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FOREWORD

The first two articles in this issue describe the activities of two of the four Project Units in the ITER design organization: the Physics Group and the Basic Device Engineering Group. These articles have been prepared by the group leaders Douglas Post, USA, and Ettore Salpietro, EC. Articles in the next issue of the ITER Newsletter by the leaders of the two other Project Units — the Nuclear Engineering Group and the System Analysis Group — will provide similar information on achievements in those areas.

MAJOR ACTIVITIES OF THE ITER PHYSICS GROUP

by D. Post, Group Leader

The Physics Group has the responsibility for providing physics guidance and specifications for the tokamak design. These include:

— physics guidelines, such as optimum methods to use for current drive,
— physics specifications, such as plasma current required for ignition, maximum toroidal field ripple, etc.,
— plans for the experimental operation of ITER and
— identification of the physics R & D required for ITER.

Physicists provide physics guidance and specifications for the tokamak design

In addition, the Physics Group works with the three other engineering groups to find optimized solutions for design problems.

At the beginning of the ITER activities, the Physics Group assessed the significant advances and progress that had been achieved during the previous decade with respect to the plasma parameters attained in tokamak plasmas and the various proposed extrapolations of the confinement data. On this basis, the Group developed specifications and guidelines for the ITER design to provide a reasonable degree of assurance that ITER will be able to meet its goals of ignited operation and high fluence testing.

During the course of these analyses, the Group identified a number of physics areas which are crucial for ITER. Particularly critical areas are:

— the energy and particle confinement properties, in particular the necessity of achieving enhanced energy confinement ("H-mode") without, at the same time, excessive impurity accumulation;
— the working conditions of the plasma-facing components ("plasma–wall interaction") and the related issue of power and particle exhaust; and
— the impact of plasma disruptions on the plasma-facing components and the mechanical structure of the machine.

Other important areas include the choice of heating and current drive systems and plasma equilibrium control.

These issues were addressed at specialists' workshops held by the ITER Physics Group in May and June at Garching. Experts from the major tokamak experiments in the world fusion programme, including JET and ASDEX (EC), TFTR and

DIII-D (US), T-10 (USSR) and JT-60 and JFT-2M (Japan), contributed to each of the workshops. The ITER Physics Group used the results from the workshops along with detailed studies of the critical issues both to develop the physics guidelines and specifications for the ITER design and to identify the physics issues that are uncertain and need further resolution.

Some of the unsettled issues are being addressed by detailed analyses performed by members of the ITER team. Other issues will have to be answered by further experiments on present and planned tokamaks. To guide this work, an R & D plan containing the critical questions that have to be resolved for ITER was developed. The success of ITER will crucially depend on these questions being resolved in time.

The present guidelines can be summarized as: a plasma current of ~20 MA to ensure adequate energy confinement for ignition, a maximum plasma pressure of ~4–5% of the magnetic pressure, a plasma elongation of about a factor of 2, and the use of a double null poloidal divertor for power and particle exhaust. A choice for the current drive and heating system will be made from among three options by the end of 1990 after a detailed assessment of each option.

The ITER Physics Group consists of about 15 physicists who engage in the joint work at Garching plus about 20 physicists per country who remain in each home country. These individuals are assigned to sub-groups which work on specific tasks and with different engineering groups. The intense involvement of so many working physicists, in what might be considered by an outsider as an engineering design project, is a fairly recent development for fusion and is evidence of the degree of seriousness with which the ITER design effort is taken by the world fusion community.

