Nuclear Fusion Project
Association EURATOM / Forschungszentrum Jülich

ANNUAL PROGRESS REPORT 2002

including the contributions of
the TEC Partners
ERM/KMS Brussels and FOM Nieuwegein

and the IEA Partners

Forschungszentrum Jülich GmbH
Final Version – October 2003
# CONTENTS

A. Introduction .................................................................................................................................. 4

A.1. Nuclear Fusion and Plasma Research .................................................................................. 5
A.2. Operation and further development of TEXTOR ................................................................. 6

B. General Programme on TEXTOR ......................................................................................... 7

B.1. Main Topic I – Plasma Wall Interaction ............................................................................. 7
B.2. Main Topic II – Confinement ............................................................................................... 11
B.3. Main Topic III – Impurity Transport and Radiation ............................................................ 17
B.4. Main Topic IV – Magnetohydrodynamics ......................................................................... 19
B.5. Main Topic V – Advanced Tokamak Scenarios .................................................................. 22
B.6. Main Topic VI – Dynamic Ergodic Divertor (DED) and new Diagnostics ......................... 25
B.7. Main Topic VII – Theory and Modelling ............................................................................. 27
B.8. Operation and further development of TEXTOR ............................................................... 30
  Installation of the Dynamic Ergodic Divertor (DED) .............................................................. 30
  Plasma Heating ....................................................................................................................... 34
  Data Acquisition and Processing ............................................................................................. 35
B.9. Plasma Diagnostics ............................................................................................................. 36
B.10. Contributions to ITER ....................................................................................................... 43
B.11. Contributions to Wendelstein 7-X .................................................................................... 47
B.12. Characterization of Materials and Components for Plasma/Wall Interaction .............. 49

C. Technology Programme .......................................................................................................... 51

C.1. Characterization of Materials and Components for Plasma/Wall Interaction .................. 51
C.2. Corrosion Resistance of Fusion relevant C-based Material ................................................ 54
C.3. Mechanical Properties of Fusion Materials ........................................................................ 59

D. Partners of the IEA TEXTOR Implementing Agreement ...................................................... 67

D.1. Canada ............................................................................................................................... 67
D.2. Japan .................................................................................................................................... 68
D.3. United States of America ................................................................................................... 74

E. Scientific Publications .............................................................................................................. 77
A. INTRODUCTION

The Institute for Plasma Physics takes part in international fusion research with the long-term aim of imitating on earth the sun's method of producing energy and thus harnessing a practically inexhaustible energy source with favourable safety and environmental features for mankind. The progress achieved in recent years at fusion devices provides a solid data base today for extrapolation to a fusion machine with tenfold power gain. This decisive step is to be made by implementing the ITER experiment planned in international cooperation, which will furnish a fusion power of 500 MW for a burning time of approx. 8 minutes per plasma pulse and will be the last intermediate stage prior to the construction of a continuously operating demonstration power plant (DEMO).

The Institute's research programme is oriented to the strategy of the European research programme (EURATOM), which pursues four parallel lines: a) the implementation of ITER in global cooperation, b) an ITER-accompanying research programme at smaller devices, c) the development of the necessary fusion technologies for DEMO and d) further research into alternative confinement concepts.

For the research programme accompanying ITER the TEXTOR tokamak is available in Jülich. In 1996, the EURATOM-associated fusion laboratories in the three-frontier region, Institute of Plasma Physics of Research Centre Jülich, Instituut voor Plasmaphysika Rijnhuizen of FOM and Laboratoire de Physique des Plasmas of ERM/KMS Brussels have joined forces forming the Trilateral Euregio Cluster (TEC) with the aim of carrying out a joint research programme at the large central TEXTOR device. TEC allows resources to be combined (e.g. the radiofrequency heating schemes are provided and operated by the TEC partners), favourably combines different expertises complementing each other and provides a centre of attraction for the universities in the region. The Institute additionally cooperates in the use of TEXTOR with Japan, the USA and Canada under an IEA Implementing Agreement.

Apart from TEXTOR, experimental facilities outside Jülich are also used to an increasing extent. This includes above all the JET tokamak used under the European Fusion Development Agreement (EFDA). At the national level, the Max Planck Institute of Plasma Physics, Garching, Research Centre Karlsruhe and Research Centre Jülich have joined as Helmholtz centres in the Nuclear Fusion Development Association to coordinate their work. Within Research Centre Jülich all fusion-relevant activities at the institutes are coordinated by the Nuclear Fusion Project.

In order to proceed from ITER to DEMO, the continuous operation of a fusion reactor must be implemented. To this end, it is above all necessary to achieve a sufficient lifetime of the wall components under strong load. The TEXTOR tokamak experiment will contribute in the years to come with the Dynamic Ergodic Divertor (DED) pioneering experiment towards exploring the fundamental possibilities of reducing wall exposure with the aid of external perturbation fields. Moreover, the basic concept of TEXTOR with in part unique provisions for experiments allows detailed research into fundamental processes, so that more reliable models for predicting the lifetime of wall components can be made e.g. by a better understanding of the plasma-wall interaction. In this field, close cooperation also takes place with the material-oriented investigations performed at IWV-2.

For the planning and construction of ITER, the European associations will have to furnish their contributions in accordance with existing expertise. The Institute of Plasma Physics aims at tackling problems from the fields of plasma diagnostics and plasma heating.

Due to its inherently steady-state plasma operation, the stellarator is considered to be the most promising alternative to the tokamak. With the Wendelstein 7-X stellarator in Greifswald to become operational in about 2010 Germany will have a worldwide leading experiment in this field. The Institute of Plasma Physics will contribute to the construction and scientific use of the new stellarator by solving electrotechnical problems and developing and providing diagnostics.
A. INTRODUCTION

A.1. NUCLEAR FUSION AND PLASMA RESEARCH

Tasks and Objectives

Participation in the development of magnetic confinement concepts to develop nuclear fusion as a new primary energy source. The central facility is the tokamak TEXTOR (FE-E06), which is operated together with the partners from TEC (Trilateral Euregio Cluster). Moreover, participation in the scientific exploitation of the European experiment JET in Culham, construction and use of the stellarator Wendelstein 7-X in Greifswald and contributions to the development of the next generation tokamak (ITER). The work concentrates on key issues being crucial for the control of a stationary fusion plasma.

Main Achievements

During the shut-down phase of TEXTOR last year experiments have been performed on JET and data from TEXTOR have been further analysed.

In the field of plasma-wall interaction significant progress in understanding hydrogen recycling at various surface materials (e.g. C, W) has been achieved by employing sophisticated spectroscopic methods. Emphasis is put on the question of erosion and deposition of wall materials, in particular for graphite, the migration of which has been studied in detail.

The investigation of energy confinement in radiation cooled plasmas showed that impurities can influence certain instabilities. Impurities can also have a beneficial effect on intermittent transient heat loads at the plasma boundary (ELMs), while strong local particle sources (gas puff) can generate local turbulence having detrimental effect on the global energy confinement.

In the field of magneto-hydrodynamic (MHD) stability it has been shown how impurity accumulation in the plasma centre can suppress the sawtooth instability and that fast puffing of noble gases (He, Ne, Ar) can mitigate the negative effects of plasma disruptions. In conjunction with ELMs new MHD modes have been identified, constituting an additional energy and particle loss mechanism.

The exploration of so-called advanced tokamak scenarios identified the existence of transport barriers in various phases of the plasma discharge with the help of well localised plasma heating (ECRH).

Preparatory work for the exploitation of the new Dynamic Ergodic Divertor (DED) in TEXTOR concentrated on the calculation of the expected magnetic field structures.

The development of diagnostics on TEXTOR is focussing also on the needs for the new experiments Wendelstein 7-X and ITER.

The development of numerical models for various plasma regions (wall, edge, core, impurities) is an important element in the theoretical work.

The materials research for ITER and Wendelstein 7-X explores the thermo-mechanical properties of highly loaded components and graded systems.
A.2. OPERATION AND FURTHER DEVELOPMENT OF TEXTOR (SUMMARY)

Tasks and objectives

TEXTOR is a medium size tokamak, which for the study of fundamental processes in fusion plasmas is equipped with a highly flexible instrumentation. In the years 2001/2002 TEXTOR has undergone a major upgrade. Operation has been suspended for the installation of the dynamic ergodic divertor (DED). The DED is a unique new experiment for the improvement of the heat load distribution reaching the plasma facing wall components, the optimization of impurity screening and radiation cooling and the control of confinement and stability by rotating magnetic fields. The main objective of 2002 was the completion of the DED. The reconstruction activities were accompanied by upgrades and new developments of plasma diagnostics and the enhancement of the plasma heating capability.

Main achievements

The DED achieves the ergodisation of the edge magnetic field, i.e. the breaking of the closed magnetic flux surfaces, by a set of helical magnetic field coils accommodated at the inboard side of the toroidal plasma chamber. The unique new feature is the dynamic component: The coil currents can be modulated, resulting in a rotation of the magnetic field structure. The magnetic field strengths, generated by the DED, correspond to coil current amplitudes of up to 15kA in a frequency range from DC up to 10 kHz. Therefore, coils for high voltage, high current density and (in terms of electrical engineering) medium frequency have been designed. To ensure efficient current penetration into the electrical conductor, the coils consist of intertwined copper wires. For a similar reason, the coils have been placed inside the plasma chamber, as otherwise the oscillating magnetic field would not penetrate sufficiently through the conducting wall. The cooling requirements of the coils are determined by the TEXTOR discharge repetition rates and the discharge lengths of up to 10 s. In order to dissipate the heat from the coil to chillers, a mixture of water and gaseous helium cooling has been devised. The coils are mounted onto the vacuum vessel by a special support structure and protected by ceramic shields and graphite tiles, which have been designed for low eddy current losses and optimum distribution of the plasma heat. For the electrical connection of the coils to the power supplies, but also for the supply of cooling water and helium, vacuum feed throughs have been developed, meeting the demands for minimum inductance, stray fields and heating by eddy currents. Besides these explicitly mentioned activities, the DED installation also implicated major modifications to the liner, preparation of the power supply and control systems, installation of chillers and major rearrangements of diagnostics. Meanwhile the installation of the DED coils inside the vacuum vessel, including graphite tile cover, has been completed. The coils and their support structure have successfully passed electrical and mechanical tests. After completion of other in-vessel components, e.g. diagnostics, pump-down and leak testing of the vacuum vessel is under way. Still outstanding is the commissioning of TEXTOR as a whole, including various plasma diagnostics. First plasma operation is envisaged for early February 2003.

Parallel to the DED installation the electron cyclotron resonance heating (ECRH) system has been upgraded. A new gyrotron, resonantly heating the plasma electrons by micro-wave radiation at 140 GHz, has been installed. In first acceptance tests at the manufacturer 850 kW have been achieved for 3 s and more than 1 MW for 100 ms. After delivery and first commissioning already 670 kW could be sustained for 10 s. Now, for the first time, TEXTOR is equipped with an ECRH system which approaches the power levels of the other heating methods.
Plasma Wall Interaction affects the energy release and fuel dilution in the plasma core by impurities released from the walls, the lifetime of wall components by erosion and the long term retention of the fuel gas in the walls. This year, the activities were concentrated to evaluate erosion and deposition from post mortem tile analysis, on further analysis of hydrogen recycling and retention and on diagnostic development. Involvement on JET (UK) within the Task Force E (exhaust and edge physics) has been continued.

Hydrogen recycling properties

A way of studying the properties of released fuel components is the determination of their velocity distribution and atomic and molecular composition. This has been done in TEXTOR on different limiter materials and during H-D isotope experiments, and in JET by Balmer spectroscopy and analysis of the line widths.

In previous experiments it was shown that for carbon materials the ratio of atomic to molecular emission increases from temperatures of 1300 K on. This has been done with tungsten and tantalum limiters showing that Ta has a similar behaviour whereas the molecular release from W is obviously much smaller (see fig. 1).

![Graph](image)

*Fig. 1: Atoms and molecules as a function of surface temperature for tungsten and tantalum*

At JET the experiences gained on TEXTOR were applied for the investigation of carbon (fig. 2) and Balmer line emissions. The pattern can serve for a non-ambiguous identification of the location of the emission. A fit of D$_β$ with three velocity components again reveals the existence of a cold component with a temperature of much less than 1 eV.

Isotope exchange experiments are helpful to identify the local and global fuel recycling in more detail. Fulcher-band spectroscopy can support these measurements by measuring the variation of
the molecular composition of the hydrogen isotopomers in front of PFCs. This could be shown in TEXTOR (fig. 3) and will also be extended to tritium containing compounds in JET.

![Intensity vs. wavelength](image1)

\[ |B| = 0.88 \text{ T} \]

![Intensity vs. wavelength](image2)

\[ |B| = 2.40 \text{ T} \]

**Fig. 2**: Line shapes of a CII line for different magnetic field strength at JET

**Fig. 3**: Molecular plasma mixture during isotope exchange experiments

**Atomic and molecular data**

For the interpretation of the measured spectral line intensities in terms of fluxes and densities the conversion factor \( S/XB \) (ionisations per photon) has to be known. Various tools exist for the determination of these values – codes like GKU, R-matrix, databases (ADAS) etc. TEXTOR offers also the possibility of comparing these theoretical data with experimentally found results. \( S/XB \) values for Si II (fig. 4) have been obtained by SiD\(_4\) puffing and are in good agreement with the calculations.

The corresponding D/XB values for the methane family have also been completed and are now ready for the implementation into erosion-deposition codes for the modelling of the break-up of hydrocarbons in front of PFCs in fusion plasmas.
Erosion and deposition

In TEXTOR the vast majority of carbon is re-distributed inside the torus. Laser profilometry before and after exposure (7625 s) and SIMS depth profiling show that the major carbon source (22 g/h) is the graphite belt limiter and a significant part (10 g/h) of the carbon is directly redeposited on the tiles. It accumulates to thick deposits (flakes) in zones which are less affected by the deuterium ion flux because of the grazing incident field lines.

The remaining carbon is transported to obstacles in the SOL (poloidal limiters, antennae protection limiters, the rear of the belt limiter structures, 6 g/h). The liner and the graphite bumper limiter on the high field side do not contribute much to the carbon interchange. Another part (6 g/h) is deposited on the neutraliser plates in form of thick deposits (1 g/h). The rest leaves the system in form of stable volatile hydrocarbons and carbon oxides (mainly CO). This is estimated to account for 2 g/h.

Colorimetry of the thin films and EPMA show that only a negligible amount of carbon (0.02 g/h) is deposited in the pump ducts. These films are soft and contain deuterium with ratios up to D/C = 0.7, which is 10-100 times more than found in the deposits inside the machine and contributes significantly to the fuel retention.

The short range transport of tungsten and silicon along the surface of roof like limiters into shadowed areas has been investigated and modelled with the ERO-TEXTOR transport code (fig. 5). The figure shows areal densities (circles and crosses) with increasing distance from the source in comparison with the calculated values (dots).

**Fig. 4:** Theoretical S/XB values obtained by the code GKU from the P.N.Lebedev institute, Moscow

**Fig. 5:** Areal W- and Si-densities as a function of distance from the source
In JET a new in situ diagnostic has been taken into operation (the Quartz Microbalance, QMB) to measure the material deposition shot by shot at the entrance of the inner divertor pump duct. Figure 6 shows the measured integral deposition rate over a period of about 85 shots. The mean deposition rate is much smaller (about a factor of 100) than estimated from the previous JET campaign with the MkIIA divertor configuration. This is attributed to the different divertor strike point geometries. Large deposition is only observed for shots with the strike point in the vicinity of the louver entrance and preferentially on the horizontal target tile for which the louver entrance is in the SOL. This was normally the case for the tritium campaign in JET while the strike point at present is mostly on the vertical tile with the louver entrance in the private flux region. This leads to less deposition.

![Graph showing carbon deposition on the QMB vs total ion flux.](image)

*Fig. 6: Carbon deposition on the QMB in the inner divertor of JET versus the total ion flux*

**Modelling**

In the ERO-TEXTOR code new atomic data for the break up of methane have been implemented. This leads to significantly larger D/XB-values for test limiter conditions at electron temperatures above ~ 20 eV, in the extreme being elevated by a factor of ~ 60 in case of \( T_e = 100 \) eV and \( n_e = 1 \times 10^{12} \) cm\(^{-3}\). The computed fraction of local carbon re-deposition decreases accordingly. These effects are due to the significantly smaller total rate coefficients for electron re-actions at higher electron temperatures.

The observed carbon deposition at the inner louvers of JET MkIIA can be only reproduced by the ERO-JET code under the assumption of very high chemical erosion yields (5% for CD\(_4\) and 7% for C\(_2\)D\(_4\)). However, the resulting carbon erosion yield of 19% together with the estimated background carbon flux of 5% would result into a net-erosion of the inner divertor which is in contradiction to the observed net-deposition behaviour. A possible explanation for this behaviour would be that such large erosion yields account only for the carbon material which is deposited on the tiles.

The modelled CIII emission in the MkGB divertors of JET has been compared with measurements from tomographic reconstructions. Based on the background plasma parameters taken from B2-Eirene the agreement is poor, in particular in the outer divertor. The assumed temperature there has to be increased significantly (about a factor of 5) to obtain a satisfactory agreement between measured and simulated CIII emission. The calculated ratios of CD- and CIII-emission with and without external CD\(_4\) puffing in the divertor region shows a satisfactory agreement with experimental values if chemical erosion yields of about 10% for the inner and 3% for the outer divertor are assumed, being in reasonable agreement with other conclusions.
Plasmas with a radiating plasma mantle to allow for acceptable power exhaust have been a main subject of investigation. The experiments reported on have been conducted both on the tokamak TEXTOR in Jülich and on JET in Abingdon, UK. To understand the impact of the radiating impurities on transport in the plasma core and the global confinement properties, also transport processes at the plasma edge are of major importance, their investigation in various plasma regimes is the further main topic described in this report.

Experiments and modelling on radiating plasmas at JET under EFDA

The experiments at JET, the world largest tokamak device, have been jointly conducted under the European Fusion Development Agreement (EFDA) by the various EURATOM-Associations. The Trilateral Euregio Cluster (TEC) is participating in these activities. One of the main subjects is the exploration of plasma regimes, where the power is exhausted from the plasma in form of radiation onto large wall areas by radiation of impurities. Thereby, excessive heat loads on plasma facing components can be reduced at locations where the magnetic field directs charged particles on relatively small areas.

Two aspects have been especially investigated during last years campaign: the reduction of both steady-state and transient power loads by the impurities and the impact of the seeded impurities on turbulence driven transport in the confined plasma. For the latter the comparison to results obtained on the medium sized TEXTOR device is of special importance.

The plasma regime chosen for the impurity seeding experiments has been the so-called High confinement mode (H-mode) where a transport barrier at the edge is formed and energy and particles are released in periodic, burst-like events (so called edge localised modes, ELMs). The ELMy H-mode is the reference scenario presently foreseen for the next step fusion experiment ITER.

The seeding of argon into such kind of plasma discharges allows to establish high energy confinement at high plasma densities (close to the operational density limit of tokamak discharges, the so called Greenwald density) in combination with a radiating plasma mantle as illustrated in Fig. 1. This figure shows the radiated power density distribution along the major plasma radius in JET for two different plasma shapes, small and large triangularity $\delta$ (a measure how triangular the poloidal cross section of the plasma is). Up to 70% of the total heating power could be dissipated to large wall areas. Correspondingly the electron temperature in front of the divertor target is reduced with respect to the un-seeded reference and some degree of detachment from the target plates is observed.
Furthermore, the impact of impurities on the transient power loads associated with ELMs have been investigated. High energy confinement in H-modes is generally linked to the occurrence of large ELMs (so called type-I ELMs). With argon the ELM frequency is reduced in line with the reduction of power flow into the plasma edge. At the same time the relative energy loss per ELM is reduced. This fact is attributed to the increase of the collisionality in presence of the impurities or the parallel transit time in the region of open field lines where the energy is transported along the magnetic field to the divertor target plates. This correlation is generally observed in type-I ELMy H-modes. The reduced power flow is observed from thermographic measurements of the surface temperature of the divertor target as shown in Fig. 2. Note that both during the ELM and in between the ELMs the temperature is reduced (a consequence of the reduced steady power flow). The latter feature allows for larger temperature excursions before the ablation limit of the target material (carbon) is reached.

**Fig. 1:** Profiles of the radiated power density obtained with argon seeding in high (#53146) and low (#50473) triangularity plasmas

**Fig. 2:** IR temperature profile as a function of the distance along the inner and outer divertor target during (red) and in between (blue) ELMs for an un-seeded (left) and argon seeded (right) medium triangularity discharge
Transport calculations based on the TRANSP code show reduced energy transport in the core in the presence of radiating impurities. Further analysis of the growth rate of micro-instabilities reveals a reduction of the so-called ion temperature gradient (ITG) driven mode as a possible reason of the transport reduction.

Nevertheless, a clear bifurcation to an improved confinement state as observed on TEXTOR, which is termed the Radiative Improved Mode (RI-mode) and typically linked to a strong peaking of the density profiles, could not be observed in H-mode discharges at JET. This fact can be understood within a transport model which was successfully applied before to discharges with a radiating plasma mantle in TEXTOR. The lower collisionality in JET leads to a reduced particle pinch owing to the so-called dissipative electron mode, which is responsible for the density peaking observed as soon as the ITG mode is reduced. The characteristic density peaking facilitates a further reduction of the ITG mode and the bifurcation-like character of the confinement transition observed in TEXTOR. The transport model, however, prescribes a possible transition in JET at much higher impurity concentration, facilitated by a peaking of the plasma pressure and an associated turbulence reduction via sheared ExB flow. Such a behaviour has been experimentally observed at JET in L-mode discharges (discharges without edge transport barrier) with neon seeding.

Experiments and modelling on radiating plasmas at TEXTOR

In order to achieve high plasma density necessary in a future fusion reactor, puffing of neutral working gas is ordinarily applied in fusion devices. However, a too intensive gas puff leads normally to a confinement degradation. Therefore, the experiments at TEXTOR conducted before the shut down to install the Dynamic Ergodic Divertor started were mainly concentrated on the effect of external gas injection on the global confinement properties of discharges with a radiating plasma mantle at high density.

Further analysis of these experiments has shown, that under conditions of strong gas fuelling a significant local perturbation of the edge plasma takes place and the formation of a cold and dense plasma cloud can be observed facilitated by the localised fuelling and the subsequent localised recycling of the injected particles. At the same time an increase of density fluctuations at the plasma boundary is observed. The degradation of the global energy confinement time is closely correlated with the strength of the local perturbation at the plasma edge. Based on the edge properties determined experimentally we can estimate a substantial increase of edge turbulence owing to drift resistive ballooning modes. Self-consistent modelling shows that such an increase of edge transport significantly influences the dynamics of the seeded impurities which govern the core transport caused by the ITG mode. Both the reduction of the impurity content and the change of the plasma background profiles associated with strong gas fuelling are confirmed by experimental observations.

The analysis of the isotope effect in discharges with a radiating plasma mantle has been extended. The RI-mode energy confinement time scaling law possesses a dependence in atomic mass approximately equal to $A_i^{0.5}$ which is also the usual isotopic dependence in L- and H-modes. The correlations of the energy confinement time with the density peaking and the recycling flux at the main limiter in hydrogen plasmas are similar to those observed in deuterium plasmas. However, in hydrogen plasmas it appears to be more difficult to reach densities close to the empirical Greenwald density limit without degradation of the confinement.

A detailed study of this effect has been undertaken by first seeding neon impurity in a medium density plasma to produce a radiating mantle followed by a D or H gas puff to rise the density.
Different negative effects associated to hydrogen fuelling were observed: (i) a degradation of the confinement time is observed as compared to the case of deuterium injection even if the plasma isotopic composition stays nearly unchanged; (ii) the peaking of the plasma density generated by neon fuelling is counteracted by the injection of hydrogen. A similar negative effect of fuelling can occur in deuterium injection as described before albeit at a much higher fuelling rate and correspondingly at high plasma densities. Fig. 3 illustrates these finding comparing two discharges where either hydrogen or deuterium were injected into identical target plasmas with a radiating plasma edge. Note, that the confinement reduction with hydrogen injection cannot be explained with a change of the effective mass of the plasma ions as mentioned before but indeed a confinement roll-over is observed (the change of $A_i$ owing to the H puff is small).

Fig. 3: Evolution of the energy confinement time as a function of the line averaged central electron density normalised to the Greenwald density showing the difference between H and D puff into identical target plasmas with neon seeding.

The investigation of possible differences of hydrogen and deuterium puffing with respect to the local perturbation of the plasma close to the injection zone will be the subject of future experiments.

Transport processes at the plasma edge

The 2D multi-fluid code TECXY was used to study the radial electric field structure and the properties of the global circulation layer (GCL, 1-2 cm inside the last closed flux surface with an electric field spike and a corresponding local channel of the perpendicular (binormal) electric drift velocity) under the influence of i) external gas fuelling at high plasma density and ii) under the influence of externally driven radial polarization currents.

Different forces contribute to the strength and the direction of the plasma flows in the GCL: the momentum loss owing to neutrals, the pressure force and the centrifugal force. As seen in Fig. 4, which shows the poloidally integrated forces, pressure and centrifugal force almost balance each other. As a consequence the plasma flow in the GCL is strongly affected by the momentum input owing to neutrals: The strong reduction of the total force with additional external gas fuelling (most pronounced if the puffing location is 45° above the outer mid-plane) leads to a significant reduction of the electric field spike in the GCL and the resulting counter-clockwise poloidal
plasma flow as shown in Fig. 5. Note that experimentally a corresponding reduction of the toroidal rotation in the GCL with increasing gas fuelling has been observed.

The reduction of the shear of the radial electric field found in the modelling with TECXY and the associated impact on the edge turbulence level may further contribute to the increase of edge transport observed in plasma discharges with a radiating plasma mantle under conditions of strong gas fuelling as described before.

In a similar way the plasma flows in the GCL can be influenced by inserting and biasing an electrode with its tip a few centimetres inside the last closed flux surface. Negative polarization currents enhance the naturally appearing GCL while positive currents tend to reverse the resulting plasma flow to clockwise direction. For the latter case the calculations could almost quantitatively reproduce experimentally determined values based on probe measurements for the radial electric field, the poloidal as well as the parallel flow velocity.

