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Association Euratom - Risø National Laboratory, Technical University of Denmark - Annual Progress Report 2007

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Abstract (max. 2000 char.):

The programme of the Research Unit of the Fusion Association Euratom - Risø National Laboratory, Technical University of Denmark, covers work in fusion plasma physics and in fusion technology. The fusion plasma physics research focuses on turbulence and transport, and its interaction with the plasma equilibrium and particles. The effort includes both first principles based modelling, and experimental observations of turbulence and of fast ion dynamics by collective Thomson scattering. The activities in technology on investigations of radiation damage of fusion reactor materials have been phased out during 2007. Minor activities are system analysis, initiative to involve Danish industry in ITER contracts and public information. A summary is presented of the results obtained in the Research Unit during 2007.

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Preface

In 2006 seven parties, EU, Japan, Russia, China, USA, Korea and India, signed the agreement to build and exploit ITER, and to place ITER in Cadarache in France. ITER is a major experimental facility for the development of fusion as an energy source. It is expected that ITER will be ready for scientific exploitation in 2016. The mission of ITER is to demonstrate that nuclear fusion can be exploited as an energy source. ITER represents an unprecedented international cooperation in the field of science and technology. It also represents a valuable opportunity for cooperation between public research organisations and private industry. Risø DTU participates in the internationally coordinated activities to develop fusion and sees itself as having a key role in facilitating the participation of Danish industries in the international fusion programme.

The principle being pursued with ITER is the fusion of hydrogen isotopes to form helium. To make the fusion process run at a significant rate the hydrogen gas must be heated to high temperatures where it ionises and turns into a plasma. The plasma must be confined to achieve suitable densities and sustain the high temperature. ITER will use a magnetic field for the confinement. While fusion holds the promise of providing a sustainable source of energy, which is environmentally sound, it also presents considerable scientific and engineering challenges. Key issues in the final steps towards realising fusion energy production include:

Improving the plasma energy confinement, that is the ratio between the energy of the plasma and the heating power required to sustain the plasma energy. Improving energy confinement implies reducing energy transport out of the plasma, which principally is due to turbulence. So what we really need to do is to understand and control turbulence.

Channelling the energy of fast ions, produced in fusion reactions, into heating the bulk plasma without driving turbulence and without premature exit of the fast ions from the plasma requires understanding and control of the dynamics of the fast ions in interaction with other particles and with waves.

1 January 2007 Risø National Laboratory, and four other Danish institutes have been merged with the Technical University of Denmark (DTU) with DTU as the continuing unit. As DTU covers many technical and scientific fields of interest for the development of fusion energy, the possibility for expanding the Danish activities in the field has been investigated. Investigations of advanced superconductors operating in high magnetic field have now been included in the work plan 2008-2011. Other possibilities e.g. new material studies are under consideration. The activities in technology on investigations of radiation damage of fusion reactor materials have been phased out during 2007.

Risø's main contributions to fusion research in 2007 have been: 1) codes, modelling turbulence and transport, are continually improved, and benchmarked against experiments. 2) Central to understanding the dynamics of fast ions is are temporally and spatially resolved measurements of the fast ion velocity distributions in the plasma. Risø, in collaboration with MIT (USA) and EURATOM partners, is exploiting and developing millimetre wave based collective Thomson scattering (CTS) diagnostics at the TEXTOR and ASDEX upgrade tokamaks in FZ-Jülich and the Max-Planck Institute for plasma physics in Garching (near Munich). Of particular note this year has been detailed measurements of fast ion populations in the TEXTOR which are in excellent agreement with Fokker-Planck modelling of the fast ion dynamics. Significant effort also goes into developing a fast ion CTS diagnostic for ITER.

1 Summary of Research Unit activities

The activities in the Research Unit cover the main area:

Fusion Plasma Physics, which includes:

- *Theoretical and numerical turbulence studies*. Turbulence and the associated anomalous transport is investigated using first principles based models and solving these by means of numerical codes in full toroidal geometry. These models are continuously being developed and benchmarked against experimental data and codes at other associations. The dynamics of bursts of fluctuations leading to profile relaxation have been studied in models for flux-driven interchange mode turbulence, where the back reaction of the turbulence on the equilibrium flows and profiles are accounted for.

- *Fast Ion Collective Thomson Scattering.* Risø has taken the lead in the development and exploitation of fast ion collective Thomson scattering diagnostics for TEXTOR, ASDEX Upgrade (AUG) and ITER. These projects are carried out in close collaborations with MIT, and with the TEC† and AUG teams.

Other activities in 2007 have been:

- Final investigations and reporting of the effects of irradiation on the microstructural evolution and on the physical and mechanical properties of metals and alloys.
- Participation in the EFDA programme on developing a multi-region global long term energy modelling framework called EFDA-TIMES.
- Activities to inspire Danish companies and make them aware of the possibilities of being a supplier to the construction of ITER
- Activities on public information about fusion energy. This includes development and presentation of the "Danish Fusion and Plasma Road Show".

The **global indicators** for the Research Unit in 2007 are:

Professional staff:	13.3	man-years
Support staff:	3,6	man-years
Total expenditure - incl. mobility:	2.58	MioEuro
Total Euratom support:	0.73	MioEuro

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† TEC: the Trilateral Euregio Cluster, a collaboration of FOM Institute for Plasma Physics, Holland; ERM/KMS, Belgium and Forschungszentrum Jülich, Germany.

2 Plasma Physics and Technology

2.1 Introduction

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A plasma is a dense collection of free ions and electrons. The transitions from solids to fluids to gases are associated with increases in internal energy, the breaking of bonds and changes of physical properties. The same is true of the transition from a gas to a plasma; in fact the plasma is rightfully described as the fourth state of matter, its physics differing as much from that of gases as that of solids does. Just as solid state physics is involved in a broad range of applications, so it should be no surprise that plasmas have a wide range of applications, that their physics and chemistries are rich, and that the methods of generation and diagnosis are wide and complex.

Our activities in high temperature plasmas, aimed at developing fusion energy, are coordinated with the European EURATOM fusion programme through an agreement of association on equal footing with other fusion laboratories in Europe. Our EURATOM association facilitates extensive collaboration with other fusion research laboratories in Europe, crucial in the ongoing build-up of competencies at Risø, and gives us access to placing our experimental equipment on large fusion facilities at the Max-Planck Institute for Plasma Physics in Garching and at the Research Centre Jülich, both in Germany. Our association with EURATOM also provides the basis for our participation in the exploitation of the European fusion research centre, JET, located in England. With its organisation of national programmes as EURATOM associations, the European fusion programme is a successful example of a large *European Research Area.* Our activities in high temperature plasma research and the development of fusion energy are introduced in subsection 2.1.1, and described in further detail in subsection 2.2 discussing turbulence and transport in fusion plasmas, and in subsection 2.3 discussing our use of millimetre waves for investigating the dynamics of fast ions in fusion plasmas.

2.1.1 Fusion plasma physics

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Producing significant amounts of fusion energy requires a plasma with a temperature of 100 to 200 million degrees and densities of 1 to 2 times 10^{20} particles per cubic metre, corresponding to a pressure of 1 to 5 atmosphere. Unlike gases, plasmas can be confined and compressed by magnetic fields. At the required temperatures the plasma must be lifted off material walls to prevent the plasma from rapid cooling. This is done by suspending the plasma in a toroidally shaped magnetic field that also acts to balance the plasma pressure. The required temperature and densities have been achieved in the joint European fusion experiment, JET. The production of net energy adds the requirement that the energy in the plasma be confined at least on the order of six seconds. The confinement time is the characteristic time for cooling off if heating was switched off or, equivalently, the ratio of plasma energy to required heating power to sustain that energy content. Achieved confinement times are on the order of one second. Higher density could compensate shorter confinement time and visa versa, so a simplified statement of the target is that the product of temperature, density and confinement time should be six atmosphere × seconds and is currently one atmosphere × seconds. Progress towards the goal principally involves improving the confinement time or, equivalently, reducing the energy transport in the plasma. The energy transport in fusion grade plasmas is principally due to turbulence, one of our main research activities reported in subsection 2.2. Significant progress towards the goal is expected with the next step fusion experiment, ITER. In ITER significant fusion rates are expected and with that the fast ion populations in the plasma will increase dramatically compared with present machines. The fast ions may then influence the plasma significantly. As a consequence, the dynamics of fast ions and their interaction with the rest of the plasma is one of the central physics issues to be studied in ITER. It is in fact also one of our main research topics in fusion as reported in subsection 2.3.

The fields of turbulence, transport and fast ions are closely knit. With steep gradients in plasma equilibrium parameters and with populations of energetic ions far from thermal equilibrium, fusion plasmas have considerable free energy. This energy drives turbulence, which in turn acts back on the equilibrium profiles and on the dynamics of the fast ions. The turbulence naturally gives rise to enhanced transport, but also sets up zonal flows that tear the turbulent structures apart and result in edge transport barriers; most likely at the root of the poorly understood, but experimentally reliably achieved, high confinement mode (H-mode). This non-linear interplay between turbulence and equilibrium also supports transient events reminiscent of edge localised modes (ELMs) where energy and particles are ejected from the plasma edge in intermittent bursts.

This set of topics is the focus of our fusion plasma physics research: With first-principles based codes we seek to model the interplay between plasma turbulence, transport and equilibrium. This modelling is tested against experimental data in collaboration with other fusion plasma physics institutes. To elucidate the physics of fast ions and their interplay with turbulence, waves and transient events, we are engaged in the diagnosis of confined fast ions by collective Thomson scattering (CTS) at the TEXTOR tokamak at the Research Centre Jülich and at the ASDEX upgrade tokamak in the Max-Planck Institute for Plasma Physics in Garching, both in Germany.

2.2 Turbulence and transport in fusion plasmas

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The transport of heat, particles, and momentum across the confining magnetic field of fusion plasmas is one of the most important, but also most difficult areas of contemporary fusion research. It is well established that the "anomalous" transport component due to low frequency turbulence is usually far larger than the classical and neo-classical collisional transport, nearly always in the edge region. Therefore it is of utmost importance to achieve a detailed understanding of anomalous transport and the underlying turbulence for the design of an economical viable fusion reactor based on magnetic confinement schemes. In spite of the dramatic progress in experiment, theory and computations during recent years the quantitative understanding is still sparse and any predictive capacity is at best rudimentary. Even fundamental phenomena such as transitions from low confinement regime (L-mode) to high confinement regime (H-mode), the profile resilience and the particle pinch that are routinely observed and classified experimentally have no generally accepted explanations.

The activities within plasma turbulence and transport are mainly focused on topics related to edge and scrape-off-layer (SOL) regimes of toroidal plasmas, but also investigations of core turbulence and transport are taken up. Generally, it is acknowledged that the conditions near the edge of the plasma are dictating the global performance, which seems natural since all transport has to go through the edge region, but certainly the coupling to the core plasma dynamics is essential. Theoretical and numerical investigations of first principle models form the majority of the work performed. We emphasize benchmarking of results and performance, both with other codes and analytic results (verification) and then also with experimental observations (validation).

Our activities are fully integrated into the EURATOM fusion program, and we have active collaborations with several EURATOM laboratories on theoretical issues as well as on direct comparisons of our results with experimental observations. We are increasingly involved in the EFDA-JET program, with V. Naulin presently being task force co-leader of Task-Force Transport. We are actively participating in the Integrated Tokamak Modelling (ITM) Task Force on validation and benchmarking of codes as well defining the ITM data structures, and we are getting involved in the new Topical Groups, such as the transport topical group. Several of our numerical codes are in use at different European laboratories, where they are employed for specific purposes, ranging from experimental comparisons to education of students.

The work carried out through 2007 included the following items:

- The involvement in the JET work program is described in Sec. 2.2.1. It is focused on modelling and simulation. It comprises modelling of transient transport events in the plasma core by using transport models including turbulence spreading and non-local interaction; modelling of toroidal and poloidal momentum transport and comparison with experimental observations; and investigations of impurity transport and control of impurity accumulation.

- Investigations of the turbulence and transport at the edge and SOL of toroidal plasmas by participating in experimental investigations and applying the two dimensional, electrostatic edge-SOL turbulence code, ESEL, which describes perpendicular dynamics and transport events in the SOL. It is well established that the turbulence and transport in the edge and SOL of toroidal plasmas are strongly intermittent and involve outbreaks of hot plasma. These structures, often referred to as “blobs”, are formed near the last closed flux surface (LCFS) and propagate far into the SOL. They have a profound influence on the pressure profiles in the SOL, the ensuing parallel flows, and the power deposition on plasma facing components. In Sec. 2.2.2 we describe experimental results from TCV (EPFL, Lausanne) clearly revealing the importance of propagating blob structures on the turbulence and transport in the SOL and the ensuing pressure profile for varying collisionality. Extensions of the ESEL code and comparisons with various other experiments, including JET, are discussed in Sec. 2.2.3. Investigations of the turbulent transport in the SOL of ASDEX Upgrade in ELMy H-mode as well as L-mode are described in Sec. 2.2.6. It is observed that the turbulent density flux in intervals between ELMs is significantly lower than the flux in L-mode. Comparisons with ESEL simulations for the L-mode data are underway. Finally, Sec. 2.2.7 reveals the difference between turbulence measurements using standard Langmuir probes and emissive probes.

- In order to extend our turbulence modelling in the edge/SOL we have derived a gyro-fluid model for the two dimensional interchange dynamics as a generalization of the ESEL code (see Sec. 2.2.4). Initial investigations reveal that the basic characteristics of the dynamics are not altered by the finite ion temperature, but there are significant changes in the detailed dynamical evolution. Motivated by experimental results, that strong time dependent radial electric fields are present in the edge region of many tokamaks, the gyro-fluid model is being extended to account both for large electric fields and electromagnetic effects, see Sec. 2.2.5.
- An important step in benchmarking our codes is to compare with “simple” linear, well diagnosed experiments. For this purpose a global 3D code, CYTO, has been developed for describing a linear, magnetized plasma including sources as well as plasma sheath boundaries. The results are compared quantitatively with results from the Vineta device at IPP, Greifswald, and the code is found to reproduce the full discharge evolution, see Sec. 2.2.8.
- The spontaneous formation of flows in turbulence is an ongoing topic in fusion research. We have investigated various aspects of toroidal as well as poloidal flow generation and of the related transport of momentum. In Sec. 2.2.9 it is demonstrated that the existence of a poloidal flow can mediate the transport of toroidal momentum and the ensuing toroidal spin-up. The TYR code has been coupled with the EFIT code to provide a realistic magnetic geometry for investigations of flow generation, see Sec. 2.2.10, and in Sec. 2.2.11 we discuss the coupling of geodesic acoustic modes (GAMs), being essential for the zonal flow generation, and drift Alfvén waves.
- Examples of our involvement in the ITM activities are provided in Sec. 2.2.12.

2.2.1 Participation in the JET work programme

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The Risø DTU contribution to the JET work programme is focused on modelling and simulation. In 2007 the work included the following topics:

Non-local effects on plasma transport

Strong cooling effects at the edge of a tokamak result in a very fast response of the plasma core, which is outside the modelling capabilities of present transport codes, presuming a dependence of transport on the local gradients of the thermodynamic quantities. To improve this situation a simple transport model based on the spreading of turbulence has been proposed and encouraging results were obtained, however the actual fast response time could not be matched simultaneously with reproducing normal transport features. To further investigate this issue a heuristic model including nonlocal interactions in the framework of fractional diffusion was applied. This model could be matched to experiment, what is an encouraging step on the way to link it with the more first principle motivated turbulence modelling [1].

1. D. del-Castillo-Negrete, P. Mantica, V. Naulin, and J. Juul Rasmussen, Proc. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. (Europhysics Conference Abstracts, vol. 31F) O-4.003 (4 p)

Toroidal and poloidal momentum transport studies in JET

Momentum transport is a crucial issue for ITER, since it at the moment is unclear if the ITER plasmas will show a degree of rotation that is sufficient to allow suppression of detrimental MHD activity, like e.g. resistive wall modes. It is further unknown how rotation and the associated shear in detail affect confinement. Furthermore, as ITER will not have large external sources of core momentum, the transport and generation of momentum are of great importance to predict central rotation. Experiments with a modulated momentum source were performed at JET to assess momentum transport properties [1,2]. A specific difficulty for the experimental setup was to localise the NBI momentum source. It has been found that momentum transport is at an effective level of one third of the ion heat transport, and modelling is successfully assuming the existence of an inward momentum pinch.

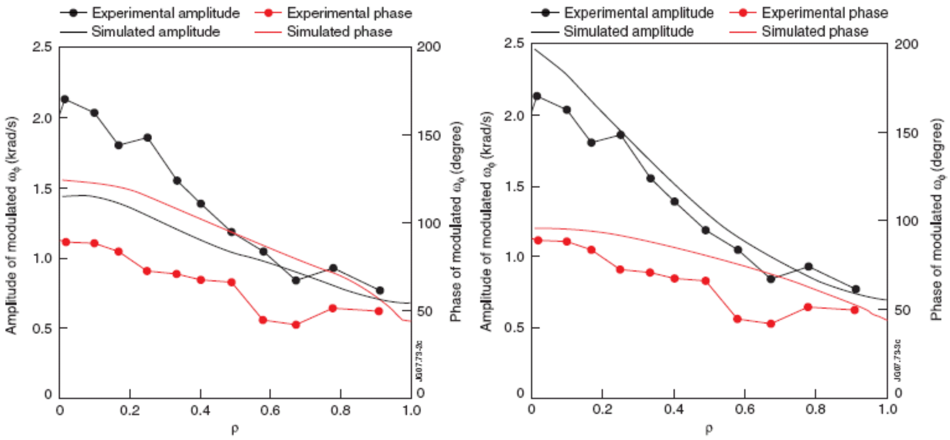

Figure 1. Comparison of the experimental (lines with dots) and simulated (lines) amplitudes (black) and phases (red) of modulated ω_φ with the simulation for which the momentum diffusivity relative to the ion heat diffusivity χ_φ/χ_i = 0.25 and the pinch velocity v_{pinch} = 0 (left frame); and χ_φ/χ_i = 1.0 and v_{pinch} = 15ms^{-1} (right frame) for JET pulse no 66128 [1].

1. T. Tala, K. Crombe, P.C., de Vries et al. Plasma Phys. Control. Fusion **49**, B291 (2007).
2. T. Tala Y. Andrew K. Crombe et al.,. Nucl. Fus. **47,** 1012 (2007).

Impurity transport and control

Impurity accumulation in the core of ITER has to be prevented, specifically with the dominating intrinsic impurity most likely to be Tungsten. As impurity induced radiation is beneficial for energy transport homogenization, the most beneficial impurity profiles are hollow. To achieve impurity control electron dominated heating in the plasma core was applied to discharges into which metallic impurities were ablated and gaseous impurities puffed. The electron core heating was increased in steps with the total heating power kept as constant as possible. Dynamical transport analysis of the penetration of the impurities into the plasma allows the modeling of the transport process and determination of transport coefficients, divided into diffusivity and pinch velocity. Hollow profiles were found for cases with dominant core electron heating, but a threshold for this behavior could not be determined. It is still debatable if the observed behavior is due to a change in anomalous transport having to do with a reversal in the poloidal phase propagation of the turbulence, or if it can be explained on the basis of neoclassical pinch changes, due to variations in the profiles [1]

1. C. Angioni, L. Carraro, T. Dannert, N. Dubuit, R. Dux, C. Fuchs, X. Garbet, L. Garzotti, C. Giroud, R. Guirlet, F. Jenko, O. J. W. F. Kardaun, L. Lauro-Taroni, P. Mantica, M. Maslov, V. Naulin, R. Neu, A. G. Peeters, G. Pereverzev, M. E. Puiatti, T. Putterich, J. Stober, M. Valovic, M. Valisa, H. Weisen, and A. Zabolotsky ASDEX Upgrade Team JET EFDA Contributors, Phys. Plasmas **14**, 055905 (2007).

2.2.2 Convective transport by filamentary structures in scrape-off layer plasmas

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High levels of turbulence and anomalous transport are ubiquitous in the boundary region of magnetically confined plasmas, experimentally observed in virtually all magnetic geometries and confinement regimes. Recent measurements indicate that the radial transport is caused by convective motions of filamentary structures which are elongated along the magnetic field lines and appear as blobs when viewed across the field lines [1,2]. Such fast transient transport events seem to be what underlies the commonly observed large relative fluctuation levels, broad particle density profiles, and strong plasma--main chamber wall interactions.

In the collisionless limit, electric currents through sheaths at the divertor targets lead to strong dissipation of the collective motions. This has been verified by numerical simulations of an isolated plasma filament structure based on a two-field fluid model for interchange motions driven by the non-uniform magnetic field [3]. However, for collisional scrape-off layer plasmas, the parallel motions are impeded and the role of sheath currents is diminished. As a result, the perpendicular transport can be strongly enhanced. This is expected to happen at high line-averaged plasma density and low plasma currents since the collisionality is proportional to both the plasma density and the magnetic connection length, which is inversely proportional to the plasma current [2].

Such a collisionality dependence of convective transport is supported by electric probe measurements from experiments in Ohmic TCV plasmas [1,2]. These comprise scans in both line-averaged plasma density and plasma current. Increasing the plasma collisionality, by altering either of these control parameters, results in a broadening of the radial plasma particle density profile and an increase of the fluctuation level and the radial convective flux to the main chamber walls. Yet the experimental data display a universal radial variation of the statistical moments of the particle and turbulent flux density fluctuations across a broad variation in these parameters, suggesting that radial interchange motions of filamentary structures prevail in all parameter regimes [1,2].

