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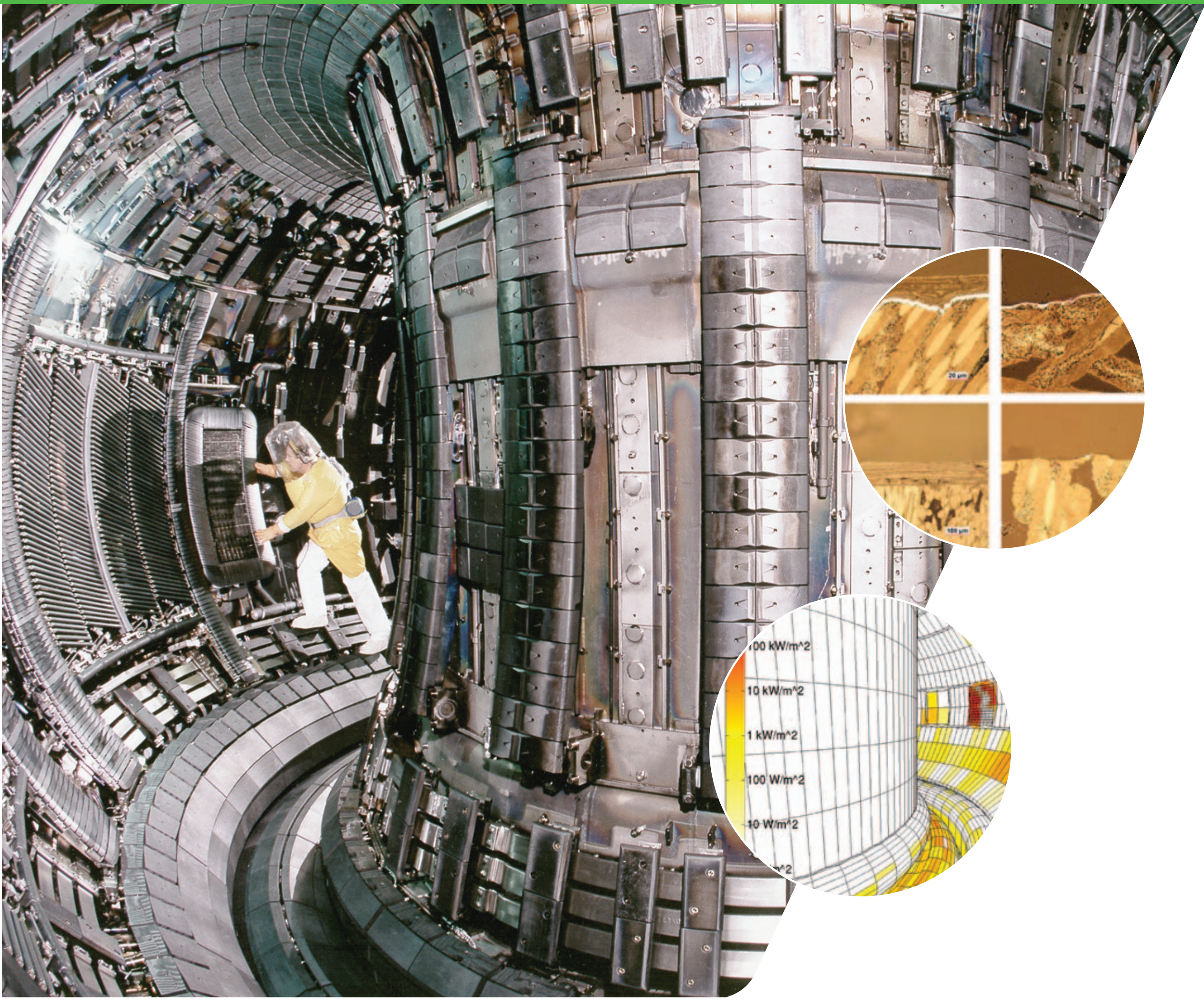

Fusion Yearbook

2008 Annual Report of Association Euratom-Tekes

VTT PUBLICATION 709

FUSION YEARBOOK

2008 Annual Report
Association Euratom–Tekes

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FOREWORD

European Fusion Programme is in a transition phase to enter new era which will be dominated by the ITER construction. Euratom is the leading ITER Party and ITER is the first priority in Europe. Procurements, design and R&D for ITER construction require financial and human resources more than was anticipated and this has an impact to the European fusion community. Human resources are in the Associations and the work must be directed to support ITER and the “Fusion for Energy”. F4E estimated that a huge amount of R&D is needed during the next ten years. This is a real challenge but also opportunity for the European fusion community.

The emphasis of the Association Euratom-Tekes has been on the new EFDA JET and EFDA work programmes and completing the remaining EFDA Technology Tasks and Contracts. Well over half of the Finnish fusion activities are technology R&D and we have suffered with fading EFDA Technology Programme as at the same time the pace of launching new F4E Grants has been slow. Fortunately, the F4E Grant for the ITER Divertor Test Platform (DTP2) was signed and the cassette multifunctional mover (CMM) was finally delivered in October 2008 and testing work is now well under way. In other vessel/in-vessel activities related to joining methods, characterisation of materials and joints, fabrication of in-vessel metal-/multi-metal components and vacuum vessel the F4E Grants would be most welcome in order to maintain the expertise and human resources in these areas.

Plasma physics and plasma-wall studies have been carried out in the EFDA JET Work programme and in the EFDA Task Forces “Plasma Wall Interactions” and “Integrated Tokamak Modelling”. The collaboration with the AUG Team IPP Garching has been very productive, too. Scientific work at JET and AUG covers experiments and modelling, plasma-wall studies and post-mortem surface studies of first wall and divertor tiles. Theoretical and numerical work deals with gyrokinetic turbulence simulations, predictive modelling of JET plasmas, fast particle studies, simulations of edge plasmas, molecular dynamic simulations and related code development. The main topics in materials research are mechanical testing of reactor materials under neutron irradiation and simulations of radiation damage effects in FeCr. Diagnostics work includes detector development for neutral particle analyser, a micromechanical magnetometer, smart tile development for erosion studies and laser spectroscopy for tritium inventory studies.

Finally, I would like to thank the fusion teams of the Finnish and Estonian Research Unit and to the companies involved for their dedicated work in fusion physics and ITER technology and their valuable contributions to Euratom fusion effort.

Seppo Karttunen
Head of Research Unit
Association Euratom-Tekes

Annual Report 2008
Association Euratom-Tekes

1 SUMMARY

This Annual Report summarises the fusion research activities of the Finnish and Estonian Research Units of the Association Euratom-Tekes in 2008. The Estonian Research Unit was established by the Agreement between Tekes and the University of Tartu in 2007. The European Fusion Programme is in a transition phase. The emphasis in the new EFDA is in physics, emerging technology and exploiting JET. ITER related technology R&D is now under F4E – Fusion for Energy (Joint European Undertaking for ITER and the Development of Fusion Energy, Barcelona) which is the European Domestic Agency for ITER.

The activities of the Research Unit are divided in the fusion physics under the Contract of Association and new EFDA. A few EFDA Technology Tasks and Contracts were still running in 2008 and are now completed. New R&D Grant work on remote handling for ITER launched by the Joint Undertaking "Fusion for Energy" started in 2008.

The Physics Programme is carried out at VTT – Technical Research Centre of Finland, Helsinki University of Technology (TKK) and University of Helsinki (UH). The research areas of the Physics Programme are:

- Heat and particle transport, MHD physics and plasma edge phenomena
- Plasma-wall interactions and material transport in SOL region
- Code development and diagnostics.

Association Euratom-Tekes participated actively in the EFDA JET Workprogramme 2008 and exploitation of JET facilities in experimental campaigns C20–C25. Three persons were seconded to the UKAEA operating team, two physicists in codes & modelling and one engineer in remote handling. One person was a Task Force Leader in TF T (transport). One engineer from VTT was seconded to the ITER IO at Cadarache in 2008 (Assembly). Practically all physics activities of the Research Unit are carried out in co-operation with other Associations with the focus on EFDA JET work. In addition to EFDA JET activities, the Tekes Association participated in the 2008 experimental programme of ASDEX Upgrade (AUG).

Several staff mobility visits of total 530 days took place in 2008. The visits were hosted by the Associations IPP Garching (282 days, MA Art. 1.2.b collaboration), UKAEA Culham (43 days), FZK Karlsruhe (30 days), FOM Rijnhuizen (10 days), task force (PWI, ITM, E, H, FT) meetings (69 days), other EFDA & ITPA meetings (16 days), Goal Oriented Traning GOTiT (57 days) and contract follow-up visits to TTM Telstar (23 days). Tekes (University of Helsinki, VTT and TKK) hosted six staff mobility visits from IPP, SCK-CEN, CIEMAT, UKAEA and CEA.

The Technology work is carried out at VTT, Helsinki University of Technology (TKK), Tampere University of Technology (TUT) and Lappeenranta University of Technology (LUT) in close collaboration with Finnish industry. The companies with fusion related activities are: Fortum (Finnish EFET partner), Luvata Pori, Metso, Hollming Works, Diarc Technology, Creanex, Hytar, Adwatec. Industrial participation is co-ordinated by Finpro. The technology research and development is focused on the remote handling, vessel/in-vessel materials and components plus some activities in physics integration and JET Technology:

- Preparation of the Divertor Test Platform (DTP2) at VTT in Tampere for remote handling of divertor maintenance and development of water hydraulic tools and manipulators
- Development of advanced welding methods and IWR cutting/welding robot
- Plasma facing materials issues, erosion/re-deposition and material transport studies and developing coating techniques
- Multi-metal components and joining technology
- in-reactor mechanical testing and characterisation of materials under neutron irradiation
- Modelling of ripple losses and wall loadings for ITER
- Contributions to the design of ITER gyrotrons
- Feasibility study for micromechanical magnetometers.

The Annual Fusion Seminar of the Association Euratom-Tekes was held on M/S Silja Serenade between Helsinki and Stockholm, 4–5 June 2008. Over 60 people representing 12 nationals participated in the Seminar. The seminar gave a review of the Finnish and Estonian fusion research activities in 2007–2008. Carlo Damiani from Fusion for Energy gave an invited talk on European activities and plans for the ITER remote handling systems. The *Fusion Yearbook 2007*, Annual Report of the Association Euratom-Tekes, VTT Publication 678, 2008, 136 p., was published in the Annual Seminar.

J.A. Heikkinen gave an invited Lecture on Plasma Simulation Using Particle Codes at the Cours CEA-EDF-INRIA, Modèles numériques pour la fusion contrôlée, Université de Nice, Nice, 8–12 September 2008.

Lecture course on *Fusion Technology* was given at the Lappeenranta (LUT) and Helsinki University of Technology (TKK). Several articles related to fusion energy research and ITER were published in newspapers and weekly journals.

Invited talk for high school physics and chemistry teachers ’From Teraflops to Megawatts – fusion research at the Helsinki University of Technology, Vaasa, Finland, 6–7 May 2008.

In addition, several newspaper articles and interviews on fusion energy and ITER were published in 2008.

2 FUSION PROGRAMME ORGANISATION

2.1 Programme Objectives

The Finnish Fusion Programme, under the Association Euratom-Tekes, is fully integrated into the European Programme, which has set the long-term aim of the joint creation of prototype reactors for power stations to meet the needs of society: operational safety, environmental compatibility and economic viability. The objectives of the Finnish programme are:

- To develop fusion technology for the ITER project in collaboration with Finnish industry
- To provide a high-level scientific contribution to the accompanying Euratom Fusion Programme.

This can be achieved by close collaboration between the Research Unit and Finnish industry, and by strong focusing the R&D effort on a few competitive areas. Active participation in the EU Fusion Programme and accomplishing ITER technology development Grants by Fusion for Energy provide challenging opportunities for technology R&D work in research institutes and Finnish high-tech industry.

2.2 Association Euratom-Tekes

The Finnish Funding Agency for Technology and Innovation (Tekes) is funding and co-ordinating technological research and development activities in Finland. The Association Euratom-Tekes was established on 13 March 1995 when the Contract of Association between Euratom and Tekes was signed. Other agreements of the European Fusion Programme involving Tekes are the multilateral agreements: European Fusion Development Agreement (EFDA), JET Implementing Agreement (JIA) and Staff Mobility Agreement. In 2007, Tekes and the University of Tartu (Estonia) signed an Agreement to establish the Estonian Research Unit under the Association Euratom-Tekes offering for Estonia a full participation in the European Fusion Programme. The fusion programme official in Tekes is Mr. Juha Lindén.

2.3 The Fusion Research Unit

The Finnish Research Unit of the Association Euratom-Tekes consists of several research groups from VTT and universities. The Head of the Research Unit is Mr. Seppo Karttunen from VTT. The following institutes and universities participated in the fusion research during 2008:

1. VTT – Technical Research Centre of Finland
VTT Materials and Buildings (co-ordination, physics, materials, diagnostics)
VTT Industrial Systems (remote handling, beam welding, DTP2)
VTT Microtechnologies and Sensors (diagnostics)
2. Helsinki University of Technology (TKK)
Department of Engineering Physics and Mathematics (physics, diagnostics and system studies)

3. University of Helsinki (UH)
Accelerator Laboratory (physics, materials)
4. Tampere University of Technology (TUT)
Institute of Hydraulics and Automation (remote handling, DTP2)
5. Lappeenranta University of Technology (LUT)
Institute of Mechatronics and Virtual Engineering (remote handling)

The following industrial companies collaborated with the Fusion Research Unit: Fortum Nuclear Services Ltd. (Fortum is the Finnish EFET partner), Luvata Pori Oy, Hollming Works Oy, Metso Oy, Diarc Technology Inc., Creanex Oy, Hytar Oy, Advatec Oy, Delfoi Ltd., TP-Konepaja Oy and Oxford Instruments Analytical Oy. The fusion related industrial activities were co-ordinated in the Tekes Big Science project by Finpro. The Finnish Industry Liaison Officer (ILO) is Mr. Hannu Juuso from Tekes.

The Estonian Research Unit of the Association Euratom-Tekes consists of research groups from the **University of Tartu** and the **National Institute of Chemical Physics and Biophysics.** The Head of the Estonian Research Unit is Mr. Madis Kiisk from University of Tartu.

There are two Finnish staff persons and one contract person in the ITER IO team, in Cadarche and two Finnish staff persons in F4E, in Barcelona.

2.4 Association Steering Committee

The research activities of the Finnish Association Euratom-Tekes are directed by the Steering Committee, which comprises the following members in 2008:

Chairman 2006	Mr. Yvan Capouet, EU Commission, Research DG Mr.
Members	Reijo Munther, Tekes
	Mr. Chris Ibbott, EU Commission, Research DG
	Mr. Steven Booth, EU Commission, Research DG
	Mr. Marc Pipeleers, EU Commission, Research DG
	Mr. Jouko Suokas, VTT
	Mr. Harri Tuomisto, Fortum Oy
Head of Research Unit	Mr. Seppo Karttunen, VTT
Head of Estonian RU	Mr. Madis Kiisk, UT, Estonia
Secretary	Mr. Jukka Heikkinen, VTT

The Steering Committee had one meeting in 2008, for the first time by video conferencing on 24 October 2008.

2.5 National Steering Committee

The national steering committee advises on the strategy and planning of the national research effort and promotes collaboration with Finnish industry. It sets also priorities for the Finnish activities in the EU Fusion Programme. The national steering committee had the following members in 2008:

Chairman	Mr. Jaakko Ihamuotila, Millennium Prize Foundation
Members	Ms. Mirja Arajärvi, Ministry of Education
	Mr Hannu Juuso, Tekes
	Ms. Anna Kalliomäki, Finnish Academy of Sciences
	Mr. Kimmo Kanto, Tekes
	Mr. Ben Karlemo, Luvata Pori Oy
	Mr. Jari Liimatainen, Metso Oy
	Mr. Reijo Munther, Tekes
	Mr. Juho Mäkinen, VTT
	Mr. Herkko Plit, Teollisuuden Voima Oy
	Mr. Pentti Pulkkinen, Finnish Academy of Sciences
	Mr. Dan-Olof Riska, Helsinki Institute of Physics
	Mr. Jorma Routti, Creative Industries Management Oy
	Mr. Jouko Suokas, VTT
	Mr. Harri Tuomisto, Fortum Nuclear Services Oy
	Ms. Janica Ylikarjula, Confederation of Finnish Industries
Head of research Unit	Mr. Seppo Karttunen, VTT
Secretary	Mr. Pekka Tolonen and Mr. Markus Ranne, Finpro

The national steering committee had three meetings in 2008.

The research activities are steered by three Topical Advisory Groups for 1) physics and diagnostics chaired by Heikki Sipilä, Oxford Instruments Analytical, 2) for materials research chaired by Ilpo Koppinen, Luvata Oy and 3) for remote handling systems chaired by Olli Pohl, Hytar Oy.

2.6 The Finnish Members in the EU Fusion Committees

Euratom Science and Technology Committee (STC)

Rainer Salomaa, TKK

Consultative Committee for the Euratom Specific Research and Training Programme in the Field of Nuclear Energy – Fusion (CCE-FU)

Reijo Munther, Tekes
Seppo Karttunen, VTT
Marco Kirm, UT, Estonia
Madis Kiisk, UT, Estonia

EFDA Steering Committee

Juha Lindén, Tekes
Seppo Karttunen, VTT
Madis Kiisk, UT, Estonia

Science and Technology Advisory Committee (STAC)

Rainer Salomaa, TKK

Governing Board for the Joint European Undertaking for ITER and the Development of Fusion Energy, ”Fusion for Energy” (F4E GB)

Reijo Munther, Tekes
Seppo Karttunen, VTT
Rein Kaarli, MER, Estonia
Ergo Nõmmiste, UT, Estonia

Executive Committee for the Joint European Undertaking for ITER and the Development of Fusion Energy, "Fusion for Energy" (F4E EXE)
Kari Törrönen, Enegywave

Finnish representatives in the following fusion committees and expert groups in 2008:

Reijo Munther and Seppo Karttunen are members of the IEA Fusion Power Co-ordinating Committee (FPCC).
Jukka Heikkinen, Chairman of the International Programme Committee of the Plasma Edge Theory Workshop (PET).
Taina Kurki-Suonio is a member of the Programme Committee of the ASDEX-Upgrade, Max Planck Gesellschaft.
Rainer Salomaa is the Tekes administrative contact person in EFDA JET matters.
Harri Tuomisto is a member of the International Organising Committee, of the Symposium on Fusion Technology (SOFT).
Hannu Juuso is an Industry Liaison Officer for Fusion-Industry matters.

2.7 Funding and Research Volume 2008

In 2008, the expenditure of the Association Euratom-Tekes was about 4,65 million € including Staff Mobility actions and F4E & ITER contracts (see Figure 2.1). A clear reduction in the expenditure is mainly due to the lack of F4E contracts which were anticipated for 2008. Two teams with strong EFDA Technology background (welding and welding robots) were left without contracts in 2008. In addition, materials research remained at much lower level as compared to previous EFDA activities.

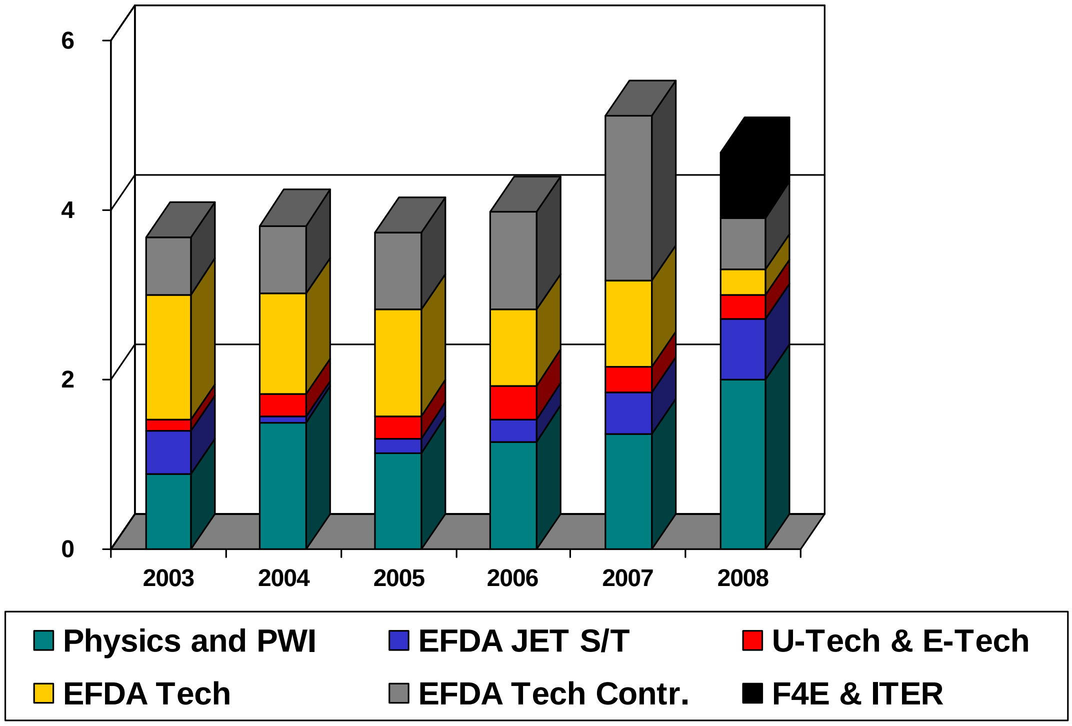

Figure 2.1. Expenditures (in Mio €) of the Association Euratom-Tekes for different physics and R&D activities in 2003–2008.

The major part of the national funding comes from Tekes. The rest of the national funding comes from other national institutions, such as the Finnish Academy, research institutes and universities participating in the fusion research (VTT, TKK, TUT, UH, LUT and UT) and industry. The funding was allocated as following: fusion plasma physics and plasma-wall studies 43%, EFDA JET activities 15%, Emerging Technology 6%, EFDA Technology Tasks (Art. 5.1a) 7%, EFDA Art. 5.1b Contracts and Preferential Support activities 13% and F4E Grant & ITER contract 16%. Staff Mobility expenditure in 2008 was 84 k€. The total volume of the 2008 activities was about 40 professional man-years.

3 PHYSICS PROGRAMME – FUSION PHYSICS

Institute: **VTT - Technical Research Centre of Finland**

Research scientists: Dr. Seppo Karttunen (Head of Research Unit), Dr. Markus Airila, Dr. Jukka Heikkinen (Project Manager), Dr. Jari Likonen (Project Manager), Dr. Tuomas Tala (TFL T at JET), Dr. Elizaveta Vainonen-Ahlgren
Student: Seppo Koivuranta

Institute: **Helsinki University of Technology** (TKK)
Department of Engineering Physics and Mathematics, Laboratory of Advanced Energy Systems

Research scientists: Prof. Rainer Salomaa (Head), Dr. Pertti Aarnio, MSc. Leena Aho-Mantila, MSc. Otto Asunta, Dr. Olgierd Dumbrajs, Dr. Mathias Groth, Dr. Antti Hakola, Dr. Ville Hynönen, MSc. Salomon Janhunen, MSc. Simppa Jämsä, Dr. Timo Kiviniemi, Dr. Taina Kurki-Suonio, MSc. Susan Leerink, MSc. Johnny Lönnroth (JOC Secondee), MSc. Markus Nora, MSc. Antti Salmi (JOC secondee), Dr. Marko Santala, Dr. Seppo Sipilä
Students: Joonas Govenius, Eero Hirvijoki, Tuomas Korpilo, Tuomas Koskela, Toni Makkonen, Antti Snicker

Institute: **University of Helsinki (UH)**
Accelerator Laboratory

Research scientists: Tommy Ahlgren , Carolina Björkas, Flyura Djurabekova, Kalle Heinola, Niklas Juslin, Juhani Keinonen (Head of Laboratory), Kai Nordlund (Project Manager), Kenichiro Mizohata, Helga Timko, Petra Träskelin and Katharina Vörtler

Companies: **Diarc Technology, Oxford Instruments Analytical**

Collaborators: **UKAEA-JET, IPP Garching**, **University of Tartu and EFDA JET Contributors**

The fusion physics work has been performed in close co-operation between VTT Technical Research Centre of Finland and Helsinki University of Technology (TKK). Participation in the EFDA JET Workprogramme is the first priority in the fusion physics activities of the Association Euratom-Tekes. Our emphasis in the S/T Order and Notification work related the experimental campaigns C20-C25 of the JET Workprogramme 2008 and in the AUG programme at IPP Garching in co-operation with other Euratom Associations. Main topics were transport and MHD studies, plasma-wall interactions and diagnostics. Dr. Tuomas Tala from VTT is a Task Force leader for TF-transport. Two persons were seconded to the UKAEA JOC team.

The fusion plasma simulation groups at VTT and TKK maintain and provide an important modelling and support centre in fusion physics and plasma engineering for the European fusion programme and ITER. In close collaboration with Finnish industry, simulation of material plasma processing, a fusion spin-off technology, will continue and related design support and expertise will be strengthened.

3.1 Energy and Particle Confinement and transport

3.1.1 Evidence of Inward Toroidal Momentum Convection in the JET Tokamak

Principal Tekes Scientist: T. Tala, Tekes–VTT
Collaboration: EFDA-JET contributors

Plasma rotation and momentum transport in tokamaks are currently a very active research area. It is well-known that sheared rotation can lead to quenching of turbulence and a subsequent improvement in confinement. Toroidal rotation also increases stability against pressure limiting resistive wall modes. Still, transport of toroidal momentum is less understood than heat or particle transport. Extrapolating the magnitude and profile shape of the toroidal rotation reliably to future tokamaks such as ITER remains a challenge, as neither momentum transport nor sources are known precisely.

Experiments where the Neutral Beam Injection (NBI) power and torque were modulated at frequencies between 6Hz and 12Hz have been performed on JET. This modulation frequency is much lower than the 10ms time resolution of the Charge Exchange Recombination Spectroscopy (CXRS) diagnostic used to measure the toroidal rotation ω_ϕ and ion temperature T_i at 12 radial points. Typically 5 MW of NBI power was modulated, the total NBI power then varying between 10 and 15 MW. The NBI induced modulated torque has been calculated with TRANSP transport code. The TRANSP torque calculations have been compared with those from the Finnish ASCOT orbit following Monte-Carlo code. The agreement between these codes is very good, showing the robustness of the NBI torque calculation for these experiments and providing a proper code benchmark of the NBI physics between TRANSP and ASCOT.

Figure 3.1 compares experimental data and simulations for the modulated amplitude $A_{\omega,\phi}$ and phase $\varphi_{\omega,\phi}$ of toroidal rotation ω_ϕ. For the simulations, two options for the momentum diffusivity χ_ϕ or Prandtl number Pr and momentum pinch v_{pinch} are compared: case (i) fix Pr=0.25 to yield $\chi_\phi = 0.25\chi_{i,eff}$ ($\chi_{i,eff}$ is the effective ion heat diffusivity) and v_{pinch}=0 and case (ii) to match the simulated and experimental phase by fitting Pr, and then vary the v_{pinch} profile to additionally match the simulated and experimental amplitudes and steady-state. All simulations for ω_ϕ have been performed with the JETTO transport code.

Case (i) with Pr = 0.25 and v_{pinch}= 0 clearly disagrees with the experiments. The simulated phase is too large, an indication of too low χ_ϕ, i.e. too low Pr used in the simulation. On the other hand, the simulated amplitude is too low towards the plasma centre, which could only be cured by lowering χ_ϕ further. This shows that the assumption v_{pinch}= 0 is not compatible with the experimental data. Case (ii) uses $Pr = \chi_\phi/\chi_i \sim 1$ and v_{pinch} varying radially between 0 and –25 m/s (both shown in Figure 3.1).

This improves the agreement between the simulated and experimental amplitudes and phases dramatically. This v_{pinch} profile reproduces best the experimental amplitude and phase profiles, together with an acceptable reproduction of the steady-state toroidal rotation profile. These results yield the first experimental evidence of an inward momentum pinch on JET and also evidence of a high Prandtl number $Pr = \chi_\phi/\chi_i \approx 1$.

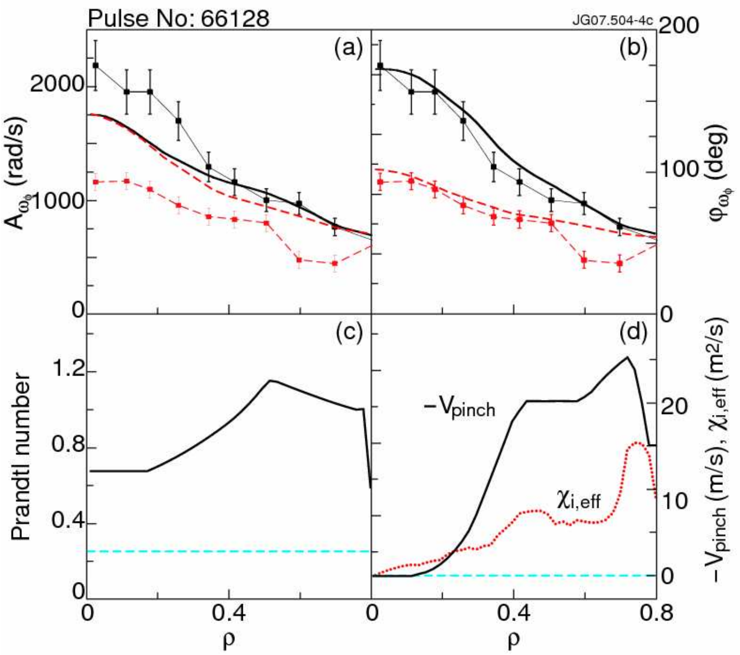

Figure 3.1. Comparison of the experimental amplitude (black solid with error bars) and phase (red dashed with error bars) and simulated amplitudes $A_{\omega,\phi}$ (black solid) and phases $\varphi_{\omega,\phi}$ (red dashed) of modulated ω_ϕ in frame (a) case (i) with $Pr = 0.25$ and $v_{pinch} = 0$ and frame (b) case (ii) with $Pr \approx 1$ and v_{pinch} taken from figure (d) (black solid). (c) Prandtl numbers and (d) pinch velocity profiles used in cases (i) (blue dashed) and (ii) (black solid). Also shown the used $\chi_{i,eff}$ (red dotted) in frame (d).

The radial profile of v_{pinch} is roughly proportional to χ_ϕ, consistent with the predictions by the theory. While the *Pr* numbers from the gyro-kinetic code GKW are in excellent agreement with experiment, there is some discrepancy in the pinch numbers, defined as Rv_{pinch}/χ_ϕ. The pinch numbers from GKW are 2–4, depending on radius, whereas the experimental ones are in the range of 3–8.

In summary, consistent evidence for a significant inward momentum pinch has been found in JET. This may have important implications on the predictions for the toroidal velocity profile in ITER. In particular, a centrally peaked toroidal velocity profile may still result even in the absence of any external core momentum source. It still remains to be assessed whether the parametric dependences of such a pinch term are such that a convective component is significant in ITER plasmas.

3.1.2 Experimental Study of Ion Heat Transport: ITG threshold and stiffness

Principal Tekes Scientist: T. Tala, Tekes – VTT
Collaboration: EFDA-JET contributors

The anomalous character of ion heat transport in tokamaks, one or two orders of magnitude higher than collisional transport, is a well documented experimental observation. A comprehensive theoretical description of turbulent ion heat transport as driven by Ion Temperature Gradients (ITG) modes has been developed and applied to physics based predictions of confinement in present and future devices such as ITER. ITG's feature a threshold in the inverse ion temperature gradient length ($R/L_{\mathrm{Ti}}= R|\nabla T_{\mathrm{i}}|/T_{\mathrm{i}}$, with R the tokamak major radius) above which the ion heat flux (q_{i}) increases strongly with R/L_{Ti}. This property leads to stiffness of T_{i} profiles with respect to changes in heating profiles. The level of stiffness characterizes how strongly T_{i} profiles are tied to the threshold. The issue is of high relevance for the operation of future generation devices, because the core T_{i} and fusion power achievable for a given T_{i} pedestal depend crucially on threshold and stiffness.

Experimentally the identification of the ITG threshold in terms of R/L_{Ti} requires a scan of the core ion heat flux (q_{i}) at constant edge heat flux, to keep the edge transport properties and profiles constant. The experiment was performed in JET L-mode plasmas with magnetic field B_t=3.36T, plasma current I_p=1.8MA, q_{95}~6 (to minimize core sawtooth activity), density n_{e0}~3-4 $10^{19}\mathrm{m}^{-3}$, $0.9<T_e/T_i\sim1.2$. The need to reach low values of normalised q_{i} to identify the threshold requires minimising the centrally deposited power from NBI. Therefore, the experiment was done in low rotating plasmas, retaining only the Charge Exchange diagnostic NBI beam (1.5 MW). Most of the heating was then provided by ICRH (3-6 MW), using the multi-frequency capability to vary the ion power distribution between on-axis and off-axis. The resulting normalised q_{i} versus R/L_{Ti} plot for this plasma is shown in Figure 3.2 (red circles). The gyro-Bohm normalization has been applied to q_{i} in two ways, to meet the inclinations of both experimentalists and theoreticians. The left scale in Figure 3.2 indicates the total power in MW within ρ_{tor}=0.33 and is normalized over $n_eT_i^{5/2}/R^2B^2$. The right scale indicates the values of q_{i} at ρ_{tor}=0.33 in gyro-Bohm units. The threshold is well identified experimentally in Figure 3.2 as the intersection at neoclassical heat flux. The ion stiffness appears to be high, as the available excursion of q_{i} norm by more than one order of magnitude does not lead to a significant change in R/L_{Ti}. Blue triangles and black squares in Figure 3.2 indicate high NBI power discharges with similar parameters but higher levels of power and torque. In the high rotation discharges (black squares) the threshold is not directly identified by low q_{i} points and therefore the key question is whether the increase in R/L_{Ti} is due to an effect of rotational shearing rate (ω_{ExB}) on the threshold only, in accordance with theory predictions (i.e. keeping the same slope for all curves), or also on the stiffness level (different slopes). The dotted lines in Figure 3.2 indicate a change of χ_s (describing the strength of stiffness or the steepness of the dashed slopes) from 7 to 0.5 with increasing rotation, leading to a factor of 3 increase in R/L_{Ti} at similar values of the normalised heat flux. We attribute this variation to rotation because both its central value and its gradient change by a factor 6 over the dataset, while other parameters have only minor variations.

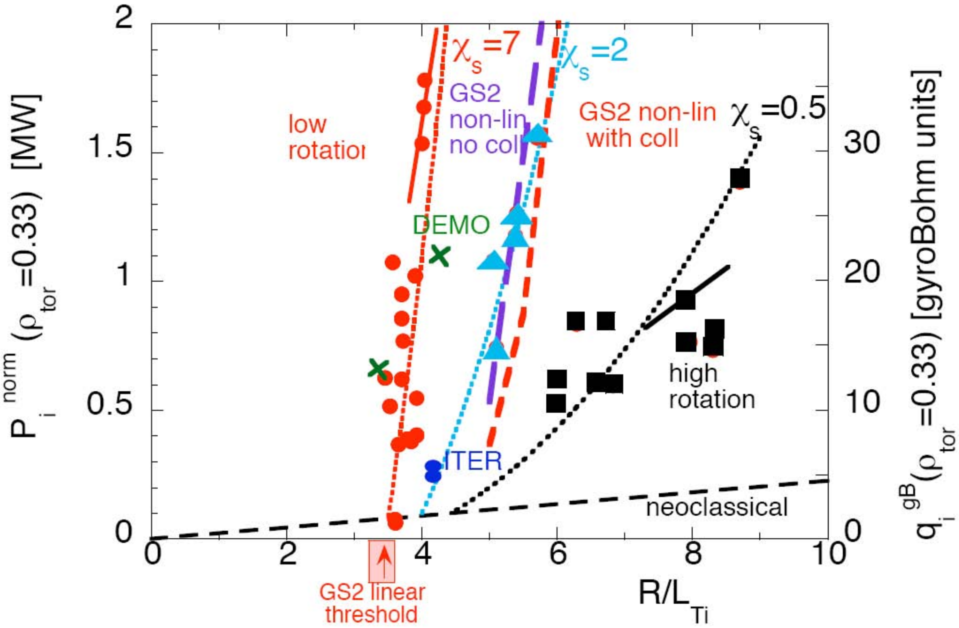

Figure 3.2. Normalized ion heat flux q_i at ρ_{tor}=0.33 versus R/L_{Ti} for similar plasmas with different levels of rotation. Red full circles, blue triangles and black squares are experimental data at the following rotation levels respectively: 1×10^4rad/s <ω_{tor}<2×10^4rad/s, 3×10^4rad/s < ω_{tor} <4×10^4rad/s, 5×10^4rad/s < ω_{tor} <6×10^4rad/s. The dashed black line is indicative of the neoclassical transport. The three dotted lines are fits indicating the stiffness level χ_s for each given group of points at different rotation levels. The dashed thicker red and purple lines are non-linear gyro-kinetic GS2 simulations with and without collisions, and the red arrow indicates the GS2 linear threshold for the low rotation shots. The ITER and DEMO positions (referring to right Y axis) are marked from simulations using the GLF23 transport model with two assumptions for the pedestal.

