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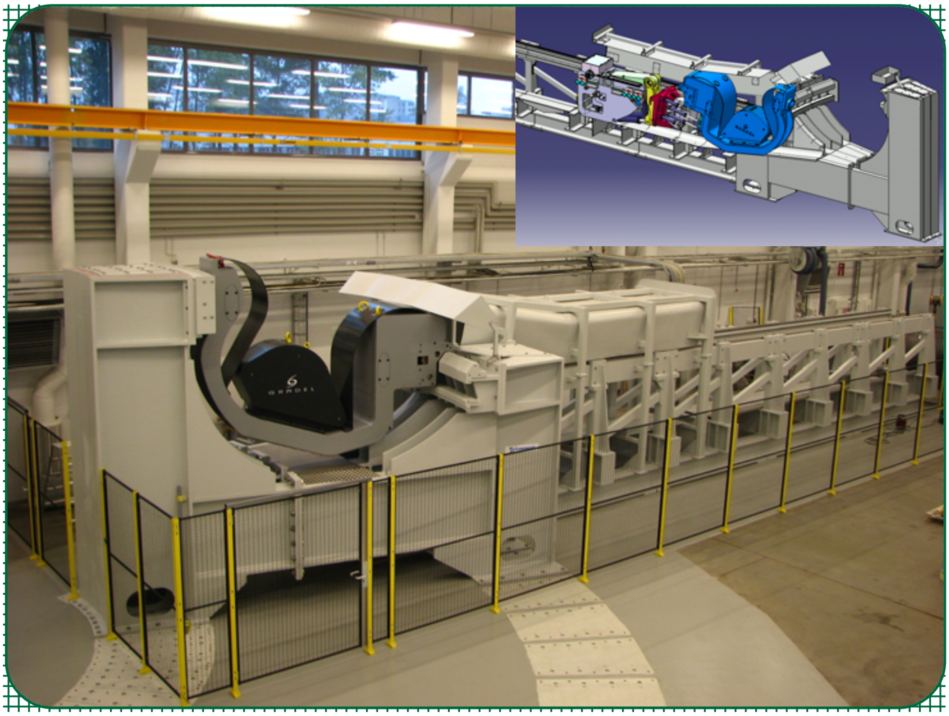

FUSION YEARBOOK

Association Euratom-Tekes
Annual Report 2007

Association
Euratom–Tekes

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Association Euratom-Tekes Annual Report 2007

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Cover ITER Divertor Test Facility (DTP2) at VTT

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FOREWORD

A new era started in the European fusion research from 2007. International ITER agreement was signed in late 2006 and the 7th Framework Programme was launched from the beginning of 2007. Euratom Fusion Programme in FP7 provides a fair funding for fusion research in parallel with ITER construction. This is extremely important to keep Europe as the leader in the worldwide fusion research. In early 2007, the Council of Ministers adopted the Statutes of *the European Joint Undertaking for ITER and the Development of Fusion Energy* "Fusion for Energy", which is the European Domestic Agency for ITER. "Fusion for Energy" (F4E) is based in Barcelona and the team is building up coming operational in early 2008. The University of Tartu in Estonia signed an agreement with Tekes to join the Association Euratom-Tekes from 2007.

The emphasis of the Association Euratom-Tekes has been on the EFDA Technology Programme. A major part of this work is very ITER related and will continue under the F4E. The flagship project is the *ITER Divertor Test Platform* (DTP2) hosted by VTT and Tampere University of Technology. The DTP2-structure was completed in early 2007. Control systems hardware and software including viewing and visualisation tools are installed and tested, a full-scale divertor cassette mock-up is on site. The multifunctional cassette mover by European industry is late, hopefully arriving in spring 2008. Prototype of the inter-sector welding/cutting robot has been completed at the Lappeenranta University of Technology and tests are starting soon. VTT's material research concentrated on mechanical testing of reactor materials under neutron irradiation in collaboration with SCK-CEN Mol and Risø, CuCrZr/SS mock-ups by powder HIP and characterisation of irradiated joints. Materials modelling at the University of Helsinki was devoted to simulations of radiation damage effects in FeCr. Modelling of global energy systems continued at VTT.

Plasma physics and plasma-wall studies at VTT, Helsinki University of Technology (TKK) and University of Helsinki (UH) have been carried out in the EFDA JET Workprogramme and in the EU Task Forces "Plasma Wall Interactions" (PWI) and "Integrated Tokamak Modelling" (ITM). The participation in the AUG experimental programme at IPP Garching has been very productive, too. Theory and modelling work at VTT, TKK and UH dealt with gyrokinetic turbulence simulations, predictive modelling of JET plasmas, fast particle studies, ERO simulations of edge plasmas and molecular dynamic simulations of plasma-wall phenomena. Experimental work dealt with plasma-wall studies at JET and AUG tokamaks and post-mortem surface studies of first wall and divertor tiles. Diagnostics work includes a neutral particle analyser, a micromechanical magnetometer and smart tile development s for erosion studies.

Finally, I would like to express my sincere thanks to the fusion teams of the Finnish and Estonian Research Unit and to the companies involved, for their dedicated work and successful contributions to Euratom Fusion Programme in fusion physics and ITER technology.

Seppo Karttunen
Head of the Research Unit
Association Euratom-Tekes

Annual Report 2007
Association Euratom-Tekes

1. INTRODUCTION

This Annual Report summarises the fusion research activities of the Finnish and Estonian Research Units of the Association Euratom-Tekes in 2007. The Estonian Research Unit was established by the Agreement between Tekes and the University of Tartu in 2007 and Tekes became the first trans-national Association in the European Fusion Programme.

The activities of the Research Unit are divided in the Fusion Physics Programme, Underlying Technology under the Contract of Association and Technology Programme under EFDA.

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
- Radio-frequency heating and current drive
- Code development and diagnostics.

Association Euratom-Tekes participated actively in the EFDA JET Workprogramme 2007 and exploitation of JET facilities in experimental campaigns C18-C19. One person was seconded to the UKAEA operating team and one person acted as a Task Force Leader in TF T (transport). S/T Order/Notification activities continued the work that started in 2000. Practically all physics activities of the Research Unit are carried out in collaboration with other Associations with the focus on EFDA JET work. In addition to EFDA JET activities, the Tekes Association participated in the 2007 experimental programme of ASDEX Upgrade (AUG).

The Technology Programme 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 involved in 2007 activities are: Fortum (Finnish EFET partner), Luvata Pori, Metso, Hollming Works, Diarc Technology, Creanex, Hytar, Adwatec and Prizztech. Industrial participation is co-ordinated by Finpro. The technology research and development under EFDA is focused on the fusion reactor vessel/in-vessel area with some activities in physics integration:

- Plasma facing materials issues, erosion/re-deposition and material transport studies and developing coating techniques
- Contributions to the design of ITER ICRF heating systems
- Feasibility study for micromechanical magnetometers
- Multimetal in-vessel components, joining technology and in-reactor materials testing and characterisation under neutron irradiation
- 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.

A number of EFDA Technology Tasks and Underlying Technology projects were running in 2007. Four persons were seconded to the EFDA Close Support Unit (CSU) – Garching in 2007.

Several Staff Mobility actions took place in 2007, total of 801 days: to IPP Garching (507 days), FZK Karlsruhe (30 days), UKAEA Culham (56 days), FZJ Jülich (58 days), Task Force meetings (39 days) and two visits from Estonia to University of Helsinki (77 days). Tekes Association hosted one staff mobility visit, Sergei Dudadev from UKAEA. Staff Mobility reports are given in Section 6.