A new set of experimental measurements have shown that, with decreasing plasma current at fixed line-averaged plasma density, the radial velocity of plasma filaments increases, thereby altering the branching ratio between radial and parallel transport. Moreover, the radial profile of the floating potential does not follow the shape predicted by the sheath boundary conditions at small plasma currents. Both of these signatures are consistent with an electrical disconnection from the target sheaths at high plasma collisionality. This provides further evidence that convective transport in the scrape-off layer is intimately linked to the empirical discharge density limit.

1. O. E. Garcia, J. Horacek, R. A. Pitts et al., Plasma Phys. Control. Fusion **48**, L1 (2006)
2. O. E. Garcia, R. A. Pitts, J. Horacek et al., Plasma Phys. Control. Fusion **49**, B47 (2007)
3. O. E. Garcia, N. H. Bian and W. Fundamenski, Phys. Plasmas **13**, 082309 (2006)

2.2.3 ESEL modelling for TCV, CASTOR, MAST and JET

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During 2007 the ESEL code, which simulates nonlinear interchange dynamics on the outboard mid-plane of toroidal devices, has started to be applied at several other institutions within EURATOM. A short description of the activities is given below. The motivation for running the code under different conditions close to the ones found in the respective plasma experiments is to obtain spatially resolved turbulence data, to study the EDGE/SOL dynamics numerically in greater detail, and more importantly to perform comparison of the code data with measurements, which will reveal the parametric boundaries of the ESEL model. From our side we stay in close contact with these groups, and we are in the process of upgrading the ESEL code to contain more realistic physics, making the code more user friendly, and writing documentation for the code.

There are two main limitations of the interchange model implemented in the ESEL code which we would like to address in the near future. The first one is that ESEL is a two dimensional code solving the dynamical equations in the plane perpendicular to the magnetic field with the parallel dynamics being parameterized as a loss in the SOL. Secondly, we are limited by only considering a single drift plane at the outboard mid-plane including both SOL and edge regions. These two limitations are very restrictive. In particular, we only simulate a small part of the poloidal extend due to the periodic boundary condition, and we are also forced to introduce a boundary – mimicking the coupling to the core plasma - in the edge region, As an initial attempt to cure this, we have started to develop a global version of ESEL, called DIESEL (Disk version of ESEL), where the ESEL model equations are solved on a disk domain, representing the poloidal plasma cross section, and applying a parameterization of the parallel dynamics that accounts for a realistic magnetic q-profile. Typical results are shown in Figure 2.

ESEL modeling for TCV, CRPP, Laussanne. Fluctuations and particle transport in the scrape-off layer (SOL) of TCV plasmas have been investigated by probe measurements and direct comparisons with ESEL simulations at the outer mid-plane region have successfully been performed, see [1-4]. The results from these investigations clearly demonstrate that the outboard mid-plane of TCV can be well described by the interchange model, and the ESEL results reproduced the statistically properties of the blobs both in terms of spatial and temporal scales.

Figure 2. Snapshot of the 2D density (left) and vorticity (right) variation taken from DIESEL. Plasma parameters similar to TCV parameters.

ESEL modeling for CASTOR, IPP, Prague: We have modified ESEL to model the edge and SOL regions of CASTOR, which is out of operation. The purpose is to make detailed comparisons with the post mortem results from the CASTOR tokamak. ESEL is implemented at the computer facilities in Prague and the first comparison with the CASTOR tunnel probe data shows promising agreement.

ESEL modelling of JET SOL plasmas: ESEL has been applied to simulate the perpendicular dynamics of transport events in the JET SOL and the self consistent development of the SOL profiles at the outboard mid-plane. The code results are compared to probe measurements from the JET SOL. Qualitative agreement is shown amongst others for the plasma temperature and density profiles. The magnetic field direction independent part of the parallel flow velocity in the SOL can also be reproduced by the ESEL results. This is based on the assumption that this flow is mainly driven by the overpressure of the blob structures being localized along the field lines around the outboard mid-plane. The code predict magnetic field independent parallel flows with velocities of 0.2 ion sound speed in good agreement with measurements. Moreover the correlation between parallel and perpendicular velocity fluctuations is reproduced by the code, hinting that the blob structures are the main player in parallel momentum transport through the SOL [5].

ESEL modelling for MAST, Culham: The output of ESEL will be used to model the MAST filament probe in order to identify what signature a blob would produce when interacting with the probe. Statistics of particle flux and floating potential measurements from MAST ohmic discharges shall be compared to ESEL simulations. The aim is to measure temperature, density and potential of individual filaments and thus to directly demonstrate that the filaments are similar to the structures observed in ESEL.

ESEL modeling for JET and TJ-II, Ciemat, Madrid: The project is to compare high-speed visible imaging of edge plasma obtained in magnetic confinement devices [6] with ESEL results. Quantitative analysis efforts on image sequences have produced interesting results [7] though much remain to be done. In particular the extraction of the Optical Flow or velocity map of the turbulent structures can give valuable information on the plasma fluid dynamics. However, the question arises as how the apparent motion of turbulent structures relates to the underlying fluid drifts of the turbulence dynamics. 2D codes of edge/SOL turbulence such as ESEL can help understanding and interpreting the quantitative analysis of edge plasma image sequences.

1. O E Garcia, R A Pitts, J Horacek, J Madsen, V Naulin, A H Nielsen and J Juul Rasmussen. Plasma Phys. Control. Fusion **49**, B47 (2007).

2. O.E. Garcia, J. Horacek, R.A. Pitts, A.H. Nielsen, W. Fundamenski, V. Naulin and J. Juul Rasmussen. Nucl. Fusion **47**, 667 (2007).

3. O.E. Garcia, R.A. Pitts, J. Horacek, A.H. Nielsen, W. Fundamenski, J.P. Graves, V. Naulin and J. Juul Rasmussen. Journal of Nuclear Materials **363-365**, 575 (2007).

4. R.A. Pitts J. Horacek, W. Fundamenski, O.E. Garcia, A.H. Nielsen, M. Wischmeier, V. Naulin and J. Juul Rasmussen. Journal of Nuclear Materials **363-365**, 505 (2007).

5. W. Fundamenski, O.E. Garcia, V. Naulin, R.A. Pitts, A.H. Nielsen, J. Juul Rasmussen, J. Horacek, J.P. Graves and JET EFDA contributors. Nucl. Fusion **47**, 417 (2007).

6. J. L. Terry et al. Physics of Plasmas, **10**, 1739, (2003).

7. J. A. Alonso et al. Plasma Physics and Controlled Fusion, **48**, B 465, (2006).

2.2.4 A gyro-fluid model for turbulence and transport in the edge/SOL region of toroidal plasmas

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Turbulence and transport in the edge and scrape-off-layer (SOL) of toroidally magnetized plasmas are strongly intermittent and involve large outbreaks of hot plasma, as has been revealed in experiment and simulation alike. The intermittent structures, often referred to as “blobs”, which carry most of this transport, are determining the pressure profiles in the SOL and can result in detrimental power deposition on plasma facing components. The basic dynamics of the SOL turbulence and the associated transport can be well described in terms of simple nonlinear interchange motions [1,2] in the limit of cold ions. However, the ion temperature in the SOL is at least comparable to and usually exceeds the electron temperature. Thus the cold ion approximation does not hold. We have therefore examined blob and turbulent dynamics using gyro-fluid models, which account for finite ion temperatures and finite ion Larmor radius effects. The implemented model is currently isothermal and describes the evolution of the electron and ion densities coupled through a polarization equation. Various implementations of the model differ in their respective polarization equations.

The model equations have been implemented numerically by employing a new scheme for the solution of the polarization equation. It governs two-dimensional interchange dynamics at the outer mid-plane of toroidally magnetized plasma. Thus, it is a generalization of the Risø ESEL-code [1] to finite ion temperature, and the gyro fluid code has been named GESEL.

Simulation of the turbulence and transport in the edge/SOL by using the gyro-fluid code GESEL has been initiated. The turbulence dynamics is strongly intermittent and dominated by radial propagation of blob-structures as in the case of cold ions. Preliminary results show that for high ion temperatures the bursting of blob structures tends to become more regular, i.e., blobs are generated and ejected at almost constant time intervals.

1. O.E. Garcia, V. Naulin, A. H. Nielsen, and J. Juul Rasmussen, Phys. Plasmas **12**, 062309 (2005).

2. O.E. Garcia, N. H. Bian, V. Naulin, A. H. Nielsen, and J. Juul Rasmussen, Phys. Plasmas **12,** 090701 (2005); O.E. Garcia, N. H. Bian, and W. Fundamensky, Phys. Plasmas **13,** 0082309 (2006).

2.2.5 A gyro-fluid formulation for situations with strong fields

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An extension of current gyro-kinetic and gyro-fluid models to more correctly describe edge tokamak physics is under development. The work is motivated by the well known experimental result that strong time dependent radial electric fields are present in the edge region of many tokamaks [1,2].

At present, gyro-kinetic models cannot properly describe plasmas with strong time dependent perpendicular electric fields [3]. In addition current models do not include electromagnetic effects in the presence of a strong electric field [4]. In this work we derive the proper gyro-kinetic equations in the presence of both electromagnetic effects and the effects of a strong radial electric field. As the gyro-kinetic formalism rests on the guiding centre approximation [5] this has to be adapted correspondingly. The results of this work will allow us to further develop the GESEL code towards more realistic profile conditions.

1. B. W. Rice, D. G. Nilson, K. H. Burrell, and L. L. Lao, Rev. Sci. Instrum., **70**, 815, (1999).
2. S K Erents, R A Pitts, W. Fundamenski, J P Gunn, and G F Matthews, Plasma Phys. Control. Fusion, **46**, 1757 (2004).
3. T.S. Hahm, Phys. Fluids, **31**, 2680 (1988).
4. T. S. Hahm. Phys. Plasmas, **3,** 4658 (1996).
5. R. J. Littlejohn, Phys. Fluids, **24**, 1730 (1981).

2.2.6 Measurements of fluctuation and radial transport in the L- and H-mode Scrape-off Layer of ASDEX Upgrade.

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The radial turbulent particle flux in the in the scrape-off layer (SOL) of ASDEX Upgrade was investigated both for L-mode and ELMy H-mode plasmas. We have applied a fast reciprocating probe at the mid-plane manipulator with a probe head containing five Langmuir probes, of which three were measuring the floating potential and its fluctuations. The other two probes were biased to ion saturation current and swept, respectively. The poloidal electric field component was derived from the floating potential of the two probes on the same poloidal meridian assuming equal electron temperatures on both probes. The density was derived from the ion saturation current. A detailed statistical analysis of the density fluctuations and the particle flux was performed and compared for the L- and H-mode discharges. For the H-mode case, the signals are further divided into intervals during type-I ELM events and intervals in the ELM-free periods, and these signals are analyzed separately.

For the density fluctuations it was revealed that the probability density functions, PDFs, for the cases of L-mode, H-mode ELM intervals and H-mode inter ELM intervals have a similar form with a significant skewnes toward positive events. Rescaling the PDFs with the standard deviation we observe them to fall on top of each other.

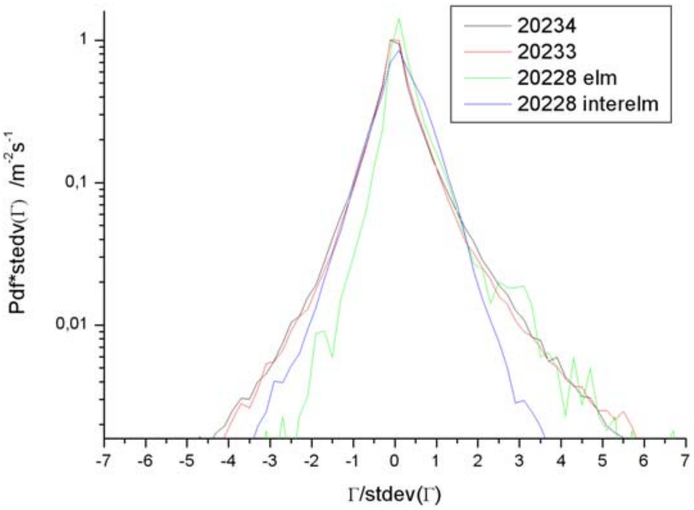

Figure 3. PDFs of the fluctuation induced particle density flux normalised by its standard deviation: during ELMs (green), inter-ELM intervals (blue) and L-modes (dark blue and red). The shot numbers are given in the inserted frame.

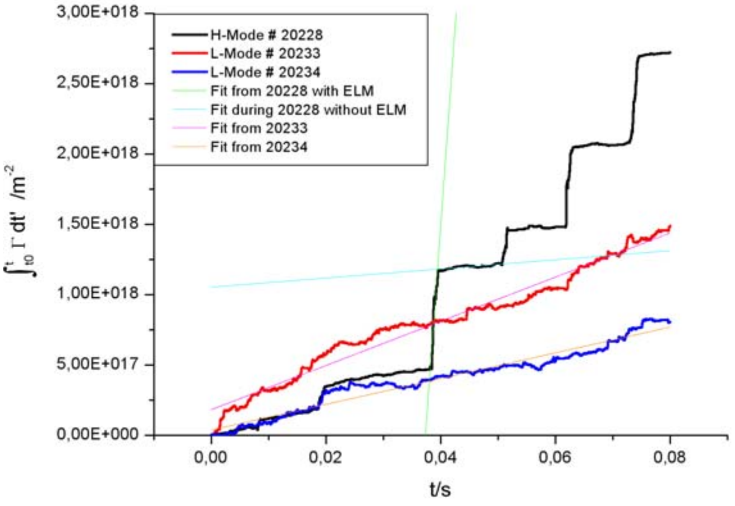

Figure 4. Integrated fluctuation induced particle density flux with linear fits of the slopes for the L-mode shots (red and blue) and during the H-mode shot (black).

For the particle flux the PDF during ELM periods is found to be the broadest and most skewed, showing the expected strong outward transport carried by the ELM filaments. However, in the inter ELM intervals the PDF is very narrow and almost symmetric, and significantly narrower than the PDFs of the flux during the L-mode shots. Rescaling these PDFs we observe that the L-mode and ELM interval PDFs are similar to each other in particular regarding the side of positive events, as illustrated in Figure 3. Thus, for the case of the specific shots investigated here, the transport during the L-mode in the outer SOL appears to be larger than the flux in between ELMs. This is further emphasized in

Figure 4, which shows the integrated particle fluxes versus time. It is clearly observed that the slope in the inter ELM intervals is much smaller than the slope in the L-mode cases.

1. R.W. Schrittwieser, S. Konzett, F. Mehlmann, P. Balan, C. Ionita, A. Kendl, V. Naulin, J. Juul Rasmussen, A.H. Nielsen, O.E. Garcia, H.W. Müller, A. Herrmann, V. Rohde, M. Maraschek and the ASDEX Upgrade Team, , Proc. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. (Europhysics Conference Abstracts, vol. 31F) P1-125 (4 p)

2.2.7 Turbulence and transport measurements with cold and emissive probes in ISTTOK

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Probe arrays of emissive probes and cold cylindrical probes were used for edge plasma measurements in ISTTOK. The arrays allow for the simultaneous registration of the density and the poloidal electric field, necessary for the derivation of the radial fluctuation-induced particle flux. Emissive probes are particularly suitable for turbulence studies as they deliver more accurate measures of the plasma potential by reducing the effect of the electron temperature. This makes it possible to compare the parameters by turning on and off the probe heating on a shot-to-shot basis and once recording the cold floating potentials and once the emissive floating potentials. The most recently constructed probe array consists of four emissive probes in a row above each other, thus on the same poloidal meridian, and one cold cylindrical probe. This was used for the simultaneous determination of the poloidal electric field, once from the difference between the floating potentials of two staggered unheated probes and once of two staggered heated emissive probes [1].

Radial profiles of the floating potential, the plasma potential and the electron temperature were recorded. The statistical properties of the poloidal electric field and of the turbulent particle flux were compared. Both, the root mean square of the poloidal electric field and the fluctuation-induced particle flux were found to be significantly larger when measured with the emissive probes. The probability distribution of the particle flux was found to be more peaked and positively skewed when measured with the emissive probes. This elucidates the importance of temperature fluctuations for the measurement of the particle flux. The flux was finally determined in cases with and without negative edge biasing through a second emissive electrode. In this case a clear reduction of the turbulent flux during the biasing was seen only when measured with emissive probes.

1. R. Schrittwieser, C. Ioniță, C. Silva, H. Figueiredo, C.A.F. Varandas, J. Juul Rasmussen, V. Naulin, and P. Balan, Plasma Phys. Control. Fusion **50,** 055004 (2008).

2.2.8 Three-dimensional global fluid simulations of cylindrical magnetized plasmas

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Plasma dynamics in cylindrical geometry, with many well diagnosed experiments in operation worldwide, is of fundamental interest. These linear machines can provide a unique testing ground for direct and detailed comparisons of numerical simulations of nonlinear plasma dynamics with experiments. Thus, it is possible to assess the reproductive and predictive capabilities of plasma simulations in unprecedented detail. Here, three-dimensional global fluid simulations of a cylindrical magnetized plasma are presented. This plasma is characterized by the existence of spatially localized sources and sinks. The traditional scale separation paradigm is not applied in the simulation model to account for the important evolution of the background profiles due to the dynamics of turbulent fluctuations. Furthermore, the fluid modelling of sheath boundary conditions, which determine the plasma conditions, is an important ingredient to the code presented here. The linear properties of the model equations are studied and are shown to agree well with experimental observations of linear drift modes. The fully nonlinear simulations are characterized by turbulent fluctuations, which are dominated by low mode numbers in the large radial pressure gradient region. In the far plasma edge, the fluctuations display an intermittent character due to convection within radially extended spatiotemporal potential fluctuations.

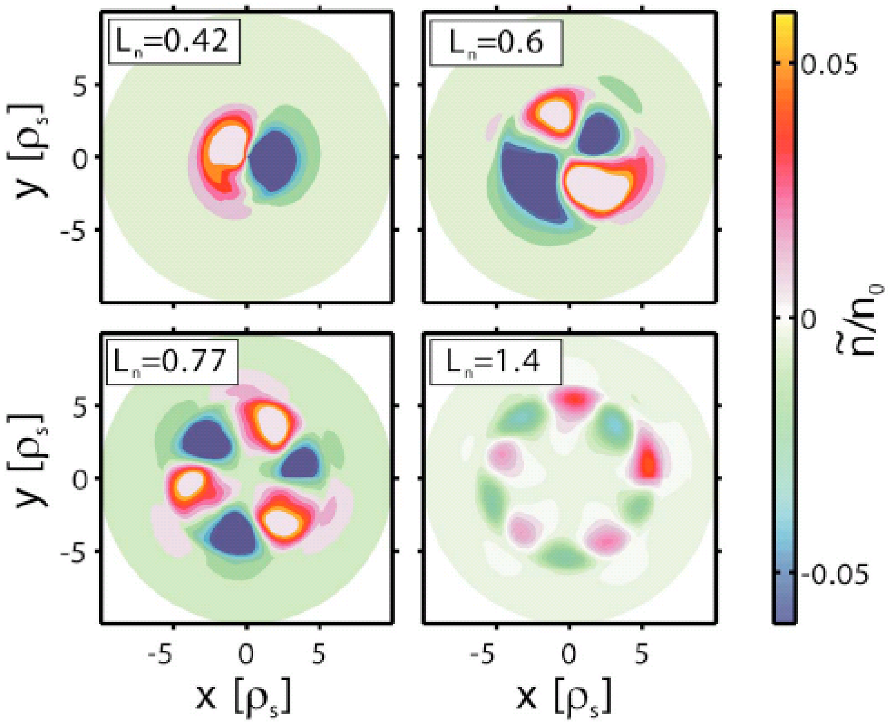

Figure 5. Increasing poloidal mode number with steepening of the pressure profile from the simulation.

The 3D global CYTO code [1] could thus be successfully employed to quantitatively reproduce the properties of the whole discharge, including profile evolution and fluctuations, see Figure 5. This is an important step in validating the sheath boundary conditions and global plasma fluid properties as an ingredient into a three-dimensional edge-SOL code for toroidal devices.

1. V. Naulin, T. Windisch, and O. Grulke, Phys. Plasmas **15**, 012307 (2008).

2.2.9 Transport of parallel momentum by collisionless drift wave turbulence

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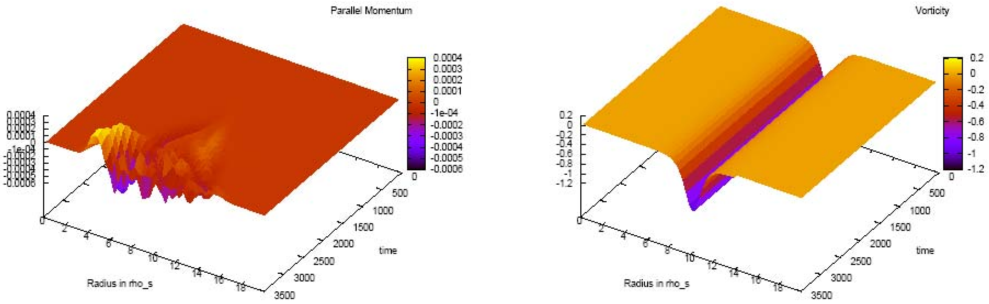
Parallel momentum transport has gained a lot of interest as rotation levels are an important ingredient to reach the confinement necessary for reaching the ITER design parameters. Here the transport and local generation of parallel momentum is investigated theoretically as well as through supporting nonlinear simulations [1-2]. A basic outcome of the investigations is that momentum transfer by waves can generate parallel flows, if the symmetry in the parallel wave motion is broken due to poloidal flow shear. In transport models these residual stress effects would appear as sources/sinks of parallel momentum.



