OPINION
OF
THE CONSULTATIVE COMMITTEE FOR THE FUSION PROGRAMME (CCFP)
ON
THE INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR (ITER)
DETAILED DESIGN REPORT, COST REVIEW AND SAFETY ANALYSIS (DDR)

Brussels, 16 April 1997

INTRODUCTION

- The ITER Council at its December 1996 meeting accepted for consideration by the ITER Parties the ITER Detailed Design Report, Cost Review and Safety Analysis (DDR), with a view to approve it at its July 1997 meeting. The DDR is supported by the "Technical Basis for the ITER Detailed Design Report, Cost Review and Safety Analysis" together with other technical documents produced by the Joint Central Team, and the "Non-Site Specific Safety Report" (NSSR-1).

- The Services of the Commission have asked the CCFP to conduct the European assessment of the DDR with the involvement of industries and laboratories.

- The CCFP has set up a complete bottom-up review of the physics and technology basis of the ITER DDR, of the DDR itself, and of the Safety Report, with a wide participation of laboratories and industry, resulting finally in the recommendations of the Fusion Technology Steering Committee - Planning (FTSC-P) (Attachment).

- In January 1997, the Services of the Commission provided the DDR to the Council of the Union for information.

OPINION

The CCFP

having had an in-depth exchange of views on the basis of the report from the FTSC-P:

endorses the Recommendations of the FTSC-P on the European Domestic Assessment of the ITER Detailed Design Report, Cost Review and Safety Analysis, and

expresses the opinion that

- there has been clear progress in the physics R&D since the IDR. Indeed, on the basis of scaling laws derived from on-going Tokamaks experiments, the uncertainties in predicting the performance of ITER have been reduced in most areas. However, specific technical recommendations made by the FTSC-P on the issues that deserve particular attention in the remaining design and R&D activities should guide the position of the Euratom representatives in the various ITER bodies:

- experimental work on the Tokamaks with ITER-like geometry, especially on JET, has to continue on the regimes and operating scenarios envisaged for ITER,
- in engineering, while the machine structure presented in the DDR is fully responding to the operational requirements, work has to continue on a number of items, in particular remote maintenance and repair procedures, to finalize the design and to complete the supporting R&D and prototype testing;

- the R&D activities included in the EDA to enlarge the technological databases are fully under way, involving the European Associations and Industry. It is to be noted that, by the end of the EDA, EU Industry will have, overall, manufactured prototypical models of all the key fusion specific components of ITER;

- the DDR confirms and corroborates the design as presented in the Interim Design Report, Cost Review, and Safety Analysis (IDR). The ITER parameters are commensurate with the ITER objectives, and the design provides the requisite flexibility to deal with the remaining uncertainties by allowing for a range of operating conditions and scenarios for the optimization of the plasma performance.
  The detailed design, as presented in the DDR and annexed documents, represents a satisfactory basis to address the remaining open issues in view of the Final Design Report to be delivered at the end of 1997;

- the efficient management by the ITER Director together with the continuing integration process of the activities of the Home Teams and the Joint Central Team, which should be further pursued, have been instrumental in achieving substantial progress in the design and definition of technical details;

- major improvements have been made to the safety analysis of ITER since the IDR; work should continue on occupational exposure and the consequences of the worst accidents not only to prepare for the licensing of ITER but also for its impact on demonstrating the potential benefits of fusion. It would be appropriate to start soon a dialogue between the JCT and experts from the regulatory bodies of all interested Parties. The work reported in NSSR-1 forms a good basis for proceeding; improvements for incorporation in NSSR-2 have been identified by the FTSC-P;

- due to the stability of the design, no substantial change to the cost of ITER has been introduced between the IDR and the DDR; a fully revised cost estimate with Industry input is expected to be included in the Final Design Report;

- as for the construction time schedule, this will be highly dependent on the duration of the licensing process and/or on the possibility of launching construction activities while the licensing procedure is carried out. The proposed time schedule, which appears to be very tight, will have to be reassessed once detailed inputs become available from possible host countries and also from potential manufacturers;

- it is appropriate that the on-going informal quadripartite "explorations" aim at preparing the technical basis for a start, early in 1998, of negotiations concerning ITER activities after July 1998, so as to avoid any hiatus.

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Recommendations of the FTSC-P
on the
European Domestic Assessment
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INTRODUCTION

The ITER Detailed Design Report (DDR) was accepted by the ITER Council at its December 1996 meeting for consideration by the ITER Parties. The ITER Detailed Design Report, Cost and Safety Analysis document is supported by the "Technical Basis for the ITER Detailed Design Report, Cost Review and Safety Analysis" together with the other design documents produced by the Joint Central Team (JCT) and by the "Non Site Specific Safety Report".