During the experiments rapid changes in the polarization driving current have been used as a diagnostic tool to study the causality between rotational shear and confinement improvement. The flow shear is clearly leading the transport changes and as a result, a hysteresis between the imposed shearing rate and the particle diffusion coefficient arises. This supports the hypothesis that the rotational shear is the responsible agent for turbulence suppression.

Analysis codes have been developed to investigate turbulence measurements during electrode biasing experiments in more detail. In order to test their functioning, some elements of the codes have been applied on existing data of earlier campaigns to investigate the basic properties of edge turbulence and self-organized critically (SOC) characterized transport of the TEXTOR plasmas. It has been found that before biasing the frequency spectrum of floating potential fluctuations exhibits a shape similar to the typical SOC-system spectrum obtained from the running sand pile models. This suggests a possible existence of SOC-type transport on TEXTOR.
biasing is applied, the results explicitly show that the de-correlation effects of the induced ExB shear and plasma flow affect not only the local plasma turbulence but also cause avalanche-characterized transport events.

On the basis of the *neoclassical theory of plasma rotation and electric fields including the modifications owing to finite Larmor radius effects* ELM-free H-mode discharges in Alcator C-Mod (MIT, Cambridge, USA) have been analysed. It could be shown, that the experimentally observed toroidal rotation in the plasma core can be well reproduced. During the L-to H-mode transition this toroidal velocity experiences a jump from a few kms\(^{-1}\) in the counter-current direction to some tenths kms\(^{-1}\) in the co-direction. The theoretical analysis shows that the jump occurs essentially across the H-mode transport barrier at the plasma edge which is characterised by steep gradients of the plasma temperature and density. As a result, in Alcator C-Mod, the toroidal rotation in the plasma core is in co-current direction under H-mode conditions because the edge pedestal is in the high collisionality regime.

The gradient of the toroidal velocity predicted by neoclassical theory at the inflection point of the H-mode pedestal of a discharge characterised by \(q_{95} = 3.4\) turns out to be close to the threshold value for the parallel velocity shear Kelvin-Helmholtz (K-H) instability to be excited. This theoretical result has been linked to the experimental observation that the H mode properties undergo a transition for \(q_{95}\) in the range 3.5 to 4 in ALCATOR C-Mod: in the EDA (Enhanced D\(_{a}\)) H-mode (at \(q_{95} > 3.5-4.0\)), the particle confinement time (\(\tau_p\)) is strongly reduced (but not the energy confinement time) and there is no impurity accumulation; moreover, a quasi-coherent (QC) oscillation is always present in EDA, but never in ELM-free discharges. It turns out that the wave number and the frequency of this QC mode agree with those expected for the most unstable K-H mode. Moreover, a theoretical model based on the assumption that the anomalous particle transport caused by the QC mode quenches the equilibrium profiles close to marginally unstable ones and on the neoclassical theory of rotation explains well the reduction of \(\tau_p\) in EDA discharges. Given the suitability of the latter to reactor environment (no beam, reduced \(\tau_p\) and impurity contamination), similarity experiments are planned in ASDEX Upgrade and JET. Theory can help to assert which are the most judicious dimensionless parameters to keep identical in the similarity experiments.
In 2002 most of the group’s activities were dedicated to the promotion of diagnostic tools and to the further advancement of sophisticated spectroscopic analysis procedures and evaluation of previous experimental campaigns. The first package is linked to the TEC commitments to Wendelstein 7-X (W7-X) and ITER. For both experiments the TEC team has taken a leading role in the conceptual design of a Charge Exchange Recombination Spectroscopy (CXRS) and Beam Emission Spectroscopy (BES) based on a diagnostic neutral beam of 60 keV/amu (W7-X) and 100 keV/amu (ITER), respectively. The original ITER design challenge has put the main emphasis on the diagnostic capability of measuring in ITER the helium ash level. CXRS has been recognised as the sole path to this goal. At the same time experience gained at present day’s fusion experiments (TEXTOR, JET, ASDEX-upgrade) has clearly demonstrated that any quantitative analysis and physical interpretation of ion densities in a plasma is only valid if all impurity ions (intrinsic and seeded impurities) and bulk background ions (fuel ions) are included. Moreover, the overall consistency of ion densities and ion temperatures and bulk plasma rotation with observed plasma energy and neutron production must be ensured at all times.

One important aspect of global data consistency procedures is the need for absolute calibration. In the case of W7-X and ITER with pulse durations much longer than those of present machines, it is expected that spectroscopic collection systems will suffer from systematic deterioration of optical transmission properties of its periscopes even during a single pulse. On-line calibration techniques are therefore inevitable. Recently, we have successfully demonstrated at TEXTOR that via a combination of CXRS and BES absolute ion densities can be derived from CXRS and BES intensity ratios and their respective atomic excitation rates. In fact, the evaluation of TEXTOR data suggest a review of atomic excitation rates for a further step in accuracy in future applications. This feed-back-effect on atomic data strongly highlights the indispensable need for present fusion experiments for diagnostic development work.

This leads directly to the next topic, which is the advancement of spectroscopic evaluation tools tested in the environment of a well-diagnosed fusion plasma. The aims of this work are multi-fold. On the one hand it is important to promote the ultimate goal of achieving perfect convergence of modelled synthetic spectra based on atomic predictions and absolutely calibrated experimental spectra. This implies a continuous interchange and feedback with the atomic physics community testing atomic data boundaries and accuracy levels. For example, in the case of the modelling of the x-ray spectra, the atomic data have been recalculated for He-like argon by three different methods, such as R-matrix theory and structure calculations as used by the ADAS group, the ATOM / MZ package developed by L. Vainshtein, Lebedev Institute, and the approach by J. Dubau, OBSPM / France. Minor deviations between theory and experiment have been identified and are taken into account by experimental fine-tuning factors. The factors are being checked on calculations of higher-z elements such as Fe and are compared to measurements on TORE SUPRA and TEXTOR.
The current TEXTOR evaluations are to be included into the atomic data-bases and will thus contribute to a general improvement of the modelling of spectra in plasma- and astrophysics.

On the other hand, as a result of the progress and gain in confidence in atomic data in a further step the underlying plasma model can be refined, and, for example, the role of a neutral background for recombination processes be taken in account. Moreover, the fact, that several ionisation stages of the same atom may be involved in complex line structures allows the study of the ionisation balance and the role of transport effects.
The work of the topic group concentrated on the various collapse instabilities observed in a tokamak plasma: sawteeth, edge localized modes (ELM), and disruptions.

Sawtoothing is a commonly found instability in tokamak plasmas. The occurrence of sawteeth is connected with the existence of a rational surface with a safety factor $q$ equal to 1. The current density distribution in the plasma has a tendency to contract on the magnetic axis and this is counteracted by the sawtooth instability, which leads to periodic collapse events which expel heat and particles out of the plasma centre and redistribute the plasma current to form a less peaked profile. Although the sawtooth instability leads to a slightly reduced energy content of the plasma, it prevents e.g. impurities to accumulate, and is therefore beneficial. The mechanism of sawteeth is still unclear, and the investigation of situations where sawteeth are suppressed or stabilized can help to identify the underlying physics of sawteeth.

There are different situations where no sawteeth are observed. The simplest one is, when no $q=1$ surface is present in the plasma, i.e. when the current distribution is broadened. This can occur after impurity accumulation in the plasma centre. But there are still situations where a $q=1$ surface in the plasma is present, and sawteeth are stabilised. An example is shown in figure 1 where the line integrated electron densities measured from the HCN interferometer are plotted. There is a strong modulation of the central channels which indicates an odd mode, the internal $m=1$ kink mode. The mode amplitude is 5 cm as can be seen from the movement of the electron density profile. This amplitude is larger than the amplitude of the normal sawtooth precursor mode, which is believed to trigger the sawtooth crash. The result is in good agreement with recent measurements of the magnetic perturbation amplitude of the $m=1$ mode. The mechanism leading to stabilization of sawteeth remains unclear. The observations of stable and saturated kink modes with large amplitudes question models which describe sawtooth stabilization in terms of the stabilization of the $m=1$ mode.

Sawteeth play an important role as trigger for so-called neo-classical tearing modes (NTM). These modes are destabilised by the perturbed bootstrap current in the island, but require a minimum size for this effect to prevail. These seed islands are generated by other core MHD ac-
tivity. It has been observed that long sawtooth-free phases are often followed by a sawtooth with a very large amplitude which triggers the NTM. Results with ICRH /ICCD from JET have shown that more frequent sawteeth have smaller perturbations and result in a higher critical beta above which NTMs occur. On TEXTOR experiments with ECRH to influence sawteeth were performed. Figure 2 shows a plot of the sawtooth period versus the ECRH deposition radius. Heating inside the inversion radius destabilizes the sawteeth, i.e. more frequent sawteeth with smaller amplitudes occur. Heating outside the inversion radius leads to sawtooth stabilization. This offers a future possibility to enhance the beta limit of RI-mode discharges, where central heating with the new 140 GHz gyrotron will be possible.

Disruptions lead to very large transient heat losses which exceed the limits for plasma facing components; in addition strong forces on the tokamak occur. Methods for early detection and avoidance of disruptions, as well as the mitigation of disruption effects are needed. On JET experiments with strong gas puffs using He, Ne, and Ar in order to mitigate a disruption were done. Besides the suppression of runaway electron generation, which is found for all gases, higher Z leads to a faster current decay, and results in lower forces on the vessel. TEXTOR work on real-time detection of the $m=2$ disruption precursor mode was continued. The cross-correlation of two signals from ECE channels measuring on the high-filed side and low-field side at the $q=2$ radii is calculated, and depending on the amplitude trigger pulse is generated. This pulse can be used to start counter acting the coming disruption by e.g. starting neutral beam injection in order to create rotation shear at mode rational surface and stabilize the mode. Another possibility is to trigger a strong He gas puff to quench the plasma current without generating runaway electrons and with uniform distribution of thermal loads on plasma facing components. The statistics of a large number of discharges show a high degree of mode detection. The observed evolution of the mode frequency was successful modelled.

Edge localised modes occur in diverted plasmas under H-mode conditions. Especially the so-called type-I ELMs are of particular interest, because the transient heat loads onto divertor plates are of concern for large tokamaks like ITER. Various kinds of MHD activity associated with type-I ELMs were observed at JET. The so-called palm tree mode is triggered by the ELM and interpreted to be caused by transient edge ergodisation due to the magnetic perturbation of the ELM. The range of global parameters where this mode is observed coincides well with the parameter range of H-mode plasmas. Magnetic precursor modes of type-I ELMs have been de-
tected. They show a wide range of mode numbers. Figure 3 shows the toroidal mode number $n$ as function of the pedestal pressure and the collisionality. At low collisionality modes with small $n$ were identified to be external kink modes. Modes with medium to high $n$ at higher collisionality are ballooning-kink modes, consistent with modelling results.
The goal of "advanced tokamak scenarios" is to reach a higher pressure at a given plasma current and approaching steady state operation with a large fraction of bootstrap current, i.e. a non-inductive, self generated current. These scenarios can be realized by modification of the plasma current profile, which has been shown on many tokamaks to lead to internal transport barriers, thus improving the confinement quality. Moreover, these transport barriers lead to regions of high temperature and pressure gradients which in turn lead to a high bootstrap current. The main aim of the TEC topic group advanced tokamak scenarios for the moment is to create such an operational scenario with internal transport barriers and then focus on the role of rational values of the helical winding number q (directly related to the current density) and the electron transport in these regimes. Furthermore, by local heating or current drive with the electron cyclotron heating system, an active manipulation of the plasma current density profile is foreseen.

Although TEXTOR was not operational in the past year, progress has been made by analysing data of the last experimental campaign on these three items:

1. **Electron internal transport barriers (eITB) in the steady state phase of ohmic plasmas heated by ECRH**

A clear electron transport barrier around the q=1 surface was identified in three different ways: i) by scanning the deposition radius of the ECRH system a clear drop in the central temperature was observed for heating close to the sawtooth inversion radius (Fig. 1), ii) in modulated ECRH experiments a modest change of the deposition radius around the inversion radius caused a sharp transition in the phase profile of the perturbation and iii) a strong gradient in the electron temperature is observed around the q=1 surface.

**Fig. 1:** The central $T_e$ achieved in ohmic discharges with ECRH as a function of the ECRH deposition radius $\rho_{dep}$. The ECRH deposition radius is varied by changing the toroidal field. Two data-sets are shown: squares for $I_p=255$ kA and circles for 357 kA. A distinct drop in central temperature is observed, when ECRH is deposited outside the sawtooth inversion radius.

In these discharges control of the sawteeth has been demonstrated as well by changing the deposition radius of the ECRH: heating inside the inversion radius destabilized the sawteeth,
whereas a complete stabilisation was observed for heating in a relatively broad region outside the q=1 radius (Fig. 2).

![Fig. 2: The corresponding sawtooth period for the ohmic discharges in Fig. 1 as a function of the ECRH deposition radius for $I_p=255 \, \text{kA}$. The sawteeth are stabilised, when ECRH is deposited within a region just outside the sawtooth inversion radius.](image)

2. **eITBs in the current ramp phase**

A generally used technique to create a hollow current density profile is by means of early heating during the current rise phase of the discharge. This method has been employed at TEXTOR with the aim of exploring a possible "negative central shear (NCS)" regime. Although no true NCS regime could be established by applying neutral beam heating and ECRH in the current ramp phase, double transport barriers were observed (Fig. 3).

![Fig. 3: $T_e$ profiles from Thomson Scattering at $t = 0.35 \, \text{s}$ for different positions of ECRH deposition as indicated by the bar at the top. Two electron transport barriers can be identified.](image)

3. **eITBs in RI-mode plasmas**

In RI-mode plasmas an internal transport barrier was observed as well. This barrier apparently prevents the expected degradation of confinement with the increasing power from ECRH: the relative change in diamagnetic energy in proportion to the relative change in the total power for heating inside the barrier (Fig. 4).

A theoretical activity on the possible suppression of turbulence by rotational shear was initiated as well. By taking the ambipolarity constraint and momentum equation from neoclassical theory and taking into account friction with neutral gas and anomalous viscosity due to the ITG turbulence, rotation profiles in TEXTOR, Alcator and JET could be reproduced. The effect of a resonant magnetic perturbation to this, like in the TEXTOR DED case, would yield a local minimum of this rotation (Fig. 5). This might yield a sufficiently large velocity shear to quench the ITG turbulence and in this way an internal transport barrier might be generated.
**Fig. 4:** The normalised efficacy \((\delta W_{\text{dia}}/W_{\text{dia}})/(\delta P/P_{\text{tot}})\) from diamagnetic measurements achieved in RI-mode discharges as a function of the normalised ECRH deposition radius. The datasets are shown for \(q_a=3.8\) (circles) and \(q_a=2.9\) (squares). The full (dashed) line indicates the expected efficacy of ECRH without (with) power degradation. For both datasets a sharp drop in normalised efficacy is observed close to the sawtooth inversion radius (indicated by arrows), i.e. the footprint of a transport barrier in that region.

**Fig. 5:** Calculated rotation profile for TEXTOR with and without a resonant perturbation at the \(q=2\) surface
The primary goal of the topical group is the application of the DED to the TEXTOR plasma, the understanding of the resulting physics and the test of new diagnostics for TEXTOR.

Electric currents in the coils of the DED superimpose a resonant perturbation magnetic field to the equilibrium field of the plasma; this additional field “weaves” the magnetic field lines such that a field line fills a whole volume instead of a surface. This ergodisation increases the plasma transport at the boundary such that the deposited heat will be distributed over a relatively large wall area – in a future fusion reactor, the high heat flux density to the walls is one of the critical issues. In addition, the DED of TEXTOR is unique in so far as the perturbation field can rotate with a velocity up to the order of the ion drift velocity in the plasma edge. By this rotation, new possibilities may open up for improving the plasma confinement.

For the analysis of the DED, the following tasks have been performed in the recent year:

- For investigating the particle transport in the ergodic area, a new mapping method for the guiding centre motion of ions and electrons has been derived. The particle orbits depend on the direction of motion (co- or counter-rotating particles), on their parallel and perpendicular energy and on a superimposed electric field. The ergodisation is more pronounced for counter-rotating particles than for co-rotating ones.

- In order to characterise the perturbed edge zone, an atlas has been prepared showing the ergodic zone, the field line connection length of the laminar zone and the strike zones of the magnetic field lines at the divertor target plate for different plasma conditions ($I_p, \beta_{pol}$). The atlas will be a main tool for referring a specific measurement with respect to the complicated 3-D structure of the ergodic zone.

- 3-D models for the plasma transport in the laminar and ergodic zones are under development. Since stellarators (e.g. Wendelstein 7-X) have a boundary structure of similar complexity as the one imposed by the DED, the efforts of developing the EMC3-EIRENE and E3D codes are combined with the activities in Greifswald. A first converged result has been obtained.

- The concept of a weak ergodisation on low order rational surfaces has been applied for the explanation of transport barriers (braiding of magnetic field lines). The concept is based on the non-uniform distribution of low rational numbers $q$ (representing magnetic surfaces) near values like $q = 1$, $q = 3/2$ and $q = 2$. 
The penetration of the rotating perturbation field into the plasma is still an unsolved problem in case of an ergodic background field pattern. On the other hand, the problem is fundamental and relates both to laboratory and astrophysical plasmas. With respect to the DED, several groups (TEC partners, groups in Graz/Austria, Sao Paulo/Brazil, Kharkov/Ukraine and Novosibirsk/Russia) are contributing. The groups are applying a different ansatz and technique such as the analysis of low frequency wave propagation, an analytical linear model or a non-linear numerical code. The different methods calculate the shielding current induced in the edge of the plasma due to the rotating magnetic field, the radial decay of the perturbation field into the plasma and the force transferred from the external coil currents to the plasma. All these quantities can be measured and compared to the code predictions.

Finally, the group participates in an international effort of exploiting positive effects of ergodisation on fusion devices. The efforts concentrate on the mitigation of Edge Localized Modes (ELMs); these ELMs are a prominent feature of so called High Confinement Discharges (H-modes) and are linked with high transient power losses. For a fusion reactor, methods are investigated to reduce these extreme heat fluxes. The group collaborates in this respect with the fusion groups in Cadarache/France (Tore Supra) and San Diego/USA (DIII-D).
A substantial fraction of the theoretical activity of the TEC, being closely related to experimental research, is reported in the corresponding Topic Group sections. The present review covers complementary activity.

Transport, impurities and RI-mode

It was discovered on TEXTOR that the localised injection of gas into the discharge – e.g. for raising the plasma density – led to degradation of the energy confinement in the plasma. Theoretical models have been developed to investigate the reaction of the plasma parameters to such an injection and it was found to lead to a local reduction in temperature and to an increase of density, also seen in the experiment, which destabilizes the drift ballooning modes, thus explaining the density fluctuations observed by reflectometry, and hence the ensuing reduction of confinement. This phenomenon was also investigated using the TECXY code.

It is known that toroidal plasmas generally rotate about their symmetry axis, usually with a spatially non-uniform rotation speed. A new neoclassical theory of transport, valid in regions of sharp gradients such as the plasma edge, was developed in the past years. The resulting transport coefficients were introduced into a numerical code being able to reproduce the observed rotation in TEXTOR and allowing for predicting the modifications of rotation that will be induced in the JET plasma when the saddle coils will be energized.

A new neoclassical theory is also being developed that would take into account the non-Maxwellian distributions generated by the external heating of the plasma by electromagnetic waves.

The current international plasma edge simulation code package B2-EIRENE (applied e.g. to the plasmas of ITER, JET, ASDEX Upgrade, …) has been upgraded from a “periodic cylinder” to a full “torus-geometry” option, being relevant for divertor regimes with significant volume recombination.

The 3D EIRENE Monte Carlo code has been extended from a neutral particle transport model for fusion edge plasmas towards an additional optional photon gas (radiation transfer) simulator. It is currently applied to assess possible effects of Lyman line re-absorption on detached divertor operational windows. An interface to a full 3D finite element CFD discretization scheme (using tetrahedrons as basic cells) has been developed to permit coupling of the EIRENE code to the commercial plasma simulation code FIDAP for simulation studies of technical plasmas, such as the high pressure gas discharges used for lighting purposes. An entirely revised and up to date collision database for hydrocarbons up to C_3H_8 (cross sections and rate coefficients) for typical fusion edge plasma conditions has been built-up and published. It is currently implemented into the ERO gyro-kinetic and EIRENE drift-kinetic particle simulation codes.
**Plasma heating physics**

The work on non-linear Fokker-Planck codes and simulation of ion cyclotron heating scenarios for ITER was completed. It was found that ITER precisely lies in the “intermediate” parameter region where the non-linear collision effects (slowing down of the heated population on itself) matter – as opposed to the extreme cases where the heated population either is nearly Maxwellian or is extremely energetic and slows down on electrons. This may lead to a reduction in the order of 20% of the fraction of the heating power coupled to the ions and thereby to a reduction of the reactivity of the plasma as compared to previous simulations ignoring non-linear effects.

The effort towards the development of a consistent *plasma wave + Fokker-Planck* description accounting for non-Maxwellian distribution functions and finite width of the drift orbits in tokamaks has been pursued. The general formulas have been incorporated into the Fokker-Planck part of the code, which is on its way to completion.

The effort in the modelling of the antennas and the coupling of power to the plasma in ion cyclotron heating has been pursued, leading to a better description of the behaviour of the antenna in vacuum (Micro Wave Studio™ code) on the one hand, and to a better description of the antenna geometry with coupling to the plasma (ICANT code) on the other hand.

A power balance for waves in resonant dissipative media, valid for any frequency, is formulated. It generalizes the well-known expressions for dielectric wave energy density, wave energy flux, and dissipated power density to the case in which the anti-Hermitian elements of the dielectric tensor are non-negligible.

For electron cyclotron heating, the current generated by two oblique counter-propagating waves has been computed. The importance of non-linear effects in the computation of current drive has also been investigated. Both the non-linearities in the collision operator and in the particle trajectories inside the wave were considered. The consequences of strong focussing of a wave beam for the localisation of the ECRH deposition have been studied. For a typical TEXTOR case the deposition profile strongly broadens when the wave power is focussed in a waist smaller than 1 cm.

**Nonlinear plasma dynamics, turbulence and plasma behaviour in stochastic magnetic fields**

One important aspect of the plasma dynamics is the interplay between the magnetic field structure and the particle flows and currents inside the plasma. The dynamics and stability of current-vortex filaments and the universal phenomenon of magnetic field reconnection reveal this interplay. The description of this nonlinear dynamics exploits the mathematical properties (Hamiltonian, symmetries, conservation laws) of a reduced geometry plasma model with a drift-kinetic description of the electrons. This model resolves the singular current and vorticity sheets appearing in 2-fluid modelling. A description of reconnexion in the presence of temperature and density gradients shows that they modify the current and vorticity distributions and hence the very geometry of the reconnexion layer. Another approach to the reconnexion problem in tokamaks is based on Hamiltonian mappings (like improved versions of the TOKAMAP), through which reconnexion during the crash of a sawtooth was simulated. This method also allows investigating the formation of internal transport barriers in the plasma.

The decay of 2½-dimensional electron-MHD turbulence has been studied numerically – using a spectral code – and analytically. The turbulence is found to obey different self-similar scalings
for lengths much larger and much smaller than the intrinsic scale-length in the model, the electron inertial skin depth. At larger scales the spectra are consistent with the classical (Kolmogorov) spectrum while at small scales this is not the case and an inverse cascade phenomenon is seen at long wavelengths.

Another approach is the dynamic subgrid scale model, which decomposes the turbulence into a “large eddy” part described numerically and a small-scale (subgrid) one described by a model. The accuracy of such models is under investigation by comparison with numerical simulations.

The role of strong electromagnetic turbulence on tokamak transport and transport barriers is studied using the CUTIE code developed in Culham. The present focus is on a non-local effect seen in RTP and other tokamaks: Edge cooling can induce a rise of the central electron temperature that is dubbed "non-local" as it is much faster than the diffusive timescale. CUTIE-simulations qualitatively reproduce this effect for RTP parameters.

A variety of advanced MHD software tools have been developed. These fall into two general categories: those to diagnose the MHD stability by spectral means, and those to perform detailed simulations of multi-dimensional, non-linear phenomena in magnetized plasmas. These codes rely on the MHD equilibrium code FINESSE that accurately computes axisymmetric MHD equilibria with flow. The spectral code PHOENIX predicts all MHD waves and instabilities. This set of codes allows the first ever studies of MHD stability in tokamaks accounting for both toroidal and poloidal plasma flows. 3D dynamics in magnetized plasmas is computed with the multi-dimensional, non-linear MHD code: the Versatile Advection Code, which, for better accuracy, uses a solution-adaptive mesh refinement strategy. A specific example study using this code is the investigation of the interplay between Kelvin-Helmholtz and current-driven instabilities in astrophysical plasmas.

Another field of active investigation is that of the behaviour of plasmas stochasticity, the latter being either generated by external perturbation fields, like in the case of the Dynamic Ergodic Divertor (DED) of TEXTOR (to come in operation soon), or generated by the plasma itself in the form of unstable electromagnetic modes. Methods are developed for computing the drift trajectories of particles in this stochastic environment.

**The theory groups in the TEC**

The Jülich group is mainly active in transport modelling, edge and plasma wall interaction codes and DED modelling.

In the Netherlands at FOM, there are two theory groups: the Nonlinear Dynamics and Transport group and the Numerical Plasma Dynamics Group.

In Belgium, the team of ERM/KMS (Ecole Royale Militaire / Koninklijke Militaire School, Brussels) investigates ion cyclotron heating, DED field penetration and edge flows. The team of ULB (Université Libre de Bruxelles) focuses on turbulence, transport theory, plasma heating and current drive.
Installation of the Dynamic Ergodic Divertor (DED)

Technical Concept

The Dynamic Ergodic Divertor (DED) has been installed in TEXTOR in order to influence transport parameters in the plasma edge and to study the resulting effects on heat exhaust, edge cooling, impurity screening, plasma confinement and stability. The DED consists of four sets of coils at the inboard side of the TEXTOR vacuum vessel, each with four helical conductors (Fig. 1). Two additional conductors at the top and at the bottom are necessary for the compensation of edge effects due to the combination of four coils each at the vacuum feed-throughs.

For the installation of the coils the TEXTOR liner has been removed, a 120 deg section cut out poloidally and re-inserted. A support structure welded to the vacuum vessel clamps the coils and also the target plates to the vessel. Coaxial vacuum feed-throughs include connections for coil currents and cooling media.

