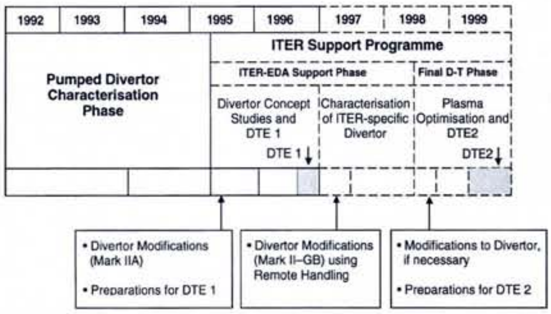
JET EXTENSION

ITER Support Phase



A European Commission proposal to introduce a three-year ITER-Engineering Design Activity (EDA) Support Phase into the JET Programme is awaiting the opinion of the European Parliament and approval by the European Union Council of Ministers.

This ITER-EDA Support Phase aims to provide further data of direct relevance to ITER's detailed design and to demonstrate key ITER technologies such as remote handling and tritium handling. In following on from the 1992-95 Pumped Divertor Characterisation Phase, it begins with the installation of an improved divertor (Mark IIA) to allow the study of ITER divertor concepts. Deuterium-Tritium Experiments (DTE 1) generating up to 2×10^{20} neutrons would then assess whether the favourable D-T confinement shown recently on the TFTR tokamak in the USA is likely to apply to ITER. More accurate scalings of the performance and heating of ITER could then be made. The experiments would also constitute the first large-scale tests of tritium processing technology with an operating tokamak.

Using remote handling, the divertor assembly would then be changed to the Mark II – Gas Box design to test a specific divertor concept for ITER using high-power deuterium plasmas. To capitalise on performance improvements, an extended series of D-T experiments (DTE 2) with an overall maximum neutron budget of 5×10^{21} would follow.

Low-density H-modes showed degraded performance, but the ITER-related ELMy H-mode discharges and nitrogen seeded radiative divertor discharges were essentially unchanged. Furthermore, in high power swept operation, a record 180 MJ of input energy was deposited on the target, causing additional melting.

Implications for ITER

The results for detached, radiative divertor plasmas are quite promising for ITER. The achieved radiated power fractions of 80-85% are sufficient to prevent target damage, overheating and erosion. Energy confinement in the main plasma would be just sufficient for ignition in ITER. Detachment is accompanied by a transition from large isolated ELMs to more benign "grassy" ELMs which should not cause target damage. There is somewhat more of a problem with main plasma purity from contamination by the seed impurity. The observed impurity concentrations would be barely acceptable in ITER with argon, and are too high with either neon or nitrogen. The scaling from the present JET experiments to ITER has, however, yet to be established. In JET, improvements are expected (see insert) with the more closed geometries of the Mark IIA divertor (start of operation in early l996) and the Mark II-Gas Box divertor (middle of 1997).

For operation with beryllium divertor target tiles, gross melting damage to the tiles was avoided by careful operation, although some superficial damage was produced by giant ELMs. Significant tile damage was inflicted during a controlled melt experiment when ITER reference heat fluxes of 25 MW/m^2 were applied and only a moderate degree of self-protection of the beryllium target was found. Following melting, the effect of a damaged beryllium target on the operating regimes relevant to ITER was found to be small. All in all, beryllium should remain one of the candidate plasma facing materials for ITER. The final choice will therefore depend largely on other considerations such as the retention of tritium in the materials.

PLASMA PHYSICS AND CONTROLLED FUSION CONFERENCE

Focussing on Tokamak Research

Most of this year's *22nd European Conference on Controlled Fusion and Plasma Physics* (Bournemouth, 3-7 July 1995) dealt with new experimental and theoretical results from magnetic confinement fusion research. Summaries of the invited papers give a "flavour" of the scope of the meeting and the significance of the latest results.

Topics at the *22nd European Conference on Controlled Fusion and Plasma Physics* covered: tokamaks; stellarators; alternative magnetic confinement schemes; magnetic confinement theory and modelling; plasma-edge physics; plasma heating; current drive and profile control; diagnostics; and basic collisionless plasma.

• ***Tokamaks***

The worldwide tokamak programme is focused on the needs of ITER, a joint effort between the European Union, Japan, Russia and the USA to design and plan to build a device providing an ignited fusion plasma for pulse lengths of typically 1000 s duration. An overview of the present status of **ITER** was given by G. Janeschitz (see page 110). A key problem is the energy and particle exhaust. One solution could possible come from a concept in which a large fraction of power is radiated from the plasma periphery, preferably from the divertor region, to large wall areas of the vacuum vessel. Under these conditions, the plasma may "detach" from the divertor target plates which then show a strongly decreased convective power fluxes.

