IC Member. The Meeting also recorded its thanks to Dr. Toschi, on the occasion of his retirement, for his dedicated efforts on behalf of ITER from its very inception. The Meeting took note of the designation of Dr. Karl Lackner to succeed Dr. Toschi as EU Home Team Leader. The Meeting noted the designation of Mr. M. Drew to succeed Mr. J.-P. Rager as future EU MAC Member.

1..2 The Meeting noted an oral report from the RF Delegation on progress of the Explorers at their first two meetings, including the adoption at EX-2 of an Interim Explorers Report.

1.3 The Meeting adopted the Agenda (**Attachment 2**).

1.4 The Meeting heard reports from the Delegations on their Parties' status, noting, in particular:

- the favourable overall results of domestic assessments of the Outline Design Report for the new ITER design; and
- preparations being made within each Party to support progress towards possible Joint Implementation of ITER.

2.1 The Meeting took note of the Director's Status Report, as revised in the light of MAC comments and further discussions, and endorsed the Director's commendation to all concerned in the successful realization of the Central Solenoid Model Coil project. (**Attachment 3**).

2.2 The Meeting noted that the Director will address to the IC Chair, for the information of IC Members, his views on the co-ordinated technical activities and related resources deemed necessary after the end of the EDA to prepare for possible Joint Implementation of ITER.

2.3 The Meeting supported the MAC recommendations on:

i) approval of the consolidated Joint Fund Accounts for 1999, noting the Director's Observations on the operation of the Joint Fund in 1999 (**Attachment 4**);
ii) discharge of the US agent from Joint Fund responsibilities, taking account of MAC comments on reimbursement of the agent's close-out costs.

2.4 The Meeting agreed to set a provisional Joint Fund budget for 2001 based on current levels of Parties' contributions, pro-rated for the period to the end of the EDA. This matter will be considered again at the end of 2000.

3.1 Having noted the Director's presentation on Progress in Design and validating R&D for ITER (**Attachment 5**) and the presentation from the TAC Chairman, the Meeting:

i) endorsed the assessments and recommendations of the TAC Report (**Attachment 6**); and
ii) approved the ODR as updated following domestic assessments and as outlined to TAC, as the basis for preparation of the Final Design Report.

3.2 The Meeting congratulated the Director, JCT and Home Teams for their successful joint work to establish a single mature design for ITER consistent with its revised objectives.

4.1 The Meeting accepted the Report and Advice from the MAC Meeting (**Attachment 7**) noting, in particular, the need to devise solutions to a number of administrative issues relating to the termination of the EDA.

4.2 The Meeting noted a continuing need to secure formal approval/endorsement of applicable MAC recommendations.

5.1 The Meeting took note of the CPs' Report.

5.2 Having noted the input from the EU delegation on work done in Canada on public identification of ITER (**Attachment 8**), the Meeting emphasized the importance of promoting public acceptance of ITER in all Parties and the value of using professional expertise in this area. The Meeting invited the Parties to review and exchange comment on public identification of ITER, including the meaning of "ITER" acronym for the future and asked the CPs to facilitate this exchange.

5.3 The Meeting agreed not to modify the ITER EDA logo and to retain the "name" ITER-FEAT for the device for the remaining period of the EDA

6.1 The Meeting approved MAC Further Tasks (**Attachment 9**).

6.2 The Meeting asked TAC to review the Draft Final Design Report, to be submitted by the Director by the end of the year, and to report to the Council at its next Meeting. The cost analysis will be reviewed through an ad hoc group involving the Home Teams and industry upon invitation from the Director.

6.3 The Meeting approved CPs' Further Tasks (**Attachment 10**).

7 The Meeting shared the view that it is now opportune to encourage the industries in the ITER Parties to conduct under their own auspices the dialogue initiated at the San Diego and Tokyo ITER Industry Liaison Meetings. It is recommended that the 3rd Meeting should be held in Toronto in November this year.

8 Upon invitation of the EU Party, the Meeting decided to hold the next IC Meeting in Toronto in February-March 2001. The Meeting dates will be confirmed through the CPs.

9 The Meeting approved this ROM.

Attachment 1

ITER MEETING
Moscow, 29-30 June 2000
List of Attendees

EU	Prof. J. Routti	IC Member
	Dr. U. Finzi	IC Member
	Prof. R. Toschi	Expert, HTL EU
	Dr. J-P. Rager	Expert
	Dr. D. Dautovich	Expert
JA	Mr. M. Konaka	IC Member, Head of the Delegation
	Dr. M. Yoshikawa	IC Co-Chair, MAC Chair
	Mr. M. Nakamura	Expert
	Mr. H. Oka	Expert
	Mr. Y. Yukimatsu	Expert
	Mr. T. Hoshino	Expert
	Dr. H. Kishimoto	Expert
	Dr. T. Tsunematsu	Expert, HTL JA
	Dr. H. Takatsu	Expert, CP JA
	Dr. T. Fukuda	Expert
	Dr. Y. Miura	Expert
	Mr. N. Usui	Interpreter
RF	Acad. E. Velikhov	IC Chair
	Dr. Yu. Sokolov	IC Member
	Dr. V. Korzhavin	Expert
	Dr. O. Filatov	Expert, HTL RF
	Dr. V. Fomenko	Expert
	Dr. K. Chernov	Expert
	Dr. L. Golubchikov	Expert, CP RF
ITER	Dr. R. Aymar	Director
	Dr. Y. Shimomura	Deputy to the Director
	Prof. V. Chuyanov	Deputy Director
	Mr. M. Drew	PC w/D
	Prof. M. Fugiwara	TAC Chair
	Dr. V. Vlasenkov	Scientific Secretary

ITER MEETING

Moscow, 29-30 June 2000
AGENDA

1. **Meeting Opening**
   Attendance
   Information on EX-2
   Parties' Status
   Adoption of Agenda

2. **Director's Status Report**
   2.1 Joint Fund Accounts for 1999

3. **TAC Matters**
   3.1 Director's Progress Report
   3.2 TAC Report

4. **MAC Report and Advice**

5. **CPs' Report**

6. **Further Tasks**
   6.1. MAC
   6.2 TAC
   6.3 CPs

7. **Other Business**

8. **Next Meetings - Dates and Places**

9. **Approval of the ROM**

Adjourn

ITER EDA STATUS REPORT

Report by the Director

1 This note summarises progress made in the ITER Engineering Design Activities in the period between the ITER Meeting in Tokyo, (Jan 2000) and June 2000.

Overview

2 Following acceptance at the Tokyo Meeting of the Outline Design Report, technical work in the EDA has focused on resolving the open issues from the ODR, including points raised by TAC, and on responding to questions arising from the Parties' domestic assessments of the ODR. Progress in this area has now been outlined in a report to TAC. A companion paper to TAC discusses the R&D programme in support of the new ITER design, including both pertinent results achieved and priorities for further work.

3 A key feature of current work is the preparation of "procurement packages" as the basis for detailed industrial costing studies during the second half of 2000, with the objective of generating a complete estimate of the costs of the new design to be incorporated in a draft Final Design Report around the turn of the year. As previously, the project cost estimates will be expressed in IUA, with the emphasis on the relative costs of the different systems and on comparative assessment of physical processes and unit costs, so as to allow proper collation of the input from all Parties. For this reason, the Home Teams are asked each to achieve broad coverage of ITER systems and to stress to their industrial participants the importance of transparency in the documentation supporting their presentation of results of the cost studies.

4 In the area of Safety, the JA Party has designated a new Safety Contact Person as the focus for informal interactions on Safety/Regulatory matters. The EU has established an ITER Licensing Working Group charged to elaborate a basis for a possible EU common approach to ITER licensing. The RF Party has been invited also to nominate a Contact Person so that all Parties will be able to interact informally on progress in this vital area for the successful implementation of ITER.

5 Since the Tokyo meeting, the CS Model Coil facility at Naka has come into full operation. The test programme for the model coil is proceeding very well with results to date that confirm expected behaviour. All concerned in bringing this complex international project to the successful fruition can be justly proud of their joint achievement.

6 As requested, the Director has assisted the exploration process, in particular providing information on co-ordinated technical activities towards a start of possible future ITER construction.

Termination of the EDA

7 Protocol 2 of the EDA Agreement requires the Council, assisted by the Director, to provide for a timely and co-ordinated termination of the work to be carried out under the Agreement and to make proposals for actions as appropriate. For the sake of such planning it is assumed that the Parties will be aiming to progress, through Explorations and Negotiations, towards possible joint implementation of ITER, following the lines of the SWG-P2 report.

8 Against this background, at the end of the EDA extension period, the Parties will have at their disposal technical information necessary for future decisions on construction of ITER. Technical activities will, however, still be necessary in support of the preparations for possible joint implementation, for instance in adapting the design to specific sites offered, in safety and environmental analyses to prepare for licence applications, in collating and interpreting latest fusion physics and technology R&D results in anticipation of possible future construction, operation and exploitation and in preparing for procurement actions.

9 It is presumed that the Parties will need to maintain collective, first hand involvement in the definition and execution of technical activities that affect the nature of the device that they envisage to implement jointly.

10 In planning such activities and their possible framework, it will be essential to ensure the coherence of the Project following the dissolution of the framework for joint action that the ITER EDA Agreement provides. This implies providing for co-ordination of the Parties' technical activities, so that the design integrity and configuration control are maintained, and that the evolution of cost/schedule and safety/environment matters are seen to proceed satisfactorily from the perspective of the Parties collectively.

11 In addition, there should be some coherence in the overall evolution of management structures towards a future project configuration that is oriented towards joint construction, for instance, in relation to the Parties' necessary preparations of their respective procurement organisations and their interfaces to overall project management.

12 For the efficiency and effectiveness of both the co-ordinated technical work and of the organisational preparations, it will be most important to use the accumulated expertise and effective operational networks that have evolved in the Project to date. To this end there should be a smooth transition from the current EDA configuration towards the joint implementation structure. An appropriate framework to enable such a transition should be developed to come into operation with effect from July 2001.

13 An analysis of the co-ordinated activities deemed necessary in support of tasks outlined above leads to the following indicative figures for PPY/y effort required during period foreseen for negotiations towards a possible construction decision. Signs indicate the likely trend of requirements over time. The table excludes the resources that each candidate host country will need to allocate to preparing the analysis and documentation to submit to the license process.

14 The overall decrease in necessary co-ordination team efforts would be more marked if it were able to concentrate its resources at a single site.

Table 1: Co-ordinated technical tasks and estimated efforts needed post July 2001

Co-ordinated Technical Tasks post-July 2001	**co-ordination team effort (PPY/yr)**	**complementary domestic efforts (PPY/yr)**
Safety Analyses to support licensing preparations	6 =	10[1]
Site Adaptations (2 sites)	10 -	20[2] -
R&D co-ordination Technology Physics	 10 - 10 =	 30 - (Voluntary efforts)
Procurement preparations	20 -	40 +
Design Integration and general co-ordination	25 +	10 =
Total	81[3] -	110 +

[1] for co-ordinated technical analyses - excludes potential host party efforts to prepare licensing documents
[2] mainly potential host effort
[3] plus technical (CAD etc) and admin. support at comparable levels to those under the present structure.

Joint Central Team and Support

15 The status of the Team at the start of June 2000 is summarised in Table 2 below. There has been an overall fall of eight in JCT staff on site in all categories. Eight EC members have left the team. The other Parties have each matched departures to new arrivals. Three further three RF team members are expected to arrive in the near future; one is expected to leave.