The international collaboration faced and successfully solved the challenging problem of co-ordinating the support work being carried out in the home countries with the work in Garching. Each physicist in Garching maintained contact with the work of 6 to 8 physicists in his home country. Regular mail was much too slow, so that heavy use was made of telefax, telephones, and electronic mail. Although most of the co-ordination of the work within each home country was handled through the ITER physicists from that country, there was also a significant amount of direct communication between group members at Garching from one country and home team members from another country. The different time zones for each country also made life interesting. For example, physicists in Garching could finish a day's work and then communicate the problems that arose that day to their colleagues in the US who were just arriving at work. They could then begin the day by reading their computer mail to find out what needed to be done that day. The home team then sent its results to Garching at the end of the day in the US, and the ITER team member could look at it when he came to work in the morning. This effectively almost allowed double shift operation.

In summary, during the first summer together in Garching, the group of 15 physicists with very different background, culture, and languages quickly began to function as a team working towards a single goal: the best possible design for ITER. The result was agreement of all Parties on the set of parameters and specifications that were incorporated in the ITER concept definition.

RESULTS OF THE ITER BASIC DEVICE ENGINEERING GROUP

by E. Salpietro, Group Leader

The plasma system is capable of confining a range of shapes

Starting from the previous national experience (NET, FER, TIBER, OTR), the common work carried out at INTOR, and the help of experts consulted in a series of specialists meetings held during the summer in Garching, the Basic Device Engineering Group defined the design philosophy and criteria to be followed in the design phase of ITER. Because all contributors to ITER were experienced in the design of "next step" devices, the definition of philosophy and criteria was possible in some detail.

In parallel with this activity, an assessment of the physics data base was carried out by the Physics Group, leading to the definition of the physics performance required from the machine. Due to the imprecision of physics extrapolations the machine must be flexible and able to operate with a range of plasma parameters.

The reference ITER device presented in this article is the result of trade-off studies performed in this phase of the ITER work. The main parameters are reported in Table 1. The cross section is shown in Fig. 1 for the technology phase plasma and in Fig. 2 for the physics phase basic plasma.

Table I: ITER TYPICAL OPERATING PARAMETERS

	Phys. Phase	Technology Phase
R (m)	5.8	5.5
a (m)	2.2	1.8
A	2.6	3.1
k_{95}	1.9	2.0
q_{psi} (95%)	3.2	3.1
g	1.7	2.9
I_p (MA)	22.0	18.0
B (T)	5.0	5.3
P_{fus} (MW)	1040	850
P_n (MW/m^2)	1.0	1.1
P_{cd} (MW)	—	90
Q	—	10
n_e (10^{20} m^{-3})	1.0	0.7
T (keV)	10	18
τ_E (s)	3.1	2.1
H_{SO}/H_{RL}	1.7/0.8	1.8/0.9
H_G/H_{t10}	1.8/1.9	1.6/1.6
τ_{burn}	~300	steady state

At this stage there are still some design alternatives to be studied in more detail during the Design Phase in 1989–90. The magnet system design philosophy, for example, is that all the coils will be superconducting, should be independently removable, but will form part of the semipermanent structure and should not need to be removed during normal machine maintenance. Within this guideline, different concepts can be considered.

Initially, the reference concept for support of the toroidal field (TF) coils is wedging of the inner legs to form a central vault structure. This structure, in combination with an outer intercoil structure, will withstand both the centering and out of plane forces. The winding pack will be monolithic, using vacuum impregnated, glass-fiber-reinforced epoxy resin, which must remain fully bonded for the machine lifetime in order to provide the required strength.

Two concepts were identified which, if justified by analysis, would be expected to lead to a reduction in machine cost. The first of these is support of the toroidal field coils onto the central solenoid by bucking, rather than by a wedged vault. This offsets the outward forces of the solenoid by inward compression by TF coils. The second is to design so that a debonded winding pack, resulting from failure of the epoxy bond between conductors due to irradiation, can be tolerated.

Another example of the design philosophy is that the machine should be designed for full remote maintenance, but with provisions for hands-on maintenance where possible without compromising the machine design. A combination of vertical and horizontal access should be considered for maintenance of the components inside the main shielding. In addition, replacement of components with short service lives or high failure rates should be possible without moving other components or disturbing the reactor's internal environment. During the design definition phase this philosophy has been applied to a working set of parameters. Each major component has been assigned a working area which it can occupy.