The coil sets will be energized by DC or 4-phase current at selected frequencies (50 Hz and between 1 kHz and 10 kHz) with amplitudes of up to 15 kA.

Manufacturing of Components

The DED coils (Fig. 2) have been designed for high voltage, high current density and medium frequency. They consist of 294 twisted polyimide insulated wires with gaseous helium in-between them for improved heat conductivity to a water cooling tube in the centre of the bundle. An outer tube separates the coil from the vacuum. The bundle is equipped with insulation layers and mechanical protection.

All coils have been manufactured and successfully tested for vacuum tightness and high voltage withstand capability at 5 kV.

The coils are mounted inside the TEXTOR vacuum vessel and protected by the divertor target plates. All in-vessel components (Fig. 3) comprising coil support structure, coil clamps, tile support structure, ceramic shields and graphite tiles have been fabricated after design optimization for low eddy current losses and optimum heat distribution.

Fig. 1: Location of the DED coils inside the TEXTOR vacuum vessel.

Fig. 2: DED coil. Cooling water tube, twisted wires, insulation, mechanical protection.

Fig. 3: In-vessel components of the DED. Coil support structure, coils, coil clamps, tile support, ceramic tiles, graphite tiles.
tance, minimum stray field and eddy current heating a coaxial
design has been chosen, allowing for compensated current
feeding through the vessel wall. A sophisticated system of
high-voltage insulation and sealing has been developed in or-
der to meet the design requirements.

All feed-throughs have been manufactured and passed the
relevant high-voltage and vacuum test.

Prototype Testing and Simulation

Numerous tests of the support structures, the coils, the feed-
throughs, the eddy current heating and the assembly of DED
components have been performed using a specially built mock-
up (Fig. 5), which is equipped with a spare toroidal field coil of
TEXTOR for generation of relevant magnetic fields and a pro-
totype power converter, allowing for operation of the DED coils
at full frequency range (DC and 50 Hz to 10 kHz).

A first quartet of DED coils inside the TEXTOR vacuum vessel
has been fed with nominal current at different frequencies.
With the toroidal field switched on simultaneously this test ap-
plied maximum forces to the coil clamping in the feeder region.
The coils and the clamping successfully passed the test.

All design activities have been accompanied by extensive
magnetic and electrical circuit simulation as well as mechanical
stress analysis with a finite element method (FEM). The influ-
ence of skin effect and eddy current losses as well as electro-
magnetic forces has been determined. The simulations have
been continued during prototype testing for the evaluation of
test results. Parameter studies provided the input for design
optimizations.

Integration

During the major shut down all preparations for the DED have
been performed and the components have been integrated. In
parallel TEXTOR components have been modified to allow for
the integration of the DED and for improvements of the TEX-
TOR performance. General maintenance has been carried out,
systems have been improved and wear parts exchanged.

New platforms have been planned, manufactured and set up in
the TEXTOR bunker in order to allow for the installation of
DED-components as well as diagnostics.

Electrical Systems

Only two separate power supplies are required to produce
4-phase currents. 9 power supply units with 750 kW each sup-
plied by a single rectifier transformer are foreseen to limit the
unit size, to have 9 identical units and to allow for special
asymmetrical patterns of current distribution. Each power sup-
ply unit feeds a load unit of two coils. The details of the power
supply concept (Fig. 11, Fig. 12) have been defined together
with industry.
The maximum operating frequency of 10 kHz led to the choice of IGBT inverters. Between 1 kHz and 10 kHz the reactive load is about 20 times the active load. For compensation capacitor banks are connected in series to the load thus forming resonant circuits. Two capacitor banks in three different configurations each, plus the parallel connection of both, yield 7 resonant frequencies.

Fig. 7: The modified TEXTOR liner with auxiliary support.

Fig. 8: Modified liner with turnable support (top). Coil support structures mounted on pads, welded onto the vacuum vessel.

Fig. 9: Mounting of DED coils inside the TEXTOR vacuum vessel.

Particular attention has to be paid to the minimization of the additional inductance introduced by all power supply components. The design value of the voltage withstand capability is strongly influenced by this.

Three different matching transformers covering the range of operating frequencies and transformation ratios are necessary to match the voltage level of the IGBTs to that of the load at maximum output power.

Fig. 10: View into the TEXTOR vacuum vessel with DED coils, divertor and alignment rail system.

Fig. 11: Arrangement of the DED power supply system.

A central control unit co-ordinates the feedback control of current amplitudes and the mutual phase shifts of all power supply units. The control unit comprises of a programmable logic controller (PLC), digital signal processors (DSP) and field programmable gate arrays (FPGA). A fast fiber-optic transmission links the controller with the converter and the data acquisition.

The DED power supply system has been completely installed and commissioned. After testing with a full size dummy load and final modification of the control software the system has past the final acceptance test.

The bus-bar system (Fig. 13) combines high current and high frequency capabilities at minimum cross section. The design has been optimized for maximum accessibility of diagnostics at TEXTOR. Despite the very limited space, the assembly has been completed. The bus-bar system, including sophisticated high voltage/high frequency compatible joints, has passed the high voltage test.

The connecting racks and the de-coupling transformer have been installed. The final cabling (Fig. 14), comprising 9 bundles of 12 coaxial cables in parallel, has been routed between the power supply system and the connecting racks as well as between the racks and the bus-bar system. All cable connections at the power supply terminals, the racks and the bus bars are completed.

The stray field of the de-coupling transformer has been measured and simulated. In order to stay within the limits for the exposure of the general public to electromagnetic fields given by legal regulations, specific areas have been closed or shielded, respectively.
Cooling System

A new cooling system (Fig. 15) supplying both the DED coils and the DED power supply system with de-ionized water has been laid out and procured. It has successfully been tested during commissioning of the power-supply system.

Control Systems

A new local control system co-ordinating the DED power supplies, the DED cooling system and the monitoring of DED components has been developed. The local systems have been integrated in the central control system of TEXTOR.

Due to the large amount of I/O data to be processed, field bus techniques had to be implemented. This also provides an interface between the power-supply manufacturer’s control system and the TEXTOR control system and additionally a comfortable processing of the peripheral electrical components’ I/O.
**Plasma Heating**

*Electron Cyclotron Resonance Heating (ECRH)*

Preliminary ECW experiments on TEXTOR have been performed using a gyrotron at 110 GHz with about 350 kW power and a pulse length of 200 ms. This frequency is suitable for 2nd harmonic heating at reduced field (~2 T). It is also possible to remove resonances from the plasma, and to obtain a minimum of (ECE) background radiation by increasing the magnetic field to 2.6 T. This makes it possible to use the gyrotron as a source for Collective Thomson Scattering (CTS). The system has been operating reliably and, despite the relatively low power and short pulse length, it has yielded significant results on electron thermal transport (transport barriers) and fast ion behaviour. During 2002, the ECW system has been upgraded with a gyrotron of more than 800 kW and pulses of 3 s and longer. A frequency of 140 GHz was selected for this gyrotron to enable 2nd harmonic (X-mode) central heating and especially current drive at the usual value of the toroidal field (2.3 T). At this higher frequency the plasma is also accessible up to the highest (RI mode) densities. At slightly reduced field strengths, studies of the interaction of ECRH with externally created and controlled magnetic islands and ergodic field regions near the inner wall – created by the DED – are possible. Operation of the old 110 GHz gyrotron will remain possible mainly for diagnostic purposes (CTS).

The two gyrotrons share a common high voltage power supply, which has been completely overhauled and upgraded to 80 kV, 50 A and 10 s. They can, therefore, not be operated simultaneously. They each have their own beam forming and polarizer units but the main part of the quasi-optical transmission line is used both for transmission of the 140 and the 110 GHz power, including window and launcher. For the new installation a high pressure (8 bar), low flow and a low pressure, high flow (1500 l/min) cooling system has been installed. Pulse lengths extending up to 10 s have already been demonstrated on a dummy load. But for initial plasma experiments the duration will be limited to 1–2 s. With the installation of a new launcher and torus window in summer of 2003, the full pulse length capability will be available on TEXTOR. The old launcher used with the 110 GHz gyrotron consisted of a fixed focusing mirror (copper) and a steerable flat mirror (Stainless Steel). The SS mirror has now been equipped with a copper coating and heat sink to extend the pulse length capability somewhat, but a new launcher is being developed for the 10 s pulse length capability. This new launcher will be able to withstand disruption forces using a full copper mirror and the mirror will also be shielded from deposition during boronisation and other deposition processes. With the installation of the new launcher, the present fused silica torus window will also be replaced with a CVD diamond window.

The control software for the ECW installation was re-written and extended. Although the PLC allows convenient control of the installation, it is slow. For fast feedback purposes on the basis of diagnostic signals it is therefore necessary to have direct access to the timing of the gyrotron pulses (e.g. for mode stabilisation or DED diagnostic purposes) and to the launcher angle (e.g. to track the mode position as it changes in time). The possibilities for this direct control are already provided in the present control system. They will be the subjects of further developments.

*Ion Cyclotron Resonance Heating (ICRH)*

To improve the power handling capability of the ICRH-antennas on TEXTOR, one antenna has been modified by replacing the usual radiating strip by a set of three cylinders. This is expected to lower the electric field and therefore to improve the power coupling capability.
The coupling of ICRF-power into ELMy H-mode discharges, which is the basic regime for ITER, is limited due to tripping of the generators, since the ELMs (edge localized modes) either cause a fast increase of the antenna load or induce arcs. Induced by the rearrangement of the diagnostic positions resulting from the DED installation on TEXTOR, a new antenna system has been designed, which allows a large flexibility of operation and can test, in particular, the load-variation-tolerant “conjugated-T mode” of operation foreseen for the new JET ITER-like antenna. The control of the ICRH-systems has also been renewed.

Ion cyclotron radio frequency has been used to produce plasmas for machine conditioning purposes. A comparative study using ECRH has now also been performed.

On the theoretical side, important results relate to ICR heating with large minority fractions such that the interaction of the tail particles with themselves were obtained with a non-linear Fokker-Planck model. The antenna modelling with ICANT has concentrated on the description of straps with a realistic, non-zero thickness, in view of the latter’s influence on both the real and imaginary part of the antenna impedance.

**Data Acquisition and Processing**

Within the last year the basic rearrangement of the data acquisition and data retrieval systems is continued and appropriated for the restart of TEXTOR (Fig. 1). The diagnostics being installed at TEXTOR are increasingly controlled by the new Java based data acquisition system JDAQ. Since it can be operated through the Internet, a remote control of the diagnostic systems is possible. The data storage has been moved to FZJ's Central Institute for Applied Mathematics (ZAM) where an expandable data storage of 1.2 Terabyte for common raw data (CSF) is available.

A new feature is the intershot analysis of the plasmas, which is started automatically in between the discharges to calculate the necessary physical information for the characterisation of the plasma. Also these quantities are stored in a database. Since this database allows also the offline storage of calculated physical quantities, a data pool with fully diagnosed plasmas arises within some time. The TEXTOR physics database (TPD) contains all important measured quantities and is accessible not only by users in the institute but also by world wide partners (TEC, EFDA, IEA, HGF).

The TEC web umbrella handles the data retrieval from the CSF as well as from the TPD. It is based on the universal HTTP-protocol and allows in principal also the retrieval of data from other European fusion experiments. Therefore, the newly developed data acquisition and retrieval structure is a module for a more network oriented European fusion research programme.

**Fig. 1:** Scheme of the newly developed data acquisition and retrieval structure at TEXTOR
Core diagnostics

For the experimental investigation of large-scale and small-scale instabilities and their relation to plasma transport and confinement in the plasma core, various diagnostics are operated and further developed. These diagnostics include the measurement of the main parameters of the bulk plasma (densities, temperatures) and magnetic properties as well as the detailed analysis of plasma radiation in various energy ranges. In the course of the year 2002, major progress has been achieved in the following fields:

The design for a set of new VUV/XUV spectrometers has been developed, which shall be used for impurity monitoring and impurity transport studies at the stellarator W7-X [1]. The four new systems cover the entire wavelength range from 2.5 nm to 160 nm, divided into four subsections with some overlapping, thus achieving a complete coverage of prominent spectral lines from the relevant impurity elements. Numerically optimised toroidal holographic diffraction gratings are designed and the spectrometer geometries and detector properties are chosen to obtain a high efficiency at a good wavelength resolution. The performance of the spectrometers is tested and optimised by means of ray tracing calculations. In order to investigate the possibilities for line identification as well as the expected levels of accuracy of the new systems, simulated spectra have been calculated using the impurity transport code STRAHL. Under typical plasma conditions the new spectrometers will allow to clearly identify practically all relevant impurity elements in the plasma. The large collected photon flux allows to achieve a high accuracy for the measured line intensities even when operating the spectrometers at spectra rates of 1000/sec.

The design for a new high-resolution imaging X-ray spectrometer at TEXTOR has been finalised [2] and the construction has been started. The system will record the spectra of H- and He-like lines and their satellites with spatial resolution along 6 radial chords and good time resolution (3 ms). An array of 8 different spherically bent Bragg crystals interchangeable under vacuum will allow to access different medium-Z species from Si (Z=14) to Ni (Z=28) within subsequent TEXTOR discharges. The astigmatism of the crystals is used to image the spectra in sagittal direction onto an array of 6 detectors. An additional and interchangeable set of detectors, an array of three two-dimensional multi-wire proportional counters with high time resolution, will allow to adapt the spectrometer to a broad range of plasma conditions. The installation at TEXTOR is foreseen in 2003.

The conceptual design of a dispersion interferometer for TEXTOR has been finished. This instrument measures the line integrated electron density by comparison of the phase shift of a CO₂-laser beam with a frequency-doubled component of the same beam. Advantages are that this method does not require a rigid frame around the tokamak vessel and it is insensitive to vibrations coming from mirrors mounted inside the vacuum vessel. A detailed design will be devel-
oped within a contract with the Budker Institute in Novosibirsk. The TEXTOR prototype will allow to study the feasibility of this new diagnostic method for ITER.

The **ECE diagnostic** at TEXTOR has been upgraded by new elliptical mirrors, wave guide switches, a new local oscillator for the magnetic field range relevant to DED operation \((B = 1.9 \text{ T})\) as well as a recently developed 140 GHz notch filter to protect the ECE radiometers during the operation of the new ECRH heating system.

The **reflectometer** system at TEXTOR has been amended by two additional spatial channels and a new antenna system is developed for the measurement of toroidal and poloidal correlations at different poloidal positions in the plasma.

A new type of **Mirnov coil system** has been constructed and installed at TEXTOR. In order to allow measurements at higher frequencies than those having been accessible in the past, the coils are made from ceramics, which contain two layers with windings of Mo wire. The coils have been fabricated by plasma spraying ceramic onto an Al body, supplied with windings which are covered with sprayed ceramics. Afterwards the Al body was removed by etching. There are two different types of coils that measure the poloidal and radial field, respectively. The coils together with their feeds and RF filters to cut off the 30 MHz frequency range used for ion heating have been tested with alternating magnetic fields of up to 1.5 MHz. They show a flat characteristic from 0 to 400 kHz. Two new compensated loops had to be built in order to fit behind the DED coils.


**Edge diagnostics**

Traditionally many of the diagnostics for the investigation of the plasma boundary and surface interaction region in TEXTOR are based on optical techniques. Existing methods in astronomy, low temperature plasma discharges and surface analysis have been tested in laboratory experiments and then adapted to TEXTOR. Moreover, TEXTOR also allows the use of active techniques, where either atoms or laser light is introduced into the region to be diagnosed.

In order to have experimental access to additional radicals from the methane family a **laser absorption diagnostics (LAS)** has been built-up on TEXTOR. Fig. 1 shows a sketch of the beam geometry and the detection system. The detection limit for CH\(_4\) and CH\(_3\) is \(10^{12}\) and \(10^{10}\) cm\(^{-3}\), respectively.

The **passive spectroscopy** of molecules and line profile measurements has been considerably improved by the use of an Echelle spectrometer, which allows the simultaneous recording of a wavelength range between 375 nm and 700 nm with a high resolution of \(\lambda/\Delta\lambda = 20000\). Fig. 2 gives an example for a discharge on JET, which demonstrates the possibilities of the instrument.
Active diagnostics of the boundary plasma could also be largely improved by a modification to a supersonic He beam, where both divergence and beam density will now additionally allow the determination of temperature fluctuations. An increase of beam density was achieved by pulsed operation with a factor of 3 higher pre-pressure in comparison to continuous operation. A further increase of a factor 3 was realised by a reduction of the distance between nozzle and skimmer (Fig. 3). Due to the corresponding increase of the beam divergence the injection system will be located nearer to the observation volume to maintain the necessary beam width of 1 cm. Simultaneously the data acquisition for the fast recording of the emission from 3 helium lines line via a VXI-system was upgraded to frequencies of 750 kHz.
Fig. 3: Supersonic He beam: flux increase by changing the distance of the nozzle

Charge exchange recombination spectroscopy (CXRS) applied on a high energetic (50 keV) neutral H diagnostic beam is used for the measurement of radial profiles of ion temperature and impurities. In order to measure the poloidal rotation velocity profile it was necessary to shift the whole diagnostic toroidally to section 10/11 at TEXTOR. There a gap between two ALT II blades allows the simultaneous observation of the red and blue Doppler shifted CXR lines from top and bottom of the vessel. The observation system consists of 20 spatial channels distributed over the last close flux surface (LCFS) at 47 cm. The light is conducted via fibres onto an entrance slit of a high resolution spectrometer.

Wall diagnostics

A neutral gas diagnostics has been developed to measure the neutral gas pressure in front of the DED tiles. The far distance microscopic system has been further optimised in the lab for visual inspection of a DED tile especially instrumented with erosion and deposition markers. The new Quartz Micro Balance diagnostic has been taken into operation at JET. The development of further QMB systems has been continued for installation in JET and TEXTOR in the near future, in particular with the aim to actively control the temperature of the deposition quartz. Probe heads for the fast reciprocating probe system have been developed. One ALT pump duct was modified for measurements of carbon deposition in remote areas with long term collector samples and QMB systems.

DED diagnostics

In the recent year of the extended TEXTOR shut down, the R&D work was concentrated on the preparation of installations for the DED and on maintenance work of other components.

A set of 18 Langmuir probes for measuring electron densities and temperatures at the divertor target plate of the DED was fabricated. In addition, thermocouples with high time resolution for measuring the heat flux have been tested and inserted into the DED target plates. Finally, a set of Hall probes is ready for the installation on a fast probe drive; these probes will measure the modification of the magnetic field at the low field side due to the influence of the DED. A new fast IR camera has been delivered which was tested extensively.
One of the Langmuir probes mounted in a DED divertor target plate.

The pump limiter blades were removed from TEXTOR for surface analysis and subsequent exchange of the graphite tiles and for the replacement of thermocouples, probes and gas lines. Finally, the blades and pumping systems were re-installed.

The pellet injector system was removed from TEXTOR and re-installed for testing and improvement in the laboratory. The main items of improvements concern the test of the pellet path alignment and the microwave cavities for measuring the pellet mass.

For experiments on the mitigation of the adverse effects of disruptions, a new fast valve has been developed. The valve opens in less than a millisecond after receiving a trigger signal and releases some hundred millibar-liter of gas into a discharge chamber.

**Diagnostics FOM-Instituut voor Plasmafysica**

TEXTOR is the first tokamak on which fast ion collective Thomson scattering has become a routine diagnostic. The system, which is a collaboration with Risø, Denmark and MIT, USA has been successfully used to measure the velocity distribution of fast ion populations created by NBI and ICRH. Significant results were obtained on generic fast ion dynamics (e.g. the evolution of the fast ion velocity distribution after switch-on/off of NBI and ICRH was measured; redistribution by sawteeth; the detailed heating mechanisms of ICRH). In the course of 2002 the detection system has been considerably improved and work is underway for the installation of a second receiver to be installed at a toroidally separated port.

Since the start of the DED shutdown a significant effort has been on-going to develop a combined 2D ECE-I/MIR system for TEXTOR. The detailed design and the manufacturing of the optical and microwave set-up of this system, which is jointly developed by FOM, UC Davis and Princeton, has been completed. Very extensive laboratory tests using a rotating corrugated mirror as test bed have clearly demonstrated the potential of the imaging reflectometer and the specific advantages with respect to standard reflectometers if it comes to quantitative density fluctuation measurements.

Thanks to a successful application to the Innovationsfond of FZJ, a collaboration in the field of Thomson scattering has been started involving physicists from FOM and IPP. The present double-pulse system will be upgraded to a >10 kHz burst-mode operated system. The duration of
each burst is up to 10 ms, and in total three bursts can be generated during a TEXTOR discharge. Successful laboratory tests of the new concept have been performed. Parallel to the upgrade of the laser system and the beam line, an extra edge viewing system will be mounted to monitor the electron temperature and density in the ergodic layer with a spatial resolution of 3 mm. The manufacturing of the edge Thomson scattering system as well as that of the high repetition rate laser are well underway, while two fast CMOS cameras for detection have been ordered.

A special pneumatic construction has been developed to position the cameras of the ultra-soft x-ray tomography system, for studying impurity transport, very close to the plasma boundary. When not in operation, the cameras are retracted and positioned behind a vacuum valve for protection. All five cameras of the tomography system are equipped with pneumatic drivers to make it possible for each individual camera to observe the full poloidal plasma cross section. The cameras have been partly installed on TEXTOR. The remaining cameras are waiting for some other jobs on the TEXTOR machine and will be installed early 2003.

A prototype MSE (Motional Stark Effect) system with in-vessel optics has been tested. The front-end optics will be mounted on a similar pneumatic driver as used for the ultra-soft x-ray tomography system to protect it from deposition when not in use. At the same time the system is further improved and upgraded to a total of 20 channels.

**Diagnostics LPP – ERM / KMS**

The isotopic dependence of the confinement properties of the RI mode has been studied by performing similar discharges in pure D, in pure H and mixed H/D plasmas. The energy confinement time dependence on atomic mass was found similar to that in L and H modes. The correlation of energy confinement time with density peaking factor and recycling flux was studied. Particular attention has been paid to understanding why at densities close to the Greenwald limit confinement was degraded in hydrogen plasmas. By varying the fuelling rate it was proven that the gas puff flux, although much smaller than the recycling flux, plays an important role in the control of the energy confinement time of the plasma.

For the design of later probe systems to measure plasma rotation, the influence of the collector shape on the accuracy of the derived Mach numbers has been analyzed. The accuracy of the 1D-fluid model has been tested by comparing the exact numerical solutions with the approximate ones.

The effect of externally driven radial currents on the imposed electric field and rotation has been studied using a one-dimensional model including inertia, shear viscosity terms and particle transport reduction due to shear in the $E\times B$ velocity. Simulations support the hypothesis that the rotational shear is the responsible agent for turbulence suppression. A probe is being developed that will allow determining Reynolds stresses and their influence on the plasma radial conductivity.

Alternative techniques for the measurement alpha particle losses in the future fusion experiment ITER have been studied. Based on the activation induced by charged particle induced activation a particle loss diagnostic has been developed. Calculations with MCNP4C2 code demonstrated the proof of principle of the proposed diagnostic. For TEXTOR a pinhole camera carrying a nuclear track detector for position sensitive measurements has been prepared.
To improve the power handling capability of the ICRH-antennas on TEXTOR, one antenna has been modified by replacing the usual radiating strip by a set of three cylinders. This is expected to lower the electric field and therefore to improve the power coupling capability.

The coupling of ICRF-power into ELMy H-mode discharges, which is the basic regime for ITER, is limited due to tripping of the generators, since the ELMs (edge localized modes) either cause a fast increase of the antenna load or induce arcs. Induced by the rearrangement of the diagnostic positions resulting from the DED installation on TEXTOR, a new antenna system has been designed, which allows a large flexibility of operation and can test, in particular, the load-variation-tolerant “conjugated-T mode” of operation foreseen for the new JET ITER-like antenna. The control of the ICRH-systems has also been renewed.

Ion cyclotron radio frequency has been used to produce plasmas for machine conditioning purposes. A comparative study using ECRH has now also been performed.

On the theoretical side, important results relate to ICR heating with large minority fractions such that the interaction of the tail particles with themselves were obtained with a non-linear Fokker-Planck model. The antenna modelling with ICANT has concentrated on the description of straps with a realistic, non-zero thickness, in view of the latter’s influence on both the real and imaginary part of the antenna impedance.

Theoretical work is also under way to study the penetration of the waves excited by the (poloidally rotating) perturbation imposed by the DED.

LPP-ERM/KMS has forcefully contributed to the experimental program of JET especially in the Task forces S1 (Confinement) and H (Heating). Task force S1, for which LPP provided the Task force leadership, further substantiated the ITER stationary plasma conditions. New impurity seeding experiments allowed mitigating the negative impact of Type-I ELMs. Near double-null discharges indicated first prospects for benign Type-II ELMy operation. In Task Force H, LPP-ERM/KMS contributed to transient heat transport studies in L-mode and in ITB-plasmas. Exploitation of the He$^+$ minority scheme showed that central electron heating after mode conversion allows a confinement improvement of about 20%. Some support was also given to Task forces E and D.

LPP-ERM/KMS is the lead Association in the JET Enhanced Performance project aiming at constructing an ITER-like ICRH antenna, which should be capable of delivering multi-second pulses at 8 MW/m$^2$ power flux combined with adequate ELM resilience under H-mode conditions. The small JET enhancement project, for filtering of RF harmonics in transmission lines, has been completed.
Within the TEC collaboration, IPP Jülich is working on several scientific tasks which are directly related to the planning of ITER diagnostics. Furthermore, IPP Jülich is preparing to take over significant contributions to the detailed design of heating and work is going on for the development and qualification of materials for plasma facing components (see also report of the institute for materials and processes in energy systems, IWV).

Contributions to the physics base of ITER and confinement improvement are described in the results obtained from TEXTOR and JET.

**Diagnostics**

In the course of 2002, the available expertise and resources for these planned contributions have been analysed within the TEC and a planning of possible diagnostics to ITER has been undertaken and coordinated with the EURATOM partners.

As a result of the ITER diagnostics planning among the EU partners, the TEC has expressed its interest to participate in the following ITER diagnostic systems:

1. Core Thomson scattering (LIDAR) as a participating Association.
2. Polarimeter (poloidal field measurement) as the leading Association.
3. Collective Thomson scattering as a participant.
4. Divertor impurity monitors as a participant.
5. Charge exchange resonance spectroscopy based on the diagnostic beam as a participant.
6. Motional Stark effect (MSE) based on the heating beam as the leading Association.
7. Electron cyclotron emission as a participant.
8. Main plasma reflectometry as a participant.
9. IR/visible cameras as a participant.
10. Assembly of the equatorial port plug no. 10, possibly together with Forschungszentrum Karlsruhe.