Overall, we conclude that the available experimental evidence points consistently to a significant effect of rotation on ion stiffness in addition to a smaller effect on threshold. The implication of these findings is that rotation effects on stiffness cannot be ignored along with effects on threshold when interpreting experiments in present day machines aimed at identifying the role of rotation on confinement. Such results require careful, physics based extrapolation to future devices. In fact, depending on how high above threshold in the normalized plot ITER or DEMO will operate (see their position in Figure 3.2, the larger effect of rotation on stiffness may or may not dominate over the smaller effect on threshold. In any case, blind extrapolations of the effect of rotation on core confinement from present devices should not be made without knowing at which point of the normalised q_i versus R/L_{Ti} diagram the experiment is carried out and at which point ITER/DEMO will operate.

3.1.3 Understanding pedestal performance and ELM behaviour

Principal Tekes Scientist: J. Lönnroth, Tekes – TKK
Collaboration: EFDA-JET contributors

The new integrated transport code JINTRAC, a coupling of the 1.5D core transport code JETTO, the 2D edge transport code EDGE2D, the Monte Carlo guiding centre following code ASCOT and the 3D Monte Carlo neutrals code EIRENE, has been used to study the dynamics of an ELM cycle self-consistently. The motivation for the work has been to test JINTRAC by applying it to a problem requiring the full capabilities of the new code for self-consistent treatment. In particular, modelling the ELM cycle self-consistently requires the following two features: 1) the capability to model the core plasma and scrape-off layer in an integrated fashion, because the ELM phenomenon involves both the core and the scrape-off layer, and 2) a kinetic treatment for the fast particle interaction with the thermal plasma and neutral background, because charge exchange is important during ELMs. In JINTRAC, the so-called COCONUT coupling of JETTO and EDGE2D makes it possible to model the whole plasma self-consistently, whereas ASCOT and EIRENE take care of the kinetic treatment for hot ions and hot neutrals, respectively.

Two simulations have been compared against each other: one run in which charge exchange losses have been taken into account in ASCOT within JINTRAC and one run without charge exchange losses of fast ions. (Thermal ion charge exchange has been included in both runs.) As expected, the run taking into account charge exchange losses has a lower level of absorbed neutral beam power due to these losses. The lower level of absorbed power translates into a lower ELM frequency. This seemingly obvious result is a demonstration of the need for a kinetic treatment and thereby for this capability provided by JINTRAC.

A second observation in the simulations is that the boundary condition at the boundary between JETTO and EDGE2D (i.e. between the core and the edge) in the COCONUT coupling in JINTRAC evolves dramatically during the ELMs. The only way to evolve this boundary condition self-consistently is to use a coupled code such as JINTRAC. Getting the boundary evolution right is crucial from an MHD stability point of view, for instance, because the MHD stability of the pedestal depends very sensitively on the plasma profiles within the pedestal. This result again demonstrates the need for a coupled code such as JINTRAC.

3.1.4 Turbulence simulations using ELMFIRE

Principal Scientists: T. Kiviniemi, Tekes – TKK
J. Heikkinen, Tekes – VTT

Turbulence, appearing as fluctuations in macroscopic quantities, deteriorates plasma confinement. This can be investigated with full-f gyrokinetic particle code ELMFIRE. The main focus of the ELMFIRE work has been in comparison of simulations to the experimental results on plasma rotation and turbulence spectra. Also, more advanced methods are now in use to investigate the simulation data in more detail.

Experimental benchmarking of the ELMFIRE code is performed in co-operation with the small FT-2 tokamak experiment at the Ioffe Institute in St Petersburg. The poloidal velocity obtained from ELMFIRE simulations is compared to experimental results from reflectometer diagnostics. Doppler reflectometry measures the poloidal velocity by evaluation of the rotational velocity from the Doppler frequency shift of back scattered radiation. The output signal of the microwave mixer is given as a function of a complex spatial weighting function and density fluctuation. The weighting function depends on the antenna and the receptivity of the waves and is obtained by a ray tracing code. In our model the density fluctuations are produced by the ELMFIRE code, and the microwave signal *I(t)* can be reproduced by multiplication and integration of the density fluctuations with the weighting function. Recent comparisons between the experimental and simulated power spectrum of I(t) show good agreements in both the shift as well as the width of the power spectrum. In Figure 3.3, the simulated power spectra for three different radial locations are shown. The poloidal velocity, and thereby the Doppler shift, is increasing when going deeper into the plasma, consistent with experimental results. Underlying phenomena causing the poloidal velocity can now be studied with the ELMFIRE code.

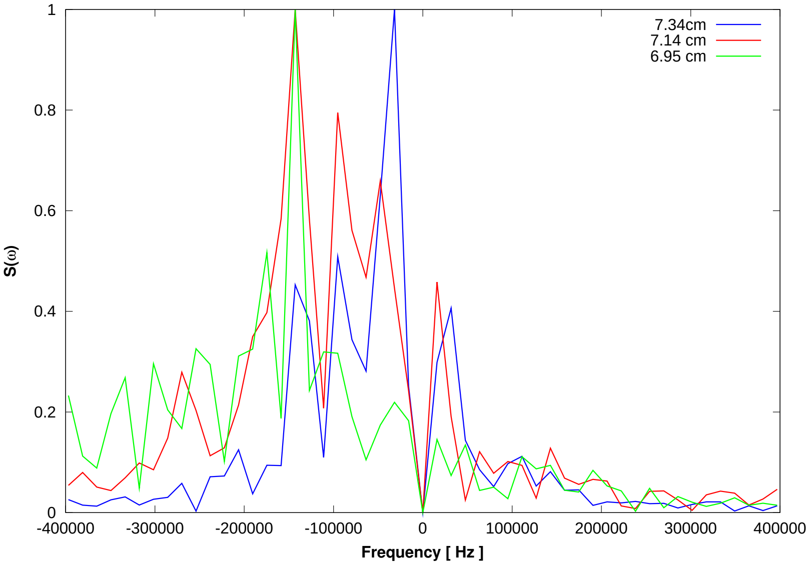

Figure 3.3. The simulated power spectra of the Doppler Reflectometry signal at the radii 6.95 cm (green), 7.34 cm (red) and 1.14 cm (blue).

The study of turbulent fluctuations from ELMFIRE simulations is done using new diagnostics based on the 2-D continuous wavelet transform on poloidal cross sections. The wavelet transform decomposes data into the wavelet basis connecting the power, scale, place and rotation of structures in the data. This enables localized fluctuation analysis, i.e., makes it possible to extract fluctuations of a given size from the background and to study their directional properties. The focusing on turbulent structures is done by proper thresholding in wavelet space. As an example of such wavelet analysis, the localization of fluctuations through a simulation allows tracking movement of individual fluctuations in the poloidal cross section. This is illustrated in Figure 3.4.

Active code development and optimisation, including EUFORIA co-operation, is also ongoing as well as code benchmarking effort in context of ITM#4 project. Further code optimisation was also necessary in order to simulate middle-sized tokamaks. In these efforts the DEISA resources have been in extensive use, but more optimisations and computing power is still needed for reliable results.

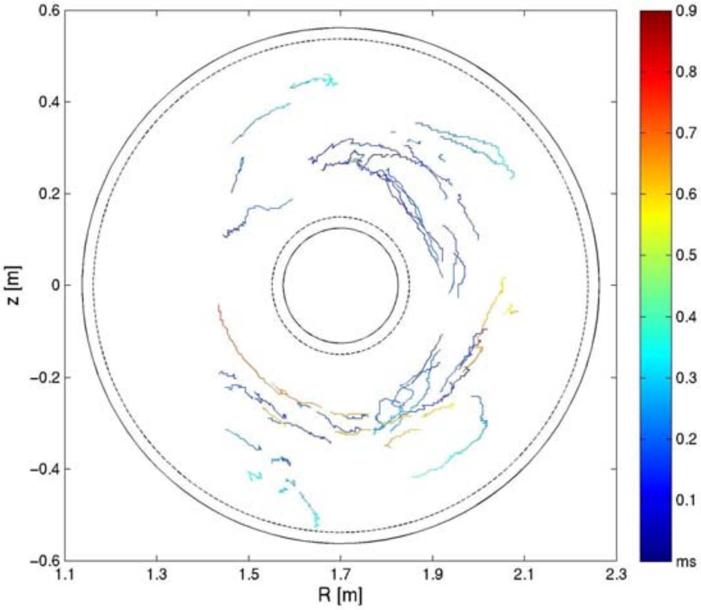

Figure 3.4. The movement of the most powerful and most long-lived large-scale fluctuations in time using wavelet analysis. The movement is mainly poloidal.

3.2 MHD Stability and Plasma Control

3.2.1 Stochastic magnetic field in AUG

Principal Tekes Scientist:	O. Dumbrajs, Tekes–TKK
Collaboration:	IPP Garching

Studies of fast MHD events in ASDEX-Upgrade (AUG), illustrated in Figure 3.5, suggest that stochastization plays an important role in these processes. In spite of the short time duration and small region of stochastization, it can lead to strong changes in plasma confinement. This is because of the strong mixing of the magnetic field lines which destroys magnetic surfaces and strongly increases the radial transport. Two such phenomena were studied: the frequently interrupted regime of neoclassical tearing mode (FIR-NTM) and the sawtooth crash. The role of stochastization of magnetic field lines is analyzed by applying the mapping technique to trace the field lines of a toroidally confined plasma. Understanding of the FIR mechanism allows one to construct a model for FIR periods. This model also shows a transition to FIR regime and back.

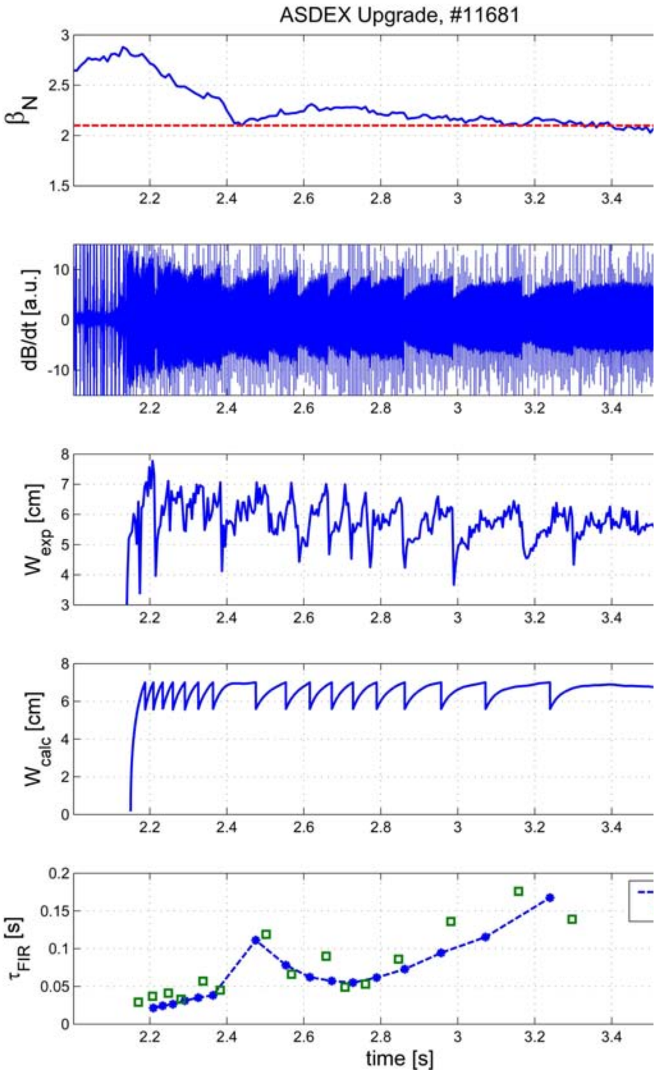

Figure 3.5. Temporal evolution of β_N, dB/dt, W_{exp}, W_{calc}, and τ_{FIR}. The red dashed line marks the border between the absence (below) and presence (above) of the FIR phenomenon. The heating power was reduced by 2.5 MW between 2.38 s and 2.42 s, which causes the fast β_N drop during this time.

The proposed stochastic model for the sawtooth crash is able to explain fast losses of heat from the plasma core with simultaneous small changes in the safety factor profile. It is found that the sawtooth crash does not change the position of the q=1 surface. This observation disagrees with ordinary sawtooth models but is in agreement with the stochastic picture of the crash. The important parameters for the creation of a stochastic region are:

(i) perturbation amplitudes;
(ii) safety factor profile;
(iii) number of perturbations with different helicities;
(iv) coupling of perturbations.

3.2.2 Quiescent H-mode studies in AUG

Principal Tekes Scientist:	T. Kurki-Suonio, Tekes – TKK
Collaboration:	IPP Garching

In the so-called Quiescent H-mode (QHM), a continuous, benign MHD behaviour called Edge Harmonic Oscillations (EHO) replaces the detrimental ELMs. This MHD activity has all the desired properties: it appears to facilitate density control and impurity exhaust while leaving the good core confinement intact. It is not clear what triggers the EHO, neither is it understood what suppresses the ELMs, but fast ions probably play a role because, until this year, QHM together with EHO was only achieved with counter-injection of the neutral beams, which is very counter-productive if one is to look for a way to protect the material surfaces.

However, in May 2008, DIII-D stumbled on QHM operation with co-injected beams when heating the edge with ECRH. Later this year, in dedicated experiments, it was found that edge ECRH was actually detrimental and that it is high edge rotation that is the prerequisite for the QHM operation.

In November 2008 an attempt to produce QHM operation with co-injected neutral beams on AUG was made (shots 23995 – 24001). Figure 3.6 shows that the target edge temperature was achieved in shot #24001 but that the target rotation values were not obtained. ELM-free phases were observed, but these were of the classical type with uncontrollable density rise. However, in a couple of ELM-free phases EHO-type MHD activity was observed. Counter-intuitively, EHO activity was observed in the shots with more radial beam injection.

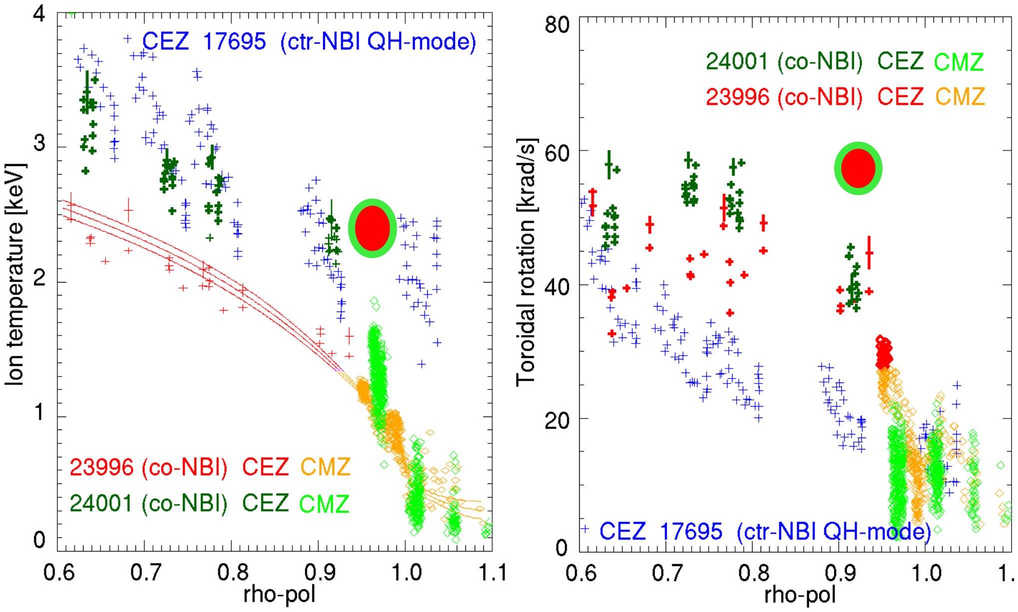

Figure 3.6. The ion temperature and toroidal rotation profiles in a QHM shot obtained with counter-injected neutral beams (17695) and in two recent attempts to achieve EHM operation in AUG with co-injection (23996 and 24001).

3.3 Code Development

3.3.1 ASCOT-3D for realistic modelling of fast ion wall loads

Principal Scientists: S. Sipilä, V. Hynönen, Tekes – TKK

Like most guiding-centre orbit-following codes, ASCOT too was initially built on the assumption of axisymmetric configurations. However, over the years the finite toroidal ripple has been discovered to play a significant role even in tokamak physics, most notably for energetic ions. Furthermore, ITER will have a much larger ripple than, say, JET. Therefore it is very important to be able to evaluate the confinement of fast ions, especially fusion alphas, in tokamak geometry where the axisymmetry is broken by the finite number of toroidal coils.

Within the EFDA RIPLOS project, a new magnetic field module was constructed for ASCOT. The new module allows reconstructing the total magnetic field from a vacuum field generated by a finite number of coils and an equilibrium field that has been solved using the Grad-Shafranov equation. The former is necessarily 3-dimensional, while the latter is 2-dimensional. Furthermore, the vacuum field can be specified as a number of toroidally limited sectors, together with a recipe on how these have to be duplicated/mirrored to obtain the full 360 degree torus.

The wall collision model used in ASCOT was also refurbished within the RIPLOS project: The wall is now genuinely 3-dimensional, including individual tiles, ports, limiters etc. Furthermore, the Larmor radius effects are also taken into account when determining the location of the ion impinging on the wall structures.

3.3.2 Developing the JET integrated transport code, JINTRAC

Principal Tekes Scientist: A. Salmi, Tekes – TKK
Collaboration: EFDA-JET contributors

A considerable amount of work has been done to integrate two Monte Carlo codes, ASCOT and EIRENE, with the JET transport code JETTO and with each other to create a cutting-edge transport solver for JET now known as **J**ET **In**tegrated **Tra**nsport **C**ode, JINTRAC. By including these new Monte Carlo modules the capabilities of the transport code have risen to a new level and it is now capable of attacking some novel areas of research. TEKES responsibility of the integration project is limited to the integration of our in-house code ASCOT. ASCOT is a guiding centre following Monte Carlo code for following charged particles (or fast neutrals) in toroidal magnetic field configurations.

Figure 3.7 shows schematically how ASCOT is integrated with JETTO, EIRENE and optionally EDGE2D. The role of ASCOT within the integrated code package is to follow the ionised NBI particles and produce relevant output such as ion and electron heating, beam driven current and beam driven torque. The initial conditions for ASCOT (plasma and cold neutral profiles, magnetic field and NBI source) are updated before each step. Typically for JET parameters ASCOT is called every 5–10ms dictated mainly by the slowing down time of the NBI ions. ASCOT outputs are then used by the transport code as sources to evolve the plasma.

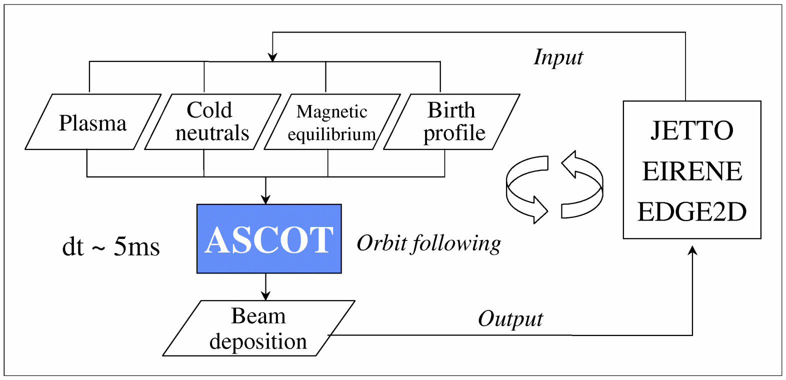

Figure 3.7. Schematic flow chart of the JINTRAC transport code.

Figure 3.8 shows the effects that are captured in ASCOT ion tracing. Compared to typically very fast Fokker-Plank beam modelling, slower Monte Carlo techniques have the benefit of including more physics. The technique allows a straightforward way of including orbit width effects, pitch and energy scattering, orbit losses, CX losses and re-capturing. It allows modelling of complex geometry and distributions close and outside the separatrix, thus enabling e.g. heat load analysis. Trapped particle effects on e.g. toroidal beam driven current are also included.

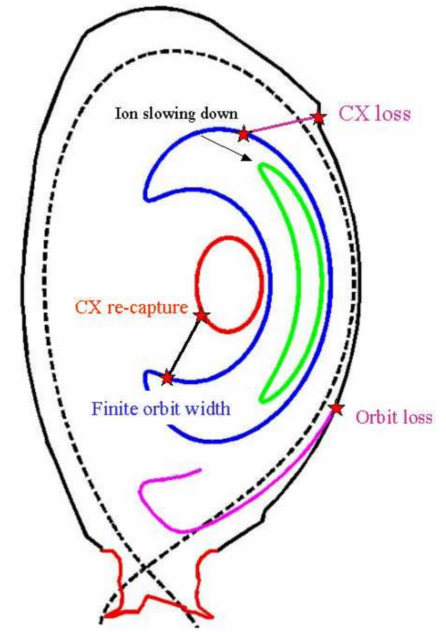

Figure 3.8. NBI physics included in ASCOT.

In summary: the goals of the project have been achieved and JINTRAC has been released for general use in JET. Users can operate these new features through the JAMS graphical interface. During the validation phase of the NBI treatment JINTRAC has been benchmarked against the previous model PENCIL and against TRANSP. All comparisons have shown good agreement.

3.3.3 SOFI – Single Orbit Following Implement

Principal Scientist: A. Snicker, Tekes – TKK

In computational physics, there is a trade-off between the degree of detail and scale of the simulation: phenomena like MHD events can not be studied with codes that follow the gyro motion of individual particles. Even guiding-center orbit-following codes are too time consuming and noisy for such purposes. In the level of detail, bounce-averaging codes are just below the ones using guiding centre approximation. For a bounce-averaging code to give reliable results, it is very important to have accurate description of the orbits in various parts of the tokamak plasma.

Developed as part of the EFDA Work Programme 2008 in the field of Integrated Tokamak Modelling (ITM, IMP#5), SOFI uses the guiding centre approximation to solve particle orbits in a realistic tokamak geometry. A nontrivial aspect of this work was ensuring that the particle is followed *exactly* one orbit, i.e., that the starting and finishing points overlap in the poloidal plane. Moreover, SOFI yields detailed information of the orbit, e.g. the orbit type and various extrema of the orbit. Figure 3.9 shows the seven different orbit types identified by SOFI.

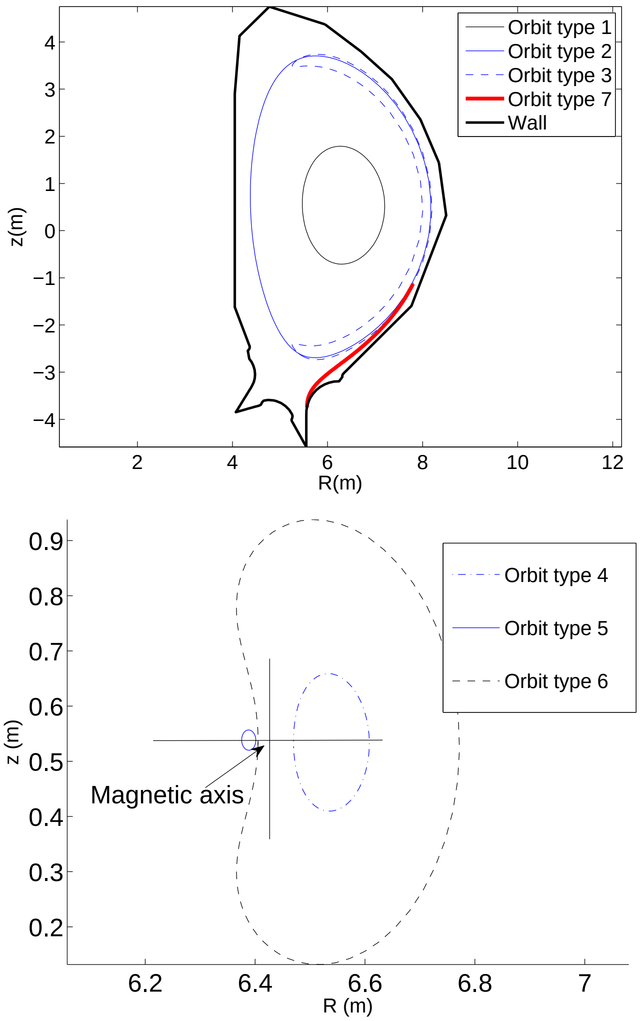

Figure 3.9. The seven different orbit types identified by SOFI (ITER geometry).

SOFI will be integrated into a computational platform, EFDA-ITM Gateway, that will serve as a collection of plasma and fusion codes. Combined, these codes will eventually form a single computational model for a real fusion reactor. The task is not easy, and is planned to be accomplished around the year 2011. Codes at the Gateway, SOFI among them, will enable the simulation, preparation and analysis of future ITER plasma discharges.

3.3.4 Neutral beam injection module for ASCOT

Principal Scientist: O. Asunta, Tekes – TKK

A new NBI model for ASCOT has been developed. It is based on modelling individual beamlets, the smallest structures in an NBI source. To generate an NBI test particle, a neutral particle from a random beamlet of a random injector is chosen. The particle is then advanced along its velocity vector until it is ionized and a test particle for ASCOT is recorded. The dispersion distribution of each beamlet is taken into account in the model. An example of an ensemble of NBI-generated ions in ITER geometry is shown in Figure 3.10.

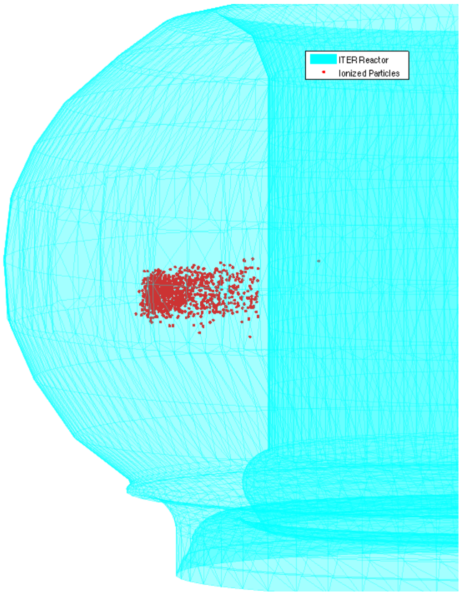

Figure 3.10. An Ensemble of NBI-generated ions in ITER geometry as produced by the new NBI module in ASCOT

3.4 Power and particle exhaust, plasma-wall interaction

3.4.1 Material transport and erosion/deposition in the JET torus

EFDA-JET Task:	JW8-FT-3.38
Principal Investigators:	J. Likonen, Tekes – VTT
Collaboration:	P. Coad, UKAEA-JET

Background: The transport of material as well as erosion and deposition in the JET torus have been studied since 2001, and this has covered a number of different divertor configurations. The MkII-GB (Gas Box) was in operation between 1998 and 2001, the MkII-SRP (Septum replacement Plate) in 2001–2004, and it was followed by the MkII-HD (High Delta) in 2005. During these different configurations, JET has been operated with CFC as the plasma-facing material. Deposition in the divertor region has been highly asymmetric during each period, with heavy deposition at the inner divertor but just small net erosion at the outer divertor. This behavior is not properly understood. In the ITER-like wall (ILW) project, the main wall of JET has been planned to be covered with solid beryllium and the divertor tiles be replaced with tungsten-coated ones. In addition, there are certain so-called shine-through areas at the inner wall which are exposed to high power fluxes due to neutral beam injectors, and these areas will also be covered with tungsten. In 2008, some tungsten-coated test tiles from the shine-through and divertor regions have been characterized using Secondary Ion Mass Spectrometry (SIMS) and optical microscopy. Moreover, erosion and deposition in the divertor tiles exposed to plasma during the period 1998-2007 have been investigated. The work has been done in close collaboration with JET under the JET Task Force Fusion Technology.

Main results in 2008: The main emphasis in 2008 was in the analysis of coated test tiles for the ILW project. There are regions at the inner wall in line with the neutral beam injectors where high power fluxes are expected if part of the beam power passes through the plasma down to the inner wall. This may happen if the plasma density falls rapidly before the beams are switched off. Figure 3.11 shows a coated Inner Wall Guard Limiter (IWGL) tile after its exposure in 2005–2007.

The two coated regions are clearly visible, and the SIMS depth profile in the inset shows a tungsten layer with a thickness of about 1 μm. There is a thin layer on the surface containing typical impurities in the plasma such as beryllium, carbon, and nickel. No significant differences in the thicknesses of the deposited layers either across the tile, or in comparison to the metal films on masks used during the coating process, could be attributed to erosion during the campaign in question. This experiment shows that there is no evidence of any shine-through effects of neutral beams.

Erosion and deposition at the divertor during the 1998-2007 operations were investigated using SIMS and optical microscopy. Deposition in the divertor tiles was observed to be asymmetric, i.e., deposition occurs in the scrape-off layer (SOL) at the inner divertor whereas there is erosion at the outer divertor. There is very heavy deposition in the sloping part and shadowed areas on divertor tiles 4 and 6 (see Figure 3.12 and Figure 3.13). The thickness of the co-deposited layer is about 400 μm on the sloping part of tile 4, but there is even a thicker film on the corresponding parts of tile 6.

The shadowed areas, the sloping parts and the louvers contain the highest amounts of retained hydrogen isotopes at JET.

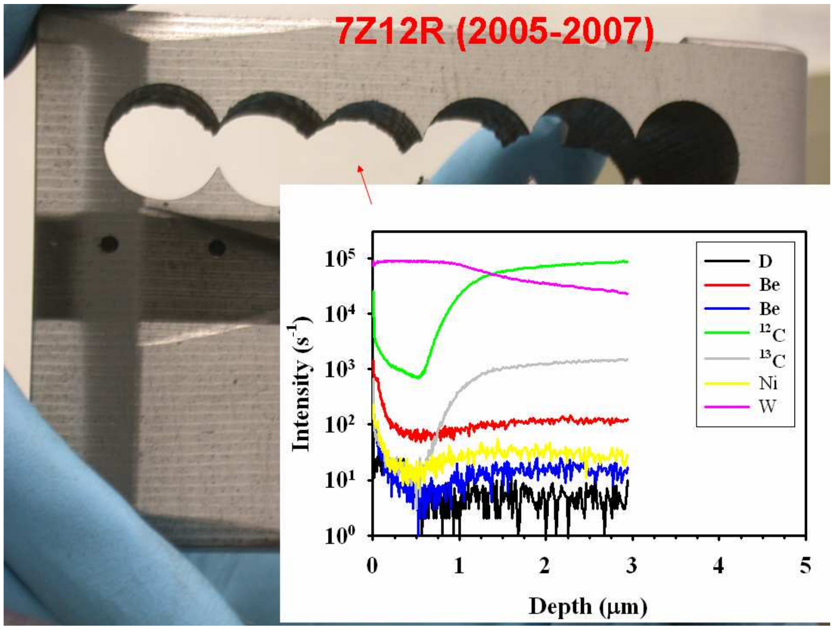

Figure 3.11. Coated IWGL tile after exposure at JET. The upper half of the tile was coated with tungsten and the lower part with rhenium. In addition, a SIMS depth profile of different elements taken from one of the analyzed samples is shown in the inset.

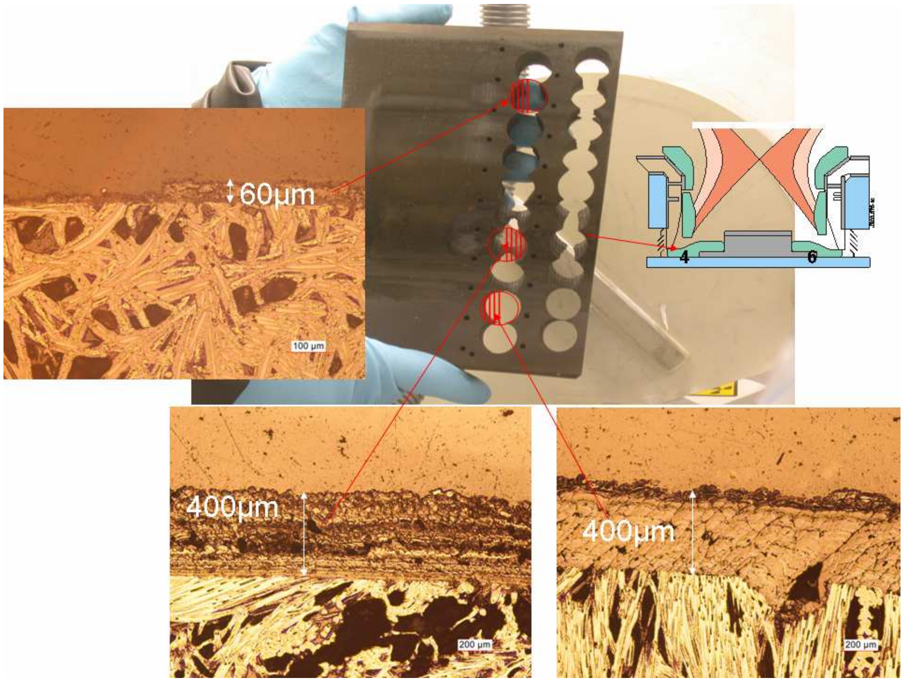

Figure 3.12. JET divertor tile 4 and optical microscope images of cross-section samples. The divertor MkII-SRP is also shown in the figure.

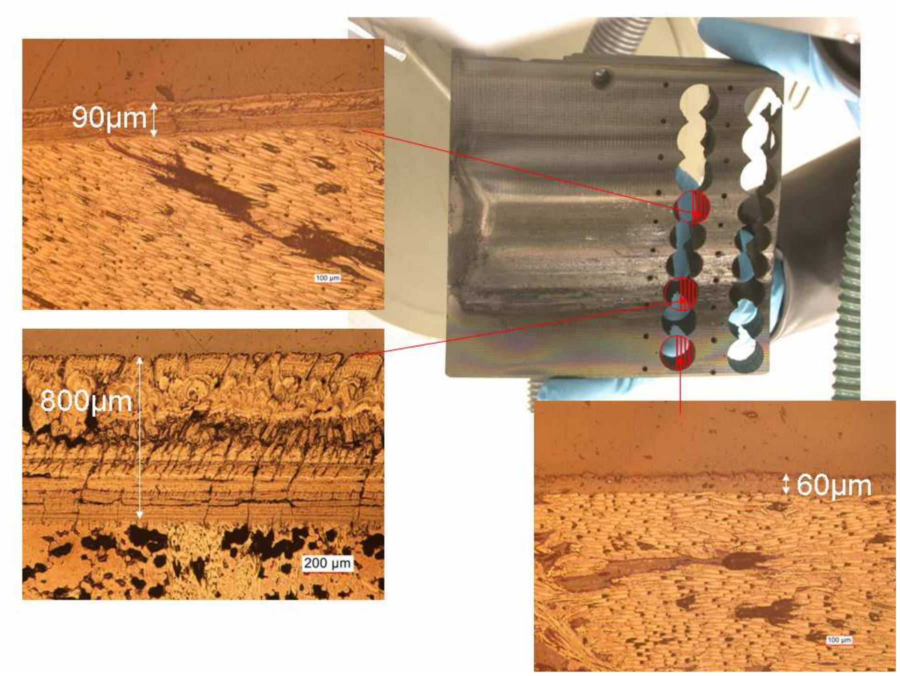

Figure 3.13. JET divertor tile 6 and optical microscope images of cross-section samples.

3.4.2 Erosion and deposition studies in ASDEX Upgrade

EFDA PWI Tasks:	PWI-08-TA-01/04, TA-06/08, TA-07/08
Principal Investigators:	A. Hakola, Tekes – TKK J. Likonen, Tekes – VTT
Collaboration:	V. Rohde, R. Neu, M. Mayer, IPP Garching J. Kolehmainen, DIARC Technology Inc.

Principal Investigators -> Principal tekes scientists:

Main results in 2008: The main effort in 2008 was put in analyzing a set of wall tiles of ASDEX Upgrade using the SIMS technique; the tiles had been removed from one poloidal cross section after the 2007 campaign. By the beginning of that campaign, the whole first wall was covered with tungsten-coated graphite tiles and, as a result, ASDEX Upgrade was operated for the first time as a full-tungsten device. SIMS results were therefore anticipated to give important information on the erosion of the tungsten films and deposition of different elements, particularly carbon (mainly 12C) and deuterium, on the tiles. In addition to the analysis of layers accumulated on the tile surfaces during the campaign, the transport and subsequent deposition of carbon in different locations was investigated more closely by injecting ^{13}C into the torus in the last experimental day of the campaign and determining the poloidal ^{13}C deposition profile.

