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INSIDE

IAEA: FUSION RESEARCH COUNCIL MEETING

ITER activities and their influence on fusion research programmes throughout the world were a major subject of discussion at the meeting of the International Fusion Research Council (IFRC) in Vienna on 26 January 1990.

The ISTAC Chairman, B. Kadomtsev, briefly described the principal features of the conceptual design before stating the ISTAC's opinion. That is, that the design is soundly based on scientific and technological developments and promises to be capable of meeting the objectives prescribed in the Terms of Reference. ITER Council member, C. Maisonnier, followed with a status report on the ITER Council's exploration, as part of the Conceptual Design Activities, of ways and means needed for the possible conduct of ITER Engineering Design Activities after conclusion of conceptual design at the end of 1990. Both Kadomtsev and Maisonnier are members of the IFRC.

ITER was a major subject discussed by IFRC

In the subsequent discussion, the IFRC took note of the challenging problems of multinational collaboration on hardware of a construction project. Also noted was the important, continuing role of smaller scale experiments in generating information not only for ITER but for the total world effort to achieve fusion. In this regard, Prof. P. K. Kaw, of India, pointed out that the urgency of developing fusion as a viable option may be even greater in developing countries than among ITER Parties.

IFRC purpose and role

Since its establishment by the IAEA in 1971, the IFRC has served a dual purpose. At its periodic meetings, leaders in fusion-related research in the various countries summarize status, exhange views and reach understandings that enable more effective direction of their programmes. The second important purpose of the IFRC is to advise the Director General and his staff on current and potential activities of the IAEA in the development of fusion as a practical source of energy.

All countries that are active in fusion development are represented on the IFRC. Currently there are 14 members, including representatives of all participants in ITER activities. Australia, China and India are also represented.

The IFRC generally meets once a year. The next meeting will be in Washington in conjunction with the 13th IAEA Conference on Plasma Physics and Controlled Nuclear Fusion Research in October 1990.

EXPLORATION OF WAYS AND MEANS GOES ON

by Helen Donoghue, Secretary, ITER Council's Ways & Means Working Party

Second meeting of Ways & Means Working Party

The ITER Council's Ways and Means Working Party held the second of their three scheduled meetings in Vienna on 29 - 31 January 1990. Their first meeting, held on 9 - 11 October 1989 in Garching to allow ease of interactions with the IMC, had resulted in an Initial Report, now published by the IAEA. The Initial Report had been discussed by the ITER Council at their meeting on 30 November - 1 December 1989. As a result, the Working Party had received more specific guidelines from the Council for their work on their Final Report. The Council had accepted the main thrust of the Working Party's thinking on Engineering Design Activities (EDA) for ITER, principally the logical flow of actions, both technical and non-technical, implied by the technical needs of engineering design. The Council had asked for further exploratory work on task sharing, organization and management, EDA work site, stability/robustness of any EDA arrangements, and possible formal mechanisms. The Working Party bore in mind the Council's view, given to the Parties, that the appropriate next technical step in ITER should be engineering design, that it would be highly desirable to avoid any unnecessary hiatus in the technical work after completion of the Conceptual Design Activities (CDA) at the end of 1990, and their suggestion to the Parties that they consider entering discussions, ideally soon after the Council's April 1990 meeting, with a view toward negotiations on an instrument to allow an EDA.

Seeking mutual understanding with practical realities in mind

The Working Party's discussions, which form an element of the current CDA, proceeded within this framework. In this second round of explorations of views on possible arrangements for an EDA, Working Party members sought greater precision in the understanding of their various ideas. There was constant reference to the practical realities of any engineering design venture, namely, the list of tasks which have to be carried out. This provided a solid basis from which the sometimes differing approaches of Working Party members could be explored. It also made clear the importance of continued interaction with the IMC, scheduled during the third meeting. In terms of the Initial Report (which was confirmed by the Working Party as a sound basis from which to prepare the Final Report), several elements were modified or elaborated further, notably, the figure showing the logic of an EDA, organizational arrangements, and material on the EDA work site. However, the concentration during this meeting was on mutual understanding and exchange of views, rather than on the drafting of agreed text for the Final Report. The Working Party will meet again in Vienna on 13 - 16 March 1990 to prepare their Final Report for presentation to the ITER Council at their April meeting.