VTT and TUT/IHA organized Remote Handling Workshop in 4 December 2007. The objective of the meeting was to gather together all European associations which are working with Remote Handling. The overall objective of the European RH was to discuss how to support "Fusion for Energy" and ITER in RH issues and to increase the understanding of the importance of the ITER remote handing, in particular:

- to obtain higher priority for RH activities and funding
- to increase coherence in European RH activities
- to participate in overall RH strategy planning for ITER
- to provide support to F4E and ITER in RH planning, design procurement, preparation, contract follow up
- to agree common tools, standards, codes, control systems.

In the meeting there were participating experts from 7 Euratom Associations, representatives from ITER, Fusion for Energy and EFDA (23 participants).

Remote Handling Working Group has internet pages: http://www.iha.tut.fi/research/rh/.

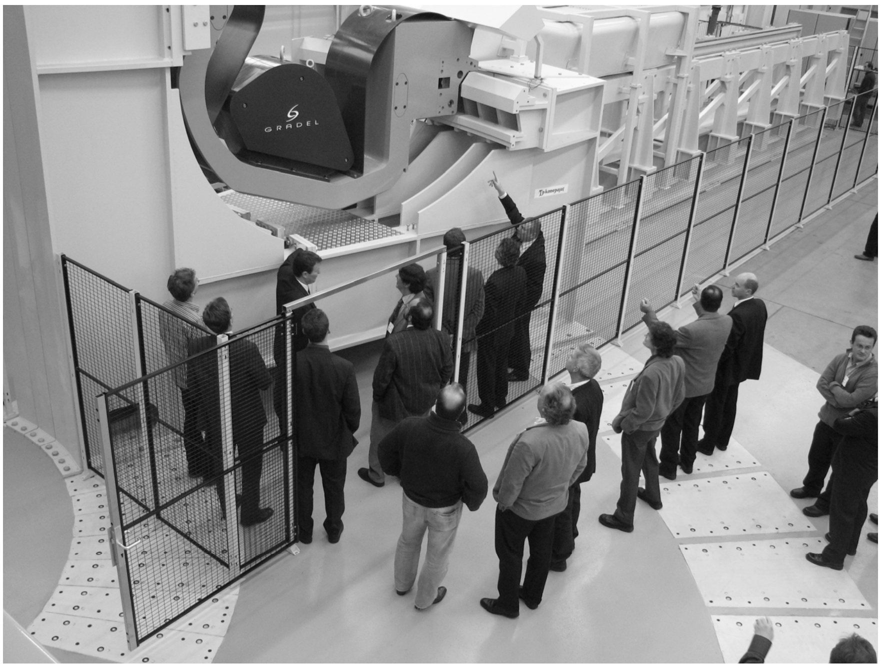


Figure 1.1: Remote Handling Meeting on 4 December 2007. Participants at DTP2 Facility.

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 (i) to carry out high-level scientific and technological research in the field of nuclear fusion and (ii) to make a valuable and visible contribution to the European Fusion Programme and to the international ITER Project in our focus areas. 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 including ITER technology development provides a challenging opportunity for technology R&D work in research institutes and Finnish high-tech industry increasing their technological know-how and benefiting from the technology transfer.

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 Fusion Research Units

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 2006:

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 Energy and Pulp&Paper (neutronics, system studies)
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), Outokumpu Oyj, Luvata Pori Oy, Hollming Works Oy, Metso Oy, Diarc Technology Inc., Creanex Oy, Hytar Oy, Advatec Oy, Delfoi Ltd., TP-Konepaja Oy, Oxford Instruments Analytical Oy and Patria Oyj. The fusion related industrial activities were co-ordinated by the Tekes Big Science project (Finpro and Prizztech).

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 UT.

The contact persons and addresses of the participating research institutes and companies can be found in the Appendix.

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 2007:

Chairman 2006	Mr. Reijo Munther, Tekes
Members	Mr. Yvan Copuet, EU Commission, Research DG
	Mr. Chris Ibbott, EU Commission, Research DG
	Mr. Douglas Bartlett, EU Commission, Research DG
	Mr. Marc Pipeleers, EU Commission, Research DG
	Mr. Jouko Suokas, VTT
	Mr. Harri Tuomisto, Fortum Nuclear Services 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 2007, at VTT, Tampere, on 17th October. In this meeting Mr. Yvan Capouet was replaced by Mr. Douglas Bartlett from the Commission.

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 2007:

Chairman	Mr. Jaakko Ihamuotila, Millennium Prize Foundation
Members	Ms. Mirja Arajärvi, Ministry of Education
	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, Finpro.

The national steering committee had three meetings in 2007.

The research activities are steered by three Topical Advisory Groups for 1) physics and diagnostics, 2) for materials research and 3) for remote handling systems.

2.6 The Finnish Members in the EU Fusion Committees

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

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

Euratom Science and Technology Committee (STC)

Rainer Salomaa, TKK

Science and Technology Advisory Committee (STAC)

Rainer Salomaa, TKK
Rauno Rintamaa, VTT
Seppo Karttunen, VTT

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, Energywave

Association Euratom-Tekes hosted the 34th EFDA Steering Committee Meeting in Dipoli, Espoo, 4–5 June 2007.

Finnish representatives in the following fusion committees and expert groups in 2007:

Reijo Munther is a member of the IEA Fusion Power Co-ordinating Committee (FPCC).

Rainer Salomaa 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.

Seppo Tähtinen is a Materials Liaison Officer in the European Blanket Project (EBP).

Harri Tuomisto is a member of the International Organising Committee, of the Symposium on Fusion Technology (SOFT).

Taina Kurki-Suonio is a member of the Programme Committee of the 34th EPS Conference on Controlled Fusion and Plasma Physics, Warsaw, Poland.

Jukka Heikkinen is a member of the Scientific Committee of the European Fusion Theory Conference.

Leena Jylhä is an Industry Liaison Officer for Fusion-Industry matters.

2.7 Public Information

The Summary Fusion Seminar covering the years 2003–2006 was held in Otaniemi, Espoo, 8 March 2007. The seminar gave a comprehensive review of the Finnish fusion research activities during the 6th Framework Programme. The EFDA Associate Leader for Technology, Dr. Maurizio Gasparotto gave an invited talk on European preparations for the ITER construction. The four year summary of the research activities of the Association Euratom-Tekes is published by Tekes: *FUSION Technology Programme 2003–2006*, Final Report, Technology Programme Report 1/2007, Tekes, Helsinki 2007, 175 p. A Finnish-Estonian fusion seminar was held in Tallinn in August. In particular, DTP2 facility which was completed in 2007, attracted a lot of interest in Finnish media.

Public information actions included participation in the *Launching FP7 Conference for Information Multipliers,* Brussels, 7–8 February 2007 and *ITER Business Forum*, Nice, 10–12 December 2007. Lecture course *Introduction to Plasma and Fusion Physics* was given at the Helsinki University of Technology. Several articles related to fusion energy research and ITER were published in newspapers and weekly journals. Lecture course on Fusion and Plasma Physics was given at Helsinki University of Technology.

2.8 Funding and Research Volume 2007

In 2007, the expenditure of the Association Euratom-Tekes was about 5,1 Mio Euro including Staff Mobility actions (see Figure 1). A fairly strong growth in the expenditure is mainly due to the fact that the Contract and CSU activities were increased and the Estonian Research Unit started in 2007. 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 36% including EFDA JET activities, Underlying Technology 6%, EFDA Technology Tasks (Art. 5.1a) 20%, EFDA Art. 5.1b Contracts and Preferential Support activities 31% and EFDA CSU Secondments 7%. The hot cell work, capital investments and co-operation with other Associations under the preferential support exceeded M€ 1,0 and the expenditure on the Staff Mobility actions were k€ 93. The total volume of the 2007 activities was about 50 professional man-years.