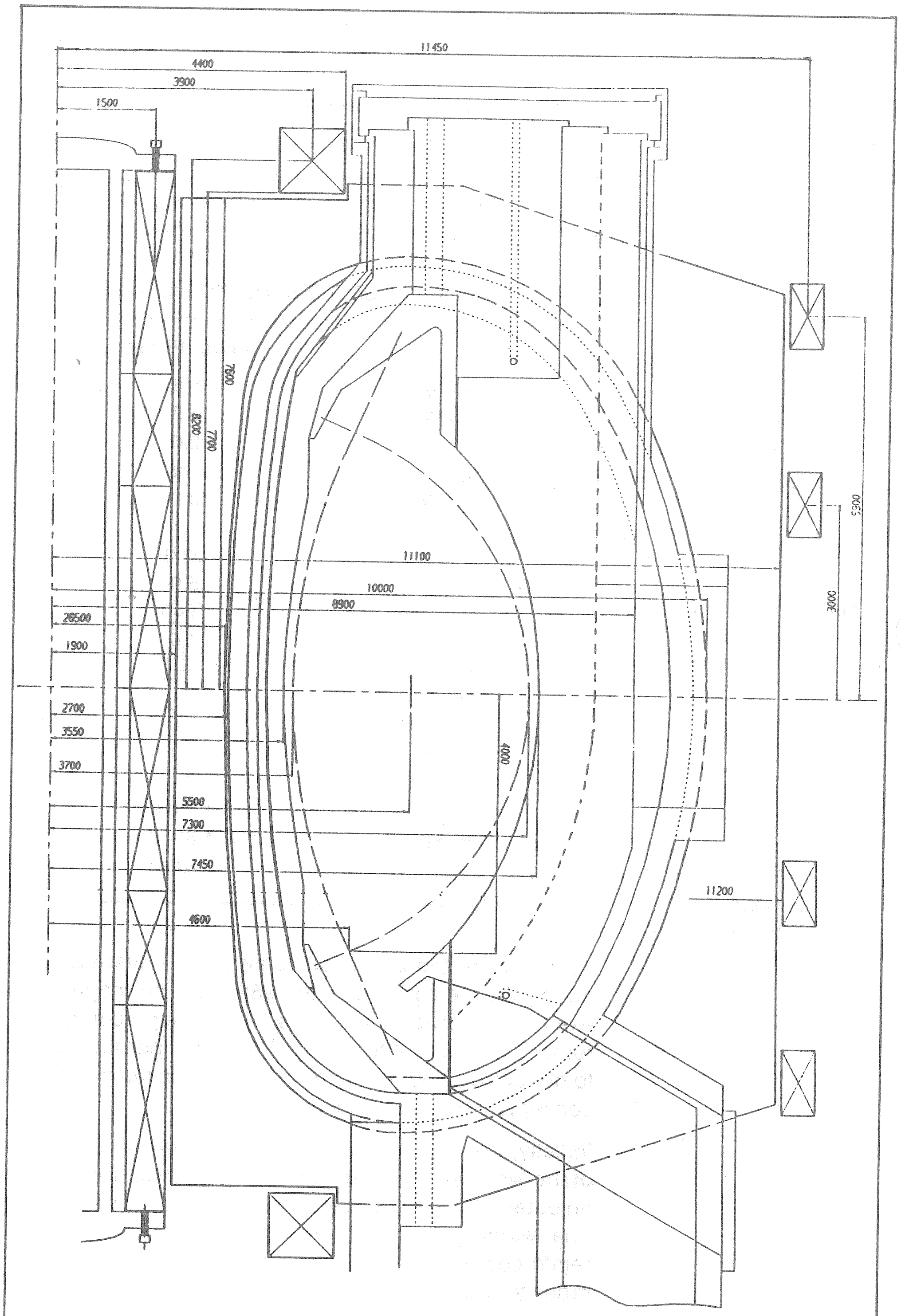


FIG. 1. Cross-section ITER machine: technology phase.