PARTICIPATION OF CZECHOSLOVAKIA

by L.Golubchikov, Ministry of Atomic Power and Industry, USSR

Involvement of Czechoslovakia through the USSR contribution to ITER

As provided in Article 9 of the ITER Terms of Reference, Czechoslovakia will be involved in the USSR's contribution to ITER. Participation of Czechoslovakia was discussed and then endorsed by the ITER Council at its recent meeting in December 1989, based on the presentation made by the USSR delegation and the IMC's favourable assessment of the proposed contribution of the Czechoslovakian experts and facilities in some particular design areas.

To prove Li-Pb eutectic blanket design option for ITER, the Soviet Union and Czechoslovakia have agreed to carry out a joint research programme on the existing experimental stand at Nuclear Research Institute in Rez, CSSR. The programme covers studies of corrosion and embrittlement of the construction materials facing liquid eutectic, specific corrosion effects due to impurities and thermochemical behaviour of the construction elements. The Soviet side is represented in this work by the Research and Development Institute of Power Engineering, Moscow.

Another area is the current drive and heating (CD&H) system of ITER. Theoretical contribution is planned in the field of interaction of alpha-particles with lower hybrid (LH) waves, used for plasma CD&H, and of the generation of the driven current by means of LH-waves. In the experimental part, Czechoslovakian experts can significantly contribute to the application of the electron cyclotron resonance technique and its assessment for ITER in a series of experiments in tokamak T-15 in view of physical and technological needs of ITER.

During many years, the USSR and Czechoslovakia have accumulated positive experience of co-operation through participation in the joint fusion research programme of the countries belonging to the Council of Mutual Economic Assistance (CMEA). This co-operation covers a rather broad spectrum of R&D including magnetic confinement in small tokamaks, joint experimental work on Soviet tokamak T-15 and Czechoslovakian participation in the Soviet national project of the experimental fusion reactor OTR.

Editor's Note

The Newsletter begins a new series of articles presenting the major home fusion research centres of the ITER Parties to give our readership an overview of the potentials involved in the joint design activities and to illustrate a broad range of contributions to the ITER-related R&D programme. Included in this issue are the first two publications provided by the Lawrence Livermore National Laboratory, USA, and by the EURATOM-CEA Association on Fusion, Centre d'Etudes Nucléaires de Cadarache, France.

LAWRENCE LIVERMORE NATIONAL LABORATORY ACTIVITIES FOR ITER

by W.M. Nevins

Established in 1952, the Lawrence Livermore National Laboratory (LLNL) is operated by the University of California for the U.S. Department of Energy (DOE). The Laboratory, with about 8,000 employees, is located at Livermore, California, in the San Francisco Bay Area. Research and development work is performed in a number of scientific and technical areas, including both magnetic fusion and inertial confinement fusion.

A major part of the magnetic fusion programme at LLNL is our participation in the international design and research and development effort for an international Thermonuclear Experimental Reactor (ITER). LLNL participates in ITER management, systems and operational analysis, magnetics, and current drive and heating. In addition, other LLNL programmes are providing information in the key area of divertor physics and developing new technologies that may be used for disruption control and fuelling.

LLNL manages U.S. ITER effort

At the outset of the formal international collaboration on ITER, DOE assigned management responsibility for ITER technical activities in the United States to LLNL. John R. Gilleland of LLNL is the U.S. Managing Director for ITER. He directs the U.S. technical activities in support of ITER and proposes design and validating R&D activities to DOE for approval. Deputy Managing Director Carl D. Henning helps to co-ordinate the approved design activities performed by various U.S. institutions, while Head Engineer James N. Dogget co-ordinates engineering work on ITER within the United States. Other members of the U.S. management team include Head Physicist Douglass E. Post of the Princeton Plasma Physics Laboratory and Charles C. Baker of Oak Ridge National Laboratory, who heads the U.S. effort in nuclear engineering.

