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FOREWORD

Development of nuclear fusion as a practical energy source could provide great benefits for all mankind. This fact has been widely recognized and fusion research has enjoyed a level of international co-operation unusual in other scientific areas. From its inception, the International Atomic Energy Agency has actively promoted the international exchange of fusion information.

In this context, the IAEA responded in 1986 to calls for expansion of international co-operation in fusion energy development expressed at summit meetings of governmental leaders. 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 a joint venture called International Thermonuclear Experimental Reactor Conceptual Design Activities. The Director General then invited each interested party to co-operate in ITER activities in accordance with the Terms of Reference that had been worked out. All four Parties accepted this invitation.

ITER Conceptual Design Activities, under the auspices of the IAEA, began in April 1988 and are scheduled to be completed in December 1990. The plan includes two phases, the Definition Phase and the Design Phase. In 1988 the first phase produced a concept with a consistent set of technical characteristics and preliminary plans for co-ordinated R&D in support of ITER. The Design Phase is producing a conceptual design, a cost estimate and a description of site requirements. All information produced within the Conceptual Design Activities is being made available for all ITER Parties to use either in their own national programme or as part of a larger international collaboration.

As part of its support of ITER Activities, the IAEA is pleased to publish the documents that summarize the results of the Conceptual Design Activities.

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PREFACE

A previous report by the ITER Council[1] described the status of ITER Conceptual Design Activities (CDA) as of December 1989. Since that time there has been significant progress in all aspects of the quadripartite efforts. The present report updates the previous report, especially in Chapter 3, which addresses considerations that are relevant to a possible next phase of co-operation.

The Council suggested in December 1989 that the Parties consider entering discussions with a view toward negotiations on an instrument to allow Engineering Design Activities (EDA). At its meeting on 26-28 April, 1990, the Council was pleased to hear from all delegations expressions of willingness to enter exploratory discussions with a view toward negotiation of such an instrument.

1. INTRODUCTION

Based on results of experiments in many countries, there is good reason for confidence that thermonuclear fusion, which powers the sun and other stars, could be produced in a controlled manner here on earth. Efforts to develop fusion as a safe, environmentally attractive and practically inexhaustible source of energy are worldwide. The bulk of the effort is in four large programs that are currently of approximately equal size: in the European Community, in Japan, in the Soviet Union and in the United States. In 1985 government leaders in summit meetings began to call for more concrete international co-operation in order to increase the efficiency and minimize the cost of fusion energy development. In response, the International Thermonuclear Experimental Reactor (ITER) activities have been conceived to fully confirm the scientific feasibility and to address the technological feasibility of fusion power.

Beginning in 1988 and continuing through 1990, these four Parties have been co-operating in the ITER Conceptual Design Activities (CDA) under the auspices of the IAEA. This collaboration stems from the recognition in each of the four programmes that a very large experimental facility would be needed to prove the technical feasibility of magnetic confinement fusion. Collaboration in the ITER CDA was undertaken to provide a design concept which might lead to international design, construction and operation of such

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, ITER Activities Status Report: December 1989, ITER Documentation Series, No. 9, IAEA, Vienna (1990).

an experimental thermonuclear reactor which could provide each Party with more benefits and at less cost than if each had undertaken such a step alone.

Although the four fusion programmes had similar objectives for an experimental reactor and were in agreement on the general technical approach at the beginning of the ITER activities, there were differences in the specific design concepts that each had developed. Understanding and resolution of these differences were accomplished through effective joint work and, by the end of 1988, the Parties agreed upon a single concept definition.[2] The CDA will be concluded and the results reported at the end of 1990.

2. CONCEPTUAL DESIGN ACTIVITIES

2.1 Objectives

ITER is expected to fully confirm the scientific feasibility and to address the technological feasibility of fusion power. Consequently, the machine must be designed for controlled ignition and extended burn of deuterium-tritium plasmas. It must also demonstrate and perform integrated testing of components required to utilize fusion power for practical purposes.

2.2 Organization and Progress

The ITER Terms of Reference anticipated that each Party would contribute a total of about 80 to 100 person-years over the course of the CDA. As the CDA have developed and the influence on each Party's programme has grown, each Party has actually supported ITER with more than the anticipated effort. Part of this effort is being spent domestically, part at the ITER Technical Site at Garching near Munich. During joint work sessions, more than 40 scientists and engineers are in residence while an even greater number continue work at home locations. About 200 individuals have participated in shorter term assignments at the joint work site. As shown in Fig. 1, there were five months of joint work in 1988, six in 1989 and seven months are planned for 1990. Figure 1 also shows meetings of the ITER Council and the ITER Scientific and Technical Advisory Committee (ISTAC).