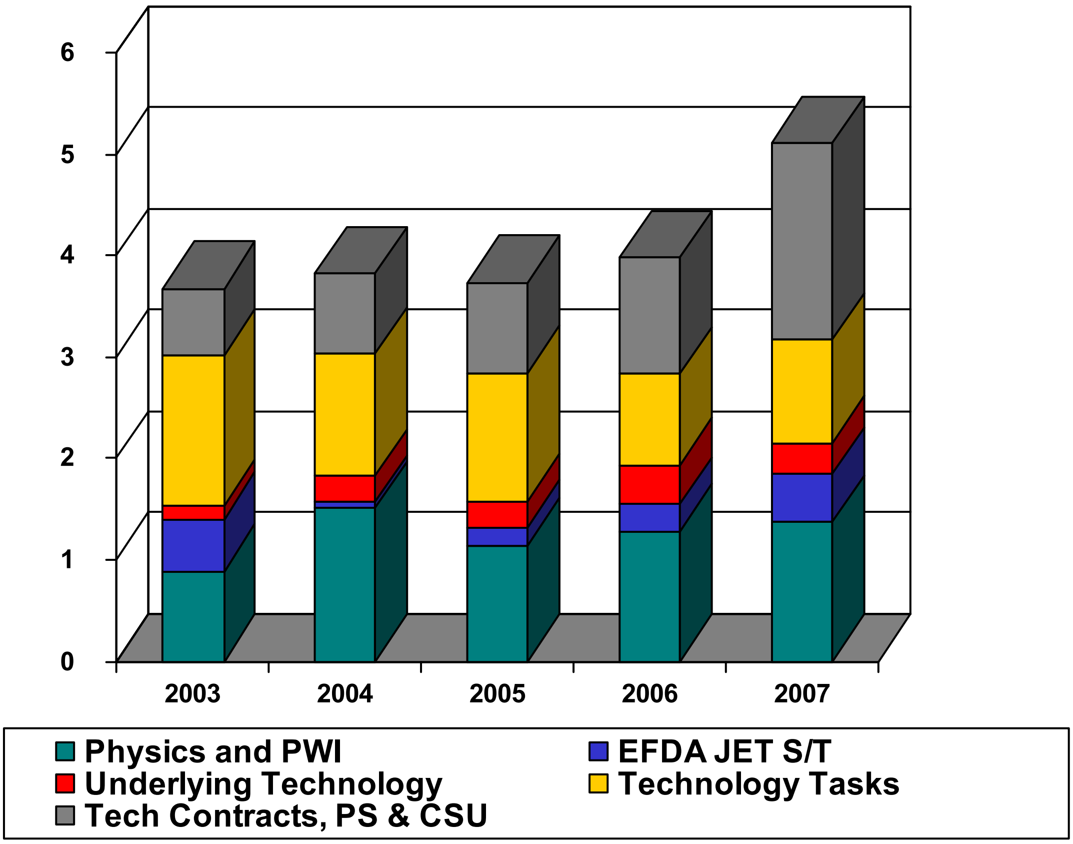


Figure 2.1: Expenditures (in Mio €) of the Association Euratom-Tekes for different physics and R&D activities in 2003–2007.

3. PHYSICS PROGRAMME – FUSION PHYSICS

The fusion physics work has been performed in very close co-operation between VTT Technical Research Centre of Finland and Helsinki University of Technology. The main emphasis of the fusion physics work is in the participation in the experimental campaigns C18–C19 of the JET Workprogramme 2007 and in the AUG programme at IPP Garching in collaboration with other Euratom Associations. Activities under JET Task Force Fusion Technology are given the next Chapter dealing with EFDA Technology Programme.

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 and design support and expertise in a fusion spin-off technology, material plasma processing will continue and will be strengthened.

Institute:	**VTT – Technical Research Centre of Finland**
Research scientists:	Dr. Seppo Karttunen (Head of Research Unit), Dr. Jukka Heikkinen (Project Manager), Dr. Petri Kotiluoto, Dr. Jari Likonen (Project Manager), Dr. Karin Rantamäki, MSc. Tommi Renvall, Dr. Tuomas Tala (TFL T at JET), Dr. Elizaveta Vainonen-Ahlgren and Dr. Frej Wasastjerna
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, Dr. Markus Airila, MSc. Otto Asunta, Dr. Antti Hakola, MSc. Ville Hynönen, MSc. Timo Ikonen, MSc. Salomon Janhunen, Dr. Timo Kiviniemi, Dr. Taina Kurki-Suonio, M.Sc. Matti Kortelainen, MSc. Susan Leerink, MSc. Johnny Lönnroth, Dr. Mervi Mantsinen, MSc. Markus Nora, Dr. Francisco Ogando (Euratom Fellow, seconded from UNED), MSc. Antti Salmi (JOC secondee), Dr. Marko Santala (JOC secondee) and Dr. Seppo Sipilä Students: Miikka Heikkinen, Simppa Jämsä, Tuomas Korpilo, Tuomas Koskela and Andre Xuereb
Companies:	**Diarc Technology, Oxford Instruments Analytical**

3.1 Participation in EFDA JET Work Programme 2007

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 C17–C19 was in transport studies, plasma-wall interactions and rf-coupling issues. Dr. Tuomas Tala from VTT is a Task Force leader for TF-transport. The work described in this Section has been carried out in collaboration with the EFDA JET contributors and all authors are given in the list of publications in Sec 8.

3.1.1 Experimental toroidal momentum transport studies on JET

Plasma rotation and momentum transport are currently very active areas of research, both theoretically as well as experimentally. It is well-known that sheared plasma rotation can stabilise turbulence while the rotation itself has beneficial effects on some MHD modes, such as resistive wall modes. Although recently recognising the importance of rotation, transport of toroidal rotation is much less known than heat or particle transport in tokamaks.

Recently, a large rotation database has been created in JET. The results from the over 600 entry rotation database show that the effective Prandtl number $P_{r,eff}$ (defined as $P_{r,eff} = \chi_{\phi,eff}/\chi_{i,eff}$) is substantially below one in the core plasma, typically $P_{r,eff} \approx 0.1$–0.4 in JET plasmas. This low $P_{r,eff}$ is in apparent contradiction with the gyro-kinetic calculations that indicate the 'purely diffusive Prandtl number' (defined as $P_r = \chi_\phi/\chi_i$) is always around 1.0. New developments in theory, however, suggest that this discrepancy could be resolved through the existence of a momentum pinch velocity, allowing thus $P_{r,eff}$ differ from P_r.

An experiment where the NBI power and torque were modulated has been performed on JET with the modulation frequency of 6.25 Hz. An H-mode plasma with type III ELMs at low collisionality and high q_{95} to avoid sawteeth was chosen to perform the cleanest possible rotation modulation. Active CX spectroscopy was used to measure the toroidal rotation ω_ϕ and T_i with a time resolution of 10 ms at 12 radial points. The NBI induced torque has been calculated with the NUBEAM package inside TRANSP. As the modulated torque is not radially localised, determination of the momentum diffusivity and pinch is carried out with help of modelling with the JETTO transport code.