The deposition of carbon (^{12}C) was studied by evaluating from the measured SIMS depth profiles the integrated amount of carbon in the tungsten coating as a function of the poloidal s coordinate; this coordinate starts from the innermost corner of the lower divertor and runs counter-clockwise along the tile surfaces, around the poloidal cross section down to its starting point. The deposition was observed to have been peaked close to the strike points but significant carbon surface layer densities were also found in the whole outer divertor and in the samples from the innermost divertor tiles. What comes to the main-chamber tiles, carbon was noticed to be present to a high degree in samples from the upper divertor the top and middle parts of the heat shield. The calculated concentrations were comparable to those obtained from the strike-point samples, which indicates that the inner wall all over to the top of the torus is dominated by deposition for the discharge type used in the C13 injection experiments.

The retention of the deuterium fuel in the vessel structures was investigated in a similar way: the integrated amount of deuterium in the samples was evaluated as a function of the s coordinate. The analysis was complicated by the fact that the D signal could not be adjusted to totally reside inside the measurement window simultaneously with the stronger signal from the heavier tungsten. This led to huge variations in the determined D contents and in the poloidal retention profile. However, the results suggest that retention is higher in the inner than in the outer divertor.

To study erosion, the thicknesses of the remaining W layers were calculated from the SIMS data. The true, quantitative amount and extent of erosion can only be determined after the reference data has been analyzed but, nevertheless, highest erosion (by assuming that the original thicknesses of the coatings have been approximately the same everywhere) has clearly taken place at the outer roof baffle and the outer divertor. This is accordance with earlier observations that outer divertor is an erosion-dominated region.

^{13}C was injected into ASDEX Upgrade in the form of labelled methane ($^{13}CH_4$) during 12 identical, lower single-null L-mode discharges in deuterium. The poloidal distribution of ^{13}C was taken from the same samples as in the long-term deposition and erosion studies discussed above, and the integrated ^{13}C surface densities at different places are shown in Figure 3.14 and Figure 3.15. The deposition is larger at the inner than at the outer divertor but generally rather small. Especially at the outer divertor, it is hard to see any ^{13}C on the W surface exceeding the background level. Clear peaks can only be observed close to the inner strike point and in the innermost divertor tiles. Surface densities of the same order of magnitude were also measured for some of the samples from the analyzed limiter and upper-divertor tiles, as well as for small silicon samples mounted under the roof baffle.

For the 2009 ASDEX Upgrade campaign, selected divertor tiles were coated by DIARC Technology Inc. in December 2008, and they have been installed in the torus in January-February 2009. The strike-point and the outermost lower-divertor tiles have marker stripes on them along with the W film to enable detailed erosion studies, whereas an insulating layer has been prepared on two innermost lower-divertor tiles to investigate arcing close to them.

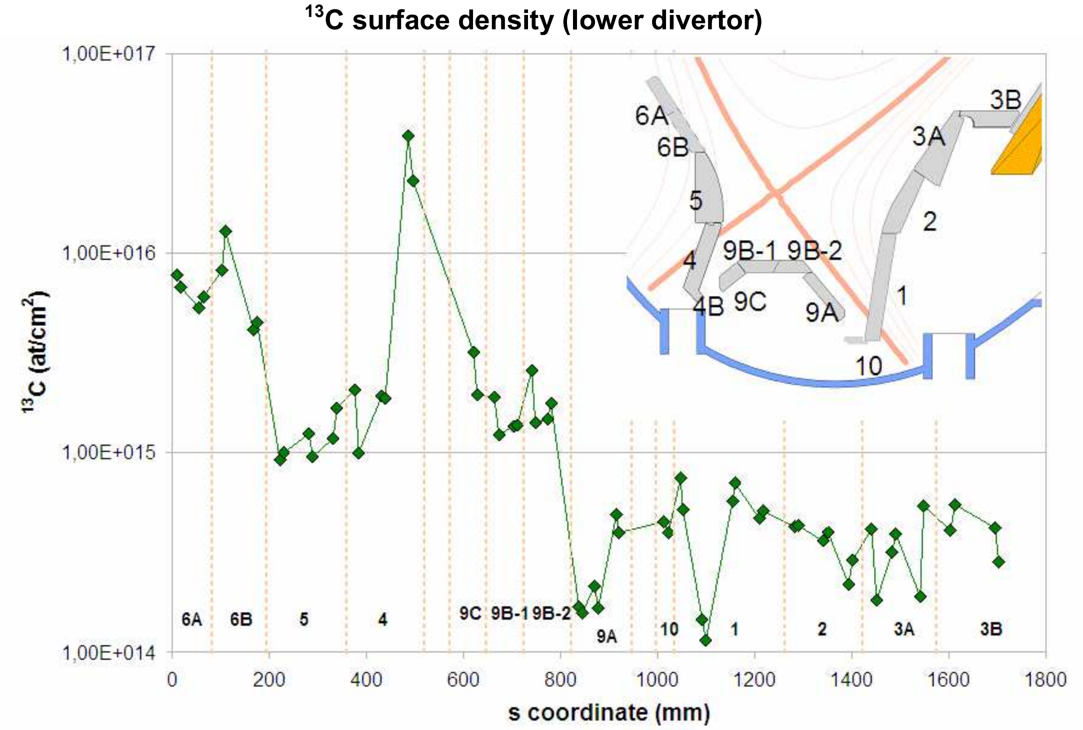

Figure 3.14. Integrated ^{13}C surface density as a function of the s coordinate in the lower divertor.

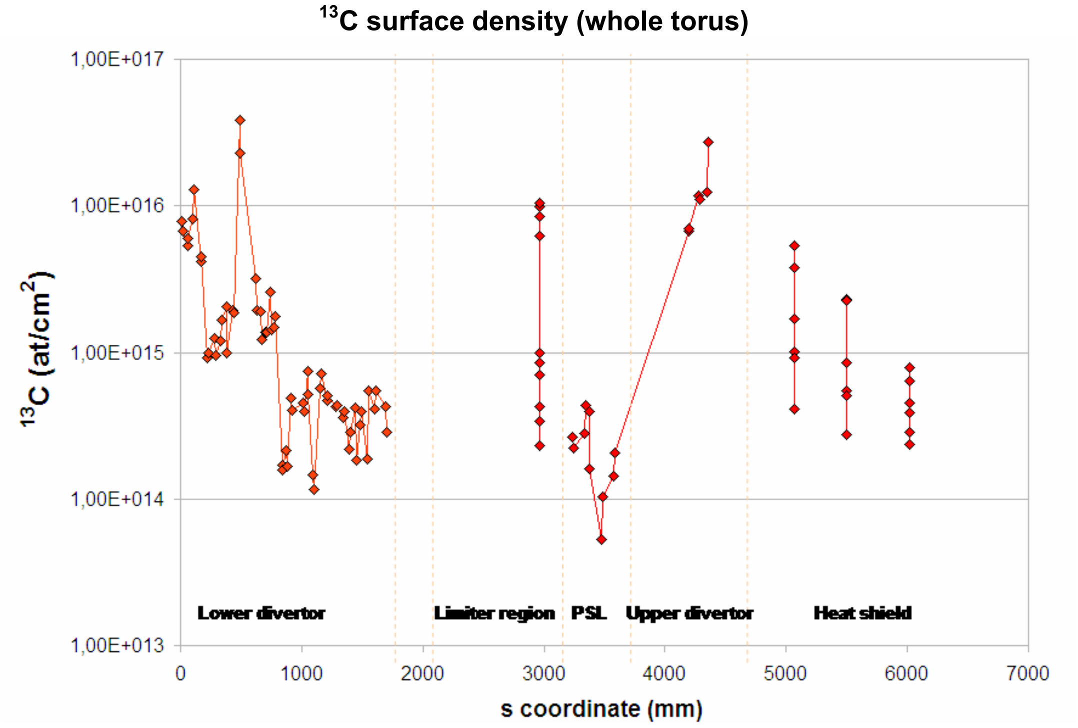

Figure 3.15. Integrated ^{13}C surface density as a function of the s coordinate around the whole torus.

3.4.3 Understanding of impurity transport in plasma edge

Principal Tekes Scientists:	M. Airila, Tekes – VTT L. Aho-Mantila, T. Makkonen, Tekes – TKK
Collaboration:	A. Chankin, M. Wischmeier, R. Pugno, D. Coster, K. Krieger, IPP Garching

Introduction: Tracer injection experiments in tokamaks provide information on material migration and deposition under constant plasma conditions. In plasma devices with carbon plasma-facing components a suitable tracer is the natural isotope ^{13}C that can be distinguished from ^{12}C in post-mortem surface analyses. The principal carbon migration can be investigated by injecting a tracer-containing molecule such as $^{13}CD_4$ from a net erosion zone.

Carbon migration in plasma is a complex process starting from physical or chemical erosion of the surface by particle bombardment, followed by transport under the influence of electromagnetic forces, plasma flow, thermal forces and diffusion. Finally, the eroded or injected particles are deposited on the plasma-facing surfaces, where re-erosion may occur, or in remote areas. The diagnostic capabilities for studying the details of this process are limited: The density distributions of impurity species in the plasma can be obtained in situ by spectroscopy, and the final tracer distribution on plasma-facing components can be measured ex situ by e.g. ion beam techniques. Interpretation of the measurements requires in addition computer simulations.

We have modelled the local transport process in the vicinity of the divertor surface with the 3D Monte Carlo impurity transport code ERO, developed at IPP Garching and FZJ Jülich, Germany. In 2008 this simulation work was directed to a series of tracer experiments of ASDEX Upgrade (AUG) in 2003–2008 and the 2004 tracer experiment of JET. Global migration of carbon in the AUG scrape-off layer has been modelled with DIVIMP, focusing on the experiment conducted in 2007.

SOLPS/ERO modelling of the 2003–2008 AUG outer divertor tracer experiments: Local transport of carbon has been investigated at AUG by means of $^{13}CH_4$ tracer injection at the outer divertor. In 2003, the experiment was conducted in H-mode. Thereafter the experimental series has been continued in L-mode which, mainly due to the lack of ELMs, can be modelled with better confidence than the H-mode. A so-called reference L-mode experiment was carried out in 2007. In summer 2008, the effect of a reversed toroidal magnetic field in this scenario was investigated, but problems with the discharge configuration hindered the outcome of the experiment. At the end of the year 2008, possible local perturbation of the divertor plasma was investigated by injecting the methane with half the original rate. Global plasma conditions of the 2007 experiment were well reproduced in this experiment, and the analysis of the deposition layer is ongoing.

The main characteristics of the deposition patterns have been obtained via post-mortem NRA measurements of the divertor surface layer. In addition, the tungsten coating used during the L-mode experiments allows for a colorimetric analysis of the deposition. The analyses indicate that in both H- and L-mode, practically all of the carbon injected from the outer divertor gets locally deposited around the injection location. The deposition tail follows the magnetic field line except for a small deviation in the direction of the ***ExB*** drift, being opposite in the reversed ***B*** experiment. In the reference L-mode experiment, a significant fraction of the carbon (~40%) was also found deposited upstream from the gas valve.

Simulations of the 2003 H-mode injection experiment were completed in year 2008. The shape of deposition pattern was reproduced with a close match for both toroidal and poloidal decay lengths of ^{13}C surface density, but the deposited amount is only 14% in simulations. In contrast, the NRA analysis indicates that virtually all puffed carbon was locally deposited also in this experiment. The deviation of the deposition tail from ***B*** direction can be reproduced by imposing a uniform electric field in the simulation.

Modelling of the local transport in AUG focuses nowadays on the L-mode experiments. The scrape-off layer plasma has been simulated with the combined 2D fluid plasma – Monte Carlo neutrals code SOLPS, with the objective of reproducing all available diagnostics data. In 2008, a reasonable solution for the reference L-mode experiment was obtained. The injection of methane and consequent layer formation has been modelled with ERO, using both various SOLPS solutions and user-defined constant plasma backgrounds. The simulations indicate that the carbon deposition pattern, in particular the amount of upstream deposition, is very sensitive to the local plasma conditions. This observation is consistent with the experimental results and emphasizes the importance of realistic modelling of the divertor plasma. The modelling underestimates the deposited fraction, but future efforts to describe the surface roughness are likely to improve the match.

ERO modelling of the 2004 tracer experiment of JET: In the 2004 tracer experiment of JET, $^{13}CH_4$ was injected into H-mode plasma at the outer divertor through 48 injectors distributed around the torus. Deposition measurements and spectroscopy are available from this experiment, which provides a possibility to benchmark the physics models of ERO. However, there are considerable experimental uncertainties, e.g., leakage of the tracer gas away from the injector, which make precise quantitative comparison difficult.

In ERO modelling, EDGE2D fluid plasma solutions for inter-ELM and ELM-peak phases were used as plasma backgrounds. Local 2D deposition patterns at the vertical outer divertor target plate were obtained for comparison with post-mortem surface analyses. ERO also provides emission profiles for comparison with radially resolved spectroscopic measurements. Modelling indicates that enhanced re-erosion of deposited carbon layers is essential in explaining the amount of local deposition. Assuming negligible effective sticking of hydrocarbons, the measured local deposition of 20–34% is reproduced if re-erosion of deposits is enhanced by a factor of 2.5–7 compared to graphite erosion. If deposits are treated like the substrate, the modelled deposition is much higher, about 55%. The shape of deposition pattern is strongly affected by the divertor geometry near the injection point which casts a shadow onto neighbouring tiles. Deposition at the shadowed area and inside tile gaps was simulated with a simple model included in ERO. This model inhibits re-erosion in the shadow, which helps explaining SIMS and ion beam measurements. More detailed modelling of neutral deposition in tile gaps has been initiated and will be carried out in collaboration with FZJ Jülich.

Since the 2004 injection experiment was in H-mode, it is obvious that ELMs may have affected the material migration. The effect of ELMs on deposition was investigated with a simple model utilizing successively two different EDGE2D solutions (ELM-peak and inter-ELM) as the plasma background in ERO. The results suggest that ELMs slightly change the deposition pattern and decrease the time-averaged deposition efficiency.

DIVIMP modelling of the 2007 AUG global migration experiment: At the end of the 2007 AUG campaign, a global carbon migration experiment was conducted by injecting $^{13}CH_4$ at the outer plasma midplane. A poloidal set of wall tiles was then removed and the deposition profiles measured at VTT using SIMS. The 2007 experiment was modelled using the 2D impurity transport code DIVIMP to replicate the measured deposition profile. DIVIMP follows ion guiding centre along the magnetic field lines and applies effects such as ionization and diffusion in a probabilistic, Monte Carlo manner.

The main idea behind the work is to benchmark the DIVIMP code. If successful, DIVIMP can further be used to make predictions about the co-deposition of tritium with carbon. DIVIMP also allows for the study of important physics behind carbon migration. Perhaps it is possible to identify key plasma parameters controlling the process. Computer simulations also open up the possibility of studying other, more intricate processes. Diffusion of particles in plasma is not very well understood, but effective values of the diffusion coefficient are perfectly suitable to be studied with DIVIMP by parameter scans.

The early results have been promising. DIVIMP can reasonably well replicate the deposition profile at the lower divertor. The scan for diffusion coefficients produced a value in the range of 1 to 2 m²/s. Still, much remains to be improved.

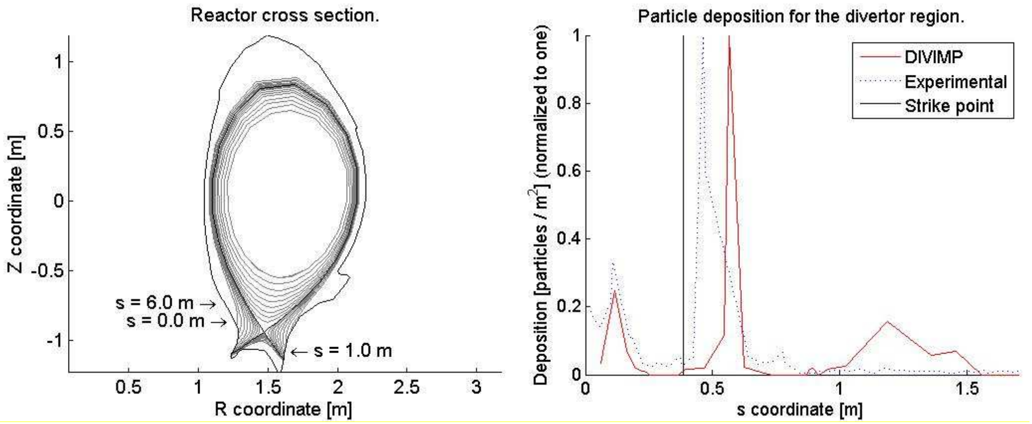

Figure 3.16. Left: Cross section of the reactor wall, the magnetic geometry, and the s-coordinate. (The s-coordinate runs along the wall and is used for plotting the results.) Right: Deposition in the divertor region from experiments and simulation.

3.4.4 Inclusion of ELMs, shadowed areas and electric fields in ERO modelling

Principal Tekes Scientist: M. Airila, Tekes - VTT

In connection to the modelling of the 2004 JET H-mode tracer experiment a need of accounting the effect of ELMs was identified. All earlier ERO modelling studies have assumed a stationary plasma background. As there are EDGE2D fluid plasma solutions available for both ELM-peak and inter-ELM time moments, it is possible to simulate the effect of the cyclic loading by alternating the inter-ELM and ELM-peak plasmas at successive time steps of ERO simulation. The lengths of time steps were chosen to match the respective phases, that is, the ELM-peak plasma is effective only about 1% of the total simulation time. Due to considerably higher edge temperatures, local sputtering during this phase is significant, which leads to redistribution of the deposited marker carbon. The steady-state deposition efficiency, however, decreases only little in comparison to the deposition in the pure inter-ELM plasma. It was found that the steady-state surface composition is reached quickly after a short transient if the cyclic simulation is started from the equilibrium surface obtained with the inter-ELM plasma. The model would need improvement e.g. in the handling of thermal effects which are presently neglected.

Another characteristic feature of the 2004 JET tracer experiment was the fact that the marker methane was injected through a region shadowed from the plasma. In surface analyses the shadowed neighbourhood of the gas injection module showed significant deposition. We first developed a simple model which allows the accumulation of deposits in the shadow by preventing hot, dense plasma from reaching the region in simulations. This assumption improves remarkably the match between ERO results and surface analyses, as shown in Figure 3.17. More detailed modelling with interchange of data between ERO and the 3DGap code, under development at FZJ Jülich, is planned

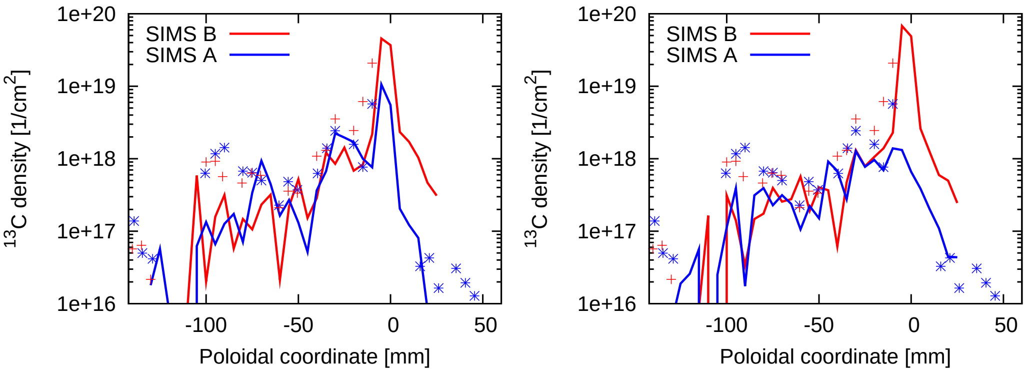

Figure 3.17. Comparison of measured (markers) and simulated (lines) poloidal deposition profiles at the outer divertor in the 2004 JET tracer injection experiment. Left: The simulation with the simple shadow model. Right: Simulation without shadow. The match along the line "SIMS A" (blue) is much better with the shadow than without it.

Local $^{13}CH_4$ tracer injection experiments at AUG have revealed that the ionized methane molecules experience a significant ***ExB*** drift in the vicinity of the divertor surface. The electric field required to reproduce the experimental drift is observed to be a lot stronger than that calculated by the ERO code for the sheath. Up to now, we have determined the required magnitude of the electric field for the simulated experiments, but the aim in the future is to develop the ERO description of local electric field. This includes comparisons with the SOLPS solution for plasma potential.

3.4.5 Hydrogen migration in high Z plasma-facing materials

Principal Scientist: K. Nordlund, Tekes – UH

In our earlier experimental work we have implanted deuterium (D) into polycrystalline tungsten (W) and studied its trapping into implantation induced defects with various experimental methods, i.e. secondary ion mass spectrometry (SIMS) for measuring the D depth profile, nuclear reaction analysis (NRA) for deducing the total number of trapped D and quadrupole mass spectrometry (QMS) for measuring the dynamics of out-diffused D_2 gas. This work has revealed the existence of at least four different defect types in W that can trap deuterium. In 2008 we have done computational studies to examine hydrogen diffusion and trapping behaviour in W and as well the energetics of W defects.

The diffusion parameters, i.e. migration barrier for diffusion E_m, hopping frequency Γ and the diffusion constant D, were studied using electron density functional theories (DFT). The DFT calculations were performed with the Vienna *ab initio* Simulation Package (VASP). A supercell containing 128 W atoms was used to describe W bulk properties. The semi-core electrons (12 *e*) were included in the calculations, but recent re-calculations with 6 *e*'s have shown better agreement with the experimental bulk properties. The hydrogen ground state was found at the tetrahedral site in accordance with the experiments. The migration barrier E_m between two adjacent ground states was calculated using the nudged elastic band (NEB) method. E_m was found to be somewhat less than the experimental result. This discrepancy can be partly explained as a DFT related issue and partly as not having an ideal pure perfect W lattice in real experiments. Calculated Γ and D were determined in accordance with the harmonic transition state theory (TST). Hydrogen binding energies to a W monovacancy was determined using DFT calculations. It was found that H doesn't form molecules inside a vacancy. Up to six H atoms can be occupied by a single monovacancy at room temperature when the hydrogen zero point energies (ZPE) are taken into account. This is a relevant factor when considering W as hydrogen trapping plasma facing material in ITER.

A reactive interatomic bond-order potential for W was developed. Bond-order potentials are semi-empirical real space potentials to calculate interatomic interaction energies from the local arrangement of atoms. Special attention in this work was given to obtain accurate formation and migration energies for W point defects, making the potential useful in atomic scale simulations of point and extended defects. The vacancy cluster configurations up to ten vacancies with the lowest formation energies were determined with the developed potential, see Figure 3.18. These configurations will be used in studying the interaction of hydrogen and W vacancy clusters and voids. The recombination radius for a W self-interstitial atom (SIA) and a monovacancy, i.e. Frenkel pair, see Figure 3.19, was found after calculating the SIA configuration with the lowest formation energy. According to our result the recombination radius has not spherical, but an ellipsoidal dependence being larger to the direction of SIA lattice symmetry. This can be explained by the quasiparticle behaviour of the SIA, since it is formed by the SIA and six other W atoms displaced from their initial lattice sites. This self-interstitial configuration will lead to a very high mobility of SIA's in W and can explain the recovery stage Ia.

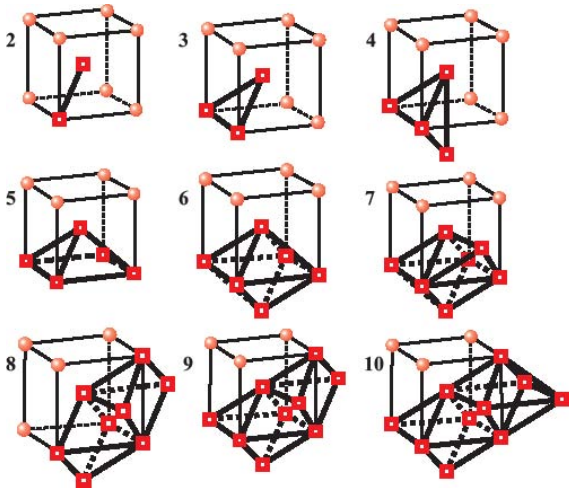

Figure 3.18. Vacancy cluster configurations with the lowest formation energies. Calculations were done using present bond-order potential together with the molecular statics method.

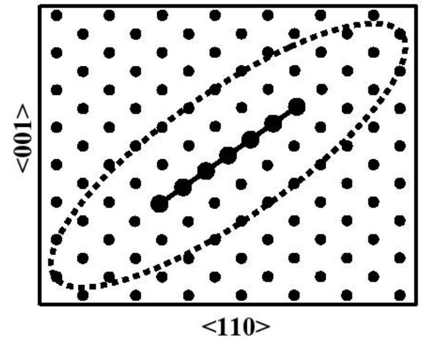

Figure 3.19. A vacancy inside the dotted line (recombination radius) is immediately annihilated by the self-interstitial. The semi major axis in <111> direction is about 18 Å and the semi minor axis is about 5.4 Å.

3.5 Theory and Modelling for ITER

3.5.1 ASCOT modelling of fast ion power loads in ITER

Principal Tekes Scientists:	T. Koskela, V. Hynönen, Tekes – TKK
Collaboration:	G. Saibene, F4E V. Parail, UKAEA-JET

The new physics introduced by ITER operation, of which there is very little prior experience, is related to the very energetic (3.5 MeV) alpha particles produced in large quantities in fusion reactions. These particles not only constitute a massive energy source inside the plasma, but also a potential hazard to the material structures that provide the containment of the burning plasma. In addition, non-isotropic fast ion populations are created by external heating: the negative neutral beam injection (NBI) produces ~1 MeV deuterons and the application of ICRH minority ions in multi-MeV range.

The wall loads due to fusion alphas as well as NBI- and ICRF-generated fast ions were simulated for ITER Scenario-2 and Scenario-4 including the effects of ferritic inserts (FI) and Test Blanket Modules (TBM). The simulations were carried out using the Monte Carlo guiding centre orbit-following code ASCOT.

The ferritic inserts were found very effective in ameliorating the detrimental effects of the toroidal ripple: the fast ion wall loads are reduced practically to their axisymmetric level. The thermonuclear alpha particles overwhelmingly dominate the wall power flux. The load is concentrated on the port limiters, with very little power flux to other components in the first wall or even the divertor. In contrast, uncompensated ripple leads to unacceptable peak power fluxes of 0.5 MW/m^2 in Scenario-2 and 1 MW/m^2 in Scenario-4, with practically all power hitting the port limiters and noticable flux arriving even at the unprotected first wall components. This is illustrated in Figure 3.20. This is an improvement to earlier results, where hot spots were observed on a 2D wall.

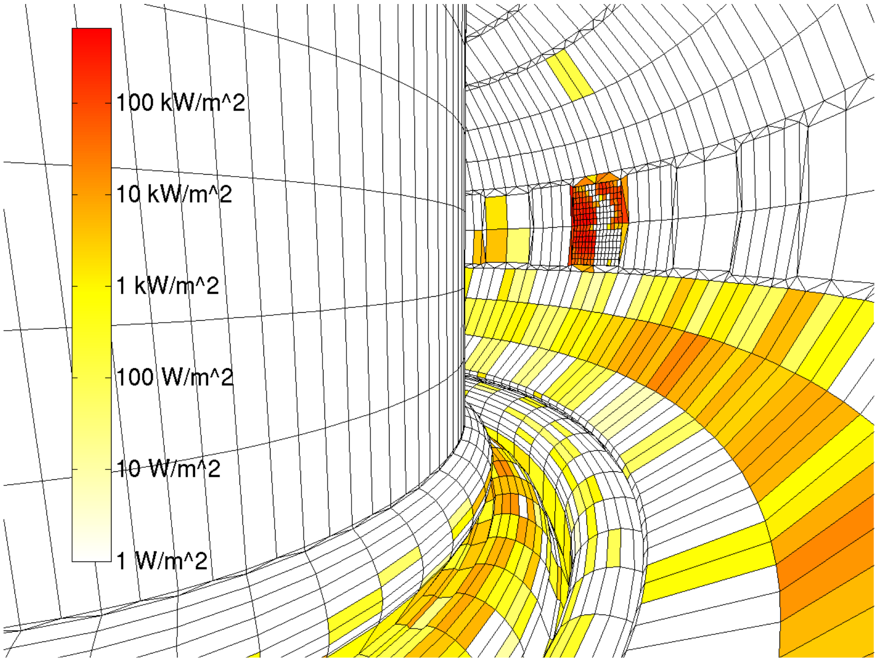

Figure 3.20. The wall power fluxes due to fusion alphas in ITER as given by ASCOT simulations of Scenario-2 plasma with uncompensated toroidal ripple.

The introduction of the local Test Blanket Modules (TBM) was found to perturb the magnetic field structure globally and lead to increased wall loads. The load increase was qualitatively different from that brought about by the ripple: even the passing particles were found to be transported anomalously albeit on a long time scale, leading to an increased flux of slowed-down particles. The total wall load approaches that of the uncompensated ripple case, but its distribution on the wall is more benign with practically no power flux on the unprotected wall components. In the case of NBI ions, most of the power ended up at the divertor, not at the limiters like with ripple transport.

However, the simulations overestimated the influence of the TBMs due to an over-simplification in the vacuum field.

3.5.2 Predictive modelling of ITER scenarios

Principal Tekes Scientist: J. Lönnroth, Tekes – TKK
Collaboration: EFDA-JET contributors

Under the auspices of EFDA, predictive modelling of ITER plasmas is carried out within the ITER Scenario Modelling (ISM) group of the Integrated Tokamak Modelling Task Force (Task Force ITM). The aim of the activity is to support the ITER organization by studying various physics issues relevant to the design and performance of ITER.

The Tekes contribution has included several topics. First, the MHD stability of ITER-like JET current ramp-down plasmas has been studied. These are JET discharges with a special ITER-like configuration. Experimentally, it has been observed that a current ramp-down in these discharges triggers a transition from type I to type III ELMs characterized by an increase in the ELM frequency and a deterioration of plasma confinement. By studying the MHD stability of these discharges at various times during the current ramp-down, it has been concluded that a current-ramp down in these plasmas may trigger a transition from second to first ballooning stability. The reduction in critical pressure gradient due to the transition could explain the increase in the ELM frequency and the deterioration of plasma confinement seen experimentally.

In other related work, it has been studied how well different transport models, in particular the original Bohm transport model developed for L-mode plasmas at JET many years ago, reproduce the plasma profiles and various other plasma parameters in ITER-like JET L-mode discharges with current ramp-down. It has been concluded that the original Bohm transport model will be accurate also for ITER Ohmic L-mode plasmas with current ramp-down.

After this, most effort has been directed at trying to establish the level of marginal stability for ITER plasmas. Knowing the marginally stable level of the edge pressure gradient is important, because all predictive transport analysis makes use of this information. The MHD stability analysis has so far proved to be somewhat inconclusive due to the occurrence of spurious unstable modes in large regions of the parameter space. Work aimed at resolving this issue is still in progress.

3.6 Plasma Diagnostics

3.6.1 Upgrading JET NPA detectors

Principal Tekes Scientist: M Santala, Tekes – TKK
Collaboration: EFDA-JET contributors

Neutral particle analysers (NPAs) detect atoms (ie. neutralised ions) which escape the plasma. As neutral atoms are not bound by the magnetic field they may escape the plasma and give information on the ion population even deep inside the plasma. The

NPAs measure the escaping atom flux in terms of atom species and energy as function of time.

There are two NPAs at JET. The high energy NPA (GEMMA-2M, diagnostic ID KF1) is installed on top of the JET machine and has a vertical line-of-sight. It can be configured to measure one ion species on eight energy channels with an energy of 250-1600 keV for hydrogen isotopes and up to 3500 keV for He. The low energy NPA (ISEP, diagnostic ID KR2) has a horizontal, radial line-of-sight through the plasma centre. It measures simultaneously all three hydrogen isotopes on a total of 32 channels. The energy range can be configured from 5 keV to 750 keV (for H) by varying the electric and magnetic fields within the diagnostic. The diagnostic hardware as well as all data collection electronics has been supplied to JET by Ioffe Institute, St. Petersburg.

Presently, thin CsI(Tl) detectors coupled to photomultipliers are used to detect the ions in the NPAs. These detectors are limited due to slow response of CsI(Tl), their background sensitivity and poor energy resolution. A major drawback is that it is not possible to distinguish between alphas and deuterons in a single detector.

JET EP2 diagnostic project- NPA detector upgrade: In the JET EP2 project, thin silicon detectors have been developed using SOI technology. Earlier, the detectors have been designed and prototypes manufactures. The performance of the detectors was assessed during year 2008. Tekes is the leading association in this project and the collaboration involves Helsinki Institute of Physics, VTT Microelectronics, Helsinki University of Technology and Ioffe Institute.

Laboratory testing was carried out at VTT Microelectronics and Helsinki University of Technology. The beam testing was initially subcontracted from a group in Helsinki Insititute of Physics, however, after unacceptable delays the beam tests were carried out as a direct collaboration between Helsinki University of Technology and the Pelletron facility at Jyväskylä University. Pulse height spectra measured with protons from 190 keV to 1500 keV are shown in Figure 3.23.

From the physics point-of-view the performance of the detectors meets the goals that were laid out in the beginning of the project. Detection of protons and alphas over a wide energy range was demonstrated and the pulse-height response is narrow enough to permit separation of different ion species based on their pulse height spectra. Weak sensitivity to gamma ray background was demonstrated in laboratory.

Although the leakage current of the reverse-biased detectors was generally low, several of the detectors exhibited creep of the leakage current during beam tests. This has raised concerns over long-term viability of the detectors. It has been proven that the origin of the problems is at the detector surface, however, so far it has not been possible to pinpoint the mechanism. Further tests are planned to find detectors that do not suffer from the creep.

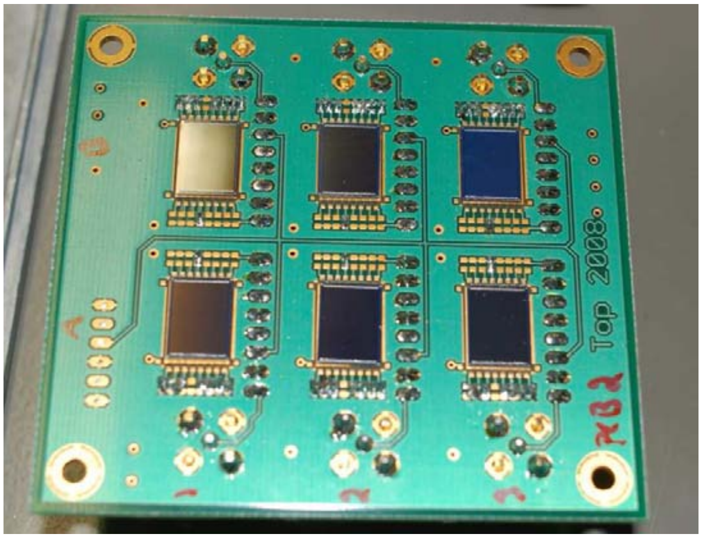

Figure 3.21. A test PCB made for beam tests with six installed detectors

Figure 3.22. Rutherford backscatter chamber used for the beam tests. The test setup has been installed to the front-left port

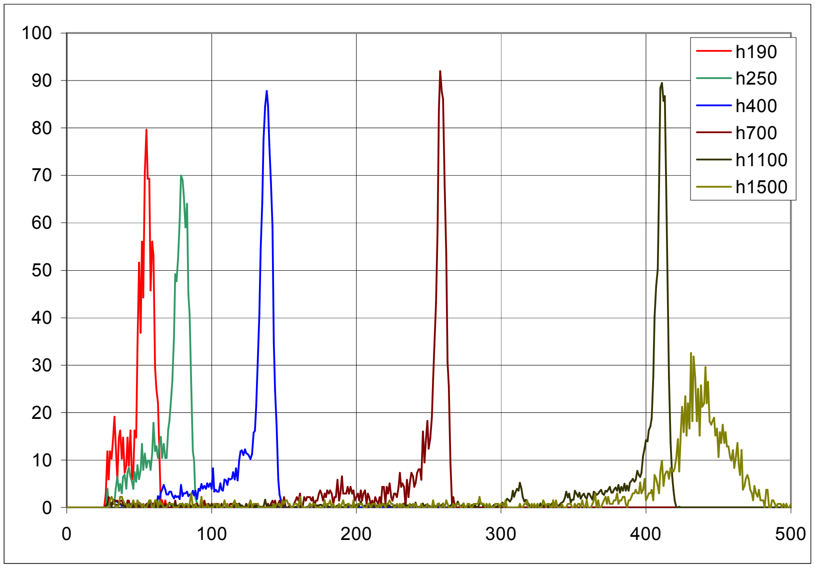

Figure 3.23. Pulse height spectra measured with protons from 190 keV to 1500 keV. The detector thickness was 26 µm and the strips were 95 µm wide.

3.6.2 Developing AUG NPA and FILD diagnostics

Principal Scientist: S. Jämsä, Tekes – TKK
Collaboration: W. Suttrop, H.-U. Fahrbach, IPP Garching

The data acquisition system (DAQ) hardware of neutral particle analyser (NPA) at ASDEX Upgrade was enhanced in 2007. The software was finalised in 2008 and is now run automatically. The results are automatically available to all ASDEX Upgrade team members.