Table 2: JCT - Status by Joint Work Site and Party at 1 June 2000

	Garching	Naka		Total
by Site	46[1]	50[1,2]		96[1,2]
	EU	JA	RF	
by Party	38[1]	33	25[2]	96

[1] includes three Canadians provided through the Canadian association with the EU Party.
[2] three additional RF members are due to arrive shortly; one more is due to depart.

16 Pending completion of the revalidation of the EDA Agreement the extension of secondment agreements has still to be completed.

17 The JCT numbers have been supplemented by VHTP's (~3-4 PPY from RF and 5-6 PPY from EU) and other temporary attachments to the JCT.

Task Assignments

18 Tables 3 and 4 on the next page summarise the status of R&D and Design Task Agreements. More details and commentary are presented in the specific papers to this MAC

meeting. Table 3 covers the numbers of Task Agreements over the entire period of the ITER EDA.

Table 3. Summary of Task Agreements (cumulative)

TA Status	R&D Number	Design Number
Task Agreements committed (EU,JA,RF)	**620**	**540**
Task Agreements completed or to be completed	480	426
Task Agreements on-going	140	114
US (to 7/99)	*173*	*162*

19 Table 4 summarises the cumulative total values of task agreements concluded to date.

Table 4. Task Agreements Summary per Parties

Party	**R&D** (IUA) TAs concluded	**Design** (PPY)
EU	222,366	295.52
Japan	219,360	267.98
Russia	95,013	231.70
US(to 7/99)	*108,023*	*170.71*
Total	644,762	965.91

Joint Fund

20 Consolidated Accounts and details of the Joint Fund operations in 1999 are presented to the current MAC meeting, for review before submission to the ITER Council.

21 Pending completion of the EDA revalidation, the Joint Fund has been implemented on a provisional basis following proposals supported by MAC in July 1999 which realigned the Joint fund to the three-Party configuration and took other measures to regularise the arrangements following uncertainties and disruptions in 1998/99.

22 Following approval of the Joint Fund accounts for 1999, it will be possible to discharge the US Joint Fund Agent from its Joint Fund responsibilities, including returning to IAEA the small residue of funds still held by the Agent.

23 Approval of the 1999 accounts will also allow to implement in 2000 the proposed offset of Parties' contributions to the 2000 Budget by unspent 1998 appropriations.

24 On the assumption that all three Parties will contribute their full shares of the Joint Fund Budgets after the offset (including a JA amount still outstanding in respect of 1999), and

given the current outlook for expenditure in 2000, then the expected balance of unspent appropriations at the end of 2000 would be sufficient to cover likely requirements for expenditure in the period to the end of the EDA extension period in July 2001. Accordingly, the Director proposes to make no request for new funds in a 2001 Joint Fund Budget.

25 The RF Joint Fund agent is pursuing design support contracts at about the levels foreseen. So far in 2000, contracts to the value of $326,000 have been concluded with four Institutes. The full list of these contracts is attached as Appendix 1.

ITER Physics

26 The Physics Basis document was published at the end of 1999 as a special edition of "Nuclear Fusion", the costs of which were shared equally among the four original Parties. In addition a special reprint of the overview chapter was produced for wider circulation.

27 The seven ITER Physics Expert Groups, with their modified titles and charges, are now in full operation and the arrangements for continued interaction with US fusion scientists on generic issues of tokamak physics are now proceeding smoothly. A new framework for continued joint work on tokamak physics databases is being developed.

28 The priorities for physics research in 2000 as set by the ITER Physics Committee are set out in Appendix 2. The main objectives are to strengthen further the physics basis for the inductive Q=10 operating scenario and to explore further and clarify scenarios for new modes of operation that could be used to approach steady-state operation.

APPENDIX 1: RF DESIGN SUPPORT CONTRACTS — 2000

Ref.No.	Title/Dates/Volume	Institute	Financial status
01-00	**Magnet Design** Start - 1 Jan Interim Rep.- 30 Jun. Final Rep.- 31 Dec.	Efremov Institute	2 Stages: $60,000 each **$ 120,000**
02-00	**Cryoplant Design** Start - 1 Jan Interim Report - 30 Jun Final - 31 December	Efremov Institute	2 Stages $7,500 each **$15,000**
03-00	**VV Thermal shield and Supports** Start - 1 Jan Interim Report - 30 Jun Final Rep. - 31 Dec.	Efremov Institute	2 Stages $11,250 each **$22,500**
04-00	**Neutronic analyis of the ITER Vacuum Vessel/Cryostat environments** Start - 1 Feb Quarterly Prog. Reps. Final Rep.- 30 Jun 2001.	Kurchatov Institute	2 stages in 2000 $10,000 each **$20,000** plus 1 stage in 2001
05-00	**Steady State Electrical Power Network** Start - 1 Jan Stage 1 complete - 31 Aug Stage 2 - 31 Dec.	VNIPIET	2 stages $10,500 and $7,500 **$18,000**
06-00	**Support of the Power supply systems for ITER-FEAT** Start - 1 March Subtask 1 complete - 15 Oct Subtask 2 complete - 31 Dec	Efremov Institute	2 subtasks $11,250 each **$22,500**
07-00	**3-D Magnetic Analysis of NB systems of ITER-FEAT** Start Stage-1 Jan end of Stage 1 - 30 Apr end of Stage 2 - 30 Sept	Efremov Institute	2 Stages: $11,250 each **$22,500**
08-00	**Study of toroidal Field Ripple with Ferromagnetic Inserts** Start Stage-1 Jan end of Stage 1 - 31 Mar end of Stage 2 - 30 Jun	Efremov Institute	2 Stages: $1,500 each $**3,000**
09-00	**Module Attachment Analysis** Start - 15 Mar Prog Rep - 31 July Final - 30 Nov.	ENTEK	2 Stages $6,000 each **$12,000**
10-00	**Diagnostic Design** Start - 1 February Final Rep. - 31 Dec	Kurchatov Institute	2 Stages $30,000 each $**60,000**
11-00	**Water Leak Localisation System** Start - 1 June. Final - 31 Dec	MIFI	**$6,000**
12-00	**Vacuum Pumping and Fuelling** Start - 1 June Final Rep. - 31 Dec.	Kurchatov Institute	**$5,000**
	Total Contracts let in 2000		**$326,000** + $10,000 in 2001

APPENDIX 2: URGENT (BOLD) AND HIGH PRIORITY PHYSICS RESEARCH AREAS

Urgent: Essential to confirm the feasibility of the inductive Q=10 scenario for the draft Final Design Report of ITER-FEAT at the end of 2000

High: Information valuable for design of ITER-FEAT, especially for establishing a scenario for steady-state operation of ITER-FEAT

Research Areas	Issues
Finite-b effects	**Tolerable ELMs (dW/W<2%) with good confinement alternate to type-I ELMs** (e.g. type II, Type III+core confinement) **Stabilisation of neoclassical islands** and recovery of ß
Plasma termination and halo currents	**Runaway electron currents:** production and **quenching, e.g. at low safety factor**
Sol and divertor	Achievement of high n_{sep} and relation of $n_{sep}/\langle n_e \rangle$ in ELMy H-modes Carbon Chemical sputtering and deuterium retention/cleaning methods
Diagnostics	Determine requirements for q(r) and assess possible methods that can be applied to ITER Determine life-time of plasma facing mirrors and optical elements(incl. Those in divertor) Reassessment of measurement requirements in divertor region + recommendation of diagnostic techniques
Core confinement	Non dimensional scaling and identity experiments; effect of finite b and flow shear Determine dependence of t_E upon shaping, density peaking etc.
Internal transport barrier properties	ITB power thresholds vs n, B, q, Te/Ti, V rotation etc. for strong reversed shear (q_{min}>3), moderate reversed shear(q_{min}>2, and weak shear (q_{min}>1).
H-mode power threshold	H-mode accessibility in ITER-FEAT , Data scatter
Density limit physics	Confinement degradation onset density; its dependence on aspect ratio, shape and neutral source
Pedestal physics	Scaling of pedestal properties and ELMs Effects of plasma shape on pedestal and ELMs

ITER Joint Fund - Accounts for 1999
Report by the Director

1. Introduction
In accordance with Section 8 of the ITER Joint Fund Financial Rules, this paper provides the consolidated accounts of 1999 of the ITER Joint Fund and the Director's report on the operation of the Joint Fund in 1999. The report was presented to MAC for review before submission to ITER Council.

2. Operation of the Joint Fund
During 1999 the ITER Joint Fund operated in accordance with the Joint Fund Rules first agreed at IC-5 in January 1994 (IC-5 ROD 3.2). The Joint Fund is established as a Trust Fund of the IAEA who collect the Parties' contributions and distribute monies, at the instruction of the Director or his designees, to four Agents each of whom has legal personality in the territory of one of the Parties and has undertaken to administer the expenditure of the fund at the request of the Director and his designees.

The Agents that operated the Joint Fund in 1999 were unchanged from previous years, namely:

Territory	Agent
EC Party	IPP Garching
JA Party	Nippon Advanced Technologies
RF Party	Minatom
US Party	SAIC

In accordance with Article 5.11 of the Financial Rules, delegated powers were exercised by Heads of Sites for authorizing items of expenditure at their Sites and for approving consequent payments. The Deputy to the Director also exercised general delegated powers in the Director's absence.

The withdrawal of the US Party from the ITER EDA and other uncertainties associated with the EDA extension had significant effects on operation of the Joint Fund during 1999. The main impacts and consequential management actions were outlined in general terms to the MAC and ITER meetings in July 1999 (MAC Garching July 1999 Attachment 11) and are reflected in the financial data presented in this report.

3. The 1999 Budget
In July 1998 MAC-14 reviewed and recommended for IC approval the Director's proposals for a 1999 Joint Fund Budget and allocation by main budget articles to the Agents, for a total of $2,500,000 (MAC-14 R&A 5, IC-14 ROD 5). On the advice of the ITER meeting in Yokohama (ROD 5.2,3) the Director advised the IAEA of the Budget figures and, after confirmation from IAEA, issued the calls for contributions.

The Director's proposals were, at that time, based on the presumption of a smooth transition into the ITER EDA extension on a four-Party basis. As the impact of the US withdrawal and of other uncertainties associated with the extension were felt, it became necessary to reconsider the situation. In July 1999, the Director presented a revised budget proposal based on the three-Party configuration, which was supported by the ITER meeting in Grenoble in July 1999 on recommendation of MAC.

The revised proposals were based on the following policies:

1. to run down the balance of unspent 1998 appropriations that had built up during the periods of uncertainty over the EDA extension, in order to finance expenditures in 1999, whilst holding some reserve to allow retrospective equalisation of Parties' contributions in respect of 1998. This would allow to make a clean separation between four Party operation of the Joint Fund — to 1998 — and three-Party operation — from 1999 onwards;
2. to use residual unspent 1997 appropriations to offset Parties' contributions in 1999;
3. to levelize the Parties' contributions for 1999 and 2000

On this basis the revised budget proposals for 1999 provided **for a total expenditure budget of $1,584,651**, distributed to Agent and budget Item as shown in Table 1 below.