Consistently with the JET rotation database, $P_{r,eff} \approx 0.25$ was found in this experiment. In the following analysis, two set of parameters, both predicting the steady-state toroidal angular frequency ω_ϕ within an acceptable accuracy (RMS error < 15%) are compared to quantify the magnitude of the momentum pinch: (a) $\chi_\phi/\chi_i = 0.25$ with $v_{pinch} = 0$ and (b) $\chi_\phi/\chi_i = 1.0$ with a constant $v_{pinch} = 15$ m/s. As steady-state results do not allow to distinguish between the two choices, the amplitudes and phases of the experimental toroidal velocity modulation are compared in Figure 3.1 with the modelled ones. The simulation with $\chi_\phi/\chi_i = 1.0$ and $v_{pinch} = 15$ m/s reproduces the amplitude and phase of the modulated wave much better than the simulation with $\chi_\phi/\chi_i = 0.25$ and $v_{pinch} = 0$, which rather is in disagreement with the modulation data. This result thus shows the existence of a significantly large inward momentum pinch. Using the choices χ_ϕ/χ_i in the range of 0.8–1.2 and v_{pinch} in the range of 8–15 m/s all reproduce the experimental phase and amplitude roughly within the same accuracy, this being considered indicative of the range of error bars resulting in the analysis. These results yield the first experimental evidence of an inward momentum pinch on JET and also evidence of the high diffusive Prandtl number $P_r = \chi_\phi/\chi_i \approx 1$, consistent with gyro-kinetic simulations.

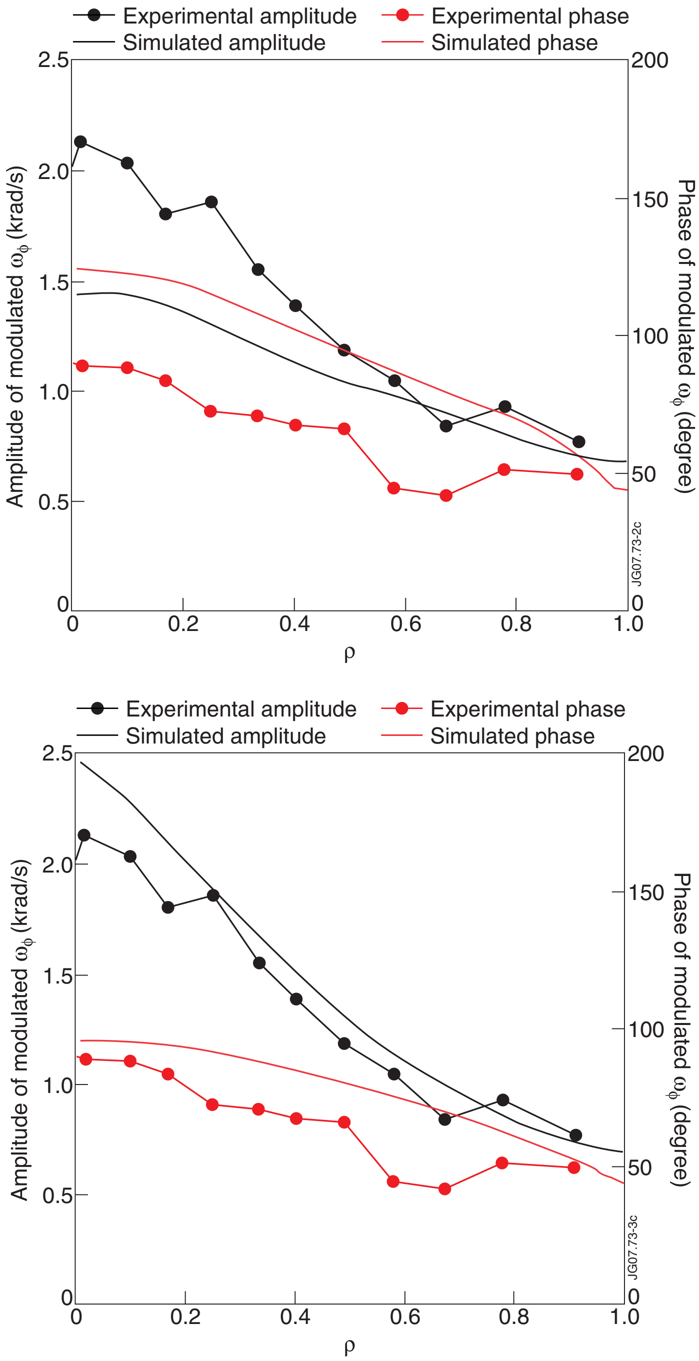


Figure 3.1: Comparison of the experimental (lines with dots) and modelled (lines) amplitudes (black) and phases (red) of modulated ωϕ with the two simulation choices $\chi_\phi/\chi_i = 0.25$ and $v_{pinch} = 0$ (left frame) and $\chi\phi/\chi i = 1.0$ and $v_{pinch} = 15$ m/s (right frame) for JET pulse no. 66128.

Linear gyro-kinetic simulations with the GKW code for the JET pulse no. 66128 predict $\chi_\phi/\chi_i = 1.01$ and a pinch number of $Rv_{pinch}/\chi_\phi = 2.3$ using the experimental data at $r/a = 0.4$. The experimental value for the pinch number $Rv_{pinch}/\chi_\phi \approx 4$–$5$ is somewhat larger than that of GKW, but the predicted and experimental P_r are in excellent agreement, giving further confirmation on the substantially large inward momentum pinch and high $P_r \approx 1$ on JET. This inward momentum pinch also is able to explain the low effective Prandtl number as then $P_{r,eff} < P_r$ becomes apparent. Predictive transport modelling study with a version of the Weiland model that takes into account the new momentum pinch theory, is on-going.

3.1.2 ITB physics studies with varying toroidal rotation

Advanced Tokamak scenarios are proposed to provide the conditions needed for a steady-state demonstration in ITER. These scenarios often involve modification of the current profile, which has been shown to lead to internal transport barriers (ITBs) that improve the confinement, and hence, performance of the fusion plasma. However, the physical mechanism behind ITB formation and sustainment has not yet been clearly identified. Studies of the physics of internal transport barriers in Tokamak plasmas have indicated two factors that play a crucial role in their formation and development – magnetic shear (or *q*-profile) and $E\times B$ shear in plasma rotation.

On JET, Advanced Tokamak scenarios usually use predominantly neutral beam injection (NBI) as auxiliary heating. The large toroidal torque by the JET NBI system, and consequently fast toroidal rotation v_ϕ, enhances the rotational shear. The main objective in this study is to vary rotational shear, often called as $E\times B$ shearing rate, by modifying the toroidal rotation profile. On JET, one way to do it is to vary the current in the Toroidal Field (TF) coils in order to introduce a variation of the toroidal magnetic field, i.e. toroidal magnetic field ripple (denoted here as δ). Increasing the TF ripple modifies the plasma rotation profile due to the torque arising mainly from lost fast ions coming the NBI heating. Hence, tuning the TF ripple provides the possibility to alter the plasma rotation and $E\times B$ shearing rate.

The toroidal rotation is lower for higher TF ripple amplitude and even reverses direction in the outer part of the plasma and furthermore, the toroidal rotation profiles are different, as shown in Figure 3.2 (left frame). The key point here is to compare the gradient of the toroidal rotation just before the onset of ITB (dashed lines) between the 4 discharges and estimate the impact of this on the strength and sustainment of the ITB. As shown in Figure 3.2, the toroidal rotation gradient at the location of the ITBs (R~3.45–3.5 m) is reduced with ripple amplitude.