The fast ion loss detector (FILD) measures the flux of fast ions escaping from the plasma. The flux is measured by taking pictures of a scintillator plate that the ions hit. In addition, high frequency time series of the fluxes are recorded with fast photo-multiplier-tubes. During 2008, Simppa Jämsä wrote the software that post-processes and stores the pictures.

3.6.3 Development of Micromechanical magnetometer for ITER

Principal scientist: Jukka Kyynäräinen, Tekes – VTT

Background: Magnetic diagnostics for ITER is to a large degree based on coils of different shapes at various locations, which respond to changes in the magnetic field. This is adequate for characterisation of short plasma pulses, but for longer pulses errors related to integration drift becomes excessive. To eliminate these errors introduction of DC-sensors based on the magnetostatic force generated on current carrying coils have been proposed. Such sensors would not replace the coils, but strategically distributed they could provide a calibration reference for elimination of long term drift errors in coil outputs. The need for such sensors has been recognized in the central documents defining ITER diagnostics.

Proposed and tested force type sensors for fusion diagnostics have so far been constructed by conventional mechanical techniques, which make them bulky and expensive to produce. Micromechanical sensors fabricated on silicon wafers are on the other hand very small and can be cheaply reproduced in large quantities. Such sensors are typically based on the force balance of an elastic element formed from single crystal silicon. This technique is inherently suited for making force type magnetometers, into which the current coils readily be integrated by standard methods used in microelectronics. Prototypes of micromechanical low-field magnetometers have been developed at VTT for measuring e.g. the geomagnetic field.

These magnetometers were irradiated in the VTT FiR research reactor at a fast neutron flux of 1.5×10^{12} n/cm^{2}s and thermal neutron flux of 1.4×10^{12} n/cm2s. The components survived the radiation test without changes in their mechanical or electrical characteristics but the dose was an order of magnitude too small compared to predicted ITER radiation environment. ITER environment will pose a tremendous challenge not only to the sensor but also to the readout electronics owing to radiation, temperature, cable length, and the non-serviceability of the sensors.

Goals: Characterisation of the micromechanical steady state magnetometer in laboratory environment. Irradiation of the sensors with higher dose. Testing and development of the readout electronics for the magnetometer. Characterisation of the magnetometer in a tokamak environment.

Progress in 2008: The redesign of the magnetometer included scaling up the measurement range of the magnetic field, simplifying the manufacturing process, and wafer-level vacuum encapsulation of the sensors. Magnetometers were under fabrication within another project (RESTLES) but the processing was delayed due to other obligations and could not be completed in 2008. Figure 3.24 shows the mask drawing of the new magnetometers and Figure 3.25 a microscope image of the semi-finished sensor. Characterization and irradiation tests will be done in 2009. Readout electronics was under development but magnetometer sensors will be required for finalizing the design and for testing.

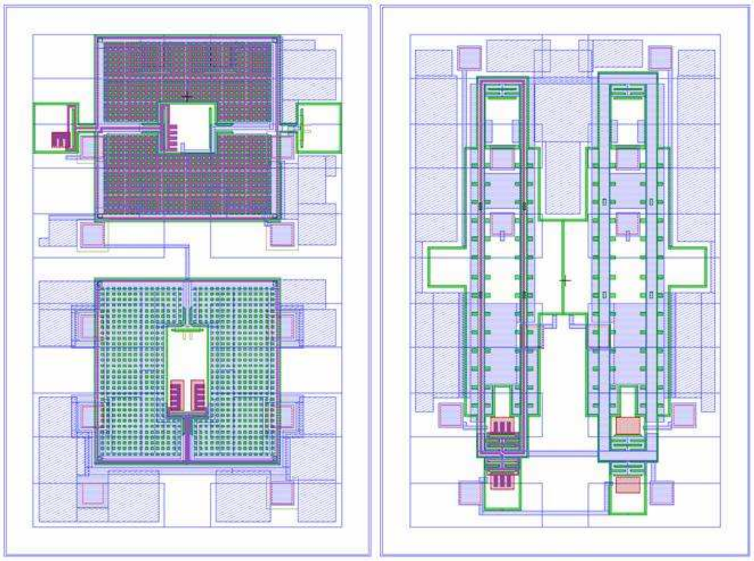

Figure 3.24. Mask drawings of micromechanical magnetometers.

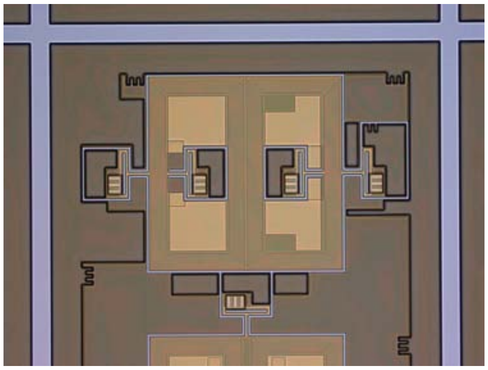

Figure 3.25. Microscope image of a micromechanical magnetometer before vacuum encapsulation

3.6.4 Measuring fast ion distributions in ITER

Principal Tekes Scientist: A. Salmi, Tekes – TKK
Collaboration: EFDA-JET contributors

Collective Thomson Scattering (CTS) diagnostic is foreseen to be used for measuring the distribution of fusion-born alpha particles in ITER. However, in addition to the fusion alphas, CTS will also detect other fast particles in the MeV range, e.g. neutral beam injected (NBI) and ion cyclotron resonance heated (ICRH) ions. To study the effect of the different fast particle populations to the CTS signal, their distributions in a standard steady-state ITER burning plasma equilibrium were calculated. For NBI ions, the distribution, shown in Figure 3.26 was obtained with ASCOT and for fast ions generated by ICRH with PION.

By calculating the CTS scattering functions for fast deuterons, fast tritons, fast ^{3}He, and the fusion born alphas, it was discovered that, in the frequency ranges typical for fast ions, the fusion alphas dominate the measurable signal by an order of magnitude or more. In limited regions in space some non-negligible signal due to beam ions or fast ^{3}He were observed, giving rise to about 30% and 10-20% of the detectable signal, respectively.

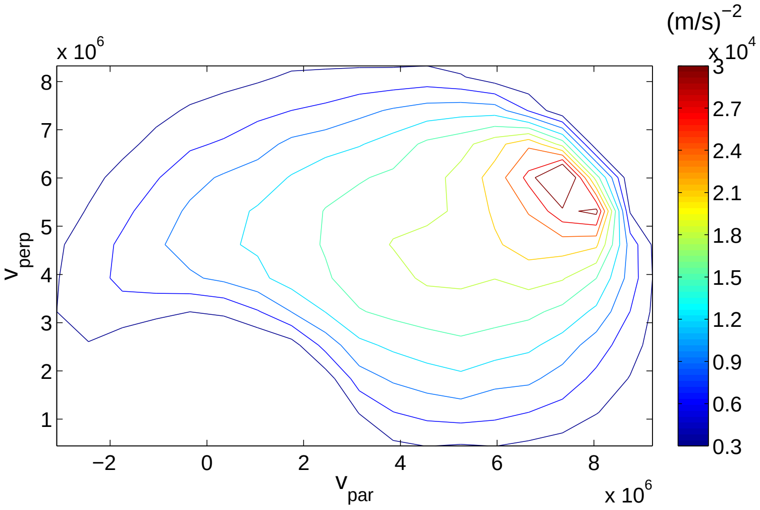

Figure 3.26. The ASCOT-calculated velocity distribution of neutral beam injected ions within the scattering volume of the CTS diagnostics.

3.7 Research Activities of the Estonian Research Unit

3.7.1 Development of in-situ erosion/deposition diagnostics using LIPS

Institute:	Gas Discharge Laboratory (GDL), Institute of Physics, University of Tartu
Principal Scientists:	Matti Laan, Mart Aints, Ants Haljaste, Peeter Paris and Jüri Raud

Like in 2007, LIPS was produced by pulsed UV laser (λ = 248 nm). Most of results were obtained recording temporally non-resolved spectra arising during a single laser shot and preliminary recording of time-resolved spectra were carried out. The main attention was paid to the finding of most suitable combinations of materials of marker layers, which could be used for in situ characterisation of erosion/deposition processes. Besides, the dependence of spectra on the background pressure in the testing chamber as well as the correlation between the material of the layer and laser-induced current pulses were found. It was found that the intensity of characteristic lines of spectra depends strongly on the background pressure: at atmospheric pressure the intensities were about by an order of magnitude higher than at 10 Pa.

Finnish company DIARC Technology prepared samples tested. Samples were prepared on graphite (G) and steel (S) substrates. Diamond-like carbon (DLC) of 1 & 2 μm thickness as a top layer, tungsten (W, 2 & 5 μm) and Re as interlayers were used. It appeared that unlike of W coating on C substrate, in the case of DLC-W-C samples the spectrum of W was not detectable: all recorded intensive lines belonged to carbon species. This unexpected result indicates that in the case of these samples tungsten is not evaporated and tungsten atoms are not excited. Likely the laser causes the delamination of tungsten layer and removal of tungsten in form of flakes. Photos of the sample surface supported the latter assumption: laser traces were surrounded by long tracks. The likely reason of the delamination of tungsten layer is the mismatching of thermal properties of DLC and W coatings. At the same time the amplitude of current pulses, induced by the laser radiation, correlate with the sample material (Figure 3.27): current pulse belonging to the first shot of W-C differs from that belonging to the DLC-W-C sample. When the top layers were removed, the peaks of current pulses coincided.

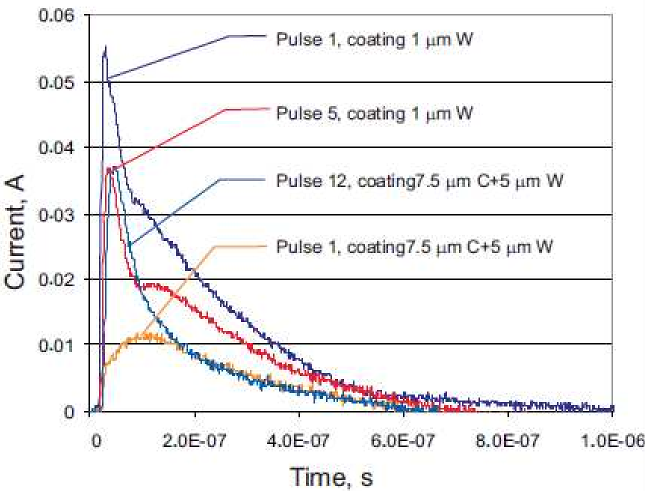

Figure 3.27. Current pulses arising during laser ablation.

As photos of the sample surface showed, the using of DLC-W-Re and DLC-W-Re samples allowed to diminish the effect of delamination and the spectrum of the W interlayer became detectable (Figure 3.28). It was found that as a result of first five laser shots the coatings were removed and the spectrum identical with the shot 2 was recorded. However, only few lines in the spectrum could be assigned to W.

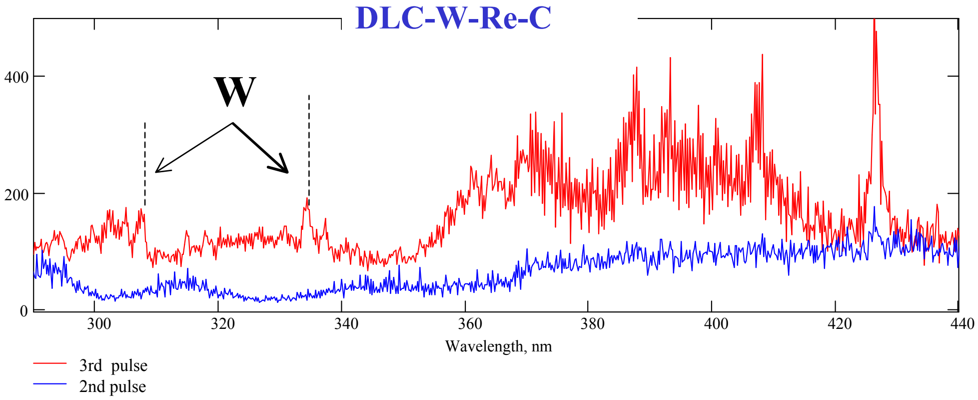

Figure 3.28. The lower spectrum belonging to shot 2 characterises upper DLC layer; the upper belongs to shot 3 and it gives the spectrum of tungsten.

The overlapping of spectral lines is not caused only by the poor spectral resolution of the used USB4000 spectrometer. Figure 3.29 demonstrates how the spectrum recorded by ME 5000 spectrometer, changes with time: immediately after the laser pulse the temperature of the plasma plume is high and it leads to a considerable widening of spectral lines. Later the temperature of the plume is lower and the spectral lines are easily resolved.

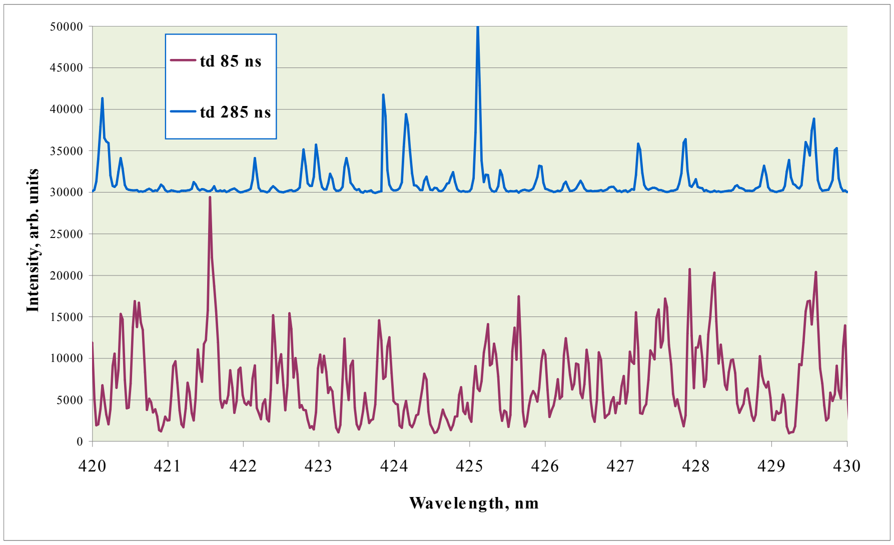

Figure 3.29. W-C sample, first shot; spectra are recorded at two different moments from the beginning of the laser pulse; width of the time-gate is 200 ns.

3.7.2 Radiation damage of dielectric and composite materials of interest for a fusion reactor

Institute:	Laboratory of Physics of Ionic Crystal (LPIC), Institute of Physics, University of Tartu
Principal Scientists:	Aleksandr Lushchik, Sergei Dolgov, Irina Kudryavtseva, Tiit Kärner, Peeter Liblik, Vitali Nagirnyi, Fjodor Savikhin, Evgeni Vasil'chenko

Main Results: Many specialists in the field of radiation material science find that one of the significant obstacles impeding the development of nuclear and especially thermonuclear energetics is insufficient radiation resistance of various construction materials: primarily metals and alloys, but also semiconductors, wide-gap dielectrics and superconducting materials. In particular, the radiation resistance of wide-gap materials (WGMs, $E_g = 7$-15 eV - Al_2O_3, MgO, $MgAl_2O_4$, Y_2O_3, $Y_3Al_5O_{12}$, SiO_2, Li-containing materials etc.) promising for future industrial high-temperature heat ($\geq 1000°C$) fusion stations should be substantially enhanced. It is obvious that this complicated task can be solved only on the basis of subsequent basic researches.

In metals, one of the most harmful effects is the creation of structural defects at elastic collisions of fast particles with the atom nuclei of a crystal. In WGMs, besides this universal for solids impact (knock-out) mechanism, Frenkel defects (FDs, vacancies and interstitials) are created due to the decay of various electronic excitations (EEs) or recombination of electrons and holes, formed during irradiation (non-impact mechanisms connected with the so-called ionization energy losses). Many metal oxides, such as Al_2O_3, MgO and SiO_2 are resistant against γ- and x-rays (i.e. under conditions of low excitation density) because the energy released at the recombination of relaxed electrons and holes does not exceed the threshold for the creation of Frenkel defects, $E_{FD} > E_g$. However, the radiation resistance of these materials is considerably reduced at high excitation densities. For instance, under conditions of extremely high density of EEs in the tracks of GeV-swift heavy ions (about 99% of energy losses of ~25 keV/nm are connected with the formation of EEs) the non-impact mechanisms of FD creation should be also taken into account. One of these mechanisms is caused by the recombination of hot (non-relaxed) electrons and holes. The energy released at such hot recombination exceeds the value of E_{FD} and the efficient defect creation occurs under high-density irradiation even in WGMs with $E_{FD} > E_g$. According to our recent suggestion, the efficiency of FD creation via hot recombination could be significantly reduced by doping the materials with some impurity ions - the energy excess of hot carriers is partly spent on the direct excitation of impurity centres resulting in impurity luminescence emission or heat release.

In 2008 refractory MgO single crystals (T_{melt} ~2830°C), both highly pure and doped with Sr^{2+}, Ca^{2+} and Be^{2+} ions, have been grown as well as powder samples of Al_2O_3:Gd^{3+} have been synthesized by the method of solid state reactions in our laboratory. MgO crystals together with Al_2O_3 (pure and doped with Cr^{3+}, Sc^{3+}) were preliminary irradiated by fast neutrons (~2 MeV) or swift heavy ions (~2 GeV) at room temperature and then investigated by several methods. A significantly modernized cathodoluminescence setup allowed to detect the emission of 1.7-11 eV in a very large dynamic range of intensities (10^7) through a VUV double grating and a double prism monochromators at/or after excitation by electrons (tunable acceleration voltage in the range of 1–30 kV and beam current 10-10^3 nA), whereas sample temperature can be varied in the range of 6-400 K. In addition, previously irradiated single crystals and $Lu_2O_3:Eu^{3+}$ and $Lu_2O_3:Tb^{3+}$ nanocrystalline powders (particle size from 6 to 46 nm) were investigated using synchrotron radiation at HASYLAB at DESY. Exciting photons of 5-40 eV caused the creation of single excitons and electron-hole pairs as well as the associations of spatially correlated EEs.

It is worth noting that there are favourable conditions to the separation of impact and nonimpact mechanisms of FD creation under irradiation of WGMs with swift heavy ions: EEs are responsible for the radiation damage along the main part of the ion track, while elastic collisions (i.e. impact mechanism) contribute to defect creation mainly at the end of the ion range. Furthermore, in LiF crystals - the modelling system of the processes in Li-containing blanket materials - the contribution of impact and nonimpact mechanisms of FD creation by 10 MeV Au^{198} is approximately the same, while about 99% of energy losses are connected with the formation of EEs in the tracks of ~GeV gold and uranium ions. In our opinion, the coexistence of the classical impact and the nonimpact mechanisms of radiation damage has a particularly detrimental effect on the resistance of WGMs against high-dense irradiation. Under such irradiation conditions there arise additional possibilities to form highly stable associations of elementary defects thus preventing their fast spontaneous recombination.

Particular emphasis has been placed on investigation of undoped MgO and Al_2O_3 previously irradiated with light ions (α-particles) or swift heavy ions (^{198}Au, ^{238}U). The resistance of these WGMs against subsequent radiation defect creation via hot *e-h* recombination can be significantly increased due to the carrier interaction with the nanosize intrinsic structural defects (e.g., F, F^+ and F_2 colour centres) created during previous irradiation. The energy excess of hot carriers will be transformed into luminescence (via the excited states of defects) or phonon package. This "self-protection" mechanism against radiation damage in pure WGMs can be considered as the second version of the solid-state Frank-Hertz effect (SFHE). The concentration of intrinsic defects is drastically increased in MgO crystals exposed to uniaxial (along [100]) plastic deformation at 300 K. Similar to F-type colour centres, these deformation-induced anion and cation defects serve as a competitive channels of the energy transfer by hot carriers via the direct excitation of defects resulting in typical luminescence or heat release. The existence of the first version of SFHE has been confirmed by the example of Al_2O_3 single crystals. A comparative study of Al_2O_3 pure crystals and those doped with Cr^{3+} or Sc^{3+} ions has shown that in Al_2O_3:Cr and Al_2O_3:Sc there are additional channels of the energy transfer by hot carriers via the direct excitation of impurity centres resulting in impurity luminescence or heat release. Conduction electrons and valence holes loose the excess of their kinetic energy via these channels, thus suppressing hot *e-h* recombination, decreasing the efficiency of FD creation due to the recombination of non-relaxed electrons and holes and increasing the radiation resistance of these materials. According to our investigations with the use of synchrotron radiation, different mechanisms of the energy transfer from the host to Eu^{3+} or Tb^{3+} ions take place in $Lu_2O_3:Eu^{3+}$and $Lu_2O_3:Tb^{3+}$ nanocrystalline powders.

The processes of high-temperature stabilization of oxygen interstitials have been thoroughly studied in MgO single crystals with $E_{FD} > E_g$, which are radiation resistant against low-dense radiation. Using EPR and thermoactivation spectroscopy methods it has been shown that the stabilization occurs due to the association of an oxygen interstitial with a hole located near a cation vacancy. A thermal dissociation of such associations takes place at about 700 K. A comparative study of MgO irradiated by different types of radiation has shown that swift heavy ions mainly create oxygen interstitials and vacancies, while fast neutrons provide the creation of F^+ centres and oxygen interstitials associated with the holes nearby cation vacancies or small-radius impurity ions (Be^{2+}).

The novel opportunity for selective detection of fast neutrons by Al_2O_3:Gd^{3+},Dy^{3+} has been suggested. Gd nuclei can be excited by fast neutrons (e.g. 14-MeV fusion neutrons), while Dy^{3+} ions serve as efficient luminescence centres even at 450–500 K. Enormously inertial n,α-reactions in Gd^{3+} allow, in principal, the selective detection of fusion neutrons after the second measuring of thermoluminescence for previously irradiated Al_2O_3:Gd^{3+},Dy^{3+}. The further experimental investigations lie ahead.

Concluding, the obtained results clearly demonstrate that the formation of intrinsic defects causes both the reduction and the increase of radiation resistance of WGMs. The complex investigation of radiation effects under the conditions of actual coexistence of the classical impact and novel nonimpact mechanisms of defect creation by high-dense irradiation of WGMs is needed. The results are presented as 5 journal papers, 3 conference contributions and PhD Thesis.

3.7.3 Tritium depth profile analysis

Institute:	Laboratory of Nuclear Spectroscopy (LNS), University of Tartu
Principal Scientist:	Madis Kiisk

Specific objectives: Setting up a dedicated beam line for tritium analysis on an electrostatic tandem accelerator and initiate tritium depth profile measurements of samples from JET by using Accelerator Mass Spectrometry.

In 2008, principal agreement for joint collaboration with Horia Hulubei National Institute of Physics and Nuclear Engineering, Laboratory of Accelerator Mass Spectrometry was founded experiments on tritium depth profile measurements. However, the Tandem accelerator facility was going during 2008 under major upgrade of the accelerator system including the injection apparatus of the Accelerator Mass Spectrometry (AMS) system. First test runs of the upgraded AMS system were made in the end of 2008. It was agreed to begin with measurements of T-containing samples in 2009.

4 EFDA ACTIVITIES 2008

4.1 Technology: Physics Integration

4.1.1 3-D calculations of ion losses and wall loads in ITER due to toroidal ripple

EFDA Art. 5.1b Contract: TW6-TPO-RIPLOS
Principal Investigator: Taina Kurki-Suonio, Tekes – TKK

The EFDA 5.1b Contract, TW6-TPO-RIPLOS (06-1435) was brought into completion after obtaining half a year extension due to the new and unforeseen complications in physics due to the introduction of the test blanket modules (TBM). The TBM's are made of Ferritic material and were known to perturb the magnetic field. However, this perturbation was expected to merely possibly reinforce the toroidal ripple effects, and the appearance of island structures came as a total surprise. Furthermore, several flaws were discovered in the magnetic backgrounds originally used in the simulations and, therefore, practically all ASCOT simulations had to be repeated using backgrounds with improved quality. The main physics results from this task are summarized in Section 3.

RIPLOS is likely to be continued under a new task in 2009.

4.1.2 European development of a gyrotron for ITER

EFDA Art. 5.1b Contract: TW6-THHE-CCGDS5
Principal Investigator: Olgierd Dumbrajs, Tekes – TKK

Gyrotron oscillators can have wide new applications, including technological processes, atmospheric sensing, ozone conservation, artificial ionospheric mirror, extra-high resolution electron spin resonance spectroscopy, nuclear magnetic resonance spectroscopy, new medical technology spectroscopy, etc. In all these applications, the possibility of tuning the gyrotron frequency is a great advantage.

There are several possibilities to change the frequency of a gyrotron oscillator by changing: i) the accelerating and modulation voltages (electrical tuning), ii) the magnetic field (magnetic tuning) and iii) the physical dimensions of the oscillator using a split cavity structure or a movable piston (mechanical tuning). Coaxial cavity gyrotrons open new possibilities in tuning the frequency in a truly continuous way. This is achieved by moving a tapered inner conductor in the axial direction. By moving the conical insert to the left the outer to inner radii ratio $C = R_{cav,0}/R_{in,0}$ decreases, leading to a relevant change to the resonance frequency.

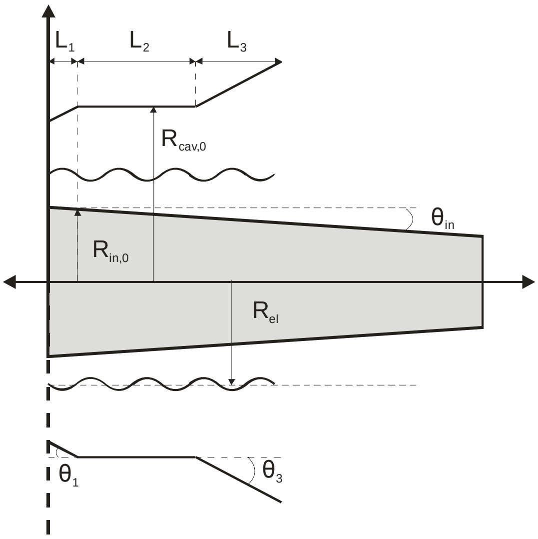

Figure 4.1. The geometry of a coaxial cavity with an axially movable tapered insert.

The main application of powerful gyrotrons is electron cyclotron resonance plasma heating in tokamaks and stellarators and the non-inductive current drive in tokamaks. The study of one very interesting phenomenon – hysteresis – is relatively limited, although perfect understanding of hysteresis is important in connection with mode competition, frequency tuning, voltage overshooting, amplitude modulation of the signal, etc. In gyrotrons, hysteresis is the phenomenon that causes the amplitude of oscillations to lag behind the magnetic field and the voltage, so that operation regions of modes for rising and falling magnetic field and voltage are not the same.

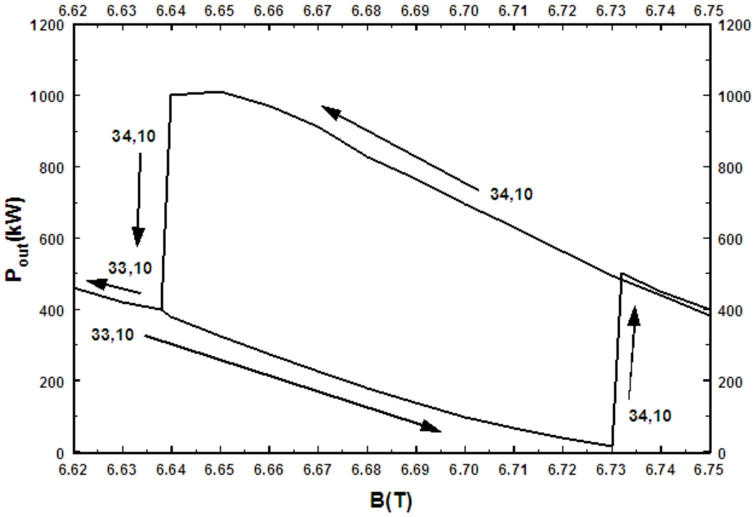

Figure 4.2. Hysteresis loop for the operating $TE_{34,10}$ and the parasitic $TE_{33,10}$ modes.

Important issue which still needs better explanation in powerfull gyrotrons is the electron dynamics in the process of gyrotron switching from one mode to another.

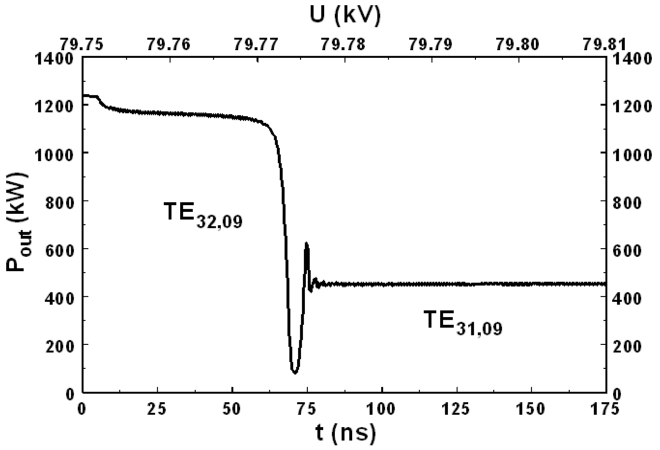

Figure 4.3. Switching in the process of voltage rise in a 1.2 MW, 170 GHz European gyrotron which is currently under development for ITER.

4.1.3 Erosion and deposition of mixed materials

EFDA Art. 5.1a Task:	TW6-TPP-BETUNCMOD
Principal Investigator:	Kai Nordlund, Tekes – UH

The presence of various plasma facing materials in ITER will invariably lead to the formation of mixed materials whose properties and interaction with hydrogenic isotopes will be fundamentally different from those of the pure materials. The formation of carbides and BeW alloys is expected to take place and it is important to understand the details of this formation and of their interaction with the species present in the divertor plasma flux (D/T, C, hydrocarbons, Be, W, He, Ne, Ar). A detailed understanding of the complex non-equilibrium systems can be obtained with atom-level simulation of the interactions among the species involved.

We have developed the necessary models needed to describe Be-C-H and W-C-H interactions under conditions relevant in fusion reactors. The models have been extensively tested and are now used for studies aimed at obtaining understanding of mixed material formation at the ITER divertor and first wall.

Metal carbides, such as tungsten carbide, can be formed when hydrocarbon molecules, eroded under particle bombardment, react with metal parts in other sections of the plasma chamber. Thus, mixed WC layers can form due to re-deposition of eroded hydrocarbon molecules. We have used the W-C-H potential to perform molecular dynamics simulations that would mimic processes occurring under device operation at the reactor first walls. We have performed cumulative simulations of deuterium with impurities (W, C, and noble gases) impinging onto WC structures and studied the effect of the C erosion on the surfaces and the role of the impurities on the erosion.

To simulate the change in surface structure of WC during erosion, we first created W-terminated (outermost surface layer is W) and C-terminated (outermost surface layer is C) WC structures. We then bombarded them either with pure D, or with a mix of D and 10% of the plasma impurity elements He, Ne, Ar, C, or W. Both cumulative and non-cumulative bombardments were done. In the cumulative case, a deuterium ion was placed above the surface before each bombardment, at a distance larger than the cut-off radius of the model. It was assigned a speed equivalent to 10, 20, 50, 100, 200, 600, 1000 or 2000 eV and aimed to the surface at 0–20° angle of incidence from the surface normal, corresponding to the most common bombardment conditions in divertors.

The centre of the surface was always selected as the point of impact. In order to achieve a uniform sampling of the surface, the cell was randomly shifted along the x and y directions before the next bombardment was initiated, using the periodic boundaries to ensure the atoms stayed within the simulation cell. Typical simulation runs consisted of 1000–5000 ion impacts.

In agreement with experiment, we observed preferential erosion of carbon. This suggests that WC layers formed by C re-deposition will be reduced in C content if subjected to hydrogen/deuterium bombardment. Hence, if a section of the reactor first wall is subject to both re-deposition of hydrocarbons and hydrogen bombardment, a dynamic balance in the C content could be reached under prolonged operation. At energy of 100 eV, we observed that D bombardment with 10 % C impurities leads to a balance between C erosion and deposition, see Figure 4.1**.** In contrast to that, we observed that W impurity bombardment leads to a deposition of W on the surface. D bombardment with noble gas impurities showed clearly higher C erosion yields.

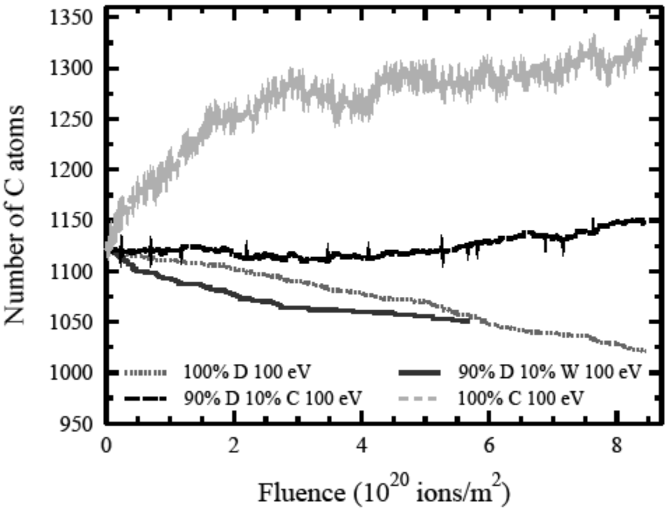

Figure 4.4. Development of number of C atoms in simulation cell during bombardment by pure D, a mixture of 90% D and 10% C or W, and pure C bombardment. The energy of the incoming ions was in all cases 100 eV. Note that the case of 90% D + 10% C bombardment has an almost constant C concentration, indicating that this is a steady state condition of neither not erosion nor deposition. Pure D or D+W bombardment leads to net erosion, and pure C bombardment to net deposition.

We have also examined the bombardment of Be by incoming D with energies 10–100 eV. These results can be compared directly with experiments carried out by R. Doerner et al at the PISCES facility in San Diego. In particular, we analysed the sputtered species with respect to whether they were in the form of single Be atoms or

BeD molecules. Unfortunately the experiments were carried out at lower fluxes than what can be achieved in the simulations, and the sample temperature is not well known. With this caveat, we can conclude that the simulated and experimental sputtering yields of the fraction of Be sputtered in molecules are in good agreement with each other, see Figure 4.5. Most importantly, both the simulation and experiment show that a major fraction of Be is sputtered as molecules, i.e., that chemical effects are active during the sputtering. This further implies that Be will be sputtered in fusion reactors even for quite low energies of D or T escaping the fusion plasma.

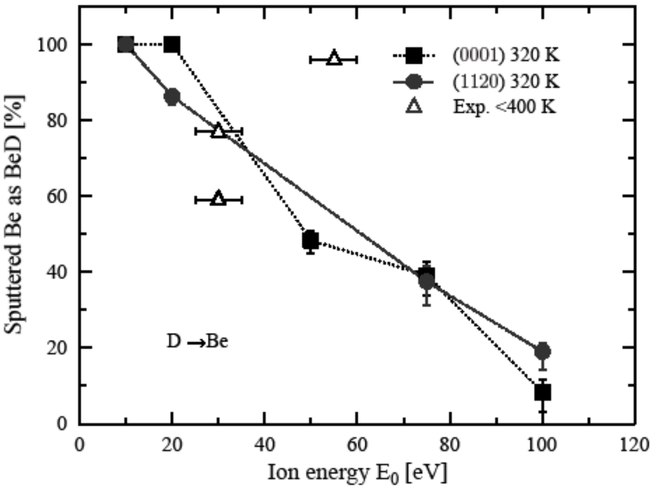

Figure 4.5. Fraction of Be sputtered in BeD molecules during D bombardment of initially crystalline Be as a function of energy.

4.2 Technology: Vessel/In-Vessel

4.2.1 Implementation of a DTP2 safety system for testing, and final CMM/SCEE integration and commissioning

EFDA Art 5.1b Contract:	TW6-TVR-DTP2OP2
Principal Investigators:	Jouni Mattila, Tekes – TUT/IHA Jorma Järvenpää, Tekes – VTT

Objectives: The Cassette Multifunctional Mover (CMM) and Second Cassette End Effector (SCEE) are currently under manufacture, and are planned for delivery to the Divertor Test Platform 2 (DTP2) in August 2007, where they will join the other components of the system.

At the same time, additional work is being carried out by VTT and IHA to provide the necessary infrastructure for the DTP2 to operate, such as installation of cable trays, development of a viewing and visualisation systems for eventual remote operation, procurement of a hydraulic jack to enable testing of the divertor Cassette Locking System (CLS), and development of procedures required for cassette installation & removal. This task defines a number of further essential steps which will need to be carried out prior to the start of formal trials in the DTP2. These are: Implementation of a safety system for hands-on testing of the CMM system, CMM/SCEE system and final integration and commissioning.

This work is considered essential to ensure that the DTP2 system is in a full state of readiness to commence operational trials in early 2008.

Deliverable 1: A Project Management Plan (PMP) showing the breakdown of responsibilities between various contributing parties and a project time schedule.