After analysis of both main line concepts and alternatives, it has been possible to redefine the working parameters and make a selection between design alternatives based on a common set of working conditions and satisfying common design criteria.

The ITER concept is characterized by the following features. The plasma system, forming the heart of the machine, is capable of confining a range of shapes of the double and semidouble null form. The plasma and the first wall/blanket units are contained inside their own vacuum vessel with double containment at the joints to monitor tritium leakage, and incorporating sufficient nuclear shielding to protect the coils.

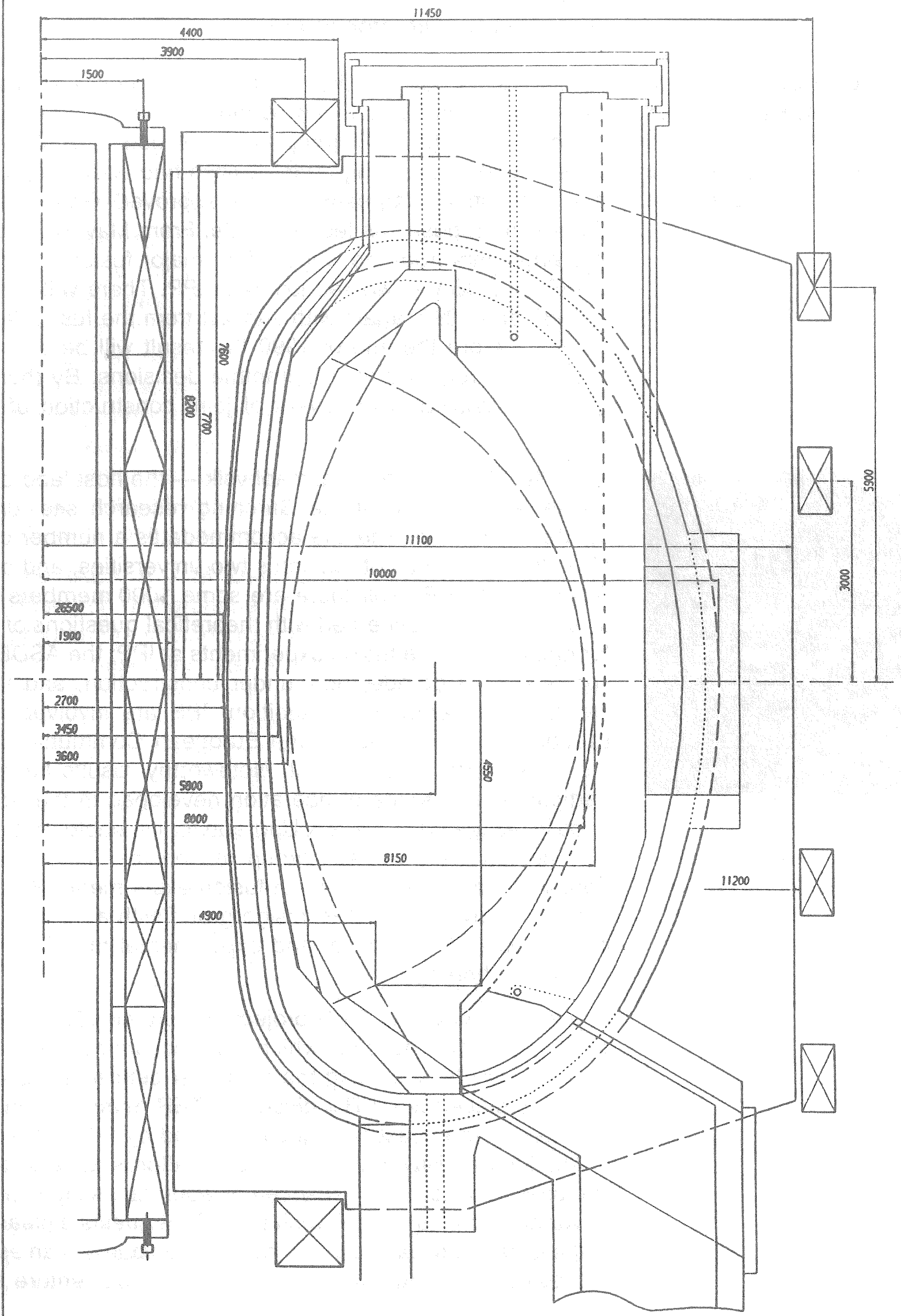


FIG. 2. Cross-section ITER machine: base plasma (physics phase).

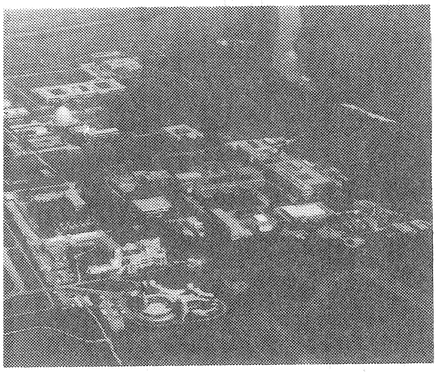
In conclusion, the ITER concept, produced by the Basic Device Engineering Group, at the end of the Definition Phase satisfies the requirements specified in the ITER Terms of Reference. The variations to be studied during the Design Phase are not expected to significantly change the overall machine size but could improve the cost and reliability of the design. Because extensive studies during the definition phase have resolved the main design alternatives, major changes in the machine size should only come from an improvement in the expected plasma performance arising from new experimental evidence. The ITER concept defined by the design philosophy and the design solutions for the components will not be much affected by such changes. During the Design Phase only small readjustment of the component parameters should be expected.

THE IPP — HOST LABORATORY FOR ITER ACTIVITIES

by K. Pinkau, Director of the IPP

One of the largest research centres in Europe accommodates the ITER team