Parallel momentum $P_{\|} =< m_e V + M_i U >$ and imposed vorticity profile.

Figure 6. Profile of the parallel momentum and the imposed vorticity profile from simulations of drift wave turbulence.

1. V. Naulin, P.H. Diamond, O.D. Gurcan , and J. Juul Rasmussen, European Fusion Theory Conference,October 2007, Madrid, Spain.
2. P. H. Diamond, C. J. McDevitt, O. D. Gurcan, T. S. Hahm, and V. Naulin, Phys. Plasmas **15**, 012303 (2008).

2.2.10 EFIT geometry in the TYR code and q dependence of flow generation

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The TYR code has in the past been used for basic investigations of electromagnetic edge turbulence, looking into the dynamics of transport and flow generation including GAMs and Maxwell stress [1]. The goal of this project is to investigate the details of flow generation in realistic geometries. The actual metric coefficients are therefore calculated from EFIT using a newly developed module EFIT_TYR. The module reads data from JET EFIT and prepares an input file for TYR. Initial investigations have been started to look into the connection between rational magnetic surfaces and the different components of flow drive, motivated by the fact that in experiments sheared flows are often triggered at or near rational q-surfaces.

1. V. Naulin, A Kendl, O.E. Garcia, A.H. Nielsen, and J. Juul Rasmussen, Phys. Plasmas, **12**, 052515 (2005).

2.2.11 Excitation of Geodesic Acoustic Modes by drift-Alfvén waves

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Geodesic acoustic modes (GAMs) are low frequency modes in toroidal plasmas, first predicted theoretically by Winsor *et al.* [1]. GAM oscillations are observed in several experiments, see e.g. [2]. They have been found to play an important role in connection with the generation of zonal flows by low frequency turbulence and are thereby of a key player in the understanding of turbulent transport, see, e.g., [3]. We have studied the nonlinear excitation of GAMs by coupling to drift-Alfvén modes in the edge region of toroidal plasmas. This extends earlier studies in which GAMs were excited by resonant coupling to two electrostatic drift waves [4] by including finite beta effects. GAMs excited by the drift-Alfvén modes are found to have a zonal magnetic field, which introduces a threshold condition for the excitation. The growth rate of the parametrically excited GAMs is strongly reduced when the drift wave frequency approaches the Alfvén frequency.

1. N. Winsor, J. L. Johnson and J. M. Dawson, Phys. Fluids, **11**, 2448 (1968).
2. G. R. McKee *et al.* Phys. Plasmas **10**, 1712 (2003).
3. V. Naulin, A Kendl, O.E. Garcia, A.H. Nielsen, and J. Juul Rasmussen, Phys. Plasmas, **12**, 052515 (2005).
4. N. Chakrabarti, R. Singh, P.K. Kaw, and P.N. Guzdar, Phys. Plasmas **14**, 052308 (2007).

2.2.12 Participation in ITM-activities

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The participation in the Integrated Tokamak Modeling (ITM) activities has mainly been concentrated in the working group IPM4. The main topic has been to develop a common data structure based on the freeware software HDF5. We ported this software to 3 of the working group codes, ATTEMPT (see below), GEM and DIESEL and demonstrated that we could exchange data between the different codes.

As a test for exchanging data between different groups we have started a project simulating radial propagation of blobs in the flux tube code ATTEMPT. The 2D turbulence code ESEL has extensively been used in previous studies on blob dynamics in the edge region of tokamak plasmas. It has been found that size and radial propagation of density blobs can be reproduced with quite remarkable agreement with experimental findings. However, the 2D-model of ESEL considers the parallel dynamics due to sound waves and drift Alfven waves approximately by inclusion of effective sources and sinks in the drift plane. To overcome this limitation and to take into account the parallel dynamics in a more realistic way the ATTEMPT code has been employed to study the blob dynamics in a full 3d tokamak geometry including edge and SOL region as well. Previous studies with the ATTEMPT code proved that density blobs appear for typical parameters of the TEXTOR tokamak. Collaboration has been started to undertake a systematic study of density blobs initialized in the plasma edge. The code has been prepared for flux driven simulations with detailed control of the blob initial state. First results show that a decrease of Alfvénic interaction of electric potential and current density leads to the expected radial blob motion. This is to be expected in the SOL and the first results are in agreement with previous studies, [1] based on simplified 2D-models and approximate closures for the Alfvénic interaction. The ongoing work aims at a detailed understanding of the dependence of blob motion on collisionality and SOL boundary conditions at the plasma material boundaries.

1. S. I. Krasheninnikov, D. A. D'Ippolito, and J. R. Myra. To appear in J. Plasma Physics (2008).

2.3 Millimetre waves used for diagnosing fast ions in fusion plasmas

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Millimetre waves, corresponding to frequencies in the 100 GHz range, permit probing and imaging on the centimetre scale and transmission of signals with bandwidths in excess of 10 GHz. Coherent sources are now available from the micro- to Megawatt range, CW.

In the world of fusion, the millimetre waves are used extensively both as a diagnostic tool and for heating and manipulating the plasma locally as well as globally. Central to achieving these objectives is the fact that millimetre waves, like laser light, can be projected in narrow focused beams, but unlike laser light, the millimetre waves can interact strongly with the plasma.

At Risø DTU millimetre wave diagnostics for measuring the velocity distribution of the most energetic ions in fusion plasmas are developed and exploited. The measurements have spatio-temporal resolutions on the centimetre and on the millisecond scales.

The most energetic (or fastest) ions are the result of fusion reactions and auxiliary heating. Their interaction with the bulk plasma is the main mechanism by which the fusion plasmas reach and sustain the high temperatures of 100-200 million degrees Kelvin required for fusion. The considerable energy associated with the fast ions can also drive turbulence and instabilities in the plasma, and degrade the confinement of the plasma and of the fast ions themselves. Understanding and controlling the dynamics of fast ions are central tasks in the development of fusion energy, and one of the main research topics for the next large fusion facility, ITER. It is a task we seek to contribute to by developing and exploiting the unique diagnostic capability of millimetre wave based collective Thomson scattering (CTS).

The group has developed and implemented fast ion CTS diagnostics for the TEXTOR and ASDEX Upgrade tokamaks, which are located at the Research Centre Jülich and at the Max-Planck Institute for Plasma Physics in Garching, both in Germany. These CTS projects are conducted in collaboration with the Plasma Science and Fusion Center at MIT (USA), the Max-Planck Institute for Plasma Physics in Garching and the TEC[1] consortium.

The upgraded CTS system for TEXTOR was brought into operation in 2005 where the first results were obtained. In 2007 the experimental CTS campaigns of the previous years were continued. An overview of the campaigns and results is found in subsection 2.3.1. The Risø DTU groups involvement at TEXTOR has also lead to participation in related projects. Two of these are described in subsections 2.3.2 and 2.3.3.

The activities of the group at ASDEX Upgrade, including the preparations for experiments, development of dedicated test equipment and the first commissioning results are presented in subsections 2.3.4 – 2.3.10.

The proposed fast ion CTS system for ITER and the development of the design including calculation of heat loading on the mirrors are described in subsection 2.3.11 – 2.3.14, while an account of an EFDA task on modelling of the effect on the measurement capability of the ITER CTS diagnostic under different plasma and heating scenarios is given in subsection 2.3.16.

Finally, as the group has recently become involved in CTS experiments at other machines, a brief description of this is given in subsection 2.3.17.

1. TEC: the Trilateral Euregio Cluster, comprising Association EURATOM-Forschungszentrum Jülich GmbH, Institut für Plasmaphysik, Jülich, Germany; Association EURATOM-FOM, Institute for Plasma Physics, Rijnhuizen, The Netherlands; and Association EURATOM-ERM/KMS, Belgium.

2.3.1 Overview of results from CTS at TEXTOR

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A number of physics campaigns were conducted in 2007 and early 2008 to study the fast ion dynamics in the TEXTOR tokamak using CTS. The main focus was on the start-up phase during neutral beam heating and the effect of co-current and counter-current beam injection. Furthermore, investigations of the fast ion dynamics during the operation of the Dynamic Ergodic Divertor, and the effect of tearing modes were initiated.

The effect of switching from co-current NBI to counter-current NBI was investigated by CTS in a geometry where the projected 1D fast ion velocity distribution in the plasma center (R = 1.8 m) were resolved at an angle of 45° to the background magnetic field. The fast ion distribution function is shown in Figure 7 where a clear effect of the fast ions travelling co-current is seen at positive velocities during injection of NBI1 ($t < 2.15$ s), whereas during the NBI2 phase ($t > 2.15$ s) a clear non-thermal fast ion population is seen at negative velocities. These results also indicate that the co-current fast ions are confined better than the counter-current fast ions. This can be seen from the fact that the amount of non-thermal ions in the NBI1 phase is larger than in the NBI2 phase.

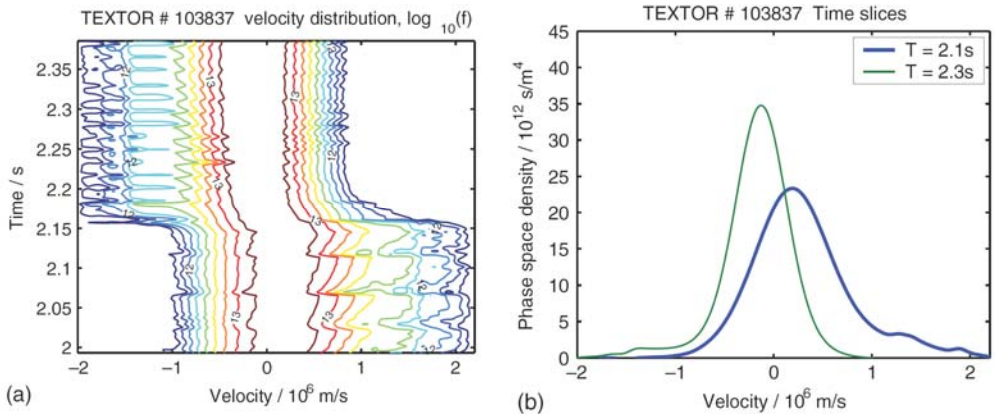

Figure 7. (a) Fast ion distribution during co-current NBI injection ($t < 2.15$ s) and counter-current NBI injection ($t > 2.15$ s). (b) Time slices during co- (blue) and counter-current NBI injection (green).

In order to study the build-up of the confined fast ions during neutral beam injection, a density scan was performed. During the turn-on phase of the NBI, the central fast ion population was monitored at a resolved angle of 67° to the magnetic field. In Figure 8, the measured fast ion densities in a given part of phase space (dots) are compared to numerical Fokker-Planck simulations. The slowing down of the fast ions is strongly dependent on density, such that with high density the slowing down is fast, which results in a smaller fast ion density. Good agreement between the measurements and the simulations is seen which indicate that the fast ion population in this resolved angle is building up as expected.

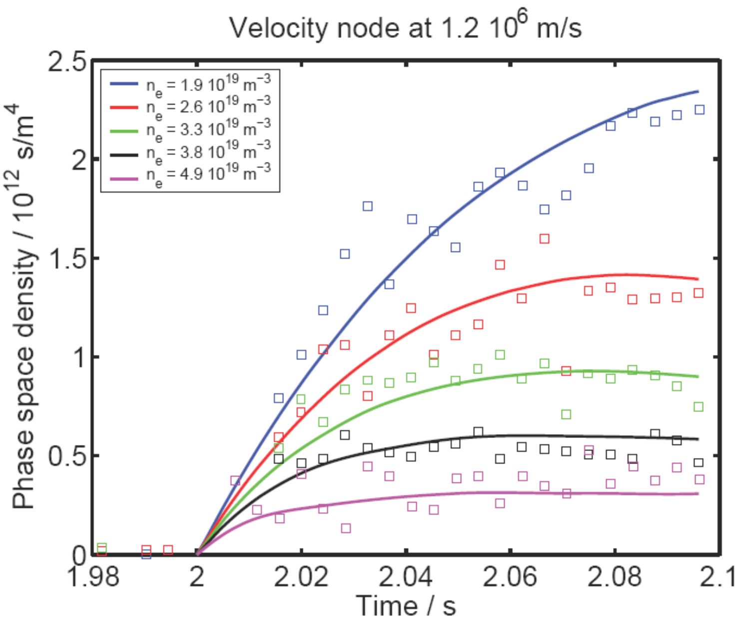

Figure 8. Build-up of confined fast ions during the injection of neutral beams for different plasma densities. The co-I_p NBI was turned on at $t = 2$ s.

TEXTOR has the capability of changing the neutral beam power without changing the acceleration voltage. This is done by changing the so-called V-target of the injector and thereby scraping off a part of the beam. The velocity distribution was measured during two discharges with different injected powers of 0.4 MW and 1.0 MW but with a constant acceleration voltage of 50 kV. In both cases hydrogen atoms were injected into a hydrogen plasma. The inferred fast-ion velocity distributions are displayed in Figure 3. It can be seen that even though the change in beam power is 150%, the fast particle contribution is increased by a factor of 3. Since the electron and ion temperatures are measured to be higher in the high-beam power discharge, the fast ion slowing down rate will be lower. This, combined with the difference in in-flux of injected fast particles, explain the difference seen in the suprathermal part of the distributions. Fokker-Planck simulations of these discharges have been performed and are also presented in Figure 9.

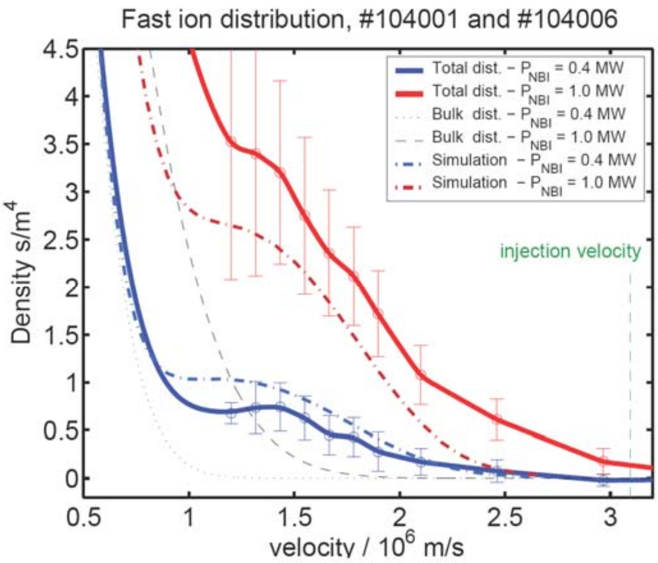

Figure 9. Measured velocity distributions and overlaid Fokker-Planck simulation velocity distributions for different injected beam powers (for constant acceleration voltage of 50 kV). In both discharges the scattering volume was located at R=1.81 m. The resolved direction was 140° to the magnetic field.

2.3.2 Mirror design at TEXTOR for the gyrotron feed back system

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The FOM group at TEXTOR has designed an ECE receiver with the same Line-of-Sight as the ECRH gyrotron [1]. The purpose is to be able to more precisely predict where to deposit ECRH power in order to e.g. mitigate neo-classical tearing modes. The radiation coming from the plasma and into the ECE receiver is eventually detected by a horn antenna. Risø DTU participated in the project, in particular by the following two tasks: 1) Measurements of the characteristics of the horn antenna provided by the FOM group, and 2) Design of a mirror, which transforms the reflected beam coming from the beam splitter to a beam shape suitable to be accepted by the horn antenna (see Figure 10).

1. J.W. Oosterbeek, et al., Fusion Eng. Des. **82** (2007) 1117

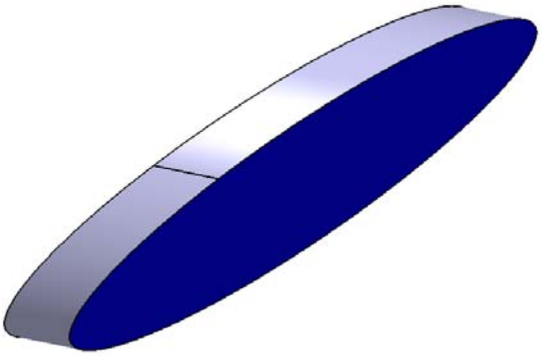

Figure 10. . Mirror to reshape the beam (CATIA design).

2.3.3 Participation in the TEXTOR PIT project

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A collaborative project between FOM, IAP (Russia), ENEA-CNR, and Risø DTU to create a pilot version of a so-called PIT diagnostic was initiated in 2006. The plan was to use the 140 GHz gyrotron and the CTS transmission line and receiver on TEXTOR. Since the PIT signals would be at frequencies around 250 GHz a separate receiver front end for the PIT project is needed. The PIT front end would be provided by the Milan group who had available equipment. The main responsibility of the Risø DTU group was to integrate the PIT front end into the CTS receiver. Drawings and some equipment was made before the PIT project was put on hold due to reasons external to Risø DTU.

2.3.4 Overview of the AUG CTS diagnostic

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The CTS diagnostic installed on ASDEX Upgrade uses the 1 MW dual frequency gyrotron [1] as the probe. The 105 GHz mode is used where powers up to 620 kW can be attained. Near back-scattered radiation is collected by the other ECRH antenna located in the same port where it is coupled to the CTS receiver system via the 80 m ECRH transmission line. This second transmission line will also be used by the 4-frequency step tunable gyrotron set to arrive in summer 2008. Additional mirrors for the CTS measurement modes are installed in the MOU box#2. One of the mirrors a movable and can intercept the incoming radiation between the universal polarizers and the phase correcting mirror permitting the polarization of the received radiation to be defined The fixed mirror redirects radiation to the CTS receiver. This system will make use of the very substantial investments at AUG in fast ion sources (Neutral Beam Injection and ICRH) and in new Mega-Watt power level gyrotrons to be used as sources of the probing radiation in the CTS system. In addition to permitting fast ion dynamics to be studied in new and more ITER relevant conditions, the proposed system for AUG will also provide experience with the use of high power gyrotrons in a CTS system, as would be required in a fast ion CTS diagnostic for ITER

1. D. Wagner et al, Fus. Sci. and Tech., **52**, No.2 (2007)

2.3.5 Alignment and technological development for the commissioning activities on the CTS diagnostic at ASDEX Upgrade

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Careful design, construction, alignment and quality assurance of the of the CTS transmission line section and its coupling to the ECRH transmission line are important not only to achieve low loss transmission, but also to provide good spatial localisation of the measurement and accurate definition of the location of the movable measurement volume and resolved velocity direction. The ECRH mirrors in the MOU#2 box have been repositioned by the IPP ECRH team for the up-coming gyrotron Odyssey-1 scheduled to arrive in the summer of 2008. The task of coupling the CTS transmission portion was only possible with the essential tools that were constructed by the Risø DTU team. The first phase of the alignment process is achieved using a diode laser and optical quality mirrors mounted on the quasi optical mirrors. The second phase is the alignment using microwaves. The challenge was to couple the CTS mirrors into a three dimensional transmission line without modifying the ECRH alignment. Risø DTU has constructed a telescopic system to couple waves from a source into a HE11 wave guide mode [see subsection 2.3.8 *Device for alignment of the CC transmission line at ASDEX Upgrade* below]. The coupler was installed into a Mitre bend coupling and radiating the HE11 mode through the transmission line towards the MOU box. The radiation beam pattern was measured at different locations in the transmission line, by the compact 2D scanning rig (micro-rig) equipped with a sniffer probe connected to 110 GHz detector diode constructed at Risø DTU. This valuable tool enables us not only to improve the alignment, but also verify the beam quality. A technique has been developed using a two way laser and the micro-rig where each beam segment is aligned. Starting from the horn, the piecewise alignment is done between two components. The two-way laser is used as a reference that connects the geometrical centres of the two mirrors. The laser is then removed and the micro-rig measures the beam pattern in between. The CTS mirrors have been adjusted and aligned to match the microwave radiation from the waveguide to the ECRH quasi optical mirrors. The microwave absolute position was measured throughout the optical path and the CTS mirrors were adjusted and aligned to match the centre of the microwave beam. This includes the matching of the microwave centre to the centre of the horn. The final stage of the alignment matching was achieved by installing a microwave source in the receiver radiating outward to the horn and measuring the radiation pattern at the entrance of the waveguide. The angle of the horn was adjusted using the same technique using the two way laser and microwave. Fine adjustments (alignment and astigmatism) of the entire quasi-optical transmission line were achieved by modifying the fixed CTS mirror and measuring the beam pattern with the micro-rig at the waveguide entrance.

The polarization properties (ellipticity, angle of ellipticity and phase direction) as a function of polarizer settings has been also measured and compared to theory. A source with known polarization was installed in the vacuum vessel where its properties were measured at the horn position using a device constructed at Risø DTU consisting of an orthogonal pair of fundamental wave guide detector [see subsection 2.3.6 below].