Table 1: Revised ITER Joint Fund Budget for 1999 ($)

Budget Article	IPP	NAT	Minatom	**Total**
Travel and Subsistence	195,000	185,000	20,000	**400,000**
Other Expenses	381,825	376,826	426,000	**1,184,651**
Total Budget	576,825	561,826	446,000	**1,584,651**

In accordance with Article 3.7 of the JF Financial Rules. **the income budget was set equal to the payments budget at $1,584,651K**. Following approval of the 1998 Accounts, this total was financed by three equal contributions from the three Parties of $440,783, plus an offset from the application of the unspent 1997 appropriations (already distributed to Agents in 1998), as shown below:

Total Income Budget		**$1,584,651**
funded by:		
Parties' 1999 contributions	(3 x $440,783)	$1,322,349
Unspent 1997 Appropriations		$ 262,302

4. Submission of Accounts

The IAEA and the Agents submitted timely accounts after the end of the year and cooperated in analysis and consolidation. They also confirmed that their Joint Fund activities fell within the scope of their normal external audit arrangements and undertook to advise the Director of any audit observations relating to their actions in respect of the Joint Fund. No such observations have been reported at the time of writing concerning Joint Fund Activities for 1999 or for previous years of Joint Fund operation.

5. Implementation of the Budget in 1999

Contributions to IAEA and Distribution to Agents

The EU and RF Parties have contributed their full shares of the revised budget ($440,783 per party). , The JA Party's contribution was delayed because of uncertainties over the EDA extension. At the time of writing $70,783 of the JA contributions was still outstanding. The project was regularly informed by IAEA of the receipt of contributions.

At the request of the Project, the IAEA transferred to Agents a total of $1,473,000 during 1999.

Table 1 shows the statement of contributions to and transfers by the IAEA.

Agents' Expenditure against Budget appropriations

The Council-approved budget allocations for each Agent, including appropriations carried forward from 1998, and expenditure against Budget are shown in Table 2.

$1,145,475 of the unspent 1998 balances, which totalled $1,469,475, were spent during 1999. The residue of $324,000 was reserved, as planned, in part to offset the three Parties' contributions for 2000 and also to equalise retrospectively the four Parties' net contributions in respect of 1998. Total expenditure of 1999 Budget provisions by the Agents (including commitments) was $518,651 against the total budget of $1,584,651

Travel and Subsistence

Total Joint Fund expenditure on Travel and Subsistence, including use of the carry-forward from 1998, amounted to $423K. This total exceeds by 5% the 1999 Budget provision for that Article and is in line with the general expectation that travel patterns under the new, three-Party/two JWS configuration would be at about 75% of the previous budget levels. Most of the expenditure ($323K) was funded from the provisions carried forward from 1997. 71%; ($304K) was accounted for by the top levels of JCT management to whom the ITER Council agreed that Joint Fund travel arrangements should apply---the Director, Deputy Directors, Division Heads and the Head of Physics Unit---ten people in total.

The ITER Council has accepted that, under the Director's authority, the Joint Fund could support the priority travel needs of other members of the JCT having no Joint Work Site on their territory. Total expenditure in this area amounted to $100K distributed among 25 JCT members. In addition, Travel and Subsistence costs incurred by RF staff travelling to the Joint Work Sites in connection with the RF Design Support work are also charged to this Budget Article. $13.4K was incurred for this purpose in 1999.

The Joint Fund was also used to support the travel and subsistence costs of bringing the Secretary of the ITER Office at IAEA to assist at ITER Council meetings (IC-6 ROD Attachment 11). In 1999 $6.3K was incurred for this purpose.

Other Expenses

Total expenditure on Other Items amounted to $1,241K, of which $823K represented expenditure of the 1998 appropriations carried forward and $418K was expenditure against the final 1999 Budget for this article of $1,185K.

The note to Table 2 shows the charges for Agents' costs of administration. As in previous years, these costs vary according to the different modes of operation of the Agents in the context of their normal operations.

Agents' Flows of Funds

Table 3 shows, for each of the Agents, the flow of funds, ie receipts of funds from the IAEA, disbursement of funds in accordance with expenditure instructions, and opening and closing balances.

The Flow of Funds Statements show any reported exchange variations resulting from the fact that the fund and its accounts are denominated in US Dollars but are normally spent in the domestic currency of each Agent.

Director's Observations on the operation of the Joint Fund in 1999

1 Redistribution of project assets

As foreseen, selected joint fund assets - almost all in the area of information technology - were transferred from San Diego to the Garching and Naka Joint Work Sites, where IPP and NAT took over formal ownership from SAIC in accordance with Joint Fund Rules. Obsolete equipment that was either not possible or not economical to upgrade and transfer was not retained by the Project. The US Agent was requested to write off and dispose of such items in accordance with its normal local practice. In terms of original purchase cost, the total price of hardware items shipped was about $620K while items not retained by the project represented less than $90K of original purchase cost. (Since the rejected items consisted almost entirely of obsolete infor-mation technology equipment, realisable current market values would be negligible.)

Similar transfers were made of software purchased through the joint fund in San Diego. In accordance with normal commercial practice, the commercial software packages are treated as fully depreciated in the year of procurement.

The US Agent undertook packing, shipping and insurance for transferred Joint Fund items at the expense of the fund. In addition, selected items of Host funded equipment and software were also transferred from San Diego to Garching under the terms of a loan agreement between IPP and the US authorities. The costs of transfer for these items were also borne by the Joint Fund.

The total expenditure incurred by the US Agent in relation to these activities was about $128K. All of the expenditure on this matter was covered by unspent appropriations carried forward from the US Agent's allocation of the 1998 Joint Fund Budget.

Costs of receiving the items at Garching and Naka, including customs, taxes and unpacking, were borne by the Joint Fund at those sites. Thanks to extensive preparatory and negotiating efforts by the local Agents it was possible to limit the customs and tax charges to less than $7000 in total.

SAIC, IPP and NAT are to be commended for their co-operative efforts in completing the transfers efficiently on behalf of the project.

2 Proposed Discharge of the US Agent

According to the present accounts, the US Agent now holds a residue of $6994 of Joint Funds. No Joint Fund transactions beyond 31 December 1999 are foreseen for this Agent. It is therefore proposed that, following ITER Council approval of the 1999 Joint Fund Accounts, the ITER Council should:

- request the Agent to remit the residue to the IAEA trust fund; and
- then discharge it from its Joint Fund responsibilities, subject to the requirements of Article 9 of the Joint Fund Financial rules concerning the retention of records and supporting documents for at least three years.

3 Currency Variations

In response to difficulties identified last year with the accumulation of currency variations, considerable attention was paid to matching transfers of funds more closely to expected payments and to monitoring expenditure data both in dollars and in local currencies. Consequently, the resulting currency variations were limited in 1999, resulting overall in positive variations - ie notional “gains” - of $5,336 for IPP and of $132 for NAT as is shown in the Table 3.

4 Carry-forward of unspent appropriations

As noted above, the Director reserved a total of $324,000 of unspent 1998 appropriations to be used in part ($243,000) to offset the three Parties’ contributions to the 2000 budget and also ($81,000) to equalise the four Parties’ contributions in respect of 1998. The unspent balance of 1999 budget will be carried forward for use in 2000 in accordance with Joint Fund Rules (5.8).

5 Joint Fund Property

The Agents have presented their inventory records of joint fund property. most of which consists of items of information technology equipment. Following the transfers from San Diego, the distribution among the three Agents is as shown in the attached Table, in terms of original purchase price.

IPP	NAT	Minatom	Total
$1,085K	$1,319K	$250K	$2,654K

As noted above the realisable market value of IT equipment of ages varying up to six years now will be greatly depreciated.

RECOMMENDATION:

The ITER Council is invited:

1. to approve the consolidated Annual Accounts of the ITER Joint Fund for 1999;
2. to note the Director’s report on the operation of the Joint Fund in 1999;
3. to approve the discharge of the US agent from Joint Fund responsibilities as proposed in this paper.

ITER JOINT FUND
1999 ACCOUNTS

TABLE 1: Statement of Joint Fund Contributions to and Transfers by IAEA

	US Dollars
1) Opening Balance of Funds carried forward from 1998 Budget	$1,223,000.00
2) 1998 budget contributions received	$281,000.00[1]
3) Transfers made to Joint Fund Agents in respect of 1998 Budget	($1,223,000.00)
4) Closing Balance of Funds from 1998 Budget	$281,000.00
5) Contributions to 1999 Budget received from ITER Parties	$1,251,566.00[1]
6) Transfers made to Joint Fund Agents in respect of 1999 Budget	($250,000.00[2])
7) Closing Balance of Funds from 1999 Budget	$1,001,566.00[1]

Notes:
[1] Outstanding Joint Fund Budget contributions are as follows:

Outstanding Contributions	EC	JA	RF	US	Total
1998	-		-	81,000	81,000
1999	-	70,783	-	-	70,783

[2] The Joint Fund Agents in the territories of the ITER Parties were: IPP, Garching (EC); Nippon Advanced Technology (JA); Minatom (RF); and SAIC (US). During 1999, funds were transferred to the Agents in the four territories as follows:

US Dollars	EC	JA	RF	US	Total
1997 Budget	373,000	295,000	375,000	180,000	1,223,000
1998 Budget	50,000	200,000	-	-	250,000

Table 2: Statements of Budget and Expenditure (U.S. Dollars)

		IPP	NAT	Minatom	SAIC	Total
Travel and Subsistence						
1998 Budget carry forward	(1)	101,550	179,444	29,466	157,124	467,584
Expenditure of 1998 Budget c/f		101,550	179,444	12,924	28,832	322,750
Unspent 1998 Budget appropriations		0	0	16,542	128,292	144,834
Initial Allocation of 1999 Budget		200,000	210,000	25,000	315,000	750,000
Amendment of 1999 Budget		(5,000)	(25,000)	(5,000)	(315,000)	(350,000)
Final 1999 Budget Allocation	(2)	195,000	185,000	20,000		400,000
Expenditures of 1999 Budget:						
Payments	(3)	81,311	12,168	0	0	93,479
Commitments charged to 1999 accounts		0	0	6,700	0	6,700
Other Expenses						
1998 Budget carry forward	(1)	165,349	225,937	309,151	301,454	1,001,891
Expenditure of 1998 Budget c/f		131,333	225,937	309,151	156,304	822,725
Unspent 1998 Budget appropriations		34,016	0	0	145,150	179,166
Initial Allocation of 1999 Budget		360,000	400,000	560,000	430,000	1,750,000
Amendment of 1999 Budget	(4)	21,825	(23,174)	(134,000)	(430,000)	(565,349)
Final 1999 Budget Allocation	(2)	381,825	376,826	426,000	0	1,184,651
Expenditures of 1999 Budget:	(5)					
Payments	(3)	66,275	207,848	99	0	274,222
Commitments charged to 1999 accounts		0	0	144,250	0	144,250
Total Expenditure						
1998 Budget carry forward	(1)	266,899	405,381	338,617	458,578	1,469,475
Expenditure of 1998 Budget c/f		232,883	405,381	322,075	185,136	1,145,475
Unspent 1998 Budget appropriations		34,016	0	16,542	273,442	324,000
Initial Allocation of 1999 Budget		560,000	610,000	585,000	745,000	2,500,000
Amendment of 1999 Budget		16,825	(48,174)	(139,000)	(745,000)	(915,349)
Final 1999 Budget Allocation	(2)	576,825	561,826	446,000	0	1,584,651
Expenditures of 1999 Budget:						
Payments	(3)	147,586	220,016	99	0	367,701
Commitments charged to 1999 accounts		0	0	150,950	0	150,950

(1) The 1998 carry forward is derived from the approved1998 accounts (MAC Garching July 1999 R&A 4)