Joint work on defining the ITER technical concept was inaugurated at Garching, near Munich, on 23 April 1988 when the European and local hosts had the pleasure of welcoming the ITER group and their guests at Max-Planck-Institut für Plasmaphysik (IPP) in Garching. The facilities had been prepared after the four parties to this international agreement had approved Garching, in accordance with the European proposal, as technical site. From May to September, about 50 scientists and engineers from the world's four major fusion programmes — Europe, Japan, USSR and USA — worked jointly at IPP. There will be similar joint work sessions in 1989 and 1990, again with support from the fusion laboratories operated by the parties. Before the end of 1990 the result will be a conceptual design and other information required for programme decisions. By then, legal and organizational questions arising in the event of joint construction of ITER will also have to be treated.



Max-Planck-Institut für Plasmaphysik — the host laboratory during the ITER study phase — is located at the Garching research site, one of the largest research centres in Europe. The site accommodates a number of scientific institutes of the Max Planck society, of Munich's two universities, and of the Bavarian Academy of Sciences. At IPP itself there are some 1000 members of staff, a quarter of them scientists either concerned with theoretical questions of plasma physics or working for one of the three fusion experiments at IPP: the ASDEX tokamak and its successor, ASDEX Upgrade, now under construction, and the WENDELSTEIN VII-AS stellarator experiment. In addition, IPP are involved in the work on JET (Joint European Torus), which is the European Community project, the world's largest fusion experiment at present. Noteworthy results have been achieved with JET, particularly in a mode of operation developed in the ASDEX experiment and now to be investigated in ASDEX Upgrade for its reactor potential. Since 1983, IPP have also hosted the European group responsible for designing NET (Next European Torus), the next joint European fusion experiment. IPP are therefore confident that they can provide the ITER design group with a stimulating discussion forum, both in the fields of theoretical and experimental plasma physics and in questions of plasma technology.