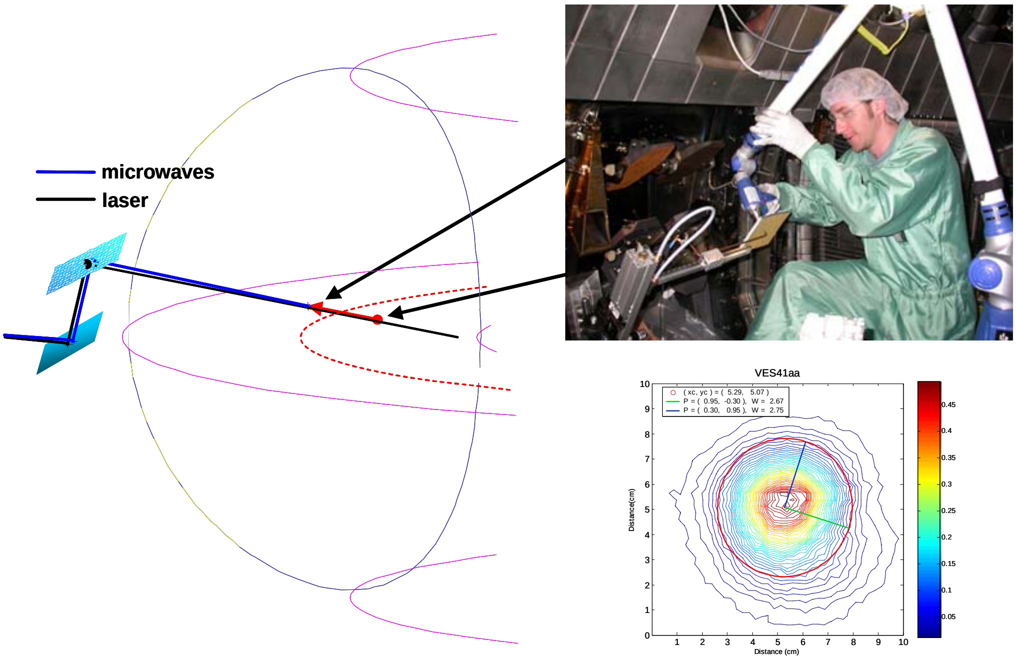

Figure 11. In vessel microwave alignment. The schematic shows the concept of measurement of the microwave beams centres using Risø DTU's micro-rig and its absolute position measurement using a FARO arm system (supplied and operated by IPP). For each antenna position, the microwave centre was measure at two distances from the mirror. This vector is then compared to the laser alignment performed by the ECRH group.

Finally, Figure 11 shows the in-vessel alignment process that compares the microwave alignment to the laser alignment. It also compares the beam dimensions and quality.

2.3.6 Characterization of the gyrotron transmission line at ASDEX

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In order to measure and characterize the polarisation of the transmission line of ASDEX Upgrade, a 107.5 GHz microwave source was placed in the CTS receiver. The radiation emitted from the receiver has its E-vector pointing in the vertical direction. The detection device [1] was placed in front of the mirror box located at the entrance of the tokamak. A focusing flipping mirror could either direct radiation outwards or into the vacuum vessel. The orientation of the ellipse, the ellipticity and the rotation of the electrical field after passing the transmission line was detected at various settings (0 to 180°) of the polarizer plates in the MOU box. The polarizer plates are a lambda/4 and a lambda/8 plates at 122.5 GHz. The polarizers were turned in steps of 15°. A rotation step of 15° means a clockwise rotation when looking on the surface of the polarizer.

The zero-zero positions of the polarizers are defined so that the incident linearly polarized electric field from the gyrotron is parallel to the grooves of the polarizer plates. Consequently, the reflected electric field is also linearly polarized. The orientation of the corkscrew device is chosen so that the major axes of the corkscrew device do not coincide with the direction of the linearly polarized electric field. Each channel sees a component of the linearly polarized electric field, which must have the same phase. The detected phase difference between the channels is due to the different transmission length in the channels. The detected phase difference in the zero-zero position is used for phase calibration. The local coordinate system of the corkscrew device is rotated by 51° compared to a coordinate system where the x-axis is horizontal at the mirror box.

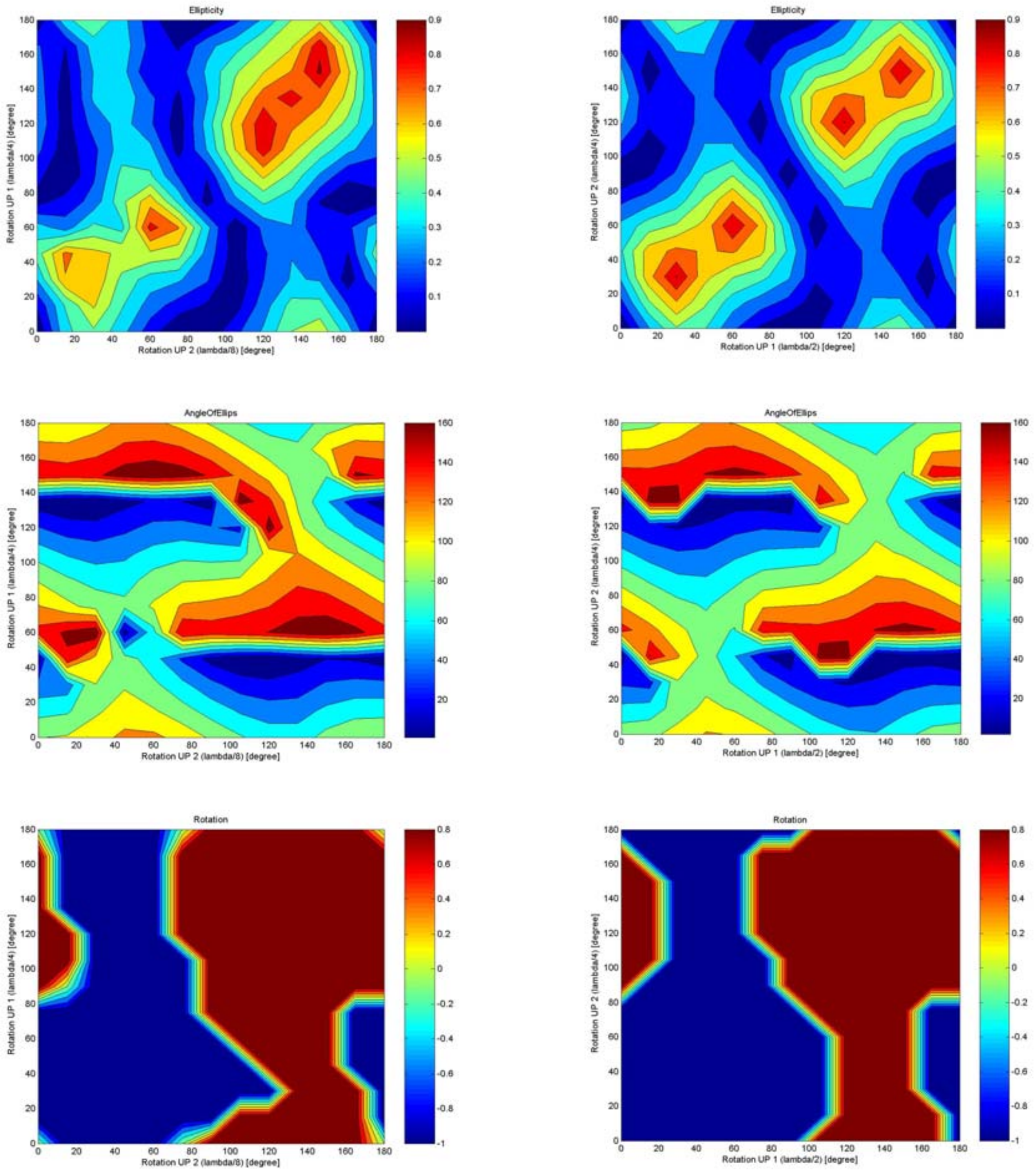
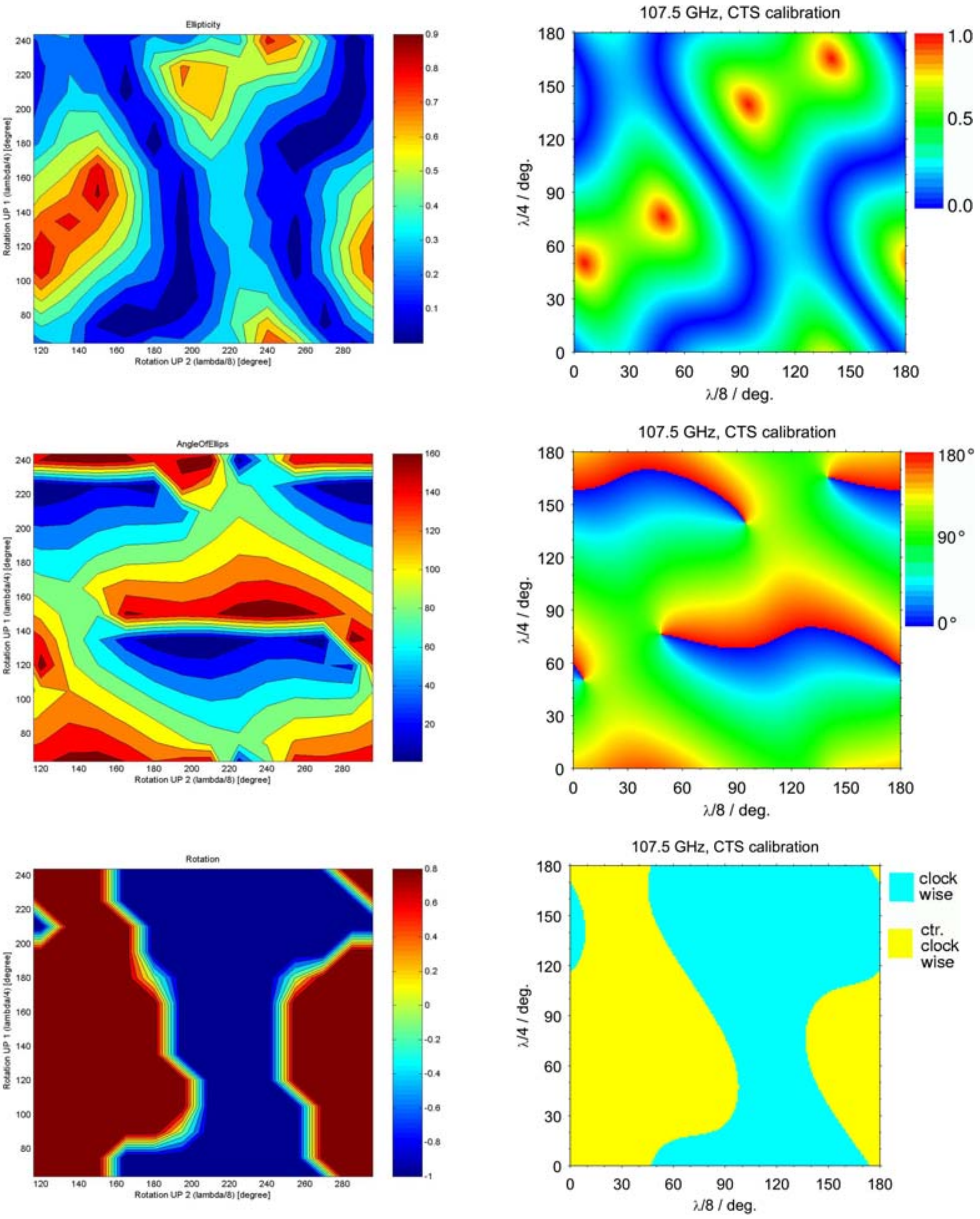


Figure 12. Measured (left column) and calculated (right column) ellipticity, angle of ellipticity, and rotation at the ASDEX Upgrade mirror box. The grid or resolution for measurements and calculations is 15°.

For the intensity calibration, the polarizer plates were varied until one channel in the corkscrew device was zero. Therefore, all intensity went to the other channel. The measured signal served as calibration. The same procedure was done for the other channel.

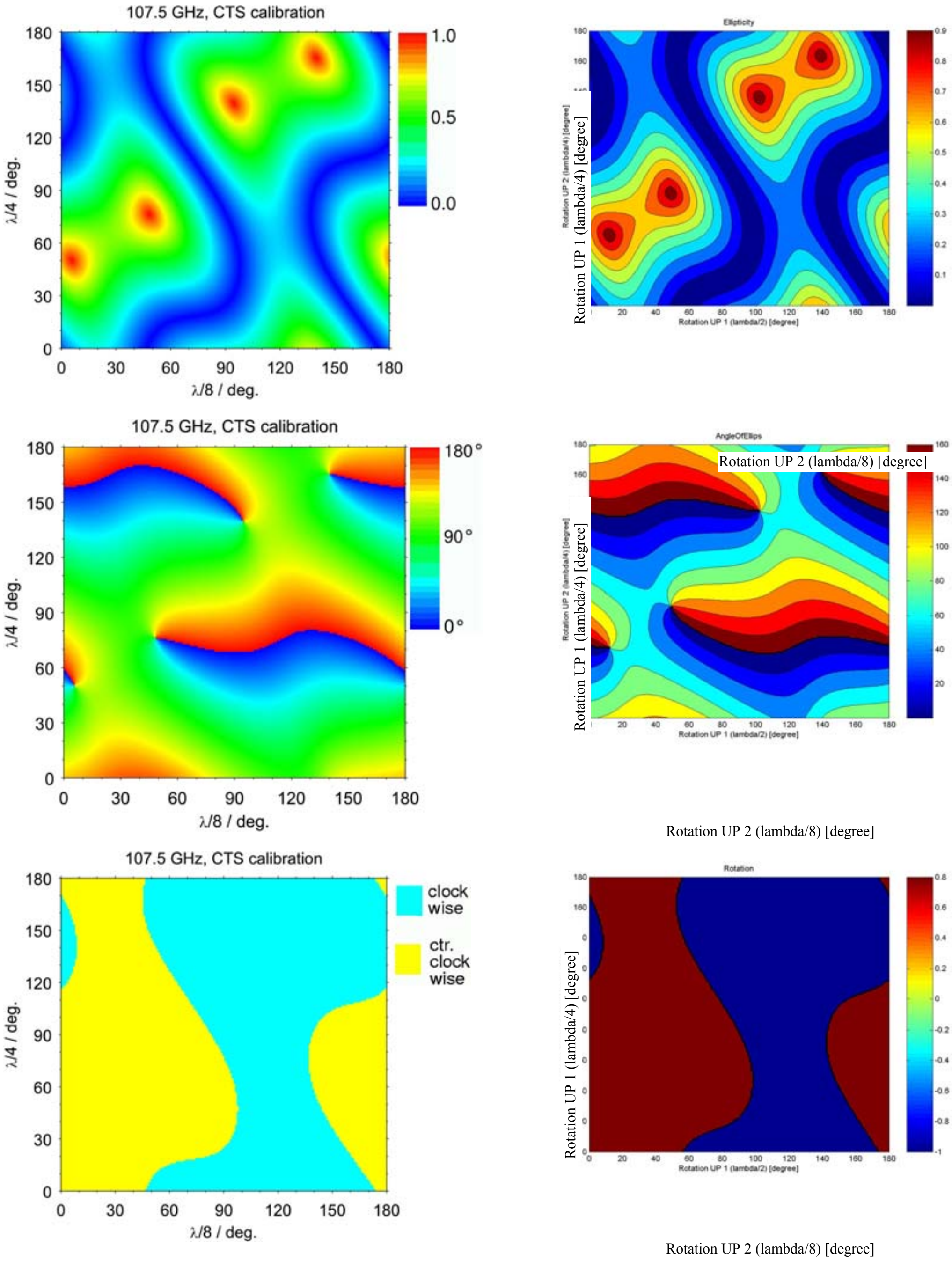
For the calculation the phase shifts of the polarizers for a frequency of 107.5 GHz were assumed to be 69° and 138° for lambda/8-polarizer and lambda/4-polarizer, respectively.



Measurement grid: 15°. The offset of the lambda/8 polarizer is 116°, and the offset of the lamda/4 polarizer is 64° compared to the ASDEX coordinate system. The angle of ellipticity has an offset of 51° compared to the graph in fig. 1 due to the different local coordinate systems being used.

Calculation grid: 1°, made by IPP Garching [2].

Figure 13. Ellipticity, angle of ellipticity, and rotation at the ASDEX Upgrade mirror box. The axis sections have been chosen to easily compare the measurements to the calculations made by [2] using the ASDEX Upgrade coordinate system.



Calculation made by IPP Garching [2]. Calculation by Risø DTU.

Figure 14. Calculated ellipticity, angle of ellipticity, and rotation at the ASDEX Upgrade mirror box. grid: 1°.

The zero-zero position was found by rotating the upper polarizer (lambda/8) by 64° (equivalent to 116° in the mathematically positive direction) and the lower polarizer (lambda/4) by 116° (equivalent to 64° in the mathematically positive direction) clockwise (when looking on the surface of the polarizers)

The contours of the electric field parameters (direction of rotation, ellipticity and the angle of the ellipse to the x-axis) are displayed versus the polarizer settings in the left column of Figure 12. The right column in Figure 12 shows the calculation of the electric field parameter settings with step increments of 15°. The measurements in Figure 13, left column, are displayed with an offset in the axis. This makes it easier to compare the graphs of the measurements with the graphs from Dietmar Wagner (IPP Garching) calculations which are based on the ASDEX Upgrade coordinate system. Figure 14 shows the code from IPP Garching and from Risø DTU with a 1° resolution in the ASDEX Upgrade coordinate system.

The excellent agreement between measurements and calculation made at Risø DTU and IPP shows, that both models can be used to predict the characteristic of the circular polarized light going into the tokamak.

1. F. Leipold et al., “Heterodyne detector for measuring the characteristic of elliptically polarized microwaves”, submitted to Review of scientific instruments
2. D. Wagner, F. Leuterer, Broadband Polarizers for High-Power Multi-Frequency ECRH Systems, Int. J. Infrared and Millimeter Waves, 26 (2005), 163-172.

2.3.7 In vessel experimental verification of the ASDEX transmission line code

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To confirm the polarizer codes throughout the complete transmission line, a source with different polarizations was placed inside ASDEX Upgrade during the shutdown phase. Elliptically polarized light (like the CTS signal) must be transformed to the linearly polarized light received by the detector. This transformation is performed by a universal polarizer consisting of two polarizer plates in the transmission line. A MatLab code was written to calculated the polarizer settings and calculate the transformation of elliptically polarized light from the tokamak through the transmission line to the detector.

In order to verify the Matlab code, a microwave source, producing elliptically polarized light was constructed by means of a Gunn diode and a rotatable polarizer plate. The elliptically polarized wave was characterized by means of a polarization sensitive detector [1]. The characterization of the source for various polarizer settings can be seen in Table 1. The source was placed inside the tokamak with a polarizer setting of 30 degree (yellow highlighted in Table 1). The detector was in the location of the CTS receiver. The polarizer settings were calculated using the MatLab code. The polarizers were adjusted, until the best transmission was achieved. The code predictions agreed well with the polarizer settings, thus supporting the reliability of the code.

1. F. Leipold et al., “Heterodyne detector for measuring the characteristic of elliptically polarized microwaves”, submitted to Review of scientific instruments

Table 1. Characteristic of the elliptically polarized light source for various polarizer angles. The z-axis is the direction of propagation.

Angle [degree]	(horizontal) x_rp	(vertical) y_rp	Phase for notation $e^{i(wt-kz)}$
0	0.0000	1.0037	180
10	0.1328	0.9664	291
20	0.1899	0.9585	286
30	0.2429	0.9469	271
40	0.2664	0.9469	260
50	0.2675	0.9444	255
60	0.2403	0.9585	247
70	0.1937	0.9664	238
80	0.1298	0.9859	224
90	0.0632	1.0071	225
100	0.0269	1.0212	180
110	0.0795	1.0245	62
120	0.1256	1.0224	57
130	0.1551	1.0207	56
140	0.1551	1.0187	56
150	0.1362	1.0178	59
160	0.0984	1.0245	50
170	0.0579	1.0170	22
180	0.0568	1.0037	180

2.3.8 Device for alignment of the CC transmission line at ASDEX Upgrade

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In order to optimally align the shared quasi-optical transmission line for the ECRH gyrotron and the CTS system at ASDEX Upgrade, a low power mm-wave source is required. A device was built, so that the beam of a horn antenna fed by a Gunn diode is transformed into a Gaussian beam, which propagates in the corrugated waveguide, simulating a CTS signal. The beam radius in the beam waist is given by the dimension of the corrugated waveguide; in the case of ASDEX Upgrade it is 27 mm. A lens was designed to transform the beam from the horn antenna to a beam having a waist radius of 27 mm. The horn antenna and lens were combined to a unit which can be inserted in the waveguide, which allows the beam to be directly coupled into the waveguide (see Figure 15).

In order to quantify the misalignment of the unit, it was rotated inside the corrugated waveguide. Measurements of the beam pattern were taken at 0°, 90°, 180° and 270° rotation. The horn-lens-unit was placed in the end of the 1 m CC waveguide. The distance between the unit and the detector was 1575 mm. The beam centres of the four measurements were located on a circle with a radius of 4.84 mm as presented in Figure

16. These measurements indicated a misalignment angle of 0.18° with respect to the centre line. This misalignment was optimised by the adjustment screws of the unit.