It is expected that the necessary coordination of the diagnostic tasks between the ITER partners (EU, Japan, Russia, Canada and possibly USA) will lead to a slight reduction of the total number of EU contributions, possibly followed by a further concentration of the work packages among the EU partners.

Much work has been devoted to a feasibility study for the poloidal polarimeter for current density measurements in ITER. The work, that has been done by a consortium of EU Associations has concentrated on a detailed sensitivity study, optical raytracing calculations and on calculations of the optical characteristics of retro-reflectors.
Heating

The particular expertise on heating methods within the TEC is offered for contributions in the procurement of ECRH and ICRH for ITER. Regarding the ICRH system, it has been agreed among the EU partners that the TEC is ready to provide the ICRH antenna plus the corresponding port plug. A test version of the antenna is prepared and will be tested at JET. While the Belgian TEC partner is working on the physics design and related modelling, the IPP would concentrate more on the support of the electro-mechanical part of the project. For the development of the ECRH system for ITER, a team of 6 full-time professionals of the Dutch TEC partner FOM is involved in the design of the upper-port launcher. Contrary to the conventional front-steering system, where mirrors rotate very close to the plasma, FOM is developing the remote-steering launcher. Here, the required scan of +/- 5 degrees in the vertical plane, is achieved by means of rotating a mirror far away from the plasma, launching the mm-wave beam into a square waveguide, resulting at the end of the waveguide in the same scanning angles.

Modelling

As an ongoing long term support of the ITER team the B2-EIRENE plasma edge and divertor modelling code is permanently supported by IPP. In 2002 in particular the implementation of elastic collision processes between noble gas atoms (in particular Helium) and the plasma deuterons has led to a revision of the predicted ITER helium removal capabilities. Due to it’s size the dynamics of the ITER divertor will also be significantly affected by opacity effects of the Lyman line radiation (distinct from present experiments). Corresponding code extensions and first applications of the EIRENE neutral particle Monte Carlo code (as used by the ITER-divertor design team) towards a radiation transfer simulation tool has been carried out and will be made available to ITER with one of the next updates of the EIRENE code package.

In connection with edge modelling efforts addressing the critical Carbon erosion and Tritium retention issues an entirely new and up to date collision database for hydrocarbon particles (up to C3H8), involving more than 500 individual reaction channels, has been established, published and made available to the ITER team.

Materials development

The plasma facing components in thermonuclear fusion devices are subjected to intense fluxes of charged and neutral plasma particles and radiation. Resulting from these plasma-wall-interaction processes the materials will be degraded with respect to their thermal and mechanical properties; in addition wall erosion is another critical issue which has significant impact on the lifetime of plasma facing components and on the contamination of the fusion plasma. The plasma facing materials in future fusion devices are primarily based on beryllium, boron, carbon or silicon as well as tungsten in combination with copper as a heat sink. A major aim of the R & D activities is to develop and fabricate new materials for ITER or Wendelstein 7-X and to characterise and to test them under simulated operation conditions, i.e. at thermal loads up to 20 MWm⁻² and at neutron fluences up to approx. 1 dpa.

To improve the performance of plasma facing components which are subjected to extreme thermal loads new plasma compatible materials with favourable thermal and mechanical properties have to be developed. Today in most of the existing fusion devices carbon based materials, in particular isotropic and carbon fibre reinforced graphites (CFC), are the prime candidates for the first wall protection or the divertor armour. To reduce the sputter erosion during plasma exposure and to improve the oxidation resistance, different manufacturing processes for siliconised CFCs are being investigated. The liquid silicon infiltration process is an approved method to partially
convert carbon based materials into more erosion resistant SiC. However, the presence of excess silicon is a severe drawback as it is a possible source for plasma contamination. In a modified C/SiC manufacturing process silicon is introduced as highly dispersed reactive filler into a carbon matrix. Due to the intimate mixing a complete conversion to SiC during the final 1450 °C treatment is obtained.

The lifetime of plasma facing components under intense cyclic heat fluxes strongly depends on the interface between plasma facing material (PFM) and the metallic heat sink which in general consists of a copper alloy. Hence, beside the materials selection and the geometry the type of joining technology has strong impact on the quality and the robustness of the joint. To reduce inherent stresses which originate from the mismatch of the thermal expansion coefficients of the armour and the heat sink materials, graded interface structures are being developed. In particular the promising material candidates tungsten (PFM) and copper (heat sink) exhibit substantial differences in their thermal and mechanical properties. Two different processes have been selected to produce functionally graded materials (FGM), namely laser sintering using the blown powder process and vacuum plasma spraying. For both processes composite materials with a wide variation of the W/Cu ratio have been manufactured successfully. The resulting test samples have been utilized to provide a database with thermal and mechanical properties; these data will be used to optimise the performance of graded interfaces by finite element methods.

**Thermal fatigue and thermal shock behaviour**

In existing or next step fusion devices the plasma facing materials and components are subjected to cyclic quasi stationary thermal loads up to ≈ 20 MWm⁻² during normal operation, and short transient thermal pulses with energy densities of several 10 MJm⁻² during plasma disruptions or vertical displacement events. These events may be associated with intense thermal fatigue and thermal shock damage. To evaluate the component behaviour and the resulting material damage under ITER relevant conditions high heat flux simulation tests are being performed in powerful electron beam (JUDITH, hot cells at FZJ) and ion beam test facilities (MARION, IPP at FZJ). These experiments are focussed on different design options of high heat flux components with beryllium, carbon, B₄C and tungsten armour.

Pre-existing or thermal fatigue induced defects in high heat flux components can be detected by infrared thermography; this non-destructive inspection technique allows the assessment of surface temperature variations by means of a sensitive IR scanner. The newly developed IR test stand IRINA (IR Inspection by Non-destructive Analysis) is equipped with well calibrated cold and hot water loops; it allows the detection of defects and internal thermal barriers in actively cooled plasma facing components.

The generation of dust during off-normal plasma scenarios is another critical concern. Melt layer instabilities e.g. during plasma disruptions can generate significant amounts of activated W-dust in future fusion reactors. On the other hand, carbon based materials are damaged by brittle destruction; this processes results in a macroscopic erosion of graphite or CFC components forming carbon dust particles with diameters up to approx. 100 microns. The latter process has been analysed by electron beam simulation experiments. In these tests the threshold for the onset of the brittle destruction process has been determined for different pulse durations from 1 to 100 ms; in terms of the heat conduction parameter Pt¹/₂ this threshold is > 100 MJ m⁻²s⁻¹/₂.
Neutron induced material degradation

Complex neutron irradiation campaigns have been carried out in the High Flux Reactor (HFR) at Petten (NL) to investigate the degradation of materials and components under ITER-specific neutron doses. In the latest irradiation programme PARIDE 3 and 4 fluences up to 1 dpa have been applied to Be, CFC, W and Cu samples at irradiation temperatures of 200 and 700 °C. The post irradiation examination of the test samples which was initiated in 2002 includes comprehensive analyses of thermal and mechanical properties (thermal diffusivity, mechanical fatigue) as well as high heat flux tests up to 1000 thermal cycles in the hot cell electron beam test facility JUDITH.
The stellarator concept is the most promising alternative to the tokamak because of its inherent stationary plasma operation. The prospect of stationarity opens new possibilities to investigate reactor-relevant physics issues. However, it also requires additional solutions for the accompanying technical problems which are for instance related to the superconducting field coils, the durability and cooling issues of wall elements as well as the control and data analysis of diagnostics. FZJ participates in the design and construction of diagnostics for the stellarator Wendelstein 7-X which is presently being built at Greifswald by taking over a large work package. In the future, FZJ will also participate in the scientific exploitation of the project.

For Wendelstein 7-X possible construction tasks supporting the assembly of the machine have been identified. Two major activities have been defined and already started: The superconducting bus-bar system will be laid out and manufactured in Jülich. This includes routing, development of electrical insulation and mechanical support as well as appropriate testing. Secondly, electromagnetic and mechanical calculations for the detailed design of Wendelstein 7-X will be done in Jülich together with the Efremov Institute, St. Petersburg. In particular, the design, construction and installation of support structures to be located between the planar and non-planar coils will be made.

The design for a set of new VUV/XUV spectrometers has been developed, which shall be used for impurity monitoring and impurity transport studies at the stellarator Wendelstein 7-X. The four new systems cover the entire wavelength range from 2.5 nm to 160 nm, divided into four subsections with some overlapping, thus achieving a complete coverage of prominent spectral lines from the relevant impurity elements. Numerically optimised toroidal holographic diffraction gratings are designed and the spectrometer geometries and detector properties are chosen to obtain a high efficiency at a good wavelength resolution. The performance of the spectrometers is tested and optimised by means of ray tracing calculations. In order to investigate the possibilities for line identification as well as the expected levels of accuracy of the new systems, simulated spectra have been calculated using the impurity transport code STRAHL. Under typical plasma conditions the new spectrometers will allow to clearly identify practically all relevant impurity elements in the plasma. The large collected photon flux allows to achieve a high accuracy for the measured line intensities even when operating the spectrometers at spectra rates of 1000/sec.

A high energetic diagnostic hydrogen beam is presently successfully operated on TEXTOR. A similar beam is foreseen on Wendelstein 7-X. In the frame of a co-operation between the Budker Institute of Nuclear Physics (BINP) in Nowosibirsk, Russia, a diagnostic injector will be developed, the beam of which provides an equivalent current of more than 5 A at 60 keV. During the whole duration of injection (10 s) the beam properties (divergence < 0.5º, particles with full energy > 70 %) should be maintained. The pulse duration shall also cover the phases with addi-
tional neutral particle heating and will – with a pulse frequency of at least 0.5/min – also allow measurements during very long discharges. An additional beam modulation of 100 Hz will help to discriminate active and passive signal intensities and to improve the quality of the data. Under the co-ordination of FZJ/IPP the necessary actions, such as ordering and construction of peripheral components has been started.

In 2002 the disposition of the available budget for Wendelstein 7-X diagnostics was discussed and updated. As a result, limited resources led to a concentration on the most necessary parts. In particular there was a reduction of the present efforts in the edge and divertor diagnostics. Shifted, however not cancelled, were the high-resolution X-ray imaging spectrometer and the Target Tile Manipulator. It was agreed that the devices can be fitted later to the vessel without too much additional effort and that for the latter, the necessary preparations would be made in the divertor modules. Similar as to the other two projects, for which a co-operation contract already exists, another contract could be placed soon.

The plasma facing components in thermonuclear fusion devices are subjected to intense fluxes of charged and neutral plasma particles and radiation. Resulting from these plasma-wall-interaction processes the materials will be degraded with respect to their thermal and mechanical properties. A major aim of the activities is to develop and fabricate new materials for Wendelstein 7-X and to characterise and to test them under simulated operation conditions, i.e. at thermal loads up to 20 MWm$^{-2}$. To evaluate the component behaviour and the resulting material damage under Wendelstein 7-X relevant conditions high heat flux simulation tests are being performed in powerful electron beam (JUDITH, hot cells at FZJ) and ion beam test facilities (MARION, IPP at FZJ). These experiments are focussed on different design options of high heat flux components with carbon, B$_4$C and tungsten armour.
The plasma facing components in thermonuclear fusion devices are subjected to intense fluxes of charged and neutral plasma particles and radiation. Resulting from these plasma-wall-interaction processes the materials will be degraded with respect to their thermal and mechanical properties; in addition wall erosion is another critical issue which has significant impact on the lifetime of plasma facing components and on the contamination of the fusion plasma. The plasma facing materials in future fusion devices are primarily based on beryllium, boron, carbon or silicon as well as tungsten in combination with copper as a heat sink. A major aim of the R & D activities is to develop and fabricate new materials for future fusion devices such as ITER or Wendelstein W7-X and to characterise and to test them under simulated operation conditions, i.e. at thermal loads up to 20 MWm$^{-2}$ and at neutron fluences up to approx. 1 dpa.

Materials development

To improve the performance of plasma facing components which are subjected to extreme thermal loads new plasma compatible materials with favourable thermal and mechanical properties have to be developed. Today in most of the existing fusion devices carbon based materials, in particular isotropic and carbon fibre reinforced graphites (CFC), are the prime candidates for the first wall protection or the divertor armour. To reduce the sputter erosion during plasma exposure and to improve the oxidation resistance, different manufacturing processes for siliconised CFCs have been investigated. The liquid silicon infiltration process is an approved method to partially convert carbon based materials into more erosion resistant SiC. However, the presence of excess silicon is a severe drawback as it is a possible source for plasma contamination. In a modified C/SiC manufacturing process silicon has been introduced as highly dispersed reactive filler into a carbon matrix. Due to the intimate mixing a complete conversion to SiC during the final 1450°C treatment has been obtained.

The lifetime of plasma facing components under intense cyclic heat fluxes strongly depends on the interface between plasma facing material (PFM) and the metallic heat sink which in general consists of a copper alloy. Hence, beside the materials selection and the geometry the type of joining technology has strong impact on the quality and the robustness of the joint. To reduce inherent stresses which originate from the mismatch of the thermal expansion coefficients of the armour and the heat sink materials, graded interface structures are being developed. In particular the promising material candidates tungsten (PFM) and copper (heat sink) exhibit substantial differences in their thermal and mechanical properties. Two different process have been selected to produce functionally graded materials (FGM), namely laser sintering using the blown powder process and vacuum plasma spraying. For both processes composite materials with a wide varia-
tion of the W/Cu ratio have been manufactured successfully. The resulting test samples have been utilized to provide a database with thermal and mechanical properties; these data will be used to optimise the performance of graded interfaces by finite element methods.

Materials characterization

The generation of dust during off-normal plasma scenarios is another critical concern. Melt layer instabilities e.g. during plasma disruptions can generate significant amounts of activated W-dust in future fusion reactors. On the other hand, carbon based materials are damaged by brittle destruction: this processes results in a macroscopic erosion of graphite or CFC components forming carbon dust particles. To approach the erosion mechanism, optical diagnostics, i.e. emission spectrometer (400 - 800 nm) and a silicon photodiode have been newly installed in the electron beam test facility JUDITH. First attempts were successfully carried out on carbon based materials at high heat fluxes of 2.2 GW/m². The results showed that the initiation temperature of particle release depends on the surface temperature. The time evolution of light emission indicated that the particle release processes were clearly different between graphite and CFC. In addition, particle release in the cooling phase was observed in CFC. The particle release due to brittle destruction is related to the thermal stress in the materials. Ionised vapour clouds were observed by the detection of CII lines and lines from the C2 Swan system. The intensity ratio of lines indicated that the density and temperature of the vapour clouds were dependent on the materials.
C. TECHNOLOGY PROGRAMME

C.1. CHARACTERIZATION OF MATERIALS AND COMPONENTS FOR PLASMA/WALL INTERACTION

IWV, E.11203.04, J. Linke

An important task of the technology programme is the development of plasma-interactive components for ITER (International Thermonuclear Experimental Reactor) and future electricity generating fusion reactors. Major aim of this research programme is the characterization of plasma facing materials and actively cooled components and their assessment with respect to their thermo-mechanical and neutron irradiation behaviour.

Thermal fatigue and thermal shock behaviour

In existing or next step fusion devices the plasma facing materials and components are subjected to cyclic quasi stationary thermal loads up to \( \approx 20 \text{ MWm}^{-2} \) during normal operation, and short transient thermal pulses with energy densities of several \( 10 \text{ MJm}^{-2} \) during plasma disruptions or vertical displacement events. These events may be associated with intense thermal fatigue and thermal shock damage. To evaluate the component behaviour and the resulting material damage under W7-X or ITER relevant conditions high heat flux simulation tests have been performed in a powerful electron beam test facility (JUDITH, hot cells at FZJ). These experiments are focused on different design options of high heat flux components with beryllium, carbon, and tungsten armour.

High heat flux tests on primary first wall mock-ups have been carried out in the electron beam facility JUDITH. These modules consisted of beryllium as a plasma facing material, a heat sink from copper alloys and a back plate from stainless steel. They were 100 mm in width and up to 250 mm in length. Joining processes were hot isostatic pressing (HIP), brazing or diffusion bonding. A typical example for these mock-ups is shown in fig. 1. Most of the mock-ups survived thermal fatigue experiments up to 1.5 MW/m\(^2\) (absorbed), but between 1.5 and 2.5 MW/m\(^2\) the failure limits were reached.

Five CFC mock-ups for divertor applications have been tested under thermal fatigue conditions. All samples were of the flat tile type. They were produced by HIPing and diffusion bonding, respectively. The failure limits for the HIPed samples were found to be around 10 MW/m\(^2\). This is less than for former CFC flat tile mock-ups which had been produced by active metal casting and electron beam welding which showed failure beyond 20 MW/m\(^2\). A first diffusion brazed mock-up failed at a low power density of 4.9 MW/m\(^2\). But the performance could be improved by modification of the braze metal, and the failure limits were risen up to 15 MW/m\(^2\).

(TW2-TVP/PFCFT, TW2-TVV-FW MUHF)
A Round Robin Test (RRT) with identical CFC armoured actively cooled mock-ups has been initiated in 5 different electron beam test facilities. Within this test campaign an additional high heat flux test is scheduled in the NB teststand at JET in January 2003.

Since the industrial manufacturing process of the test modules has been delayed significantly; first emissivity calibrations tests have been performed in April 2002. In different Round Robin Test campaigns which were performed in JUDITH and in the FE-200 facility (Le Creusot, F) thermal load tests have been carried out at power densities levels of 2.5, 5, 7.5 and 10 MWm\(^{-2}\). After reaching the thermal equilibrium, surface temperatures and temperatures at the thermo couple positions were compared.

\((DW0-TV1/02, JWX-FT-6.3)\)

Pre-existing or thermal fatigue induced defects in high heat flux components can be detected by infrared thermography; this non-destructive inspection technique allows the assessment of surface temperature variations by means of a sensitive IR scanner. The newly developed IR test stand **IRINA** (**IR** INSpection for **N**on-destructive **A**nalysis) is equipped with well calibrated cold and hot water loops; it allows the detection of defects and internal thermal barriers in actively cooled plasma facing components.

**Dust formation during transient thermal loads**

The generation of dust during off-normal plasma scenarios is another critical concern. Melt layer instabilities e.g. during plasma disruptions can generate significant amounts of activated W-dust in future fusion reactors. On the other hand, carbon based materials are damaged by brittle destruction; this process results in a macroscopic erosion of graphite or CFC components forming carbon dust particles with diameters up to approx. 100 microns. The latter process has been analysed by electron beam simulation experiments. In these tests the threshold for the onset of the brittle destruction process has been determined for different pulse durations from 1 to 100 ms; in terms of the heat conduction parameter \(P.t^{1/2}\) this threshold is \(> 100 \text{ MJ m}^{-2} \text{s}^{-1/2}\).

\((Underlying Technology Task)\)

**Mechanical characterization of CzCrZr-SS-joints**

The cooling tubes of plasma facing components in ITER are made from CuCrZr, but they have to be joint to tubes from stainless steel 316. Tubular joints between these two materials have been produced by several producers by HIPing. These joints are tested in internal pressure tests, tensile tests and under fatigue conditions. In all tensile test the fracture is observed at the edge between the copper and the steel. The mean tensile strength was 330 MPa. which is about 75% of the tensile strength of CuCrZr.

\((TW1-TVP/MAN1)\)
Neutron induced material degradation

Complex neutron irradiation campaigns have been carried out in the High Flux Reactor (HFR), Petten (NL) to investigate the degradation of materials and components under ITER-specific neutron doses. In the latest irradiation programme PARIDE 3 and 4 fluences up to 1 dpa have been applied to Be, CFC, W and Cu samples at irradiation temperatures of 200 and 700°C. The post irradiation examination of the test samples which was initiated in 2002 includes comprehensive analyses of thermal and mechanical properties (thermal diffusivity, mechanical fatigue) as well as high heat flux tests up to 1000 thermal cycles in the hot cell electron beam test facility JUDITH.

(GB8 - DV6, TW1-TVP/TU1)

In order to study the influence of neutron irradiations on the thermal conductivity of tungsten al-
loys, samples were cut from materials irradiated in the irradiation experiments PARIDE 1 – 4. Thermal diffusivities for W, W-La$_2$O$_3$ and W-5Re were measured by a laser flash apparatus. For all materials a reduction of thermal diffusivity is observed. This reduction is more severe for lower irradiation temperatures and for higher neutron doses (s. fig. 2).

(TW1-TVP/TU1)

Fig. 1: Primary first wall mock-up from beryllium / CuCrZr / SS316IG

Fig. 2: Thermal diffusivity of W-La$_2$O$_3$ after neutron irradiation
Dr. K. Kühn; Dipl.-Ing. H.-K. Hinssen; Dr. R. Moormann, PES-FZJ Task GB9-V65

Introduction

Oxidation examination of CFC – materials, partly developed for fusion applications (first wall) where certain mechanical and thermal properties like strength and thermal conductivity are needed, were continued. This is required, because in contrast to these advantageous properties the carbon materials show decreasing oxidation resistance with increasing temperatures: In high temperature systems with non-oxidising environment (like vacuum vessels or inert gas controlled atmospheres) an ingress of oxidising gases (air or steam) leads to corrosion of the carbon materials and thereby to a loss of their mechanical and thermal properties, combined with radioactive release.

Oxidation measurements in air and steam were done in the chemical reaction controlled regime I [1] in order to support the development of innovative carbon materials which are foreseen for fusion reactors. In regime I the reactions between gases and homogeneous porous solids at low temperatures are controlled by the chemical reaction itself: The material is oxidised homogeneously within the pore system, resulting in high strength loss. The reactive surface is changing during oxidation and a strong dependence of the volume related rate on burn-off with a maximum is found. An extrapolation of regime I data to higher temperatures is comparatively easy.

Experiments

The investigated materials are two- and three directional carbon fibre composites (2D-CFC; 3D-CFC) whereas one material was doped with 8 – 10 % silicon. The main data of the investigated material are given in Tab. 1. N31/NS31 are reference materials for ITER.

Tab.1: Investigated materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
<th>Density [kg/m³]</th>
<th>Ash-content</th>
<th>Si-content [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO5</td>
<td>2D-CFC</td>
<td>1870</td>
<td>&lt;200 ppm</td>
<td>-</td>
</tr>
<tr>
<td>N31/NB31</td>
<td>3D-CFC</td>
<td>1920</td>
<td>&lt;0,1%</td>
<td>-</td>
</tr>
<tr>
<td>NS31</td>
<td>3D-CFC</td>
<td>2120</td>
<td>&lt;0,1%</td>
<td>8-10</td>
</tr>
</tbody>
</table>

The experimental investigations were performed under isothermal conditions at temperatures between 773 – 1073 K in air and between 1173 – 1253 K in steam. Long term experiments at low temperatures (773 K) take place in an annealing furnace, all other experiments in a thermogravimetric apparatus (THERA) [1, 2]. The partial pressures (ambient / 1 bar in air and a slightly
overpressure of 1.05 bar in steam to inhibit air ingress into the cavity) and the gas flow rates were held constant during experiments. The experiments were stopped after achieving a total weight loss of about 60 – 90 % which corresponds to a run time between 8 – 1000 h in air and 18 – 45 h in steam.

**Results**

The experimental investigations in air and in steam show clearly a different oxidation behaviour as well material as oxidising gas dependent [3].

**AO5:**

In case of the 2D-CFC AO5 during oxidation in air a rate increase with increasing burn off can be observed. An example for this behaviour is given in Fig. 1 for 1023 K. In this case the rate increase of AO5 is about a factor of 2.2 to a maximum of 30 % burn off. The activation energy is 150 kJ/mol.

![Fig. 1: AO5: burn off vs. rate at 1023 K (air)](image1)

In steam a less pronounced rate maximum was determined for AO5 at 1173 and 1253 K (Fig. 2). These values are very close to that of the 3D-CFC NS31 (see Fig. 6) and obviously smaller than that of the NB31 (Fig.4).

![Fig. 2: AO5: burn off vs. rate at 1173 and 1253 K (steam)](image2)
N31/NB31/NS31:

The 3D-CFC N31 show during oxidation in air at 773 K relatively high corrosion rates in relation to the Si-doped 3D-CFC NS31 (Fig. 3). In long term experiments a burn off value of 70–80\% was reached between 800 – 1000 h, whereas the NS31 reach at maximum only 50 \% burn off in the same time span due to protection by SiO\textsubscript{2} formation. In general the materials of Fig. 3 reveal comparatively high rates due to heat treatment temperatures of the matrix not sufficient for achieving ordered graphitic structures.

![Oxidation in air at 773 K](image)

**Fig. 3:** N31 and NS31: burn off vs. time at 773 K (air).

In steam the 3D-CFC NB31 shows a pronounced maximum at 20 \% burn-off for 1253 K, whereas this maximum is less pronounced at 1173 K (Fig. 4). The activation energy for 20 \% burn off is 215 kJ/mol.

![NB31 burn off vs. rate at 1173 and 1253 K (steam)](image)

**Fig. 4:** NB31 burn off vs. rate at 1173 and 1253 K (steam)

Experiments on the Si-doped 3D-CFC NS 31 reveal a rate maximum at 15 \% burn off at 1023 K in air (Fig. 5). Here the weight change stems from C burn off and from the generation of solid SiO\textsubscript{2}: The doping of Si into the carbon implicates a higher density and lower porosity and is agreed to increase the oxidation resistance of the material by formation of SiO\textsubscript{2}-layer impermeable for oxidants.
An activation energy of 175 kJ/mol was evaluated for the rate maximum. The oxidation rates of NS31 are not smaller than that of AO5, but a factor of 2 smaller than that of the undoped 3D-CFC N31 (see Fig. 3).

![Graph of 3D CFC NS31 Oxidation in air at 1023 K (regime I)](image)

**Fig. 5:** NS31: weight loss vs. rate at 1023 K (air)

Except of the rates being a factor of about 2 smaller the behaviour of NS31 in steam is very similar to that of N31/NB31 (see Fig. 4). Here the maximum is less pronounced at 1253 K in comparison to the NB31 and again less pronounced at 1173 K in comparison to the higher temperature. The activation energy is only 160 kJ/mol at 10 % burn off.