The organisation of the European domestic assessment was assigned by the CCFP to the Fusion Technology Steering Committee - Planning (FTSC-P), under the chairmanship of Dr R. Andreani.

The FTSC-P appointed a European ITER Assessment Group (see Annex) consisting of 74 experts from Research Institutions and Industry addressing three main areas of the project: Physics, Engineering and Safety - the Engineering sub-group had 50% of its members, including the co-chairman, from EU industry. The Group started working in January 1997 and prepared its findings for consideration by the FTSC-P at its meeting on 24 and 25 March 1997.

On the basis of the ITER Assessment Group findings, the FTSC-P makes the following recommendations to the CCFP.

1. STATUS OF THE PROJECT

The integration in the conduction of design and R&D activities between the JCT and the Home Teams of the Parties has worked very satisfactorily also in the period after the Interim Design Report (IDR).

Considerable progress has been made in the definition of the general machine concept as presented in the IDR and in the design of the core components and auxiliary plant. As a result, no changes in the main machine parameters and cost from the IDR are needed.

Although the design has still to be definitely frozen in several significant details, the basic structure of ITER is now well defined.

A large amount of work has also been made in the field of Safety. A preliminary version of the Non Site Specific Safety Report (NSSR-1), which already collects an impressive amount of information related to all aspects of the Safety and environmental impact of ITER, has been produced. This document is being continuously updated following progress in design and discussions with the experts of the parties and it will be a good basis for preliminary interaction with the licensing authiorities.

2. PHYSICS

2.1 Progress since the Interim Design Report

There has been clear progress in the physics R&D since the ITER IDR which has reduced the uncertainties in predicting the performance of ITER in most areas. New data from a range of medium and large devices has further substantiated confidence in the global energy confinement scaling. The results from a number of experiments on helium transport and pumping have demonstrated that helium removal can be ensured by proper divertor design and is no longer a major issue. This permits operation at lower densities than those in the Interim Design Report, to around the empirical scaling value (Greenwald density), which can be exceeded on present devices with pellet fuelling. The confinement picture has been further reinforced by a range of dimensionless scaling studies on individual devices and between devices, which confirm the favourable confinement scaling as the normalised Larmor radius decreases. Another approach is the use of local transport models supplemented by specified edge plasma parameters. These are currently not favoured because even with specified edge parameters they give a larger spread in predictions when compared with existing experiments, and should therefore be developed further before they can be used reliably for predicting ITER's performance. The compatibility of the global confinement picture with a highly radiating edge/cold divertor remains an issue. The database on vertical displacement events has been improved and the vacuum vessel strengthened to withstand them. Disruption mitigation techniques have been demonstrated, but runaway electron production remains to be clarified. Although the recently observed neo-classical tearing modes can reduce the β limit at the ITER collisionality in some experiments, the β values are nevertheless within acceptable values for ITER.

2.2 Findings

The operational flexibility of the present ITER design can accommodate a variety of different scenarios, ranging from the conventional ELMy H-mode to the high β_p optimised shear mode. The baseline scenario presently envisaged for ITER is the ELMy H-mode with limited power flow to the divertor target plates.

2.2.1 Confinement and Divertor

The confinement time predicted for ITER by the ELMy H-mode scaling expression is compatible with ITER reaching ignition and offers an approximately 30% reserve on confinement time for obtaining 1.5 GW of fusion power by driven operation. Confidence in these predictions has been strengthened by the dimensionless similarity experiments, which support in particular the scaling of confinement time with size (as the inverse of the normalised gyro-radius). Access for ITER to the H-mode is predicted by a best fit to the database for H-mode threshold conditions, but the uncertainties in this prediction remain substantial. The planned work on ITER-relevant devices during the remaining part of the EDA should reduce these uncertainties, moreover the expected benefits of D-T and pure T operation for the H-mode threshold and confinement extrapolation should be clarified on JET.

Considerable progress in demonstrating particle and power exhaust which satisfy the divertor requirements has been made and a range of options with respect to ELM type, radiated power fraction and degree of detachment has emerged. These investigations have so far, however, shown a tendency for the confinement to deteriorate at high densities.