The joint work at the Technical Site is managed by the ITER Management Committee (IMC). This work is completely integrated with regard to the technical work of personnel from the four Parties. Consequently

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[2] INTERNATIONAL ATOMIC ENERGY AGENCY, ITER Concept Definition, Vols. 1 and 2, ITER Documentation Series, No. 3, IAEA, Vienna (1989).

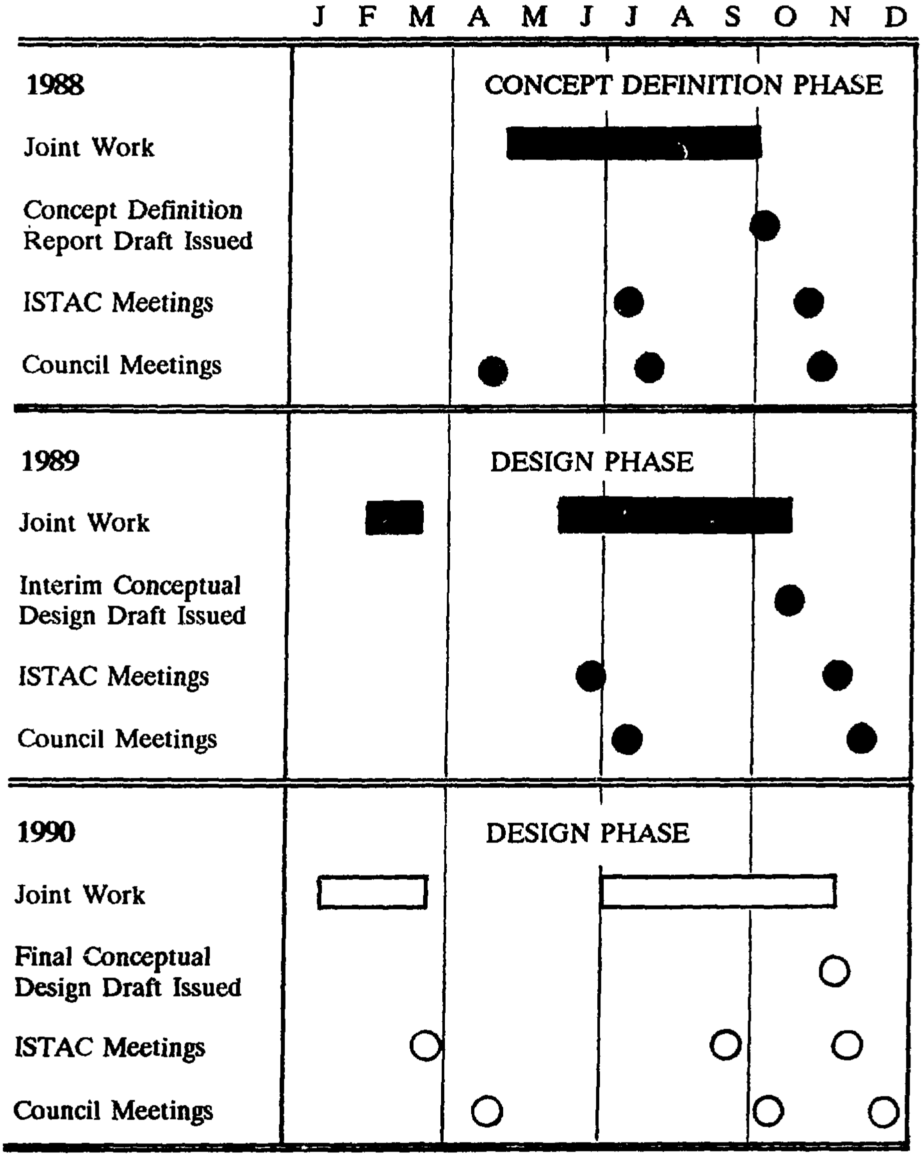

Fig. 1. Schedule for ITER Conceptual Design Activities

each major design issue has been resolved by formation of a consensus among the Parties at the technical level.

During the Concept Definition Phase in 1988 the IMC developed a technical description of a single concept. Site requirements for ITER have been under study and major characteristics have been defined. This concept was favorably reviewed by ISTAC and approved by the ITER Council. During 1989-90 design analyses have been improved and the design has progressively evolved. The results as of November 1989 were described by the IMC in the ITER Conceptual Design Interim Report.[3] The Council, following the advice of ISTAC, agreed that the interim conceptual design was fully compatible with the objectives set forth in the CDA Terms of Reference.