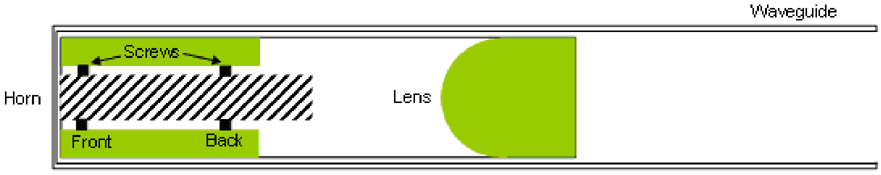

Figure 15. Sketch of the circular, corrugated waveguide and the assembly of the horn and lens. The distance between the horn and the lens is 245 mm. The indicated screws are used for aligning the horn.

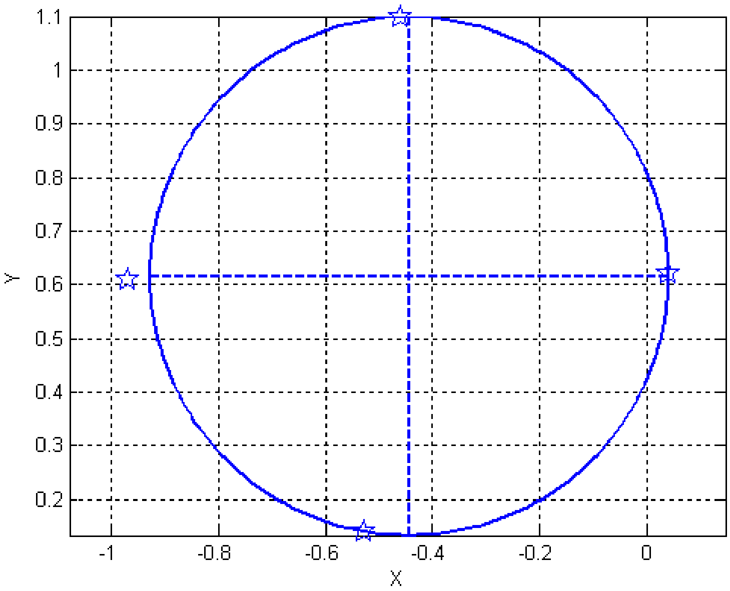

Figure 16. The positions of beam centres are indicated by asterisks for the four alignment measurements. The units on the axes are cm.

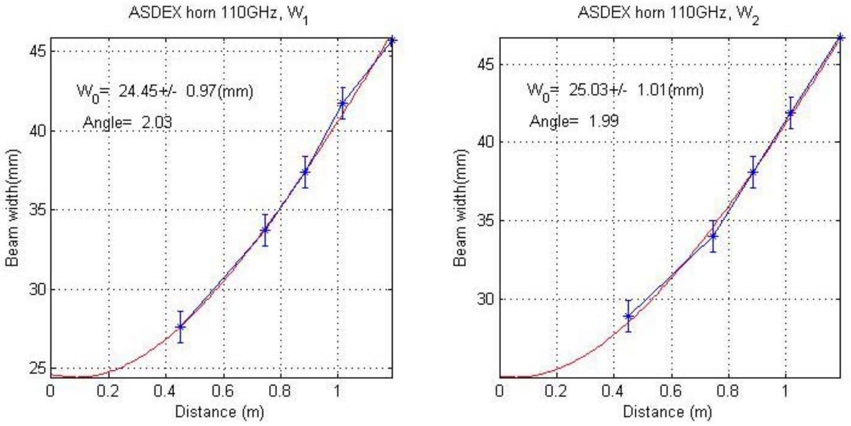

Figure 17. Beam radius of the beam in two perpendicular directions versus distance from the exit of the corrugated waveguide.

After alignment the beam pattern was measured in a number of distances from the end of the corrugated waveguide. The beam width in two perpendicular directions was measured, see W1 and W2 in Figure 17. The measurements were fitted to a Gaussian beam. The waists at the exit of the corrugated waveguide (Distance=0) in the two perpendicular directions are 24.45 mm and 25.03 mm, respectively. The fit results in confirming a circular beam pattern with an inaccuracy of less than 2.4 %. The values are in good agreement with the expected beam waist of 27 mm.

2.3.9 Gyrotron commissioning at ASDEX Upgrade

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The final stage of the commissioning was to measure the detailed frequency dynamics of the Odyssey-2 gyrotron at different operating scenarios. Experiments to measure the gyrotron frequency of the Odyssey-2 were done where stray radiation was collected from a pick-off horn/waveguide installed in MOU box. The signal was heterodyned down using a harmonic mixer/oscilloscope set-up and fed into a 1 GHz bandwidth Tektronix DPO 7104 Oscilloscope with 20 MB memory purchased by Risø DTU. The results have shown a reproducible frequency chirp that is dependent on the beam voltage and pulse length. This information is needed to tune the notch filter to the correct frequency and bandwidth. In addition, it also determines the time intervals useful for CTS measurements during a gyrotron pulse time. The next stage is to verify any spurious modes that may occur in the gyrotron during the operation. Experiments were carried out while gyrotron power was launched into the ASDEX Upgrade vacuum vessel and measured by the CTS receiver. Results show that the Odiyssey-2 gyrotron is free of any spurious modes.

2.3.10 First scattering results of the CTS installed on ASDEX Upgrade

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Figure 18 shows the fist scattered radiation results, an important milestone for the diagnostic. It was performed during an Ohmic discharge in ASDEX Upgrade. The center most channels are plotted as a function of time during a plasma discharge where the receiver antenna is swept twice across gyrotron beam. The vertical lines are the time points where the receiver antenna position is expected to have maximum overlap. From the graph, one can see the good agreement with the receiver antenna position as expected by calculations based on prior in-vessel alignment of the antenna and ray-tracing. Experiments were only performed for near perpendicular scattering geometry. The commissioning is in its final stages and physics exploitation is expected in the 2008 campaign.

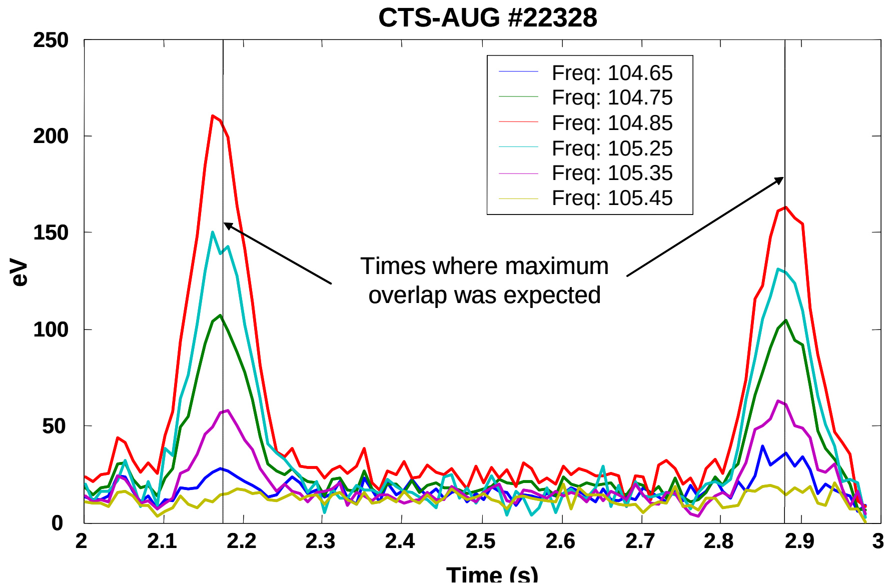

Figure 18. Centre channel signals versus time during a two sweeps of the receiver antenna across the probe beam. The vertical lines are the time points where maximum overlap was expected.

2.3.11 The fast ion CTS diagnostic for ITER

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Since the ITER CTS feasibility study of 2003 [1] a continual effort at Risø DTU has been made to mature the design of a fast ion CTS diagnostic for ITER. As described in e.g. Ref. 1, the proposed fast ion diagnostic comprises of two parts, a receiving antenna located on the high field side (HFS) behind the blanket modules, and a receiving antenna on the low field side (LFS) in equatorial port plug #12. Each antenna is viewing the scattered light from two dedicated 60 GHz 1 MW gyrotron sources. With the proposed system it is possible to resolve the dynamics of confined fast ions (including fusion born alphas) in the direction perpendicular to the magnetic field (LFS antenna) and in the direction parallel to the magnetic field (HFS antenna), within the ITER measurement requirements. Due to the spatial constraints, the HFS antenna is the most challenging part of the diagnostic, and much emphasis has been put on obtaining a good solution for that part of the system. It should be noted that the HFS antenna will give information on dynamics of fast ions on passing orbits, and as a spin-off it will also give the toroidal bulk ion rotation velocity.

The CTS diagnostic was not sufficiently matured at the time of the 2001 ITER baseline design, and therefore CTS has been carried as a so-called un-credited diagnostic. With the maturity of the diagnostic based on the results and experiences on TEXTOR and ASDEX Upgrade, and the progress of the ITER CTS design at Risø DTU, the ITER diagnostic working group decided - as part of the design review - to include the LFS part of the fast ion CTS diagnostic in the new ITER baseline design. In the following sections development of the design, modelling of heat load on mirrors, and mock-up testing of components is described.

Risø DTU was also part of multi association EFDA task to investigate the measuring capabilities of diagnostics under different ITER plasma and heating scenarios. Some results of these studies are also presented.

1. ITER CTS reports by Risø DTU. Please find via http://cts.risoe.dk

2.3.12 Progress in the HFS antenna design and testing

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In order to verify the design of the mirror and the propagation of the anisotropic Gaussian beam modelled in MatLab [1], a 1:1 mock-up has been built. The mock-up consists of the mirror assembly, parts of the two surrounding blanket module and the receiver horn. The verification of the beam propagation is done by tracking the beam reversely, where the horn is fed by a mm-wave source of 60 GHz. The beam is guided through the quasi-optical transmission line and detected by a detector diode mounted on a x-y-translation stage in order to characterize the beam.

The beam characteristic at the receiver end has been calculated [1]. According to the calculations, the horn has to be capable of receiving a beam with a waist radius of 4.5 mm corresponding to a divergence angle of 20.3°. A circularly corrugated horn suitable for accepting the beam was designed and built. Figure 19 shows a CATIA drawing of the corrugated horn.

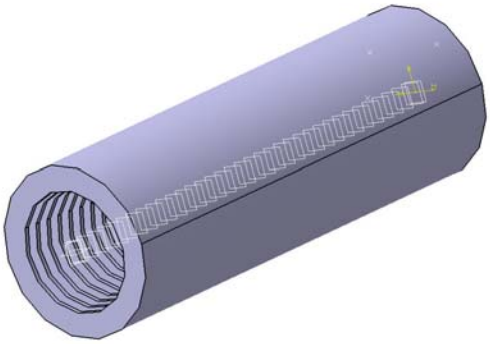

Figure 19. Circularly corrugated horn for the 60 GHz HFS ITER CTS antenna.

Table 1: The measurements with the micro rig. Data for the horn only.

Distance from the horn [mm]	W_1[cm]	W_2[cm]
194	7.26	7.56
245	8.93	9.25
320	11.35	11.59
415	14.54	14.79
500	17.40	18.07

In order to verify whether the horn meets the requirements, a 60 GHz oscillator was mounted to the horn and the device was used as a mm-wave source. The beam pattern in front of the horn opening was measured at various distances from the horn. The measurements are shown in Table 1. W1 and W2 are the beam radii in two orthogonal directions (major and minor axes of the generally elliptical beam shape). Figure 20 shows the beam radius versus the distance for the major and minor axes. From these measurements, the divergence angles are obtained. They were found to be 19° and 19.8° for the major and minor axis, respectively. The results show that expected and measured beam shapes are in good agreement.

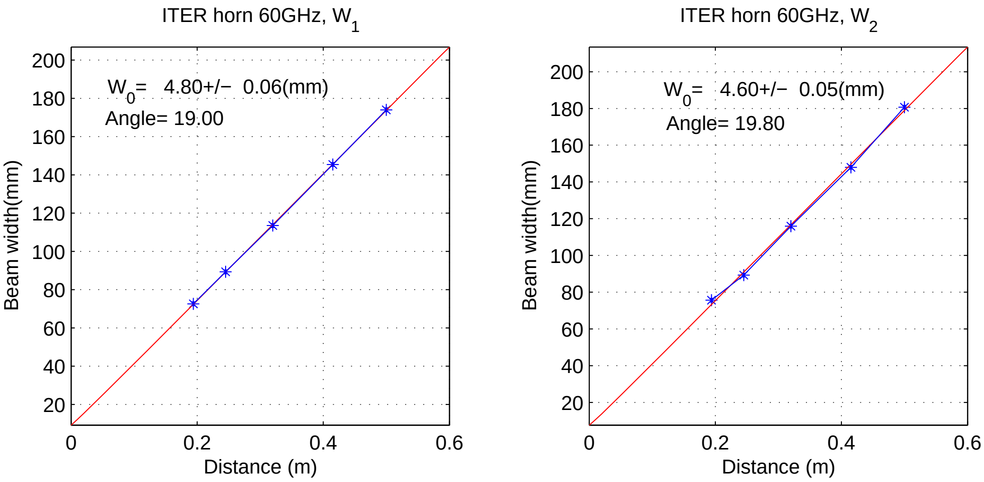

Figure 20. The beam envelope of the ITER HFS CTS antenna horn. Divergence angle Θ_{w0} is in the range 19.00 - 19.80° and the beam waist w_0 4.60 - 4.80 mm. W1 and W2 are the minor and major axis, respectively. Since the horn is circular, W1 and W2 should be close to each other. The error is less than 3 %.

The mirror mock-up of the HFS CTS antenna has been manufactured of aluminium for easier production, while the actual mirrors for ITER will be produced in stainless steel or similar materials. Figure 21 shows photographs of the mirror assembly.

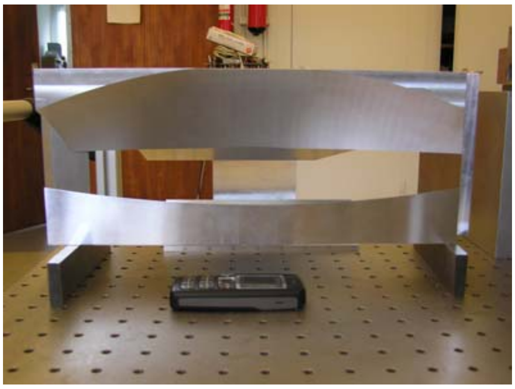
Figure 21a. Mirror assembly (front view).

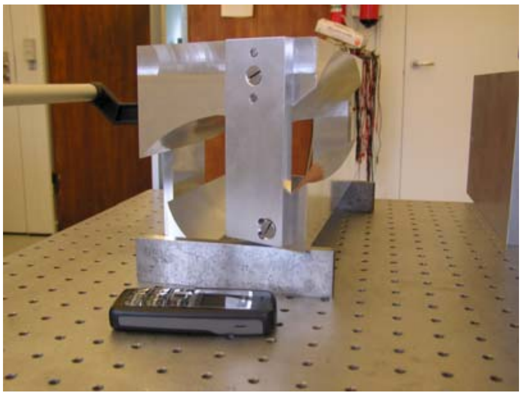
Figure 21b. Mirror assembly (side view).

In order to measure the properties of the quasi-optical transmission line, the horn antenna is placed in front of the exit mirror. Figure 22 shows a schematic of the setup.

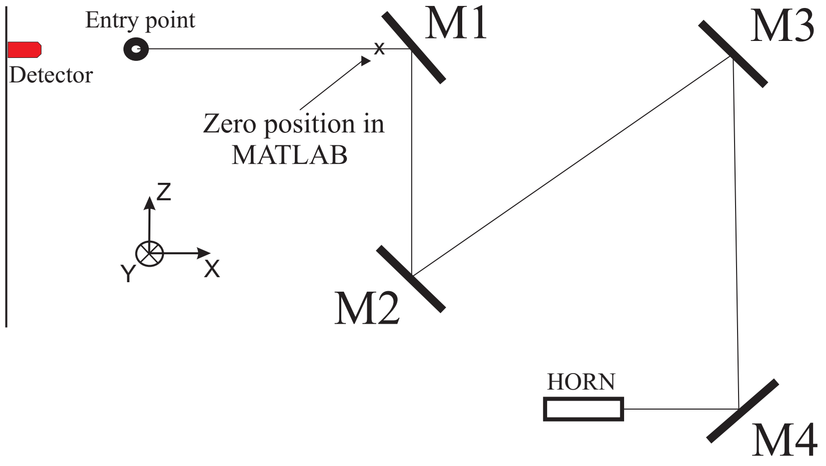

Figure 22. Schematic of horn, mirror assembly and detector alignment.

The beam passes the quasi-optical transmission line reversely. The beam characteristic is measured at various distances between the "Entry point" (the slit in the blanket) and the detector. The detector scans the y-z-plane. The measurement of the beam pattern can be seen in Table 2. Ideally, W1 is the beam size in y-direction and W2 is the beam size in z-direction. The major and minor axes of the elliptical beam pattern deviate slightly from the y- and z-axis respectively.

Table 2. The measurements with the detector. The measured points given by the diode detector are fitted to a Gaussian beam. From the values it is clear that we have astigmatic beam propagating between the first mirror M1 and the detector.

D[mm]	W_1[cm]	W_2[cm]
123	1.52	10.07
172	2.41	9.29
214	3.1	9.33
260	3.62	8.67
348	5.16	8.46

Figure 23 shows the beam radius at a number of distances. The distance 0 m is the extrapolated beam size at the entry point.

The measured beam expansion in the z-direction (Figure 5) and the fitting to a Gaussian beam shape resulting in a beam waist of w0 = 9.49 mm is in good agreement with the expected beam waist of 9.375 mm. The displacement of the location of the beam waist (approximately 50 mm) in the z-direction is caused by the determination of the entry point of the mirror assembly. The measured beam expansion in y-direction is more difficult. The beam waist in the y-direction is expected approximately 2.8 m from the entry point. At this position, the beam intensity is decreased significantly causing a low S/N ratio. Therefore the beam could only be measured up to a distance of 0.35 m. The extrapolation to a location 10 times further away than the range of the measurement could be connected to a significant error. It can only be concluded from these measurements that the measured beam size in the y-direction (0.103 m at a distance of 50 mm) is in good agreement with the expected size of 0.1 m. The measured beam size is taken at the distance, where the beam shape in the z-direction has its waist.

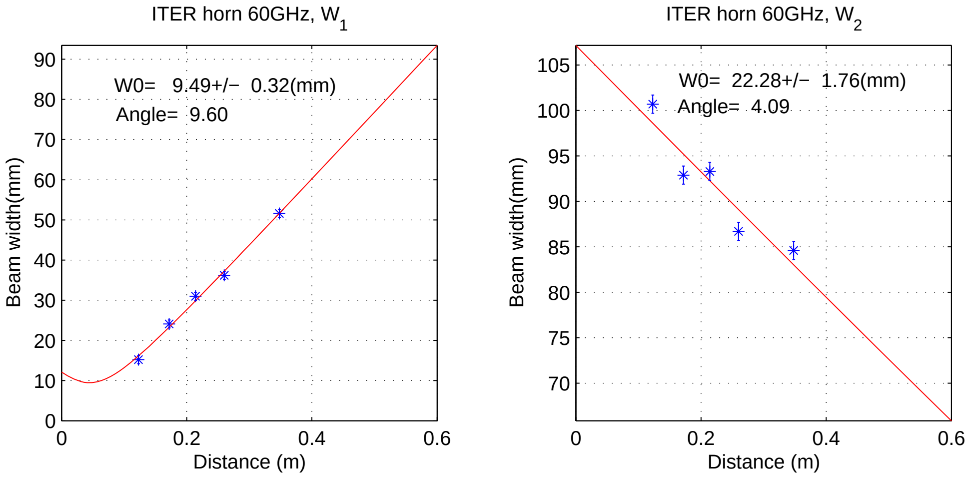

Figure 23. The beam envelope at various distances from the entry point.

Due to limited space in the blanket module, fundamental waveguides with bends having a curvature radius of several times the wavelength cannot be used. Sharp bends are required. The application of mitre bends is investigated by simulations of the wave propagation by ANSYS. The simulations demonstrate that mitre bends are suitable for a fundamental waveguide. Figure 24 shows the electrical field component perpendicular to the major viewing surface in the picture and the energy flux density (Poynting vector) through a piece of waveguide containing a mitre bend.

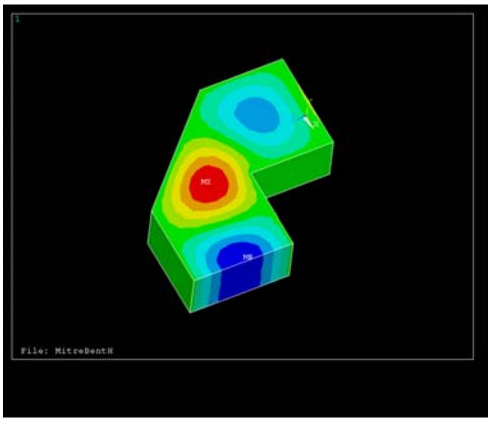

Figure 24a. Strength of the electrical field component perpendicular to the top surface.