ISCUS provides forum to broaden U.S. ITER effort

Alexander J. Glass, LLNL Associate Director for Magnetic Fusion Energy, and his deputy B. Grant Logan have organized an ITER Steering Committee - U.S. (ISCUS) of leaders in the U.S. national fusion programme (Table 1). ISCUS will provide scientific and technical advice on possible U.S. roles in the ITER design and R&D, both for the joint international activities and for the contribution of U.S. institutions. ISCUS will also consolidate the U.S. fusion community's viewpoints on major technical, organizational, and personnel issues relating to ITER and will identify ways to more fully integrate ITER requirements into the U.S. fusion programme.

TABLE 1. MEMBERS OF THE ITER STEERING COMMITTEE - U.S

Weston M. Stacey, Chairman
Georgia Institute of Technology

Harold P. Furth
Princeton Plasma Physics Laboratory

Melvin B. Gottlieb
Argonne National Laboratory

Rulon K. Linford
Los Alamos National Laboratory

B. Grant Logan
Lawrence Livermore National Laboratory

David O. Overskei
General Atomics

Ronald R. Parker
MIT Plasma Fusion Center

John Sheffield
Oak Ridge National Laboratory

Don Steiner
Rensselaer Polytechnic Institute

Systems and operational analysis

The Systems and Operational Analysis group headed by John Perkins at LLNL contributes to the technical guidange for ITER in systems and operational analysis. Collaborating with a similar group at Oak Ridge National Laboratory/Fusion Engineering Design Center, this group uses the tokamak systems code to define ITER parameters and to study possible parameter variations. They have helped to identify an optimum set of machine parameters for the ITER conceptual design and have also investigated operational scenarios. Operational scenarios and burn control are expected to become increasingly important for the remainder of the ITER Conceptual Design Activities.

An integrated magnet programme

LLNL carries out an integrated programme in magnetics, aimed at developing high-field, radiation-tolerant magnet designs. This effort includes axisymmetric MHD calculations to define the interface between the poloidal field (PF) magnet system and plasma, ITER magnet design, and research and development of critical superconducting magnet technologies.

Axisymmetric MHD

The LLNL effort in axisymmetric MHD is led by L. Donald Pearlstein. Working in close collaboration with John Wesley of General Atomics (a member of the permanent ITER team in Garching), this LLNL team has provided free-boundary MHD equilibrium calculations to support the ITER PF magnet design. They have helped to identify the optimal locations for the PF coils to meet engineering constraints in the PF coil system while minimizing the stored magnetic energy and maximizing the volt-second capability of the PF system and control over the plasma configuration. They are currently examining ITER operation with a single PF null and divertor; investigating operating scenarios, with particular attention to volt-second requirements and resistive volt-second consumption; and developing a design code for the vertical control system.

ITER magnet design

John R. Miller heads both the magnet design effort at LLNL and the ITER magnet design unit in Garching. In the LLNL effort, advanced magnet design principles and newly developed data on radiation damage to superconductors, radiation tolerance of insulators, and characterization of magnet materials are applied to new concepts for the ITER magnet systems.

High-field superconducting magnets

Much of the data for magnet component development comes from the High Field Test Facility (HFTF) at LLNL. The centerpiece of this facility is the Fusion ENgineering International eXperimental (FENIX) magnet facility, but it also includes (among other unique equipment) a 0.3-m-bore, 11-T superconducting solenoid and a 200-kN, 15-T conductor tensile tester. Valuable engineering data on high-field (15-T), force-cooled magnets at ITER-relevant operating conditions is being obtained at LLNL from the design, construction, and operation of special model coils: the Conductor-Performance-Qualification (CPQ) coil and the Proof-of-Principle (POP) coil.

The FENIX magnet facility currently being completed at LLNL will allow testing of ITER conductor alternatives at full design current and field. Developmental conductors produced by ITER participants are presently scheduled for testing. This facility will provide a test volume at a magnetic field of up to 14 T.