M. Keilhacker presented for the **JET** Team the results obtained with the new pumped divertor in JET, the world's largest tokamak device, and analysed the implications for ITER (see page 105). G. Matthews gave detailed results on the divertor detachment in JET with deuterium gas puffing. At the very high levels needed for detachment, the confinement usually degraded from ELMy H-mode to L-mode. With neon and nitrogen injection, the appearance of ELMs changed. This was associated with a decrease of confinement. With neon, 50% of the radiation occurred from the bulk plasma, whereas nitrogen showed a factor of 2-3 more radiation from the divertor. T.T.C Jones reported on scenarios for high performance at JET. The most promising one is the hot ion H-mode requiring low hydrogen recycling to obtain peaked density profiles together with central beam deposition. High edge shear and triangularity are important for long, ELM-free periods.

• ***Divertor physics***

S.L. Allen discussed recent results from divertor investigations at San Diego's **DIII-D** (the largest divertor tokamak in the USA), notably gas-puffing experiments with deuterium and neon. With deuterium, a stable radiating zone in the divertor was found, resulting in a partially detached divertor plasma. For neon, radiation occurs from inside the confined plasma which suffered from enhanced values of effective ionic charge; the divertor heat flux was reduced by factors of 3-5. Active particle control by a cryopump installed in the divertor region has demonstrated density control, efficient helium exhaust, and reduction of the particle inventory in the wall.

J. Neuhauser described studies on the compatibility of enhanced energy confinement and complete divertor detachment. Using feedback control of injected neon and deuterium, the **ASDEX**-Upgrade team succeeded in establishing a stable radiative plasma boundary, reducing the divertor heat flux to very low values, with frequent small ELMs, and H-mode factors around 1.7 (CDH-mode: completely detached H-mode).

The latest results from the large **JT60-U** tokamak in Japan were presented by M. Itami. With deuterium and neon injection, 5 MW of a total of 25 MW injected power were radiated at a toroidal field of 2 T maintaining ELMy H-mode confinement, whereas a loss of confinement was observed at higher toroidal fields. Other parts of the presentation related to studies of high confinement modes.

A general problem for detached divertor regimes is the shrinkage of operation space. At the high densities needed, the plasmas tend to fall out of the high confinement regimes. Seeding by impurities is often associated with increased impurity influx causing a deterioration of the core plasma. Future work on the divertor tokamaks will address the effects of divertor geometry for the optimization of energy and particle exhaust. Plans for modifications of the present geometries were presented for all devices.

• ***Confinement, heating and control***

M. Tokar presented experiments from TEXTOR and detailed modelling efforts on

The 22nd European Conference on Controlled Fusion and Plasma Physics was hosted by the JET Joint Undertaking and was held at the Bournemouth International Centre on 3-7 July 1995. The excellent facilities helped to make the meeting not only a scientific success but also very pleasant to attend in spite of the crowded schedule. The framework of the presentations was set by 9 invited "review" lectures and 171 invited "topical" lectures. From about 600 submitted abstracts, 492 were selected by the International Programme Committee for presentation, with a total 24 of the contributed papers given as "oral" contributions.

As the major fusion plasma physics conference in 1995, the meeting attracted 575 participants from 30 countries. Thanks to sponsorship it was possible to provide several scientists from countries of the former Soviet Union with travel grants.

There was for the first time in the series of *European Conferences on Controlled Fusion and Plasma Physics* a special sponsored lecture (The Institute of Physics Lecture) entitled "Recent D-T Results on TFTR" by D. Johnson. It is anticipated that such sponsored lectures will continue at future conferences. The participants were most impressed by the excellent preparation and organization provided by the Local Organising Committee under its Chairman, P.E. Stott from JET. The abstracts of invited and contributed papers are published in the *Europhys. Conf. Abst.* (orders to the EPS Secretariat, Geneva) and the invited presentations in *J. Controlled Fusion & Plasma Physics.*

the **influence of impurities** on tokamak plasmas. The presentation addressed in particular the improvement of confinement with increasing edge radiation as observed in the limiter tokamak TEXTOR. Progress has been made in coupling the E-B2-EIRENE code package with the one-dimensional code RITM, which describes the mutual effects of particle and energy transport and impurity radiation in the plasma interior.

The problem of **particle removal** in plasmas with highly radiative edges was discussed by T. Loarer, with the example of Tore Supra. Special emphasis was placed on very long plasma pulses. Encouraging initial results have been obtained using a "vented limiter", a structure with a perforated surface. Deuterons which have undergone charge-exchange processes are scattered into the holes and pumped away. The vented limiter has the advantage of minimising leading edges. The performance for pumping helium has still to be investigated systematically.

Another problem critical to tokamaks are **disruptions** (rapid loss of plasma current). These become more important as plasma current and elongation increase in large devices. Severe forces are exerted on the vessel and wall components are exposed to very high thermal loads. The present status of the characterisation and understanding of the underlying mechanisms of disruptions were reviewed by C. Schüller who highlighted a series of possible control measures.