(2) 1999 initial Budget allocations, are as approved at IC-14 (IC-14 ROD 5)

(3) excluding commitments charged to the 1998 accounts

(4) budget amendments are as proposed in July 1999 (MAC Garching July 1999 R&A 4)

(5) Other expenditures include charges for Agents' costs of Administration as follows:

US Dollars	IPP	NAT	Minatom	SAIC	Total
Budget Provisions	25,000	75,000	15,000	19,212	134,212
Actual Charges (paid and committed)	20,000	75,000	15,000	19,212	129,212

ITER JOINT FUND
1999 ACCOUNTS

Table 3: Flow of Funds Statements

		IPP [1]	NAT [2]	Minatom	SAIC	Total
1)	Opening Balance (01-Jan-1999)	7,648	126,736	587	12,130	147,101
2a)	Transfers received from IAEA					
	1998 Budget	373,000	295,000	375,000	180,000	1,223,000
	1999 Budget	50,000	200,000	0	0	250,000
2b)	Other credits (interest)	0	4,825	0	0	4,825
2)	Total credits (1+2a+2b)	430,648	626,561	375,587	192,130	1,624,926
3a)	1999 Payments	380,469	625,398	322,174	185,136	1,513,177
3b)	Commitments charged to 1999 accounts	0	0	150,950	0	150,950
3)	Total Expenditure (3a+3b)	380,469	625,398	473,124	185,136	1,664,127
4)	Currency Variation (2-3-5)	(5,336)	(132)	0	0	(5,468)
5)	Ending Balance (31-Dec-1999)	55,516	1,295	(97,537)	6,994	(33,732)

Notes:

(1) Expenditure of currencies other than U.S. dollars are evaluated using transactional-based exchange rates for 1999 as provided by the Agent. Any final balances of other currencies are evaluated at the latest exchange rate applied.

(2) Expenditure of currencies other than U.S. dollars is evaluated at an average exchange rate for 1999 provided by the Agent. Any final balances of other currencies are evaluated at the latest exchange rate applied.

ITER MEETING
Moscow

28 June 2000

ITER - Progress in Design and Validating R&D
note by the Director

ITER - Progress in Design and Validating R&D

note by the Director

1 Introduction

In January 2000, the ITER Meeting (Tokyo) *"accepted the ITER-FEAT Outline Design Report, taking note of the TAC Report and recommendations and agreed to transmit the report to the Parties for their consideration and domestic assessment"*. Recognising the importance to optimise a single agreed design, the Meeting *"asked the Director and JCT to interact with the Parties during the course of their domestic assessments.....with a view to optimising the design for approval following TAC review, at the coming ITER Council meeting."*

This note summarises, for ITER Council, material presented in detail to TAC, in the report "Progress in Resolving Open Design Issues from the ODR", including:

- further investigation of Physics issues raised in the TAC report or in the course of the Parties' domestic assessments, and
- features of the ITER design which reflect a resolution of choice of options.

In addition, the note summarises and illustrates recent progress in the programme of validating technology R&D, as presented in the report to TAC, "ITER Technology R&D Progress Report".

2 ITER Physics

2.1 Highlights of recent progress.

The TAC report (Dec 99) and subsequent interactions with the Home Teams in the course of their domestic assessments indicated a number of questions and recommendations of areas for further physics investigation. The design progress report to TAC elaborates work undertaken by JCT and Home Team members and other experts of the Parties, under the following headings:

- sensitivity analyses of inductive (Q=10), hybrid (Q=5) and non-inductive (Q=5) scenarios to a range of assumptions or modelling;
- possible high Q (~50) and transient ignition with a short pulse heating;
- analysis of requirements for steady state operation;
- pedestal database used for ITER performance projections;
- divertor physics and, in particular, design robustness against ELM's;
- possible suppression of neoclassical tearing modes by ECCD.

The work reported has generally taken the form of further detailed modeling studies using the latest experimental results, and further developments and analysis of ITER databases. In some areas, work has included new approaches and new insights into important physics issues. Highlights include:

- recent recognition of the relation between the H-mode pedestal temperature and core energy confinement which has provided insights into the importance of high triangularity in achieving good confinement at high density; a model has been developed to quantify pedestal energy content scaled from present experiments; nevertheless, a better understanding of ELM phenomena is needed;

- the sensitivity of plasma performance against density profiles (for the same average density) confirms the need for the development and appropriate modelling for pellet injection from the high field side.
- the novel approach of a dimensional extrapolation technique based on a system code applied to the ITER H-mode Energy Confinement Database tries to overcome the problem of hidden interaction among certain parameters, particularly when close to their limits.
- recent work in Divertor modeling has included validation of the B2-Eirene code against ASDEX-U and JET experimental results and an analysis of the effects of divertor geometry which supports the adoption of a V-shaped target configuration.
- modelling using modulated ECCD to stabilise neo-classical tearing modes suggests that NTM detection in the early stage of evolution allows the power requirements on the EC power to be eased; further experimental work is now required to verify the models used.

2.2 Continuing Physics R&D

The degree and quality of recent progress in ITER physics, bears witness to the effectiveness of the framework of voluntary collaboration established for ITER Physics activities, even if the need for more modelling and experimental work on key issues is recognized to strengthen further the basis for extrapolation.

To a large degree, physics issues raised by TAC or during the course of the Parties' domestic assessments have already been recognised through the ITER Physics Committee system and are included in the list of Urgent and High Priority Physics Research Areas that the Physics Committee has recommended to the Parties for their experimental programming. (see Table 1 below).

It is most important to continue a co-ordination of the Parties' physics efforts in order to maintain the focus on deepening and strengthening the physics basis for ITER in preparation for possible operation and exploitation of ITER.

Table 1 Urgent (Bold) and High Priority Physics Research Areas

Urgent: Essential to confirm the feasibility of the inductive Q=10 scenario for the draft Final Design Report of ITER-FEAT at the end of 2000

High: Information valuable for design of ITER-FEAT, especially for establishing a scenario for steady-state operation of ITER-FEAT

Research Areas	Issues
Finite-β effects	**Tolerable ELMs (dW/W<2%) with good confinement alternate to type-I ELMs** (e.g. type II, Type III+core confinement) **Stabilisation of neoclassical islands** and recovery of ß
Plasma termination and halo currents	**Runaway electron currents:** production and **quenching, e.g. at low safety factor**
Sol and divertor	Achievement of high n_{sep} and relation of $n_{sep}/<n_e>$ in ELMy H-modes Carbone Chemical sputtering and deuterium retention/cleaning methods
Diagnostics	Determine requirements for q(r) and assess possible methods that can be applied to ITER Determine life-time of plasma facing mirrors and optical elements(incl. Those in divertor) Reassessment of measurementrequirements in divertor region + recommendation of diagnostic techniques
Core confinement	Non dimensional scaling and identity experiments; effect of finite β and flow shear Determine dependence of τ_E upon shaping, density peaking etc.
Internal transport barrier properties	ITB power thresholds vs n, B, q, Te/Ti, Vrotation etc. for strong reversed shear (q_{min}>3), moderate reversed shear(q_{min}>2, and weak shear (q_{min}>1).
H-mode power threshold	H-mode accessibility in ITER-FEAT , Data scatter
Density limit physics	Confinement degradation onset density; its dependence on aspect ratio, shape and neutral source
Pedestal physics	Scaling of pedestal properties and ELMs Effects of plasma shape on pedestal and ELMs

3 Engineering Design - assessments and choices.

The report "Technical Basis for the Outline Design of ITER-FEAT Report" left a number of engineering design choices open for further analysis and evaluation. TAC comments and points raised in the course of the Parties' domestic assessments have also been examined by the JCT and Home Teams.

The report presented to TAC sought to present the rationale for the design choices by making the balanced judgement between a wide spectrum of considerations, like operation performance, engineering margins, manufacturing costs, etc. Thus previous design options have converged to a reference design for all the major system, in particular:

1 for the **magnet system** in relation to:
   - support of TF coils loads, with additional pre-compression rings to improve the capacity to resist out-of-plane loads
   - conductor and winding design issues, maintaining the radial plate configuration for the TF coils and keeping two options for R&D related to material for the CS conductor jacket.
   - limits to elongation/triangularity

2 a separated manifolding for the **blanket coolant system,** limiting its interaction with the VV

3 for the **vacuum vessel** design
   - double wall vessel, reinforced by the cylindrical housings for the blanket modules attachments, in addtion to the poloidal ribs
   - analysis of VV load conditions and related structural assessments

4 **materials** choices for the **divertor** targets

5 **building/services** and **hot cell** design

4 ITER Safety

The extensive analysis base available in the ITER non-site-specific safety report (NSSR) is being used to improve the implementation of safety in the design. Specifically the confinement approach is being reviewed and refined to obtain a balance of safety requirements imposed on the systems with confinement functions, in terms of required levels of assurance, reliability etc.

Working from the NSSR, the safety design focuses on confinement as the key safety function whilst other safety-related considerations (such as heat removal, control of chemical or magnetic energy, control of coolant enthalpy etc) are analysed from the perspective of protecting confinement barriers. A “lines-of-defence” methodology is being used to provide a systematic way to obtain the required level of safety while balancing the requirements imposed on systems and components.

Appropriate design measures to control inventories and to reduce operational losses, are being pursued so that project release guidelines can be met without needing a tall stack. (A controlled, monitored release point will still be needed, the height of which would be set as necessary to satisfy the regulatory requirements of the host.)

The target for the current phase of ITER is to provide the Generic Site Safety Report (GSSR), which will document the safety assessment of the new design, as part of the final output of the ITER EDA. The GSSR is also intended to provide a basis from which to start preparing regulatory submissions for siting, subject to the further site-specific design adaptations and host country specific safety assessments that will be needed to obtain regulatory approval for construction.

5 Status of ITER Technology R&D

The present status of technology R&D in the main areas of joint work during the EDA was presented to TAC in a specific report; an overview is presented below. Selected illustrations of the projects are appended to this note.

The major technical challenges in ITER are:

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

The new design of ITER relies mostly on technical solutions, which have been qualified in the R&D programme launched previously for the 1998 ITER design. Major developments and fabrication have been completed and tests have significantly progressed. The technical output from the R&D validates the technologies and confirms the manufacturing techniques and quality assurance incorporated in the ITER design, and supports the manufacturing cost estimates for important key cost drivers.

The testing of models is continuing to demonstrate their performance margin and/or to optimize their operational use.

The realisation of major joint technology projects offers insights useful for a possible future collaborative construction activity. Valuable and relevant experience has already been gained in the management of industrial scale, cross-party ventures. The successful progress of these projects increases confidence in the possibility of jointly constructing ITER in an international project framework.

Significant efforts and resources (about half of the total) have been devoted to the Seven Large R&D Projects which cover all the major key components of the basic machine of ITER and their maintenance tools. All participants are to be commended for their dedication and co-operation. **The success of both the process and the outcomes merit recognition and wide dissemination throughout the Parties as exemplars of what focused international joint activities in science and technology can achieve**.

Central Solenoid (CS) and Toroidal Field (TF) Model Coils Projects (Ll and L2))

These two projects are working towards developing the superconducting magnet technology to a level that will allow the various ITER magnets to be built and to operate with confidence. The Model Coil Projects are intended to drive the development of the ITER full-scale conductor, including the manufacturing of strand, cable, conduit and terminations, and the conductor R&D in relation to AC losses, stability and joint performance. These Model Coil Projects also integrate the supporting R&D programmes on coil manufacturing technologies, including electrical insulation, winding processes (wind, react, and transfer) and quality assurance. 29 t of Nb_3Sn strand, from seven different suppliers throughout the four Parties, has been produced and qualified. This reliable production expanded and demonstrated the industrial manufacturing capability for the production of the 480 t of high performance Nb_3Sn strand as now required for ITER.