![Graph of 3D-CFC NS31 Oxidation in steam at 1173 and 1023 K (regime I)](image)

**Fig. 6:** NS31 burn off vs. rate at 1173 and 1253 K (steam)

Comprising, the experimental investigations show, that the oxidation behaviour of homogeneous materials in the chemical reaction controlled regime I is characterized by a continuous rate versus burn off curve with one (more or less pronounced) maximum. However, whereas the shape of rate versus burn off curves is roughly similar in air and in steam, the rates differ remarkably: Achieving similar rates in regime I as in air requires for steam oxidation about 250 K higher temperatures.


These tasks comprise investigations on the effects of the transmutation products hydrogen and helium on elastic and mechanical properties and microstructure of materials in the first-wall and blanket of a fusion reactor. The materials investigated are iron, reduced activation martensitic stainless steels, tungsten and ceramic materials. Implantation of hydrogen and helium ions by the Jülich compact cyclotron CV28 is used to simulate the loading by transmutation. In the case of hydrogen also loading from plasma and from gas-phase is employed.

A. Long Term Programme / Task Area: Materials Development

Subtask: TW2-TTMS-001 (Irradiation performance)

D1: Helium implantation in pure iron and RAFM steels in support of D8 activities

In this subtask specimens of pure iron and EUROFER97 were prepared and implanted at about 60°C and 350°C to helium concentrations of 1, 10 and 100 appm. Part of the specimens were analysed by positron annihilation spectroscopy at Riso National Laboratory, another part was installed in a fast reactor (Mol) to study the effect of helium on cavity formation in subsequent investigations.

Subtask: TW2-TTMS-003 (Compatibility with Hydrogen and Liquids)

D1: Improved modelling of H diffusion and trapping and effect of He on H retention. T-range: RT-300°C

Permeation and diffusion of deuterium in He-implanted EUROFER97

Permeability \( P^* \) of deuterium in EUROFER97, implanted to 500 appm helium, is reduced in comparison to virgin as well as to pre-irradiated material (Fig.1). Annealing of the helium implanted specimens at 750°C for 10 hours, reduces permeability additionally. Diffusivity \( D^* \) of deuterium in EUROFER97 is also strongly reduced in the helium-implanted material, but is at least partially recovered by annealing (Fig. 2). This indicates trapping of deuterium by irradiation defects, but even more by atomic as well as by clustered helium. Solubility of deuterium given by \( P^*/D^* \) as shown in Fig. 3. It indicates that solubility is enhanced by atomic helium, but reduced when He bubbles are formed by annealing.
The enhanced decrease of $D^*$ at temperatures below about 250°C (Fig. 2) indicates trapping of hydrogen by defects. If these low-temperature values are compared at various pressures to diffusivity in the lattice $D_L$ without defects, as obtained by extrapolation from higher temperatures, the plot in Fig. 4 is obtained. According to the saturable trap model, the following equation holds:

$$\frac{D_L}{D^* - 1} = 3\alpha \left(1 + 2\left(1 - \left(1 + \frac{1}{\beta}\right) \ln(1 + \beta)/\beta\right)\right)$$

with $\alpha = n_T/n_H$ and $\beta = (n_H/n_L)\exp(E_b/RT)$ ($n_L = 6n_0$), with $n_L$, $n_T$, $n_H$, $n_0$ giving the densities of normal diffusion sites for hydrogen, of trap sites, of hydrogen atoms, and the number density of lattice atoms, respectively. From the initial slope of these curves, corresponding to high pressures, the ratio of trap concentration to solubility is obtained: $D_L/D^*-1 = 3\alpha = 3 \cdot n_T/Kp^{1/2}$, while the asymptotic value, corresponding to low pressures, gives the ratio of traps to lattice sites: $D_L/D^* - 1 = \alpha \cdot \beta = (n_T/n_L)\exp(E_b/RT)$, with $E_b$ the binding energy of hydrogen to traps. These data are plotted in Figs. 5 and 6, respectively.
From Fig. 6 an increase of $n_T/n_L$ due to pre-irradiation as well as due to helium implantation is obtained, while the binding energy is unchanged within experimental error around 45 kJ/mol.

**Desorption of deuterium from helium implanted EUROFER97**

The binding energy can also be derived from desorption experiments, when helium implanted specimens are loaded with hydrogen from the gas phase. Desorption curves from pure iron are shown in Fig. 7 for different heating rates.
Two peaks are clearly separated which give similar dissociation energies of 19 and 24 kJ/mole, respectively (Fig. 8). These values are significantly smaller than the binding energies derived from the above diffusion measurements.

D2: Low temperature embrittlement of EUROFER by implanted H and He

Tensile tests were performed on EUROFER97 after implantation of hydrogen or helium to various concentrations. The data on stresses and strains are summarised in Figs. 9 to 12.

The results can be summarised as follows: Hydrogen causes much less hardening and much lower loss of ductility than helium. For both transmutants hardening and embrittlement decreases with increasing test-temperature.
B.1.: Field: 1.TP Physics / Task Area: 1.4.TPH: Heating and Current Drive

Subtask Title: Microstructure of Oxide Ceramics and Diamond Containing High Helium Concentrations

Diamond and oxides are candidates for special purpose materials, mainly insulators and HF-windows. The irradiation field in a fusion reactor will affect their electrical as well as mechanical properties by atomic displacements and by producing transmutation products, mainly hydrogen and helium. In the present subtask diffusion and desorption of helium is investigated, as well as microstructural and mechanical changes induced by high helium concentrations.

In-situ desorption from oxides

Helium was implanted at temperatures from 350° to 750°C in Al₂O₃ specimens of thicknesses up to 250 µm. Implantation depth R was adjusted by varying the ion energy. During implantation, desorption through the backside surface was recorded. The fractional flux as a function of R is shown in Fig. 13. It increases only slightly with increasing temperature and decreases strongly with increasing distance of the implantation from the surface.

Results from Transmission-Electron-Microscopy

Systematic TEM investigations on Al₂O₃ were performed under improved control of implantation conditions. The specimens were soldered during implantation to a water-cooled heat sink and were subsequently annealing from 800° to 1400°C for 0.1 to 10 hours. Above 900°C, 2-dimensional features with void contrast (platelets) form on basal-planes (Fig. 14). At 1000°C they begin to transform to 3-dimensional bubbles. Concurrently I-loops form on prismatic planes (Fig. 15). The loops are elongated along directions parallel to the basal-plane (Fig. 16). They form networks above 1200°C. At 1000°C no significant time evolution is observed from 0.1 to 10 hours.
B.2.: Field: 2.TV Vessel in Vessel / Task Area: 2.1.TVP Plasma Facing Components

Sub-Task Title: Microstructure of Tungsten Containing High Helium Concentrations

First wall and divertor materials of future fusion reactors will experience severe changes of their microstructural and mechanical properties by irradiation effects due to atomic displacement and transmutation products, mainly hydrogen and helium. In the present subtask, which continues previous work on carbon-based materials, SiC, ceramics and Be, the effects of helium on microstructural and mechanical properties of tungsten are studied and attempts are made to identify the underlying mechanisms.

Lattice strains in helium implanted tungsten

After implantation and subsequent isochronal annealing in steps of 50°C up to 1350°C, the evolution of lattice strains was measured by surface profilometry (Fig. 17). At annealing temperatures up to 1000°C irradiation induced strains are reduced, which can be ascribed to annealing of lattice defects. Above 1200°C strain increases again due to bubble growth. Thus, by the present method of strain measurement, which was developed in this programme for ceramic materials, the detection of bubble growth at much lower concentration is possible than by TEM.
Microstructure of helium implanted tungsten

600 appm helium were implanted into hot-rolled tungsten at room temperature and parts of the specimens were annealed for 1 hour at various temperatures. Only above 1250°C bubbles become visible by transmission electron microscopy (Fig. 18). Without hot rolling, the defect structure of the tungsten made observation of helium bubbles even more difficult as seen in Fig. 19 for a concentration of 2000 appm (equal magnification as Fig. 18).

![Fig. 17: Isochronal annealing of lattice strains in tungsten after implantation of 29 appm He at room temperature in a layer of 70 µm. For comparison, annealing curves from literature are given after neutron-irradiation, cold-working and quenching. The increase in strain above 1200°C in the implanted specimen indicates the growth of helium bubbles.](image)

![Fig. 18: Transmission electron microscopy of hot-rolled tungsten, implanted at room temperature to 600 appm He and annealed for 1 hour at 1350°C.](image)

![Fig. 19: Transmission electron microscopy of tungsten, implanted at room temperature to 2000 appm helium and annealed for 1 hour at 1350°C. A few bubbles are visible, mainly along grain boundaries.](image)
Desorption of helium from tungsten during implantation

Helium was implanted into tungsten to various depths (by changing the implantation energy) at temperatures from 570° to 830°C. The time evolution of helium desorption gives information on the migration and trapping behaviour of helium. Only a small fraction of the implanted helium is desorbed, which slightly increases with increasing temperature (Fig. 20). Only for implantation within 5 µm from the surface, the desorption flux exceeds 1% of implantation.

Fig. 20: Relative current of helium desorbing from tungsten during implantation as a function of minimum distance $R_{\text{min}}$ of implantation from surface ($j_{\text{ion}}$ is the implantation current, $d$ is the specimen thickness). Results for molybdenum are shown for comparison.
Collaboration between IPP Jülich and the University of Toronto

Steven Lisgo and Detlev Reiter

The focus of the collaboration is the development and application of the EIRENE computer code for the purpose of modelling neutral particle behaviour in a tokamak divertor environment. EIRENE has been made part of OEDGE; a suite of computer codes used for interpretative studies of the edge plasma and the associated vacuum regions. It provides the neutral solution throughout the modelling region, and also the mass, momentum and energy source terms from neutral-plasma interactions that are required when calculating the plasma solution.

Results from the OEDGE modelling of partially detached plasma conditions in the divertor of the Alcator C-Mod tokamak were recently presented by the University of Toronto [Lisgo, Ph.D. thesis, 2003]. The calculated plasma and neutral solutions indicated high levels of volume recombination and high neutral atom densities, which suggest that photons are being trapped in the C-Mod divertor. This is consistent (qualitatively) with experimental observations. Photon transport was not explicitly included in the OEDGE simulations, although it was being developed concurrently for EIRENE at Jülich. The EIRENE development is now completed, and the detached plasma solutions will be revisited with OEDGE to determine how photon trapping will affect the radiation field and the net production of neutral particles.

EIRENE development associated with this collaboration will be incorporated into the circulated version of OEDGE, to the benefit of modelling efforts at IPP Garching, JET, C-Mod and DIII-D.
Plasma wall interaction of low activation ferritic steel

K. Tsuzuki, JAERI

Aims

Low activation ferritic steel is one of the candidate materials for a demo-reactor. It shows better properties on thermal and neutron load, but it is ferromagnetic material and the vacuum properties are worse than that of the stainless steel. Thus, the compatibility of the ferritic steel with plasma has been investigated in the JFT-2M tokamak at JAREI. In the case of JFT-2M, global parameters such as the total radiation loss were not affected by the installation of the ferritic steel. However, local measurement of the impurity release behaviour has not been investigated. In addition, local magnetic fields may affect the plasma wall interaction. The main purpose of this work is as follows:

(1) To examine the response of low activation ferritic steel under plasma exposure with spectroscopic measurements.

(2) To examine the influence of (local) magnetic fields on PMI with heat and H emission profile.

Work performed

Preparation of the sample: The limiter head with F82H was fabricated in 2002. The F82H was buried in a limiter head made of stainless steel (SUS304), so that the visible spectroscopy can see the surface of the ferritic steel. By rotating the limiter head, the surface of the stainless steel can also be investigated. Impurity desorption behaviour from F82H and SUS304 can be compared. For the design, the electro-magnetic force was investigated and additional ferritic steel was inserted to balance the torque due to the magnetic force. However, it was pointed out that anomalous heating would occur due to the gap between the ferritic steel and stainless steel. This problem is now under discussion.

Work Planned

Participation in TEXTOR experiments: The experiment was planned in 2002, but it was delayed due to the delay of installation of DED. The experiment will be carried out in 2003 after solving the problem of sample structure and discussing diagnostics for this study.
Millimetre-Wave Imaging Diagnostics

A. Mase, Kyushu University

Aims

To develop 2D-3D millimetre-wave imaging system for measurements of temperature/density profiles and fluctuations.

Work Performed

1) An improved version of a dichroic plate to separate radiation in the ECE range of frequencies higher than 100 GHz from the lower frequency signals (< 90 GHz) obtained from microwave imaging reflectometry (MIR) on TEXTOR has been manufactured and tested in Japan. The characteristics are in good agreement with the designed values.

2) A. Mase has visited the Institut für Plasmaphysik at Forschungszentrum Jülich in order to study the comparison between TEXTOR- and LHD-imaging experiments. The various results were obtained from the discussions with Dr. Tony Donné and Dr. Marc van de Pol on the improvement of focusing optics, planar-type imaging antennas, and intermediate frequency (IF) systems. The future plans for the advanced imaging diagnostics on TEXTOR and MAGNUM have also been discussed. The seminar “Microwave diagnostic on LHD and application to industry” has been given by A. Mase at FOM, the Netherlands, and at Institut für Plasmaphysik, Forschungszentrum Jülich, on April 1st and April 3rd, 2003, respectively.

3) The experiment of ECE imaging has been performed on LHD. The cross-correlation spectra between two different detectors (poloidal direction) and different IF channels (radial direction) were obtained from NBI and ICRF heated plasmas. The low frequency spectrum of 10-50 kHz in the range of MHD mode was enhanced, and drift-wave like modes with 100-500 kHz have not been observed, which has been observed in the TEXTOR experiment.

Work planned

The ECE imaging diagnostics have been routinely applied to both TEXTOR and LHD. In the next experimental campaign, the advanced imaging system (combined system of ECE-imaging and MIR) will be applied to obtain both density and temperature fluctuations.

Application of BIXS to analyses of tritium retention in JET divertor tiles

M. Matsuyama, Toyama University

Aims

(1) To examine the applicability of β-ray-induced X-ray spectrometry (BIXS) to materials exposed to D-T plasmas.

(2) To examine the distribution of tritium retained on/in CFC divertor tiles used for D-T campaign in JET.
Work performed

(1) Observation of X-ray Spectra from Divertor Tiles

To evaluate the amount and distribution of tritium retained on/in poloidal tiles in JET, the technique of BIXS was applied to six cylindrical samples hollowed out the poloidal tiles. The tile number is as follows: the inner (IN1 & IN3), the base (BN4 & BN7), and the outer tiles (ON8 & ON10). Both a cylindrical sample and the head of a high pure Ge X-ray detector were placed in argon atmosphere, and then an X-ray spectrum was observed for a given time. Measurements of the X-ray spectra were carried out at TLK in FZK.

An X-ray spectrum induced by the $\beta$-rays from tritium was clearly observed for all the samples. Basically, it consisted of two peaks: one is the characteristic X-rays of argon, and the other is the bremsstrahlung X-rays. From the Ar(K$\alpha$) X-ray intensity, it was seen that the amount of surface tritium on the inner and the base tiles is about 10 times greater than that on the outer tiles. A similar difference was also observed for the bremsstrahlung X-ray intensity: namely, the intensity of the inner and the base divertor tiles was about 20 times greater than that of the outer tiles.

In addition to these X-ray peaks, several small peaks appeared in the spectra, indicating that metallic impurities deposit on the tile surface. Intensities of these peaks were highest at surfaces of the IN1 sample, and they decreased totally in the direction of the outer tiles. These metallic impurities were assigned to Cr, Fe, Ni, and Mo from energy of each peak, and the deposition amount was the order of Ni>Fe>Cr>Mo. It is considered that the deposition of such metallic impurities forms compounds of a carbide type and they affect the kinetic behaviour of fuel particles on the carbon tiles.

(2) Analyses of the Observed X-ray Spectra

To determine depth profiles of tritium, simulation analyses was applied to all the observed X-ray spectra. The depth profiles obtained showed that most of tritium in the samples is retained in a region of 100 $\mu$m beneath the surface. Depth profiles of the inner and the outer tiles were very similar, while those for base tiles were quite different. It was suggested that the surface temperature of the tiles as well as the shape of the magnetic field plays an important role for the distribution of tritium.

Tritium amounts in surface layers and in the bulk were estimated from the depth profile for each sample. Amounts in the bulk of the inner and base tiles were 20-100 times greater than those of the outer tiles, but the difference in surface layers was smaller than that in bulk.

Work planned

(1) Analyses of the detailed distribution of tritium retained in all the poloidal tiles.
(2) Examination of the effects of X- and $\gamma$-rays emitted from activated materials on measurements by BIXS.
PMI studies related High Z materials in TEXTOR 2002

T. Tanabe, Nagoya University

Aims

(1) Investigations of behaviour of high-Z impurities in main and boundary plasmas.
(2) Understanding of local phenomena (sputtering, reflection redeposition, etc.) in front of the high-Z limiter surface.
(3) Examination of high-Z materials behaviour exposed to plasma heat load.
(4) Tritium distribution analysis on PFM tiles by imaging plate technique.
(5) Simulation of PMI.

Work performed

(1) Ta/W twin limiter test (Analysis)

Tungsten and tantalum were examined in the TEXTOR tokamak as a test limiter to study the performances and the differences of endothermic (W) and exothermic (Ta) hydrogen absorbers. Some remarkable differences between these two materials were revealed, i.e. the deuterium release mechanism (different release ratio of molecules and atoms), the distribution of the deposition and its microstructures and the amount of deuterium retention in the bulk materials. As a result of poor thermal conductivity, the surface temperature of Ta had been higher than that of W and increased shot by shot. It is caused by degradation of thermal properties due to surface modification. In these points, the endothermic hydrogen absorber (W) is superior to the exothermic hydrogen absorber (Ta).

(2) Preparation of new high-Z limiters for DED

Three different kinds of high-Z limiters were prepared. (i) One W bulk limiter for examination of behaviour of high-Z impurity in edge of DED plasma. (ii) One W bulk limiter with a small hole for gas puffing during discharge to investigate local hydrogen behaviour in front of high-Z materials. (iii) Two Ta bulk limiters for continuation of Ta/W limiter experiments. (iv) Two CVD-W covered Cu limiters for examination of material behaviour. One of them was heat load tested with 10 Mw/m², resulting no change.

(3) Tritium distribution measurements by imaging plate technique

The areal distribution of tritium retention in tiles from TEXTOR, TFTR, JT-60U and JET has been measured via the imaging plate technique and the results are discussed from the perspective of carbon-hydrogen chemistry. It is found that the observed tritium distribution clearly shows asymmetries in poloidal and toroidal directions and also reflects the local temperature history of the analyzed tiles. We show the first clear evidence of the loss of high energy tritons by toroidal magnetic field ripple. We distinguish three different contributions to tritium retention in tokamaks with carbon plasma facing components: high energy tritons escaping from the core plasma, low energy ions and neutrals from the edge plasma, and molecular tritium from gas fuelling. These components are retained at different depths and with different concentrations. Tritium from the edge plasma dominates the retained inventory but could be reduced if the surface temperature was higher.

(4) Simulation of hydrogen recycling in front of the limiter
A Monte Carlo simulation of transport of atomic and molecular hydrogen and hydrocarbons released from W, Ta and C in edge plasmas of TEXTOR were performed. The simulation derives thermal, dissociation and reflection components from the observed radial distribution of Dγ line intensity around W-Ta and W-C twin test limiters. The Dγ intensity in front of the limiter is dominated by thermal re-emission of atomic hydrogen, whereas at the position well away from the limiter, dissociation of reemitted molecular hydrogen and reflection of incident hydrogen are important. Due to less deposition of C impurity from the background plasma, the Dγ distributions for W and Ta are much less influenced by dissociation of chemically sputtered hydrocarbon. For C, large chemical sputtering yields and small reflection coefficients influence the shape of the distribution in different ways.

**Work Planned**

(1) Continuation of high-Z limiter test using different kinds of materials  
(2) Artificial hot spot experiments with laser irradiation  
(3) Investigation of heat load, local erosion and deposition with Brush limiters  
(4) Simultaneous measurements of several Balmer line emissions using a parallel detector  
(5) Utilization of ferritic steel as a first wall material (New proposal by JAERI)

**PMI studies related High Z materials in TEXTOR 2001**

*T. Tanabe, Nagoya University*

**Aims**

(1) Investigations of the behaviour of high Z-impurities in main and boundary plasmas.  
(2) Understanding of local phenomena (sputtering, reflection redeposition, etc.) in front of the high-Z limiter surface.  
(3) Examination of high-Z material behaviour exposed to plasma heat load.  
(4) Tritium distribution analysis of PFM tiles by imaging plate techniques.  
(5) Simulation of PMI.

**Work performed**

(1) Ta/W twin limiter test

Following the W/C twin limiter experiments in the year 2000, Ta/W twin limiter experiments were conducted. Owing to the characteristic difference of Ta and W for hydrogen, i.e. the former is an exothermic hydrogen occluder and the latter an endothermic one, Balmer series emission intensity in front of the W and Ta sides showed significant differences. At lower temperatures, hydrogen recycling at the Ta side was smaller than that at the W side. With increasing temperature, both became similar. At elevated temperatures, emission of excited molecules and/or atomic reemission was observed.

The difference of thermal conductivity between Ta and W, being 3 times lower for Ta than W, shows a larger temperature increase of the Ta side than for that of the W side under the same heat load, confirming the importance of high thermal conductivity of PFM. Thermal desorption analysis showed that deuterium retention in W was negligibility small, while a certain amount of deuterium was homogeneously distributed in Ta with some precipitation of hydride.
(2) Brush tungsten limiter

The Brush W limiter was made by Evlemov Institute based on a Russian design for the ITER divertor. The performance of the limiter was generally the same as that of the sole W limiter previously examined. Because of the separate structure, each block showed different temperature responses during plasma exposure, which lead us to analyze the heat load distribution on the limiter surface very successfully. After extremely high heat load shots, one block was damaged, while the neighbouring blocks were not damaged as expected. On the other hand, a melted Cu layer was spilt over one block. Probably the temperature of the brazed region has been above the melting point of Cu, because the Cu base was cooled only initially. Significant redeposition was found between each block, which is very important for future use of this type of divertor tiles.

(3) Tritium distribution measurements by imaging plate techniques

The surface distributions of deuterium and tritium on graphite limiter tiles used in TEXTOR under D-D operation were analyzed by means of an ion beam analysis and a tritium imaging plate technique, respectively.

Tritium produced by the D-D reaction did not fully lose their energy before being implanted onto the plasma facing surfaces. As a result, tritium distributions on the tiles were generally homogeneous. High energy injection was confirmed by the observation of tritium beneath the deposited layer. Tritium was detected even in the plasma shadow, probably owing to their gyration in the scrape-off layer. The profiles of deuterium were completely different from tritium. They are co-or re-deposited with carbon and boron on plasma facing surfaces at the deposition dominated regions, whereas little deuterium was observed at the erosion dominated regions.

(4) Simulation of hydrogen recycling in front of the limiter

Using the hybrid simulation code EDDY, penetration depths of spectroscopic lines of deuterium and of impurities were successfully simulated, indicating that the large part of hydrogen reflected at high-Z limiters is likely in electrically excited states. It also successfully showed that most of the released high-Z impurities are promptly redeposited.

Work Planned

(1) CVD-W coated Cu limiter experiments.  
(2) Simultaneous measurements of several Balmer line emissions using a parallel detector.  
(3) Gas puffing on high-Z limiter experiments.  
(4) Impurity transport and hydrogen recycling in the DED configuration.
Main activities during the past year for the US/TEXTOR collaboration have been focused on:

1. joint participation with Oak Ridge National Laboratory (ORNL) in JET Experiments via the Tri-Euregio cluster, and
2. GA/UCSD collaboration in the TEXTOR Dynamic Ergodic Divertor.

(1) Joint participation in JET Experiments via the Tri-Euregio cluster (ORNL)  
(prepared by D. Hillis)

The main activities during the past year for the ORNL/TEXTOR collaboration have been focused on joint participation in JET Experiments via the Tri-Euregio cluster in the areas of:

- RI-mode (Ar/Ne Impurity Seeding) at JET  
- He Transport and exhaust at JET  
- He wall changeover experiments at JET  
- Evaluation of possible participation in DED Experiments

During Fall 2002 and Feb 2003 radiation improved (RI) mode experiments were performed on JET with Argon and Neon being the seed impurities. These and other RI mode experiments resulted in presentations at the Division of Plasma Physics Meeting of the American Physical Society in Orlando, Florida (Nov 2002) entitled “Influence of recycling on confinement in JET discharges with impurity seeding” (D. Hillis). Three US/TEXTOR experiments are planned for 2003 on JET as part of the ORNL collaboration. These experiments are:

General Atomics, the University of California, San Diego, and the Jülich Nuclear Research Center have initiated a collaboration to explore the feasibility of using edge resonant magnetic perturbations in diverted tokamaks to control ELMs and edge pedestal parameters (and hence core performance). This collaboration is motivated by the critical need, in next-step burning plasma experiments such as ITER, for the ability to control or mitigate the deleterious effects of large ELMs, including: erosion of the divertor target plates by the impulsive heat flux from large ELMs, and excessive tritium inventory in the plasma-facing components when the eroded material is co-deposited with hydrogenic species [1]. Controlling ELMs, however, is complicated by the need to provide a steady-state high performance operating environment with density control and without impurity buildup in the absence of the transport associated with ELMs.

The overall goal of this collaboration is to develop the capability to predict the plasma response to stochastic magnetic fields in high performance, diverted tokamak plasmas. We will apply the knowledge gained over several decades of stochastic boundary experiments in devices such as TEXT, JIPP T-IIU, JFT-2M and Tore Supra, as well as experience in the TEXTOR Dynamic Ergodic Divertor (DED) program, to develop an effective ELM and pedestal control scenario for diverted tokamaks. We propose a three-element plan to achieve this goal:

(3) Participation by TEXTOR DED (K-H. Finken) and other international scientists (N. Ohyabu, P. Thomas, J. Harris) in dedicated DIII-D experiments to control ELMs with a stochastic boundary. The first experimental day is scheduled for July 29, 2003. These experiments will utilize the newly commissioned 12-segment I-coil for producing an edge resonant magnetic perturbation in either n=1 or n = 3 operation.