Emphasis should therefore be put during the remainder of the EDA on developing integrated scenarios satisfying divertor, impurity, and energy confinement constraints, and on further increasing the confidence level of confinement time extrapolations, by dedicated parameter scans (including isotope variations) in all devices with ITER-like geometry.

2.2.2 Instabilities and Control

MHD-related events and limits can be adequately accommodated within the present ITER design provided that it retains its present operational flexibility and that means for disruption mitigation are further developed. The successful implementation of adequate plasma control measures in the design is welcome, although a comprehensive analysis of the relation between diagnostics and control requirements is still needed.

2.2.3 Heating and Current Drive

The provision of 100MW of heating power for reaching ignition and for extended burn has to be achieved by a combination of two or more of the proposed heating and current drive systems, since no single method can satisfy all of the physics needs for ITER. Given the rapid developments in the R&D for the heating and current drive systems to meet the ITER specifications, a final selection should be made at a later stage.

2.2.4 Diagnostics

Substantial progress has been made in the conceptual design of many diagnostics systems. Nevertheless, in view of the central role which the diagnostics will play in the control and optimisation of ITER plasmas, it is recommended that additional emphasis must now be placed on the further detailing of the design solutions chosen and on the assessment of diagnostic capabilities.

2.2.5 Conclusions on Physics

The design of ITER, in particular its divertor, provides the required flexibility to allow a range of operating conditions in order to optimise the plasma performance. Therefore, in the opinion of the FTSC-P, ITER has the capability to deal with the remaining uncertainties concerning the different aspects of plasma performance.

3. ENGINEERING

3.1 Magnet Systems

The design of the magnet systems described in the IDR has been developed during 1996.

The TF mechanical structure now supports the vacuum vessel and the in-vessel components and takes the horizontal and vertical forces originating from plasma vertical displacement events or seismic loads. Stress analysis of the TF magnets in the different plasma operating scenarios should be completed.

As far as the central solenoid is concerned, the study of alternative "split" solutions, which offer more flexibility in plasma control, has continued. No final choice has been taken yet.

Issues concerning the use of Incoloy as jacket material for the magnet conductors appear to have been clarified, but so far only at laboratory scale.

Through the steady progress in the production of strands, cables and conductors, the satisfactory testing of their dynamic response, and the manufacturing of the model coils of the toroidal field magnets and the central solenoid, the design of the ITER magnet system appears to be appropriate to provide the specified machine performance.

The design of the power supply system feeding the TF and PF coils has been defined and a prototype module of the thyristor amplifier is under construction. R&D is being performed on the large vacuum switches and on the making switches to prove their correct operation at the current levels required by ITER.

3.2 Cryostat, Vessel and In-Vessel Components

3.2.1 Cryostat, Vessel and First Wall/Shielding Blanket

The layout of the cryostat, vacuum vessel and in-vessel components of the machine has been developed following the lines proposed in the Interim Design Report. The design of the back plate and of the shielding blanket / first wall has evolved in the right direction in order to provide easier and reliable maintainability of the modules. A bolted flexible attachment system has been designed to cope with the attainable position tolerances of the back plate. The forces and the torques generated by plasma disruptions will be taken by the robust back plate. Within the ongoing R&D programme one of the seven large projects is devoted to verify the proposed solutions.

3.2.2 Divertor and High Heat Flux Plasma Facing Components

The design of the divertor has been satisfactorily completed and will be validated through the execution of two of the seven large projects on which the EDA R&D activities have been focused. In particular the concept of a modular divertor comprising 60 dismountable cassettes will be extensively tested in a full scale facility which is under construction.

Also the design and the choice of materials for the high heat flux components of the baffle and the limiter has been progressing. The final decision involving the distribution of tungsten, beryllium and carbon fibre composites as armour material in the different areas should take into due account the lifetime in normal and off-normal conditions, tritium retention, and other safety aspects. Additional R&D is still required.

3.3 Assembly and Remote Maintenance

A well integrated solution for the remote handling maintenance of in-vessel components has been designed and is being supported by two large R&D projects. In general, assembly procedures should be examined in more detail. Improvements in design have been made in order to achieve a high degree of compliance with expected tolerances. An overall study is being carried out in order to optimise required manufacturing and assembly tolerances of the ITER core.

In the final design report, more detailed consideration should be given to remote and hands-on maintenance in the space outside of the vacuum vessel and within the cryostat. The feasibility of leak detection and repair in the space between the back plate and the vacuum vessel should also be considered.