The conceptual design process has been supplemented by an extensive programme of supporting research and development. The ITER Terms of Reference anticipated that this R&D would amount to approximately $10 million per year for each Party. At the recommendation of the IMC, all of this committed effort was devoted to technology R&D. Furthermore, a substantial programme of physics research was developed and the Parties agreed to contribute this research support in addition to the technology R&D. Over ninety reports of these additional physics research tasks have already been submitted for use in the design.

Furthermore the Council chartered a Working Party on Ways and Means, whose purpose is to identify means to attain the objectives of the co-operation. The Working Party's findings are reflected in Section 3 of this Status Report, "Consideration of Possible Engineering Design Activities," and are reported more fully in a separate report.[4]

2.3 Design Philosophy

The tokamak device represented in Fig. 2 would be the heart of the ITER facility. Its principal parameters are listed in Table 1.

The main machine characteristics and parameters follow from the technical objectives of the programme. Extended burn requires superconducting coil systems. Ignition sets the plasma current and approximate size. The design target for the first wall fluxes and fluence both dictate minimum shield thicknesses in the device. When these are combined with considerations of plasma stability, impurity control, and current drive, the general features of the reactor are determined. Safety considerations are an integral part of the design activities and safety is being enhanced by the use of passively safe

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[3] INTERNATIONAL ATOMIC ENERGY AGENCY, ITER Conceptual Design: Interim Report, ITER Documentation Series, No. 7, IAEA, Vienna (1990).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Report of the ITER Council's Ways and Means Working Party, ITER Documentation Series, No. 11, IAEA, Vienna (1990).

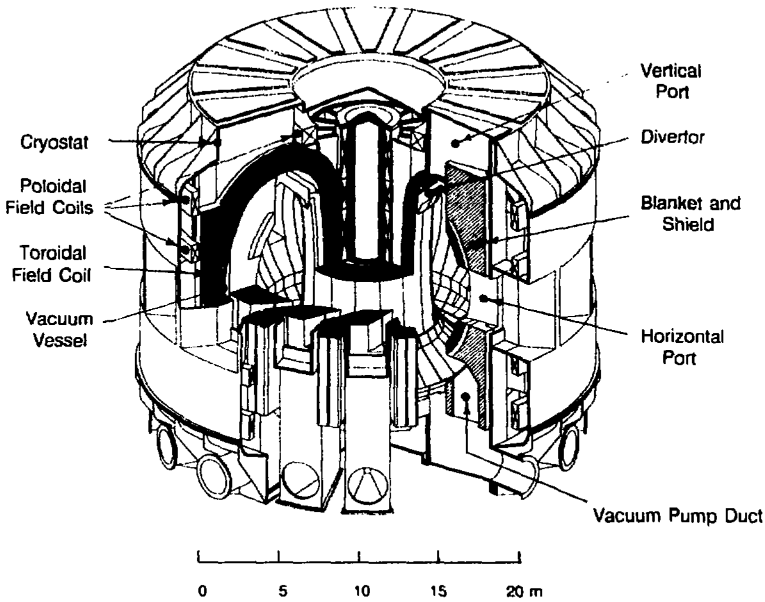

Fig. 2. Basic Elements of ITER Tokamak

TABLE 1. PRINCIPAL PARAMETERS OF ITER TOKAMAK

Plasma major radius, R (m)	6.0
Plasma half-width at midplane, a (m)	2.15
Elongation, 95% flux surface	1.98
Toroidal field on axis, B_o (T)	4.85
Nominal maximum plasma current, I_p (MA)	22
Nominal fusion power, P_f (MW)	1000

systems wherever possible. Within the freedom allowed by the objectives, the design philosophy has been to control size and minimize cost.

The ITER design is based upon scientific knowledge and on extrapolations derived from the operation of dozens of tokamaks over the past decade and upon the technical know-how flowing from the extensive technology R&D programmes of the four Parties. Design policy has been to: (1) proceed essentially upon the basis of actual performance reached in the present generation of tokamaks; (2) provide the maximum machine performance consistent with prudent engineering practices and reasonable costs; (3) build in as much experimental and operational flexibility as practical in a machine of ITER's size; (4) implement physics and technology R&D plans, using existing facilities, to validate the ITER design concept.