(4) Participation by R. Moyer and T. Evans in TEXTOR DED experiments that address issues associated with the plasma response to stochastic boundaries. This approach makes the best use of limited DIII-D run time by exploring physics issues in TEXTOR and incorporating the understanding gained into design and modeling of DIII-D experiments, including the design of optimized coils for producing stochastic boundaries that are proposed in the DIII-D 5-Year Plan.

(5) Development of a self-consistent model for predicting the plasma response to stochastic boundaries in collaboration with the E3D Monte Carlo heat transport code group [D. Reiter (FZJ), S. Kasilov (Kharkov Institute for Physics and Technology), and A. Runov, R. Schneider (MPI-Greifswald)] As a first step, we have proposed, under a separate DoE theory grant, to couple the existing TRIP3D field line integration code with the E3D Monte Carlo heat transport code to calculate the parallel and anomalous perpendicular heat transport and electron temperature profiles consistent with the calculated magnetic field line topology for comparison with experimental measurements.

TEXTOR provides a unique facility for testing such numerical models of the plasma response to stochastic boundaries, including: 1) dedicated edge resonant magnetic perturbation coils, combined with 2) high auxiliary heating power (4 MW fast wave RF and 5 MW neutral beam injection), and 3) flexible momentum input capability (co-, counter-, and balanced injection in a single discharge). TEXTOR can provide much of the data needed to benchmark models without the complications of X-point geometry, and can make connections with the extensive ergodic boundary results from other non-diverted tokamaks, such as Tore Supra. Ultimately, a self-consistent
model for the plasma response will need to encompass additional factors, such as: 3-D equilibrium, MHD stability (e.g. ballooning/peeling modes), and transport (including turbulence).

Reference:

E. SCIENTIFIC PUBLICATIONS

2002 — Journals

Abdullaev, S. S.
The Hamilton-Jacobi method and Hamiltonian MAPS
Abdullaev, S. S.; Finken, K. H.
Hamiltonian guiding center equations in a toroidal system
Physics of plasmas, 9 (2002), 10, S. 4193 - 4204

Spectra of OII in the plasma boundary of TEXTOR-94
Plasma physics and controlled fusion, 44 (2002), S. 2251 - 2269
Borodin, D.; Beigman, I.*; Vainshtein, A.*; Pospieszczyk, A.; Brezinsek, S.
Spectra of OII in the boundary plasma of TEXTOR
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 36 (2001), S. 176

Data for spectral measurement of oxygen fluxes in the plasma boundary
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 37 (2002), S. 23

Brezinsek, S.; Mertens, Ph.; Pospieszczyk, A.
Laser-induced fluorescence at Lyman-alpha in the plasma edge of TEXTOR-94
Contributions to plasma physics, 42 (2002), 6-7, S. 657 - 662

Brezinsek, S.; Mertens, Ph.; Pospieszczyk, A.; Sergienko, G.; Greenland, P.T.*
Freisetzung von HD-Molekülen von einer plasmabegrenzenden Graphitoberfläche
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 37 (2002), S. 23

Brezinsek, S.; Mertens, Ph.; Pospieszczyk, A.; Sergienko, G.; Greenland, Th.*
Molecular and atomic deuterium in the plasma edge of TEXTOR-94
Contributions to plasma physics, 42 (2002), 6-7, S. 668 - 674

Brezinsek, S.; Mertens, Ph.; Pospieszczyk, A.; Sergienko, G.; Greenland, P.T.
The behaviour of deuterium in front of a heatable test limiter in TEXTOR
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 36 (2001), S. 154

Bruchhausen, M.; Burhenn, R.*; Endler, M.*; Pospieszczyk, A.; Zoletnik, S.
Untersuchung der Struktur von Elektronendichtefluktuationen am Stellerator W7-AS mit einem suprathermischen atomaren Lithiumstrahl
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 37 (2002), S. 24

Cordey, J. G.*; McDonald, D. C.*; Borrass, K.*; Charlet, M.*; Coffey, I.*; Kallenbach, A.*; Lawson, K.*; Lomas, P.*; Ongena, J.*; Rapp, J.*; Ryter, F.*; Saibene, G.*; Sartori, R.*; Stamp, M.*; Strachan, J.*; Suttrop, W.*; Valovic, M.*

Dastgeer, S.*; Sing, R.*; Nordman, H.*; Weiland, R.*; Register, A.
Nonlinear structures in interchange mode turbulence
Physical review E, 66 (2002), S. 036408-1 - 036408-6

Confinement properties of high density impurity seeded ELMy H-mode discharges at low and high triangularity on JET
Plasma physics and controlled fusion, 44 (2002), 9, S. 1845 - 1861
Duran, I.*; St`ckel, J.*; Mank, G.; Finken, K.H.; Fuch, G.; van Oost, G.*
Measurements of magnetic field fluctuations using an array of Hall detectors on the TEXTOR tokamak
Review of scientific instruments, 73 (2002), 10, S. 3482 - 3489

Endler, M.*; Bruchhausen, M.; Bleuel, J.*; Schubert, M.*
The impact of magnetic shear on the spatial structure of edge fluctuations in Wendelstein 7-AS
Stellarator news, (2002), S. 83

Feng, Y.*; Sardei, F.*; Grigull, K.*; McCormick, K.*; Kisslinger, J.*; Reiter, D.; Igitkhanov, Y.*
Transport in island divertors : physics, 3D modelling and comparison to first experiments on W7-AS
Plasma physics and controlled fusion, 44 (2002), 5, S. 611 - 625

Finken, K. H.
Divertor concepts I : edge physics, divertors, pump limiters
Fusion science and technology, 41 (2002), Suppl. T, S. 330 - 336

Finken, K. H.
Divertor concepts II : the dynamic ergodic divertor (DED)
Fusion science and technology, 41 (2002), Suppl. T, S. 337 - 341

Finken, K.H.; Mank, G.; Krammer-Flecken, A.; Jaspers, R.*
Mitigation of disruptions by fast helium puffs
Nuclear fusion, 41 (2001),11, S. 1651 - 1661

Gerhauser, H.; Zagürski, R.*; Claer en, H. A.; Gunn, J.*; Boucher, C.*
Numerical modelling of a pump limiter biasing on TEXTOR-94 and Tore Supra
Nuclear fusion, 42 (2002), S. 805 - 816

Gravier, E.*; Gunn, J. P.*; Lachambre, J.L.*; Loarer, T.*; Mank, G.; Boucher, C.*; Finken, K.H.*; Jachmich, S.*; Lehnen, M.; van Oost, G.*
Ion flows in the scrape-off layer with biased limiter : implications for Tore Supra toroidal pumped limiter design
Nuclear fusion, 42 (2002), 6, S. 653 - 662

Hey, J. D.*; Chu, C.*; Brezinsek, S.; Mertens, Ph.; Unterberg, B.
Oxygen ion impurity in the TEXTOR tokamak boundary plasma observed and analysed by Zeeman spectroscopy

Hey, J. D.*; Chu, C.*; Mertens, Ph.
Zeeman spectroscopy as a tool for studying atomic processes in edge plasmas 2002
Contributions to plasma physics, 42 (2002), 6-7, S. 636 - 645

Huber, A.; Beigman, I.*; Borodin, D.; Mertens, Ph.; Philipps, V.; Pospieszczyk, A.; Samm, V. N.; Schweer, B.; Sergienko, G.*; Vainshtein, L. A.*
Spectroscopical observation of Si I- and Si II-emission line in the boundary of TEXTOR and comparison with kinetic calculations
Plasma physics and controlled fusion, 44 (2002), S. 1 - 15

Effects of impurity seeding in DIII-D radiating mantle discharges
Nuclear fusion, 42 (2002), S. 28 - 41

Comparison of L-mode regimes with enhanced confinement by impurity seeding in JET and DIII-D
Plasma physics and controlled fusion, 44 (2002), 9, S. 1893 - 1902
Janev, R. K.*; Reiter, D.
Collision processes of CH−y and CH+y hydrocarbons with plasma electrons and protons
Physics of plasmas, 9 (2002), 9, S. 4071 - 4081

Kallenbach, A.*; Beurskens, M. N. A.*; Korotkov, A.*; Suttrop, W.*; Charlet, M.*; McDonald, D.C.*; Milani, F.*; Rapp, J.; Stamp, M.*
Scaling of the pedestal density in type-I ELMy H-mode discharges and the impact of upper and lower triangularity in JET and ASDEX upgrade
Nuclear fusion, 42 (2002), 10, S. 1184 - 1192

Kaslov, S. V.; Reiter, D.; Runov, A.M.*; Kernbichler, W.*; Heyn, M. F.*
On the magnetic nature of electron transport barriers in tokamaks
Plasma physics and controlled fusion, 44 (2002), 6, S. 985 - 1004

Kobayashi, M.; Eich, T.; Abdullaev, S. S.; Finken, K.H.
Topological properties of the edge ergodic layer in tokamak plasma
IEEE transactions on plasma science, 30 (2002), 1, S. 66 - 67

Modeling analysis of the transport properties in TEXTOR-DED laminar zone with a finite element code
Contributions to plasma physics, 42 (2002), 2-4, S. 163 - 168

Koslowski, H.R.
Operational limits in tokamaks and limiting instabilities
Fusion science and technology, 41 (2002), Suppl. T, S. 77 - 84

Krümer-Flecken, A.
Microwave and far infrared diagnostics
Fusion science and technology, 41 (2002), Suppl. T, S. 402 - 409

Lang, P. T.*; Alper, B.*; Baylor, L. R.*; Beurskens, M.*; Cordey, J. G.*; Dux, R.*; Felton, R.*; Garzotti, L.*; Haas, G.*; Horton, L. D.*; Jachmich, S.*; Jones, T. T. C.*; Lorenz, A.*; Lomas, P. J.*; Maraschek, M.*; Moller, H. W.*; Onega, J.*; Rapp, J.; Renk, K. F.*; Reich, M.*; Sartori, R.*; Schmidt, G.*; Stamp, M.*; Suttrop, W.*; Villedieu, E.*; Wilson, D.*
High density operation at JET by pellet refueling
Plasma physics and controlled fusion, 44 (2002), 9, S. 1919 - 1928

Lang, P. T.; Alper, B.*; Baylor, L. R.*; Beurskens, M.; Cordey, J. G.*; Dux, R.*; Felton, R.*; Garzotti, L.*; Haas, G.*; Horton, L. D.*; Jachmich, S.*; Jones, T. T. C.*; Lomas, P. J.*; Lorenz, A.*; Maraschek, M.*; Moller, H. W.*; Onega, J.*; Rapp, J.; Reich, M.*; Renk, K. F.*; Sartori, R.*; Schmidt, G.*; Stamp, M.*; Suttrop, W.*
Optimization of pellet scenarios for long pulse fuelling to high densities at JET
Nuclear fusion, 42 (2002), 4, S. 388 - 402

Lehnen, M.; Loarer, T.*; Gunn, J.*; Hourtoule, J.*; Lachambre, J. L.*; Spuig, P.*
Str’mme in der Abschließung des Tokamaks Tore Supra (CIEL Projekt)
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 37 (2002), S. 24

ELM moderation with ICRF heating on JET
Plasma physics and controlled fusion, 44 (2002), 9, S. 1937 - 1952

Mantsinen, M. J.*; Angioni, C.*; Eriksson, L. G.*; Gondhalekar, A.*; Hellsten, T.*; Johnson, T.*; Mayoral, M. L.*; McClements, K. G.*; Nave, M. F. F.*; Nguyen, H. P.*; Podda, S.*; Rapp, J.; Sauter, O.*; Sharapov, S. E.*; Westerhof, E.*
Analysis of ion cyclotron heating and current drive at omega = 2 omega ch for sawtooth control in JET plasmas
Plasma physics and controlled fusion, 44 (2002), 8, S. 1521 - 1542

Marchuk, O.; Bertschinger, G.; Biel, W.; Kunze, H. J.*; Urnov, A.*; Goryaev, E.
Modelling of argon XVII spectra and measurements on TEXTOR
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 37 (2002), S. 28
Mertens, Ph.; Brezinsek, S.; Greenland, P.T.*; Hey, J.D.*; Pospieszczyk, A.; Reiter, D.; Samm, V. N.; Schweer, B.; Sergienko, G.*; Vietzke, E.
Hydrogen release from plasma-facing components into fusion plasmas
Plasma physics and controlled fusion, 43 (2001), 12A, S. 349 - 373

Mueck, A.*; Goodman, T.*; Gude, A.*; Koslowski, H.R.; Ryter, F.*; Sesnic, S.*; Westerhof, E.*; Zohm, E.*
The influence of ECRH/ECCD on the sawtooth behaviour of ASDEX upgrade discharges
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 37 (2002), S. 24

Neubauer, O.; Nowak, S.
The power supply system of the dynamic ergodic divertor at TEXTOR-94
Fusion engineering and design, 59 (2001), S. 11 - 20

Nicolai, A.; Rogister, A.; Daybelge, U.*
Numerical and analytical interpretation of rotation and radial electric fields in collision dominated edge plasmas
Contributions to plasma physics, 42 (2002), 2-4, S. 241 - 246

Recent progress on JET towards the ITER reference mode of operation at high density
Plasma physics and controlled fusion, 43 (2001), 12A, S. 11 - 30

Philipps, V.
Plasma wall interaction and its control by wall conditioning
Fusion science and technology, 41 (2002), Suppl. T, S. 319 - 329

Philipps, V.; Wienhold, P.; Kirschner, A.; Rubel, M.*
Erosion and redeposition of wall material in controlled fusion devices
Vacuum, 67 (2002), S. 399 - 408

Pospieszczyk, A.
Spectroscopy
Fusion science and technology, 41 (2002), Suppl. T, S. 394 - 395

Puiatti, M.E.*; Mattioli, M.*; Telesca, G.*; Valisa, M.*; Coffey, I.*; Dumortier, P.*; Giroud, C.*; Ingesson, L.C.*; Lawson, K.D.*; Maddison, G.*; Messiaen, A.M.*; Monier-Garbet, P.*; Murari, A.*; Nave, M.F.F.*; Ongena, J.*; Rapp, J.; Strachan, J.*; Unterberg, B.; von Hellermann, M.*
Radiation pattern and impurity transport in argon seeded ELMy H-mode discharges in JET
Plasma physics and controlled fusion, 44 (2002), 9, S. 1863 - 1878

ELM mitigation by nitrogen seeding in the JET gas box divertor
Plasma physics and controlled fusion, 44 (2002), 6, S. 639 - 652

Reiser, D.; Tokar, M.Z.
Influence of neutral gas fueling on edge instabilities in the scrape-off layer of TEXTOR-94
Contributions to plasma physics, 42 (2002), 2-4, S. 401 - 406

Reiser, D.; Unterberg, B.
Neutralgasgetriebene Driftwelleninstabilitäten in Tokamak-Randschichtplasmen und anomaler Transport
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 37 (2002), S. 20

Reiter, D.
Helium removal and recycling
Fusion science and technology, 41 (2002), Suppl. T, S. 342 - 351
Reiter, D.; Wiesen, S.; Born, M.*
Towards radiation transport modelling in divertors with the EIRENE code
Plasma physics and controlled fusion, 44 (2002), 8, S. 1723 - 1737

Register, A. L.
Drift wave based anomalous transport models
Fusion science and technology, 41 (2002), Suppl. T, S. 251 - 267

Register, A. L.; Rice, J. E. *; Nicolai, A.; Ince-Cushman, A. *; Gangadhara, S. *
Theoretical interpretation of the toroidal rotation velocity observed in Alcator C-mod ohmic H-mode discharges
Nuclear fusion, 42 (2002), S. 1144 - 1154

Rubel, M. *; Cecconello, J. A. *; Malmberg, G. *; Sergienko, G. *; Biel, W.; Darake, J. R. *; Hedqvist, A. *; Huber, A.; Philips, V.
Dust particles in controlled fusion device: morphology, observations in the plasma and influence on the plasma performance
Nuclear fusion, 41 (2001), 8, S. 1087 - 1099

Saibene, G. *; Sartori, R. *; Loarte, A. *; Campbell, D. J. *; Lomas, P. J. *; Parail, V. *; Zastrow, K. D. *; Andrew, Y. *; Sharapov, S. *; Korotkov, A. *; Becoulet, M. *; Huysmans, G. T. A. *; Koslowski, H. R.; Budny, R. *; Conway, G. D. *; Stober, J. *; Suttrop, W. *; Kallenbach, A. *; von Hellermann, M. *; Beurskens, M. *
Improved performance of ELMy H-modes at high density by plasma shaping in JET
Plasma physics and controlled fusion, 44 (2002), 9, S. 1769 - 1799

Samm, V. N.
Radiation cooling experiments and reactor application
Fusion science and technology, 41 (2002), Suppl. T, S. 352 - 358

Savitchkov, A.; Finken, K. H.; Mank, G.
Development of a fast valve for mitigating disruptions in tokamaks
Review of scientific instruments, 73 (2002), 10, S. 3490 - 3493

Shoucri, M. *; Gerhauser, H.; Finken, K. H.
Formation of steep gradients with plasma detachment at grazing B-field incidence at a plasma-wall transition
Czechoslovak journal of physics, 52 (2002), 10

Tanabe, T. *; Miyasaka, K. *; Rubel, M. *; Philips, V.
Tritium and deuterium retention in graphite limiters in TEXTOR
Fusion science and technology, 41 (2002), S. 924 - 928

Tanabe, T. *; Ohgo, T. *; Wada, M. *; Rubel, M. *; Philips, V.; von Seggern, J.; Ohyama, K. *; Huber, A.; Pospieszczczyk, A.; Schweer, B.
Material mixing on W/C twin limiter in TEXTOR-94
Fusion engineering and design, 49-50 (2000), S. 355 - 362

Tanabe, T.; Philips, V.
Tritium detection in plasma facing component by imaging plate technique
Fusion engineering and design, 54 (2001), S. 147 - 149

Tokar, M.
Consideration of multi-faceted asymmetric radiation from the edge (MARFE) as a dissipative structure
Physics of plasmas, 9 (2002), 5, S. 1646 - 1653

Tokar, M.
Theoretical models for transport barriers
Fusion science and technology, 41 (2002), S. 268 - 275

Tokar, M. Z.; Yamakazi, K. *; Funaba, H. *; Nakamura, Y. *; Noda, N. *; Peterson, B. J. *; Sargara, A. *; Takeiri, Y. *
Synergy of heavy and light impurity radiation in breathing oscillations in large helical device
Contributions to plasma physics, 42 (2002), 2-4, S. 413 - 418

Tokar, M. Z.; Biel, W.; Rapp, J.; Reiser, D.; Samm, V. N.; Sergienko, G. *
Study of the relevance of thermal instability caused by impurity radiation to MARFE development in a limiter tokamak
Contributions to plasma physics, 42 (2002), 2-4, S. 290 - 295
Tokar, M.Z.; Nordmann, H.*; Weiland, J.*; Ongena, J.*; Parail, V.*; Unterberg, B.
Predictive modeling of impurity seeded plasmas in JET
Plasma physics and controlled fusion, 44 (2002), 9, S. 1903 - 1910

Unterberg, B.; Samm, V. N.
Overview of plasma edge physics
Fusion science and technology, 41 (2002), S. 311 - 318

Unterberg, B.; Samm, V. N.
Overview of tokamak results
Fusion science and technology, 41 (2002), S. 421 - 427

Unterberg, B.; Sergienko, G.; Brezinsek, S.; Pospieszczyk, A.; Lehnen, M.
Influence of a local neutral particle source on the plasma boundary in TEXTOR
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 37 (2002), S. 24

Valovic, M.*; Rapp, J.; Cordey, J. G.; Budny, R.*; McDonald, D. C.*; Garzotti, L.*;
Kallenbach, A.*; Mahdavi, M. A.*; Ongena, J.*; Parail, V.*; Saibene, G.*; Satori, R.*;
Stamp, M.*; Sauter, O.*; Strachan, J.*; Suttrop, W.*
Long time-scale density peaking in JET
Plasma physics and controlled fusion, 44 (2002), 9, S. 1911 - 1917

Vietzke, E.
Isotope dependence of the chemical erosion of graphite by hydrogen/deuterium implantation

Vietzke, E.
Surface effects on hydrogen release in the plasma edge
Contributions to plasma physics, 42 (2002), 6-7, S. 590 - 595

Deposition von erodiertem Wandmaterial in TEXTOR an Orten weit entfernt vom Plasma
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 37 (2002), S. 42

Westerhof, E.*; Sauter, O.*; Mayoral, M. L.*; Howell, D. F.*; Mantsinen, M. J.*; Nave,
M. F. F.*; Alper, B.; Angioni, C.*; Belo, P.*; Buttery, R. J.*; Gondhalekar, A.*;
Hellsten, T.*; Hender, T. C.*; Johnson, T.*; Lamalle, P.*; Maraschek, M. E.*;
McClements, K. G.*; Nguyen, H. F.; Pècquet, A.L.*; Podda, S.*; Rapp, J.; Sharapov, S.
E.*; Zabiego, M.*
Control of sawteeth and triggering of NTMs with ion cyclotron resonance frequency waves in JET
Nuclear fusion, 42 (2002), 11, S. 1324 - 1334

Wienhold, P.
Kurz- und langreichweitiger Transport von erodiertem Wandmaterialien in TEXTOR
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 37 (2002), S. 20

Zagórski, R.*; Gerhauser, H.
Numerical investigations of the influence of localized gas puffing on the electric field structure in the boundary layer of TEXTOR-94 tokamak

2002 — Proceedings

Biel, W.; Bertschinger, G.; Burhenn, R.; Krönig, R.*
Design of VUV/XUV spectrometers for impurity studies on W7-X
Europhysics Conference Abstracts. - 26B (2002). - S. P-5.098

Brezinsek, S.; Greenland, P.T.*; Hey, J.D.*; Lehnen, M.; Mertens, Ph.; Pospieszczyk,
A.; Samm, V. N.; Schweer, B.; Sergienko, G.*; Vietzke, E.
Interplay between DO and D2 in front of a graphite surface in the plasma edge of TEXTOR
Bruchhausen, M.; Burhenn, R.*; Endler, M.; Pospieszczyk, A.; Zoletnik, S.*
Measurements of electron density fluctuations in the scrape-off layer (SOL) and edge plasma of the stellarator Wendelstein 7-AS by means of lithium laser blow-off

Ehmler, H.*; Burhenn, R.*; Baldzuhn, J.*; Dinklage, A.*; Giannone, L.*; Hartmann, D.*; Kick, M.*; Knauer, J. P.*; Kreter, A.; McCormick, K.*; Pasch, E.*; Klinger, T.*; Weller, A.*
Comparative study of intrinsic edge impurities in the W7-AS stellarator during high confinement discharges

Hey, J. D.*; Chu, C. C.*; Brezinsek, S.; Mertens, Ph.; Unterberg, B.
Oxygen ion impurity in the TEXTOR-94 boundary plasma observed by Zeeman spectroscopy

Ivanov, A.A.*; Deichuli, P.P.*; Kreter, A.; Maximov, V. V.*; Podminogin, A.A.*; Schweer, B.; Shikhovtsev, I.V.*; Stupishin, N.V.*; Uleman, R.*; Usoltsev, D.V.*
Characterization of ion species mix of the TEXTOR diagnostic hydrogen beam injector with an RF and ARC-discharge plasma box
Siberian Branch of the Russian Academy of Science : Budker Institut of Nuclear Physics, Novosibirsk, Russia. - 2002. - (Budker INF 2002-41)

Jakubowski, M.; Abdullaev, S. S.; Finken, K.H.; Kobayashi, M.
Atlas for the TEXTOR-DED operation

Jaspers, R.*; Hogeweij, G.M.D.*; Merkulov, A.*; Westerhof, E.*; Schuller, F.C.*; Koslowski, H.R.; Messiaen, A.M.*
Electron transport barriers in TEXTOR plasmas

Kreter, A.; Baldzuhn, J.*; Ehmler, H.*; Hirsch, M.*; Kick, M.*; Kislyakov, A. I.*; Maflberg, H.*
Optimized confinement discharges with high ion temperatures after installation of the island divertor in W7-AS
Europhysics Conference Abstracts. - 26 B (2002). - S. P-5.033

Lindner, P.*; Brix, M.; Mertens, Ph.; Pospieszczyk, A.; Samm, V. N.; Schweer, B.; Unterberg, B.
Spectroscopic studies of the velocity distribution of helium and neon atoms released from carbon and tungsten limiters in TEXTOR-94

Nicolai, A.
TSC-simulations of MAST - discharges without primary current swing
Europhysics Conference Abstracts. - 26 B (2002). - S. P-1.051

Nicolai, A.; Daybelge, U.*
Transport analysis of H-mode plasmas in ohmic ALCATOR C-MOD discharges based on neoclassical theory
Europhysics Conference Abstracts. - 26 B (2002). - S. P-1.052

Pautasso, G.*; Savvichkov, A.; Egorov, S.*; Dux, R.*; Finken, K.H.; Gruber, O.*; Haas, G.*; Mank, G.; Maraschek, M.*; Rohde, V.*; Seidl, U.*
Mitigation of disruptions with fast impurity puff of ASDEX upgrade

Perez, C.; Koslowski, H.R.; Huysmans, G.T.A.*; Smeydlers, P.*; Alper, B.*; Hender, T.C.*; Meneses, L.*; Zerbini, M.*
Type-I ELM precursor modes in JET
Europhysics Conference Abstracts. - 26 B (2002). - S. P-1.023
Ramasubramanian, N.*; König, R.*; Grigull, P.*; McCormick, K.*; Giannone, L.*; Feng, Y.*; John, A.*; Schweer, B.; Brix, M.
Spectroscopic characterisation of W7-AS island divertor plasma
Europhysics Conference Abstracts. - 26B (2002). - S. P-5.034

Savtchkov, A.; Pautasso, G.*; Finken, K.H.; Mank, G.
Fast valve for mitigating disruptions in tokamaks

Tokar, M.; Kalupin, D.*; Reiser, D.; Unterberg, B.
Effect of gas puff on edge transport
Europhysics Conference Abstracts. - 26B (2002). - S. P-1.097

van Wassenhove, G.*; Messiah, A.M.*; Kalupin, D.*; Ongena, J.*; Unterberg, B.; Bonheure, G.*; Dumortier, P.*
Influence of isotopic composition on the performance of plasmas with a radiating mantle in TEXTOR

VanGorkom, J.C.*; Soldatov, S.V.*; Donné, A.J.H.*; Krümer-Flecken, A.; Schiller, F. C.*
Density fluctuation measurements at TEXTOR by pulsed radar and CW reflectometry