For the CS model coil, the cabling and jacketing technologies and winding techniques have been established and all these activities have been completed. The next critical step, the heat treatment to react the superconducting alloy without degrading the mechanical properties of the Incoloy jacket, has been successfully completed. By using approximately 25 t of the strand, the inner module (US), the outer module (JA), and the insert coil (JA) were fabricated and assembled. In April 2000, the maximum field of 13 T with a cable current of 46 kA and magnetic stored energy of 640 MJ has been successfully achieved in the ITER dedicated test facility at JAERI. Pulse operation has been experienced under conditions more severe than during ITER-FEAT operation. The insert coil has been also tested at 13 T and more tests are ongoing. The size of the CS model coil (3.6 m in diameter and 2 m in height) is almost the same as a module (4 m in diameter and 2 m in height) of the Central Solenoid in the new design and the maximum field is also the same.

For the TF model coil, forging and machining of the radial plates have been completed. Cabling, jacketing, winding, reaction treatment and transfer of the reacted conductor in the radial plates have also been successfully demonstrated. The coil is fully assembled except for the final impregnation of the winding pack in the coil case, which is underway. All the work has been performed in EU. The coil is expected to be delivered to FZK, Karlsruhe in the summer of 2000. The Model Coil uses a cable similar to the full-size TF coil cable and the cross section of the TF model coil is smaller but comparable in size to that of the actual TF coil. The model coil will be tested first on its own and later in conjunction with the LCT coil in the TOSKA facility. With the LCT coil, a field of 9.7 T at 80 kA will be achieved. By comparison, the peak field and the operating current are 11.8 T and 68 kA in the new design of ITER.

In addition, a TF insert coil with a single layer will be tested inside the bore of the CS model coil test facility at JAERI at a field up to 13T. This insert coil will be completed in the RF this year.

A 1 km jacketing test, which exceeds the design requirements, has been separately demonstrated in the RF.

For the development of the manufacture of the TF coil case, large forged and cast pieces (about 30 t and 20 t respectively) have been produced in the EU. Investigation of the properties of the forging has revealed values exceeding the requirements of 1000 MPa yield stress and 200 $MPam^{1/2}$ fracture toughness, with low fatigue crack growth rates. The casting also shows properties adequate for the low stress regions of the case (yield stress about 750 MPa). Welding trials have demonstrated successful welding of the cast to forged sections.

For the case assembly welds, electron beam (EB) welding is planned for the first pass followed by submerged arc welding for the remainder, to minimise distortion. The welding processes have been qualified, and preparations for the final welding demonstration are underway.

Vacuum Vessel Sector Project (L3)

In the Vacuum Vessel Sector Project, the main objectives are to produce a full-scale sector of the ITER vacuum vessel for the 1998 FDR design including the equatorial port, to establish the tolerances, and to undertake initial testing of mechanical and hydraulic performance. The key technologies have been established and, in relation to manufacturing techniques, two full-scale vacuum vessel segments (half-sectors) have been completed in JA industry, using a range of welding techniques, within the required tolerances. At JAERI, they were welded to each other and the equatorial port fabricated in the RF was attached to simulate the field joint planned to be done at the ITER site during assembly of the machine. Remotised welding and cutting systems prepared by the US were also tested and applied; remotised tools for non-destructive testing will be soon experimented.

Blanket Module Project (L4)

The Blanket Module Project aims at producing and testing full-scale modules of the first wall and shield elements and full-scale, partial prototypes of mechanical and hydraulic attachments. The key technology has been successfully developed, tested and qualified.

- A range of crucial material joints such as Be-Cu and Cu-stainless steel have been successfully made by using hot isostatic pressing (HIP) and other advanced techniques inside each of the four Parties.

- A full-scale model module, without the attachments, has been completed in JA by using mainly forging and drilling.for the shield block manufacturing.

- The module attachments have been developed and tested in the RF.

- A full-scale module with attachments is under fabrication in the EU. The full-size shield block has been completed by using powder HIP. After the first wall is attached to this block, the module will be tested to confirm that it meets the requirements for anticipated loads, electrical insulation and remote handling together with the necessary accuracy of positioning.

- A port limiter mock-up with Be tiles has been fabricated by using a fast breezing technique in the RF.

- In parallel with these fabrications, heat cycle and irradiation tests have been performed for the base materials and the bonded structures and have demonstrated that the performance is well within the acceptable level.

Divertor Cassette Project (L5)

The Divertor Cassette Project aims at demonstrating that a divertor can be built within tolerances and withstand the high thermal and mechanical loads.

- A full-scale prototype of a half cassette based on the 1998 ITER design has been built by the four Parties. Plasma facing components shipped from JA and the RF were installed in the divertor cassette body fabricated in the US, and hydraulic flux and mechanical tests were performed at Sandia National Laboratory.

- Various components for high heat flux were fabricated and tested in the four Parties. High heat cycle tests show that CfC monoblock survives 20 MW/m^2 x 2000 cycles (EU) and W armours survive 15 MW/m^2 x 1000 s (EU / RF). A large divertor target mock-up with CfC attached to DSCu through OFCu has been successfully tested with 20 MW/m^2 x 1000 cycles from a large hydrogen ion beam with a diameter of 40 cm, a performance consistent with ITER operational needs.

- Irradiation tests have been also performed. For example, CfC brazed on Cu survived 20 MW/m^2 x 1000 cycles after 0.3 dpa irradiation at 320°C. Tests with pulse heat deposition simulating the thermal load due to disruptions have demonstrated erosion but no disruptive failure of CfC armours even with 0.4 dpa irradiation. (The average neutron fluence of 0.3 MWa/m^2 at the first wall gives 0.38 – 0.59 dpa on the CfC divertor target.)

Blanket Remote Handling Project (L6) and Divertor Remote Handling Project (L7)

The last two of the Large Projects focus on ensuring the availability of appropriate remote handling technologies which allow intervention in contaminated and activated conditions on reasonable timescales. These technologies should provide the flexibility needed for ITER to pursue its scientific and technical goals whilst satisfying stringent safety and environmental requirements. In this area, full-scale tools and facilities have been developed. Their testing will be extended over a long period of time including the ITER operation phase. This is necessary not only for developing the right procedures but also for optimizing their use in detail and minimizing the intervention time. Rescue procedures and equipment to recover failed equipment are also being developed. The facilities will also allow training of operators.

The Blanket Module Remote Handling Project aims at demonstrating that the ITER blanket modules can be replaced remotely. This involves proof-of-principle and related tests of remote handling transport scenarios, including opening and closing of the vacuum vessel, and of the use of a transport vehicle on a monorail inside the vacuum vessel for the installation and removal of blanket modules. At first, the procedures were demonstrated at about one fourth scale. Work is now in progress on a full-scale demonstration. The fabrication of the full-scale equipment and tools, such as a 180° rail, a vehicle with telescopic type manipulator, and a welding / cutting / inspection tool, have been completed in JA. The simulation of installation and removal of a simplified, dummy shield blanket module of 4 t has been successfully performed by using a teach and play-back procedure. The dummy module was installed with only 0.25 mm of clearance between dummy keys and keyways using the intrinsic compliance of the manipulator. Integrated tests in a blanket test platform which simulates the full-scale structure of a 180° ITER in-vessel region are providing comprehensive validation of the remote handling system so as to allow completion of the detailed design of the components and the remote handling equipment. The real in-vessel operation will be done in a gamma field of 10^4 Gy / h. Key elements such as motors, position sensors, wires/cables, glass lenses, electrical insulators, periscopes and strain gauges have shown to survive tests at 10^6 –10^7 Gy.

In the Divertor Remote Handling Project, the main objective is to demonstrate that the ITER divertor cassette can be installed and removed remotely from the vacuum vessel and remotely refurbished in a hot cell. This involves the design and manufacture of full-scale prototype remote handling equipment and tools, and their testing in a divertor test platform (to simulate a portion of the divertor area of the tokamak) and a divertor refurbishment platform (to simulate the refurbishment facility). Construction of the necessary equipment and facilities has been completed and successful tests carried out with the remote handling transporters and tools procured in the EU, including a central cassette carrier from JA and a transporter from Canada. The system is based on a toroidal transporter that moves on the same rails to which the individual divertor cassettes are attached. This can move a cassette in front of a remote handling port from where the cassette is extracted with a radial transporter that is deployed from a transfer cask. Redesign of equipment is underway commensurate with design changes to the divertor cassette that were necessary for the reduced size of the new ITER.

Other R&D

In addition to the Seven Large R&D Projects, development of key components for fuelling, pumping, tritium processing, heating / current drive, power supply, diagnostics, as well as safety-related R&D have significantly progressed.

- For example, a tritium pellet injector has been tested with a total amount of 36 g T_2 and 28 g DT and ejection of a large pellet (10 mm) from a 80 cm radius curved guide tube has been successfully achieved with 285 m / s in the US. Further tritium pellet injector development is being continued in the RF.

- A full-scale cryogenic pump for DT, He and impurities has been completed and is under testing in the EU.

- A tritium processing system with 180 g T was successfully operated for 12 weeks in the US.

- Key components for the ICRF antenna and the transmission line have been developed and tested at a higher voltage than the expected operational voltage.

- Gyrotrons at 170 GHz have been developed and successfully operated at 0.5 MW x 8 s in JA and at 1 MW x 1 s in the RF. More developments are needed to reach the objective of reliable CW operation at 1 MW per tube. Diamond windows capable of transmitting multi-megawatts at 170 GHz have been developed in the EU.

- Almost full-size negative ion sources and high voltage technology (1 MeV) have been developed for NB injection in JA and the EU. Final objectives of CW operation under specified performance have been only partially achieved, and more experimental improvements and tests are needed.

- Mechanical bypass switches and fast-make switches have been developed and successfully tested at 66 kA and explosively actuated circuit breakers at 66 kA and 170 kA at Efremov Institute (although 170 kA is no longer required for ITER).

- Irradiation tests of key components of diagnostics have provided values required for shielding of components and planned replacement. The unexpected radiation-induced emf (RIEMF) effect especially on measurement by magnetic probes is an important issue and is under study. Lifetimes of mirrors set near the plasma will be limited by deposition / sputtering and are under investigation.

- Safety-related R&D, such as characterisation of dust in tokamaks, tritium co-deposited with carbon, and experiments on steam-material reactions, has provided inputs for the key phenomena and data for ITER safety assessments. The current R&D emphasis is now on verification and validation of data, models and computer codes. Measurement and removal of radioactive and tritiated dust in the vacuum vessel are under investigation.

- Neutron shielding tests by using a 14 MeV neutron source in JA and the EU demonstrates that the accuracy of shielding calculation is within 10 %.

ITER ROM
Attachment 6

ITER TECHNICAL ADVISORY COMMITTEE MEETING

25 - 27 June 2000
Efremov Scientific Research Institute of Electrophysical Apparatus
St. Petersburg, Russian Federation

MINUTES

The ITER Technical Advisory Committee (TAC) was held on June 25-27, 2000 at the Efremov Scientific Research Institute of Electrophysical Apparatus in St. Petersburg, Russian Federation. The objective of the meeting was to review the progress in ITER-FEAT design, based on the two documents, "Progress in Resolving Open Design Issues from the ODR" and "ITER Technology R&D Progress Report," issued by the Director on 15 June, considering the key recommendations made at the last TAC at Naka on 20-22 December, 1999. It is also intended to provide the 17th ITER Meeting scheduled on June 30 in Moscow with a technical assessment and key recommendations of the above mentioned progress reports.