3.4 Fuel Cycle

The design of fuel cycle systems has advanced substantially since the IDR. In particular a cryopump system which copes with plasma exhaust gases in all operating conditions has been designed. Fast cycling of the pumps remains a key issue which will be addressed in a recently defined programme.

In addition, in view of the possible need for deep fuelling, it is recommended that alternative deep fuelling methods be investigated and qualified for ITER.

Tritium accountancy principles and methodology require further definition and development.

3.5 Balance of Plant

The ITER Balance of Plant (BOP) does not present any critical issues for the feasibility of the project and, although the design of some parts is still at an early stage, it is a sound basis for the subsequent project phases. In general it will be less technologically demanding than other areas of the ITER project but cost and scheduling will have to be carefully monitored.

The impact of dismantling on the general infrastructure and the buildings should be verified during the EDA phase in order to optimise the design from this point of view.

It would be wise to place only a moderate emphasis on site-dependant areas that may yet be subject to major changes, and to concentrate design effort on areas of the BOP that will not be affected by the site selection or the authorisation process.

Effective integration of engineering activities will be especially beneficial to the BOP. The ITER team should establish and promote common design requirements and standardisation, monitor design changes that arise during the project that could affect cost and scheduling, resolve pending items and maintain centralised and continuous control over the project configuration.

3.6 R&D

The R&D activities included in the EDA to enlarge the technological data base needed from the project and to validate a number of engineering issues are fully launched. In particular the three large projects (i.e. Toroidal Field Model Coil, Blanket/First Wall, Divertor Remote Handling) where responsibility lies with the EU have reached a well advanced stage. The TF coil is at an advanced stage of manufacture. The erection of the facilities to demonstrate divertor replacement and refurbishment is on schedule. The manufacturing of the first wall/ shielding blanket prototype is being launched. A wide panoply of minor but essential research tasks is under way in industry and in the European Associations.

While the fabrication of the main prototypes will be finished or close to completion by the end of the EDA, testing will have to extend beyond July 1998.

The EU is also a major contributor to two other large projects (i.e. Divertor Target manufacturing and superconducting cable for the Central Solenoid Model). Overall EU industry, within the frame of the EDA, will have manufactured prototypical models of all the key fusion specific components of ITER, i.e. magnets, blanket, divertor and remote handling tools.

3.7 Conclusions on Engineering

The continuing integration process of the activities of the Home Teams and Joint Central Team has been instrumental in achieving substantial progress in the design and definition of technical details, and should be further improved.

The structure of the machine and its engineering performance are well established. In some areas design optimisation is still dependant on the results of R&D activities or on more elaborate numerical investigations. A satisfactory remote maintenance system is being developed for the in-vessel part of the machine. However, assembly, maintenance and repair are crucial and deserve further effort. The detailed design, as presented in the DDR and annexed documents, represents a satisfactory basis to address the remaining open issues in view of the Final Design to be delivered at the end of 1997.

4. SAFETY

4.1 Background Information and Safety Objectives

Since the time of the IDR, safety-relevant design changes have been made and major extensions to the safety analyses have been performed. The NSSR-1 has been assessed against two prime objectives for ITER design and safety analysis. Firstly, ITER must be licensable in any of the Parties. It is acknowledged that NSSR-1 and its planned successor, NSSR-2, are not intended to be licensing documents: however, NSSR-2 must provide all the technical information necessary for the initiation of licensing procedures by an interested host country. Secondly, the safety analysis must support the safety and environmental advantages of fusion. In brief, these are that the consequences to the public from even the worst possible accident would be very limited, and that activated waste from developed fusion plants should not pose long-term burden on future generations.

4.2 Findings

It is clear from NSSR-1 that major improvements have been made to the design and the safety analysis since the Interim Design Report. In particular, a large amount of high quality work has been performed on the analysis of accident sequences and on the quantification of inventories of energy and hazardous materials. Progress in the design has followed the recommendations made in the previous European review of ITER safety documentation: in particular, the provision of a closed confinement of the Heat Transport System rooms, and the definition of a plasma shutdown system.

The presentation of the logic of the safety methodology and its implementation should be improved, with greater reference made to the various levels of Defence in Depth. In particular, it should be better shown how prevention objectives are explicitly implemented in the design.

A programme of Accident Analysis Code Validation should be set up, especially for fusion-specific conditions of use. The effort could be entrusted to a specially created international team.