Current drive and heating

W.M. Nevins and Walter B. Lindquist of LLNL hold lead roles at Garching for current drive and heating (CD&H) physics and engineering, respectively. The ITER conceptual design includes an ambitious CD&H system that can provide full steady-state operation at low plasma density. In moderate-to-high-density operating modes, the CD&H system will work with the PF system to provide long-pulse operation and control over the plasma current profile.

A substantial modelling effort is required to define the physics requirements for the CD&H system and to support the engineering design. The ITER baseline CD&H scenario (including neutral-beam, lower-hybrid, and bootstrap currents) is modelled at LLNL using a code developed jointly with JAERI.

Neutral-beam system

Lindquist co-ordinates both the international and U.S. efforts in neutral-beam system design. In the U.S., neutral-beam system design is performed in collaboration with both Grumman Aerospace Company and Lawrence Berkeley Laboratory (LBL). Research and development for the 1.3-MeV negative-ion-based neutral beams required for ITER is performed at LBL.

Disruption control

Another important part of the CD&H concept is an electron-cyclotron system for start-up and disruption control. The ITER electron-cyclotron system has been designed to allow real-time adjustment of the launch angle of the electron-cyclotron waves. LLNL is currently developing disruption-control scenarios for ITER that make use of this capability.

The key technological problem for the electron-cyclotron system is developing efficient high-power microwave sources at 140 GHz. At LLNL, Frederic H. Coensgen oversees the work by Varian Associates on 140-GHz, 1-MW gyrotron tubes. To date, this programme has achieved 960-kW, short-pulse operation at 140 GHz.

The MTX experiment

Keith I. Thomassen heads the Microwave Tokamak eXperiment (MTX) at LLNL, in which an induction linear accelerator drives a free-electron laser (FEL) to demonstrate an alternative source for the ITER electron-cyclotron system. Microwave pulses with peak powers of 150 MW have been transmitted into the tokamak, while pulses with peak powers in the range of 300-400 MW have been transmitted into a dummy load. Demonstration of high-average-power operation (about 0.5 MW for more than an energy confinement time) is expected in 1991.

If successful, the FEL technology may be the best choice for disruption control in ITER because it allows real-time variation in the microwave frequency as well as in the launch angle. This additional flexibility can lead to substantial reductions in the power required for disruption control.

The FEL is an amplifier, so frequency tunability can be provided by a low-power tunable oscillator. LLNL, Varian, and Massachusetts Institute of Technology recently completed work on a low-power backward-wave oscillator capable of ± 10% tunability at about 140 GHz. The installation of this tunable oscillator on the MTX facility would help to investigate ITER-relevant disruption control scenarios.

Key physics issues

A key physics issue for disruption-control is the feasibility of localized electron-cyclotron current drive. Electron-cyclotron current drive is predicted by the theoretical models used in designing the ITER electron-cyclotron system; however, these models have yet to be verified experimentally. Electron-cyclotron current-drive experiments are being performed on the DIII-D tokamak as part of a collaboration between LLNL and General Atomics. Gary D. Porter is the contact person for this work.

Another key physics issue for ITER (and tokamak fusion reactors in general) is the behaviour of the scrape-off-layer (SOL) and the power loading on the divertor plates. This issue is also being addressed on DIII-D, where new divertor diagnostics have been installed as part of the LLNL/General Atomics collaboration. This year a new, advanced divertor will be installed on DIII-D to investigate the effects of currents and poloidal electric fields in the SOL, pumping at the divertor plates, and the relative merits of an open versus a more closed divertor geometry.

The RACE experiment

A pysics and technology issue for ITER being addressed at LLNL is central fuelling, which may be beyond the practical capabilities of "traditional" methods of fuelling tokamaks (gas puffing, pellets, and neutral beams). Theoretical calculations suggest that injection of field-reversed plasma rings may be suitable for central fuelling in tokamak reactors. In the Ring ACcelerator Experiment (RACE) at LLNL, Charles W. Hartman is developing the technology required to form and accelerate the high-field, high-density plasma rings that theoretical calculations say will be required for fuelling ITER.