Deliverable 2: Report on the design of a flexible safety system which will be used during the earlier testing phases while the equipment is operated in hands-on mode only.

Deliverable 3: According to the EFDA contract the Deliverable 3 of the TW6-TVR-DTP2OP2 task should consist of final Integration and Commissioning of the CMM/SCEE system. However, the arrival of the CMM to the DTP2 was delayed (until October 2008) and therefore the Integration and Commissioning could not be done within this task. Instead, the Deliverable 3 includes Test Plans of the CMM/SCEE describing how the Integration and Commissioning is done. It also includes Integration and Commissioning supportive development of the system. Deliverable 3 has been divided into 2 sub-tasks:

Subtask 1: DTP2 test preparation
Subtask 2: Integration and Commissioning supportive software development

Main results in 2008:

Deliverable 1:
Project Management Plan is finalized.

Deliverable 2:
CMM test trials were started at first on the test rig. The test rig needs a flexible safety system. System has to take care about occupational safety and safety of the CMM itself. For this purpose was designed the safety system. The test rig was surrounded by safety fences closed by a safety door. The door is connected to the emergency circuit of the control system. Extra emergency buttons are installed at critical places around the area. An extra living emergency button is on the control desk.

During the first loading tests the CMM/SCEE was possible to overload by driving the load too far left. To avoid this system was equipped with a stopping barrier. If the test load hits the barrier it causes the emergency stop for the system.

The safety system was tested and taken in use during the first test trials.

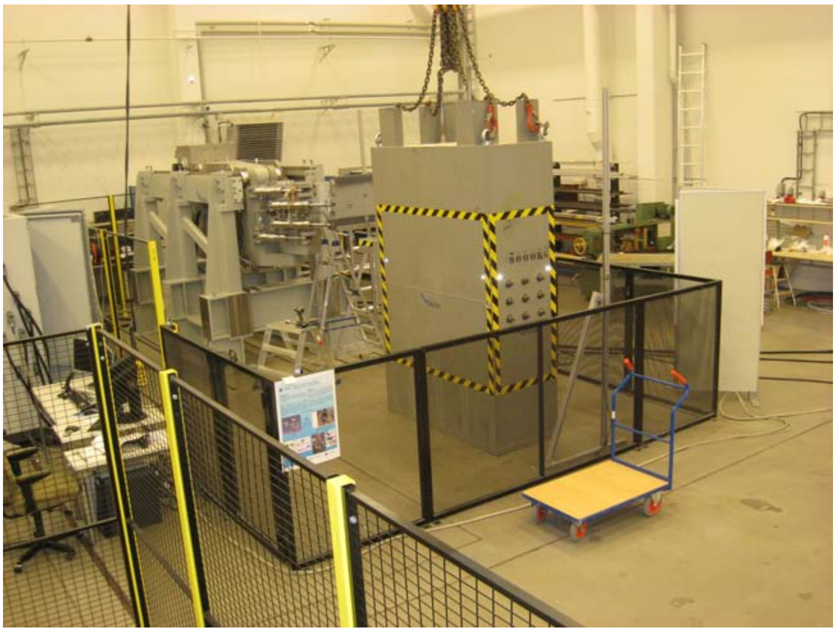

Figure 4.6. Safety system of the test rig.

<u>Deliverable 3:</u>

Subtask 1: Preparation for the CMM arrival to the DTP2 is done in a way that the CMM/SCEE Integration and Commissioning is done most efficiently. Test plan was written in order to execute desired actions after SAT tests specifying the following tests:

- Digital and analogue I/O tests
- CMM functionality tests on test stand (includes also software tests): ES circuit, Limit switches, soft limits, manual movements and safety features.
- Calibration of the Zero points
- Tuning the Controllers
- Kinematic Calibration.

Subtask 2: Additional features to the CMM control software (CMM HLC) supporting the final Integration and Commissioning were implemented. The Graphical User Interface (GUI) for Tuning the LLC (MSC's) and LLC integration with the HLC were already implemented in 2007. In 2008 Drivers for resolvers were be designed, implemented and tested together with the CCS. Requirements for the resolvers were documented.

4.2.2 Industrialisation and weld quality issues of high productive laser/arc hybrid for thick section welding of ITER grade SS material

EFDA Art. 5.1b Contract: TW6-TVA-IHYB

Principal Investigators: Miikka Karhu and Veli Kujanpää, Tekes – VTT

Introduction: Although the austenitic stainless steel grades are commonly considered to be quite easily weldable, there are certain applications which make exception to the above statement. As an example, which has also attributed to this study, it could be mentioned a welded assembly which forms a very rigid structure and has welds with fully austenitic microstructure. It is generally known that hot cracking of austenitic stainless steel during welding is very much coupled to chemical composition and the strains formed during solidification stage of the weld. Chemical compositions which lead to fully austenitic weld microstructure are verifiably considered to be the most susceptible for hot cracking. The level of strains is dependent on e.g. a groove design, used welding parameters and the rigidity of the structure to be welded. In above mentioned structure, a risk of solidification cracking (i.e. hot cracking) in produced welds could be a significant problem, if necessary precautions are not taken into account well in advance.

The scope of this study is related to research area, where new high efficiency joining possibilities for an assembly of very massive thick section vacuum vessel, made out of austenitic stainless steel, were explored. Considering the assembly phase of above mentioned vacuum vessel, if hot cracking occurs, it could be highly detrimental, because minor hot cracks cannot be revealed during welding, but only later in NDT inspections, in the worst case long time after the whole weld is finished. This could cause laborious and time-consuming repair procedure with additional costs and delay of the work. Repair welding may also be very harmful with regard to welding distortion control. Therefore it is extremely important to avoid hot cracking as complete as possible.

Objectives: The main objective of this work is to get understanding of hot cracking susceptibility of rigid ITER grade stainless steel material in hybrid laser welding. Significant issues are to get more knowledge about the behaviour of hot cracking of ITER grade stainless steel, to find a method for studying thick section hot cracking and give a view of suitable filler metal choice for ITER VV application both in sector welding and assembly.

Hot Cracking Test Set-Up: Rigid clamping table and test piece design: A very rigid clamping system was designed and built in order to emulate rigid welding conditions and strains which can occur in massive components assembly welding. The test system consists of rigid 170 mm thick table and clamping system for that, Figure 4.7. In clamping system, the total of 6 pieces of Ø 30 mm diameter high strength bolts together with 40 mm thick holder blocks was used to minimize angular distortions caused by welding heat. Each bolt was tightened into the moment of 1500 Nm with using dial torque wrench. That equals approx. a 300 kN compression per bolt.

Figure 4.7. The lay-out of the experimental set-up: Laser-arc-hybrid welding head attached to the KUKA-robot's wrist flange. Rigid 170 mm thick table with clamping system.

Test Pieces: The test piece used was planned to be rigid as it self and to simulate the rigidity of assembly welds. The tested material was AISI 316 L(N)-IG ITER Grade austenitic stainless steel with original thickness of 60 mm. Test piece consisted of two 400 mm x 150 mm plates with thickness of 60 mm. Those 60 mm thick halves were machined in order to posses following features when combined together (Figure 4.8): Both ends have close square preparation at the length of 60 mm. The joint thickness, which is intended to be filled using multi pass welds, is 20 mm. The length of the welded joint is 250mm and the joint has a root gap of 1,2 mm.

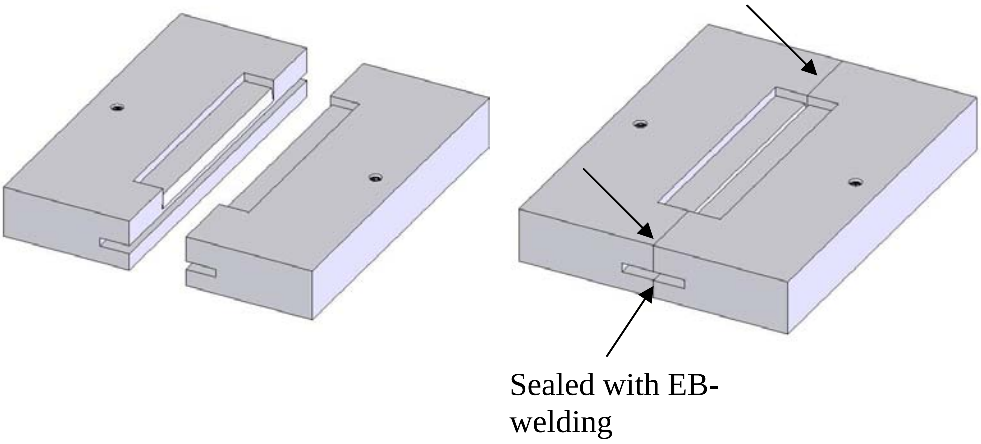

Figure 4.8. Test piece used in hot cracking tests. Two machined halves are put together and sealed using electron beam welding into the one test piece.

Two kinds of 20 mm thick groove geometries were used in hot cracking tests. The groove geometries are shown in Figure 4.9. The basic idea was to use wider (Figure 4.9a) and narrower (Figure 4.9b) groove configurations, in order to get two different multi pass weld shapes together with different depth to width ratios of produced multi pass welds.

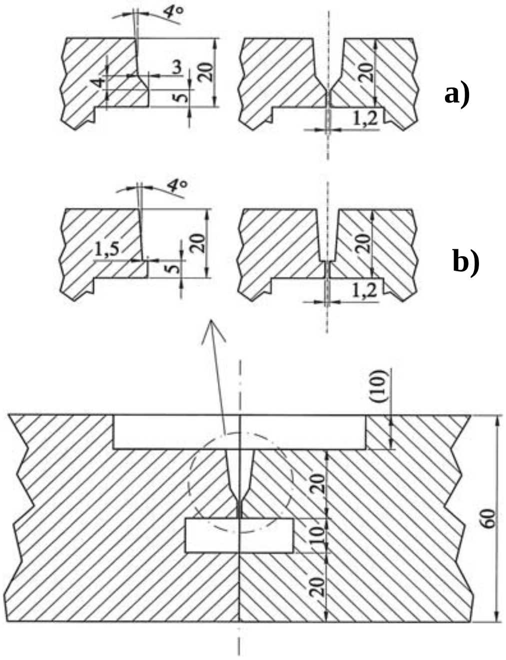

Figure 4.9. Two different groove geometries were used in hot cracking tests.

Main Results: Multi pass technique was used in hot cracking welding tests. In test welds of series A (wider groove), a total of 5 passes were needed to fill the groove, whereas in test series B (narrow groove), 7 passes were needed. Macrographs from the weld cross-sections of test series A (weld H1, H2 and H3) and test series B (weld H4, H5 and H6) are presented in Figure 4.10 and Figure 4.11, respectively.

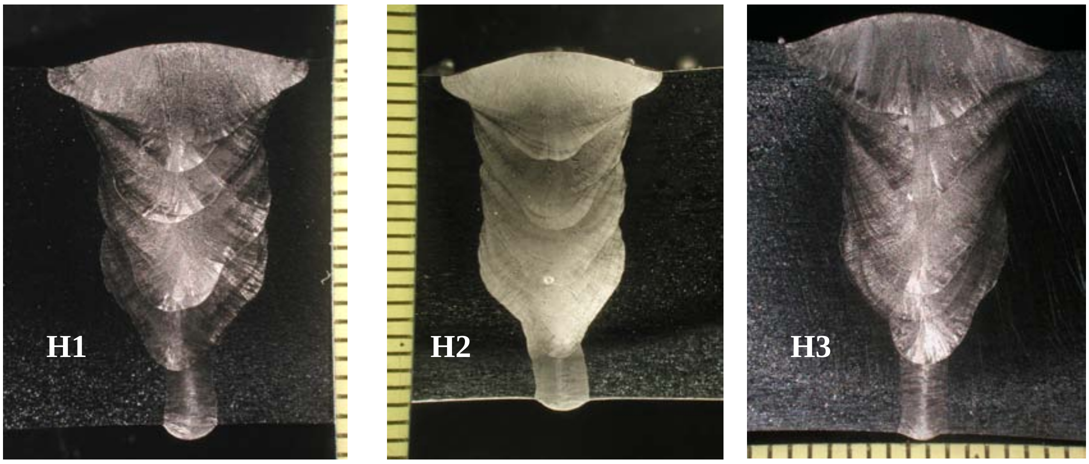

Figure 4.10. Welds from the test series A (from left to right): Weld H1, Weld H2 and Weld H3.

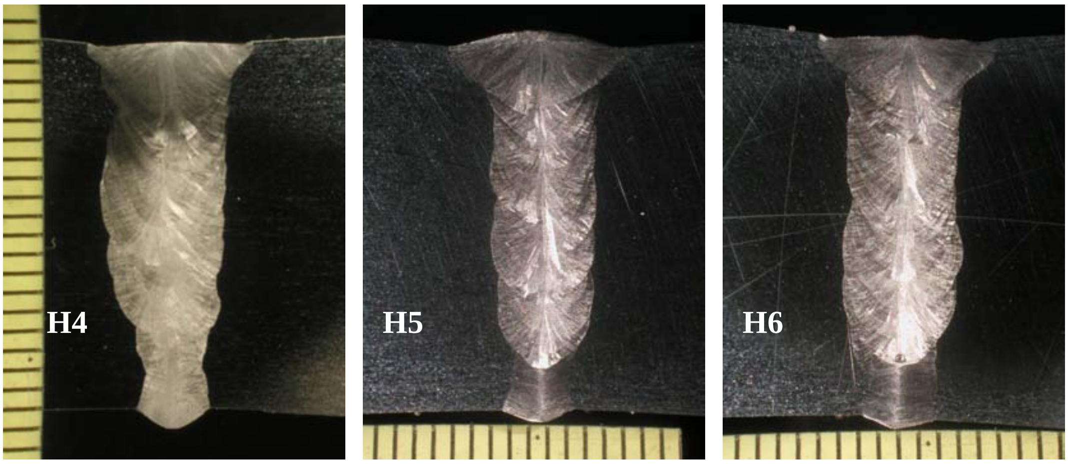

Figure 4.11. Welds from the test series B (from left to right): Weld H4, Weld H5 and Weld H6.

During the welding experiments, great attention was paid to the visual inspection of the surface of the intermediate passes. The observations clearly showed that hot cracking, which opened to the surface of the weld pass, did occur. In test series A, hot cracking occurred only in one test piece of all three: in welding of the first filling pass of multi pass weld H3. In test series B, hot cracking occurred in every test piece. In those test pieces, hot cracking was occurred in the first, second and third filling passes, whereas in root passes no cracking was observed to occur. Under the circumstances, narrow groove configuration used in series B tended to cause more hot cracking than wider groove configuration used in series A. Observations of hot cracking occurrence in both series are summarized in Table 4.1 and Table 4.2.

Table 4.1. Occurrence of hot cracking in test series A.

Test series A	Occurrence of hot cracking		
	Weld H1	Weld H2	Weld H3
Root pass	no	no	no
1st filling pass	no	no	**yes**
2nd filling pass	no	no	no
3rd filling pass	no	no	no
4th filling pass	no	no	no

Table 4.2. Occurrence of hot cracking in test series B.

Test series B	Occurrence of hot cracking		
	Weld H4	Weld H5	Weld H6
Root pass	no	no	no
1st filling pass	**yes**	**yes**	no
2nd filling pass	**yes**	**yes**	**yes**
3rd filling pass	**yes**	**yes**	no
4th filling pass	no	no	no
5th filling pass	no	no	no
6th filling pass	no	no	no

As mentioned earlier, visual evaluation after welding of each filling pass revealed that hot cracks occurred centred at along the weld length and opened to the surface of the weld. In Figure 4.12a, it is shown an example from the test series B, where the part of the joint was purposely left without upper filling passes in order to authenticate the presence of hot cracking in that case occurring in the first filling pass. In Figure 4.12b, it is shown the top view from the Figure 4.12a, which reveals hot cracking opened to the surface of the first filling pass.

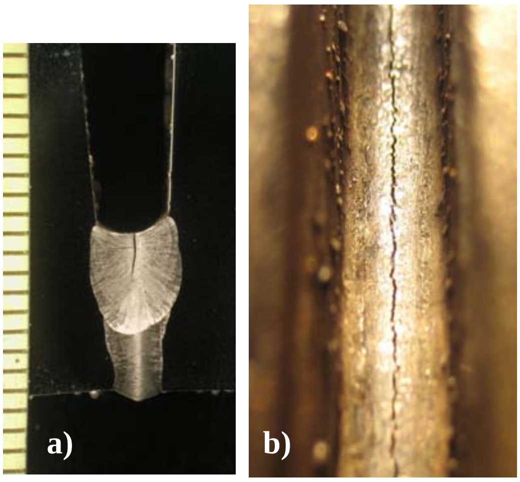

Figure 4.12. a) Macro cross-section showing hot cracking propagated into the surface of the first filling pass. b) The top view from the Figure 6a showing hot cracking along the weld length.

From the micro graphs presented in Figure 4.13, it can be seen magnifications (450x) taken from the same cross-section as shown in Figure 4.12. Micro graphs show the upper and lower part of the hot crack propagated in the fully austenitic microstructure.

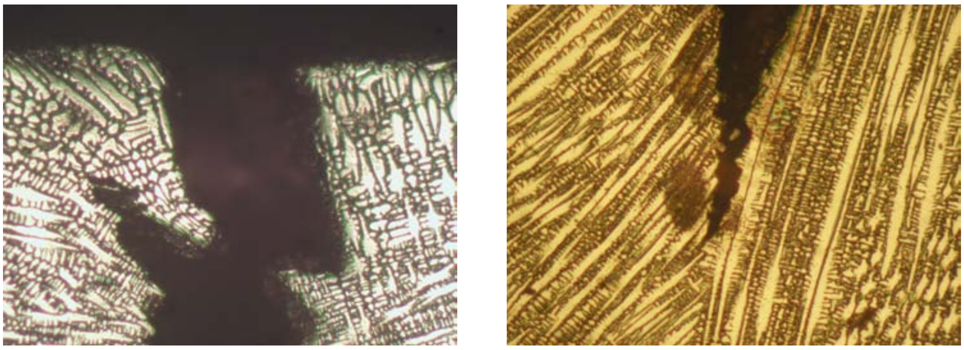

Figure 4.13. Micro graphs taken from the same cross-section as shown in Figure 6. Micro graphs show the upper (graph on the left) and lower part (graph on the right) of the hot crack in the fully austenitic microstructure. Magnification 450x.

It seems that during the multi pass welding of this study, the following filling pass has been overlapped into the previous pass such much that molten metal has “healed” the hot crack underneath. Evaluations from the X-ray radiography and from the cross-sectional macro graphs (Figure 4.10 and Figure 4.11) of the welds seem to support that observation. Anyhow, in general this healing- effect will not be always 100% certain, which must have taken into considerations in production welds of real applications.

Examination of weld metal micro graphs showed that welds have solidified in primary austenite solidification mode. These results are in good agreement with the initial data, as we knew that both parent material and filler wire used, are fully austenitic.

In the case of this study dilution in filling passes could be in the range of 10…30%, what corresponds roughly Cr_{eq}/Ni_{eq}-ratio of 1,23…1,27 in weld metal. That is way below compared to risk value of 1,5. In that respect, hot cracks in test welds approved that risk according to Cr_{eq}/Ni_{eq}-calculations is for real.

One possibility to overcome the risk of weld hot cracking is a correct filler material choice. That is to use more ferritic filler wire material, which will have e.g. a value of Cr_{eq}/Ni_{eq}-ratio about 2,0 or even higher. However, the welded application itself does not necessarily allow 5–15% room temperature delta ferrite content in weld metal, because of certain requirements or restrictions. In the case of this study initial requirement was that microstructure of weld metal in joints must be fully austenitic, containing as less as possible delta ferrite at room temperature. It was not fully clear by customer’s side, is ferrite content allowed in assembly welds of ITER-applications and furthermore if ferrite is allowed, what is the maximum allowed content in percent? Thus, it is important to clearly specify the maximum allowed weld ferrite content, because if ferrite content up to 10–15% in produced weld is allowed, weld hot cracking susceptibility would be remarkably reduced compared to fully austenitic weld microstructure.

It is advisable that hot cracking studies of ITER-grade austenitic stainless steel are extended. Further studies are recommended to carry out in order to explore and develop the ways to minimize the risk of hot cracking by means of correct filler material choice and careful selection of welding procedure and parameters.

As a whole, results showed that experimental test set-up can produce high strains enough to simulate the conditions which are correspond to those which can occur in massive and rigid components assembly welding. With using test set-up described and with using chosen filler material, hot cracking can be occurred in the rigid AISI 316L(N)-IG ITER steel grade weld joints.

4.2.3 Design and development towards a parallel water hydraulic inter-sector weld/cut robot IWR

Institution:	Laboratory of Intelligent Machines, Lappeenranta University of Technology
Principal Investigators:	Heikki Handroos, Huapeng Wu, Pekka Pessi

Introduction: Within the tasks TW3-TVV-ROBASS; Upgrade Robot to Include Water Hydraulics and a Linear Track, which was completed at the end of 2007 and TW5-TVV-IWRFS; Demonstration of IWR Operational Feasibility the parallel Inter-sector Weld/Cut, which was completed in August 2008 the special robotic system for assembly of ITER Vacuum Vessel has been developed. The robot kinematics consists of 6-DOF water hydraulic parallel robot and four additional serial degrees of freedom. A single of the additional degrees are driven by a water hydraulic cylinder while the other are driven by electrical servomotors. In total the robot has 10-degrees of mobility. The robot is mounted on a carriage that will be operated on tracks mounted on the cross sections of sectors. This arrangement for the welding/cutting robot is required since the joining of the nine sectors must be carried out from inside of the VV. The justification for using water hydraulics is its cleanness and superior power stiffness over electrical drives. The experimental robot prototype excluding the track was completed in 2007. The experimental robot was developed and manufactured by a network of sub-contractors under supervision of IMVE, LUT. The sub-contractors were Imatran Kone Oy, Compomec Oy, Hytar Oy and Stressfield Oy. The track was delivered from Ansaldo, Italy summer 2008. The prototype assembly on the track and principal tests were completed during 2008 and the research group looks forward to participation of tender of VV assembly. In addition to experimental tests, an error model was created for the robot calibration. The experimental prototype of IWR providing 10 degrees of freedom is shown in Figure 4.14.

Figure 4.14. experimental prototype of 10-DOF IWR.

The experimental prototype tests of IWR: 10-DOF IWR is set up in laboratory of Intelligent Machines Lappeenranta University of Technology. The hexapod with water hydraulic limbs can be seen in front of the mock up. The cylinders use Temposonic magnetoscrictive position encoders providing 2µm repeatability and serial digital output. The controller is built on commercially available ETHERCAT industrial PC manufactured by Beckhoff Automation. All necessary functions for the robot are tailored by the researchers of LUT. The robot can be equipped with 6-D seam tracking sensor, while carrying out the assembly welding. This decreases the need for very high absolute accuracy. It is expected that the robot can after calibration reach as high as 50 µm overall repeatability accuracy. The active robot motion during machining and welding is provided by the water hydraulic hexapod while the additional degrees of freedom are clamped. They are used for moving the work space of the hexapod since the major drawback of parallel robots is the small workspace. The prototype tests carried out in 2008 included the motion trials of individual degrees of freedom and motion trials of the complete robot on the track. The test results were promising. Problems occurred because of manufacturing tolerance of the track and small water hydraulic servo valves that limited the speed.

The error model of IWR: To calibrate such a complex robot as IWR modelling study was carried out. In literature error models for either serial kinematic or parallel is presented. The IWR robot construction combines serial and parallel kinematic subsystems that results in a complex error model. Figure 4.15, *error sources of a robot* illustrates the typical static error sources in robots. It has been acknowledged that a more cost-effective solution is to build a manipulator with relaxed tolerances and to modify the mathematical model in the controller so that the software compensates for the actual inaccuracy of the robot. Robot calibration is the process of enhancing the accuracy of a given manipulator through software modification. The error model was constructed by combining D-H approach for errors in serial part and vector differential method for the parallel part. Finally, the error models were combined to form an error model for the complete robot. In Figure 4.16, simulated position errors of serial and parallel parts of IWR as well as the complete robot is illustrated (see subscripts c, h and i respectively). The errors are shown along a single axis in Cartesian space and the pose locations are selected randomly. The errors are calculated by using approximated link errors and the calibration is not yet performed.

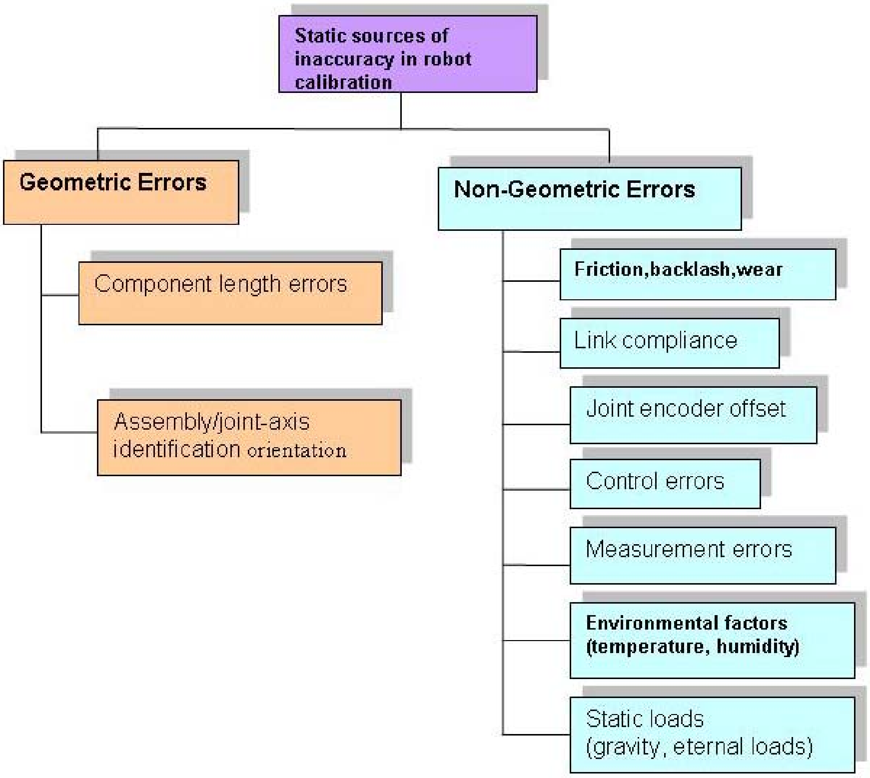

Figure 4.15. Error sources of a robot.

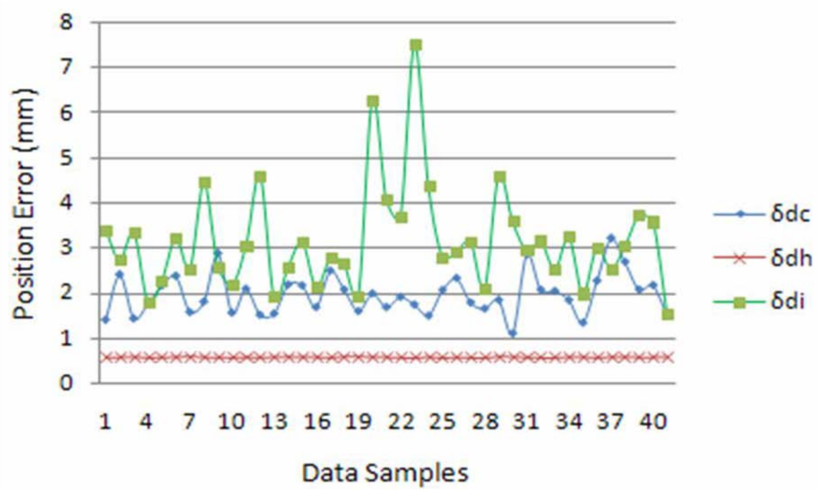

Figure 4.16. Simulated position errors of serial and parallel parts of IWR.

4.2.4 In-reactor mechanical testing of fusion reactor materials under neutron irradiation)

EFDA Art.5.1a Task: TW5-TVM-SITU2
Principal investigator: Seppo Tähtinen, Tekes – VTT

In this work different tensile specimens have been irradiated in in-reactor condition to different pre-yield dose to initiate plastic flow at different stress levels. For a given pre-yield dose and a given initial plastic flow stress, the dose (and strain) dependence of the flow stress has been followed to a certain dose (plastic strain) level and test was interrupted. The present results demonstrate that even though these in-reactor experiments are very complicated, the experimental facility and test procedure are fully capable of producing meaningful and reliable results. The present results also demonstrate that interrupted tensile tests can be used to study various aspects of the evolution of the dynamic nature of the plastic flow under the conditions of concurrent damage and dislocation production.

In the present series, a total of 8 in-reactor interrupted tensile tests were carried out. Four irradiation rigs, each containing two identical test modules were used for this purpose. These two test modules were used for carrying out two different and independent tests according to the following procedure: The specimens in the two test modules in a given irradiation rig were irradiated to different pre-field dose to achieve different yield stress. The specimens in both test modules were deformed to a given strain (dose) level and then both tests were interrupted (i.e. discontinued) at the same time. The displacement dose levels recorded at various stages of the tests is quoted in Table 4.3.

Table 4.3. Displacement dose levels at various stages of in-reactor tensile tests.

Material	**Test No.**	**Damage rate (dpa/s)**	**Displacement dose (dpa NRT) at**			
			Start of tensile test	**Yield point (σ_y)**	**End of tensile test**	**End of irradiation**
OFHC-Cu	1-1	$7.3\text{x}10^{-8}$	$2.19\text{x}10^{-5}$	-	-	-
	1-2	$7.3\text{x}10^{-8}$	$2.55\text{x}10^{-2}$	$2.81\text{x}10^{-2}$	$4.48\text{x}10^{-2}$	$4.48\text{x}10^{-2}$
	2-5	$7.3\text{x}10^{-8}$	$3.07\text{x}10^{-5}$	$3.21\text{x}10^{-3}$	$1.67\text{x}10^{-2}$	$1.67\text{x}10^{-2}$
	2-6	$7.3\text{x}10^{-8}$	$5.01\text{x}10^{-3}$	$5.07\text{x}10^{-3}$	$1.67\text{x}10^{-2}$	$1.67\text{x}10^{-2}$
	3-3	$7.3\text{x}10^{-8}$	$1.75\text{x}10^{-5}$	$1.72\text{x}10^{-3}$	$2.48\text{x}10^{-3}$	$2.84\text{x}10^{-3}$
	3-4	$7.3\text{x}10^{-8}$	$1.71\text{x}10^{-2}$	$1.81\text{x}10^{-2}$	$2.84\text{x}10^{-3}$ *	$2.84\text{x}10^{-3}$
	4-7	$7.3\text{x}10^{-8}$	$6.13\text{x}10^{-5}$	$2.10\text{x}10^{-3}$	$2.50\text{x}10^{-3}$ +	$2.52\text{x}10^{-3}$
	4-8	$7.3\text{x}10^{-8}$	$7.45\text{x}10^{-5}$	$1.65\text{x}10^{-3}$	$2.52\text{x}10^{-3}$ *	$2.52\text{x}10^{-3}$

* Test was continued after reactor shut down (e.g., in the absence of irradiation)
\+ Test was discontinued at the time of reactor shut down.

The evolution of stress as a function of strain and displacement dose level for all in-reactor interrupted tensile tests are presented in Figure 4.17**.**

The present results confirm the following main features of the deformation behaviour during in-reactor tensile tests:

- The transition from elastic to plastic regime of deformation occurs smoothly and without any transient such as yield drop.
- Both the yield stress and flow stress increase with increasing pre-yield dose.
- The uniform elongation decreases with increasing pre-yield dose (i.e. increasing yield stress).
- The initial rate of hardening (immediately after yielding) decreases with increasing pre-yield dose.
- The nature of variation of the flow stress with strain and displacement dose is very similar for different values of yield stress (i.e. pre-yield dose).
- Both the level of flow stress at any given strain (or dose) level and the maximum flow stress increase with increasing the pre-yield dose. This means that different level of flow stress is reached at a given strain (or dose) level. In other words, the evolution of flow stress is controlled by the pre-yield dose and not by the instantaneous dose during the in-reactor tests. This implies that the evolution of the microstructure and the mechanical response during the whole test is controlled by the level of pre-yield dose. This memory effect cannot be explained in terms of conventional hardening theory. Recently the problem has been treated within the framework of cascade-induced source hardening model.

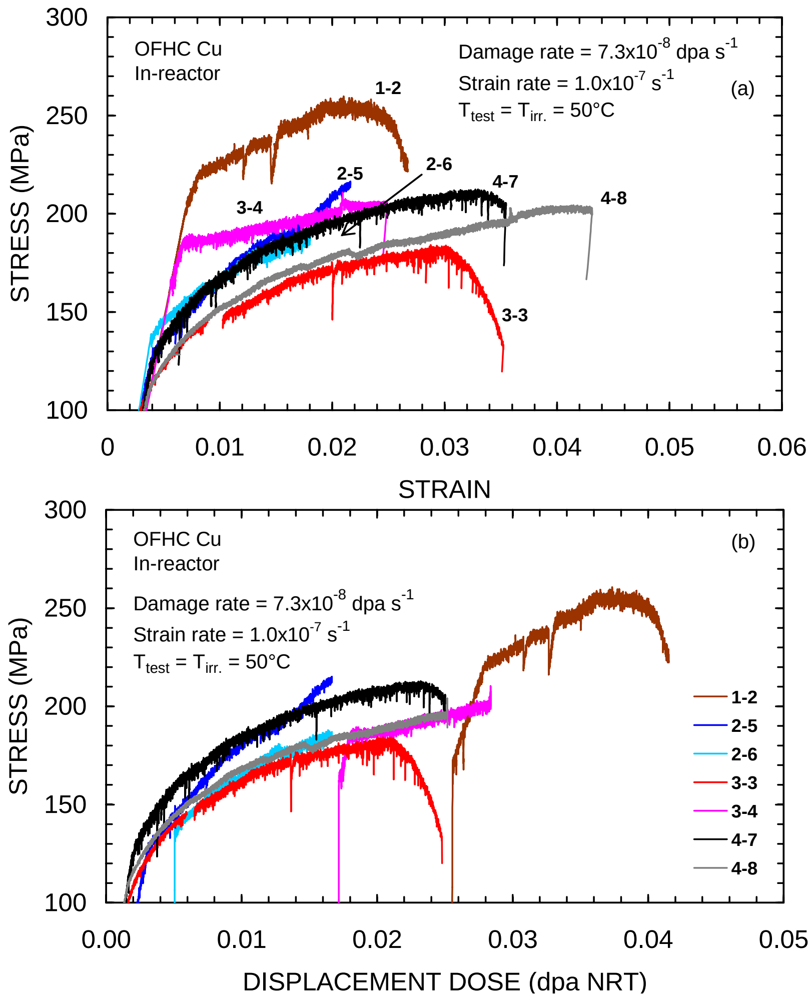

Figure 4.17. (a) Stress-strain and (b) stress dose curves for in-reactor interrupted tensile tests carried out 50°C. Note that the curves are identified by the test numbers.

4.2.5 Testing of irradiated CuCrZr/SS joints produced under different blanket manufacturing conditions

EFDA Art.5.1a Task: TW4-TVM-CUSSPIT
Principal investigator: Seppo Tähtinen, Tekes – VTT

Tensile and fracture toughness properties of CuCrZr/316LN and CuAl25/316LN HIP joint specimens and corresponding base alloys in different manufacturing conditions were determined after neutron irradiation to various dose levels of 0.001, 0.01 and 0.1 dpa (NTP) at temperature of 150°C. Post-irradiation microstructure of copper alloys was also studied after tensile tests.

The tensile results showed that the HIPing at 1040°C reduces the yield strength of the CuCrZr alloy compared to the yield strength of the CuCrZr alloy after HIPing at 980°C in the unirradiated and irradiated conditions. The tensile results clearly demonstrate that irradiation at 150°C even to relatively low doses has significant effects both on the yield strength and the uniform elongation of the CuCrZr alloy after HIPing at 1040°C and 980°C. In both cases irradiation causes a significant increase in the yield strength and correspondingly a significant decrease in the uniform elongation. The CuCrZr/316LN HIP joint specimens in all tested manufacturing conditions showed crack initiation and stable crack extension only after neutron irradiation to of dose level of 0.1 dpa at temperature of 150°C. At lower irradiation dose levels relatively ductile behaviour with extensive crack tip blunting was observed. Fracture toughness of CuAl25/316LN HIP joint specimens was very low after neutron irradiation. Typical tensile and fracture resistance test results are shown in Figure 4.18**.**

The deformed microstructure of the unirradiated and irradiated CuCrZr alloy (T13) was very similar to that of CuCrZr alloy (T10) up to a dose level of 0.01 dpa showing rather complicated deformation structure, however, no dislocation cells or/and cell walls were observed in the post-irradiation deformed specimens. A large number of cleared channels were observed in the CuCrZr alloy (T13) irradiated to a dose level of 0.1 dpa prior to tensile testing. In case of CuAl25 alloy the irradiated and deformed microstructure was dominated by the presence of small (1–2 um) sub-grains.