NSSR-1 already demonstrates that the "no evacuation" criterion is satisfied under average weather conditions for all the accident sequences considered. This constitutes a major advantage for the public acceptability of fusion. The analysis should be continued to cover all worst case accident sequences originating in the plant, in all weather conditions. For this purpose, an assessment could be performed of the release fractions, release heights and dispersion characteristics of the identified sequences. If the "no evacuation" criterion could not be met for the most adverse weather conditions after such a more refined analysis, modifications to the design might be introduced. Such an assessment might be better conducted once potential sites are identified.

Two very low probability severe accident scenarios involve hydrogen generation inside the vacuum vessel and magnet energy releases through arcing. These accidents should be further investigated and passive means to minimise the consequences should be considered.

The following issues should be addressed in greater depth in NSSR-2:

- Fire hazard, which could be responsible for common cause failure.
- Human factors (especially design and administrative provisions to minimise the consequences of human error)

Occupational safety is a critical area for an experimental facility like ITER, and it is important to ensure that the analysis is comprehensive. The total individual and collective doses should remain below current best practice in the nuclear industry. The effort in this field should be continued with great attention in order to provide a complete assessment, including provisions for exceptional maintenance. In addition, where the ALARA principle is claimed in the documents, the detailed implementation of this principle should be made explicit.

NSSR-1 shows that considerable progress has been made in giving a fuller picture of the waste resulting from ITER operations and dismantling. It is suggested to extend the description of the data over a longer time span, and to give more information on tritiated waste. An analysis and description of the dismantling procedures is required, and design provision to facilitate the dismantling should be considered, if appropriate.

The analysis in NSSR-1 is focused on the Basic Performance Phase of ITER, and it is premature to comment on the issues for the Extended Performance Phase while several design concepts for the blanket of that Phase are still under consideration.

It would be appropriate to start soon a dialogue between the JCT and experts from the regulatory bodies of the Parties. The Parties should make efforts to facilitate this dialogue.

In conclusion: substantial progress has been made in design and analysis, in providing the information needed for licensing, and in demonstrating potential safety and environmental advantages of fusion, and the work reported in NSSR-1 generally forms a good basis for proceeding to NSSR-2. Changes and improvements, for incorporation in NSSR-2, have been identified.

5. COST AND SCHEDULE

Some modifications in the cost of a number of items with respect to the IDR have been presented as a consequence of design modifications and increased level of available detail, but no reassessment of the total cost has been performed either by the Joint Central Team or by the

European Domestic Assessment Group. The project will produce a fully revised cost estimate with industry input in the Final Design Report. The Joint Central Team feels confident of maintaining the costs within the present boundaries through judicious vendor responsibility limitations, design to cost, and stimulus of commercial competition.

As far as the time schedule is concerned the importance of a strong, competent management during the construction phase is reiterated. Some components with new advanced technologies, such as the TF coils, present an optimistic construction time. The entire time schedule will be highly dependant on the duration of the licensing process and/or on the possibility of launching the actual construction while the licensing procedure is carried out. This may vary considerably among possible host countries. As a consequence, the time schedule appears optimistic and will have to be reassessed once more detailed inputs are available from potential manufacturers and possible host countries.

6. GENERAL CONCLUSIONS

The Detailed Design Report of ITER confirms and strengthens the design as presented in the IDR. ITER's main parameters have remained unchanged and have been confirmed by the results of experiments conducted on the present generation of tokamak devices in Europe and abroad.

Major progress has been achieved in demonstrating Helium exhaust and in clarifying the scaling of H-mode confinement through continued experimentation. Experimental work on the tokamaks with ITER-like geometry, especially on JET, has to continue to focus on the regimes and operating scenarios envisaged for ITER.

The ITER parameters are commensurate with the stated objectives, and the design provides the requisite flexibility to deal with the remaining uncertainties by allowing for a range of operating conditions and scenarios for the optimisation of the plasma performance.

In Engineering, while the machine structure presented in the DDR has been entirely defined and is fully responding to the operational requirements, work has to continue on a number of items, in particular remote maintenance and repair, to finalise the design and to complete the supporting R&D and prototype testing.

Major improvements have been made to the safety analysis of ITER since the IDR. Further work should continue on occupational exposure and on consequences of the worst accidents, not only to prepare for the licensing of ITER but also for its impact on demonstrating the potential benefits of fusion.

No substantial change to the cost of ITER has been introduced between the IDR and the DDR. The construction time schedule seems optimistic.

Annex - Membership of the European ITER Assessment Group

The European ITER Assessment Group was chaired by Dr. R. Andreani, and was divided into three working groups assessing the Physics, Engineering and Safety aspects of the Detailed Design Report. The membership of the groups was:

Physics:

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