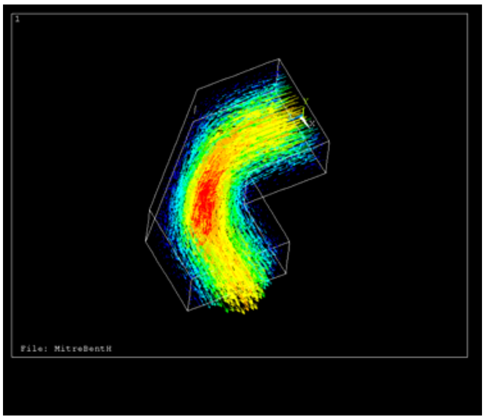

Figure 24b. Energy flux density (pointing vector) through a mitre bend.

1. ITER CTS reports by Risø DTU. Please find via http://cts.risoe.dk

2.3.13 Progress in the ITER LFS CTS diagnostic design

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The LFS part of the CTS diagnostic is located in port plug #12 on ITER. This port plug contains also the probing beam launcher quasi-optics for the LFS and HFS systems. The parts are shown in Figure 25 seen from the plasma.

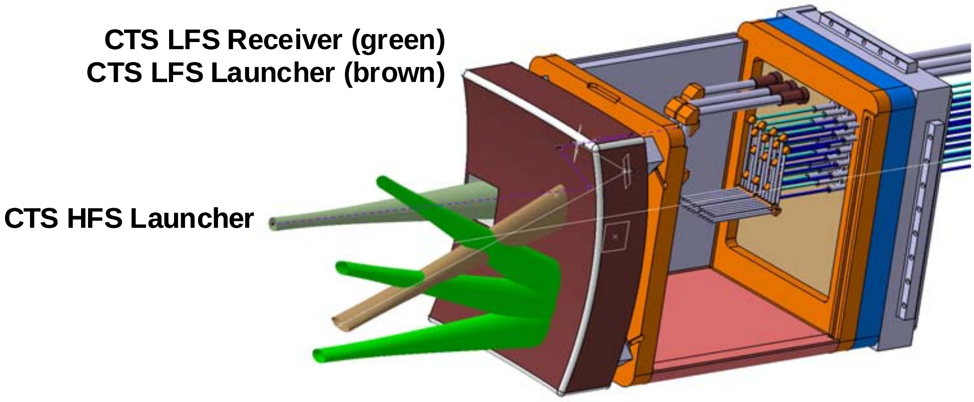

Figure 25. The beams of the ITER CTS diagnostic in port plug #12 as seen from the plasma.

The probing radiation for the CTS systems is provided by two gyrotrons. The required beam shape has been calculated in the Feasibility study [1]. In order to transform the beam characteristic, two mirrors have been designed in Matlab (see Figure 26).

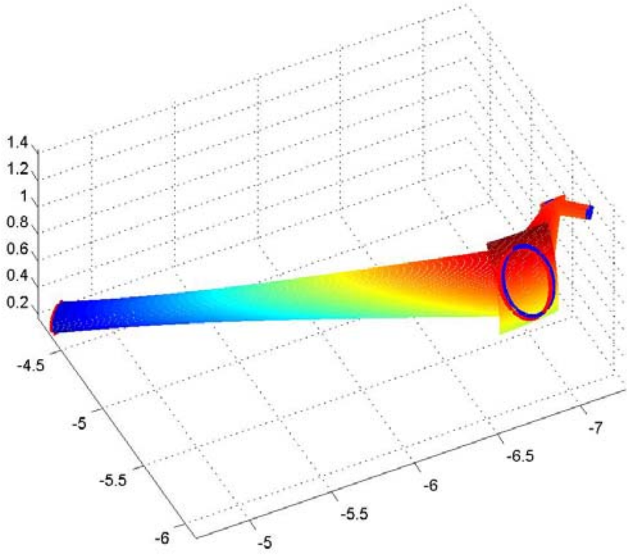

Figure 26. The beams of the LFS probe made in MatLab for the calculation of the mirror surfaces.

Figure 27. Mirrors and beam shape for the CTS LFS launcher beam made in CATIA.

The mirror shape is imported into CATIA V5, where the mirror design is performed. The mirror design and the beam pattern is presented in Figure 27.

The LFS CTS receiving antenna is depicted in Figure 28. The mirror shapes are calculated for the centre beam (the middle green beam in Figure 28). The lower and upper beams in Figure 28 represent the extreme beams. The calculation of theses beams together with the receiving antenna mirrors and the horns are currently in progress.

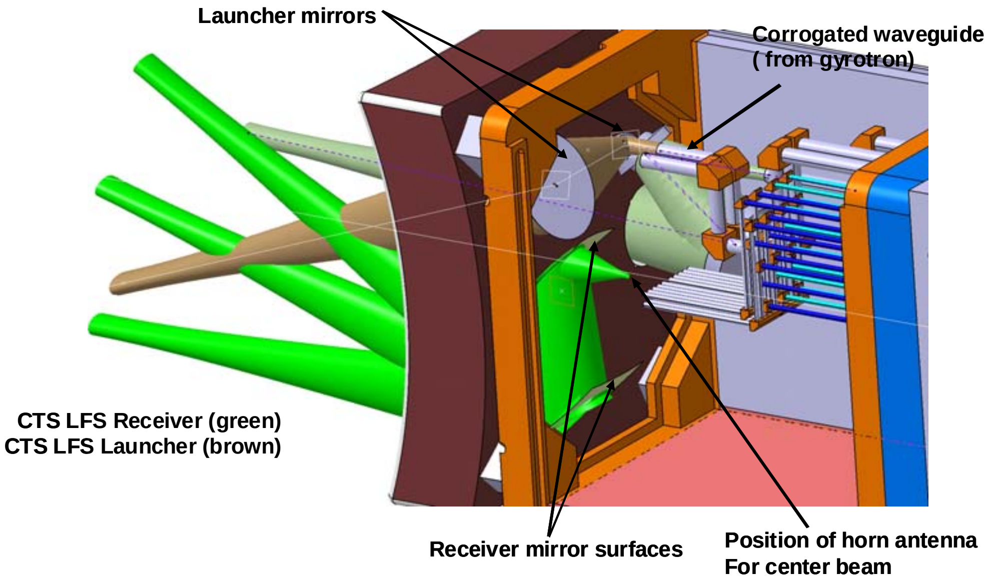

Figure 28. ITER CTS launcher and LFS receiver quasi optics in port plug #12 – seen from the port plug.

1. ITER Fast Ion Collective Thomson Scattering - Feasibility Study (2003). Please find via http://cts.risoe.dk

2.3.14 Thermo-Elastic Modelling of First Mirrors for the ITER HFS CTS System

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ITER will contain a burning plasma with significant fast ion populations originating from the fusion process and from auxiliary heating of the plasma. Collective Thomson scattering (CTS) can be used to obtain the phase space distribution of fast ions in such a burning plasma. The proposed CTS system for ITER consists of a forward scattering system to measure velocities of fast ions parallel to the magnetic field and a backward scattering system to measure velocities perpendicular to the magnetic field. Here we are concerned with the former system which is designed with a receiver on the inboard side, also called high field side (HFS), of the tokamak. The receiver requires a mirror with a direct line-of-sight to the plasma. The collected scattered radiation hits this mirror which is designed to reflect and shape electromagnetic waves at 60 GHz, so-called millimetre waves. In the CTS diagnostic, the spectral content of these waves is analyzed and various plasma parameters can be inferred. This first mirror is exposed to severe neutron and photon fluxes due to direct line-of-sight to the plasma. These are further enhanced by the necessity to cut out neutron shielding blanket material since space is limited on the inboard side of the tokamak and there is not enough room to place the receiver behind a blanket of nominal thickness. The modelling of neutron and gamma fluxes is being performed at the Radiation Research Department at Risø DTU. These fluxes cause volumetric heating of the first mirror which will expand thermally. The present modelling of neutronics and thermo-elastic stresses indicates that the mirror curvature may change. This may alter the beam quality, and therefore thermal effects have to be accounted for in the design of the mirror. Various mirror designs are being compared in terms of temperature distribution and thermal strain. An example temperature distribution is shown in Figure 29. The results are obtained numerically by the finite element method implemented in the commercially available software ANSYS.

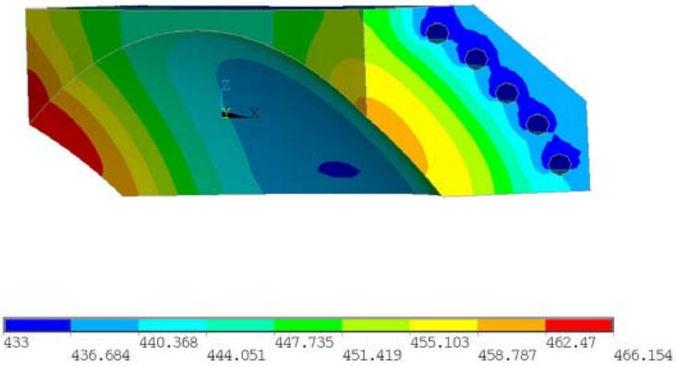

Figure 29. Example of a temperature distribution for the first mirror for the HFS CTS system.

2.3.15 Neutronics Calculations for the Collective Thomson Scattering Diagnostic System for ITER (Outboard)

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The proposed Collective Thomson Scattering (CTS) diagnostic system for ITER consists of two separate systems measuring the fast ion velocity components in direction near parallel and near perpendicular to the magnetic field [1]. The low field (LF) side system of the CTS diagnostics consists of a beam launcher, quasi-optical receiver mirrors, receiver horn arrays and waveguides, all located in the equatorial port plug #12.

The components are exposed to intense neutron and gamma radiation, which is of concern both with respect to the heat loads on the mirrors, affecting their optical properties, and with respect to the neutron fluxes streaming through the waveguides. The heat load to the mirrors provides a basis for estimating the thermal distortions of the mirror system impairing the microwave transmission properties.

Monte Carlo calculations for the neutron and photon fluxes through the waveguides and for the heat load on the LF CTS mirrors have been performed with a newly developed 40 degree geometry input model. To encompass detailed design of the diagnostic system plugs our 20 degrees simplified MCNP input model has been extended to 40 degrees lateral segment, assuming a nine-fold rotational symmetry (Figure 30). The 40 degree segment (compared to the 20 degree ITER FEAT model) allows investigating asymmetric port plug design, such as the LF CTS diagnostic system.

Figure 31 shows the proposed mirror positions of the preliminary LF CTS design. A single waveguide with the characteristic dog-leg shape is included in the figure. The waveguide is a steel tube with 20 mm inner and 25 mm outer radius. Also, the two mirrors are made of steel. The bulk material of the port plug (grey color) is in the model assumed to be a homogeneous mixture of steel (80%) and water (20%).

Preliminary results show, that the single dog-leg bend reduces both the neutron and the photon flux inside the waveguide by approx. one order of magnitude whereas a double bend does not necessarily constitute an improvement over the single-bend case.

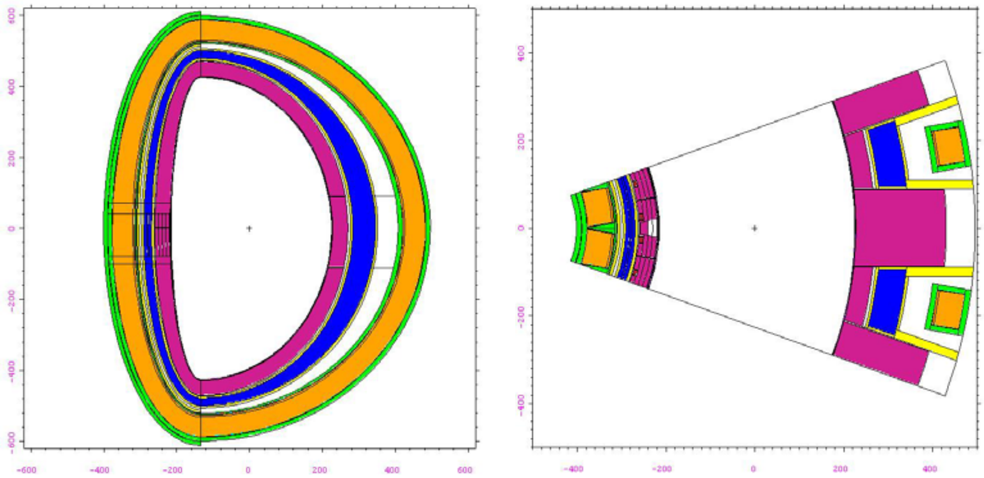

Figure 30. Poloidal (left) and toroidal (right) view of the Torus 40 degrees model.

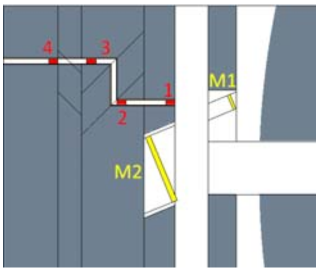

Figure 31. Port plug #12: LF CTS Mirrors position (poloidal view).

2.3.16 Modelling of the influence of ICRH and NBI on CTS capabilities

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Neutral beam injection (NBI) and ion cyclotron resonance heating (ICRH) are auxiliary heating methods to achieve high temperatures in thermonuclear plasmas. NBI and ICRH produce populations of fast ions which can reach similar energies as the fusion alphas. As one is particularly interested in the physics of fusion alphas, it is of great scientific interest, if one could diagnose fusion alphas in the presence of fast ions generated by auxiliary heating. Thus their respective contributions to the CTS signal have been compared. It was found that the alpha signal dominates the total signal for most cases.

The study was facilitated via the EFDA task TW6-TPDS-DIADEV *Assessment of effects of RF- and NBI-generated fast ions on the measurement capability of diagnostics* between multiple associations. Initially, fast ion distribution functions have to be computed as for various ITER scenarios, and these calculations have been carried out by the collaboration partners of this study being responsible for modelling, *Association EURATOM-ÖAW* and *Association Euratom-TEKES* for modelling plasma heating with NBI, and *Association EURATOM-CEA* and *Euratom-VR Association, Stockholm* for modelling plasma heating with ICRH. The results of these simulations were further analyzed at Risø DTU in terms of the various contributions to the scattering signal. We review the main results below.

For NBI, the fast deuterons do not perturb the total CTS spectra significantly for most locations of the scattering volumes. The fusion alpha velocity spectra can therefore be accurately determined in parallel and perpendicular directions with respect to the magnetic field. However, fast deuterons may affect the accuracy with which fusion alphas can be detected only within a narrow frequency band in the co-beam direction (parallel to the magnetic field) in scattering volumes through which the beam ions pass but even here the fusion alpha velocity distribution can be accurately determined in the counter-beam direction. Figure 32 shows the scattering function for this case and demonstrates that the CTS signal due to beam ions (purple curve) is much smaller than the CTS signal due to fusion alphas (dark blue curve). In the other scattering volumes, the beam ion contribution to the total signal is much lower than for the case shown in Figure 32.

For ICRH, the particular heating scenario has an impact on the ability of the fast ion CTS diagnostic to study the fusion alphas since they dominate the total CTS signal. For off-axis heating (larger R), the heating volume is large, leading to a small population of fast tritons and ^{3}He which have CTS signals several orders of magnitude below the alpha signal. Spectra of the parallel and perpendicular velocity (with respect to the magnetic field) of fusion alphas can therefore be accurately resolved everywhere in the plasma. For the case of on-axis heating, however, the power is absorbed in the core region of the plasma, leading to triton and ^{3}He signals which are not an order of magnitude smaller than the fusion alpha signal. This affects the ability to measure the alpha dynamics in the core region of the plasma only for the perpendicular velocity component as is shown in Figure 33. The Helium-3 (light blue) and Triton (purple) contributions to the CTS signal are not significantly below the alpha contribution (dark blue). The parallel velocity component can even for this case be resolved with good accuracy. Outside the core region (which has a diameter of about 50 cm), the CTS signal from ICRH generated fast ions is negligible compared to the fusion alpha signal, even for the on-axis heating scenario with large volumetric power absorption.

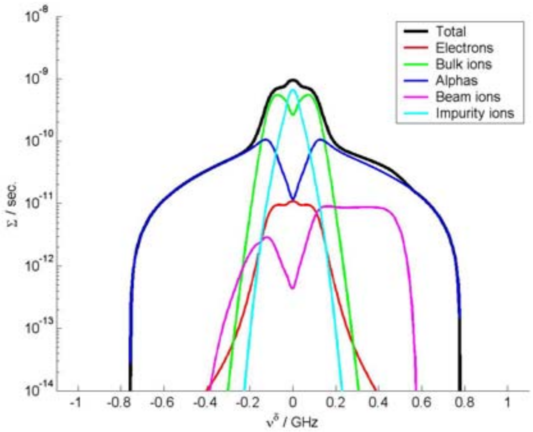

Figure 32. Contributions to the CTS signal with NBI heating (at a point for which the NBI contribution is significant).

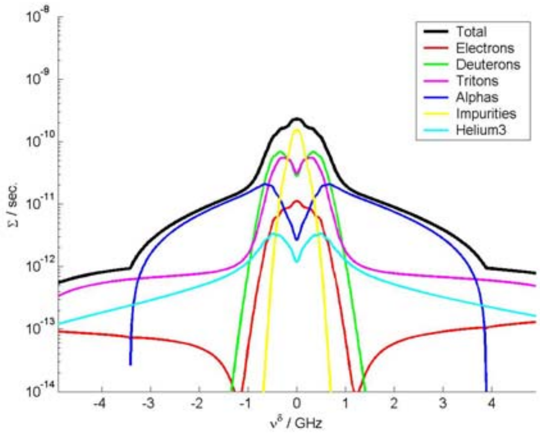

Figure 33. Contributions to the CTS signal with ICRH heating (at a point for which the ICRH contribution is significant).

2.3.17 Collaboration with the CTS teams at LHD and FTU

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During 2007 contacts to the CTS groups at LHD, NIFS, Japan, and at FTU, Frascati, Italy intensified, and agreements on collaboration was made. The aim of the NIFS CTS team is primarily to perform bulk ion temperature measurements on LHD. A secondary target will be to do measurements of H/D fuelling ratio and of fast ion dynamics. The team will initially use an existing 77 GHz gyrotron, with which they can probe between the fundamental resonance and the second harmonic. According to current planning the CTS diagnostic should be commissioned during the fall 2008 campaign of LHD. Meanwhile, they collaborate with a team in Fukui University, where it is planned to develop a 400 GHz gyrotron, with which it is possible to probe the LHD plasma above several of the harmonics. During March 2008 the NIFS team invited a Risø DTU CTS team member to facilitate discussions and sharing of experiences on building a CTS diagnostic. It was a fruitful visit and the collaboration will continue.

The planned CTS project at FTU will expand the knowledge and experience on running a CTS diagnostic with a frequency below the fundamental resonance. A key challenge is that the high power probing beam will cross the fundamental resonance in the transmission line. The solution to this challenge and other issues will be important inputs to the knowledge base, based on which the ITER CTS diagnostic will be designed. The experiments on FTU are scheduled in 2008.