Computer support

The National Magnetic Fusion Energy Computer Center (NMFECC) at LLNL provides the computer network (MFENET) that is used extensively by U.S. participants in ITER for communications both within the U.S. and between the U.S. and Garching. The NMFECC's supercomputers are used for the U.S. team's physics and engineering calculations in support of ITER, and the computational physics group headed by Arthur A. Mirin has developed codes used in modelling current drive and heating and advanced fuelling for ITER.

TORE SUPRA - FIRST LARGE SUPERCONDUCTING MAGNET TOKAMAK IN OPERATION

by R. Aymar and M. Gregoire, EURATOM-CEA Association

First laboratory formally associated with Euratom

The Controlled Fusion Research Department (Departement de Recherche sur la Fusion Contrôlée - DRFC) of the Commissariat a l'Energie Atomique (CEA) covers practically the entire French national activity in the field of Controlled Fusion by magnetic confinement, with the exception of the areas of blanket material and concept, tritium technology and reactor safety. It was the first European laboratory to sign a contract of association with Euratom in 1959. DRFC employs about 350 people, mostly engineers or physicists and technicians, including about 30 permanent employees who have the status of European Community civil servants.

Focus on tokamak programme since 1970

The Department has concentrated its efforts on the tokamak programme since 1970. The first plasma produced at the TFR tokamak on 22 March 1973 made it the largest tokamak in the world at that time. Afterwards, TFR and PETULA tokamaks enabled CEA to play a decisive role in defining objectives, mastering technologies and achieving notable results in the areas of supplementary heating methods and non-inductive current drive in tokamak plasmas. The engineers and physicists who gained experience working on both tokamaks were later able to make a major contribution to the definition, construction and operation of JET.

The decision to construct TORE SUPRA was made in 1981, and its assembly was started in 1986. The tokamaks TFR, in CEN/Fontenay-aux-Roses, and PETULA, in CEN/Grenoble, were shut down in July 1986. Integration of the staff of the two tokamaks into the DRFC team in CEA/Cadarache was completed by that time. First discharges in TORE SUPRA were produced in April 1988 and technical basic performance was reached in December 1989 i.e., 4.5 tesla achieved on magnetic axis with the superconducting toroidal magnet and a current of 1.8 MA sustained in the plasma during a few seconds.

Contributions to European programme and ITER

Although its principal activity is operating TORE SUPRA, the DRFC gives also support to JET and contributes to the European programme on fusion technology in close collaboration with the NET teams and, more recently, to thirteen ITER-related R&D tasks.