The E×B shearing rate arising from the toroidal rotation component only has been calculated for the four discharges shown in Figure 3.2 (right frame). The calculations were performed just prior to the onset of the ITBs. It is evident that the $E\times B$ shearing rate decreases significantly as the rotation gradient becomes smaller with increasing ripple amplitude. The results presented here clearly suggest that modifying the $E\times B$ shearing rate affects the dynamics of the ITBs. After the initial trigger of the ITB, which, on the other hand, seems to be related mainly to the characteristics of the q-profile rather than the $E\times B$ shearing rate, the $E\times B$ shearing rate plays a key role in the further suppression of turbulence and strengthening and sustaining the ITB for a longer time. This in turn enhances the $E\times B$ shearing rate, thus providing a positive feedback loop. In conclusion, the ITB trigger and the feedback mechanism responsible for the further development would, therefore, appear to be governed by different physics processes.

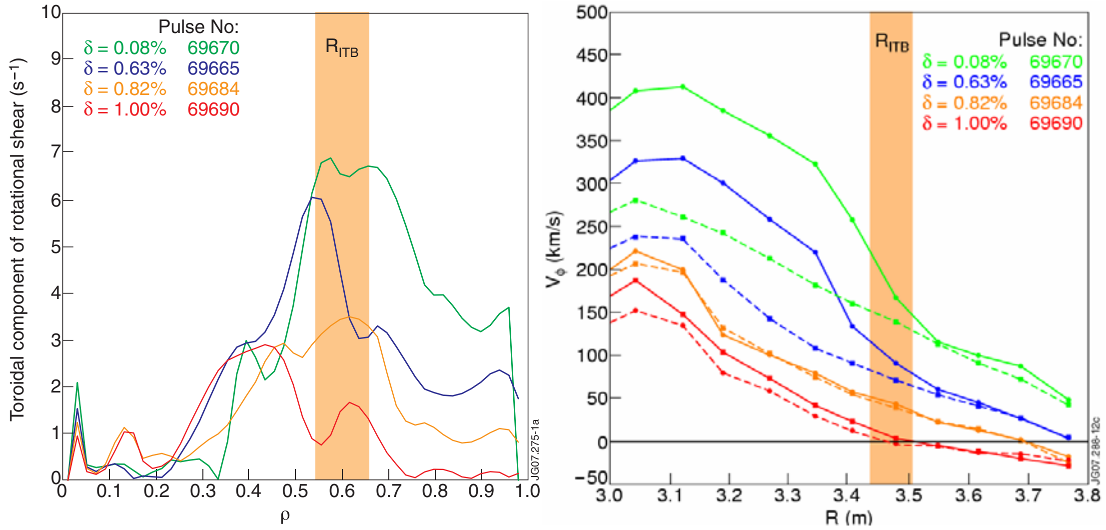


Figure 3.2: Left frame: Toroidal rotation profiles for 4 similar JET ITB shots, but with different toroidal magnetic field ripple amplitude δ. The dashed lines correspond to the instants just before the ITB onset while solid lines correspond to the instants after the ITB onset. The shadowed bar marks the radial region where the ITB is formed and located. Right frame: The component of rotational shear due to toroidal rotation only as a function of normalised minor radius for the same 4 shots, calculated just prior to the onset of the ITB (from dashed lines in the left frame).

3.1.3 Experimental study of the critical ion temperature gradient length and stiffness

The anomalous character of ion heat transport in tokamaks is a long dated experimental observation. A comprehensive description of turbulent ion heat transport as driven by Ion Temperature Gradients (ITG) modes has been developed, and is at the basis of first-principle predictions of ITER performance. The observed correlation between edge and core T_i supports the picture of ITG turbulence making T_i profiles resilient to changes in their inverse gradient length ($R/L_{Ti} = R|\nabla T_i|/T_i$) above a critical value. However, to date no dedicated experimental studies have yet been performed of the existence and value of an ion temperature gradient length threshold, of its parametric dependences and up-shifts due to rotational shear or non-linear effects, or of the ion stiffness level. These issues are of high relevance for ITER operation as the core temperature achievable for a given pedestal depends crucially on the threshold and stiffness level.

JET is equipped with high quality Charge Exchange (CX) diagnostics for T_i and rotation measurements and a multi-frequency ICRH system for flexible and fairly localized ion heating. These tools, together with JET's large size, make it ideal to perform studies of ion temperature gradient threshold and stiffness level, as previously performed on electrons on many other tokamaks, including JET.

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. To achieve low core q_i to identify the threshold requires varying the ion power deposition between on- and off-axis locations using the ICRH multi-frequency capability. The basic fundamental difficulty in the experimental set-up is that even a very small heat flux is enough to steepen the ion temperature gradient enough to excite the ITG turbulence so that the threshold between neo-classical and anomalous transport will not be seen. Therefore only the NBI diagnostic beam for CX can be used, and the direct identification of the threshold can only be performed in low rotation plasmas.

The outcome of this experiment is shown by the red circles in Figure 3.3, where gyro-Bohm normalization is used for the ion heat flux. The ITG threshold is well identified as the lower red points intercept the neo-classical heat flux, indicated by the black solid line. The ITG threshold under these plasma parameters and profiles on JET is $R/L_{\mathrm{Ti}} = 3.8$. In addition, there is an indication of a rather high stiffness level as increasing the heat flux (upper red points) does not increase R/L_{Ti} nearly at all. On the other hand, in plasmas with similar parameters and profiles, but with higher plasma rotation due to higher NBI torque, the values of R/L_{Ti} are significantly higher, shown by the blue and black points Figure 3.3. Extensive studies to clarify whether the increase in R/L_{Ti} is dominantly coming from the impact of rotation on increasing the ITG threshold or decreasing the stiffness level is on-going. Furthermore, this experimental result calls for deeper theoretical investigations to understand the role of rotation on ion heat transport.

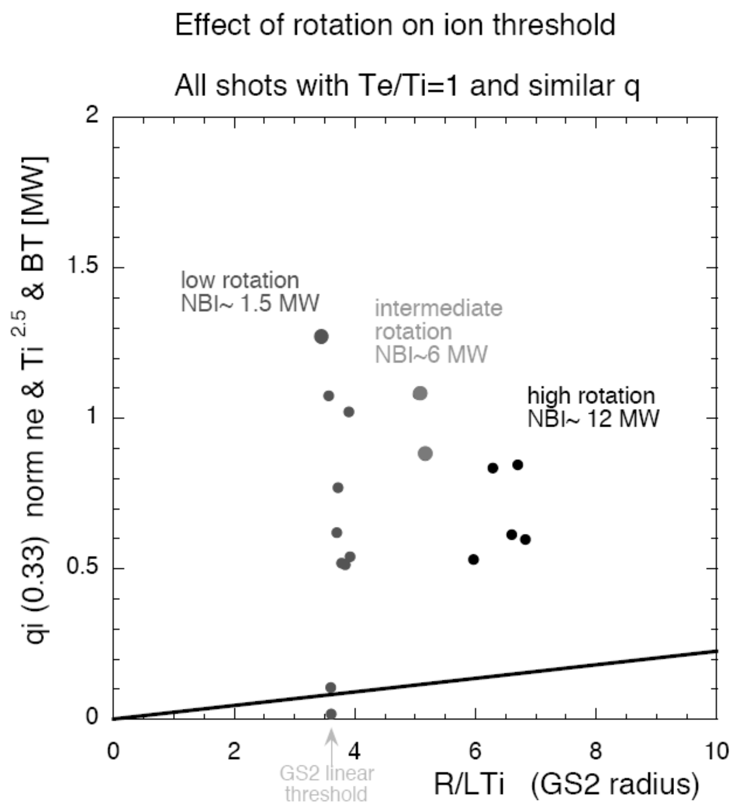


Figure 3.3: The normalised (to gyro-Bohm units) ion heat flux plotted as a function of R/LTi for three groups of similar JET shots with different levels of toroidal plasma rotation. The solid line indicates the neo-classical heat flux.