2.4 Publications

International publications

Angioni, C.; Carraro, L.; Dannert, T.; Dubuit, N.; Dux, R.; Fuchs, C.; Garbet, X.; Garzotti, L.; Giroud, C.; Guirlet, R.; Jenko, F.; Kardaun, O.J.V.F.; Lauro-Taroni, L.; Mantica, P.; Maslov, M.; Naulin, V.; Neu, R.; Peeters, A.G.; Pereverzev, G.; Puiatti, M.E.; Pütterich, T.; Stober, J.; Valovic, M.; Valisa, M.; Weisen, H.; Zabolotsky, A., Particle and impurity transport in the Axial Symmetric Divertor Experiment Upgrade and the Joint European Torus, experimental observations and theoretical understanding. *Phys. Plasmas* (2007) v. 14 p. 055905 (9 pages)

Bindslev, H.; Nielsen, S.K.; Korsholm, S.B.; Meo, F.; Michelsen, P.K.; Michelsen, S.; Tsakadze, E.L.; Woskov, P.; Westerhof, E.; Hoekzema, J.A.; Oosterbeek, J.W.; Porte, L., Fast ion dynamics in magnetically confined plasma measured by collective Thomson scattering. *Plasma Fusion Res.* (2007) v. 2 p. S1023 (8 pages)

Bindslev, H.; Nielsen, S.K.; Porte, L.; Hoekzema, J.A.; Korsholm, S.B.; Meo, F.; Michelsen, P.K.; Michelsen, S.; Oosterbeek, J.W.; Tsakadze, E.L.; Westerhof, E.; Woskov, P., Fast-ion dynamics in the TEXTOR tokamak measured by collective Thomson scattering. *Plasma Phys. Control. Fusion* (2007) v. 49 p. B551-B562

Donné, A.J.H.; Costley, A.E.; Barnsley, R.; Bindslev, H.; Boivin, R.; Conway, G.; Fisher, R.; Giannella, R.; Hartfuss, H.; Hellermann, M.G. von; Hodgson, E.; Ingesson, L.C.; Itami, K.; Johnson, D.; Kawano, Y.; Kondoh, T.; Krasilnikov, A.; Kusama, Y.; Litnovsky, A.; Lotte, P.; Nielsen, P.; Nishitani, T.; Orsitto, F.; Peterson, B.J.; Razdobarin, G.; Sanchez, J.; Sasao, M.; Sugie, T.; Vayakis, G.; Voitsenya, V.; Vukolov, K.; Walker, C.; Young, K., Diagnostics. Nucl. Fusion (2007) v. 47 (no.Progress in the ITER Physics Basis) p. S337-S384

Fundamenski, W.; Garcia, O.E.; Naulin, V.; Pitts, R.A.; Nielsen, A.H.; Juul Rasmussen, J.; Horacek, J.; Graves, J.P., Dissipative processes in interchange driven scrape-off layer turbulence. Nucl. Fusion (2007) v. 47 p. 417-433

Fundamenski, W.; Naulin, V.; Neukirch, T.; Garcia, O.E.; Juul Rasmussen, J., On the relationship between ELM filaments and solar flares (topical review). Plasma Phys. Control. Fusion (2007) v. 49 p. R43-R86

Garcia, O.E.; Horacek, J.; Pitts, R.A.; Nielsen, A.H.; Fundamenski, W.; Naulin, V.; Juul Rasmussen, J., Fluctuations and transport in the TCV scrape-off layer. Nucl. Fusion (2007) v. 47 p. 667-676

Garcia, O.E.; Naulin, V.; Nielsen, A.H.; Juul Rasmussen, J., Turbulence and transport in the edge region of toroidally magnetized plasmas. Annals Univ. Craiova Physics AUC (2007) v. 17 p. 263-286

Garcia, O.E.; Pitts, R.A.; Horacek, J.; Nielsen, A.H.; Fundamenski, W.; Graves, J.P.; Naulin, V.; Juul Rasmussen, J., Turbulent transport in the TCV SOL. J. Nucl. Mater. (2007) v. 363 p. 575-580

Garcia, O.E.; Pitts, R.A.; Horacek, J.; Madsen, J.; Naulin, V.; Nielsen, A.H.; Juul Rasmussen, J., Collisionality dependent transport in TCV SOL plasmas. Plasma Phys. Control. Fusion (2007) v. 49 p. B47-B57

Kuznetsov, E.A.; Naulin, V.; Nielsen, A.H.; Juul Rasmussen, J., Effects of sharp vorticity gradients in two-dimensional hydrodynamic turbulence. Phys. Fluids (2007) v. 19 p. 105110 (10 pages)

Milovanov, A.V.; Rypdal, K.; Juul Rasmussen, J., Stretched exponential relaxation and ac universality in disordered dielectrics. Phys. Rev. B (2007) v. 76 p. 104201 (8 pages)

Naulin, V., Turbulent transport and the plasma edge. J. Nucl. Mater. (2007) v. 363 p. 24-31

Pitts, R.A.; Horacek, J.; Fundamenski, W.; Garcia, O.E.; Nielsen, A.H.; Wischmeier, M.; Naulin, V.; Juul Rasmussen, J., Parallel SOL flow on TCV. J. Nucl. Mater. (2007) v. 363 p. 505-510

Rypdal, K.; Garcia, O.E., Reduced Lorenz models for anomalous transport and profile resilience. Phys. Plasmas (2007) v. 14 p. 022101 (11 pages)

Tala, T.; Andrew, Y.; Crombe, K.; Vries, P.C. de; Garbet, X.; Hawkes, N.; Nordman, H.; Rantamaki, K.; Strand, P.; Thyagaraja, A.; Weiland, J.; Asp, E.; Baranov, Y.; Challis, C.; Corrigan, G.; Eriksson, A.; Giroud, C.; Hua, M.-D.; Jenkins, I.; Knoops, H.C.M.; Litaudon, X.; Mantica, P.; Naulin, V.; Parail, V.; Zastrow, K.-D., Toroidal and poloidal momentum transport studies in JET. Nucl. Fusion (2007) v. 47 p. 1012-1023

Tsakadze, E.; Bindslev, H.; Korsholm, S.B.; Larsen, A.W.; Meo, F.; Michelsen, P.K.; Michelsen, S.; Nielsen, A.H.; Nimb, S.; Lauritzen, B.; Nonbøl, E.; Dubois, N., Fast ion collective Thomson scattering diagnostic for ITER: Design elements. Fusion Sci. Technol. (2008) v. 53 p. 69-76

Wagner, D.; Leuterer, F.; Manini, A.; Monaco, F.; Münich, M.; Ryter, F.; d Schütz, H.; Stober, J.; Zohm, H.; Franke, T.; Danilov, I.; Heidinger, R.; Thumm, M.; Gantenbein, G.; Kasparek, W.; Lechte, C.; Litvak, A.; Denisov, G.; Tai, E.; Popov, L.; Nichiporenko, V.; Myasnikov, V.; Solyanova, E.; Malygin, S.; Meo, F.; Woskov, P., The new multifrequency electron cyclotron resonance heating system for ASDEX upgrade. Fusion Sci. Technol. (2007) v. 52 p. 313-320

Wyller, J.; Krolikowski, W.Z.; Bang, O.; Petersen, D.E.; Juul Rasmussen, J., Modulational instability in the nonlocal chi(2)-model. Physica D (2007) v. 227 p. 8-25

Danish publications

Michelsen, P.K.; Cardozo, N.L.; Korsholm, S.B., Energy supply technologies. Fusion energy. In: Larsen, H.; Sønderberg Petersen, L. (eds.), Risø energy report 6. Future options for energy technologies. Risø-R-1612(EN) (2007) p. 63-66 www.risoe.dk/rispubl/reports/ris-r-1612.pdf

Risø-R-reports

Meo, F.; Bindslev, H.; Korsholm, S.B., ITER fast ion collective Thomson scattering. Conceptual design of 60 GHz system. Risø-R-1600(EN) (2007) 40 p. www.risoe.dk/rispubl/reports/ris-r-1600.pdf

Michelsen, P.K.; Singh, B.N (eds.), Association Euratom - Risø National Laboratory annual progress report 2006. Risø-R-1603(EN) (2007) 73 p. www.risoe.dk/rispubl/reports/ris-r-1603.pdf

Conference papers published in proceedings

Leipold, F., Inactivation of micro organisms by means of low temperature atmospheric pressure plasmas. In: Proceedings (CD-ROM). 28. International conference on phenomena in ionized gases (ICPIG XXVIII), Praqgue (CZ), 15-20 Jul 2007. Schmidt, J.; Simek, M.; Pekarek, S.; Prukner, V. (eds.), (Institute of Plasma Physics AS CR, Prague, 2007) p. 1404-1406

Michelsen, P.K.; Bindslev, H.; Korsholm, S.B.; Larsen, A.W.; Meo, F.; Michelsen, S.; Nielsen, A.H.; Nimb, S.; Tsakadze, E., Fast ion collective Thomson scattering diagnostic for ITER. In: Proceedings. 14. Joint workshop on electron cyclotron emission and electron cyclotron resonance heating (EC-14), Santorini Island (GR), 9-12 May 2006. Lazaros, A. (ed.), (Heliotopos Conferences Ltd., Athens, 2006) p. 227-231

Milovanov, A.V.; Rypdal, K.; Juul Rasmussen, J., Fractional relaxation equation from ac universality in disordered solids. In: Collective phenomena in macroscopic systems. Proceedings. Workshop, Villa Olmo, Como (IT), 4-6 Dec 2006. Bertin, G.; Pozzoli, R.; Romé, M.; Sreenivasan, K.R. (eds.), (World Scientific, 2007) p. 270-273

Nielsen, S.K.; Bindslev, H.; Hoekzema, J.A.; Korsholm, S.B.; Leipold, F.; Meo, F.; Michelsen, P.K.; Oosterbeek, H.; Westerhof, E.; Woskov, P., Recent fast ion measurements by collective Thomson scattering (CTS) at the TEXTOR tokamak. In: Proceedings. 13. International symposium on laser-aided plasma diagnostics, Takayama (JP), 18-21 Sep 2007. Kawahatqa, K. (ed.), (National Institute for Fusion Science, Toki, 2007) (NIFS-PROC-68) p. 9-14

Oosterbeek, J.W.; Bongers, W.A.; Classen, I.G.J.; Danilov, I.; Hoekzema, J.A.; Heidinger, R.; Graswinckel, M.F.; Korsholm, S.B.; Krämer-Flecken, A.; Kruijt, O.G.; Scholten, J.; Tito, C.; Tsakadze, E.; Vaessen, B.C.E.; Westerhof, E., Design of a dedicated ECE diagnostic for feedback control of instabilities by ECRH. In: Proceedings. 14. Joint workshop on electron cyclotron emission and electron cyclotron resonance heating (EC-14), Santorini Island (GR), 9-12 May 2006. Lazaros, A. (ed.), (Heliotopos Conferences Ltd., Athens, 2006) p. 232-237

Unpublished conference papers

Andrew, Y.; Hawkes, N.C.; Sartori, R.; Parail, V.; Biewer, T.M.; Crombe, K.; Giroud, C.; Korotkov, A.; Luna, E. de la; Naulin, V.; Saibene, G.; Vries, P. de, The influence of toroidal field ripple on H-mode transitions on JET. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

Carraro, L.; Puiatti, M.E.; Valisa, M.; Angioni, C.; Buratti, P.; Buttery, R.; Coffey, I.; Eester, D. van; Giroud, C.; Taroni, L.L.; Lawson, K.; Lerche, E.; Mantica, P.; Mattioli, M.; Naulin, V., Impurity profile control in JET plasmas with radio-frequency power injection. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

del-Castillo-Negrete, D.; Mantica, P.; Naulin, V.; Juul Rasmussen, J., Non-locality and perturbative transport. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

del-Castillo-Negrete, D.; Mantica, P.; Naulin, V.; Juul Rasmussen, J., Application of fractional diffusion to model perturbative transport experiments in JET. 49. Annual meeting of the Division of Plasms Physics, American Physical Society, Orlando, FL (US), 12-16 Nov 2007. Unpublished.

Eriksson, L.-G.; Bindslev, H.; Ericsson, G.; Esposito, B.; Goloborodko, V.; Gorini, G.; Hellsten, T.; Hjalmarsson, A.; Hynönen, V.; Johnson, T.; Kiptily, V.G.; Korsholm, S.B.; Kurki-Suonio, T.; Marocco, D.; Ognissanto, F.; Pedersen, J.R.; Salewski, M.; Schoepf, K.; Tardocchi, M.; Yavorskij, V.; Ingesson, L.C.; Bertalot, L., The effect of RF- and NBI-driven fast ions in ITER on various diagnostics. 13. Meeting of the ITPA topical group on diagnostics, Chengdu (CN), 29 Oct - 2 Nov 2007. Unpublished.

Garcia, O.; Horacek, J.; Larsen, J.; Madsen, J.; Naulin, V.; Nielsen, A.H.; Pitts, R.; Juul Rasmussen, J., Convective transport by filamentary structures in scrape-off layer plasmas. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

Giroud, C.; Coffey, I.H.; McDonald, D.C.; Angioni, C.; Biewer, T.; Bonheure, G.; Challis, C.D.; Guirlet, R.; Hobirk, J.; Mantica, P.; Meigs, A.; Naulin, V.; O'Mullane, M.G.; Puiatti, M.E.; Valisa, M.; Whiteford, A.D.; Zastrow, K.-D., Study of Z-dependence of impurity transport at JET. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

Giroud, C.; Naulin, V., Open issues in impurity transport. 5. EFDA JET taskforce T general workshop, Abingdon (GB), 22-26 Jan 2007. Unpublished.

Grulke, O.; Windisch, T.; Naulin, V.; Klinger, T., Propagation turbulenter Strukturen in Driftwellenturbulenz. In: Kurzfassungen der Vorträge. 71. Jahrestagung der Deutschen Physikalischen Gesellschaft, Düsseldorf (DE), 19-23 Mar 2007. (Deutsche Physikalische Gesellschaft, Berlin, 2007) (Verhandlungen der Deutschen Physikalischen Gesellschaft, Reihe VI, Band 42, No. 3) P7.30

Horacek, J.; Garcia, O.E.; Pitts, R.A.; Nielsen, A.H., Temporal correlations in TCV SOL plasma fluctuations. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

Juul Rasmussen, J., Complexity research in OPL, Risø. Complexity-NET workshop, Copenhagen (DK), 18 Apr 2007. Unpublished.

Juul Rasmussen, J.; Naulin, V.; Mantica, P., Fast pulse propagation / turbulence spreading. 5. EFDA JET taskforce T general workshop, Abingdon (GB), 22-26 Jan 2007. Unpublished.

Juul Rasmussen, J.; Naulin, V.; Nielsen, A.H.; Kuznetsov, E.A., Sharp vorticity gradients in two-dimensional hydrodynamic turbulence and the energy spectrum. Workshop on two-dimensional turbulence, Leiden (NL), 19-23 Mar 2007. Unpublished.

Juul Rasmussen, J.; Garcia, O.E.; Naulin, V.; Nielsen, A.H., Signatures of SOC in turbulent transport in the edge region of magnetically confined plasmas?. Workshop on complexity in plasma and geospace systems, Geilo (NO), 4-9 Mar 2007. Unpublished.

Juul Rasmussen, J.; Naulin, V.; Mantica, P., Turbulence spreading and nonlocal transport in magnetized plasmas. Summer college on plasma physics, Trieste (IT), 30 Jul - 24 Aug 2007. Unpublished.

Juul Rasmussen, J.; Milovanov, A.V.; Rypdal, K., Dielectric relaxation and ac universality in materials with disordered structure. Symposium on new trends in nonlinear physics, Trieste (IT), 19 Aug 2007. Unpublished.

Juul Rasmussen, J.; Garcia, O.E.; Madsen, J.; Naulin, V.; Nielsen, A.H., Turbulence and anomalous transport in the edge region of a magnetically confined plasma. International conference on new energy resources (ICNES 2007), Tbilisi (GE), 22-25 Oct 2007. Unpublished.

Juul Rasmussen, J.; Garcia, O.E.; Naulin, V.; Nielsen, A.H., Particle dispersion and mixing by turbulence in magnetized plasmas. International working session on statistical physics for anomalous transport in plasmas, Craiova (RO), 7-12 Oct 2007. Unpublished.

Korsholm, S.B., Danish industry and ITER. ITER Industrial Liaison Officers (ILO) meeting, Saariselkä (FI), 7-9 Feb 2007. Unpublished.

Korsholm, S.B.; Bindslev, H.; Furtula, V.; Leipold, F.; Meo, F.; Michelsen, P.K.; Michelsen, S.; Nielsen, S.K.; Rønby, J.; Salewski, M.; Tsakadze, E.L., Fast ion collective Thomson scattering diagnostic for ITER - progress of design. International conference on burning plasma diagnostics, Varenna (IT), 24-28 Sep 2007. Unpublished. Abstract available

Korsholm, S.B.; Meo, F.; Bindslev, H.; Leipold, F.; Leuterer, F.; Manini, A.; Michelsen, P.K.; Nielsen, S.K.; Salewski, M.; Stober, J.; Tsakadze, E.L.; Wagner, D.; Woskov, P., Preliminary results from the Collective Thomson Scattering (CTS) diagnostic on ASDEX upgrade. 13. Meeting of the ITPA topical group on diagnostics, Chengdu (CN), 29 Oct - 2 Nov 2007. Unpublished. Presentation available

Korsholm, S.B.; Bindslev, H.; Leipold, F.; Meo, F.; Michelsen, P.K.; Michelsen, S.; Nielsen, A.H.; Tsakadze, E.L.; Woskov, P., Fast ion Collective Thomson Scattering diagnostic for ITER. 12. Meeting of the ITPA topical group on diagnostics, Princeton (US), 26-30 Mar 2007. Unpublished. Presentation available

Kuznetsov, E.A.; Juul Rasmussen, J.; Naulin, V.; Nielsen, A.H., Vorticity gradients in two-dimensional turbulence and the spectrum. Workshop on solitons, collapses and turbulence, Chernogolovka (RU), 15-17 May 2007. Unpublished.

Leipold, F.; Bindslev, H.; Korsholm, S.B.; Meo, F.; Michelsen, P.K.; Michelsen, S.; Nielsen, A.H.; Salewski, M., Fast ion CTS diagnostic for ITER - state of design. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

Madsen, J.; Staerk, J.; Garcia, O.E.; Naulin, V.; Nielsen, A.H.; Juul Rasmussen, J.; Kendl, A., Finite ion temperature effects on blob dynamics in magnetized plasma. Danish Physical Society annual meeting 2007, Nyborg (DK), 18-20 Jun 2007. Unpublished. Abstract available

Madsen, J.; Stærk, J.; Garcia, O.E.; Naulin, V.; Nielsen, A.H.; Juul Rasmussen, J., 2D gyrofluid simulations of edge/SOL dynamics. 12. European fusion theory conference, Madrid (ES), 24-27 Sep 2007. Unpublished.

Manz, P.; Naulin, V.; Ramisch, M.; Scott, B.; Stroth, U., Experimentelle Untersuchung der nichtlinearen Energietransfers in zweidimensionaler Plasmaturbulenz. In: Kurzfassungen der Vorträge. 71. Jahrestagung der Deutschen Physikalischen Gesellschaft, Düsseldorf (DE), 19-23 Mar 2007. (Deutsche Physikalische Gesellschaft, Berlin, 2007) (Verhandlungen der Deutschen Physikalischen Gesellschaft, Reihe VI, Band 42, No. 3) P3.3

Manz, P.; Naulin, V.; Ramisch, M.; Scott, B.D.; Stroth, U., Experimental estimation of nonlinear energy transfer in two-dimensional plasma turbulence. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

Meo, F.; Bindslev, H.; Korsholm, S.B.; Leuterer, F.; Michelsen, P.K.; Michelsen, S.; Nielsen, S.K.; Pedersen, J.R.; Stober, J.; Woskov, P., Commissioning a microwave based Collective Thomson Scattering (CTS) diagnostic on ASDEX-upgrade. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

Michelsen, P.K., Fusionsenergi: Next step ITER. Arrangement i Ingeniørforeningens E-gruppe, København (DK), 8 Nov 2007. Unpublished.

Naulin, V., Turbulence and transport. Seminar at Warwick University, Warwick (GB), 27 Jul 2006. Unpublished.

Naulin, V., Current issues in edge plasmas and plasma wall interactions, transient and 3D effects. EFPW 14, Greoux-les-Bains (FR), 4-6 Dec 2006. Unpublished.

Naulin, V., The Joint European Torus experiment in 2008. Danish Physical Society annual meeting 2007, Nyborg (DK), 18-20 Jun 2007. Unpublished. Abstract available

Naulin, V., On turbulence spreading and the role of stable modes for transport in plasmas. Workshop on complexity in plasma and geospace systems, Geilo (NO), 5-9 Mar 2007. Unpublished.

Naulin, V., Issues in edge transport. Meeting at Culham, Culham (GB), 26 Feb 2007. Unpublished.

Naulin, V., Issues in edge transport. Meeting at EPFL, Lausanne (CH), 22 May 2007. Unpublished.

Naulin, V.; Diamond, P.H.; Gürcan, Ö.D.; Juul Rasmussen, J., Parallel momentum in a 3D cylindrical plasma simulation. 12. European fusion theory conference, Madrid (ES), 24-27 Sep 2007. Unpublished.

Naulin, V.; Fundamenski, W.; Garcia, O.E.; Nielsen, A.H.; Juul Rasmussen, J.; Goncalves, B.; Hidalgo, C., Momentum transport in the edge and into the SOL. 12. US-EU Transport Taskforce workshop, San Diego (US), 17-20 Apr 2007. Unpublished.

Naulin, V.; Juul Rasmussen, J.; Nielsen, A.H., On turbulence spreading and the role of stable modes for transport in plasmas. Complexity meeting, Geilo (NO), 5 Mar 2007. Unpublished.

Naulin, V.; Juul Rasmussen, J.; Garcia, O.E.; Nielsen, A.H.; Priego, M.; Basu, R., Clustering of inertial particles in 2D plasma turbulence. Workshop at Lorentz Center: Two-dimensional turbulence, Leiden (NL), 19-23 Mar 2007. Unpublished.

Naulin, V.; Parail, V., Edge transport issues. 5. EFDA JET taskforce T general workshop, Abingdon (GB), 22-26 Jan 2007. Unpublished.

Naulin, V.; Tala, T.; Mantica, P., TF T forward programme. 5. EFDA JET taskforce T general workshop, Abingdon (GB), 22-26 Jan 2007. Unpublished.

Naulin, V.; Tala, T.; Mantica, P.; Valisa, M.; Giroud, C.; Puiatti, M.E.; O'Mullane, M., 2007 impurity experiments. 5. EFDA JET taskforce T general workshop, Abingdon (GB), 22-26 Jan 2007. Unpublished.

Nielsen, A.H.; Naulin, V.; Juul Rasmussen, J.; Clercx, H.; Coutsias, E.A., Two-dimensional turbulence in bounded domains with no-slip walls. Workshop on complexity in plasma and geospace systems, Geilo (NO), 4-9 Mar 2007. Unpublished.