The design process has been supported by extensive physics and technology R&D efforts. The ITER physics R&D plan puts particular emphasis on reducing uncertainties. Extrapolations based largely on operational experience with present machines is adequate for present needs. However, more detailed understanding of the underlying physical mechanisms of the confinement process would be valuable. Therefore, a strong effort is being made to identify the physical basis of the mechanisms responsible for energy losses in tokamaks.

It is considered very unlikely that the results of such ongoing research would substantially change the concept. Nonetheless, continued focused physics R&D, using existing facilities will minimize uncertainties and increase confidence in ITER design assumptions so as to provide a sound basis for a decision to proceed with construction.

The basic ITER device has been designed to accommodate a number of configurations and modes of operation in the physics phase. This flexibility will prove advantageous in coping with uncertainties in the plasma physics predictions and in optimizing the plasma performance of the device itself for each of the different programme objectives.

2.4 Estimation of Costs

The Terms of Reference for the CDA require, *inter alia*, cost, manpower and schedule estimates for the realization of the ITER. Plans for the Conceptual Design Activities in 1990 include performing a comprehensive analysis of the estimated costs that the Parties would incur if they decide to continue with design, procurement, construction and operation of ITER. This cost analysis will be based upon completed conceptual design of the entire facility and conceptual plans for procurement, construction and operation.

In order to provide early information to the Parties on these matters, the Council asked the ITER Management Committee to make preliminary estimates of the capital cost of the ITER facility. Because of the incomplete state of the CDA and unresolved questions about a project plan, these preliminary estimates rest upon some assumptions which, while reasonable, could possibly change before the end of the CDA. Figure 3 shows the tentative conceptual schedule for a complete project that was developed by the IMC during 1989.[4] The preliminary estimate of the capital cost, in January

[4]INTERNATIONAL ATOMIC ENERGY AGENCY, ITER Conceptual Design: Interim Report, ITER Documentation Series, No. 7, IAEA, Vienna (1990).

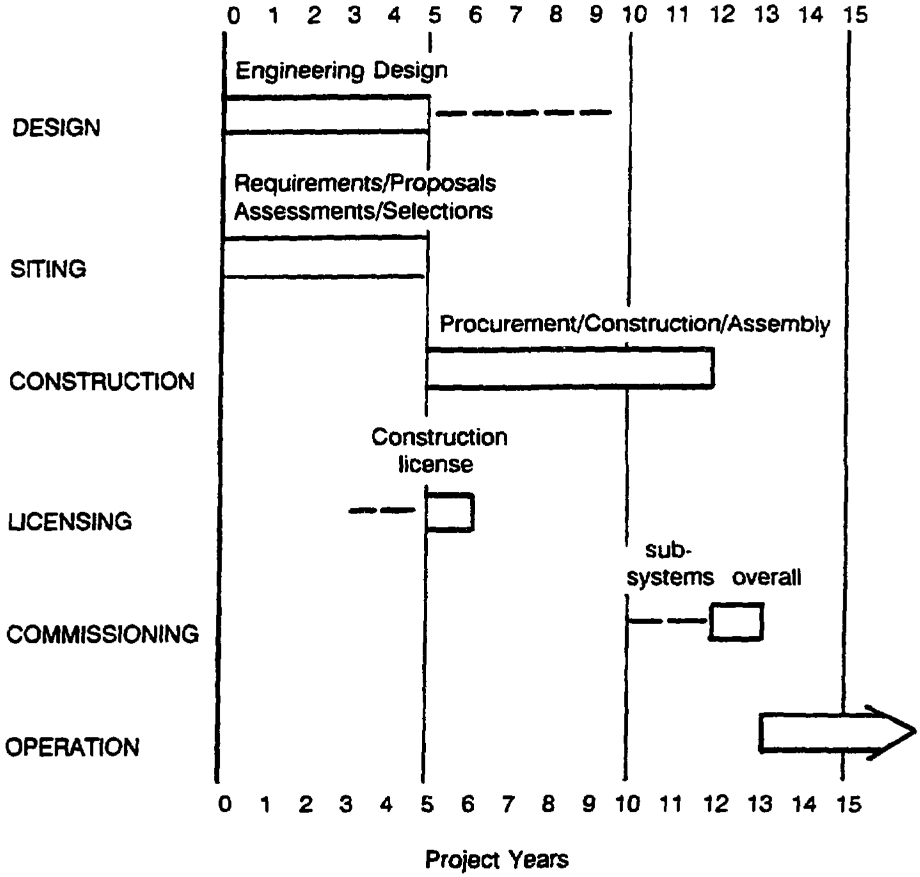

Fig. 3. Conceptual Project Schedule

1989 US$, is $4.9 billion. The cost of the EDA is discussed further in Section 3.2.

3. CONSIDERATION OF POSSIBLE ENGINEERING DESIGN ACTIVITIES

3.1 General

In 1989 the Council began to explore ways and means to comply with the objective of the ITER co-operation. The following are the present views of the Council. They are updated with respect to those expressed in the December 1989 Status Report and may be modified by further exploration.