In preparation for the ITER project, in autumn 1987 construction work was started on a new office building which now accommodates the ITER team. The infrastructure of IPP, including the computer centre, the CAD systems and the library, was also placed at ITER's disposal. ITER personnel and their families are accommodated in the guest residence provided by IPP at Garching. The close proximity of Munich, the Bavarian state capital, affords access to numerous cultural, social and scientific facilities, enhanced by abundant scope for recreation in the attractive Bavarian countryside. IPP wish their ITER guests a pleasant stay, in the awareness that a joint technical site involving all participants is an essential requirement for the successful implementation of such a complex venture as ITER.

IAEA NUCLEAR AND ATOMIC DATA ACTIVITIES RELATED TO FUSION

by J.J. Schmidt, Head of Section, IAEA

IAEA support to ITER

In the course of the last twenty years, the Agency's Nuclear Data Section has developed the expertise to manage and co-ordinate on an international scale the generation, validation, and distribution of nuclear and atomic data used in fission and fusion reactor technologies, as well as in other fields of application using radiations and isotopes. Current developments of nuclear and atomic data bases for applications in fusion reactor design, which are also pertinent to the ITER Project, are briefly described in the following.

Currently, the Nuclear Data Section, in co-operation with a number of national laboratories and data centres, is building up a comprehensive file of evaluated nuclear data for fusion reactor development. This file called Fusion Evaluated

Nuclear Data Library (FENDL) will be composed of neutron cross-sections in the thermal to 20 MeV energy range, covering elements and isotopes of fuel and blanket materials, structural and shielding materials. The file is designed primarily to support calculations of neutron (and photon) transport, tritium breeding ratios, and radiation shielding properties. This file will be composed of input from national and regional, evaluated data files, prepared in the internationally accepted ENDF/B format. It is foreseen that some of the more important data will be tested with benchmark calculations against existing benchmark experiments.

The IAEA Atomic and Molecular (A + M) Data Unit programme is at present entirely devoted to the development of an international atomic and molecular evaluated numerical data base for fusion research. This programme encompasses the whole spectrum of A + M data needs for controlled fusion research and is particularly relevant to research areas such as energy balance and confinement, impurity control and energy-particle exhaust, neutral beam heating and current drive, alpha particle transport, plasma-wall interaction processes and plasma diagnostics. There are advanced parts of this programme which cover the data base for collision and radioactive processes involving hydrogen, helium, some common impurities, and certain plasma-wall interaction processes. Recommended electron-impact ionization data also exist for all atoms of fusion interest, in all stages of ionization.

The IAEA A + M Data Unit has recently initiated a three-year Co-ordinated Research Programme (CRP) on A + M data for fusion edge plasmas. This programme should provide a more complete data base for modelling and diagnostics of these plasmas. A similar programme is planned to be organized next year for the plasma-surface interaction processes, oriented towards wall and plasma facing materials of immediate interest in fusion research. Several other actions are planned to be taken by the IAEA A + M Data Unit during the next few years devoted to the data base of metallic impurity ions, processes involved in energetic neutral beam penetration in tokamak plasmas, and to collision processes of fusion alphas and cold He-ash atoms and ions in the plasma edge.

The Nuclear Data Section will be pleased to answer any requests for nuclear and atomic data which the ITER project may need for its design studies.