3.1.4 Energy and particle confinement and transport

Using predictive transport simulations and ideal linear MHD stability analysis, it has been explored how edge transport perturbations due to toroidal magnetic field ripple affect plasma performance and ELM behaviour.

The additional transport due to ripple losses generally affects the pedestal pressure gradient profile. It has been found that plasmas with the maximum pressure gradient located near the top of the pedestal generally sustain a considerably higher level of pressure gradient than plasmas with the maximum pressure gradient near the separatrix. As a result of this, plasmas of the former kind feature considerably better pedestal performance. It has been shown that the improved performance can be attributed to the fact that the bootstrap current is effectively suppressed in the vicinity of the separatrix in these plasmas, whereby kink and peeling modes remain stable and stability is controlled by medium n ballooning modes.

The effect on ELM behaviour has been studied. It has been found that there is generally a trade-off between confinement and the benignity of ELMs. The study also shows that ripple losses can affect pedestal performance and ELM behaviour in very subtle and unexpected ways.

3.1.5 Predictive transport modelling of ITER scenarios

2007 saw the establishment of a special ITER Scenario Modelling group under the auspices of the EU Integrated Tokamak Modelling Task Force. Association Euratom-Tekes was represented in this activity through J. Lönnroth. The work of the group is foreseen to be a long-term activity. Much of the Tekes contribution in 2007 went into equipping the 1.5D core transport code JETTO for ITER simulations. The ITER neutral beam injection heating parameters were implemented and ITER equilibria and plasma profiles were set up as appropriate.

In initial simulations, it was demonstrated that JETTO is well capable of modelling ITER plasmas. It was found that the simulations reproduce the plasma characteristics for Scenarios 2 and 4 (ELMy H-Mode and Steady-State, respectively) specified by the ITER team quite well.

The MHD stability of ITER plasmas was analysed. Once diamagnetic stabilisation was taken into account, it was found that Scenario 2 plasmas seem to sustain a normalised pressure gradient $\alpha \approx 1.3$, quite typical for type I ELMy H-mode plasmas.

3.1.6 Preparation and analysis of the TF ripple campaign

Already during the C15–C17 experimental campaign, preparation was needed for the Ripple Campaign C18–C19. It is well known that when increasing the toroidal magnetic field ripple, in particular the fast ion losses will increase. Ripple breaks the axisymmetry of the toroidal magnetic field, which enhances non-collisional stochastic diffusion and induces losses due to toroidally localised trapping. Because of the concerns of the increased heat flux on the machine's first wall and on the delicate instruments inside the vessel, a careful assessment of the expected heat loads was mandatory before any experiments were allowed to go ahead.

Guiding centre orbit following codes ASCOT (VTT/TKK) and OFMC (Japan) have been extensively used for assessing the expected heat loads prior to the campaign. They were also benchmarked against each other in a code validation exercise. After the experiments it was found that the simulations and experiments agree well and that these tools are very useful both for pre- and post-campaign analysis.

Both ASCOT and OFMC have been used also after the campaigns to model the fast particle losses, power deposition, current etc. In addition to particle losses, ASCOT calculations of toroidal torque in a ripple field have been of great interest as ASCOT is the only existing code that is capable of this. ASCOT calculations have also been made to model fusion product losses, and comparison against the Scintillator Probe that measures fast ion energy and pitch angle distributions has been good.

3.1.7 LHCD studies at ITER-relevant coupling distances

A critical issue for the use of LH waves is coupling of waves from the grill to the plasma. Lower hybrid waves have a cut-off density below which they do not propagate. In ITER, the plasma-wall distance will be about 15 cm and the density at the edge drops very fast. Therefore, it has been essential to demonstrate already on current machines that it is possible to couple LH waves over a long distance.

The coupling of LH waves was studied at JET in two different ITER-like plasma scenarios at high plasma triangularity, an advanced tokamak scenario and a hybrid scenario in 2006. Gas puffing from a nearby gas injection module was used to improve the coupling. The analysis of these experiments continued in 2007.

In these experiments, very good coupling was obtained. In the hybrid scenario, up to 3 MW of LH power was coupled over a plasma–launcher distance of almost 14 cm. In the ITER-like advanced scenario, slightly over 3 MW was coupled with actually less gas than in the hybrid scenario. Moreover, in this case the plasma–launcher distance was larger; about 15 cm like it will be in ITER. Without gas from the nearby gas pipe the coupling was lost.

In the hybrid scenario, two grill phasings were tested, $n_{||} = 1.8$ and 2.3, with similar plasma parameters. The difference between the two phasings in coupling was small, although $n_{||} = 1.8$ had a slightly lower reflection coefficient than $n_{||} = 2.3$. A clear difference was, however, seen in the MHD activity. In the pulse with $n_{||} = 1.8$, a continuous m = 3, n = 2 mode remained throughout the NBI heating phase. No sawteeth or fishbones were seen. However, in the pulse with $n_{||} = 2.3$, both sawteeth and fishbones were seen, suggesting the presence of a q = 1 surface. Therefore it can be concluded that the $n_{||} = 1.8$ is more favourable for the hybrid scenario in the sense of avoiding or delaying the MHD activity associated with q = 1 surface.

The advanced tokamak scenario was one used in general for Internal Transport Barrier development at JET. The performance seemed not to suffer too much from the gas puffing, although the confinement decreases slightly with the total gas, as expected, see Figure 3.4. The specific effect of the near gas injection is weak and to some extent confusing. However, the gas levels from the nearby gas pipe were quite modest. A more systematic study would be needed to better clarify the situation. Moreover, in the experiments performed no time was allocated to optimisation of the performance.

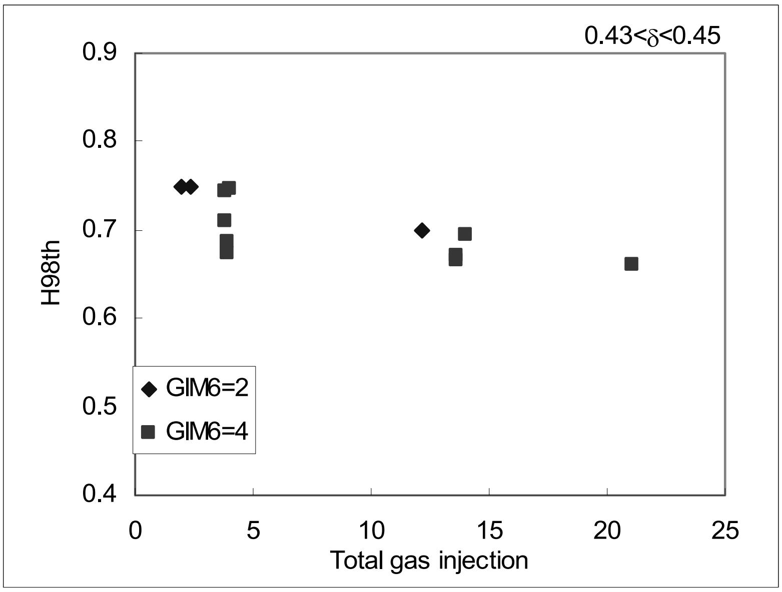


Figure 3.4: Thermal H98-factor versus total gas injection for high triangularity plasmas. The data is averaged over a 1s time period (in 4 points over 0.5 s). GIM6 denotes the gas level from GIM6 in units of 10^{21} el/s.