All Parties to the present CDA have benefitted significantly from their participation. Considering the additional benefits which are anticipated from future collaboration in an EDA as well as the impetus to world fusion progress which would be realized, the Council believes that it is appropriate to consider beginning ITER EDA.

In the Council's view, the ITER EDA would begin with acceptance by the Parties of a single conceptual design and R&D plan as well as agreement on Terms of Reference. The EDA would end with completion of the technical preparations necessary for taking a decision to start the construction phase.

3.2 Scope of EDA

The IMC made a preliminary estimate that the EDA would require, over a 5-year duration, a total of 1200 professional-man-years for an outlay totalling about $250 M. The cost of specific engineering R&D was estimated by the IMC at about $350 M during the same period. During the EDA a survey of possible sites and an assessment of related licensing procedures should be made for site selection. The time of site selection has to be considered separately. The procedures for procurement should also be developed. These estimates assume that a sufficient level of background physics and technology R&D continue in the Parties' home programs and is made available to the ITER project.

3.3 Project Organization and Management

Because of the technical complexity, the magnitude and the international character of the ITER, the organizational structure adopted for the EDA must be carefully designed to achieve maximum effectiveness while satisfying the concerns of all Parties. A possible structure is described in the Ways and Means Report.[5]

3.4 Intellectual Property Rights and Task-Sharing

Development of means to handle these two topics is central to effective conduct of the EDA. The Ways and Means Working Party has considered these matters and suggested principles for approaching the intellectual property

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[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Report of the ITER Council's Ways and Means Working Party, ITER Documentation Series, No. 11, IAEA, Vienna (1990).

rights issue. These discussions have led the Council to conclude that a workable relationship could be developed by the Parties. A set of principles has also been suggested that could be translated into a practical approach to task-sharing that balances the objectives of equity and project effectiveness.

3.5 Formal Arrangements Leading to ITER EDA

3.5.1 Approach to the Formalities

An engineering design is typically conducted with subsequent construction in mind, in large measure because of the significant resource investments required. With such a complex enterprise, extending over approximately five years, it would be exceedingly difficult to be able to specify in full detail all elements of the EDA on an *a priori* basis.

The juxtaposition of three conflicting needs requires a non-traditional approach to the EDA formalities. These three needs are the following:

1. the need for a clear long-range view of the overall engineering activity *ab initio*,
2. the immediate need for a legal basis for continuing ITER work into EDA, and
3. the need to conduct extensive engineering work in order to be able to specify the full details of all EDA agreement matters.

Consequently, the Ways and Means Working Party has suggested that agreement would require a combination of long-term intent and near-term commitment. Any formal agreement for EDA should be based on the principle of equal contributions from the Parties, define the contents of the EDA, and provide necessary arrangements for the conduct of the EDA.

3.5.2 Form of the Agreement and Possible Role of the IAEA

There appear to be two options for structuring the legal framework of the EDA arrangement:

1. a quadripartite agreement under IAEA auspices, or
2. a stand-alone, quadripartite agreement.

At this stage, the two options are open. The IAEA has provided a number of useful functions during the CDA. Consideration should be given to the possibility of having the Agency perform these and, if appropriate, additional functions in the EDA. Moreover, the IAEA could play a helpful role in assisting a Party to join the agreement.

4. ADDITIONAL POTENTIAL BENEFITS OF ITER

ITER would be a necessary experimental facility, intermediate between the current large tokamak experiments and a fusion reactor capable of reliably producing electric power. Another important consideration is that its construction and operation could well serve as a pilot project in international collaboration for the development of the high technology which is necessary for solving some of the world problems.

Energy supply is a global matter. The high-technology components of energy supply are of such a scale that international collaboration is highly desirable. Solutions must be found to many problems in large-scale, high-technology projects that are carried out by multinational teams. Some of these problems, particularly those that involve human factors which differ among the participants, have already been met and solved during the ITER Conceptual Design Activities. Others, such as allocation of procurement packages, sharing of manufacturing know-how and verification of quality assurance, would be confronted and solutions found during the course of design, construction and operation of the ITER. In addition to its more direct benefits, full implementation of the ITER project could, therefore, provide valuable experience for international collaboration in other areas.

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