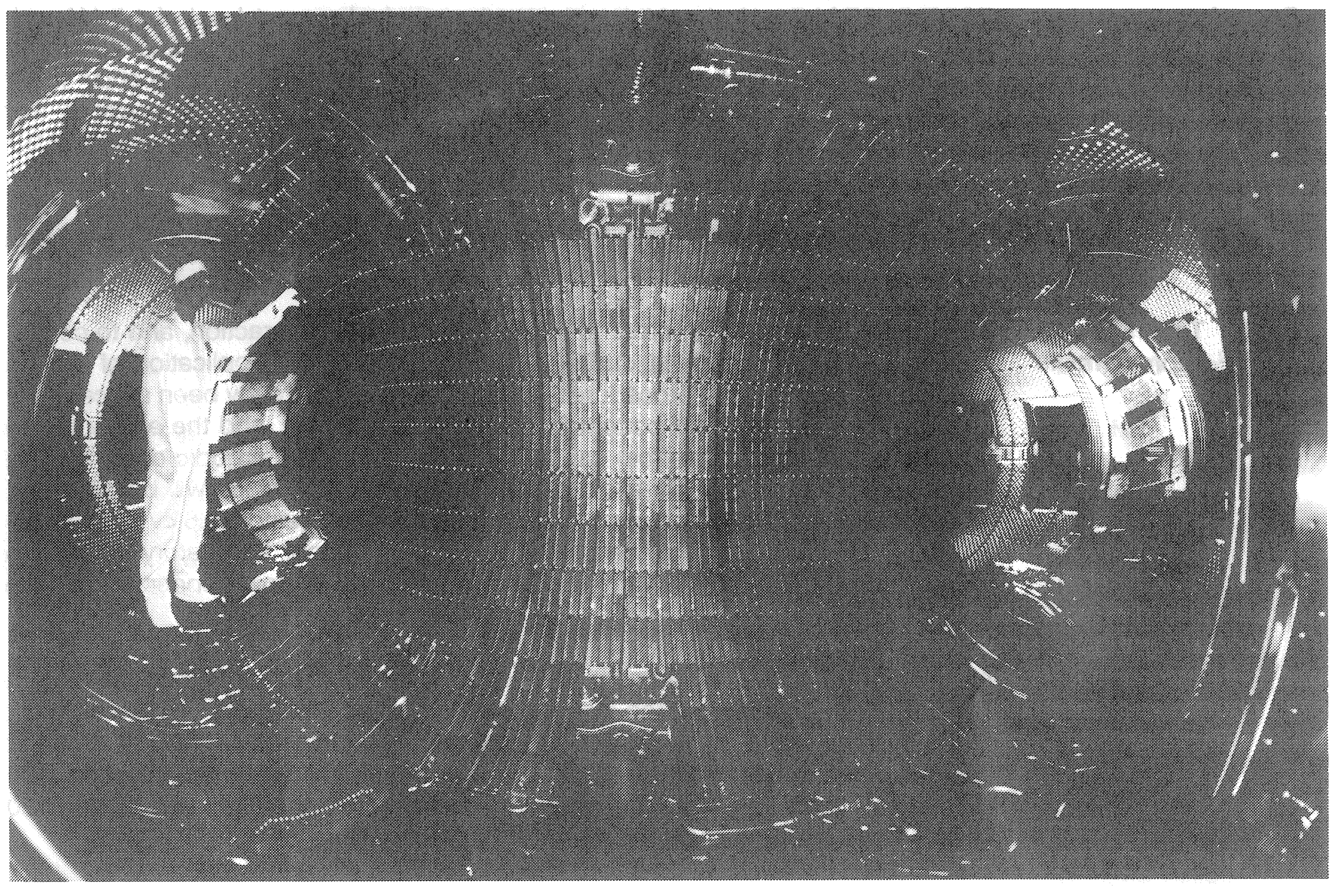


Fig. 1. Internal view of the TORE SUPRA vacuum chamber.
On the inner side(in the centre of the picture) carbon tiles
brazed on cooled stainless steel tubes act as a toroidal bumper limiter.
On the outer side (left and right) one can see two ergodic divertor coils.

TORE SUPRA

TORE SUPRA is the first large tokamak to operate with a superconducting toroidal magnet.

Research and technological missions of TORE SUPRA

The TORE SUPRA parameters are similar to those of TFTR, however, TORE SUPRA was designed to complement JET. Its superconducting magnet system provides a continuous magnetic field, which is suitable for investigating long plasma discharges. In these long discharges several lines of research are open: confinement of a dense plasma with the associated density and impurity control problems, long-duration auxiliary heating, and steady-state current drive.

The second mission assigned to Tore Supra was a technological one, namely demonstration of feasibility and reliability of a superconducting magnet in the particular environment of an operating tokamak. The technological and the research missions of the facility are quite compatible.

Superconducting magnet system

The superconducting magnet coils use niobium-titanium conductors, which are the easiest to manufacture. Magnetic fields of 9 tesla are achieved at the winding, and consequently the magnet must be cooled by superfluid helium at 1.8 K. This required the development of new cryogenic sources, in particular manufacture of a fully automated system delivering 300 W refrigeration power at 1.8 K, and the design and construction of an efficient cryostat. (The superconducting magnet is placed inside the cryostat formed by two nested tori, and the plasma is contained within the inner vessel. Thus the magnet is contained within a vacuum vessel and protected by two isothermal surfaces: a stainless steel casing at 4.5 K and radiation shield cooled at 80 K).

Operation parameters

TORE SUPRA was designed to operate at a nominal current level of 1.7 MA with pulses of more than 10 seconds every four minutes, if the plasma current is generated by an inductive method, or almost continuously at slightly lower performance if the current could be maintained by a non-inductive method. For this purpose a current drive system (16 Klystrons) providing 8 MW RF power at 3.7 GHz has been designed. A pulse of 1 MW for 100 ms has been coupled to the plasma through a "multijunction grill" system originally developed in the laboratory. This current drive experiment will be complemented by using an electron cyclotron current drive system, 2 MW - 110 GHz, now under design.