A list of TAC participants is shown in Attachment 1. The Director first summarized the major issues of concern, related to the Parties' domestic review, and presented the highlights of activities performed during the first semester of 2000 by JCT and Home Teams as a background. The Director also made an introductory talk on the descriptions of the progress report.

1. Introduction

The Chair welcomed the TAC members, ITER Director, Home Team Leaders and Experts from the co-operating countries, as well as the members of the Joint Central team (JCT). The Chair also introduced the new TAC member Prof. P. Komarek, who is the replacement of Prof. F. Troyon. In addition, the Chair acknowledged the administrative staff at Efremov Scientific Research Institute for their hospitality and efforts in arranging and hosting the meeting.

The Chair also stated that the draft agenda for this TAC meeting was elaborated in consultation with the Director, considering the discussions at the ITER Meeting held in Tokyo on 19-20 January, 2000. The agenda was adopted and shown in Attachment 2.

2. Charges to TAC

The last ITER Meeting held in Tokyo on 19-20 January, 2000 asked TAC to conduct a review of the converged engineering design and of the possible new R&D needs.

3. Technical review of the "Progress in Resolving Open Design Issues from the ODR" and "ITER Technology R&D Progress Report"

The discussion at the TAC meeting was dedicated solely to the technical review of the above reports.

The meeting consisted of 14 presentations from the JCT members, covering all the aspects of the descriptions in the reports. The presentations were made mainly on the first day of the meeting. After having detailed discussions on the second day in three consecutive plenary sessions, for the review of progress in resolving physics issues, converged engineering design options and R&D issues respectively, the preparation of a draft report and its review reading was performed on the third day. The report is appended in Attachment 3.

4. Approval of the minutes

All the participants adopted the aforementioned report in Attachment 3.

5. Future meetings

The Chair personally thanked all the members of TAC for their hard work during, and in preparation for, the TAC meeting. The Chair also expressed his desire that the TAC contribution would expedite the ITER project.

It is anticipated that the next TAC will be held in January 2001, in order to review the draft final design report of ITER-FEAT.

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AGENDA

Sunday, June 25

09h00 - 09h15	Welcome and opening addresses	Chair
09h15 - 09h30	Adoption of agenda and meeting organization	Chair
09h30 - 09h45	Announcement of logistics	Local organizer
09h45 - 10h00	Introduction Charges to TAC	Chair
10h00 - 11h00	Brief summary of the meetings held after the last TAC meeting and overview of the descriptions in the progress report	Director
11h00 - 11h15	*Break*	
11h15-11h45	Physics design	M. Shimada
11h45-12h15	Edge and divertor issues	G. Janeschitz
12h15-13h30	*Lunch and group photo*	
13h30-14h15	Design progress in the magnet system	M. Huguet
14h15-15h00	Design progress in in-vessel components	K. Ioki
15h00-15h15	*Break*	
15h15-15h45	Design progress in plant facilities and pit layout	R. Haange
15h45-16h15	Buildings and site layout	R. Hemmings
16h15-18h15	Overview of the R&D program	Y. Shimomura with contributions of many others

Monday, June 26

09h00 - 09h15	Appointment of the session organizers for plenary discussion in physics related issues, converged engineering options and R&D.
09h15 - 11h15	Discussions and production of the draft skeleton of the comments on the physics issues, focusing on where the modifications of ODR have been made, based on the previous TAC recommendations and Parties' review.
11h15 - 11h30	*Break*
11h30 - 12h30	Discussions and production of the draft skeleton of the comments on the design progress, related to the converged engineering options.
12h30 - 13h30	*Lunch*
13h30 - 14h30	Further discussions on the converged engineering options.
14h30 - 14h45	*Break*
14h45 - 16h45	Review of the R&D results, discussions on the possible R&D for ITER-FEAT and production of the draft skeleton of the comments on R&D.
16h45 - 18h00	Draft writing of the comments in physics, converged engineering options and R&D issues.

Tuesday, June 27

09h00 - 11h00	Discussions on the Chairman's summary	Chair
11h00 - 11h15	*Break*	
11h15 - 12h30	Discussions on the revised Chairman's summary	
12h30 - 13h30	*Lunch*	
13h30 - 15h30	Review of the draft minutes or IC report	Secretary
15h30 - 15h45	*Break*	
15h45 - 17h45	Approval of the minutes or IC report	Secretary
17h45 - 18h00	Future activities	Chair
18h00	Closing remarks and adjourn	Chair

REPORT OF THE TAC MEETING

1. Introduction and background

In response to the TAC recommendations made in December 1999, which urged the ITER Council to take appropriate action with the aim of converging open design issues, and the Parties' domestic review reports on the "Technical Basis for the ITER-FEAT Outline Design," the Director called for intensive investigations to perform the detailed analysis, and Detail Design Tasks were launched in the three Home Teams. Accordingly, the progress report, "Progress in Resolving Open Design Issues from the ODR" was elaborated and issued on June 15, 2000.

According to the decision taken at the ITER Meeting held in Tokyo in January 2000, TAC was charged to conduct a review of the converged engineering design and of the possible new R&D needs, based on the two reports, "Progress in Resolving Open Design Issues from the ODR" and "ITER Technology R&D Progress Report". Therefore, TAC is requested to assess the appropriateness of the proposed design options and to review the possible new R&D needs, in order to provide technical advice to the ITER Meeting on June 30 in Moscow. In addition, TAC reviewed the progress in resolving physics issues, which was discussed at the last TAC meeting and recommended to the JCT.

Thirty-two participants, including ten TAC members, ten invited TAC experts and two Home Team Leaders participated in the review. The Joint Central Team staff gave a total of fourteen presentations, related to the description of the above progress report.

2. Overall assessment and key recommendations from TAC

(1) TAC appreciates substantial and extended progress made in physics and engineering design activities, in particular, overall analysis of plasma performance and convergence of several engineering options recommended at the last TAC meeting. TAC hereby greatly acknowledges the dedicated effort and the intensive design work made by the Director, JCT and Home Team members, since the beginning of the year.

(2) TAC considers that the final design, which meets ITER objectives, is well underway to resolve remaining issues in physics and technology by using the results of on-going R&D and proposed new R&D in this TAC report.

(3) TAC is pleased to note the continuing activity on physics R&D, making the performance prediction for ITER-FEAT more robust and further reducing physics uncertainties. Progress in resolving physics questions centred on the two priority issues highlighted in the previous TAC of the profile sensitivity of all the scenarios to achieving the objectives and the compatibility of the divertor design with the various operating scenarios.

- Simulations show that the inductive and hybrid scenarios are compatible with the divertor design and there are indications that the steady-state scenario may also be compatible. It is also pleasing to note that the simulations show that sustained ignition may be possible at higher currents (17MA), consistent with the engineering design, for a

small (10%) enhancement in confinement, or a reduction in helium accumulation.
- The principal remaining physics uncertainty relates to operation at high normalized densities and the impact of energy loss fraction during an ELM on the divertor targets, emphasizing the need for a reduction in ELM amplitude whilst maintaining good confinement, and a focussed experimental programme of work on this aspect is recommended.

(4) No overall design issue is left open. In the progress report, designs have converged to a reference for all the major aspects.

(5) TAC notes that substantial progress has been made in all the R&D areas, in order to validate the design principles. Thereby, ITER-FEAT can rely on all these R&D issues originally defined for the 1998 ITER design.
- About 75% of the effort is devoted to the 7 large projects which are in most cases coming to completion by 2001.
- R&D on heating systems, particularly gyrotron and high energy ion source should be continued beyond 2001.
- Eight R&D tasks associated with the ITER-FEAT design and the reduced-cost options, mainly related to the magnet design, have been identified and detailed task specifications have been developed.

3. Progress in resolving physics issues

TAC appreciates the extensive physics analysis presented testing the uncertainties in the prediction of ITER-FEAT performance, which confirms and extends the analysis presented in the ODR. A robust window for Q=10 operation exists and the possibility of sustained ignition with 17MA operation has been demonstrated in the modelling. Simulations have also shown that the inductive and hybrid scenarios are compatible with divertor design. TAC notes that the experimental programmes in the Parties are continuing to address remaining uncertainties in the projection of fusion performance in ITER-FEAT, for example in sustaining satisfactory energy confinement at densities required for ITER-FEAT.

As requested by TAC at its last meeting, one of two priority issues was a sensitivity study of inductive (Q=10, $Q\rightarrow$infinity), hybrid (Q=5) and non-inductive (Q=5) scenarios:
- simulations of the core combined with 2-D simulations of the divertor indicate consistent scenarios for inductive and hybrid operation with Q=10 and Q=5 respectively, with a maximum heat load to the divertor target of less than 10 MW/m^2, which is within engineering limits.
- For the non-inductive scenario, more work needs to be done with contributions from the Expert Groups in the near future. Present analysis with a simplified divertor model using argon injection shows that the target power may be reduced to less than 10 MW/m^2, though with $H\sim1.5$, $\beta_N\sim3.5$ and $Z_{eff}\sim2.7$ for $Q=5$. Acceptable divertor performance needs to be confirmed by 2-D divertor modelling. Further optimization may be possible, for example taking into account ITB radius scaling, different impurities, current drive efficiency and helium behaviour.
- modelling demonstrates the improvement in performance of ITER with density peaking, ion heating and broader temperature profiles, emphasizing the importance of profile control, ion heating and inboard pellet launch. As we previously recommended at the last TAC, the last point needs detailed modelling and more experimental work if its potential benefits are to be

exploited. The impact of sawteeth, impurities (for Z_{eff} less than 2) and τ_E degradation for operation close to the Greenwald density have also been studied, with the result that the Q=10 operating window is robust. Further analysis of these aspects using physics-based transport models would be desirable.

- The modelling has demonstrated that transient ignition is possible at 17MA. Moreover, sustained ignition is possible with either a 20% reduction in $\tau_{He}*/\tau_E$ (to 4) or a 10% increase in confinement (H_{98y2} = 1.1).
- Dimensionless experimental transport studies are required for the ITER-FEAT parameters to improve the accuracy of a preliminary study which indicates confinement times close to the confinement scaling recommended by the Expert Group (IPB-98y2). The ITER-FEAT parameters are in the midst of the experimental database, with the exception of n/n_{GW}, and a concerted experimental effort is required in this area.
- The novel approach of a dimensional extrapolation based on a system code applied to the ITER H-mode confinement database tries to overcome the problem of hidden interactions among certain non-dimensional parameters, particularly when close to their limits. The approach confirms the robustness of the ITER-FEAT design to reach the Q=10/fusion power objectives. The relative merits of this method and, for example, a probabilistic performance assessment (with a normal distribution function for the confinement enhancement factor to determine an expectation value for Q for different scaling laws) might usefully be explored taking into account the confinement variation in the database arising from hidden variables, eg q_{95}, T_i/T_e, ELM type etc.