In order to see how the gas injection affects the current drive efficiency a series of 5 pulses was done. These first experiments were carried out in L-mode plasmas. The flux was controlled in real time and the plasma current was left floating. Thus a variation in the current indicates a variation in the LH current drive efficiency. The experiment was performed at 3 different gas injection levels (0, 2 and 4×10^{21} el/s) and 3 different plasma-wall distances (4, 7 and 10 cm).

The variation seen in the plasma current was very small. Comparing the two extreme cases, one with short distance and no gas to another with largest distance and largest gas level, the difference in the plasma current was less than 5%. Similar results have also been found in Tore Supra. The smaller current in the case with large distance and gas was probably due to an increased level of density fluctuation. The density fluctuation measured by O-mode reflectometry was smallest for the case with small plasma-wall distance and no gas. Consequently, there is no experimental evidence that indicate a drastic degradation in the LHCD performance when using near gas injection to couple at ITER-relevant distances. This is very encouraging for the use of LHCD in ITER.

In several LH experiments, localised hot spots have been observed on components magnetically connected to the grill region. The most probable reason is the fast electron generation by parasitic absorption of LH power in front of the grill mouth. On Tore Supra these heat loads are between 1 and 4 MW/m^2, sometimes even above 10 MW/m^2. Experiments made on TdeV suggest that the energy of these electrons is between 200 eV and 5 keV. The hot electrons are most likely produced by the high-$n_{||}$ components of the launched LH spectra. Hot spots have also been observed on JET. For the first time at JET these spots can be studied quantitatively with the new wide view infrared camera.

The parasitic absorption and the fast particle generation must be kept at a very low level. This is especially important for ITER where the pulse lengths are much longer than in present day experiments. In ITER, the absorption should be well below 1%. Experiments at

JET increase the database and knowledge of the phenomenon. This will then allow taking this process into account in the optimisation of the ITER LHCD system.

The hot spots have been studied in both high and low δ H-mode plasmas, and L-mode plasmas. The best possibility to study the spots is in L-mode, where the plasma is quiet and ELMs do not disturb the signal. Increasing wall temperature on localized spots on the limiters is observed, which is related to the LH power. The temperature may increase over 100 degrees in a few seconds and starts to decrease when PLH is turned off. Moreover, the heating rate seems to depend on P_{LH}. Figure 3.5 (left frame) shows a typical case observed during this study. The temperature on the wall starts to decrease already when PLH is decreased below 2 MW. However, when the 1 MW is produced by the middle row only, an increase in the temperature of the spot can be seen. This suggests that it is the LH power density that plays the major role here also. The temperature increases with decreasing plasma-wall distance as is seen in Figure 3.5 (right frame).

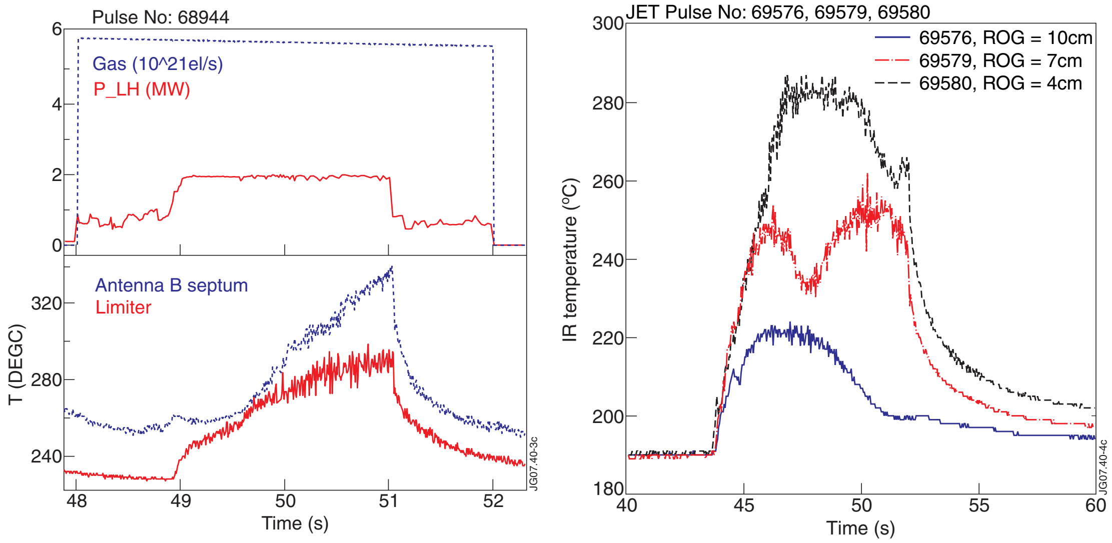


Figure 3.5: LH power (solid line) and gas level in top left frame and wall temperature on septum on Antenna B (dashed line) and Limiter (solid line) in the left bottom frame. Right frame shows wall temperature dependence on plasma – wall distance (ROG) as measured on the limiter.

For the first time at JET these spots can be studied quantitatively with the new wide view infrared camera. The best possibility to study the spots is in L-mode, where the plasma is quiet and ELMs do not disturb the signal. Hot spots were seen on the poloidal limiter of the ICRH antenna. The analysis showed a clear rise in the surface temperature. The temperature variations are clearly correlated with the LH power: rising when the power is stepped up and decreasing when it is reduced. The temperature may increase over 100°C in a few seconds. An exponential decrease is seen when the LH power is stopped. In fact the cooling of the wall component starts already when the power drops below 2 MW, see Figure 3.5. The possible power threshold still remains to be confirmed. However, a clear dependence on the plasma wall-distance was seen. The wall temperature strongly decreases with increasing distance, as can be seen in Figure 3.5. This is favourable for ITER, since ITER will operate at a large plasma-wall distance of 15 cm.

3.1.8 Material transport and erosion/deposition in the JET torus

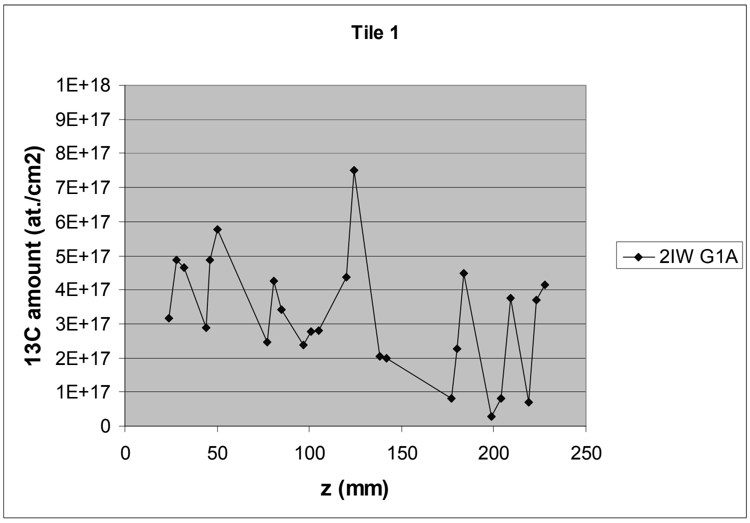
Research Scientists: Jari Likonen, Elizaveta Vainonen-Ahlgren and Tommi Renvall, Tekes – VTT
Juhani Keinonen and Kenichiro Mizohata, Tekes – UH
P. Coad, JET/UKAEA
Jukka Kolehmainen and Sanna Tervakangas, Diarc Tecnology Oy
EFDA JET Technology Task: JW7-FT-3.32

Background: A major concern with the proposed use of carbon divertor targets in ITER is retention of tritium in re-deposited films. This concern was highlighted by the deuterium-tritium experiment (DTE1) with the Mk I divertor in JET in 1997, when ~17% of the tritium fuelling was trapped in deposits at shadowed areas of the inner divertor. Another problem is that deposition in the JET divertor is highly asymmetric, with heavy deposition in the inner divertor but just small net erosion in the outer divertor, which is not understood.