ITER PRESENTATION AT THE IAEA NICE CONFERENCE

by A. Mavrin, ITER Information Officer

The Fusion community's interest in ITER development

The IAEA 12th International Conference on Plasma Physics and Controlled Nuclear Fusion Research was held from 12–19 October 1988 at Nice, France. In the traditional Artsimovich memorial lecture at the opening session, Ch. Maisonnier, Director of the Fusion Programme of the European Communities, spoke of the convergence in ITER of two subjects dear to the late Lev Artsimovich — tokamaks and international co-operation. Dr. Maisonnier told the audience "the ITER quadripartite initiative has become a reality not only because of support at the highest political levels, but also because of the proven ability of the fusion scientists to work together concretely on a complex task, which has been progressively and successfully developed through a variety of schemes". He finished his lecture with a statement that "the four large fusion programmes of the world are at present working together in the ITER Conceptual Design Activities to provide, by the end of 1990, a design which then be available for all Parties to use, either in their own national programmes or as part of a larger international co-operative programme".

In his speech at the Next Step Tokamak Session, ITER Council Chairman John Clarke, gave detailed information on the background of the project, its organizational structure and main milestones. He emphasized the significance of the ITER for the development of fusion. His talk was followed by a presentation of ITER Concept Definition, made by the IMC Chairman, K. Tomabechi. He informed participants that, based on the results of the investigation made since May 1988, an ITER concept has been defined as a machine which could be operated for a variety of plasma performances. For technology experiments, the machine can produce a sustained burn, with a plasma current of 18 MA at a major radius of 5.5 m, with tritium blanket installed. For the earlier plasma physics experiments, the same machine, except for having a thinner shield blanket instead of the breeding blanket, can achieve ignition at a plasma of 22 MA by fully inductive operation or a larger plasma current under some limited conditions. The session concluded with a report by the ISTAC Chairman, B. Kadomtsev, in which he gave a view of the Committee on the R & D plan in support of ITER, developed by the IMC.

The special evening session was devoted to the presentations of the group leaders on physics, basic device engineering, nuclear engineering and system analysis. The following discussion reflected a substantial interest of the fusion community in the ITER development.

THE 15th SYMPOSIUM ON FUSION TECHNOLOGY

by P.N. Haubenreich, IC Secretary

The progress toward maturity of engineering and technology for fusion utilization is nowhere more clearly reflected than in this series of symposia, which began in 1960. SOFT-15 papers and discussions depicted in great detail the state of the technology upon which the ITER design team based decisions in the Concept Definition Phase. The picture is realistically encouraging, as it shows continuing substantial progress in key areas.

Participation in SOFT-15 was worldwide, with 21 countries represented. Because of the location, most people and papers were from Europe — 241 of the total 315 papers originated within the European Community. Naturally papers on JET and NET were most numerous, but work in Japan, the USA, and the Soviet Union was rather well reported.

The subjects most emphasized in contributed papers were: plasma heating and equilibrium (58 papers) and materials (43). Next were first wall and vacuum (33), experimental systems (31), and magnets and power supplies (93). Although few in number, papers on reliability/availability, remote operations and maintenance showed that appropriate attention is being given to these subjects, which will become crucial in the planned D–T operations of existing devices and in ITER.

There was no paper expressly devoted to reporting ITER progress. Nevertheless, the subject of ITER came up again and again as speakers addressed the future course of fusion development. For example, in the opening address of the symposium, Dr. E. van Spiegel, Netherlands Director-General for Science Policy, in discussing the evolution toward greater industrial participation and both the necessity and the problems of international co-operation, stated "the development in the direction of ITER is therefore strongly endorsed by the Netherlands".

IMPORTANT ITER EVENTS

Definition Phase has been approved

The IMC prepared a draft of the ITER Concept Definition Report, which was evaluated by the ISTAC during its second official meeting held from 20–22 October 1988 at the IAEA Headquarters in Vienna.

The ISTAC concluded that the task of the Concept Definition Phase, defined in the Terms of Reference, has been accomplished, that the chosen parameters are satisfactory, and that the flexibility reduces risks. The final conclusion of ISTAC was that ITER activities are scientifically and technically ready to enter into the Design Phase.

On the basis of the information from the IMC and the advice of the ISTAC, the ITER Council at its meeting in November this year approved the substance of the Definition Phase.

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