The second priority issue identified by TAC-15 was the compatibility of the divertor design with the various operating scenarios, including the impact of ELMs:

- Recent studies on divertor geometry effects have shown the beneficial nature of a V-shaped target profile near the strike points, which aids plasma detachment, though restricting operational flexibility. However, a continuing activity on divertor code validation is essential, together with the incorporation of cross-field transport models, drifts, ELMs, a comparison of the SOL width database with basic physics models and the inclusion of additional impurities (eg argon). As computing power is rapidly increasing, coupling between a $1^1/_2$-D transport code and a 2-D edge code is to be encouraged, which will also improve our understanding of divertor operating windows.
- The energy loss fraction during an ELM consistent with the need for good confinement and a minimum pedestal temperature would seem to lead to excessive peak power loads on the divertor targets, and experimental action to reduce the loading without degrading confinement is urgently needed.
- Carbon has been selected for the lower part of the divertor target in the strike point region, while tungsten is used for the upper section of the vertical target, as well as the baffle, liner and dome. Tritium co-deposition and removal schemes are under investigation, but further intensive R&D by the Partiesí programmes, in conjunction with the JCT, is required to identify means of reducing or localizing tritium co-deposition to a region where controlled removal might be possible.

Two further significant issues are:

- Further work has been conducted to establish the sensitivity of the power necessary to stabilize NTMs and the necessary toroidal and poloidal launch angles. This work confirms earlier studies and indicates lower power levels if the seed island can be detected at smaller scales provided an adequate diagnostic capability is available. Experimental demonstration of a significant pressure increase resulting from NTM stabilization is a key physics R&D task.

- As in our previous report, we encourage the further quantification of the indication of favourable halo current fraction and toroidal peaking factor with size scaling, and the exploration of techniques to mitigate/avoid disruptions, together with further study of the reduction of runaway electrons in the presence of magnetic perturbations associated with disruptions and halo currents.

Recommendation

TAC recommends continuation and strengthening of co-ordinated efforts through the Physics Expert Groups to focus on the key physics R&D requirements, bringing together theory, modelling and experiments on the different facilities to further strengthen the physics basis for ITER. An initial focus should be to extend the confinement database at sustained high densities for the ITER reference parameters, together with the related problem of the reduction in ELM amplitude, which would be particularly valuable for the FDR.

4. Progress in converging engineering design options

TAC is pleased to note that no major technology issue is left open in a significant way after the progress report. Designs have converged to a reference for all the major aspects. Continuing studies for specific components are necessary to identify designs with the most attractive combination of robustness and cost-effectiveness. On-going R&D will provide key elements necessary for the final detailed designs. TAC is also pleased to note that the structural resistance of the machine would allow after recent improvements for limited operation at 17 MA operation without reducing the number of pulses specified at 15 MA.

(1) Magnet and support design

- The Design has converged to a single reference design both for the TF and the CS coils. The TF radial plate design is maintained for its overwhelming advantages in insulation properties and monitoring. The proposed TF wedged support with pre-compression rings lowers the stresses on the coils and eases compatibility with 17 MA operation. Design studies are necessary to confirm the feasibility of the required accuracy on the wedged surfaces. TAC takes notes that R&D is required to validate the choice of the high strength ring material.
- The CS conductor (Incoloy square outer jacket with reinforcement) is retained to provide the increased fatigue resistance required in ITER-FEAT. In view of the complexity of working with Incoloy, an alternative Ti/SS jacket is also considered and should be kept for R&D.

(2) Vacuum Vessel, blanket modules and cooling

- The double vacuum wall concept remains unchanged from the ODR. Full penetration housings for blanket module supports have been designed with the dual purpose of strengthening the VV while providing cost savings. HIPing and casting are the fabrication methods considered for these housings. Two options remain for the attachment of the first wall panel to the shielding blocks. Both options are technically acceptable and the choice depends on cost and manufacturing issues.
- JCT has selected separated manifolds for blanket cooling in order to prevent cross contamination between the cooling circuits and to facilitate leak detection. TAC welcomes the resulting simplification of the VV design and recommends completing the assessment of the structural integrity under the full range of combined load conditions. TAC also notes that breeding blanket helium purge pipes are still to be integrated in the design.

- TAC notes that substantial work devoted to assembly issues needs to be addressed in the machine configuration which has now been finalized .

(3) Design progress in plant facilities ad buildings
- Safety and cost considerations have led to an optimisation of the segmentation of the heat transfer systems.
- The ITER-FEAT site and buildings provide a minimum but adequate space for the ITER-FEAT tokamak machine and its necessary support facilities.

Recommendation

TAC recommends that systematic efforts should continue to integrate the results of on-going R&D into the final design. TAC also recommends the issuing of manuals for structural and design criteria specific to fusion technology, design and safety.

5. Review of the possible new R&D needs

In order to review the possible new R&D needs, TAC has reviewed the R&D results to date, and noted that substantial progress has been made in all the areas, which also corroborates the design principles. Thereby, ITER-FEAT can rely on all these results, which come from the R&D originally defined for the 1998 ITER design.

(1) Review of the R&D results to date

About 75% of the effort is devoted to the 7 large projects which are in most cases coming to completion by 2001. In summary their status was presented as follows.

- The CS Model Coil Project (L1): After resolving all manufacturing problems of the Nb_3Sn conductor and the coils with some delay, most impressive success has already been achieved in testing since it started in April 2000. For the CS model coil full field (13 T) and pulse operation condition more severe than the ITER-FEAT specification, have been reached. The CS conductor Nb_3Sn insert is just under test and will be followed by the TF conductor insert and Nb_3Al conductor insert which will be ready by the end of 2000 for being tested.
- The TF Model Coil Project (L2): After resolving many manufacturing problems delaying the completion of the model coil, its delivery to the test facility in Karlsruhe is foreseen now for September 2000, with a start of the testing in May 2001. The EU plans to make extended tests until the middle of 2002. Two full-size (35 t) sections of the TF coil case have been fabricated by forging and welding, and appropriate welding techniques for joining theses sections have been qualified. The techniques developed have revealed several promising routes to reduce the case fabrication cost while maintaining the required material properties.
- Vacuum Vessel Sector Project (L3): The main objectives were to produce a full-scale sector of the ITER vacuum vessel including the equatorial port, to establish the tolerances, and to undertake initial testing of mechanical and hydraulic performance. The key technologies have been developed, tested and qualified including welding, cutting and drilling by robotics. The project will mainly be completed by demonstration of remote handling non-destructive testing.
- Blanket Module Project (L4): The project aims at producing and testing full-scale modules of the first wall elements and full-scale, partial prototypes of mechanical and hydraulic attachments. The key technology has been successfully developed, tested and qualified. The full-size shield blocks have been completed by using powder HIP, forging and drilling. Further goal by July 2001 is lower cost techniques and materials.

- Divertor Cassette Project (L5): Two partial full-scale mock ups of the cassette body have been built. Various components for high heat flux were fabricated and tested above the specified heat loads (> 20 MW/m^2) for several thousand pulses. Irradiation tests have been also performed, and no signs of deterioration of the joints were found. The further programme until July 2001 concerns reliability and cheaper manufacturing methods.
- Blanket Remote Handling Project (L6) and Divertor Remote Handling Project (L7)**:** The last two of the large projects focus on ensuring the availability of appropriate remote handling technologies which allow intervention and repair of activated components in contaminated area on reasonable time scales. Full-scale tools and facilities have been developed, with some re-design, already under way, to be commensurate with changes necessary for ITER-FEAT. Their testing will be extended over a long period of time. The R&D confirmed the chosen RH concepts for ITER-FEAT.
- In addition to the seven large R&D projects, development of key components for fuelling, pumping, tritium processing, heating/current drive, power supplies and diagnostics as well as safety-related R&D have significantly progressed. The progress in gyrotrons and high energy negative ion sources should be particularly emphasized. Nevertheless, R&D should be continued beyond July 2001.

(2) Review of new R&D tasks

The following new R&D tasks associated with the ITER-FEAT design and the reduced-cost options have been identified and detailed task specifications have been developed. Their objectives and brief work descriptions are summarized below. Additional tasks to the benefit of reducing the ITER- FEAT manufacturing cost could be envisaged beyond 2001.

For the magnet system, R&D subjects relate to the materials and manufacturing technology database for the Central Solenoid and the TF coil winding pack.

- R&D for the CS Conductor: Incoloy is used as the reference conductor jacket material for ITER-FEAT. There are some outstanding issues with this material, in particular the weldability, for which R&D is underway. In addition to the Incoloy jacketed conductor, two other jacket material options are under investigation.
- R&D of TF Coil Winding Pack: the use of radial plates in the TF winding pack is the reference solution. The R&D work should involve improved fabrication techniques of a radial plate leading to a cost reduction.
- R&D of CS Conductor Helium Inlets: the helium inlets are placed at the high field inner bore at the point of the conductor transitions between the pancakes in ITER-FEAT. Measurements of the hydraulic properties of the flow through the inlet hole are required.
- R&D of TF Coil Out-of-plane Support Concept: the TF coil out-of-plane support requires the use of pre-compression rings. The most promising concept for the precompression ring is a bonded unidirectional glass fibre reinforced composite. Data on the allowable stress and creep behaviour of such composites is required and should be obtained with the fabrication and test of a reduced scale model.
- Test of Central Solenoid (CS) joints in pulsed field: the CS joints are placed in a configuration not tested previously. Therefore, testing in this configuration is necessary.
- R&D on NbTi conductors: a new R&D programme on NbTi conductors is not specific to ITER-FEAT. However, this type of R&D should be emphasized, as indicated in the previous TAC recommendations. The suggested programmatic issues are investigation of strand coatings, cabling and transverse resistance measurement for the AC loss evaluation, fabrication and test of a NbTi conductor/joint sample in SULTAN, production of 45kA NbTi conductor for a NbTi insert coil, and manufacture and testing of an insert coil.

In regard to the R&D, related to the modification of the divertor remote handling to ITER-FEAT, a new design for a laser viewing and metrology system and a first wall inspection robot manipulator, both suitable for deployment through the first wall at the divertor level is being studied. The small size of ITER-FEAT does not allow the use of metallic bellows. Therefore, incorporation of rectangular elastomer bellows are at present considered in the reference layout. However, their applicability needs to be confirmed by R&D.

Recommendations

The TAC recommends the execution of all the new R&D tasks.

Remarks

The TAC recognizes that the task on compression rings has not been offered for execution by the home teams yet. Further the TAC was informed that the subtask on manufacturing and testing a NbTi insert coil is in question. For the production of Be spray samples and testing of the CS joints in a US facility, a way should be found for JCT to benefit from expertise and facilities in the US which were available earlier in the EDA.

List of the TAC members present and in agreement with this report

Prof. M. Fujiwara (Chair)
Dr. J. Jacquinot
Prof. P. Komarek
Dr. D. Robinson
Prof. S. I. Itoh
Dr. K. Soda
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Prof. V. Kuchinski
Prof. A. Shikov
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MAC Report and Advice

MAC Meeting, 28 June 2000, Moscow

MAC Membership and Meeting Participation:

Participation was accepted as attached in the **MAC Moscow June 2000 R&A Attachment 2 (**Attachments not included).

Agenda:

The Agenda was adopted as attached in the **MAC Moscow June 2000 R&A Attachment 1.**

ITER EDA Status

MAC Moscow June 2000, R&A-1:

a) MAC noted the Status Report presented by the Director set out in the **MAC Moscow June 2000 R&A Attachment 3**.

b) Following in depth discussion on points 7 to 14 of the ITER EDA STATUS **(MAC Moscow June 2000 R&A Attachment 3)**, MAC recommended unanimously to delete points 13 and 14, in consideration of the on-going discussions in the "Explorations" framework. In addition, the EU and JA delegations considered it premature under the present circumstances to refer in the report to a possible continuous evolution in management structure and configuration from the present EDA status to the possible, and still to be defined joint implementation of ITER construction and operation.

c) The not yet revalidated ITER-EDA extension by one Party is causing concern among the other Parties for substantial formal reasons.