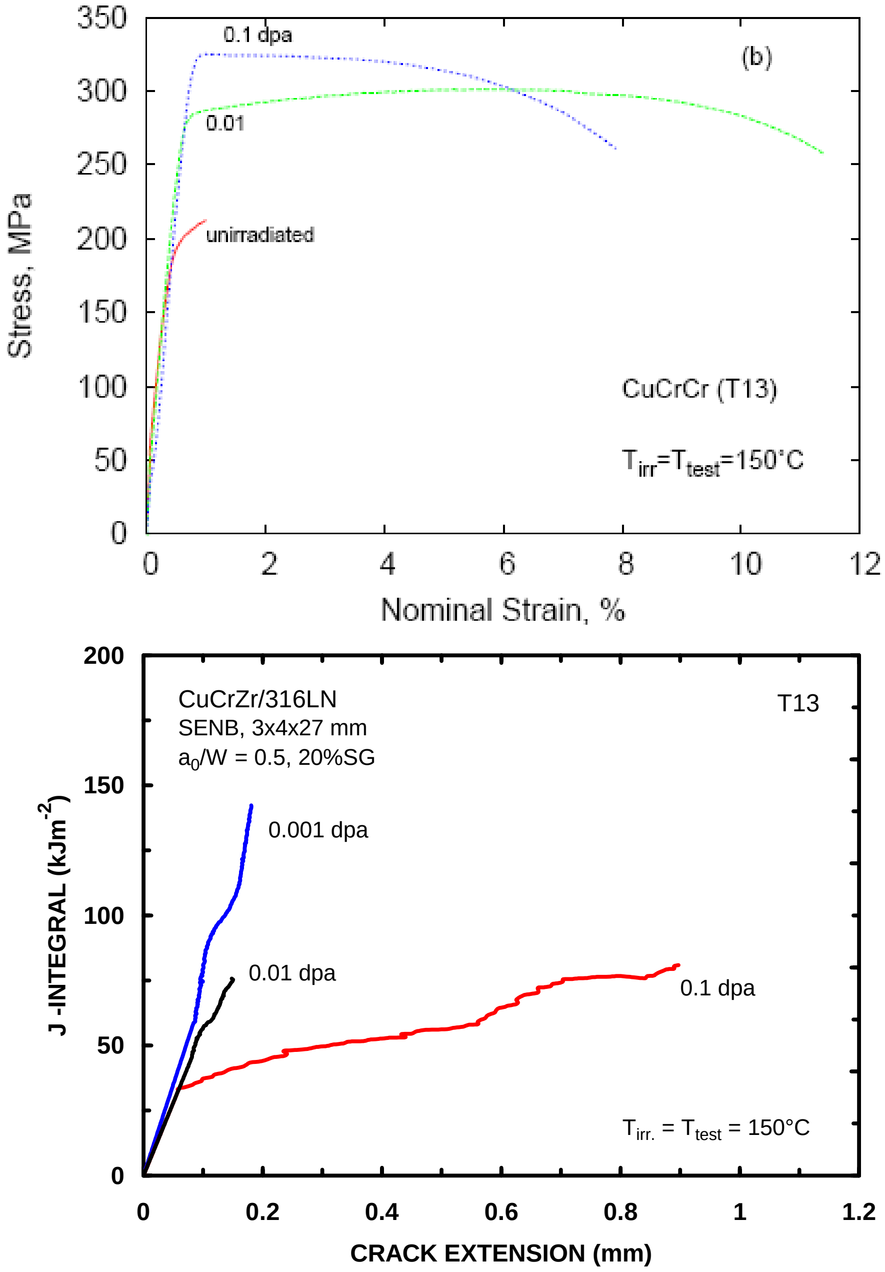

Figure 4.18. Stress-strain curves (upper) for unirradiated and irradiated CuCrZr alloy HIPed at 980°C (T13) and corresponding fracture resistance curves (lower). Specimens were irradiated at 150°C to doses of 0.001, 0.01 and 0.1 dpa. Note that the irradiation to a dose level of 0.1 dpa causes a significant reduction in the uniform elongation in tensile test and crack initiation and stable crack growth in fracture resistance test.

4.3 Euratom and EFDA Fusion Training Scheme

The training programme called GOTiT (Goal Oriented Training in Theory) is implemented on the basis of the provisions given in Art 7 of the EFDA Agreement and was recommended by the EFDA Steering Committee at its meeting of 10-11th March 2008 in Ljubljana (EFDA (08) 36/4.6). The programme officially started on October the 1st.

The EFDA GOTiT Programme trains modellers (amongst others) to the most recent mathematical and numerical methods and best practice in the use of high performance computers as well as to the state-of-the-art theoretical models developed and applied by the fusion community.

The work of GOTiT (**G**oal **O**riented **T**raining **i**n **T**heory) is performed in three work packages.

1. The first work package (WP1: **Mentored Training**) covers 16 trainees, of whom 9 will be specifically recruited, at 6 Institutes, together with their mentors;
2. The second (WP2: **High Level Courses**) covers specialized courses.
3. The third (WP3: **Monthly Seminar Series**) is a broader outreach activity consisting of a monthly seminar given via a video-link on topics affecting the entire Fusion Modelling Community.

The direct specialized training of the trainees will occur within Work Package 1, and will directly involve the smallest number of people. J. Heikkinen and T. Kurki-Suonio were appointed as the mentors within Tekes. More general training, which will also be available to a wider audience, will occur in Work Package 2. Work Package 3 provides a vehicle for bringing issues related to modelling to the widest possible audience within the European Fusion Community. T. Kurki-Suonio is in charge of the WP3.

4.4 Euratom Fusion Training Scheme, PREFIT programme

PREFIT Partners: TUT/VTT, CEA and OTL

Overview of the programme and progress so far: PREFIT is implemented as an integrated training and research programme. Each researcher works towards the award of a PhD from TUT by a combination of training work and a research project. To attain a PhD from TUT a researcher must accumulate 70 credits from all of the activities and, in addition, deliver and defend a PhD thesis of high academic quality as judged by an independent expert in the field.

The overall programme is shown schematically below:

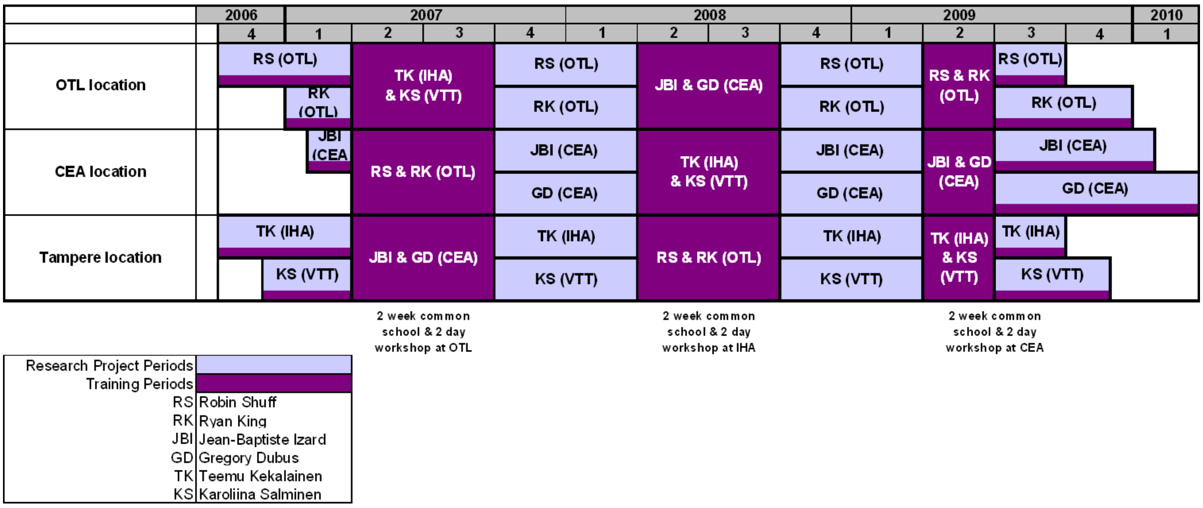

Figure 19. Schematic view of PREFIT programme.

The research project continues throughout the entire 3-year period and has two primary deliverables: a State-of-the-Art report after 1 year and a final thesis at the end of 3 years. The training programme comprises three 6-month periods at each partner site to undertake a mixture of on-the-job training, short project assignments, classroom lectures, workshops and conferences. Each researcher is required to deliver a written report at the end of each training period and a report summarising the knowledge gained during all three Common Schools.

Good progress has been made with all of the research projects. All of the researchers have completed a rigorous data-gathering phase and have successfully submitted their state-of-the-art reports. Under the guidance of TUT academic staff the researchers have developed a plan for their final thesis and have started to develop its content. In four of the six projects physical test rigs have been designed and constructed and some tests have started. There has been development of a theoretical basis for experimental validation where it was appropriate.

Training during 2008: As stated in the PREFIT contract, all six researchers were assigned to partner sites for the second 6-month period of their formal training during the summer of 2008:

- R. Shuff and R. King (OTL) were assigned to VTT/TUT, Tampere, Finland where they were conducting ITER RH related projects
- K. Salminen (VTT) and T. Kekäläinen (TUT) were assigned to CEA, Fontenay-aux-Roses, Paris and were conducting robotic based projects
- G. Dubus and J.-B. Izard (CEA) were assigned to Oxford Technologies Ltd., Abingdon, UK where they were experiencing a combination of on-the-job training at JET together with an ITER RH related assignment. Particular care has been taken, as stated in the original proposal document, to avoid conflict of interest between the trainees' activities and the Operator responsibilities at JET. To avoid difficulties similar to those experienced during the 2007 placements at JET OTL had applied for and received from the operator (UKAEA) written permission for the PREFIT researchers to conduct small hands-on projects at the JET facility.

A significant element of the PREFIT training periods is the annual Common School hosted in turn by the partners. During this reporting period, the Common School was organised and hosted by VTT with TUT. As with the first period, all six researchers attended for the full duration and were given a series of lectures about ITER remote handling related topics. In preparation for attending the Common School, the researchers were required to participate in a 6-week online course “Introduction to Water Hydraulics” organised by TUT. This online course was aimed at giving the researchers basic knowledge of water hydraulics, water hydraulic components and systems and their application to design of machines and equipment before the Common School.

During the Common School of 2008, the specialists from IHA and VTT prepared and delivered following lectures:-
- Introduction to water hydraulics (IHA)
- Modelling and simulation of fluid power systems (IHA)
- Digital hydraulics (IHA)
- Servo drives (IHA)
- Safety systems (VTT)
- Software Quality processes (VTT)
- F4E Quality Assurance (VTT).

During the two week Common School the researchers also attended the 2 day Tekes Annual Fusion Seminar which covered a broad range of ITER relevant topics including remote handling, project management, vacuum vessel manufacture, diagnostics, radiation damage and materials. During the Tekes Annual Fusion Seminar was also a visit to Alfvén Laboratory at Kungliga Högskolan in Stockholm to demonstrate the Swedish fusion research.

The year 2009 is the year when most PREFIT researchers will conclude their studies. The final training period is during the summer and the last Common School will be held in Paris in the beginning of the summer. This Common School will be organised jointly by Pierre and Marie Curie University and Commissariat à l’Energie Atomique (CEA) – Fontenay-aux-Roses.

5 FUSION FOR ENERGY ACTIVITIES

5.1 2008–2009 host activities related to DTP2 test facility operation and upgrade preparation

F4E Contract:	F4E-2008-GRT-MS-RH-01
Principal Investigators:	Mikko Siuko, Jorma Järvenpää, VTT Jouni Mattila, TUT/IHA

Objectives:

The main purpose of the Divertor Test Platform – 2 (DTP2) facility, located in VTT Tampere, Finland, is to allow for operational testing of prototypes of the Remote Handling (RH) movers, manipulators and tooling required for removal/replacement of divertor cassettes from ITER.

The objectives of the present grant are:

1. The exploitation of the existing DTP2 hardware/software, with a series of handling tests on the cassette mock-up,
2. Provision and exploitation of new DTP2 hardware/software related to operations with a manipulator arm (WHMAN),
3. Preparation of hardware procurement related to operation with a Cassette Toroidal Mover (CTM) and additional cassette end-effectors.

The present specification defines the tasks related to operation and preparation of the upgrade of DTP2 until the first Quarter of 2010. The areas of the identified action are:

- Operational testing of the prototype Cassette Multifunctional Mover (CMM) with Second Cassette End-Effector (SCEE) and CMM WHMAN required for replacement of the second divertor cassettes in ITER;
- Support in preparation for the delivery of Standard and Central Cassette End-Effectors prototypes (StCEE and CCEE, respectively) in order to allow operation on central, third and subsequent cassettes;
- Support in preparation for a DTP2 upgrade to extend the existing Divertor Region Mock-up (DRM) by 60 degrees toroidally;
- Support in preparation for delivery of a CTM prototype (optionally, the possibility to procure another WHMAN for the CTM will be explored).

The term operation is understood to mean the preparation of the DTP2 components to be handled, the set up of the ancillary services, the preparation of the data acquisition system and control system, the actuation of lifting devices for transporting components, etc.

Among the operations, in particular, a test is meant to cover a specific series of elementary instructions on DTP2 cassette mover and manipulator and tooling resulting in a divertor remote handling sequence which, in given conditions, produces experimental results suitable to be analysed and judged.

Main results in 2008:

Task-0: Quality Plan

Revised Common Part Quality Plan is completed and delivered to F4E. Quality Plan describes the common matters for all 6 Tasks in the project ‘2008–2009 host activities related to DTP2 test facility operation and upgrade preparation’. These common matters are Responsibilities in the Supplier Organisation, Project Management with Meetings, Resources, Configuration Management and how it processes, Documentation Management and Acceptance Requirements. There also and some other matters, such as used standards and safety lifecycle, explained in the Quality Plan to ensure the quality of this project.

Task-1: Stand-alone CMM tests

Deliverable 1: The Quality Plan for the CMM stand-alone tests was revised. In The Quality Plan the work breakdown structure of the Task 0 is defined and content of different phases are explained. Also Control Plan, Documentation Plan and Contract Risk Management of the Task 0 are included.

Deliverable 2: Trials preparation on the Test Stand. Integration of CMM-SCEE manipulator, CMM Control System (CCS) and software was started on Test Stand environment, which consists of a short section of linear rail and safety fences. CMM hardware and software functionality tests were done. This includes testing of I/O-signals, Emergency Stop (ES) circuit functionality and software safety functions. Zero point offsets for each joint were defined by utilizing 3D coordinate measuring device (Sokkia NET05). The same device was utilized also when the real geometrical parameters in the kinematic structure of CMM-SCEE were defined during kinematic calibration process. Joint controller tuning process was started by tuning P-controllers with velocity feed forward for each joint. Motions both in joint coordinate system and Cartesian coordinate system using joystick were done successfully. Multi-axis motions in Cartesian world were also done using Virtual Rail (VR) control type.

Figure 5.1. Installing CMM-SCEE to the Test Stand environment.

Deliverable 3: HLC v.3.0 software. This software version was released to be used during the Trials preparations, Deliverable 2. The software consists of two main parts: 1) User Interface (UI) part executing in desktop pc and 2) real-time part executing in industrial pc. Ethernet and TCP/IP communication is used between the two pc. The software is offering user interfaces to manage various system parameters, to control hydraulic system and to move CMM-SCEE using different kind of control types (joystick, VR). Testing of the software has been done according to the documentation defined in TW6-TVR-DTP2OP2, Deliverable 3.

Task-2: WHMAN tests

Deliverable 1: The Quality Plan for the WHMAN (Water Hydraulic MANipulator) tests was completed and submitted to F4E. The document describes the planning of the task and the main goals to be achieved during the period. The Control Plan, Time Schedule, Documentation Schedule and Risk Management are the main sections of the Quality Plan. The control plan and the time schedule describe the execution of the task, including deliverables and major milestones. The documentation schedule mentions all the documents needs to be crated during the execution of WHMAN tests. The risk management takes in consideration the development and the involvement of new technologies in the task.

Deliverable 2: The assembly of WHMAN was completed and first test runs of the manipulator were conducted. The WHMAN is shown during motion in the picture of Figure 5.2. The assembly of WHMAN involved the development of Hydraulic Power Unit (HPU) and the WHMAN Control System (WCS) cubicle and the hydraulic and electrical interfaces between the components. The HPU is designed to function in three different modes: independently from the local control panel, independently from the remote control panel and in connection with WCS from the remote control panel. The HPU sensor data and diagnostics are available to the operator of WHMAN on the Graphical User Interface of WHMAN-HLC (WHMAN-High Level Controller) and also from the indicator lights on the front panel of HPU. The WCS has been designed to carry all the current and future electronics required to control the WHMAN on top of CMM along with its end-effectors. The Design Description Document (DDD) of WCS is prepared and submitted to F4E.

Figure 5.2.: *WHMAN in motion on the test stand.*

Deliverable 3: The sliding table is required to install the WHMAN on top of CMM. Various possible concept of sliding table were studied and considered to fulfil the design requirements and to maximize the workspace of WHMAN without affecting the motion of CMM inside the divertor maintenance tunnel. After further analysis the conceptual designs were narrowed down and were presented to F4E. After the discussion a final design was selected for detailed analysis, refinements, design and manufacturing. Currently the detailed design is under progress and a detail report of the design is under compilation. The chosen concept with the driving motor and the gearbox aligned with the linear slide is shown in Figure 5.33.

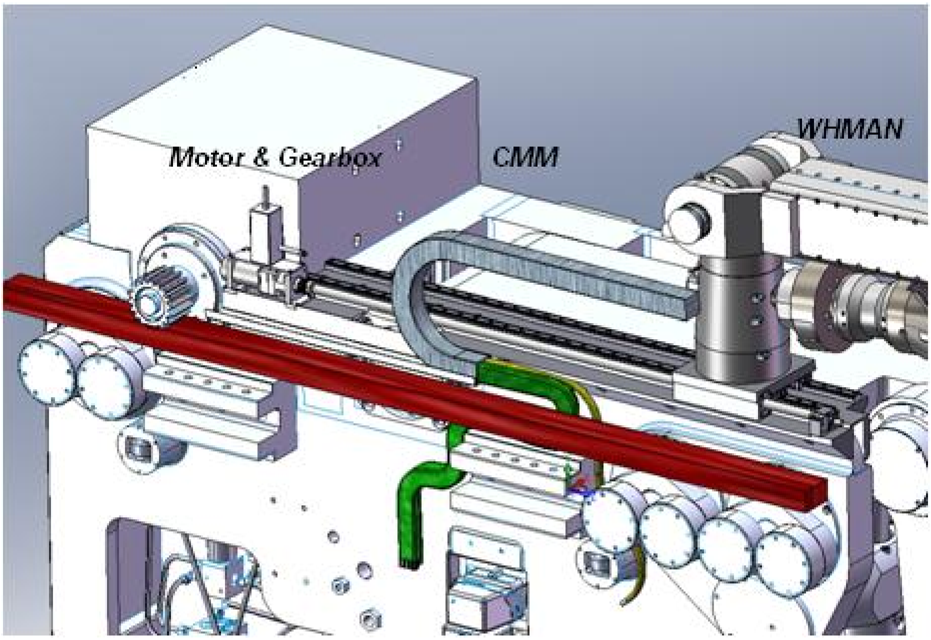

Figure 5.3. The selected concept for the sliding table.

Deliverable 4: The versions 1.0 and 1.5 of WHMAN-HLC were developed to test the functionality of the control software using a virtual 3D model of 6-DOF WHMAN. The version 2.0 of WHMAN-HLC was developed to control the actual WHMAN on the test stand. The software was used to test the functionality of the WCS and to make the first test runs of WHMAN on test stand. The new version of WHMAN-HLC makes use of reflective memory and fibre optic to transfer position and force information between master and slave manipulators. The use of Ethernet and UDP/IP has been discarded for this purpose because of experienced difficulties in consistent data transfer in real time. The concept is shown in Figure 5.4. The WHMAN-HLC 2.0 is designed to control and operate the WHMAN on the test stand. With this version of WHMAN-HLC it will be possible to achieve and test the basic functionality of the WHMAN. This version of WHMAN-HLC also lays down the foundation for the future development of WHMAN functionality. The future development will involve the operation of WHMAN from the DTP2 control room, on top of CMM inside the divertor region to perform and verify the divertor maintenance operations.

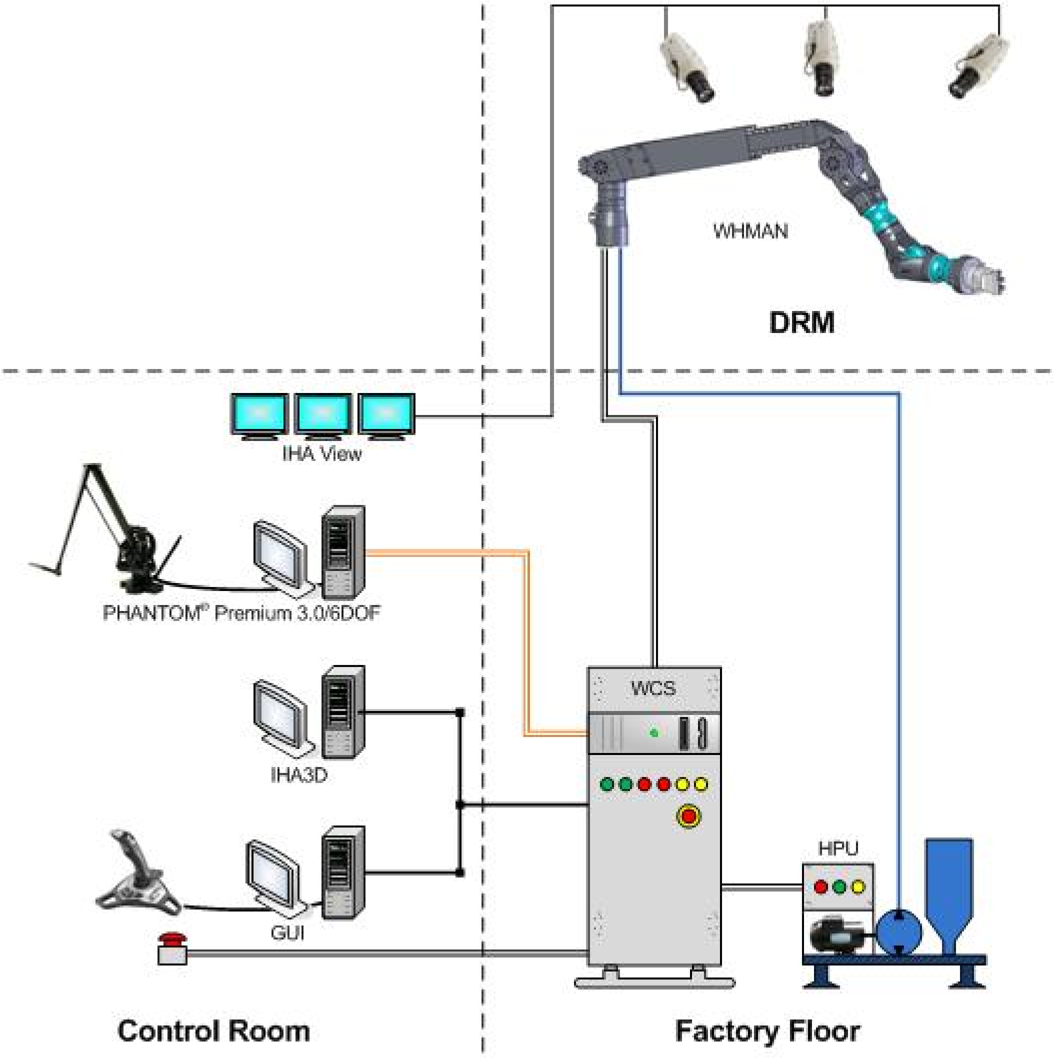

Figure 5.4. Architecture of the control system.

Task-3: Design and procurement of CMM additional end-effectors

The transportation of Divertor Cassettes from the Transfer Cask to the Vacuum Vessel are carried out by CMM (Cassette Multi-functional Mover). Depending on the type of the Cassette to be carried, different CMM end-effectors are employed. CMM additional end-effectors considered in this task are the so-called Standard Cassette End-effector (StCEE) and Central Cassette End-effector (CCEE). Figure 5.5 shows the CMM transporting a Standard Cassette in the Transfer Cask

StCEE is employed to transport those cassettes, throughout the RH maintenance tunnel, which need to be handled inside the Vacuum Vessel by the CTM. The main function of the StCEE is to provide an outboard dummy rail which closes the opening in front of the RH port. By doing so, the CTM can travel to both sides of the RH port. The CCEE is employed to handle the last inserted (or first removed) divertor cassette (i.e. Central Cassette). This end-effector also has to provide the required pushing force in order to compress the Cassette between the VV rails.

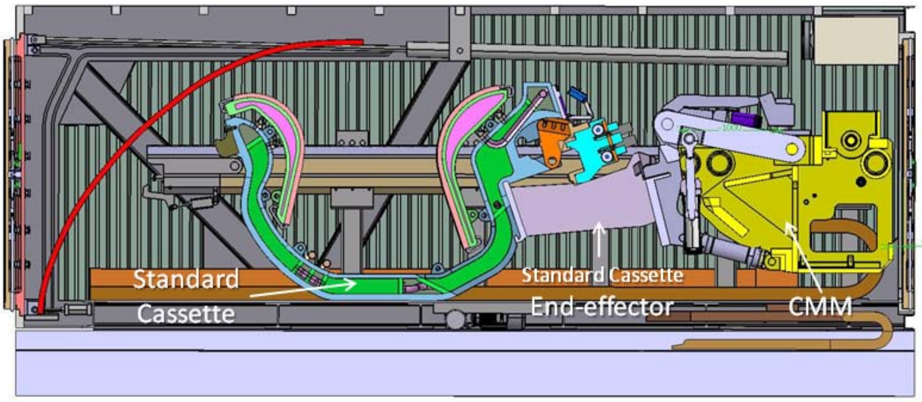

Figure 5.5. CMM, equipped with a Standard Cassette end-effector, transporting a Standard Cassette.

Deliverable 1: Quality Plan

A Quality Plan has been written explaining how the requirements set in the Management Specifications (issued by F4E) are fulfilled. The Quality Plan describes the quality provisions made and implemented by the supplier in order to perform the work according to the contractual documents.

Deliverables 2–3: Design description of CMM end-effectors (June 2009)

The supplier has assisted F4E in the collection of the necessary up-to-date input data from ITER IO. This includes System Requirements Documents (SRDs), the latest approved design changes concerning the Divertor area, latest ITER Divertor Design developments and up-to-date CAD models of the ITER Plant and RH equipment.

It is essential that requirements are well defined at an early stage. For that reason, the SRDs of the CMM end-effectors have been prepared as a precursor to the preliminary design being produced. The purpose of these SRDs is to collect and produce the design requirements of the CMM end-effectors based on all the available information collected previously and based on review meetings attended by F4E and ITER IO remote handling representatives.

Following recommendation and practices presented in *ITER Maintenance Management System*, the design of the RH equipment (StCEE and CCEE) is currently being developed in parallel with the development of RH operation methods. The design of the StCEE and CCEE will be verified against the SRDs, and against the ITER Plant contextual environment and interfaces using VR and digital mock-ups. VR tools will also be employed to assess the feasibility of the RH operations.

Deliverables 4-5: Report on selection process of the CMM end-effectors (March 2010)

Task-4: Design of DRM toroidal extension and upgrade
27° sector of the lover part of the ITER vacuum vessel and maintenance tunnel (DRM) is constructed in the DTP2 hall. This construction allows testing of the Second Cassette replacement with the CMM Mover. For the future tests the DRM has to be enlarged up to 80°. The divertor cassette locking system has to be upgraded to meet the latest ITER-design.

The toroidal rails of the DRM are mock-ups without toroidal racks. As a preparation for the Cassette Toroidal Mover (CTM), the inner and outer toroidal rails have to be upgraded to have also the toroidal rack and otherwise to meet the latest ITER design. Also interfaces for the Central cassette and further CMM end-effectors are not considered in the DRM current design, so they will be upgraded to meet the latest ITER-design.

Deliverable1: A Quality Plan has been written explaining how the requirements set in the Management Specifications (issued by F4E) are fulfilled. The Quality Plan describes the quality provisions made and implemented by the supplier in order to perform the work according to the contractual documents.

Deliverables 2–3: Design description of DRM toroidal extension and upgrade

The supplier has collected the necessary up-to-date input data from ITER IO. This includes the latest approved design changes concerning the Divertor area, latest ITER Divertor Design developments and up-to-date CAD models of the ITER Plant and RH equipment. Based on these, a System Requirements Documents (SRDs) is written.

It is essential that the latest design information is available when specifying changes in the construction of DRM. There are many interfaces to other divertor region components and therefore the SRD of the DRM is prepared as a precursor to the design produced. The purpose of this SRD is to collect and present design requirements from various reports.

Task-5: Design of CTM
In-vessel transportation of the Divertor Cassettes is carried out by the CTM (Cassette Toroidal Mover). The CTM carries cassettes to the radial port, where the CMM transports cassettes to the Transfer Cask. The CTM is moving on wheels along the

toroidal rails, driven by rack-and-pinion-system. The CTM is equipped with a lifting system supporting the Cassette during transportation. On the CTM there is a manipulator arm which is used to carry out assisting operations, like handling tools for opening the cassette locking and cutting the cassette cooling pipes. For the CTM energy supply and control- and data cables there is an umbilical system. Figure 5.66 shows main design and components of the CTM.

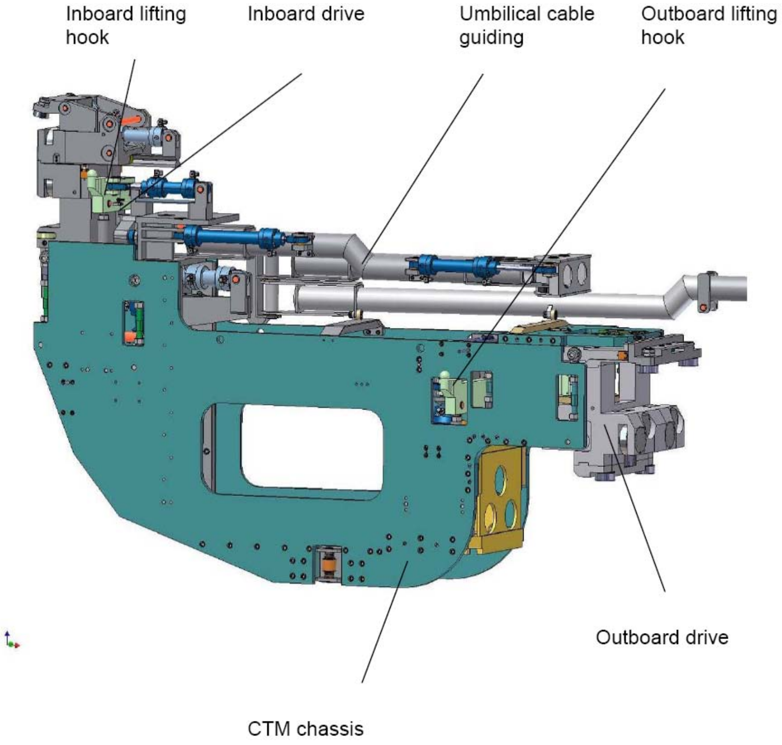

Figure 5.6. Main components of the CTM (EFET).

Deliverable1: A Quality Plan has been written explaining how the requirements set in the Management Specifications (issued by F4E) are fulfilled. The Quality Plan describes the quality provisions made and implemented by the supplier in order to perform the work according to the contractual documents.

Deliverables 2–3: Design description of the CTM

The supplier has assisted F4E in the collection of the necessary up-to-date input data from ITER IO. This includes System Requirements Documents (SRDs), the latest approved design changes concerning the Divertor area, latest ITER Divertor Design developments and up-to-date CAD models of the ITER Plant and RH equipment.

It is essential that requirements are well defined at an early stage. For that reason, the SRD of the CTM have been prepared as a precursor to the preliminary design being produced. The purpose of this SRD is to collect and produce the design requirements of the CTM based on all the available information collected previously and based on review meetings attended by F4E and ITER IO remote handling representatives.

Task-6: Design and tests of DTP2 supervisory system upgrade

Deliverable 1: Revised Quality Plan for task 6 is completed and submitted to F4E. Quality Plan describes the Task 6 and its Deliverables and Milestones. It also includes the Control plan, Time Schedule, Documentation Schedule and Risk Management of the Task 6.

Deliverable 2: Specification of the DTP2 Supervisory System version 1 (Integration of Control room sub-systems build in EFDA project TW6-TVR-DTP2DEV) was delivered to F4E in November 2008. DTP2 Supervisory System is operating in the Control room presented in Figure 5.7.

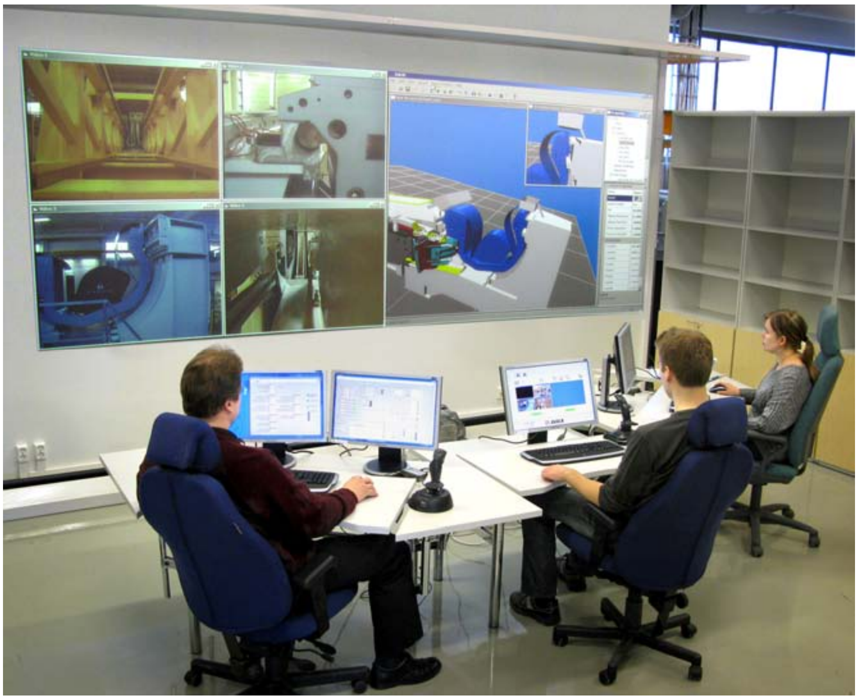

Figure 5.7. DTP2 Supervisory System operating in the Control Room.

Deliverable 2 defines the requirements of the DTP2 Supervisory System version 1. In the Requirements specification each sub-system is introduced and their environment described. Hardware, software and communication interfaces between sub-systems and their constraints are specified. Also the DTP2 Supervisory system users and their responsibilities are introduced. The requirements for the sub-systems during the operation/trials are described.

Recent hardware updates of the DTP2 Supervisory System are also documented in the Deliverable 2. Current hardware items are listed while also mentioning which ones are recently procured.

DTP2 Supervisory System version 1 is meant for driving the virtual models of maintenance devices. However, some of the sub-systems of DTP2 Supervisory System are already used for driving the real CMM Mock-up located on the Test stand. Therefore in this Deliverable hardware and software requirements and procured items for Test stand environment are also explained. This includes for example the Virtual model upgrade (Figure 5.8).

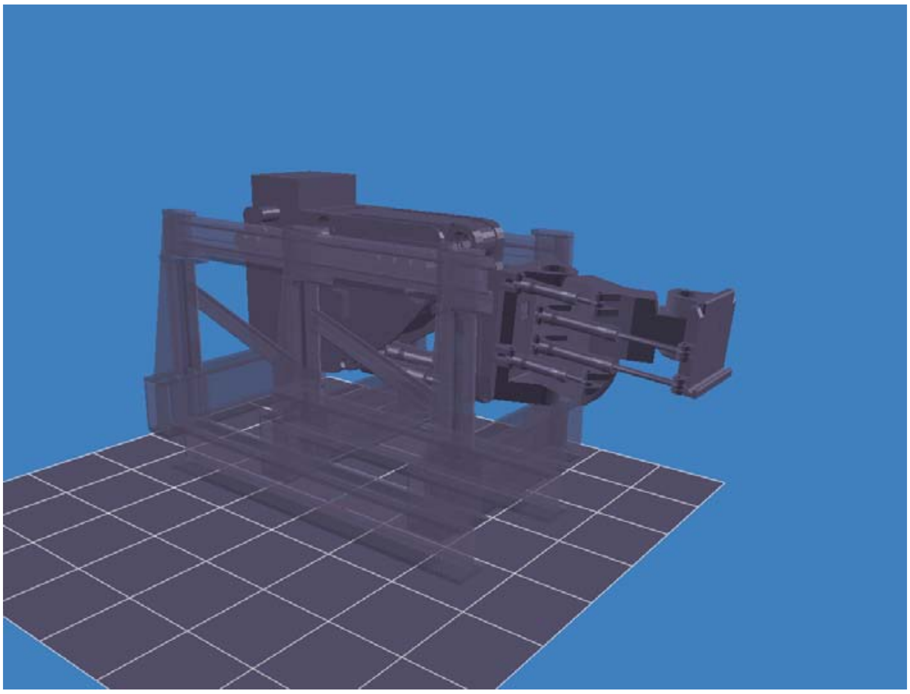

Figure 5.8. Virtual model of the CMM located on the Test stand.