Zastrow, K.-D.*; Brix, M.; Dux, R.*; Finken, K.H.; Giroud, C.*; von Hellermann, M.*; Hillis, D.*; Morgan, P.D.*; O'Mullane, M.G.*; Whiteford, A. D.*
Helium ash simulation studies with divertor helium pumping in JET internal transport barrier discharges
Europhysics Conference Abstracts. - 26B (2002). - S. O-5.02

2002 — Reports

Janev, R. K.*; Reiter, D.
Collision processes of hydrocarbon species in hydrogen plasmas I : the methane family
J. lich, Forschungszentrum, Zentralbibliothek, 2002
Berichte des Forschungszentrums J. lich ; 3966
JUEL-3966

Nicolai, A.; Daybelge, A.*; Rogister, A.; Yarim, C.*
Numerical and analytical interpretation of rotation and radial electric fields in collision dominated edge plasmas
J. lich, Forschungszentrum, Zentralbibliothek, 2002
Berichte des Forschungszentrums J. lich ; 3958
JUEL-3958

2002 — Poster

Biel, W.; Bertschinger, G.; Burhenn, R.; König, R.*
Design of VUV/XUV spectrometers for impurity studies on W7-X
29th EPS Conference on Plasma Physics and Controlled Fusion Montreux, Switzerland: 17.06.2002 - 21.06.2002

Brezinsek, S.; Mertens, Ph.; Pospieszczuk, W.; Sergienko, G.*; Greenland, P.T.*
Formation of HD-molecules in the boundary layer of TEXTOR
Satellite Meeting of 15th PSI on Hydrogen Isotopes in Fusion Reactor Materials Tokyo, Japan: 22.05.2002 - 24.05.2002

Brezinsek, S.; Mertens, Ph.; Pospieszczuk, A.; Samm, V. N.; Greenland, P.T.*; Sergienko, G.*
On the measurement of molecular deuterium particle fluxes in fusion boundary plasmas
15th International Conference on Plasma Surface Interactions (PSI15) Gifu-City, Japan: 27.05.2002 - 31.05.2002
Brooks, J. N.*; Kirschner, A.; Whyte, D.G.*; Ruzic, A. J.*; Alman, D. A.*
Advances in the modeling of chemical erosion/redeposition of carbon divertors and
application to the JET tritium codeposition problem
15th International Conference on Plasma Surface Interactions (PSI15)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Bruchhausen, M.; Burhenn, R.*; Pospieszczyk, A.; Zoletnik, S.*
Measurements of electron density fluctuations in the scrape-off layer (SOL) and edge
plasma of the stellarator Wendelstein 7-AS by means of lithium laser blow-off
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Ehmler, H.*; Burhenn, R.*; Baldzuhn, J.*; Dinklage, A.*; Giannone, L.*; Hartmann, D.*;
Kick, M.*; Knauer, J. P.*; Kreter, A.; McCormick, K.*; Pasch, E.*; Klinger, T.*;
Weller, A.*
Comparative study of intrinsic edge impurities in the W7-AS stellerator during high
confinement discharges
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 16.06.2002 - 21.06.2002

Emmoth, B.*; Wienhold, P.; Rubel, M.*; Schweer, B.; Zagőrski, R.
Particle collection at the plasma edge by the fast reciprocating probe at TEXTOR
15th International Conference on Plasma Surface Interactions (PSI)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Esser, H.G.; Neil, G.*; Coad, P.*; Matthews, G.F.*; Jolovic, D.; Wilson, D.*;
Freisinger, M.; Philipp, V.
Quartz microbalance : a real time diagnostic to measure deposition in JET
22nd Symposium of Fusion Technology
Helsinki, Finland: 09.09.2002 - 12.09.2002

Fenstermacher, M. E.*; Erents, S.K.*; Lawson, K.D.*; Matthews, G.F.*; McCracken, G.
M.*; Philipp, V.; Pitts, R.A.*; Stamp, M.F.*
Comparison of carbon and main ion radiation profiles in matched helium and deuterium
plasmas in JET
15th International Conference on Plasma Surface Interactions (PSI)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Gerhauser, H.; Zagőrski, R.*; Jachmich, S.*; Van Schoor, M.*
Numerical simulation of plasma profile changes in TEXTOR by externally driven radial
polarization currents
15th International Conference on Plasma Surface Interactions (PSI)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Giesen, B.; Neubauer, O.
Investigation of EDDY currents in the components of the dynamic ergodic divertor at
TEXTOR using analytical and numerical approaches
22nd Symposium of Fusion Technology
Helsinki, Finland: 09.09.2002 - 12.09.2002

Grosman, A.*; AnÈ, J. M.*; Barabashi, P.*; Finken, K.H.; Mahdavi, A.*; Ghendrih, Ph.*;
Huysmans, G.*; Lipa, M.*; Thomas, P.R.*; Tsitrone, E.*
H-mode barrier control with external magnetic perturbations
15th International Conference on Plasma-Surface Interactions (PSI15)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Hirai, T.; Philipps, V.; Huber, A.; Rubel, M.; Tanabe, T.*; Wada, M.*; Ohgo, T.*;
Ohya, K.; Pospieszczyk, A.; Sergienko, G.; Wienhold, P.
Testing of tungsten and tantalum limiters to TEXTOR edge plasma : material performance
and deuterium retention
6th International Conference on "Hydrogen in Fusion Reactor"
Tokyo, Japan: 22.05.2002 - 24.05.2002

Hirai, T.; Philipps, V.; Wada, M.*; Tanabe, T.*; Huber, A.; Rubel, M.*; Pospieszczyk,
A.; Ohgo, T.*; Ohya, K.*; Sergienko, G.*; Barabash, V.*
Performance and erosion of a Tumsten brush limiter exposed at the TEXTOR Tokamak
15th International Conference on Plasma Surface Interactions (PSI)
Gifu-City, Japan: 27.05.2002 - 31.05.2002
Huber, A.; Beligman, I.*; Borodin, D.; Mertens, Ph.; Philipps, V.; Pospieszczuk, A.; Samm, V. N.; Schweer, B.; Sergienko, G.*; Vainshtein, L. A.*
Spectroscopic observation of silicon emission lines
IAEA Technical Meeting on Atomic and Plasma Material Interaction Data for Fusion Science and Technology

Huber, A.; Coad, P.*; Coster, D.*; Ingesson, C.*; Kirschner, A.; Matthews, G.F.*; Mertens, Ph.; Philipps, V.; Pospieszczuk, A.; Schweer, B.; Sergienko, G.*; Stamp, M.*; Itami, K.*
Tomographic reconstruction of 2-D line radiation distributions in the JET MKIIGB divertor
15th International Conference on Plasma Surface Interactions (PSI15)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Jakubowski, M.; Abdullaev, S. S.; Finken, K.H.; Kobayashi, M.
Atlas for the TEXTOR-DED operation
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Jaspers, R.*; Hogeweij, G.M.D.*; Merkulov, A.*; Westerhof, E.*; Schiller, F.C.*; Koslowski, H.R.; Messiaen, A.M.*
Electron transport barriers in TEXTOR plasmas
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Kirschner, A.; Brooks, J. N.*; Philipps, V.; Wienhold, P.; Pospieszczuk, A.; Janev, R. K.*; Samm, V. N.
Modelling of the transport of methane and higher hydrocarbons in fusion devices
15th International Conference on Plasma Surface Interactions (PSI15)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Kobayashi, M.*; Reiser, D.; Sewell, G.*; Finken, K.H.; Abdullaev, S. S.
Modeling approach to 3D transport simulations for TEXTOR-DED configuration with a finite element method
15th International Conference on Plasma-Surface Interactions (PSI15)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Kreter, A.; Baldzuhn, J.*; Ehmler, H.*; Hirsch, M.*; Kick, M.*; Kislyakov, A. I.*; Maaberg, H.*
Optimized confinement discharges with high ion temperatures after installation of the island divertor in W7-AS
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Krämer-Flecken, A.; Finken, K.H.; Larue, H.*; Udintsev, V.S.*
Hereodyne ECE diagnostics in the mode detection and disruptions avoidance at TEXTOR
Workshop on Electron Cyclotron Emission and Electron Cyclotron Resonance Heating
Aix-en-Provence, France: 13.05.2002 - 16.05.2002

König, R.*; Ramasubramanian, M.*; McCormick, K.*; Wenzel, U.*; Schweer, B.; Brix, M.
Island divertor spectroscopy at the WendelsteinW7-AS stellarator
14th Topical Conference on High Temperature Plasma Diagnostics
Madison, Wisconsin: 08.07.2002 - 11.07.2002

Laux, M.*; Schneider, W.*; Hantzsche, E.*; Jütter, B.*; Kostial, H.*; Wienhold, P.
Arcing through a thick B4C-layer
22th International Symposium on Discharges and Electrical Insulation in Vacuum : ISDEIV
Tours, France: 30.06.2002 - 05.07.2002

Arcing at B4C-covered limiters exposed to a SOL-Plasma
15th International Conference on Plasma Surface Interactions (PSI)
Gifu-City, Japan: 27.05.2002 - 31.05.2002
Arcing at B4C-covered limiters exposed to a SOL-plasma
15th International Conference on Plasma Surface Interactions in Controlled Fusion Devices
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Lehnen, M.; Loarer, T.*; Gunn, J.*; Hourtoule, J.*; Lachambre, J.L.*; Spuig, P.*
Current measurements in the scrape-off layer of Tore Supra with the new CIEL limiter
15th International Conference on Plasma Surface Interactions (PSI)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Lindner, P.*; Brix, M.; Mertens, Ph.; Pospieszczyk, A.; Samm, V. N.; Schweer, B.; Unterberg, B.
Spectroscopic studies of the velocity distribution of helium and neon atoms released from carbon and tungsten limiters in TEXTOR-94
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Marchuk, O.; Bertschinger, G.; Kunze, G.*; Goryaev, H. J.*; Urnov, A.
Measurements and modeling of argon K-alpha spectra at tokamak TEXTOR
1st German-Polish Euro-Conference on Plasma Diagnostics for Fusion and Applications (GPPD)
Greifswald, Germany: 04.09.2002 - 06.09.2002

Mayer, M.*; Wienhold, P.; Hildebrandt, D.*; Schneider, W.*
Erosion and redeposition on the ALT limiter of TEXTOR-94
15th International Conference on Plasma Surface Interactions (PSI)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Mukherjee, S.*; Danner, W.*; Balden, M.*; Simon-Weidner, J.*; Streibl, B.*; Uhlemann, R.
Actively cooled high-intensity heat shield (form locked) design analysis
22nd Symposium of Fusion Technology
Helsinki, Finland: 09.09.2002 - 12.09.2002

Nicolai, A.
TSC-simulations of MAST - discharges without primary current swing
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Nicolai, A.; Daybelge, U.*
Transport analysis of H-mode plasmas in ohmic ALCATOR C-MOD discharges based on neoclassical theory
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Nicolai, A.; Daybelge, U.*; Yarim, C.*
Modelling of plasma rotation and radial electric fields in TEXTOR and ALCATOR accounting for neutral beam injection and recycling of the neutral gas
Theory of Fusion Plasmas
Varenna, Italy: 27.08.2002 - 30.08.2002

Ohgo, T.*; Wada, M.*; Ohya, K.*; Hirai, T.; Biel, W.; Tanabe, T.*; Kondo, K.*; Rapp, J.; Philippis, V.; Huber, A.; Sergienko, G.*; Pospieszczyk, A.; Bertschinger, G.; Noda, N.*
Effect on core plasma radiation due to high power laser injection onto C, W and Ta test-limiters in TEXTOR
14th International Conference on Plasma Surface Interaction in Controlled Fusion Devices
Gifu, Japan: 27.05.2002 - 31.05.2002

Ohya, K.*; Hirai, T.; Tanabe, T.*; Wada, M.*; Ohgo, T.*; Philippis, V.; Pospieszczyk, W.; Huber, A.; Sergienko, G.*; Brezinsek, S.*; Noda, N.*
Simulation of hydrogen and hydrocarbon release from W-Ta and W-C twin test limiters in TEXTOR edge plasma
14th International Conference on Plasma Surface Interaction in Controlled Fusion Devices
Gifu-City, Japan: 27.05.2002 - 31.05.2002
The ECW installation at the TEXTOR-Tokamak
22nd Symposium of Fusion Technology
Helsinki, Finland: 09.09.2002 - 12.09.2002

Pautasso, G.*; Savtchakov, A.; Egorov, S.*; Dux, R.*; Finken, K.H.; Gruber, O.*; Haas, G.*; Mank, G.; Maraschek, M.*; Rohde, V.*; Seidl, U.*
Mitigation of disruptions with fast impurity puff of ASDEX upgrade
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Perez, C.; Koslowski, H.R.; Huysmans, G.T.A.*; Smeulders, P.*; Alper, B.*; Hender, T.C.*; Meneses, L.*; Zerbini, M.*
Type-I ELM precursor modes in JET
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Philipp, V.; Stamp, M.*; Pospieszczyn, A.; Huber, A.; Kirschner, A.; Vietzke, E.
Analysis of chemical erosion of carbon-based material
15th International Conference on Plasma Surface Interactions (PSI15)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Pospieszczyn, A.; Schweer, B.; Philipp, V.; Huber, A.; Sergienko, G.*; Freisinger, M.; Rubel, M.*; Herrmann, A.*; Kütter, S.*; Renner, H.; Bolt, H.
B4C-limiter experiments at TEXTOR
15th International Conference on Plasma Surface Interactions (PSI15)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Ramasubramanian, N.*; König, R.*; Grigull, P.*; McCormick, K.*; Giannone, L.*; Feng, Y.*; John, A.*; Schweer, B.; Brix, M.
Spectroscopic characterisation of W7-AS island divertor plasma
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Rapp, J.; McDonald, D.*; Eich, T.*; Fundamenski, W.*; von Hellermann, M.*; Ingesson, L.C.*; Jachmich, S.*; Loarte, A.*; Matthews, G.F.*; Philipps, V.; Saibene, G.*; Sartori, R.*
Strongly radiating type-III ELMy H-mode : an operating scenario for ITER?
IEA Workshop on ELMs
Culham, UK: 24.06.2002 - 26.06.2002

Reduction of divertor heat load in JET ELMy H-modes using impurity seeding techniques
19th IAEA Fusion Energy Conference

Rapp, J.; Pamela, J.*; Solano, E.R.*
Studying ITER physics and technology issues at JET
44th Annual Meeting on the APS Division of Plasma Physics
Orlando, USA: 11.11.2002 - 15.11.2002

Savtchakov, A.; Pautasso, G.*; Finken, K.H.; Mank, G.
Fast valve for mitigating disruptions in tokamaks
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Schwanitz, V.*; Lindmayer, M.*; Braunsberger, U.*; Giesen, B.; Neubauer, O.
Electromagnetic stray fields of the power supply systems of TEXTOR in regard of the European Commission Council recommendation (1999/519/EC)
22nd Symposium of Fusion Technology
Helsinki, Finland: 09.09.2002 - 12.09.2002
Schweer, B.; Wienhold, P.; Rubel, M.*; Emmoth, B.*; Zagorski, R.*
Fast reciprocating probe system for plasma edge characterisation: construction and applications
1st German-Polish Euro-Conference on Plasma Diagnostics for Fusion and Applications (GPPD), Greifswald, Germany: 04.09.2002 - 06.09.2002

Shoji, T.*; Sakawa, Y.*; Tamura, N.*; Jachmich, S.*; Mank, G.; Finken, K. H.
Experiments on selective removal of helium by an application of radio frequency field
15th International Conference on Plasma Surface Interactions (PSI15)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Tokar, M.; Kalupin, D.*; Reiser, D.; Unterberg, B.
Effect of gas puff on edge transport
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Von Seggern, J. C.*; Soldatov, S.V.*; Donnê, A.J.H.*; Krümer-Flecken, A.; Schiller, F.C.*
Density fluctuation measurements at TEXTOR by pulsed radar and CW reflectometry
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

Wada, M.*; Hirai, T.; Ohgo, T.*; Tanabe, T.*; Ohya, K.*; Philipp, V.; Huber, A.; Sergienko, A.*; Pospieszczyk, A.; Noda, N.*
Inhomogeneous heat loading to high-Z test limiters depending upon the limiter materials
14th International Conference on Plasma Surface Interaction in Controlled Fusion Devices
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Wienhold, P.; Mayer, M.*; Rubel, M.*; Schneider, W.*
Shadowing edges as tool to investigate impurity transport in TEXTOR
1st German-Polish Euro-Conference on Plasma Diagnostics for Fusion and Applications (GPPD)
Greifswald, Germany: 04.09.2002 - 06.09.2002

Wischmeier, M.*; Pitts, R.A.*; Coster, D.*; Eich, T.*; Huber, A.; Jachmich, S.*; Ingesson, C.*; Rapp, J.; Matthews, G.*; Philipp, V.; Reiter, D.
Divertor detachment during pure helium plasmas in JET
15th International Conference on Plasma Surface Interactions (PSI)
Gifu-City, Japan: 27.05.2002 - 31.05.2002
2002 — Talks on conferences

Abdullaev, S. S.; Finken, K.H.; Jakubowski, M.; Kobayashi, M.; Reiser, D.; Runov, A.M.*; Reiter, D.
Overview of magnetic structure induced by the TEXTOR-DDED and the related transport
19th IAEA Fusion Energy Conference

Multi-pulse 20 kHz TV Thomson scattering with high spatial resolution on TEXTOR
1st German-Polish Euro-Conference on Plasma Diagnostics for Fusion and Applications (GPFD)
Greifswald, Germany: 04.09.2002 - 06.09.2002

Bertschinger, G.; Biel, W.; Rusbl,ldt, D.
New developments in X-ray spectroscopy : imaging crystal spectrometers for large fusion devices
1st German-Polish Euro-Conference on Plasma Diagnostics for Fusion and Applications (GPFD)
Greifswald, Germany: 04.09.2002 - 06.09.2002

Data for spectral measurement of oxygen fluxes in the plasma boundary
DPG Fr.hjahrstagung
Bochum, Germany: 18.03.2002 - 21.03.2002

Brezinsek, S.; Mertens, Ph.; Pospieszczyk, A.; Sergienko, G.*; Greenland, P.T.*
Freisetzung von HD-Moleklen von einer plasmabegrenzenden Graphitoberfläche
DPG Fr.hjahrstagung
Bochum, Germany: 18.03.2002 - 21.03.2002

Bruchhausen, M.; Burhenn, R.*; Endler, M.*; Pospieszczyk, A.; Zoletnik, S.
Untersuchung der Struktur von Elektronendichtefluktuationen am Stellerator W-7-AS mit einem suprathermischen atomaren Lithiumstrahl
DPG Fr.hjahrstagung
Bochum, Germany: 18.03.2002 - 21.03.2002

Increased understanding of the dynamics and transport in ITB plasmas from multimachine comparison
19th IAEA Fusion Energy Conference
Lyon, France: 14.10.2002 - 16.10.2002

An overview of JET edge modelling activities
15th International Conference on Plasma Surface Interactions (PSI)
Gifu-City, Japan: 27.05.2002 - 31.05.2002
Finken, K.H.; Krümer-Flecken, A.; Lehnen, M.; Savtchkov, A.
Disruptions - a proposal for their mitigation and their understanding due to mode-mode interaction
15th International Conference on Plasma Surface Interactions (PSI15)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Fuchs, G.; von Goeler, S.*; Ohdachi, S.*; Toi, K.*
Tangentially viewing soft X-ray camera
IEA-DED and TEXTOR-Workshop
Jülich, Germany: 25.02.2002 - 27.02.2002

Grosman, A.*; AnÈ, J. M.*; Barabaschi, P.*; Becoulet, M.*; Evans, W.E.*; Finken, K.H.; Ghendrih, Ph.*; Huysmans, G.*; Leonard, A. W.*; Lipa, M.*; Mahdavi, M.A.*; Thomas, P.R.*
Towards an experimental investigation of stochastic magnetic fields to control edge transport barriers in Next Step Tokamaks
19th IAEA Fusion Energy Conference

Hender, T.C.*; Sauter, O.*; Alper, B.*; Angioni, C.*; de Baar, M.*; de Benedetti, M.*; Belo, P.*; Bigi, M.*; Borba, D. N.*; Bozzone, T.*; Budny, R.*; Buttery, R. J.*; Gondhalekar, A.*; Gorelenko, N. N.*; Gude, A.*; Guenter, S.*; Hellsten, T.*; Howell, D.F.*; Koslowski, H.R.; La Haye, R. J.*; Hyatt, A.W.*; Lamma, P.*; Lazzaro, E.*; Mantshinen, M.J.*; Marascheok, M.*; Mayoral, M.L.*; McClements, K.G.*; Milani, F.*; Nabais, F.*; Nave, M.F.P.*; Nguyen, H. P.*; Nowak, S.*; Pecquet, A.L.*; Perez von Thun, C.*; Petty, A. V.*; Pinches, S.D.*; Pochezl, A.*; Podda, S.*; Rapp, J.*; Salzedas, F.*; Sartori, F.*; Sharapov, S.E.*; Stamp, M.*; Testa, D.*; Westerhof, E.*; de Vries, P.*; Zanca, P.*
Sawtooth, neo-classical tearing mode and error field studies in JET
19th IAEA Fusion Energy Conference

Hey, J. D.*; Chu, C. C.*; Mertens, Ph.
Zeeman spectroscopy of tokamak edge plasmas
16th ICLS International Conference on Spectral Line Shapes
Berkeley, CA: 03.06.2002 - 07.06.2002

Hirai, T.; Philippa, V.; Huber, A.; Sergienko, G.*; Linke, J.; Wakui, T.; Tanabe, M.*; Rubel, M.*; Wada, M.*; Ohgo, T.*; Oya, K.*; Pospieszczysz, A.; Barabash, V.*
Performance of tungsten brush limiter exposed in TEXTOR-94
Japan-US Workshop on High Heat Flux Components and Plasma Surface Interactions in Next Fusion Devices

Hogan, J.*; Skinner, G.*; Gauthier, R.*; Ruggieri, R.*; Cambe, A.*; Mitteau, R.*; Guilhem, D.*; Reichele, R.*; Core, Y.*; Grisola, C.*; Hillis, D.*; Mioduszewski, P.*; Wade, M. R.*; Isler, R.*; Philippa, V.; Winter, J.*; Fenstermacher, M.*; Groth, M.*; Mahdavi, A.*; Friend, A.*; Coad, P.*; Corrigan, G.*; Spence, J.*; Coster, D.*; Schneider, R.*; Reiter, D.*
Modelling erosion, deposition, and particle exchange for TFTR, Tore Supra, TEXTOR-94, DIII-D and JET
Meeting on Erosion and Deposition and Related Modelling Activities - Task Force E, EFDA CSU
Culham, UK: 20.03.2002 - 21.03.2002

Jakubowski, M. W.; Finken, K.H.; Leupold, O.; Kobayashi, M.; Lehnen, M.; Wolf, R.
Physics of the dynamic ergodic divertor
International Conference and School on Plasma Physics and Controlled Fusion

Jakubowski, M.; Abdullaev, S. S.; Finken, K.H.; Kobayashi, M.
Atlas for the TEXTOR-DED operations
IEA-DED and TEXTOR-Workshop
Jülich, Germany: 25.02.2002 - 27.02.2002

Kirschner, A.
Current status of JET modelling with ERO-JET and future plans
Meeting on Current Status of JET Edge Modelling
Culham, UK: 04.10.2002
Kirschner, A.
Modelling of carbon erosion and re-deposition in JET and ITER
2nd Divertor Meeting on International Tokamak Physics Activities (ITPA)
Lausanne, Switzerland: 21.10.2002 - 23.10.2002

Kirschner, A.; Brooks, J. N.*; Philipps, V.
Status of erosion/deposition modelling in JET MkIIa with the ERO-JET code
Meeting on Erosion and Deposition and Related Modelling Activities - Task Force E,
EPDA CSU
Culham, UK: 20.03.2002 - 21.03.2002

Koslowski, H.R.; Alper, B.*; Eich, T.; Sharapov, T.; Westerhof, E.*
The palm tree mode in Type-I ELMy H-mode discharges on JET
19th IAEA Fusion Energy Conference

Kreter, A.
Evaluation of data from neutral particle analysis (NPA) at W7-AS
2nd Workshop on Fusion Data Processing, Validation and Analysis

Lehnen, M.; Loarer, T.*; Gunn, J.*; Hourtoule, J.*; Lachambre, J.L.*; Spuig, P.*
Str"ume in der Abschlischicht des Tokamaks Tore Supra (CIEL Projekt)
DPG Fr.hjahrstagung
Bochum, Germany: 18.03.2002 - 21.03.2002

Lyssioivan, A.*; Koch, R.*; Messiaen, A.*; Durodie, F.*; Vervier, M.*; Amarante-Segundo, G. S.*; Van Eester, D.*; Weynants, R.*; Gauthier, E.*; Esser, H.G.; Hoekzema, F.*; Philipps, V.; Westerhof, E.*
New developments in ICRF antennas and non-traditional applications of HF power on TEXTOR
International Conference and School on Plasma Physics and Controlled Fusion

Marchuk, O.; Bertshinger, G.; Biel, W.; Kunze, H.J.*; Urnov, A.*; Goryaev, E.
Modelling of argon XVII spectra and measurements on TEXTOR
DPG Fr.hjahrstagung
Bochum, Germany: 18.03.2002 - 21.03.2002

Matsuyama, M.*; Bekris, N.*; Glugla, M.*; Noda, N.*; Philipps, V.; Watanabe, K.*
Nondestructive tritium measurements of Mk IIA divertor tile by BIXS
15th International Conference on Plasma Surface Interactions (PSI)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Mueck, A.*; Goodman, T.*; Gude, A.*; Koslowski, H.R.; Ryter, F.*; Sesnic, S.*; Westerhof, E.*; Zohm, E.*
The influence of ECRH/ECCD on the sawtooth behaviour of ASDEX upgrade discharges
DPG Fr.hjahrstagung
Bochum, Germany: 18.03.2002 - 21.03.2002

Pamela, J.*; Rapp, J.
Overview of JET results, near term plans
22nd Symposium on Fusion Technology

Pamela, J.*; Rapp, J.
Overview of JET results, near term plans
22nd Symposium on Fusion Technology