Studies at the ASDEX-Upgrade of disruptions and MHD stability were presented by H. Zohm. Special emphasis was placed on disruption precursors (phenomena occurring before the disruptive event), in particular, overlapping islands (regions inside the confined plasma with stochastic field lines). The MHD signatures of ELMs in H-mode plasmas and the limiting events in high-field operation were discussed.

Studies on ohmic H-mode plasmas from the TCV tokamak which went into operation recently in Lausanne were reported by J. Moret. The large flexibility of the plasma shapes in TCV makes this device particularly suited to investigating the influence of the **magnetic configuration** on, for example, stability and ELMs in H-mode plasmas.

A highlight was the report on **D-T operation at TFTR**, the US tokamak, presented by D. Johnson. Owing to the importance of the results and their uniqueness, his talk was selected for The Institute of Physics Lecture. A fusion power of 10.7 MW has been achieved in TFTR with a neutral-beam heating power of 39.5 MW. This performance was aided by the effects of wall conditioning by helium pellet injection and by a favourable isotope scaling of the ion heat conductivity. Detailed work was carried out on transport analysis. Probe measurements of α-particle losses did not show evidence for α-particle driven TAE modes (TAE: toroidicity Alfven eigenmode) or other collective α-particle driven instabilities.

F. Romanelli addressed recent attempts to model **TAE modes** in the context of a ballooning formalism and presented applications for ITER-like equilibria. Mode saturation by MHD non-linearity, and by the effects of the energetic particles' non-linearity, was discussed.

The interaction of **ICRF waves** with fast particles in TEXTOR was discussed by R. Koch. A strong coupling of the ICRF to fast ions in the third harmonic leads to a large neutron production. Fast $^3He^+$ ions from NBI (neutral beam injection) were heated by the second harmonic and a variation of the number of helium ions (measured by change-exchange spectroscopy) by a factor of two was found when the resonance zone was moved from the low- to high-field side, in agreement with several detailed Fokker-Planck calculations.

Results obtained for current drive by electron cyclotron resonance (**ECCD**) in Russia's T-10 tokamak were discussed by Yu.V. Esipchuk. Suprathermal electrons were observed in accordance with Fokker-Planck calculations and experiments showed plasma heating during ECCD with the same effectiveness as other methods.

The European programme on the development of **neutral-beam injection** by negative ions (one of the main candidates for heating and driving current in future large tokamaks) was summarised by J. Pamela. The status and understanding of fundamental processes, the ion source, the accelerator stage and the neutraliser were presented and the main issues for future work outlined.

Transport in fusion devices was addressed in presentations by C. Hidalgo, who focussed on edge turbulence and anomalous transport, and by J. Connor, who compared theoretical models of transport and experimental results in tokamaks. Although the driving mechanisms for edge turbulence have not yet been identified, evidence exists for the importance of curvature-driven instabilities, at least in the plasma edge.

High-power heating at W7-AS, the stellarator at Garching, were discussed by R. Jaenicke. Some 1.5 MW NBI in addition to 800 kW ECRH were applied systematically, and 3 MW NBI from an upgraded beam-injection system were tested for short pulses. Maximum electron temperatures of 3.5 keV were reached; the maximum density was $2.5 \times 10^{20} m^{-3}$. The heat transport was essentially neoclassical.

J. Wesson reviewed **"snakes"**, an interesting resonant structure occurring, for example, in JET when pellets are injected. He was applauded for a very pedagogical presentation on the basic questions of how the snakes are formed, how density concentrations persist, and why these structures do not arise spontaneously.

• ***Stellarators and alternative schemes***

The quasi-helical symmetry in **stellarators** was discussed by A.H. Boozer. This is a confinement concept having the good α-particle confinement of the axisymmetric tokamak without the disadvantages of major disruptions, current drive and interlocking coils. Quasi-helical symmetry is only possible on one magnetic surface, but the symmetry breaking does not lead to significant confinement losses. A small quasi-helical stellarator will be built in Wisconsin, USA.

The alternative confinement scheme of **reversed field pinches** (RFP) was addressed in S. Prager's joint paper by the MST (Stockholm) and T1 (Wisconsin, USA) groups. It covered recent results on mode coupling, the Dynamo Effect, and on plasma rotation and mode locking.

• ***Diagnostics***

B. Schweer presented for E. Hintz a review of **plasma-edge diagnostics** by atomic beam supported emission spectroscopy. He summarised recent advances in diagnostics and the potential and limitations of the various techniques. In contrast to other methods which integrate measurements over the line-of-sight, their key advantage is space resolution. A critical parameter is the penetration length of the injected atoms which serve as probes for the local plasma.

Back scattering of fast **radar pulses** from the plasma in the vicinity of the upper hybrid resonance is an interesting new diagnostic development with spatial resolution, facilitated by the progress in high-speed microwave electronics. E. Gusakov discussed the method and outlined applications for the diagnostics of fluctuations.

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CLIO - CALL FOR PROPOSALS

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