Technological improvements

A special effort is made in order to improve plasma wall interaction, and to control particle fuelling and exhaust during long discharges. The application of proven wall surface conditioning procedures (carbonization) has already been successfully tested. The magnetic field pattern in the plasma periphery, and the edge plasma conditions that result therefrom can be modified by special ergodic divertor coils. Various pumped limiters will allow particle density control which will be essential, when plasma fuelling is achieved by a multishot pellet injector (0.6<v<0.9 km/s - 10 Hz). This injector, provided by Oak Ridge National Laboratory within the framework of a USDOE-CEA collaborative agreement, is now connected to Tore Supra.

As mentioned above, equipment and technology used for additional heating in TORE SUPRA benefit from the long experience of the laboratory. However, most of the systems have been designed to operate in practically permanent mode at their full power rating: 9 MW of heating power by neutral deuterium injection (100 kV), 12 MW at the ion cyclotron resonance frequency range (between 35 and 120 MHz). They are now assembled and under technical tests.

About thirty diagnostics are now connected and maintained in working order. Data initially acquired in a buffer are then transferred continuously during the shot to the central computer memory.

From April 1988 (first shot) to April 1989 TORE SUPRA ran about 2000 shots of which 500 had a plasma current larger than 500 kA during several seconds with a toroidal field of 1.85 tesla on magnetic axis. Reduced operation at 1.85 tesla was required due to damage of one of the eighteen superconducting coils. Replacement of that coil allowed Tore Supra to reach the nominal value of magnetic field, i.e. 4.5 tesla on axis on 8 November 1989. In December 1989, shots lasting a few seconds with a plasma current of 1.8 MA were achieved.

Ready to address a broad range of ITER-related tasks

Tore Supra is now ready to carry out the experimental programme it has been designed for. The following ITER-related physics tasks will be specifically addressed:

- power and helium exhaust conditions
- viability of radiative edge
- characterization of disruptions
- control of disruptions
- use of RF in plasma formation and preheating
- use of RF in current initiation
- scaling of volt-second consumption during current ramp-up
- alpha particle losses induced by the toroidal magnetic field ripple
- steady-state operation in enhanced confinement regimes
- comparison of theoretical transport models with experimental data
- control of MHD-stability
- electron cyclotron current drive

TABLE 1. TORE SUPRA MAIN CHARACTERISTICS

Plasma major radius		$R_o = 2.37$ m
Plasma minor radius		$a = 0.80$ m
Toroidal magnetic field at $R = R_o$ (plasma centre)		4.5 T
Maximum magnetic field in conductor		9.0 T
Nb-Ti superconductor cross section		2.8 x 5.6 mm^2
Total magnetic energy		600 MJ
Plasma current (nominal)		1.7 MA
Nominal discharge duration		30 s
Repetition period		4 min
Rectified power		315 MVA
Refrigeration power	at 80 K	40 kW
	at 4.5 K	650 W + 100 litre/hour of liquid helium
	at 1.75 K	300 W

ITER EVENTS CALENDAR - 1990

Joint Work Session	Garching	22 Jan - 23 March
Meeting of Working Party on Ways and Means	Vienna	13 - 16 March
ISTAC Meeting	Garching	21 - 23 March
ITER Council Meeting	Vienna	26 - 27 Apr
Joint Work Session	Garching	2 July - 16 Nov
ITER Council Meeting	Washington	8 - 9 Oct
ISTAC Meeting	Vienna	28 - 30 Nov
ITER Council Meeting	Vienna	13 - 14 Dec

Specialists' Meetings at Garching in support of joint design work:

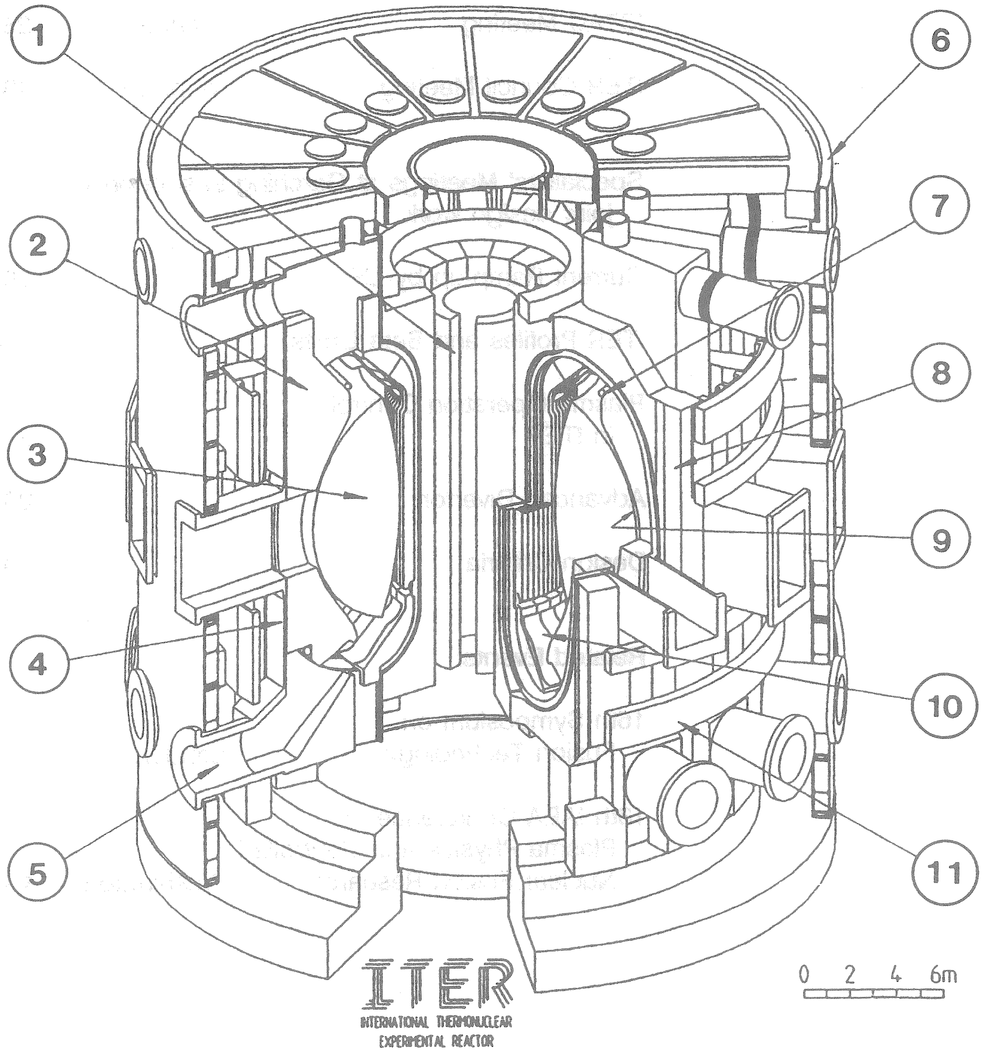
Current Ramp-up by LH	26 Feb - 2 March
ITER Profiles and Beta Limits	5 - 7 March
Plasma Operation Control in ITER	23 - 27 July
Advanced Divertor	20 - 24 Aug
Design Criteria	10 - 14 Sep

Related Events:

16th Symposium on Fusion Technology	London	3 - 7 Sep
13th IAEA Conference on Plasma Physics and Controlled Nuclear Fusion Research	Washington	1 - 6 Oct

ITER REFERENCE PARAMETERS

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



1- CENTRAL SOLENOID
2- SHIELD/BLANKET
3- PLASMA
4- VACUUM VESSEL-SHIELD
5- PLASMA EXHAUST
6- CRYOSTAT
7- ACTIVE CONTROL COILS
8- TOROIDAL FIELD COILS
9- FIRST WALL
10- DIVERTOR PLATES
11- POLOIDAL FIELD COILS

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