6 STAFF MOBILITY ACTIONS & JOC SECONDMENTS

Several staff mobility visits of total 530 days took place in 2008. The visits were hosted by the Associations IPP Garching (282 days, MA Art. 1.2.b collaboration), UKAEA Culham (43 days), FZK Karlsruhe (30 days), FOM Rijnhuizen (10 days), task force (PWI, ITM, E, H, FT) meetings (69 days), other EFDA & ITPA meetings (16 days), Goal Oriented Traning GOTiT (57 days) and contract follow-up visits to TTM Telstar (23 days). Tekes Association (University of Helsinki, VTT and TKK) hosted three staff mobility visits: Udo von Toussaint from IPP (25 days), Dmitry Terentyev, from SCK-CEN (11 days), Karl Grieger from IPP (3 days), Paul Coad and A. Widdowson from UKAEA (12 days), Francesco Ogando from CIEMAT (15 days) and Eric Gauthier and Timo Dittmar from CEA (28 days).

Regarding the EFDA JET Workprogramme 2008 (experimental campaigns C20-C25) Association Euratom-Tekes participated in the Task Forces S1/S2, E, T, D and FT by S/T Order/Notifications work including secondments and scientific coordination. Tuomas Tala is a Task Force Leader for Task Force T (transport).

Two physicists and one engineer were seconded to the UKAEA JET Operating Team, Johnny Lönnroth and Antti Salmi (code development and modelling) and Ville Takalo (remote handling). One engineer from VTT was seconded to the ITER IO at Cadarache in 2008, Tommi Jokinen (Assembly).

6.1 Staff Mobility Visits and Reports

6.1.1 Hysteresis in sawtooth crash in ASDEX Upgrade tokamak

Name of seconded person:	Olgierd Dumbrajs
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP Garching
Dates of secondment / Mission:	1 April 2008 – 31 May 2008

Work Plan / milestones: A hidden variable allowing a hard type transition in the system has to be found. Equations leading to a hysteresis have to be derived.

Report: Analytic work on *"Hysteresis in enhanced transport (crash) with respect to sawtooth amplitude"* was completed. In particular a hidden variable (temperature gradient) has been found and equations leading to hysteresis have been derived. Numerical calculations are in progress. The work will be presented at the International Workshop "Anomalous transport in fusion plasma" 6–8 October, Craiova, Romania, and submitted to the Journal Ann. Phys. Craiova Univ. (Romania).

In addition a new subject of studies has been initiated:
O. Dumbrajs, V. Igochine, A. Gude, M. Maraschek, H. Zohm and ASDEX Upgrade Team, "*Temporal evolution of neoclassical tearing modes in the frequently interrupted regime»*, submitted to Plasma Physics and Controlled Fusion.

6.1.2 NPA measurements and energetic ions in AUG

Name of seconded person:	Taina Kurki-Suonio
Sending Institution:	Helsinki Univ. of Technology
Host Institution:	IPP-MPG
Dates of secondment / Mission:	6–19 April 2008

Work Plan / milestones:

1) NPA measurements: together with Drs Fahrbach and Suttrop make more detailed plans for the ELM-resolved NPA measurements. In the first stage we wish to devise a proper measurement procedure for routinely obtaining the edge radial electric field strength and its characteristic time scale across an ELM crash. At the same time we can try to see the effect of NTMs on the NBI-generated fast ion population. Preliminary investigation has already produced signals similar to those measured by FILD. These measurements are carried out with the new NPA data acquisition system installed in June 2007.

2) Discuss the new ASCOT-calculated divertor load results with Drs. Kallenbach and Eich. The preliminary simulations failed to reproduce the results published elsewhere. We wish to improve the ELM model used, in particular the radial electric field effect on the plasma. Here the NPA measurements mentioned above can be used for guidance.

3) In collaboration with the experimental group I also wish to participate in planning the possible reversed-current campaign with reduced heating power.

Report:

1st task: Together with Drs Fahrbach and Garcia-Munoz the complementarity issues between FILD and NPA were investigated and more coherent plans were made on how to use the two diagnostics in parallel to obtain as comprehensive picture as possible of the confined and escaping fast particles in AUG.

2nd task: Drs Kallenbach and Eich have obtained additional information on the divertor load asymmetries that also indicate that the earlier, simple simulations cannot account for the physics behind the asymmetry. Therefore a new plan for the ASCOT simulations was made, and it was decided that a graduate student be assigned to the task.

3) Due to the uncertainty on the machine operation this year, this task was postponed to my late visit.

Additional, unforeseen tasks:

4th task: With Drs. Sibylle Günter and Erika Strumberger, plans for simulations of fast ions including both neoclassical transport and drift islands were made. As a first step, a set of 3D magnetic backgrounds used by ASCOT would be transferred to Strumberger for further processing.

5th task: The interesting island structures introduced by ferritic materials in 3D magnetic backgrounds were discussed with Drs. Lackner, Günter and Dumbrajs. According to Dr. Dumbrajs, a localised perturbation can, indeed, lead to such structures. However, in this particular case it was found that the effect of the ferritic insert was not properly accounted for. A proper approach is to calculate its effect on the total magnetic field, not the toroidal one. However, it is not obvious how this can be done. Nonetheless, work using Hamiltonian approach to evaluate the effect of a local perturbation on the global magnetic structure was initiated with Dr. Dumbrajs.

6.1.3 Fast ion studies with NPA and FILD

Name of seconded person:	Simppa Jämsä
Sending Institution:	Helsinki Univ. of Technology
Host Institution:	IPP-Garching
Dates of secondment / Mission:	25 May – 7 June 2008

Work Plan / milestones: The proposed visit is part of the European experimental programme carried out at ASDEX Upgrade tokamak.

Fast ions or suprathermal ions have energy far higher than the thermal bulk of the plasma. The fast ions are mostly born during non-inductive heating of the plasma. Because of their high energy, the fast ions have a potential to quickly erode the plasma facing components. On the other hand, it is believed that the fast ions play a significant role in high performance plasma operational modes.

Magnetohydrodynamic (MHD) instabilities of the plasma can drive fast ions from the plasma. Such instabilities include the Neoclassical Tearing Mode (NTM) and Edge Localised Mode (ELM).

In ASDEX Upgrade the fast ions can be measured with a number of diagnostics. In this plan the neutral particle analyser (NPA) and fast ion loss detector (FILD) are used in concert to gain further understanding of the loss mechanisms of the ions.

The fast ions can be neutralised within the plasma, and the NPA measures the flux of neutralised fast ions. The neutrals (neutralised ions) are not bound by the magnetic field and hence can fly out. The measurement provides information of the fast ion population within the plasma. The FILD is a probe close to the plasma. It gathers information of the fast ions that are lost from the plasma and hit the probe. The probe has high temporal, velocity and spatial resolution.

The data acquisition system (DAQ) of the NPA was recently retooled, and I have remotely operated the system from Finland. A new FILD2 probe has been installed into the vacuum vessel of ASDEX Upgrade.

During the mobility the following tasks will accomplished:

1. Acquaintance myself with the operation and capabilities of the FILD and FILD2 probes. Plan and prepare for ELM related filamentary structure studies planned for July, when both FILD and FILD2 probes are simultaneously in operation as well as the NPA.
2. Perform analysis of fast ion measurements performed during and before the visit. Discuss results of the analysis with doctors Suttrop, Fahrbach and García-Muñoz.
3. Increase the memory capacity of one of the NPA DAQ PCs.
   Investigate and possibly repair an unreliable clock signal used by the DAQ system.
4. Discuss further steps of an ELM-start-time detection method with dr. Maraschek.

Report: Damage to the tungsten first wall forced suspension of research on the ASDEX Upgrade tokamak for three weeks during May 2008. This forced me to postpone my visit. The new time for the two weeks of my visits was directly before the Europe’s largest annual fusion related scientific conference, The European Physical Society Conference on Plasma Physics. In addition the first week coincided with the plasma-surface interaction conference. As a result, the local scientists were excessively busy. Nevertheless, the visit was successful.

The following remarks regarding the specific tasks:

1. I took part in finalising the camera software for the FILD2-probe. While doing it, I become well acquainted with the hardware of the FILD2. The software development was successful: the camera now produces raw images and video, which are automatically stored. I also studied the physical components of the FILD1 probe, which will be installed in three weeks.
   The planning of the measurements in July was commenced, but naturally the bulk of work is still to be done here at the home institution.
2. I gained further understanding of the NPA’s measurements in Discussions with Dr. Fahrbach. A new, as of now unexplained, feature of the NPA spectrums was confirmed to exist. Discussions with Dr. García-Muñoz gave me a basis for analysing measurements done with the FILD probes.
3. The memory capacity was successfully increased in cooperation with Dr. Suttrop. Investigation of the clock signal lead to rewriting of the acquisition program for the NPA. The NPA-specific part was finished during the visit. The program needs to be integrated to the ASDEX Upgrade data storage system. Only after these steps can the clock problem be settled.
4. Dr. Maraschek was unavailable, so this task was postponed to the visit in July.

As a summary, the visit was more technically oriented than expected. The physics discussions gave guidelines for the work at home while significant progress was made in the technical side.

6.1.4 European gyrotron development for ITER

Name of seconded person:	Olgierd Dumbrajs
Sending Institution:	Helsinki University of Technology
Host Institution:	Forschungszentrum Karlsruhe
Dates of secondment / Mission:	1–30 June 2008

Work Plan / milestones: Detailed comparison of the mode competition codes written at FZK and Helsinki University of Technology, understanding of differences in mode competition scenarios predicted by the two codes, and their elimination.

Report: Milestones have been reached. The results will be reported at the 33rd International Conference on Infrared, Millimeter, and Terahertz Waves September 15–19, 2008, California Institute of Technology Pasadena. California,USA.

1. S. Kern, K.A. Avramides, M.H. Beringer, **O. Dumbrajs,** Y.H. Liu**,** *”Gyrotron Mode Competition Calculations: Investigations on the Choice of Numerical Parameters.”*

2. S. Alberti, F. Albajar, K. A. Avramides, P. Benin, W. Bin, T. Bonicelli, A. Bruschi, S. Cirant, E. Droz, **O. Dumbrajs**, D. Fasel, F. Gandini, T. Goodman, J.-P. Hogge, S. Illy, S. Jawla, J. Jin, S. Kern, C. Lievin, B. Marlétaz, Ph. Marmillod, I. Pagonakis, A. Perez, B. Piosczyk, L. Porte, T. Rzesnicki, U. Siravo, M. Thumm, M.Q. Tran *"Status of development of the 2MW, 170GHz coaxial-cavity gyrotron for ITER."*

3. **O. Dumbrajs,** Y. Kominis, and G.S. Nusinovich, *"Electron dynamics in the process of mode switching in gyrotrons,"* submitted to Physics of Plasmas.

6.1.5 Fast ion studies with NPA and FILD

Name of seconded person:	Simppa Jämsä
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP-Garching
Dates of secondment / Mission:	29 June – 26 July 2008

Work Plan / milestones: Fast ions or suprathermal ions have energy far higher than the thermal bulk of the plasma. The fast ions are mostly born during non-inductive heating of the plasma. Because of their high energy, the fast ions have a potential to quickly erode the plasma facing components. On the other hand, it is believed that the fast ions play a significant role in high performance plasma operational modes. Magnetohydrodynamic (MHD) instabilities of the plasma can drive fast ions from the plasma. Such instabilities include the Neoclassical Tearing Mode (NTM) and Edge Localised Mode (ELM). In ASDEX Upgrade the fast ions can be measured with a number of diagnostics. In this plan the neutral particle analyser (NPA) and fast ion loss detector (FILD) are used in concert to gain further understanding of the loss mechanisms of the ions.

The fast ions can be neutralised within the plasma, and the NPA measures the flux of neutralised fast ions. The neutrals (neutralised ions) are not bound by the magnetic field and hence can fly out. The measurement provides information of the fast ion population within the plasma. The FILD is a probe close to the plasma. It gathers information of the fast ions that are lost from the plasma and hit the probe. The probe has high temporal, velocity and spatial resolution. The data acquisition system (DAQ) of the NPA was recently retooled including remotely operated the system from Finland. A new FILD2 probe has been installed into the vacuum vessel of ASDEX Upgrade.

The following tasks are planned: Fast ion measurements

- Assist doctors Fahrbach and García-Muñoz in operating the FILD and FILD2 probes as well as the NPA. Specific research interests include ELM filamentary structure and NPA measurements of Helium-3.
- Perform analysis of fast ion measurements performed during the visit. Discuss results of the analysis with doctors Fahrbach and García-Muñoz.

Hand over the operating responsibility of the NPA DAQ to AUG data acquisition group. Discussions with various experts:

- Discuss further steps of an ELM-start-time detection method with Dr. Maraschek.

- Inquire Dr. Dux if a double peak visible e.g. in H_α-signal during ELMs is also visible in spectroscopy.
- Discuss with Dr. Conway about measuring the radial electric field during ELMs using the Doppler reflectometry-diagnostics and comparison with NPA measurements.

Report: The visit was 4 week long. The bulk of the first week was spent making the FILD-probe ready for measurements. I also prepared the DAQ program for handover. The second week was mostly spent making more measurements and analysing results. The third week was completely operation in Hydrogen, and NPA measurements consumed large amount of time. I dedicated the fourth week to physics discussions. Other tasks include planning a proposal for EDFA work program 2008–2009.

Fast ion measurements

- The probes were in operation as planned. During installation of FILD to the midplane manipulator, I participated in aligning the optics. I also sealed the probe casing against noise from ambient light.
- During the operation I spent most of my time controlling the FILD2 camera and creating overview spectrograms from the measured data. The last 1½ week of plasma operations were hydrogen and Helium-4 plasmas. It was unclear if the helium signal is detectable in the NPA. Measurements indicated that helium was detected in a certain class of shots. I proposed enhancing the NPA so that it could distinguish different kind of particles reaching each of the NPA’s channeltron-detectors. My physics seemed sound enough, but the practical difficulties were larger than the expectable new information. Hence the proposed enhancement will not be realised.
- Doctor García-Muñoz and I inspected the measured data. First results of the analysis were presented in the AUG program committee meeting.

After discussions, Dr. Behler, Herr Merkel and I decided that the NPA fast DAQ will be made an official AUG diagnostic. This facilitates to store the data in a publicly available (within AUG) repository. The data acquisition software will be automatically run during the following campaign without a need for manual interaction.

Discussions

- The main conclusion drawn with Dr. Maraschek is that the method is useful only if it is completely automatic. The proposed method cannot be made much more accurate than the competing methods. However, if it can be made automatic, the method can be useful. Plans for further development exist.
- I discussed filaments with Dr. Herrmann, which seemed to confirm the hypothesis that the first peak in H_α is emitted when out-flowing plasma interacts with ambient neutrals. The bigger latter peak is emitted after the plasma returns as neutral gas from the target plates and interacts with the plasma. This should still be confirmed somehow, but at present there seemed no need to interact with Dr. Dux. Other important piece of information from Dr. Herrmann is the fact that filaments are visible in the ballooning magnetic pick-up coils. This can be used to average NPA measurements over a large number of filaments.

- According to Dr. Conway, it should be possible to compare the radial electric field measurements from Doppler spectrometry and NPA. He agreed to provide data for one or more discharges. I'm currently composing a list of suitable discharges for this purpose.

6.1.6 Ion-beam measurements of selected ASDEX Upgrade tiles and collector probes

Name of seconded person:	Antti Hakola
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP-Garching
Dates of secondment / Mission:	7 July – 1 August 2008

Work Plan / milestones

1) Ion-beam measurement of collector probes exposed to plasma during the 2008 campaign and selected ASDEX Upgrade tiles already analyzed by SIMS
2) Comparison of ^{13}C profiles obtained by SIMS and ion-bem NRA, analysis of RBS results of collector probes and comparison between earlier ones
3) Getting familiar with the special computer programs and equipment used in ASDEX Upgrade.

Report: The visit was related to the ongoing plasma–wall interaction studies under the Task Force III 2008 (SOL & Divertor physics and first wall materials) of ASDEX Upgrade at Max-Planck-Institut für Plasmaphysik (IPP), Garching, Germany.

Understanding the erosion, deposition, and transport of different materials in tokamaks is of crucial importance when designing future fusion reactors. The nearest goal is ITER, whose safe and successful operation requires knowledge of not only the behaviour of plasma at the reactor core but also what happens at the edges. The structures in ITER facing the plasma edges will be primarily made of Carbon, Beryllium, and Tungsten and due to this, one should be well aware of the behaviour of these elements under all the operational circumstances of the reactor.

Milestones #1 and #2: An approximately 30-mm-diameter aluminium cylinder was used as a collector probe in an experiment in ASDEX Upgrade in April 2008. The probe was placed inside another cylinder with a radial slit in it through which the probe was in contact with plasma. Different angular sections were exposed to 1–3 plasma discharges each, after which the probe was removed from the torus to be characterized in detail.

During the visit, both angular and vertical scans of the 88-mm long probe were taken by bombarding it with a beam of 2.5-MeV $^{3}He^{+}$ ions in the accelerator lab of IPP. The spectra of protons formed in the nuclear reaction between ^{3}He and different elements as well as the spectra of backscattered ions were measured, and the results, in particular the deuterium contents in the studied locations were compared. The measurements now enable us to study the profile of the edge plasma.

To study the migration of carbon, ^{13}C in the form of $^{13}CH_4$ was injected into the ASDEX Upgrade plasma in the end of the 2007 campaign. The ^{13}C content of the divertor, limiter, and other wall tiles in one poloidal cross section of the torus was determined by Tekes using the SIMS (Secondary Ion Mass Spectroscopy) technique.

The obtained results showed significantly lower ^{13}C concentrations than what had been measured for corresponding tiles of the 2004 and 2005 campaigns although the number of plasma discharges had been almost the same in all the experiments.

During the visit, this discrepancy was studied in more detail by measuring some of the tiles using the ion-beam technique described above. Altogether six samples were analyzed, and the spectra of the protons formed in nuclear reactions between ^{13}C and ^{3}He were compared to that from a reference sample. No traces of ^{13}C could be distinguished, seemingly because ^{13}C concentrations of $< 10^{16}$ atoms/cm^{2} were below the resolution limit of the applied method. This was an expected result and proved that indeed the carbon content of the samples was low. The SIMS results were thus confirmed and their analysis can now be continued. – These milestones were reached.

Milestone #3: I met several people at ASDEX Upgrade and had useful and enlightening discussions with them. In addition, I became familiar with the software that are used to read the data of ASDEX Upgrade plasma shots. Simultaneously, the most important plasma parameters of earlier ^{13}C experiments were printed out to be used in analyzing old measurement results. – This milestone was reached.

Additional milestones: I was in charge of the ^{13}C puffing experiment on 17 July. Although only three plasma shots could be fired on that day (which is not enough for surface analyses) due to technical problems and difficulties in finding the right parameter space, one now knows how to drive the tokamak using the present control system and that heating of the plasma can be done using ECRH (Electron cyclotron resonance heating) only.

6.1.7 Modelling of scrape-off layer and plasma-surface interaction

Name of seconded person:	Leena Aho-Mantila
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP-MPG
Dates of secondment / Mission:	28 September – 18 October 2008

Work Plan / milestones: Local ^{13}C methane puffing experiments have been conducted in the divertor region of ASDEX Upgrade tokamak. In order to investigate what are the physical mechanisms leading to the deposition pattern observed at the target, the puffing is modelled with the ERO code, employing a plasma background modelled with SOLPS. Simulations with an H-mode background have not yet resulted in a sufficient match to the measured deposition. To tackle the problem, the modelling has now been steered to the 2007 L-mode experiments, which can be described with more confidence by SOLPS. Modelling of the plasma background was initiated during a mobility visit to IPP in June 2008, and will be continued during the planned visit. Preliminary ERO modelling is expected to be done by the beginning of the visit, and the results will then be discussed.

Goals:

1) Improving the SOLPS solution for the L-mode plasma background, including drifts to the model.
2) Discussion of the modelling results.

3) Discussion of the reliability/accuracy of available experimental data.
4) Interpretation of the available spectroscopic data.

Report: Modelling the L-mode plasma background for 2007 AUG injection experiment with SOLPS was continued (collaboration with M. Wischmeier, D. Coster, A. Chankin). During the visit, particular emphasis was given to the transport coefficients employed in the model, the fractions of input power assigned to the electrons and ions and the gas balance. First drift cases were also run. Available experimental data was discussed. By the end of the visit, SOLPS solutions without drifts were improved but runs with drifts require more work in the future.

First results from ERO modelling were discussed (R. Pugno, M. Wischmeier). Several suggestions were made to improve the modelling in order to reach a better quantitative correspondence between modelling and experiment. In particular, inclusion of the effect of surface roughness was discussed.

Additionally, the following discussions were taken place during the visit:

- Future $^{13}CH_4$ experiments were discussed in detail (with R. Pugno, M. Wischmeier, S. Brezinsek, R. Neu, A. Kallenbach and others).

- Possibilities to improve the surface interaction model in ERO were discussed (W. Jacob, K. Schmid, U. v. Toussaint).

6.1.8 Modelling of scrape-off layer and plasma-surface interaction

Name of seconded person:	Leena Aho-Mantila
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP-MPG
Dates of secondment / Mission:	6 November – 12 December 2008

Work Plan / milestones: Local ^{13}C methane injection experiments have been conducted in the divertor region of ASDEX Upgrade tokamak. By analysing the obtained deposition pattern important information about carbon migration can be obtained. The relevant numerical modelling has been ongoing since June 2008. The numerical tools are the SOLPS fluid plasma / Monte Carlo neutrals code package and the Monte Carlo impurity following code ERO. The modelling is a PhD thesis project and part of an EFDA PWI task. It is done in close collaboration with the IPP edge plasma modelling group.

A new injection experiment at AUG is planned for 28 November. The purpose of this experiment is to investigate the effect that the injection has on the divertor plasma and, consequently, on the carbon deposition on the tungsten tiles. Identifying the effect of the chosen injection rate on the deposition is of utmost importance for the relevant analysis of the injection experiments.

Goals:

5) Participation in the ^{13}C methane injection experiment on 28 November and analysis of the experimental data.

6) Improving the SOLPS solution for the L-mode plasma background, in particular concentrating on the effect of drifts. Collaboration with the IPP edge plasma modelling group.
7) Modelling methane transport with the ERO code, discussion of results with local experts.

Report: Local ^{13}C methane injection experiment was conducted at the end of the AUG experimental campaign. In total 4 successful discharges with injection were obtained, which resulted in sufficient amount of ^{13}C deposition at the outer target. The deposited tiles are being removed from the vessel, and they shall be photographed and sent for NRA analysis.

Modelling the L-mode plasma background for this injection experiment with SOLPS was initiated. The process involved learning how to generate the computational mesh and gathering the relevant experimental data. The lack of some important diagnostics might hinder the characterization of the discharge. However, as the acquired experimental data is in fair agreement with the 2007 injection experiment, the outlook for successful modelling is good. SOLPS runs with drifts are expected to improve with the introduction of this new mesh.

Due to the extensive work done with the actual experiment, data acquisition and plasma part of the modelling, ERO simulations of the injection could not be performed.

6.1.9 Fast ion and ELM studies with NPA and FILD

Name of seconded person:	Simppa Jämsä
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP-Garching
Dates of secondment / Mission:	16–29 November 2008

Work Plan / milestones: The proposed visit is part of the European experimental programme carried out at ASDEX Upgrade tokamak.

Fast ions or suprathermal ions have energy far higher than the thermal bulk of the plasma. The fast ions are mostly born during non-inductive heating of the plasma. Because of their high energy, the fast ions have a potential to quickly erode the plasma facing components. On the other hand, it is believed that the fast ions play a significant role in high performance plasma operational modes.

Magnetohydrodynamic (MHD) instabilities of the plasma can drive fast ions from the plasma. Such instabilities include the Edge Localised Mode (ELM).

In ASDEX Upgrade the fast ions can be measured with a number of diagnostics. In this plan the neutral particle analyser (NPA) and fast ion loss detector (FILD) are used in concert to gain further understanding of the loss mechanisms of the ions

The fast ions can be neutralised within the plasma, and the NPA measures the flux of neutralised fast ions. The neutrals (neutralised ions) are not bound by the magnetic field and hence can fly out. The measurement provides information of the fast ion population within the plasma. The FILD is a probe close to the plasma. It gathers information of the fast ions that are lost from the plasma and hit the probe. The probe has high temporal, velocity and spatial resolution.

The data acquisition system (DAQ) of the NPA was recently retooled, and I have remotely operated the system from Finland. A new FILD2 probe has been installed into the vacuum vessel of ASDEX Upgrade.

ASCOT is guiding centre following plasma simulation code developed in Helsinki. A number of AUG discharges were committed to ASCOT benchmarking via simulated NPA-diagnostic.

The following tasks were planned:

1. The measurements from the NPA diagnostics can be used to infer the radial electric field in a tokamak. Compare this method to other methods used in AUG. Possibly compile an algorithm that creates automatically an estimate for the field strength.
2. Analyse/compare simulation results regarding ASCOT benchmarking with Dr. Fahrbach and others.
3. Update the procedures used to transfer AUG backgrounds to ASCOT. The ASCOT file format has changed significantly since the procedures were written by Dr Suttrop and Ville Hynönen.
4. Perform analysis of ELMs and ELM-related filaments using the NPA and FILD to investigate the lost ion energy spectrum.

Report: The 2008 ASDEX Upgrade experimental campaign was ended a few weeks earlier than expected because of flywheel generator related issues. It happened that my visit coincided with the two last operational weeks of the campaign. This resulted in increased demand for discharges and general air of haste among the experimentalists. Nevertheless, I feel my visit was successful. I was able to gather information, do programming work and make measurements during my visit.

1. Radial electric field

I am aware of two ways (in addition to the NPA) that can measure the radial electric field E_r in ASDEX Upgrade:

a. **Doppler reflectometry:** I discussed with Mr. Happel about possible discharges for comparison between the NPA and reflectometry. There seemed to be no especially suitable discharge. After discussion with Dr. Conway, it was deemed difficult to make comparisons over an extended range of discharges. Also, creating a single E_r can take hours, Dr. Conway directed me towards a few well measured old discharges.
b. **Passive helium line-radiation:** Mr Langer can produce E_r-profiles, but his analysis program is still under intensive development. As a result he cannot offer many profiles for comparison with the NPA. He did ask for a list of shots the NPA has good data, and will inform me if he can make analysis on any of them.

As a summary, it is not a straightforward task to find a shot were the E_r is known from a measurement done with other diagnostics. Discussion with Dr. Fahrbach revealed that in fact the visibility of the E_r in the NPA is not always guaranteed. This question may warrant a study of its own.

2. ASCOT simulations

The effort related to ASCOT benchmarking branched into two parallel tracks:

a. **Benchmarking against NPA-measurements:** Dr. Fahrbach introduced me into the program IRENE used for acquiring the neutral atom density profile. The benchmarking of ASCOT depends on the profile to produce correct source rates. My understanding of the origin of this profile has greatly increased. The initial locations of the NBI-fast ions for the benchmarking are produced with the code FAFNER: I was able to acquire the documentation for this code and can now familiarize myself with the code backgrounds. I was able to acquire the 3D-wall of the ASDEX Upgrade tokamak from Dr. Lunt. Dr. Strumberger promised to produce the 3D-rippel-vacuum field of AUG for ASCOT calculations when need arises. The 3D-equilibrium is not at the moment useful for ASCOT.
b. **Benchmarking against NUBEAM and FAFNER:** There is a recent addition to ASCOT that allows users to produce the NBI ions inside ASCOT. This new module needs to be tested against other similar codes. I discussed with Dr. Tardini about benchmarking it against NUBEAM, a part of the code TRANSP. Dr. Tardini pointed me to the required simulation results already available. I also discussed benchmarking against FAFNER with Mr. Schwarzhuber and Dr. Stober. It was decided that this comparison should be done only after some issues within FAFNER have been looked into, possibly in summer 2009.

3. The procedures were updated

ASCOT can again import experimental data from AUG shotfiles, which facilitates quick simulation of AUG discharges.

4. ELMs and FILD

We measured a number of discharges with Dr. García-Muñoz using the FILD and the NPA with the aim of measuring good ELM signals. The analysis is ongoing.

I would like to report following work outside the foreseen milestones:

- Dr. García-Muñoz and I prepared for the joined work related to ITER FILD probes. This project is a related to proposals submitted to EFDA work programme 2009.
- Dr. García-Muñoz and I compared measurements done with the NPA and FILD during MHD-activity in the plasma. The reversed-shear toroidal-Alfven-eigenmodes did not seem to produce measurable effect in the NPA.

6.1.10 Mechanical measurements of JET tiles

Name of seconded person:	Jari Likonen
Sending Institution:	VTT / Association Euratom-Tekes
Host Institution:	JET/UKAEA Culham
Dates of secondment / Mission:	14–19 December 2008

Work Plan / milestones: mechanical measurements of JET tiles

Report: A surface profiler has been developed at JET during the last years. The purpose of the measurements is to record the surface profiles of the tiles before their installation at JET and do it in a repeatable way. The tiles will be exposed to plasma typically for a few years, after which they will be removed and the measurements will be repeated. By comparing the results before and after plasma exposure, erosion/deposition pattern can be determined. During this staff mobility visit the aim was to build a second system, make test measurements and compare results with the first system. Since the previous staff mobility visit in June–July 2008, the first system has been disassembled and electronics rebuild into a small cabinet. In addition, the operator at JET damaged the probe head. The system hadn't been tested at all. During this visit, the first system was rebuilt and few test measurements were made.

New system was also assembled during this mobility visit but it turned out that encoders for positioning the table (where the tile is mounted) were missing. The table was returned to the local agent who will send the table back to the manufacturer for the installation of the encoders.

7 OTHER ACTIVITIES

7.1 Conferences, Workshops and Meetings

M. Santala participated in EP2 Diagnostic Package III Project Board meeting, JET, Culham, UK, on 24 January and 17 July 2008.

M. Aints, M. Kiisk, M. Laan, Jari Likonen and P. Paris Kick-off meeting of JET Fusion Technology on laser diagnostics, Tartu Estonia, 31 January 2008. Visitors: Nicolas Bekris (EFDA CSU), Christian Grisolia (CEA), Paul Coad, (UKAEA).

S. Karttunen participated in the EFDA Programme Workshop at ENEA, Frascati, Italy, 28–29 January 2008.

M. Santala participated in Meeting on the EFDA Diagnostics Work programme 2008/2009, Garching, Germany, on 5–6 March 2008.

O. Dumbrajs participated in the Solvey workshop dedicated to memory of Radu Balescu, Brussels, Belgium, 6–8 March, 2008.

A. Hakola and T. Koskela participated in the XLII Annual Conference of the Finnish Physical Society, Turku, 27–29 March 2008.

S. Tähtinen and P. Moilanen participated in SITU2 project meeting, SCK.CEN, Mol, Belgium, 14–15 April 2008.

M. Kiisk, M. Laan and J. Likonen participated in the Task Force Fusion Technology Meeting, Culham, UK, 23–24 April 2008.

J.A. Heikkinen gave an invited talk Edge Turbulence in Fusion Plasmas at the DEISA Advancing Science in Europe 2008 Symposium, Edinburgh, Scotland, 28–29 April 2008.

J. Lönnroth participated in a Task Force ITM ITER Scenario Modelling Working Session, Innsbruck, Austria, 5–9 May 2008.

L. Aho-Mantila, M. Airila, C. Björkas, Kalle Heinola, J. Likonen and K. Nordlund participated in the 18th International Conference on Plasma Surface Interactions (PSI), Toledo, Spain, 26–30 May 2008.

62 participants (invited speaker Carlo Damiani from F4E) from 12 countries participated in the Euratom-Tekes Annual Fusion Seminar, on M/S Silja Serenade Helsinki–Stockholm Cruise, 4–6 June 2008.

Kai Nordlund participated in the 13th workshop on Multi-scale Modelling of FeCr Alloys for Nuclear Applications in Oxford, UK, 2–4 June 2008.

O. Asunta, S. Jämsä, T. Kiviniemi, T. Koskela, T. Kurki-Suonio, S. Leerink, J. Lönnroth, M. Nora, A. Salmi participated in the 35th European Physical Society Conference on Plasma Physics, Crete, Greece, 9–13 June 2008.

T. Kiviniemi and S. Leerink participated in EFTSOMP2008 Workshop, Crete, Greece, 16–17 June 2008.

O. Dumbrajs participated in the 2008 IEEE International Conference on Plasma Science, Karlsruhe, Germany, 5–19 June 2008.

J. Raud and R. Tiismus participated in the EFDA RP Meeting, Padua, Italy, 21–26 June 2008.

T. Koskela participated in the 45th Culham Plasma Physics Summer School, Oxford, UK, on 7–18 July 2008.

K. Nordlund participated in the EFDA coordination meeting on the MATREV task in Barcelona, Spain, 9–12 July 2008.

S. Tähtinen participated in Fusion modelling meeting, F4E, Barcelona, Spain, 10–11 July 2008.

O. Dumbrajs participated in the 7th International Workshop "Strong Microwaves: Sources and Applications", Nizhny Novgorod, Russia, 27 July – 2 August 2008.

M. Aints, A. Hakola, S. Karttunen, M. Kiisk, M. Laan and J. Likonen participated in a Finnish–Estonian Fusion Meeting on Plasma-Wall Interactions, Tallinn, Estonia, 20–21 August 2008.

T. Tala participated in the 13th EU-US TTF Workshop, Copenhagen, Denmark, 1–4 September 2008.

S. Tähtinen participated in 29th Risø International Symposium on Material Science, Risø, Roskilde, Denmark, 1–5 September 2008.

J.A. Heikkinen gave an invited Lecture on Plasma Simulation Using Particle Codes at the Cours CEA-EDF-INRIA, Modèles numériques pour la fusion contrôlée, Université de Nice, Nice, 8–12 September 2008.

H. Handroos, J. Järvenpää, J. Mattila, P. Paris and M. Siuko, participated in 25th Symposium on Fusion Technology, Rostock, Germany, 15–19 September 2008.

O. Dumbrajs participated in 33rd International Conference on Infrared, Millimeter, and Teraherz Waves, California, USA, 15–19 September 2008.

S. Leerink participated in a Workshop and Minicourse on Kinetic Equations, Numerical Approaches and Fluid Models for Plasma Turbulence, Wolfgang Pauli Institute, Vienna, Austria, in September 2008.

C. Björkas, N. Juslin, F. Djurabekova and K. Nordlund participated in the International Conference on Radiation Effects in Solids, 12–17 October 2008.

S. Karttunen, T. Kurki-Suonio, M. Siuko, T. Tala (plenary talk) participated in the 22nd IAEA Fusion Energy Conference, 13–18 October 2008, Geneva, Switzerland.

A. Hakola and J. Likonen participated in the EU-PWI-TF SEWG Meeting on Mixed Materials, Garching, Germany, 8–10 October 2008. (C. Björkas, K. Vörtler and K. Nordlund participated remotely)

T. Tala participated in the ITPA Transport and Confinement Topical group meeting, Milan, Italy, 20–22 October 2008.

K. Nordlund participated in the International Conference on Multiscale Modelling of Materials, Tallahassee, Florida, USA, 26–31 October 2008.

T. Kurki-Suonio participated in the ITPA Energetic Particle Topical group meeting, Lausanne, Switzerland, 22–24 October 2008.

A. Hakola and T. Kurki-Suonio participated in the Annual ASDEX Upgrade Program Seminar, Ringberg, Germany, 26–31 October 2008.

L. Aho-Mantila, O. Asunta, S. Janhunen, S. Leerink and M. Nora participated in GOTiT Course on Gyrokinetics, IPP Garching, Germany, 2–14 November 2008.

J. Lönnroth participated in a Task Force ITM ITER Scenario Modelling Working Session, Cadarache, France, 24–28 November 2008.

R. Salomaa participated in the 16th European Fusion Physics Workshop, Cork, Ireland, 1–3 December 2008.

N. Juslin participated in the EFDA coordination meeting on the MATREV Task in Athens, Greece, 10–13 December 2008.

S. Janhunen and S. Leerink participated in the Russian–Finnish Seminar on Fusion Research and Plasma Physics, St. Petersburg, Russia, 11–12 December 2008.

A. Hakola, S. Karttunen, M. Laan, J. Likonen and P. Paris participated in a kick-off meeting for collaboration between the Finnish and Estonian RUs and the FOM-Institute for Plasma Physics Rijnhuizen, Nieuwegein, the Netherlands, 10–11 December 2008.