Nielsen, S.K.; Bindslev, H.; Hoekzema, J.A.; Korsholm, S.B.; Leipold, F.; Meo, F.; Michelsen, P.K.; Michelsen, S.; Oosterbeek, H.; Tsakadze, E.L.; Westerhof, E.; Woskov, P., Fast ions in fusion plasmas measured by CTS. Danish Physical Society annual meeting 2007, Nyborg (DK), 18-20 Jun 2007. Unpublished. Abstract available

Nielsen, S.K.; Bindslev, H.; Hoekzema, J.A.; Korsholm, S.B.; Leipold, F.; Meo, F.; Michelsen, P.K.; Michelsen, S.; Oosterbeek, H.; Tsakadze, E.L.; Westerhof, E.; Woskov, P., Neutral beam start-up dynamics on TEXTOR measured by collective Thomson scattering (CTS). 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

Nielsen, S.K.; Bindslev, H.; Hoekzema, J.A.; Korsholm, S.B.; Leipold, F.; Meo, F.; Michelsen, P.K.; Michelsen, S.; Oosterbeek, H.; Rønby, J.; Tsakadze, E.L.; Westerhof, E.; Woskov, P., Fast ion behaviour in TEXTOR measured by collective Thomson scattering (CTS). International conference on burning plasma diagnostics, Varenna (IT), 24-28 Sep 2007. Unpublished. Abstract available

Pitts, R.A.; Bencze, A.; Garcia, O.E.; Berta, M.; Veres, G., On the statistics of ELM filaments measures by fast low field side wall Langmuir probes on TCV. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

Salewski, M.; Bindslev, H.; Furtula, V.; Korsholm, S.B.; Leipold, F.; Meo, F.; Michelsen, P.K., Research issues regarding the collective Thomson scattering diagnostic for ITER. Danish Physical Society annual meeting 2007, Nyborg (DK), 18-20 Jun 2007. Unpublished. Abstract available

Salewski, M.; Bindslev, H.; Korsholm, S.B.; Leipold, F.; Meo, F.; Michelsen, P.K.; Nielsen, S.K.; Woskov, P.; Oosterbeek, J.W.; Westerhof, E.; Leuterer, F.; Stober, P.; Wagner, D., Fast ion collective Thomson scattering (CTS) diagnostic results at TEXTOR, ASDEX upgrade, and status of the CTS design at ITER. 49. Annual meeting of the Division of Plasma Physics, American Physical Society, Orlando, FL (US), 12-16 Nov 2007. Unpublished.

Salewski, M.; Furtula, V.; Holm, J.H.; Jessen, M.; Korsholm, S.B.; Leipold, F.; Madsen, J.; Meo, F.; Michelsen, P.K.; Naulin, V.; Nielsen, A.H.; Nielsen, S.K.; Nimb, S.; Rasmussen, J.J.; Bindslev, H., Fusion - a future energy option. Internal DTU conference on future energy research at the Technical University of Denmark, Risø (DK), 9 Oct 2007. Unpublished.

Schrittwieser, R.; Konzett, S.; Mehlmann, F.; Balan, P.; Ionita, C.; Kendl, A.; Naulin, V.; Juul Rasmussen, J.; Nielsen, A.H.; Garcia, O.E.; Müller, H.W.; Herrmann, A.; Rohde, V.; Maraschek, M., Experimental and numerical characterisation of fluctuations in the SOL of ASDEX upgrade during L-mode and ELMy H-mode. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

Tala, T.; Andrew, Y.; Giroud, C.; Crombe, K.; Vries, P.C. de; Garbet, X.; Nordman, H.; Rantamäki, K.; Thyagaraja, A.; Weiland, J.; Baranov, Y.; Budny, R.; Challis, C.; Corrigan, G.; Eriksson, A.; Eriksson, L.-G.; Ferreira, J.; Hawkes, N.; Hellsten, T.; Hua, M.-D.; Henkins, I.; Kirneva, N.; Mantica, P.; Naulin, V.; Nave, F.; Larail, V.; Peeters, A.; Pinches, S.; Scott, B.; Strand, P.; Tardini, G.; Zastrow, K.-D., Toroidal and poloidal momentum transport studies in Tokamaks. 34. European Physical Society conference on plasma physics and controlled fusion, Warsaw (PL), 2-6 Jul 2007. Unpublished. Abstract available

Woskov, P.P.; Korsholm, S.B.; Bindslev, H.; Egedal, J.; Leipold, F.; Meo, F.; Michelsen, P.K.; Michelsen, S.; Nielsen, S.K.; Westerhof, E.; Oosterbeek, J.W.; Hoekzema, J.; Leuterer, F.; Wagner, D., Collective Thomson Scattering diagnostics of confined fast ions. 12. Meeting of the ITPA topical group on diagnostics, Princeton (US), 26-30 Mar 2007. Unpublished. Presentation available

3 Fusion Technology

3.1 Summary of work performed during 2007

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Because of the delay in irradiations at Mol of the specimens belonging to different Tasks, namely TW4-TVM-COFAT 2, TW4-TVM-CUSSPIT and TW5-TTMS-007, it was foreseen already in September 2006 that for the completion of certain segments of these tasks some work will have to be carried out during the year 2007. The Euratom/Risø Steering Committee was informed about the situation in a note written on September 4, 2006. The update of the situation was reported during the 36th Steering Committee Meeting at Risø on 24 April 2007.

The irradiated specimens belonging to the above mentioned tasks were received at Risø in January 2007. The necessary post-irradiation mechanical tests were performed immediately after and the results of these tests were reported in sections 3.2.1, 3.2.2 and 3.3.2 of the Annual Progress Report 2006 (Risø-R-1603 (EN), see Ref. 9). In order to determine the microstructural evolution during the in-reactor creep-fatigue deformation of CuCrZr alloy (COFAT 2) and the in-reactor tensile deformation of pure iron and Fe-Cr alloy (TTMS-007), a number of in-reactor deformed specimens were investigated using transmission electron microscopy. For comparison, the corresponding specimens deformed outside of reactor were investigated in the post-irradiation deformed and unirradiated and deformed conditions. In addition, the reference microstructure of specimens in the as-irradiated and the unirradiated conditions was also investigated. The results are described in detail in Risø Reports Risø-R-1629 (EN) and Risø-R-1616 (EN), respectively (see Refs. 14 and 11).

The microstructure of the post-irradiation tensile tested specimens belonging to Task TW4-TVM-CUSSPIT was investigated using transmission electron microscopy. For comparison, the microstructure of the specimens in the unirradiated and as-irradiated and undeformed conditions was also investigated. The results are described in VTT Research Report No. VTT-R-03023-08 (2008), in preparation.

Deformation experiments on “in-reactor Tensile Testing of Copper and CuCrZr Alloy” (Task TW5-TVM-SITU2) are in progress at present and are expected to be completed on April 17, 2008.

3.2 Publications and conference proceedings

Heinisch, H.L.; Trinkaus, H.; Singh, B.N., Kinetic Monte Carlo studies of the reaction kinetics of crystal defects that diffuse one-dimensionally with occasional transverse migration. J. Nucl. Mater. (2007) v. 367 (no.Pt. A) p. 332-337

Tähtinen, S.; Moilanen, P.; Singh, B.N., Effect of displacement dose and irradiation temperature on tensile and fracture toughness properties of titanium alloys. J. Nucl. Mater. (2007) v. 367 (no.Pt. A) p. 627-632

Edwards, D.J.; Singh, B.N.; Tähtinen, S., Effect of heat treatments on precipitate microstructure and mechanical properties of a CuCrZr alloy. J. Nucl. Mater. (2007) v. 367 (no.Pt. B) p. 904-909

Wu, X.L.; Pan, X.; Singh, B.N.; Li, M.M.; Stubbins, J.F., Hold-time effects on the fatigue life of CuCrZr alloys for fusion applications. J. Nucl. Mater. (2007) v. 367 (no.Pt. B) p. 984-989

Victoria, M.; Dudarev, S.; Boutard, J.L.; Diegele, E.; Lässer, R.; Almazouzi, A.; Caturla, M.J.; Fu, C.C.; Källne, J.; Malerba, L.; Nordlund, K.; Perlado, M.; Rieth, M.; Samaras, M.; Schaeublin, R.; Singh, B.N.; Willaime, F., Modelling irradiation effects in fusion materials. Fusion Eng. Des. (2007) v. 82 p. 2413-2421

Edwards, D.J.; Singh, B.N.; Tähtinen, S., Effect of heat treatments on precipitate microstructure and mechanical properties of a CuCrZr alloy. In: Fusion materials. Semiannual progress report for the period ending December 31, 2005. DOE/ER-0313/39 (2006) p. 85-90

Heinisch, H.L.; Trinkaus, H.; Singh, B.N., Kinetic Monte Carlo studies of the reaction kinetics of crystal defects that diffuse one-dimensionally with occasional transverse migration. In: Fusion materials. Semiannual progress report for the period ending December 31, 2005. DOE/ER-0313/39 (2006) p. 147-150

Singh, B.N.; Tähtinen, S.; Moilanen, P.; Jacquet, P.; Dekeyser, J.; Edwards, D.J.; Li, M.; Stubbins, J.F., Final report on in-reactor creep-fatigue deformation behaviour of a CuCrZr alloy: COFAT 1. Risø-R-1571(EN) (2007) 45 p.

Michelsen, P.K.; Singh, B.N (eds.), Association Euratom - Risø National Laboratory annual progress report 2006. Risø-R-1603(EN) (2007) 73 p.

Trinkaus, H.; Singh, B.N., Mechanisms operating during plastic deformation of metals under concurrent productions of cascades and dislocations. Pisø-R-1610(EN), (2008), in preparation.

Singh, B.N.; Huang, X.; Tähtinen, S.; Moilanen, P.; Jacquet, P.; Dekeyser, J., Final report on in-reactor uniaxial tensile deformation of pure iron and Fe-Cr alloy. Risø-R-1616(EN) (2007) 51 p.

Eldrup, M.; Singh,B.N.; Golubov, S.I., Final report on investigations of the influence helium concentration and implantation rate on cavity nucleation and growth during neutron irradiation of Fe and EURO-FER-97. Risø-R-1619 (EN), (2008), in preparation.

Moilanen, P.; Saarela, S.; Tähtinen, S.; Singh, B.N.; Jacquet, P.; Dekeyser, J., In-reactor creep-fatigue tests in BR-2 Test Reactor-Design, construction and calibration of loading devices. VTT Research Report No. VTT-R-06943-07, August (2007), 32 p.

Singh,B.N.; Johansen, B.S.; Tähtinen, S.; Moilanen, P.; Saarela, S.; Jaquet, P.; Dekeyser, J.; Stubbins, J.F., Final report on in-reactor creep-fatigue deformation behaviour of a CuCrZr alloy: COFAT2. Risø-R-1629 (EN), January (2008), 41 p.

Tähtinen, S.; Moilanen, P.; Saarela, S.; Jacquet, P.; Singh, B.N., In reactor tensile tests of Fe and FeCr alloys in BR-2 test reactor. VTT Research Report No. VTT-R-06331-07, January (2008), 12 p.

Eldrup, M., He-implanted metals: Defect characterization by positron annihilation spectroscopy. Polish seminar on positron annihilation (PSPA 2007), Ladek Zdroj (PL), 3-7 Sep 2007. Unpublished.

Tähtinen, S.; Singh, B.N., Testing of irradiated CuCrZr/ss joints produced under different blanket manufacturing conditions. VTT Research Report No. VTT-R-03023-08, (2008), in preparation.

Singh, B.N., Updates of results of experimental programme on in-reactor deformation of fcc and bcc metals and alloys. International Workshop on Fundamental Aspects of Radiation Damage, 13-15 September 2007, Oak Ridge National Laboratory, Oak Ridge, Tenn. USA. Unpublished.

Singh,B.N.; Huang,X.; Tähtinen, S.; Moilanen, P.; Jacquet, P.; Dekeyser, J., In reactor deformation behaviour during uniaxial tensile tests of pure iron and Fe-Cr alloy. 13. International conference on fusion reactor materials, Nice (FR), 10-14 Dec 2007. Unpublished.

Tähtinen, S.; Moilanen, P.; Singh, B.N.; Jacquet, P.; Dekeyser, J.; Li, M.; Stubbins, J.F.; Edwards, D.J., In-reactor creep-fatigue deformation behaviour of CuCrZr alloy. 13. International conference on fusion reactor materials, Nice (FR), 10-14 Dec 2007. Unpublished.

4 System analysis

4.1 EFDA-TIMES

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Since end of 2004 the EFDA and the Associations are developing a multi-region global long-term energy modelling framework called EFDA-TIMES. The initial version has shown several needs for revisions, updates and improvements, which are ongoing also within several other programmes, in particular IEA-ETSAP and EU Research Programmes.

After a successful Expression of Interest for the call in August 2006 (TW6-TRE-ETM-UPS, etc.), Risø has been participating in the further development of the EFDA-TIMES model under the SERF Programme during 2007. A Kick-off meeting was held in Garching in February 2007 together with an EFDA-TIMES Steering Group meeting (Risø Member P. E. Grohnheit).

The EFDA-TIMES model is a global model divided into 15 regions with the time horizon year 2100. This structure is similar to other global models in TIMES, developed for the IEA and USDOE. The work on the EFDA model was divided into subtasks representing the sectors: Upstream, Electricity, Industry, Residential, and Transport. Fusion technology is modelled in the Electricity sector in competition with renewables and electricity generating technologies based on fuels.

The contribution by Risø DTU is focusing on the upstream sector (fossil resources, refineries, renewable potentials, etc.), emphasising technology vintages, which was not considered for the upstream sector in the previous model. Risø was responsible for renewable technologies, in practice biomass technologies.

Technology progress is modelled usually by assuming higher efficiencies and lower investment and operating costs for identified existing and new technologies, which will become available in the future. The numerical values of these assumptions are based on the results of numerous studies of innovation and technology progress. This method is well-established for electricity generating technologies, which will compete directly with fusion in the future. In contrast, only few biomass technologies are sufficiently identified with well-established parameters for technology progress, e.g. incineration of urban waste, bioethanol from sugar cane, biodiesel from oil crops, or gasification from various types of waste.

In the update of the EFDA model the following simplified categories were used for forecasts of biomass energy:

- Energy crop
- Agriculture residues
- Wood fuels (including traditional wood energy, as well as wastes from wood processing industries)
- Other (municipal wastes, other industrial wastes, gas from landfill)

Technologies for conversion of these resources into electricity, heat and transport fuels are treated as sets of generic technologies with a large potential for technology progress, which will be due to the combined impact of biotechnology, logistics and regulation. Only few parameters will be needed, but their numerical values are important.

A new release of the EFDA-TIMES model is expected in spring of 2008. Further development of the model will be considered under the new work programme.

An abstract “Global transportation scenarios in the multi regional EFDA-TIMES energy model” was submitted to the IEW/ETSAP workshop hosted by the IEA in Paris, 30 June to 2 July 2008.

5 ITER and Danish industry activities

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Following the ITER site decision on June 28th 2005, Risø DTU was the main driver in the launch of activities to inspire Danish companies and make them aware of the possibilities of being a supplier to the construction of ITER as described in some detail in [1]. This effort originally initiated in 2005 was further developed in 2006 and continued in 2007.

In short overview the primary entry gate to the initiative for Danish companies is a website http://iter.risoe.dk. The website contains information on the coming tasks at ITER, background information, news and announcements of workshops etc., links to relevant international websites, description of experiences of other Danish companies, and an online database, where approximately 20 companies present their fusion relevant competences and their interests in ITER tasks. The database includes a number of significant players among Danish industries. Recently, the webpage has also – as originally intended – been used to advertise tender actions from ITER and F4E.

In parallel to the website, a mailing list of more than 50 company contact persons is maintained. This is an important way of distributing news and advertising tender actions.

A group of companies and research institutes has formed an informal, non-exclusive network (further described in [1]): the Danish ITER Industrial Network. In 2007 two meetings have been held and new members have been included in the group, which is managed by Risø DTU.

In December 2007 Risø DTU and representatives for three Danish companies participated in the first ITER Business Forum (IBF07) in Nice.

The earmarked resources for the initiative in 2007 as well as in the future have been and currently are insufficient for the desired volume of the activities at Risø DTU. Furthermore, companies and other research institutes have a wish for support of the extensive preparations for ITER tasks. Therefore, in 2007 a significant effort has been put into a search for appropriate funds. In collaboration with FORCE Technology and Teknologisk Institut a so-called *innovationskonsortium* was sought to be established. A number of companies were interested, but in the final stages prior to the funding application, sufficient support from companies failed. This was mainly due to the current over-heated situation in Danish production and engineering companies. In 2008 an attempt to apply for alternative funds to support the preparations of the network is planned in collaboration with FORCE Technology and Teknologisk Institut. In addition to the described effort meetings have been held with regional and ministry officials with the purpose of discussing collaboration on and support for the general activities on awareness of the possibilities for contracts for ITER. The ideas of Risø DTU have been well received and currently discussions on how to implement the collaboration are ongoing.

Alongside the national activities, Risø DTU has actively participated in the creation of the EU ITER Industrial Liaison Officers (ILO) network. The EU ILO network was launched in February 2007 in Finland, and meetings have been held in Culham in June and in Nice in December in relation to the IBF07. The Danish representative in the network is Søren B Korsholm, ILO of Association Euratom – Risø DTU. The network now comprises 15 ILO’s and is currently approaching F4E in order to have a formal relation to F4E as information multipliers (and more). Additionally, the network has worked towards paving the ground for international company matchmaking.

1. Association Euratom - Risø National Laboratory, Technical University of Denmark, Annual Progress Report 2006.

6 Danish Fusion and Plasma Road Show

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As part of the ongoing public information activities, the Danish Fusion and Plasma Road Show have been created by members of Association Euratom-Risø National Laboratory, Technical University of Denmark, DTU. The show was initiated in 2007 having the Dutch Fusion Road Show from FOM-Institute for Plasma Physics Rijnhuizen as inspiration. The show is funded for three years (2007-09) by the Danish Research Council for Nature and the Universe under the Ministry for Science, Technology and Innovation – by a total of approx. 40000 Euro.

The target audience of the Fusion and Plasma Road Show is primarily high school students, but has also been shown for a broader audience in public places e.g. libraries. The show is participating in the Danish National Science Festival and in the National Day of Science.

The objective of the show is to inform students and the general public about present fusion energy and plasma research and in that way give them an insight and hopefully an interest in science and its uses. In particular we hope that the students get inspired by the physics and see that fusion energy research is an exciting field with many possibilities. Another important objective is to inform about the use of fusion as a source of energy, and in that way clarify the benefits and challenges of fusion power.

The show is a combination of a regular slide based presentation and a number of small experiments that demonstrate or is related to a topic described in the presentation. The experiments are intended to surprise and excite people and also work as intermezzos in the talk. This is intended to help keep people focused on the topics. In the presentation a great effort is put in simplifying the advanced topics, and it is intended to bring the involved phenomena close to people's experiences from every day life. This is done e.g. by converting enormous numbers in strange units into meaningful sizes, and also by asking questions or giving small exercises to the audience. The show has its own website: http://roadshow.risoe.dk, where descriptions of the experiments can be found.

In the course of the road show the following experiments are conducted

- Plasma in a microwave oven: Example of a RF generated plasma
- A ball on a rotating disc/turntable: Ball will move like a charged particle in EM-field
- Smoke rings: Example of the torus shape
- Electromagnet and compasses: Example of electricity generating a magnetic field
- Eddy currents in a copper plate with a strong magnet: Example of the connection between temperature and conductivity
- Superconductor – and example of the superconductor Plasma ball lamps

Additional experiments are being developed. Figure 34 holds two photos of some of the road show experiments.

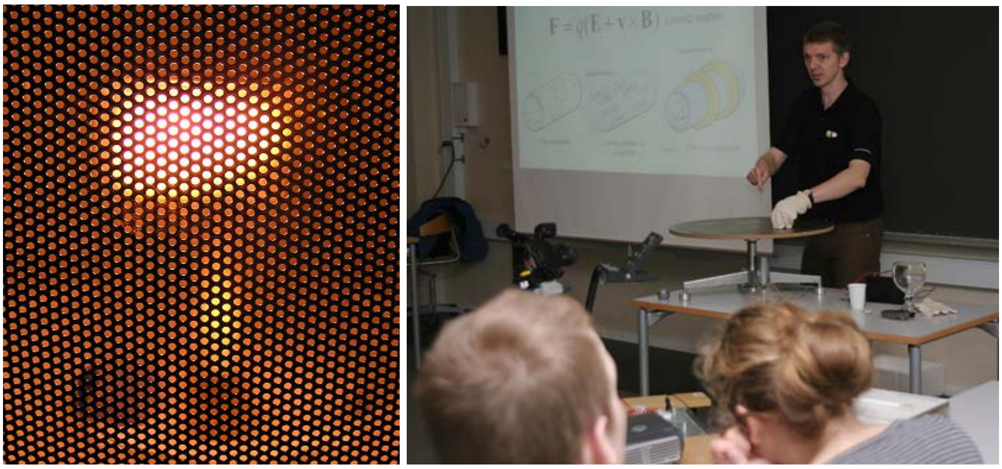

Figure 34. A plasma ball generated in a microwave oven (left) is one of the popular experiments of the road show. To the right a pictures from a performance of the road show for a class of high school students.

Risø’s research is aimed at solving concrete problems in the society.

Research targets are set through continuous dialogue with business, the political system and researchers.

The effects of our research are sustainable energy supply and new technology for the health sector.