Work Program

MAC Moscow June 2000, R&A-2:

a) MAC took note of the Task Agreements Status Summary and compiled list of Task Agreements per Party in the **MAC Moscow 2000 R&A Attachment 4**.

b) MAC reviewed and supported the two new R&D Task Agreements of which credit is more than 500 IUA as presented in Section 1 (1) in the **MAC Moscow 2000 R&A Attachment 5**. This review and support constitute Council approval according to the IC-5 ROD 4 (c) 9.

c) MAC took note of six new R&D Task Agreements of which credit is not more than 500 IUA per task in Section 2 (1) in the **MAC Moscow 2000 R&A Attachment 5**.

d) MAC took note of twenty-four new Design Task Agreements including VHTPs for which credit is not more than 500 IUA or 2.5PPY per task in Section 2 (2) in the **MAC Moscow 2000 R&A Attachment 5.**

e) MAC reviewed and supported the modifications of Task Agreements since MAC Naka December 1999 of which credit changes are more than 500 IUA or 2.5PPY, or more than 20% as presented in Section 1 (1) in the **MAC Moscow 2000 R&A Attachment 6**. This review and support constitute Council approval according to the IC-5 ROD 4 (c) 9.

f) MAC took note of the modifications of Task Agreements since MAC Naka December 1999 of which credit changes are not more than 500 IUA or 2.5 PPY, or not more than 20% as set out in Section 1 (2) in the **MAC Moscow 2000 R&A Attachment 6**.

g) MAC took note of cancellation of Task Agreements as presented at Section 2 in **MAC Moscow 2000 R&A Attachment 6.** MAC noted the need for resolution of NbTi insert coil issues among the HTLs and the Director.

Consolidated Annual Accounts of the 1999 ITER Joint Fund

MAC Moscow June 2000, R&A-3:

a) MAC reviewed consolidated ITER Joint Fund Accounts for 1999 as presented by the Director **(MAC Moscow 2000 R&A Attachment 7)** with supporting detailed information.

b) MAC noted each Party's oversight on the fund provided to the Agent in its territory.

c) On the basis of the information provided, MAC recommends ITER Council to approve the consolidated annual accounts of the ITER Joint Fund for 1999.

d) MAC recommends ITER Council to approve the discharge of the US agent from Joint Fund responsibilities taking account of US comments **(MAC Moscow 2000 R&A Attachment 8)** on reimbursement of the Agent's close-out costs.

e) MAC recognizes that, following completion of the procedure d) above, the US involvement in ITER Joint Fund arrangements will be completed.

f) MAC noted that it is expected to have an adequate balance of 2000 appropriations left at the end of 2000 to cover likely needs for expenditure till the end of EDA on the assumption that all Parties pay their contributions for 2000 Joint Fund. MAC supported this approach.

g) MAC requested the Director, at the next MAC meeting, to indicate the status of Joint Fund expenditure in 2000 and the expected patterns of expenditure during 2001.

Review the Director's Proposal for ITER Meetings

MAC Moscow June 2000, R&A-4:

a) MAC reviewed and supported the schedule of Technical Meeting and Workshops as set out in **MAC Moscow 2000 R&A Attachment 9.** In accordance with the IC-3 ROD 5.2, this review constitutes IC endorsement of the proposals for meetings.

b) MAC noted that the seven ITER Physics Expert Groups, with their modified titles and charges, are now in full operation and the arrangements for continued interaction with US fusion scientists on generic issues of tokamak physics are now proceeding smoothly.

Other Business

Initial discussion on the disposition after July 2001 of R&D hardware and facilities built during the EDA
Initial consideration of other dispositions relating to the termination of the EDA

MAC Moscow June 2000, R&A-5:

a) MAC recognized that in regard to the termination of EDA, subjects to be discussed include (1) R&D hardware and facilities (items), (2) Joint Fund Assets, (3) The closure of Joint Work Sites and (4) ITER data.

R&D hardware and facilities (items)

b) MAC invites each Party including US to nominate a person responsible for the disposition of R&D hardware and facilities. MAC requests them to clarify the ownership of the R&D hardware and facilities, and to establish the mode of disposition and associated cost for each item in the light of the MAC-CPs report (MAC Garching July 1999 R&A Attachment 15) and that of the ISG (MAC 10 Attachment 9) by the end of December. The agreed sequence is set out in **MAC Moscow 2000 R&A Attachment 10**.

Joint Fund Assets

c) MAC asked the Director in consultation with MAC-CPs to propose a uniform procedure for deriving depreciated values of Joint Fund assets in each Party and to report on this matter to the next MAC meeting.

d) MAC proposes to the ITER Council to ask the Director in consultation with MAC-CPs to define ways to deal with the outstanding issues of:
   1. approving the consolidated Annual Accounts of the Joint Fund for the 2000 budget,
   2. discharging the Director for the execution of this budget,
   3. discharging the Agents from their Joint Fund responsibilities, which can only be done after the end of EDA.

The closure of Joint Work Sites

e) MAC recognized that the obligation to provide host support shown in the compilation list (IC-1 Attachment 15) will terminate at the end of EDA.

ITER data

f) MAC urges the HTLs and the Director to finalize the work before the end of EDA with circulating the final task reports after approval, according to agreed procedures.

g) MAC recommends ITER Council to ask the Director to distribute the documentation shown in I.1.6 in Technical Basis for the ITER-FEAT Outline Design to all Parties before the end of EDA.

h) MAC recognizes the need to initiate discussions on ways to handle data produced on facilities constructed during the ITER EDA and that would be operated beyond the end of EDA. MAC asks MAC-CPs to submit a draft principle at the next MAC meeting.

Future Meeting:

MAC tentatively decided that the next MAC Meeting would be held in Garching on 22-23 January 2001 between TAC and the ITER Meeting.

MAC Report and Advice:

MAC approved the present MAC Moscow June 2000 REPORT and ADVICE to ITER Council.

EU/ITER Canada Proposal for New ITER Identification

Background

At the ITER Council meeting held last January in Tokyo, the Council requested that the Parties undertake efforts towards renaming the project to avoid confusion with the original big ITER, and to establish an identification that would be viewed favourably by government officials and especially by the public. Included in the public domain are politicians, potential host communities, environmental and special interest groups, media and the general public. Identification must avoid misunderstanding, resonate with a variety of audiences and facilitate interest and acceptance.

This document outlines efforts by ITER Canada to develop a new identification on behalf of the EU, for consideration by the Parties at the Moscow meeting.

A professional process to create an identity was undertaken by ITER Canada with the help of an international firm with offices in Japan, Europe, and the US as well as expertise in this area. They helped in establishing a number of options for public consideration and testing.

Key findings

Testing of the identification options was conducted with the public in Canada in two language regions, English and French. The options for identification were tested with groups of people, including both males and females, from diverse educational backgrounds.

Findings from the research are summarized in five areas:

1. general project knowledge,
2. the current project name,
3. messages about the project,
4. tag line (slogans) for the project, and
5. project logo.

1. General project knowledge

Even among the more educated public, there is virtually no awareness of ITER and little awareness of fusion. This presents an opportunity to educate the public about fusion and ITER.

2. Public reaction to the current ITER name

The acronym for the existing ITER name - International Thermonuclear Experimental Reactor – is not public-friendly. The public link it to conventional nuclear energy or nuclear weapons. Nuclear energy is the public's least preferred energy option. It is believed to be dangerous and unclean.

In order for ITER to gain public acceptance and understanding, it must have a name that describes what it is and does not draw the public to make misleading conclusions. To honour the ITER Parties' long history of association with the ITER name, and avoid confusion among government officials, yet adapt it so that it will not stand in the way of public acceptance of the ITER project,

- a changing of the representation of the ITER name is required;

- the name must have a real meaning with respect to the project and yet not include words that lead the public to incorrect negative associations;

3. Project description

Five possible ways to describe the project were tested with the public:

a. fusion as the way to limitless power,
b. fusion as a means to change the world,
c. the world's best scientists creating a practical energy solution,
d. fusion as the best hope for clean energy; and,
e. fusion research as a quest to tame the power of the stars.

The public's reaction to these was that the idea of limitless is not credible or relevant, the mention of scientists does not seem to be important as it is assumed scientists would be involved, but some mentioned that as a general category scientists are not necessarily to be believed. *"They brought us nuclear energy, didn't they?"*

- The description with the best impact includes reference to environmental cleanliness and solution for global energy.

4. Capturing the description in a slogan or "tag line"

Four tag lines were tested:

a. eternally clean energy;
b. virtually unlimited energy for our planet;
c. cleaner energy for our planet; and
d. the world's energy solution.

The tag line "eternally clean energy" was found to be excessive and not favoured.

- "cleaner energy for our planet " was favoured;
- there was a consensus that shorter is better.

5. Logos

Four logos were tested with the public:

a. a square showing the sun coming up over the earth's surface;
b. a globe with the star on it;
c. a stylized look of a flying saucer, and
d. a swirling circle of dots.

- The public prefers the one with the swirling dots.

This logo is the most popular and logical logo since it most signifies energy and represents the geometrical shape of the plasma. It did not have any competing or negative associations, as did some of the others.

Summary of recommendations

The recommended identification package for ITER is as follows:

Name: *Iter* (capital I since it represents a proper name, and the balance lower case to avoid being considered an acronym)
Tag Line: cleaner energy for our planet
Logo: the swirling dots

- When asked what "Iter" means, the response would be that it means "the way" (in Latin) - to cleaner energy for our planet;

- Since some will have heard or know Iter was an acronym, if pressed the response would be that it stands for the new Iter project – "international tokamak energy research";

- Examples of how this new identification could be used by all ITER Parties will be shown at the upcoming meeting in Moscow.

Considerations for Implementation

The new logo would be most effective if it were used consistently around the world. This would require:

- Eliminating all references to the old acronym, i.e. changing written materials and the web sites to eliminate ITER - International Thermonuclear and replacing it with "Iter – cleaner energy for our planet";

- Elimination of the old logo on all written materials and web sites, and replacement with the new logo;

- Utilization of the new logo on all letterhead, business cards, faxes websites etc., ideally in the same colour;

- Agreement to these changes by the ITER Parties and a universal communication to all ITER employees and associates. This communication would explain that the new identity is for the new ITER project and is to be applied by all. A set of identity specifications and examples would be included. These would show how it is easily adapted to the full range of applications and participating Parties.

- Search of web for all references to the old acronym, then connecting with each web site the new identification with a request to replace the old.

MAC FURTHER TASKS

1. Review work program

2. Review the mode of disposition and associated cost sharing for R&D hardware and facilities

3. Review proposals by the Director for the expected pattern of expenditure during 2001 and for the procedure to close the Joint Fund

4. Review ways to handle data produced on facilities that would be operated beyond the end of EDA

5. Review proposals by the Director for ITER Meetings

CPs' FURTHER TASKS

1. Update and disseminate TSOE by correspondence before next ITER Meeting.

2. Continue preparation for future possible interparliamentary actions.

3. Liaise on matters concerning public presentation , identification and acceptance of ITER

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