Pautasso, G.*; Egorov, S.*; Finken, K.H.; Gruber, O.*; Herrmann, A.*; Maraschek, M.*; Neu, G.*; Nakamura, Y.*; Rohde, V.*; Savtchkov, A.; Seidel, U.*; Streibl, B.*; Tichmann, Ch.*
Disruption studies on ASDEX upgrade
19th IAEA Fusion Energy Conference

Philipps, V.
Compilation of chemical sputtering data relevant for chemical erosion in tokamaks
1st Divertor Meeting on International Physics Activities (ITPA)
San Diego, USA: 25.02.2002 - 27.02.2002
Philipps, V.
Erosion and codeposition in JET
10th European Fusion Physics Workshop

Philipps, V.
Latest results from erosion/deposition in JET
1st Divertor Meeting on International Tokamak Physics Activities (ITPA)
San Diego, USA: 25.02.2002 - 27.02.2002

Philipps, V.
Recent data on chemical erosion and tritium retention
2nd Divertor Meeting on International Tokamak Physics Activities (ITPA)
Lausanne, Switzerland: 21.10.2002 - 23.10.2002

Philipps, V.
Status of chemical erosion of tritium retention data
2nd Divertor Meeting on International Tokamak Physics Activities (ITPA)
Lausanne, Switzerland: 21.10.2002 - 23.10.2002

Philipps, V.; Coad, J. P.*; Matthews, G.*; Rubel, M.*; Wienhold, P.; Kirschner, A.; Brooks, J.*; Federici, G. F.*; Laesser, R.*
Recent results on long term fuel retention in JET and TEXTOR and predictions for ITER
19th IAEA Fusion Energy Conference

Philipps, V.; Esser, H.G.; Huber, A.; Samm, V. N.
A rotating wheel for energy exhaust in fusion devices
1st International Workshop on Innovative Concepts for Plasma-Interactive Components in Fusion Devices
Osaka, Japan: 23.05.2002 - 25.05.2002

Pitts, R.A.*; Andrew, P.*; Coad, P.*; Coffey, I.*; Coster, D.*; McDonald, D.C.*; Eich, T.*; Erent, S.K.*; Fenstermacher, M. E.*; Fundamenski, W.*; Hidalgo, C.*; Hillis, D.*; Huber, A.; Ingesson, C.*; Jachmich, S.*; Korotkov, A.*; Lawson, K.*; Loarer, T.*; Matthews, G.F.*; McCracken, G.*; Meigs, A. G.*; Philipps, V.; Pospieszczky, A.; Rapp, J.; Reiter, D.; Riccardo, V.*; Stamp, M.F.*; Tsiitrone, E.*; Wischmeier, M.*
Comparing scrape-off layer and divertor physics in JET pure He and D discharges
15th International Conference on Plasma Surface Interactions (PSI)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

High temperature plasma edge diagnostics
IAEA Technical Meeting on Atomic and Plasma Material Interaction Data for Fusion Science and Technology

Pospieszczky, A.; Brezinsek, S.; Mertens, Ph.; Sergienko, G.
Hydrogen atom velocities and penetration depths in front of graphite surfaces
Satellite Meeting of 15th PSI on Hydrogen Isotopes in Fusion Reactor Materials
Tokyo, Japan: 22.05.2002 - 24.05.2002

Rapp, J.
Power exhaust and plasma wall interaction with respect to steady state operation
10th European Fusion Physics Workshop

Rapp, J.; Huber, A.; Ingesson, L.C.*; Jachmich, S.*; Matthews, G.F.*; Philipps, V.; Pitts, R.*
Density limits in helium plasmas at JET
15th International Conference on Plasma-Surface Interactions (PSI15)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Reiser, D.; Tokar, M.Z.; Unterberg, B.
On the impact of localised gas fueling on edge turbulence as a possible trigger for confinement degradation at high plasma densities
15th International Conference on Plasma Surface Interactions (PSI15)
Gifu-City, Japan: 27.05.2002 - 31.05.2002
Reiser, D.; Unterberg, B.
Neutralgasgetriebene Driftwelleninstabilitäten in Tokamak-Randschichtplasmen und anomaler Transport
DPG Frühjahrstagung
Bochum, Germany: 18.03.2002 - 21.03.2002

Reiter, D.
Fusion reactor plasma edge modelling codes
IAEA Technical Meeting on Atomic and Plasma Material Interaction Data for Fusion Science and Technology

Rogister, A.
EDA-LPC H-mode : a theoretical model
9th EU-US Transport Task Force Workshop

Rogister, A.; Rice, J.E.*; Nicolai, A.
Interpretation of the toroidal velocity measured in Alcator C-Mod ohmic H-mode discharges
US Transport Task Force Workshop
Annapolis, Md.: 03.04.2002 - 06.04.2002

Samm, V. N.
Kernfusion Energiesymposium Wissenschaft und Wirtschaft : Haus der Industrie
Berlin, Germany: 01.10.2002 - 02.10.2002

Samm, V. N.
Plasma wall interaction : status and data needs
IAEA Technical Meeting on Atomic and Plasma Material Interaction Data for Fusion Science and Technology

Shoucri, M.*; Gerhauser, H.; Finken, K.H.
Formation of steep gradients with plasma detachment at grazing B-field incidence at a plasma-wall transition
5th Workshop on Role of Electric Fields in Plasma Confinement and Exhaust
Montreux, Switzerland: 23.06.2002 - 24.06.2002

Tokar, M.; Kalupin, D.*; Reiser, D.; Unterberg, B.
Physics of edge and core interplay in radiative improved mode
Theory of Fusion Plasmas
Varenna, Italy: 27.08.2002 - 30.08.2002

Tokar, M.; Kalupin, D.*; Unterberg, B.
Towards understanding of density peaking in impurity seeded plasmas
10th European Fusion Physics Workshop

Tokar, M.Z.; Kalupin, D.*; Reiser, D.; Singh, R.*; Unterberg, B.
Mechanisms of gas puff effect on improved confinement
IAEA Technical Meeting on Theory of Plasma Instabilities : Kloster Seeon
Seeon, Germany: 09.04.2002 - 12.04.2002

Unterberg, B.; Sergienko, G.; Brezinsek, S.; Pospieszczyk, A.; Lehnen, M.
Influence of a local neutral particle source on the plasma boundary in TEXTOR
DPG Frühjahrstagung
Bochum, Germany: 18.03.2002 - 21.03.2002

Unterberg, B.; Weynants, R.*; Sing, R.*
Particle transport in impurity seeded plasmas at trans-Greenwald densities
9th EU-US Transport Task Force Workshop

Electron cyclotron resonance heating with the preliminary 110 Ghz system on TEXTOR
Workshop on Strong Micro Waves in Plasmas
Nizhny Novgorod, Russia: 01.08.2002 - 09.08.2002


Electron cyclotron resonance heating on TEXTOR: results from the preliminary 110 GHz system
Workshop on Electron Cyclotron Emission and Electron Cyclotron Resonance Heating
Aix-en-Provence, France: 13.05.2002 - 16.05.2002

Wienhold, P.
Impurity transport in controlled fusion devices with carbon walls
Annual Meeting of the Swedish Fusion Research Unit
Gothenburg, Sweden: 04.11.2002 - 06.11.2002

Wienhold, P.
Kurz- und langreichweittiger Transport von erodierten Wandmaterialien in TEXTOR
DPG Frhjahrstagung
Bochum, Germany: 18.03.2002 - 21.03.2002

Wienhold, P.
Reflectometry and other optical methods of film thickness determination
Workshop on Tritium Retention Diagnostics
Culham, UK: 21.01.2002 - 22.01.2002

Short and long range transport of materials eroded from wall components in fusion devices
15th International Conference on Plasma Surface Interactions (PSI15)
Gifu-City, Japan: 27.05.2002 - 31.05.2002

Zastrow, K.-D.*; Brix, M.; Dux, R.*; Finken, K.H.; Giroud, C.*; von Hellermann, M.*; Hillis, D.*; Morgan, P.D.*; O'Mullane, M.C.*; Whiteford, A. D.*
Helium ash simulation studies with divertor helium pumping in JET internal transport barrier discharges
29th EPS Conference on Plasma Physics and Controlled Fusion
Montreux, Switzerland: 17.06.2002 - 21.06.2002

2002 — Other talks

Abdullaev, S. S.; Finken, K.H.
Hamiltonian guiding center motion in a toroidal system
IEA-DED and · TEXTOR-Workshop
J.Chlich, Germany: 25.02.2002

An, J. M.*; Barabaschi, P.*; Finken, K.H.; Ghendrih, Ph.*; Grosman, A.*; Leonard, A. W.*; Lipa, M.*; Madhavi, M.A.*; Thomas, P.R.*
ELMs control with an ergodic divertor
IEA-DED and · TEXTOR-Workshop
J.Chlich, Germany: 25.02.2002 - 27.02.2002

Finken, K.H.
Zur Physik des Dynamischen Ergodischen Divertors
Universitit Graz
Graz, Austria: 11.06.2002
Finken, K.H.; Jaspers, R*; Entrop, I.*; Lopes-Cardozo, N.J.
Untersuchungen an Runaway Elektronen in Tokamaks
Ruhr-Universität-Bochum
Bochum, Germany: 20.03.2002

Finken, K.H.; Kobayashi, M.; Abdullaev, S. S.; Jakubowski, M.
Physics aspects of the dynamic ergodic divertor (DED)
Kolloquium FOM Nieuwegein
Nieuwegein, Niederlande: 04.04.2002

Finken, K.H.; Mank, G.; Krämer-Flecken, A.; Jaspers, R.*
Mitigation of disruptions
IEA-DED and TEXTOR-Workshop
Jülich, Germany: 25.02.2002 - 27.02.2002

Kobayashi, M.; Sewell, G.*; Finken, K.H.; Reiser, D.; Abdullaev, S. S.
Modelling of the DED laminar zone with finite element method
IEA-DED and TEXTOR-Workshop
Jülich, Germany: 25.02.2002 - 27.02.2002

Koslowski, H.R.; Alper, B.*; Eich, T.*; Sharapov, S.E.*
The palm tree mode in JET ELMy H-modes - a hint at ergodisation?
IEA-DED and TEXTOR-Workshop
Jülich, Germany: 25.02.2002 - 27.02.2002

Marchuk, O.; Bertschinger, G.; Kunze, H.J.*; Goryaev, F.*; Urnov, A.*
Measurements and modeling of Argon K-alpha Spectra at tokamak TEXTOR
Max-Planck-Institut für Plasmaphysik
Greifswald: 04.09.2002

Neubauer, O.
Status of TEXTOR and DED
IEA-DED and - TEXTOR-Workshop
Jülich, Germany: 25.02.2002 - 27.02.2002

Perez, C.P.; Koslowski, H.R.; Smeulders, P.*; Huysmans, G.T.A.*; Jachmich, S.*; Loarte, A.*; Saibene, G.*; Becoulet, M.*
Washboard modes as ELM related events in JET
Culham Science Centre
Abingdon, UK: 11.11.2002

Philipps, V.
Herausforderung an die Plasma-Wand-Wechselwirkung für die nächste Generation von Fusionsanlagen
Ruhr-Universität Bochum
Bochum, Germany: 14.02.2002

Philipps, V.; Wienhold, P.; Kirschner, A.; Mayer, M.*; Rubel, M.*
Carbon transport and deposition in TEXTOR
Meeting on Erosion and Deposition and Related Modelling Activities
Culham, UK: 20.03.2002 - 21.03.2002

Local plasma effects on B4C-coating
IEA-DED and TEXTOR-Workshop
Jülich, Germany: 25.02.2002 - 27.02.2002

Rapp, J.
Strongly radiating type-III ELMy H-mode : an operating scenario for ITER?
IEA Workshop on ELMs - JET
Culham, UK: 24.06.2002

Samm, V. N.
Controlled nuclear fusion - world wide efforts for a new energy source
Middle East Technical University
Ankara, Turkey: 02.10.2002
Samm, V. N.
Fusion, eine Zukunftsperspektive?
Nordrhein-Westfälische Akademie der Wissenschaften : Vortrag in der Klasse für Naturwissenschaften und Medizin
Düsseldorf, Germany: 05.06.2002

Samm, V. N.
Wo steht die Kernfusion?
VDI/VDE : Technische Universität Braunschweig
Braunschweig, Germany: 16.01.2002

Schweer, B.
Basics for atomic beam interaction
Middle East Technical University
Ankara, Turkey: 16.10.2002

Schweer, B.
DED diagnostics
IEA-DED and TEXTOR-Workshop
Jülich, Germany: 25.02.2002 - 27.02.2002

Schweer, B.
Determination of plasma parameter
Middle East Technical University
Ankara, Turkey: 15.10.2002

Schweer, B.
The TEXTOR tokamak
Middle East Technical University
Ankara, Turkey: 14.10.2002

Tokar, M.
Modelling of breathing oscillations in large helical device (LHD)
IEA-DED and TEXTOR-Workshop
Jülich, Germany: 25.02.2002 - 27.02.2002

Unterberg, B.
Transportprozesse in magnetisch eingeschlossenen Hochtemperaturplasmen mit kaltem Strahlungsmantel
Kolloquium : Gerhard-Mercator Universität Duisburg
Duisburg, Germany: 02.12.2002

2003 — Journals

Overview of magnetic structure induced by the TEXTOR-DED and the related transport
Nuclear fusion, 43 (2003), 5, S. 299 - 313

Behrisch, R.*; Federici, G.*; Kukushkin, A.*; Reiter, D.
Material erosion at the vessel walls of future fusion devices
Journal of nuclear materials, 313-316 (2003), S. 388 - 392

Bonnin, X.*; Coster, D.*; Pitcher, C.S.*; Schneider, R.*; Reiter, D.; Rozhansky, V.*; Voskoboynikov, S.*; B.Baumer, H.*
Improved modelling of detachment and neutral-dominated regimes using the SOLPS B2-Eirene code
Journal of nuclear materials, 313-316 (2003), S. 909 - 913

Brezinsek, S.; Kirschnic, A.; Mertens, Ph.; Philippis, V.; Pospieszczyk, A.; Reiter, D.; Samm, U.; Sergienko, G.
Properties of hydrogen isotopes in the boundary layer of fusion plasmas
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 38 (2003), S. 59
Brezinsek, S.; Mertens, Ph.; Pospieszczyk, A.; Samm, U.; Greenland, P. T.*; Sergienko, G.*
On the measurement of molecular deuterium particle fluxes in fusion boundary plasmas
Journal of nuclear materials, 313-316 (2003), S. 967 - 971

Brezinsek, S.; Mertens, Ph.; Pospieszczyk, A.; Sergienko, G.
Use of a high resolution overview spectrometer for fusion boundary plasmas
Verhandlungen der Deutschen Physikalischen Gesellschaft (Reihe 06), 38 (2003), S. 56

Gerhauser, H.; Zagórski, R.*; Jachmich, S.*; van Schoor, M.*
Numerical simulation of plasma profile changes in TEXTOR by externally driven radial polarization currents
Journal of nuclear materials, 313-316 (2003), S. 893 - 898

Groisman, A.*; Anê, J. M.*; Barabashi, P.*; Finken, K. H.; Mahdavi, A.*; Ghendrih, P.*; Huysmans, G.*; Lipa, M.*; Thomas, P. R.*; Tzitrone, E.*
H-mode barrier control with external magnetic perturbations
Journal of nuclear materials, 313-316 (2003), S. 1314 - 1320

Deuterium release and microstructure of tantalum-tungsten twin limiter exposed in TEXTOR-94

Huber, A.; Beligman, I.*; Borodin, D.; Mertens, Ph.; Philippus, V.; Pospieszczyk, A.; Samm, U.; Schweer, B.; Sergienko, G.; Vainshtein, L.*
Spectroscopic observation of Si I- and Si II-emission lines in the boundary of TEXTOR and comparison with kinetic calculations
Plasma physics and controlled fusion, 45 (2003), S. 89 - 103

Huber, A.; Coad, P.*; Coster, D.*; Ingesson, C.*; Kirschner, A.; Matthews, G. F.*; Mertens, Ph.; Philippus, V.; Pospieszczyk, A.; Schweer, B.; Sergienko, G.*; Stamp, M.*; Itami, K.*
Tomographic reconstruction of 2-D line radiation distributions in the JET MKIIGB divertor
Journal of nuclear materials, 313-316 (2003), S. 925 - 930

Janev, R. K.
Alternative mechanisms for divertor plasma recombination
Physica scripta topical issue, T96 (2002), S. 94

Krstic, P. S.*; Janev, R. K.; Schultz, D.R.*
Charge transfer processes in slow collisions of protons with vibrationally excited hydrogen molecules
Physica scripta topical issue, T96 (2002), S. 61

Muto, S.*; Tanabe, T.*; Hirota, A.*; Rubel, M.*; Philippus, V.; Maruyama, T.
TEM and EELS characterization of carbon dust and co-deposited layers from the TEXTOR-tokamak

Effect on core plasma radiation due to high power laser injection onto C, W Ta test-limiters in TEXTOR
Journal of nuclear materials, 313-316 (2003), S. 1161 - 1165

Simulation of hydrogen and hydrocarbon release from W-Ta und W-C twin test limiters in TEXTOR edge plasma
Journal of nuclear materials, 313-316 (2003), S. 571 - 575

Rapp, J.; Huber, A.; Ingesson, L. C.*; Jachmich, S.*; Matthews, G. F.*; Philippus, V.; Pitts, R.*
Density limits in helium plasmas at JET
Journal of nuclear materials, 313-316 (2003), S. 524 - 529
Control of neoclassical tearing modes by Sawtooth control
Physical review letters, 88 (2002), S. 105001

Scaffidi-Argentina, F.*; Ciattaglia, S.*; Coad, P.*; Penzhorn, R.D.*; Philipps, V.
First wall material issues and related activities at JET

Sergeev, V.Yu.*; Janev, R. K.; Rakovic, M.J.*
Optimization of CXRS TESPEL diagnostics on LHD in the visible spectral range
Plasma physics and controlled fusion, 44 (2002), S. 277

Long term behaviour of material erosion and deposition on the vessel wall and remote areas of TEXTOR
Journal of nuclear materials, 313-316 (2003), S. 439 - 443

Wada, M.*; Hirai, T.; Ohgo, T.*; Tanabe, T.*; Ohyo, K.*; Philipps, A.; Huber, G.; Sergienko, A.*; Pospieszczyk, A.; Moda, N.*
Inhomogeneous heat loading to High-Z test limiters depending upon the limiter materials
Journal of nuclear materials, 313-316 (2003), S. 292 - 296

Short and long range transport of materials eroded from wall components in fusion devices
Journal of nuclear materials, 313-316 (2003), S. 311 - 320

Wischmeier, M.*; Pitts, R. A.*; Coster, D.*; Eich, T.*; Huber, A.; Jachmich, S.*; Ingesson, C.*; Rapp, J.; Matthews, G.*; Philipps, V.; Reiter, D.
Divertor detachment during pure helium plasmas in JET
Journal of nuclear materials, 313-316 (2003), S. 980 - 985

Wolf, R.C.
Internal transport barriers in Tokamak plasmas
Plasma physics and controlled fusion, 45 (2003), S. R1

2003 — Reports

Janev, R. K.; Reiter, D.
Collision processes of hydrocarbon species in hydrogen plasmas II : the ethane and propane family
J.lich, Forschungszentrum, Zentralbibliothek, 2002
Berichte des Forschungszentrums J.lich ; 4005
JUEL-4005

2003 — Poster

Baeva, M.; Born, M.*; Meier, S.*; Reiter, D.; Schubert, H.*; Weiss, M.*; Wiesen, S.
Experimental and theoretical study on high-pressure Hg-Xe discharge lamps
DPG Fr.hjahrstagung 2003
Aachen, Germany: 24.03.2003 - 28.03.2003

Bertschinger, G.; Marchuk, O.; Kunze, H.J.*; Goryaev, P.*; Urnov, A.*
X-ray spectroscopy on devices for magnetic fusion (needs for atomic data)
IAEA Technical Meeting on Atomic and Plasma Material Interaction Data for Fusion Science and Technology
Biel, W.; Burhenn, R.*
Design of optimised VUV/XUV spectrometers for impurity studies on W7-X
DPG Fr. hjarstagung 2003
Aachen, Germany: 24.03.2003 - 28.03.2003

Borodin, D.; Beigman, I.*; Vainshtein, L.*; Pospieszczyk, A.
Proton impact excitation in He-like ions : close coupling and Born approach in impact parameter representation
DPG Fr. hjarstagung 2003
Aachen, Germany: 24.03.2003 - 28.03.2003

Modelling of spectra in the boundary plasma of TEXTOR and calculation of the according atomic data
IAEA Technical Meeting on Atomic and Plasma Material Interaction Data for Fusion Science and Technology

Brezinsek, S.; Greenland, P. T.*; Mertens, Ph.; Pospieszczyk, A.; Reiter, D.; Samm, V. N.; Philipps, V.
Measurement of molecular deuterium particle fluxes in fusion boundary plasmas
IAEA Technical Meeting on Atomic and Plasma Material Interaction Data for Fusion Science and Technology

Janev, R. K.
Status of collisional atomic and molecular hydrogen database
IAEA Technical Meeting on Atomic and Plasma Material Interaction Data for Fusion Science and Technology

Janev, R. K.; Krstic, P. S.*; Schultz, D.R.*
Molecule formation in cold hydrogen plasmas
44th Annual Meeting of the APS Division of Plasma Physics
Orlando, USA: 11.11.2002 - 15.11.2002

Janev, R. K.; Reiter, D.
Collision data base for hydrocarbon impurities in fusion edge plasmas
IAEA Technical Meeting on Atomic and Plasma Material Interaction Data for Fusion Science and Technology

Janev, R. K.; Reiter, D.
Complete collision database for hydrocarbon impurities in fusion edge plasmas
IAEA Technical Meeting on Atomic and Plasma Material Interaction Data for Fusion Science and Technology

Janev, R. K.; Reiter, D.
Unified analytic representation of hydrocarbon impurity : collision cross sections
15th International Conference on Plasma-Surface Interactions (PSI)
Gifu, Japan: 27.05.2002 - 31.05.2002

Kirschner, A.; Brooks, J. N.*; Philipps, V.; Wienhold, P.; Pospieszczyk, A.; Janev, R. K.; Samm, V. N.
Comparison of different rate coefficients for the methane family and their impact on hydrocarbon transport modelling
IAEA Technical Meeting on Atomic and Plasma Material Interaction Data for Fusion Science and Technology

Rogister, A.
Interpretation of the large co-rotation velocity observed in Alcator C-Mod ELM-free H-mode
10th European Fusion Theory Conference
Helsinki, Finland: 08.09.2003 - 10.09.2003
Wienhold, P.; Kirschner, A.; Philipps, V.; Rubel, M.
Short range carbon transport near plasma wetted surface in TEXTOR
DPG Frühjahrstagung 2003

Wiesen, S.; Reiter, D.; Bärner, P.; Born, M.*; Meier, S.*
Monte Carlo simulation of radiation transfer in fusion and lighting applications
DPG Frühjahrstagung
Aachen, Germany: 24.03.2003 - 28.03.2003

### 2003 — Talks on conferences

Abdullaev, S. S.
On mapping models of field lines in a stochastic magnetic field
Workshop on Stochasticity in Fusion Edge Plasmas (SEP)
Jülich, Germany: 06.10.2003 - 08.10.2003

Baeva, M.*; Born, M.*; Meier, S.*; Reiter, D.; Schubert, H.*; Wei, M.*; Wiesen, S.
Spectroscopic studies on high-pressure Hg-Xe discharges
26th International Conference on Phenomena in Plasma Physics (ICPIG)

Baeva, M.*; Reiter, D.
Radiation transport in high pressure Hg/Xe discharges
26th International Conference on Phenomena in Plasma Physics (ICPIG)

Bertschinger, G.; Marchuk, G.; Frenzi-Bonizec, C.*; Goryaev, F.*; Urnov, A.*
Benchmarking of X-ray spectra of He-like argon and titanium on Tokamak plasmas
35th Conference of the European Group for Atomic Spectroscopy (EGAS35)

Born, M.*; Baeva, M.; Meier, S.*; Reiter, D.; Schubert, H.; Strasser, M.; Wei, M.*; Wiesen, S.
Mercury free HID lamps
26th International Conference on Phenomena in Plasma Physics (ICPIG)

Brezinsek, S.; Kirschner, A.; Mertens, Ph.; Philipps, V.; Pospieszczuk, A.; Reiter, D.; Samm, U.; Sergienko, G.
Properties of hydrogen isotopes in the boundary layer of fusion plasmas
DPG Frühjahrstagung 2003
Aachen, Germany: 24.03.2003 - 28.03.2003

Janev, R. K.; Reiter, D.
Cross section database for electron and proton collisions with CHy and CHy+ hydrocarbons
3rd ICAMDATA

Rogister, A.
Theory of ion internal transport barriers
10th European Fusion Theory Conference
Helsinki, Finland: 08.09.2003 - 10.09.2003

Rubel, M.*; Philipps, V.; Tanabe, T.*; Wienhold, P.; Freisinger, M.; Linke, J.*; von Seggern, J.; Wessel, E.*
Thick co-deposits and dust in controlled fusion devices with carbon walls : fuel inventory and growth rate of co-deposited layers
Satellite Meeting of the 15th PSI: Hydrogen Isotopes in Fusion Reactor Materials
Tokyo, Japan: 22.05.2002 - 24.05.2002

Runov, A.*; McTaggart, N.*; Kasilov, S.*; Schneider, R.*; Bonnin, X.*; Reiter, D.; Zagórski, R.*
Transport modelling for ergodic configurations
Workshop on Stochasticity in Fusion Edge Plasmas (SEP)
Jülich, Germany: 06.10.2003 - 08.10.2003
Samm, U.  
Magnetische Fusion - die letzten Hürden  
300. WE-Heraeus-Seminar : Physikzentrum Bad-Honnef  
Bad-Honnef: 26.05.2003 - 28.05.2003

Shoucri, M.*; Gerhauser, H.; Finken, K. H.  
Study of the formation of a charge separation and electric field at a plasma edge using Eulerian Vlasov codes  
1st Cairo Conference on Plasma Physics and Applications  

2003 — Other talks

Esser, H. G.  
Quartz-Kristall-Mikrowaagen: Messung von redepolierten Kohlenstoffschichten in Fusionsanlagen  
Ruhr-Universität Bochum  
Bochum: 17.12.2002

(*) No employee of Forschungszentrum Jülich