S. Karttunen participated in the Heads of Research Unit Meeting, Garching, Germany, 17 December 2008.

J. Heikkinen, S. Karttunen and R. Salomaa gave a lecture course in "Fusion Technology" in Lappeenranta University of Technology, Spring Term 2008 and in Helsinki University of Technology in June 2008.

7.2 Visits

J. Lönnroth, Antti Salmi and V. Takalo were seconded to EFDA-JET, Culham, under the JET Operating Contract in 2008.

S. Karttunen visited Jozef Stefan Institute, Ljubljana, Slovenia, 10–11 March 2008.

S. Janhunen participated in EFDA ITM IMP4 Task activities, Cadarache, France, on 19–30 April 2008.

Olgierd Dumbrajs worked at Max-Planck-Institut für Plasmaphysik, Garching, Germany, from 1 April to 31 May 2008.

F. Djurabekova, K. Nordlund and H. Timko, visit to Max-Planck-Institute of Plasma Physics, Greifswald, Germany, 14–16 August 2008.

M. Santala was seconded to EFDA-JET Culham Science Centre, Oxfordshire, UK, from 7 April to 18 July and from 28 October to 11 November 2008.

T. Kurki-Suonio worked at Max-Planck-Institut für Plasmaphysik, Garching, Germany, on 6–19 April, 6–26 July and 18–31 October 2008.

S. Jämsä worked at Max-Planck-Institut für Plasmaphysik, Garching, Germany, from 25 May to 7 June, from 29 June to 26 July and 16–29 November 2008.

Olgierd Dumbrajs worked at Forschungszentrum Karlsruhe, Germany, in 1–30 June 2008.

L. Aho-Mantila worked at Max-Planck-Institut für Plasmaphysik, Garching, Germany, from 15 June to 12 July, from 28 September to 18 October and from 26 November to 12 December 2008.

Otto Asunta worked at EFDA-JET, Culham, UK, on 2 January – 1 February, from 13 April to 23 May, 14–26 September and from 17 November to 12 December 2008.

J. Lönnroth visited General Atomics, San Diego, California, USA from 31 July to 4 August 2008.

A. Hakola worked at Max-Planck-Institut für Plasmaphysik, Garching, Germany, from 6 July to 2 August 2008.

S. Karttunen visited UKAEA, Culham, UK, on 6 October 2008.

A. Salmi worked at DI NYU, Courant Institute, USA, from 24 November to 5 December 2008.

7.3 Visitors

Dr. Manuel Garcia-Munoz from the Max Planck Institut für Plasmaphysik, Germany, visited TKK on 7–13 January 2008.

Paul Coad and Anna Widdowson from UKAEA, UK, visited VTT on 3–8 February 2008.

Dr. Ralph Dux from the Max Planck Institut für Plasmaphysik, Germany lectured a course on plasma diagnostics at TKK on 4–15 February 2008.

Prof. Sibylle Günter from the Max Planck Institut für Plasmaphysik, Germany, visited TKK on 26 March 2008.

Dr. Karl Krieger from the Max-Planck-Institut für Plasmaphysik, Germany, visited TKK on 13–14 May 2008.

Dr. Udo von Toussaint, Max-Planck-Institut für Plasmaphysik, Garching, Germany, visited the Department of Physics at the University of Helsinki 3–27 June 2008.

Dr. Dmitry Terentyev, SCK-CEN Mol, Belgium, visited the Department of Physics at the University of Helsinki 11–22 August 2008.

Prof. Klaus Shoepf from the University of Innsbruck, visited TKK on 18 August 2008 acted as the examiner of the doctoral thesis of Ville Hynönen.

Eric Gauthier and Timo Dittmar from CEA, France, visited VTT on 30 October – 14 November 2008.

Dr. Ioannis Tigelis from the Department of Electronics, Computing, Telecommunications and Control, Faculty of Physics, National and Kapodistrian University of Athens visited TKK on 8–18 December 2008.

Dr. Konstantinos Avramides from the National Technical University of Athens visited TKK on 8–18 December 2008.

Dr. Luigino Petrizzi from ENEA Frascati visited TKK on 19 December 2008, acted as the examiner of the doctoral thesis of Frej Wasastjerna.

8 PUBLICATIONS 2008

8.1 Fusion Physics and Plasma Engineering

8.1.1 Publications in scientific journals

1. M. García–Muñoz; H.–U. Fahrbach, S. Günter, V. Igochine, *M. J. Mantsinen*, M. Maraschek, P. Martin, P. Piovesan, K. Sassenberg, and H. Zohm, “Fast ion losses due to high frequency MHD perturbations in the ASDEX Upgrade tokamak”, Physical Review Letters **100** (2007) 055005.

2. T. Tala, K. Crombé, P.C. de Vries, J. Ferreira, P. Mantica, A.G. Peeters, Y. Andrew, R. Budny, G. Corrigan, A. Eriksson, X. Garbet, C. Giroud, M.–D. Hua, H. Nordman, V. Naulin, M.F.F. Nave, V. Parail, *K. Rantamäki*, B.D. Scott, P. Strand, G. Tardini, A. Thyagaraja, J. Weiland, K.-D. Zastrow and JET-EFDA contributors, “Toroidal and Poloidal Momentum Transport Studies in Tokamaks”, Plasma Physics and Controlled Fusion **49** (2007) B291–B302.

3. A. Eriksson, H. Nordman, P. Strand, J. Weiland, *T. Tala*, E. Asp, G. Corrigan, C. Giroud, M. de Greef, I. Jenkins, H.C.M. Knoops, P. Mantica, *K.M. Rantamäki*, P.C. de Vries, K.–D. Zastrow and JET EFDA Contributors, “Predictive simulations of toroidal momentum transport at JET”, Plasma Physics and Controlled Fusion **49** (2007) 1931–1943.

4. J.P.S. Bizarro, X.L. Litaudon, *T.J.J. Tala* and JET EFDA contributors, “Controlling the Internal Transport Barrier Oscillations in High-Performance Tokamak Plasmas with a Dominant Fraction of Bootstrap Current”, Nuclear Fusion **47** (2007) L41–L45.

5. J.A. Heikkinen and J. Lönnroth, “Kinetic, two-fluid and MHD simulations of plasmas”, Plasma Physics and Controlled Fusion **49** (2007) B465–B477 (Invited plenary talk at the 34th EPS Conference, Warsaw, Poland).

6. L.K. Aho-Mantila, T. Kurki–Suonio, A.V. Chankin, D.P. Coster and S.K. Sipilä, "ASCOT simulations of electron energy distribution at the divertor targets in an ASDEX Upgrade H-mode discharge", Plasma Physics and Controlled Fusion **50** (2008) 065021.

7. J.P.S. Bizarro, X.L. Litaudon, *T.J.J. Tala* and JET EFDA Contributors, ”Computational Images of Internal-Transport-Barrier Oscillations in Tokamak Plasmas”, IEEE Transactions on Plasma Science **36** (2008) 1090–1091.

8. J.A. Heikkinen and N. Ohno, ”Preface: Contrib. Plasma Phys. 1–3/2008”, Contributions to Plasma Physics **48** (2008) 3–12.

9. P.C. de Vries, M.-D. Hua, D.C. McDonald, C. Giroud, M. Janvier, M.F. Johnson, *T. Tala*, K.-D Zastrow and JET EFDA Contributor, “Scaling of Rotation and Momentum Confinement in JET plasmas”, Nuclear Fusion **48** (2008) 065006.

10. P.C. de Vries, *A. Salmi*, V. Parail, C. Giroud, Y. Andrew, T.M. Biewer, K. Crombe, I. Jenkins, T. Johnson, V. Kiptily, A. Loarte, *J. Lönnroth*, A. Meigs, N. Oyama, R. Sartori, G. Saibene, H. Urano, K.D.Zastrow, JET EFDA Contributors, “Effect of Toroidal Field Ripple on Plasma Rotation in JET”, Nuclear Fusion **48** (2008) 035007.

11. *O. Dumbrajs*, V. Igochine and H. Zohm, “Diffusion in a stochastic magnetic field in ASDEX Upgrade”, Nuclear Fusion **48** (2008) 024011.

12. D. Constantinescu, *O. Dumbrajs*, V. Igochine and B. Weyssow, “On the accuracy of some mapping techniques used to study the magnetic field dynamics in tokamaks”, Nuclear Fusion **48** (2008) 024017.

13. V. Igochine, *O. Dumbrajs* and H. Zohm, “Transition from quasiperiodicity to chaos just before sawtooth crash in the ASDEX Upgrade tokamak”, Nuclear Fusion **48** (2008) 062001.

14. *O. Dumbrajs* and T. Idehara, “Hysteresis in mode competition in high power 170 GHz gyrotron for ITER”, International Journal of Infrared and Milimeter Waves **29** (2008) 232.

15. Z.C. Ioannidis, *O. Dumbrajs* and I.G. Tigelis, “Linear and non–linear inserts for Genuinely wideband continuous frequency tunable coaxial gyrotron cavities”, International Journal of Infrared and Millimeter Waves **29** (2008) 416.

16. Z. C. Ioannidis, G. P. Latsas, I. G. Tigelis, and *O. Dumbrajs*, "TM Modes in Coaxial Cavities with Inner Surface Corrugations" IEEE Transactions of Plasma Science **36** (2008) 2613.

17. P.C. de Vries, E. Joffrin, N.C. Hawkes, X. Litaudon, C.D. Challis, Y. Andrew, M. Beurskens, M. Brix, J. Brzozowski, K. Crombé, C. Giroud, J. Hobirk, T. Johnson, *J. Lönnroth, A. Salmi, T. Tala*, V. Yavorskij, K.-D. Zastrow and JET EFDA Contributors, “Effect of Toroidal Field ripple on the formation of Internal Transport Barriers”, Plasma Physics and Controlled Fusion **50** (2008) 065008.

18. *O. Dumbrajs,* V. Igochine, and H. Zohm, “Hysteresis in sawtooth crash in ASDEX Upgrade tokamak”, The Open Plasma Physics Journal **1** (2008) 9.

19. V. Hynönen, T. Kurki-Suonio, W. Suttrop, A. Stäbler, and the ASDEX Upgrade Team. 2008. “Effect of radial electric field and ripple on edge neutral beam ion distribution in ASDEX Upgrade”. Plasma Physics and Controlled Fusion **50** (2008) 035014.

20. D. Moreau, D. Mazon, M. Ariola, G. De Tommasi, L. Laborde, F. Piccolo, F. Sartori, *T. Tala*, L. Zabeo, A. Boboc, E. Bouvier, M. Brix, J. Brzozowski, C. Challis,V. Cocilovo, V. Cordoliani, F. Crisanti, E. De La Luna, R. Felton, N. Hawkes, R. King, X. Litaudon, T. Loarer, J. Mailloux, M. Mayoral, I. Nunes, E. Surrey, O. Zimmerman and JET EFDA contributors, ”A Two-Time-Scale Dynamic-Model Approach for Magnetic and Kinetic Profile Control in Advanced Tokamak Scenarios on JET”, Nuclear Fusion **48** (2008) 106001.

21. W. Fundamenski, D. Coster, *M. Airila*, P. Belo, X. Bonnin, A. Chankin, G. Corrigan, K.Erents, O.E. Garcia, S. Glowacz, B. Gulejova, A. Kirschner, V.

Naulin, A. Nielsen, G. Kirnev, V. Kotov, C. Konz, J. Rasmussen, R. Pitts, D. Reiter, T. Ribeiro, B. Scott, J. Strachan, F. Subba, E. Tsitrone, D. Tskhakaya, S. Wiesen, M. Wischmeier, R. Zagorski, EFDA-JET Contributors “Progress in edge plasma transport modeling on JET”. Contributions to Plasma Physics **48 (**2008) 190–195.

22. J.A. Heikkinen, S.J. Janhunen, T.P. Kiviniemi and F. Ogando, “Full f gyrokinetic Method for Particle Simulation of Tokamak Transport”, Journal of Computational Physics **227** (2008) 5582–5609.

23. A. Salmi, T. Johnson, V. Parail, J. Heikkinen, V. Hynönen, T. Kiviniemi, T. Kurki–Suonio, and JET EFDA Contributors, “ASCOT modelling of ripple effects on toroidal torque”, Contribution to Plasma Physics **48** (2008) 77–81.

24. S. Leerink, J.A. Heikkinen, S.J. Janhunen, T.P. Kiviniemi, M. Ora, F. Ogando. “The Implementation of a Toroidal Limiter Model into the Gyrokinetic Code ELMFIRE”, Contributions to Plasma Physics **48** (2008) 229–233.

25. A. Signell, F. Ogando, M. Aspnäs, J. Westerholm, “Scalable plasma simulation with ELMFIRE using efficient data structures for process communication”, Computer Physics Communications **179** (2008) 330–338.

26. J.D. Strachan, *J. Likonen*, P. Coad, M. Rubel, A. Widdowson, *M. Airila*, P. Andrew, S. Brezinsek, G. Corrigan, H.G. Esser, S. Jachmich, A. Kallenbach, A. Kirschner, A. Kreter, G.F. Matthews, V. Philipps, R.A. Pitts, J. Spence, M. Stamp, S. Wiesen and JET-EFDA contributors, “Modelling of carbon migration during JET 13C injection experiments”, Nuclear Fusion **48** (2008) 105002.

27. Y. Andrew, N.C. Hawkes, T. Biewer, K. Crombe, D. Keeling, E. de la Luna, C. Giroud, A. Korotkov, A. Murari, I. Nunes, R. Sartori, *T. Tala* and JET–EFDA contributors, ”Evolution of the radial electric field in a JET H-mode plasma”, Europhysics Letters **83** (2008) 15003.

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APPENDIX A INTRODUCTION TO FUSION ENERGY

A.1 Energy Demand Is Increasing

Most projections show world energy demand doubling or trebling in the next 50 years. This derives from fast population growth and rapid economic development. Energy sources that are not yet fully tapped include biomass, hydropower, geo-thermal, wind, solar, nuclear fission and fusion. All of them must be developed to meet future needs. Each alternative has its advantages and disadvantages regarding the availability of the resource, its distribution globally, environmental impact, and public acceptability. Fusion is a good candidate for supplying base load electricity on a large scale. Fusion has practically unlimited fuel resources, and it is safe and environmentally sound.

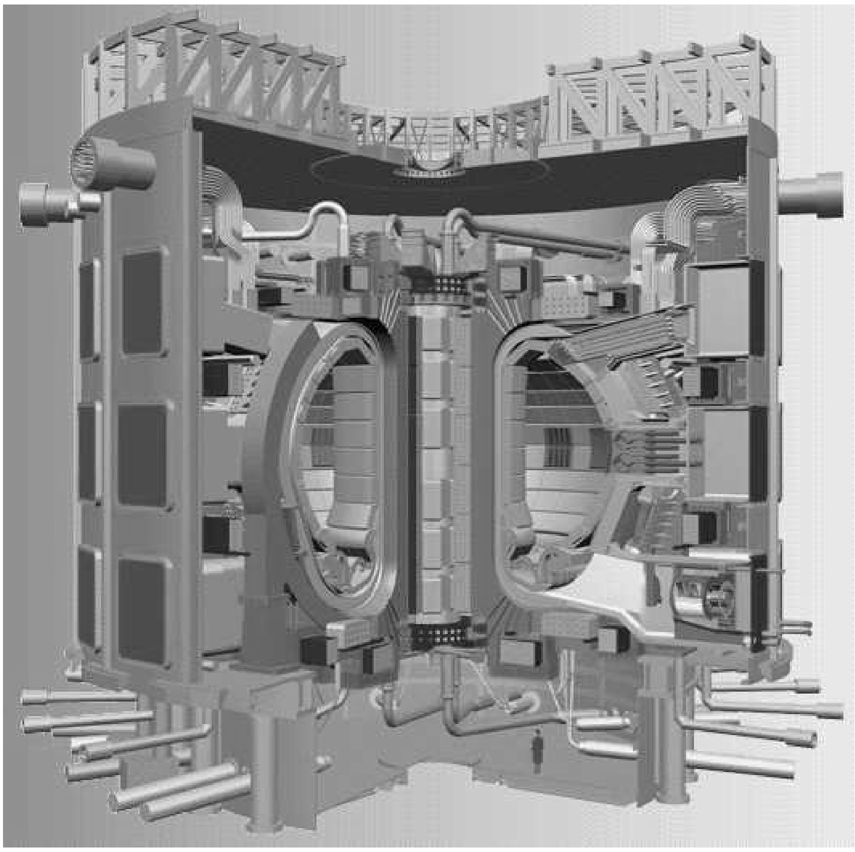

Figure A1. A design model for the experimental fusion reactor ITER, which will be constructed in Europe (Cadarache, France) as world wide collaboration.

A.2 What Is Fusion Energy?

Fusion is the energy source of the sun and other stars, and all life on Earth is based on fusion energy. The fuels burned in a fusion reactor are hydrogen isotopes, deuterium and tritium. Deuterium resources are practically unlimited, and tritium can be produced from lithium, which is abundant. The fusion reactions occur only at very high temperatures. For the deuterium-tritium reaction, temperatures over 100 million °C are required for sufficient fusion burn. At these temperatures, the fuel gas is fully ionised plasma. High temperatures can be achieved by injecting energetic particle beams or high power radio-frequency (RF) waves into the plasma. The hot plasma can be thermally isolated from the material walls by strong magnetic fields, which form a "magnetic bottle" to confine the fuel plasma. With a sufficiently large plasma volume, much more energy is released from fusion reactions than is required to heat and confine the fuel plasma, i.e., a large amount of net energy is produced.

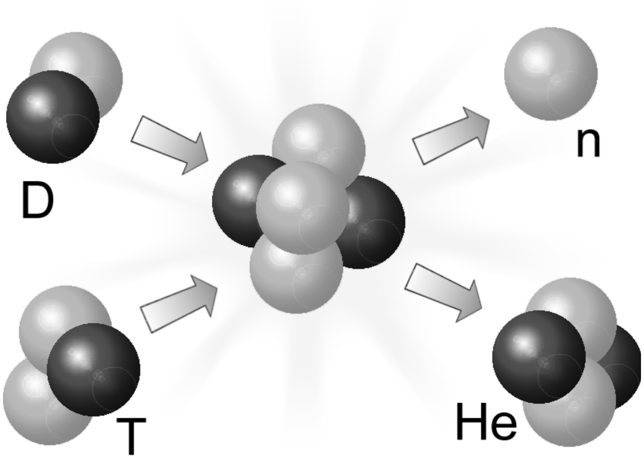

Figure A2. In a fusion reaction, deuterium (D) and tritium (T) fuse together forming a helium nucleus (^{4}He) and releasing a large amount of energy which is mostly carried by the neutron (n).

A.3 The European Fusion Programme

Harnessing fusion energy is the primary goal of the Euratom Fusion Programme in the 7th Framework Programme. The reactor orientation of the programme has provided the drive and the cohesion that makes Europe the world leader in fusion research. The world record of 16 megawatts of fusion power is held by JET device, the Joint European Torus.

Euratom Fusion Associations are the backbone of the European Fusion Programme. There are 26 Associations from the EU countries and Switzerland. The multilateral European Fusion Development Agreement (EFDA) between all the Associations and Euratom takes care of overall physics co-ordination in Europe, facilitates the joint exploitation of the JET facilities and the emerging fusion technologies.

A new organisation "The Joint European Undertaking for ITER and the Development of Fusion Energy, "Fusion for Energy" (F4E) was established in early 2007 and is coming fully operational in 2008. The main task of "Fusion for Energy" is to provide European in-kind contributions for ITER being one of the Domestic Agencies for ITER including component and system procurements and technology R&D for ITER. In addition, "Fusion for Energy" manages DEMO design activities and the European Broader Approach activities in collaboration with Japan.

A.4 ITER International Fusion Energy Organisation

To advance significantly beyond the present generation of fusion devices, a next step device, enabling the investigation of burning plasma in near-reactor conditions, is needed. This will be done in the global ITER project ("iter" is "way" in latin), which is the joint project of EU, Japan, Russian Federation, United States, China, India and South Korea. The ITER parties agreed in 2005 to site ITER in Europe (Cadarache, France) and the ITER International agreement was signed by the parties in Elysée Palace hosted by the President of France Jacques Chirac, Paris, on 21 November 2006. ITER started as an international legal entity from 27 November 2007. The director general of ITER is Dr. Kameda Ikeda and the deputy director general is Dr. Nobert Holtkamp who is responsible of the ITER construction. In 2008 the project staff exceeded 300. The total number of personnel will be close to 600.

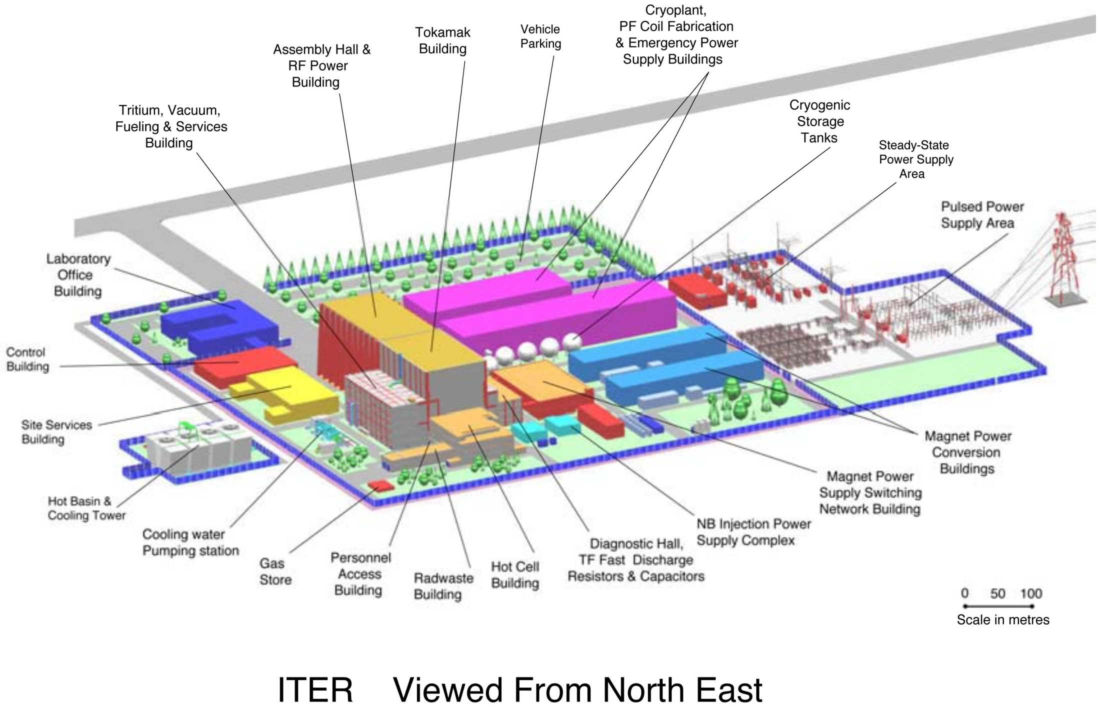

Figure A3. Lay-out of the ITER site and buildings at Cadarache.

APPENDIX B INSTITUTES AND COMPANIES

B.1 Research Institutes and Companies

Tekes – The Finnish Funding Agency for Technology and Innovation

Kyllikinportti 2, Länsi-Pasila
P.O. Box 69, FI-00101 Helsinki, Finland
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www.tekes.fi

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Hannu Juuso	hannu.juuso@tekes.fi

B.2 Finnish Fusion Research Unit of the Association Euratom-Tekes

VTT, Technical Research Centre of Finland

VTT Materials for Power Engineering

Otakaari 3A, Espoo and Kemistintie 3, Espoo
P.O. Box 1000, FI-02044 VTT, Finland
tel. +358 20 722 111; fax: +358 20 722 6390
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Jari Likonen	jari.likonen@vtt.fi
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VTT Production Systems

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Tampere University of Technology
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Laboratory of Machine Automation
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B.3 Estonian Research Unit of the Association Euratom-Tekes

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National Institute of Chemical Physics and Biophysics

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12618 Tallinn, Estonia
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www.kbfi.ee
Andi Hektor andi.hektor@cern.ch

B.4 Industrial Companies

Company: **ABB Oy**
Technology: Power and automation
Contact: ABB Oy, P.O. Box 184, FI-00381 Helsinki, Finland
Tel. +358 10 2211; fax. +358 10 2222 287
Ralf Granholm ralf.granholm@fi.abb.com

Company: **Adwatec Oy**
Technology: Remote handling, water hydraulics, actuators and drives
Contact: Adwatec Oy, Polunmäenkatu 39 H 9, FI-33720 Tampere, Finland
Tel. +358 3 389 0860; fax. +358 3 389 0861
www.adwatec.com
Arto Verronen rto.verronen@adwatec.com

Company: **Aspocomp Oy**
Technology: Electronics manufacturing, thick film technology, component mounting (SMT), and mounting of chips (COB) in mechanical and electrical micro systems (MEMS) and multi-chip modules (MCM), PWB (or also called PCB), sheet metal manufacturing and assembly.
Contact: Aspocomp Oy, Yrittäjäntie 13, FI-01800 Klaukkala, Finland
Tel. +358 9 878 01244; Fax. +358 9 878 01200
www.aspocomp.com
Markku Palmu markku.palmu@aspocomp.com

Company **Creanex Oy**
Technology: Remote handling, teleoperation and walking platforms.
Contact: Creanex Oy, Nuolialantie 62, FI-33900 Tampere, Finland
Fax. +358 33683 244, GSM +358 50 311 0300
www.creanex.com
Timo Mustonen timo.mustonen@creanex.com

Company: **Delfoi Oy**
Technology: Telerobotics, task level programming
Contact: Delfoi Oy, Vänrikinkuja 2, FI-02600 Espoo, Finland
Tel. +358 9 4300 70; Fax. +358 9 4300 7277
www.delfoi.com
Heikki Aalto heikki.aalto@delfoi.com

Company: **DIARC Technology Oy**
Technology: Diamond like DLC and DLC (Si, D) doped carbon coatings plus other coatings with potential plasma facing material in thermonuclear fusion machines.
Contact: Diarc Technology, Olarinluoma 15, FI-02200 Espoo, Finland
Tel. +358 9 2517 6130; fax +358 9 2517 6140
www.diarc.fi
Jukka Kolehmainen jukka.kolehmainen@diarc.fi

Company: **Ekono-Electrowatt/Jaakko Pöyry Group**
Technology: International consulting and engineering expert within the Jaakko Pöyry Group serving the energy sector. Core areas: management consulting, hydropower, renewable energy, power & heat, oil & gas, project services for nuclear safety and industrial processes
Contact: P.O. Box 93, Tekniikantie 4 A, FI-02151 Espoo, Finland
Tel. +358 46911, Fax. +358 9 469 1981
www.poyry.com
Vilho Salovaara vilho.salovaara@poyry.fi

Company: **Elektrobit Microwave Oy**
Technology: Product development, test solutions and manufacturing for microwave and RF- technologies, high-tech solutions ranging from space equipment to commercial telecommunication systems
Contact: Teollisuustie 9A, FI-02700 Kauniainen, Finland
Tel. +358 40 344 2000, Fax +358 9 5055 547
www.elektrobit.com
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Company: **Enprima Oy**
Technology: Design, engineering, consulting and project management services in the field of power generation and district heating. EPCM services.
Contact: P.O. Box 61, FI-01601 Vantaa, Finland
Tel +358 40 348 5511, Fax. +358 9 3487 0810
www.enprima.com
Jarmo Raussi jarmo.raussi@enprima.com

Company: **Finpro**
Role: Industry activation and support
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Porkkalankatu 1, FI-00181 Helsinki,
Tel. +358 204 6951; fax +358 204 695200
www.finpro.fi
Markus Ranne markus.ranne@finpro.fi

Company: **Fortum Nuclear Services Oy**
Technology: Nuclear Engineering
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FI-00048 Fortum, Finland
Tel. + 358 10 4511; fax. +358 10 453 3403
www.fortum.com
Herkko Plit herkko.plit@fortum.com

Company **High Speed Tech Oy**
Technology: Copper to stainless steel bonding by explosive welding
Contact: High Speed Tech Oy, Tekniikantie 4 D, FI-02150 Espoo, Finland
Fax. +358 9 455 5267
www.highspeedtech.fi
Jaakko Säiläkivi jaakko.sailakivi@highspeed.sci.fi

Company: **Hollming Works Oy**
Technology: Mechanical engineering, fabrication of heavy stainless steel structures
Contact: Puunaulakatu 3, P.O. Box 96, FI-28101 Pori, Finland
Tel. +358 20 486 5040; fax +358 20 486 5041
www.hollmingworks.com
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Company: **Hytar Oy**
Technology: Remote handling, water hydraulics
Contact: Hytar Oy, Ilmailukatu 13, P.O. Box 534, FI-33101 Tampere, Finland
Tel. +358 3 389 9340; fax +358 3 389 9341
Olli Pohls olli.pohls@avs-yhtiot.fi

Company: **Instrumentti-Mattila Oy**
Technology: Designs and manufacturing of vacuum technology devices
Contact: Valpperintie 263, FI-21270 Nousiainen, Finland
Tel +358 2 435 3611, Fax +358 2 431 8744
www.instrumentti-mattila.fi
Veikko Mattila veikko.mattila@instrumentti-mattila.fi

Company: **Japrotek Oy**
Technology: Designs and manufacturing of stainless steel process equipment such as columns, reactors and heat exchangers
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Tel +358 20 1880 511, Fax +358 20 1880 415
www.vaahtogroup.fi
Ulf Sarelin ulf.sarelin@vaahtogroup.fi

Company: **Jutron Oy**
Technology: Versatile electronics manufacturing services
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www.jutron.fi
Keijo Meriläinen keijo.merilainen@jutron.fi

Company: **Kankaanpää Works Oy**
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www.hollmingworks.com
Jarmo Huttunen jarmo.huttunen@hollmingworks.com

Company: **Kempower Oy**
Technology: Designs and manufacturing of standard and customised power sources for industrial and scientific use
Contact: Hennalankatu 39, P.O. Box 13, FI-15801, Lahti, Finland
Tel +358 3 899 11, Fax +358 3 899 417
www.kempower.fi
Petri Korhonen petri.korhonen@kempower.fi

Company: **Luvata Oy**
Technology: Superconducting strands and copper products.
Contact: Luvata Oy, Kuparitie, P.O Box 60, FI-28101 Pori, Finland
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Ben Karlemo ben.karlemo@luvata.com

Company: **Mansner Oy Precision Mechanics**
Technology: Precision mechanics: milling, turning, welding, and assembling. From stainless steels to copper.
Contact: Mansner Oy, Yrittäjäntie 73, FI-03620 Karkkila, Finland
Tel. +358 9 2248 7323; Fax +358 9 2248 7341
www.mansner.com
Sami Mansner sami.mansner@mansner.fi

Company: **Marioff Corporation Oy**
Technology: Mist fire protection systems
Contact: Marioff Corporation Oy, P.O. Box 25, FI-01511 Vantaa, Finland
Tel. +358 9 8708 5342; Fax. +358 9 8708 5399
www.hi-fog.com
Pekka Saari pekka.saari@marioff.fi

Company: **Metso Materials Technology Oy**
Technology: Special stainless steels, powder metallurgy, component technology/ engineering, design, production and installation
Contact: Metso Materials Technology Oy, P.O. Box 1100, FI-33541 Tampere, Finland
Tel. +358 20 484 120; fax +358 20 484 121
www.metsopowdermet.com
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Company: **Oxford Instruments Analytical**
Technology: Plasma diagnostics, vacuum windows
Contact: Nihtisillankuja, P.O. Box 85, FI-02631 Espoo, Finland
Tel:+358 9 329411, Fax: +358 9 23941300
www.oxford-instruments.com
Seppo Nenonen seppo.nenonen@oxinst.fi

Company: **Patria Oyj**
Technology: Defence and space electronics hardware and engineering
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Tel +358 2 435 3611, Fax +358 2 431 8744
www.patria.fi
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Company: **PI-Rauma Oy**
Technology: Computer aided engineering with CATIA.
Contact: PI-Rauma Oy, Mäntyluoto, FI-28880 Pori, Finland
Tel. +358 2 528 2521; fax +358 2 528 2500
www.pi-rauma.fi
Matti Mattila matti.mattila@pi-rauma.com

Company: **Platom Oy**
Technology: Remote handling, thermal cutting tools and radioactive waste handling.
Contact: Platom Oy, Graanintie 5, P.O. Box 300, FI-50101 Mikkeli, Finland
Tel. +358 44 5504 300; fax. +358 15 369 270
www.platom.fi
Miika Puukko miika.puukko@platom.fi

Company: **PPF Projects Oy**
Service: Industry activation and support
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Company: **Prizztech Oy**
Role: Industry activation and support
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www.prizz.fi
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Company: **Rados Technology Oy**
Technology: Dosimetry, waste & contamination monitoring and environmental monitoring.
Contact: Rados Technology Oy, P.O. Box 506, FI-20101 Turku, Finland
Tel. +358 2 4684 600; Fax +358 2 4684 601
www.rados.fi
Erik Lehtonen erik.lehtonen@rados.fi

Company: **Rejlers Oy**
Technology: System and subsystem level design, FE modelling and analysis with ANSYS, studies and technical documentation, installation and maintenance instructions, 3D modelling and visualisation of machines and components.
Contact: Rejlers Oy, Myllykatu 3, FI-05840 Hyvinkää, Finland
Tel: +358 19 2660 600; Fax. +358 19 2660 601
www.rejlers.fi
Jouni Vidqvist jouni.vidqvist@rejlers.fi

Company: **Rocla Oyj**
Technology: Heavy Automated guided vehicles
Contact: Rocla Oyj, P.O. Box 88, FI- 04401 Järvenpää, Finland
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www.rocla.fi
Pekka Joensuu pekka.joensuu@rocla.com

Company: **Selmic Oy**
Technology: Microelectronics design and manufacturing, packaging technologies and contract manufacturing services.
Contact: Selmic Oy, Vanha Porvoontie 229, FI-01380 Vantaa, Finland
Tel: +358 9 2706 3911; Fax +358 9 2705 2602
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Patrick Sederholm patrick.sederholm@selmic.com

Company: **Solving Oy**
Technology: Heavy automated guided vehicles. Equipment for heavy assembly and material handling based on air film technology for weights up to hundreds of tons.
Contact: Solving Oy, P.O. Box 98, FI-68601 Pietarsaari, Finland
Tel. +358 6 781 7500; Fax. +358 6 781 7510
www.solving.fi
Bo-Göran Eriksson bo-goran.eriksson@solving.fi

Company: **Sweco PIC Oy**
Technology: Consulting and engineering company operating world-wide, providing consulting, design, engineering and project management services for industrial customers in plant investments, product development and production.
Contact: Liesikuja 5, P.O. Box 31, FI-01601 Vantaa, Finland
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Kari Harsunen kari.harsunen@sweco.fi

Company: **Tampereen Keskustekniikka Oy**
Technology: Product development, design, production, marketing, and sales of switchgear and controlgear assemblies.
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Company: **Tankki Oy**
Technology: Production and engineering of stainless steel tanks and vessels for use in different types of industrial installations
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Company: **TVO Nuclear Services Oy**
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Company: **Woikoski Oy**
Technology: Production, development, applications and distribution of gases and liquid helium
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FUSION YEARBOOK.
2008 Annual report of Association Euratom-Tekes

Abstract

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- Heat and particle transport, MHD physics and plasma edge phenomena
- Plasma-wall interactions and material transport in SOL region
- Code development and diagnostics.

Association Euratom-Tekes participated actively in the EFDA JET Workprogramme 2008 and exploitation of JET facilities in experimental campaigns C20–C25. Three persons were seconded to the UKAEA operating team, two physicists in codes & modelling and one engineer in remote handling. One person was a Task Force Leader in TF T (transport). One engineer from VTT was seconded to the ITER IO at Cadarache in 2008 (Assembly). Practically all physics activities of the Research Unit are carried out in co-operation with other Associations with the focus on EFDA JET work. In addition to EFDA JET activities, the Tekes Association participated in the 2008 experimental programme of ASDEX Upgrade (AUG). Several staff mobility visits of total 530 days took place in 2008.

The Technology work is carried out at VTT, Helsinki University of Technology (TKK), Tampere University of Technology (TUT) and Lappeenranta University of Technology (LUT) in close collaboration with Finnish industry. The technology research and development is focused on the remote handling, vessel/in-vessel materials and components plus some activities in physics integration and JET Technology:

- Preparation of the Divertor Test Platform (DTP2) at VTT in Tampere for remote handling of divertor maintenance and development of water hydraulic tools and manipulators
- Development of advanced welding methods and IWR cutting/welding robot
- Plasma facing materials issues, erosion/re-deposition and material transport studies and developing coating techniques
- Multi-metal components and joining technology
- in-reactor mechanical testing and characterisation of materials under neutron irradiation
- Modelling of ripple losses and wall loadings for ITER
- Contributions to the design of ITER gyrotrons
- Feasibility study for micromechanical magnetometers.

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