Goals: The proposed work is focused on the studies of erosion/re-deposition of first wall materials and tritium retention in JET fusion reactor. The objective is to understand erosion/re-deposition of carbon fiber composites and tungsten coatings under various fusion plasma conditions. In addition to this, the aim is to obtain more information on tritium retention and thus to reduce tritium inventory in the JET facilities. Erosion/re-deposition are issues of major importance for ITER in that rate of erosion of the divertor targets and build up of deposited films (and the T retained therein) may either or both ultimately limit the choice of divertor materials and the operational space for ITER. This work will be done in close collaboration with JET under the Task Force Fusion Technology.

Main results in 2007: On the last day of the C19 operations prior to the shutdown in 2007 $^{13}CH_4$ was puffed into JET from the outer mid-plane, so that the TF-FT analyses could provide data for transport studies. Inner divertor and upper outer divertor tiles were analysed with SIMS. ^{13}C puffed from the outer mid-plane was detected mainly on top and centre of tile 1. ^{13}C amount on tile 3 and 8 was clearly smaller. Surface analysis of ^{13}C in other wall tiles will be continued in 2008.

a)



b)

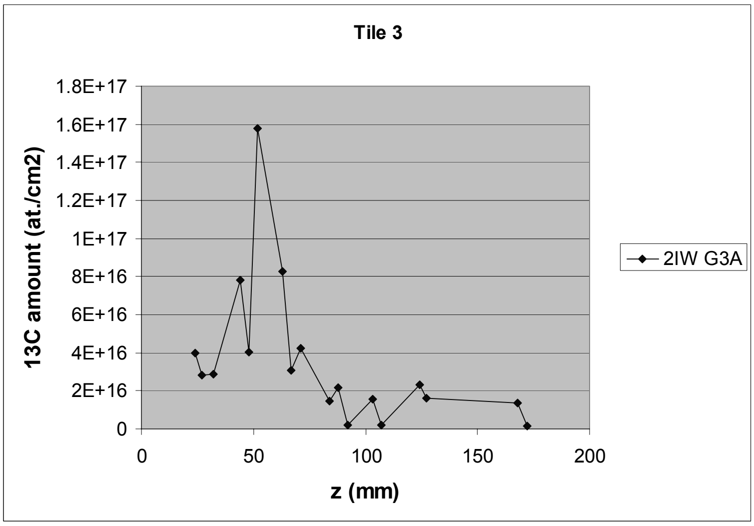
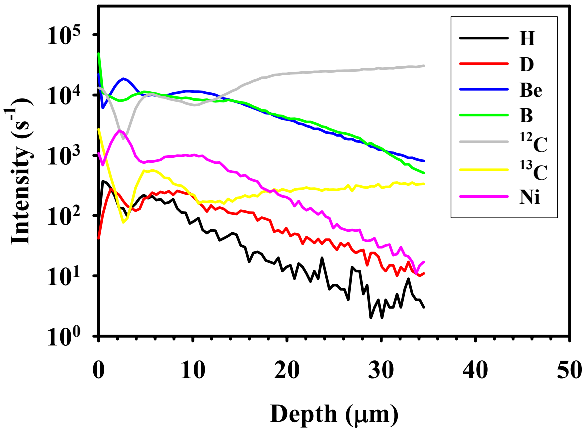


Figure 3.6: 13C distribution on divertor inner wall tiles 1(a) and 3 (b). "Top" and "bottom" are the top and bottom of the tile, respectively.

Erosion and deposition at the divertor during the 2004–2007 operations were investigated with SIMS and optical microscopy. Deposition in JET divertor tiles was observed to be asymmetric; i.e. heavy deposition occurs in the scrape off layer (SOL) at the inner divertor whereas there is erosion at the outer divertor. Figure 3.7 shows SIMS depth profile and optical microscope picture from bottom of inner divertor tile 1.

a)



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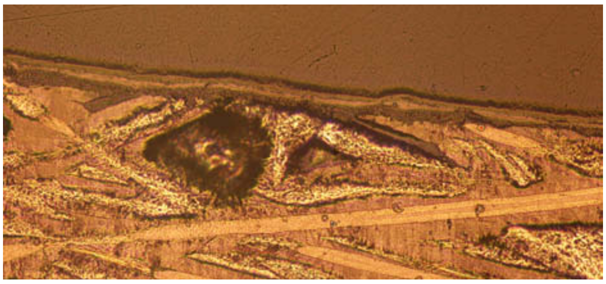


Figure 3.7: SIMS depth profile (a) and optical microscope picture from bottom of inner divertor tile 1.

The thickness of the co-deposited layer is about 15 μm and the layer contains beryllium, boron, nickel and hydrogen isotopes. The thickness of the layer in the microscope picture agrees with the SIMS result.

General picture of deposition at the inner divertor during 2004–2007 operations is quite similar to that during the MkII GB and SRP divertors. The thickness of the deposit decreases from the apron of tile 1 to the bottom and then increases on tile 3 reaching ~ 25 μm.

3.1.9 Modelling the 2004 JET divertor puffing experiment

We have modelled the 2004 JET ^{13}C injection experiment with the ERO code (for background, see Section 3.4.2). At the end of campaign, ^{13}C containing methane was injected into the divertor plasma using 48 injectors located uniformly around the torus. Deposition measurements cover several poloidal and toroidal lines within about 10 cm from a puffing hole. It is remarkable that the puffing geometry is somewhat challenging for modelling, since there are gaps in the structure through which the methane flows into the vessel, possible leakage routes behind plasma-facing tiles, and the inlet location is shadowed from the plasma. Consequently, the actual puffed amount is subject to considerable uncertainty. It is also evident that a neutral gas flow in the shadowed region plays a role and must be accounted for outside the plasma modelling carried out with ERO.

During 2007 we simulated the marker carbon deposition with a simplified model where the divertor surface consists of two planar parts and two neighbouring injectors are modelled by point sources located right at the surface. The simulations have periodic boundaries in the toroidal direction. They take into account re-erosion and are continued until the surface composition reaches equilibrium. As in AUG modelling, parameter variations are needed to cope with the parameters not constrained by experimental data. We find some toroidal dependence (whereas the measurements indicate rather good toroidal symmetry) and the deposited fraction in simulations is several times higher than the measured amount. The 3D output of ERO has been used to support the 2D long-range migration modelling work carried out with EDGE2D. Due to the uncertainties mentioned above, these simulations have little value in code benchmarking.

3.1.10 JET EP2 diagnostic project: NPA detector upgrade

Introduction

Neutral particle analysers (NPAs) detect atoms (ie. neutralised ions) which escape 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 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 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 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.

Tekes provided scientific support for the JET NPAs during the spring 2007 campaigns. KF1 has been used particularly in experiments with RF minority heating. KR2 has been a key diagnostic in the study of deuterium majority heating at fundamental frequency. Both NPAs were important diagnostics during the ripple campaign.

JET EP2 diagnostic project: detector upgrade

JET EP2 diagnostic upgrade project to develop thin silicon detectors for the NPAs to replace the present CsI(Tl) scintillator detectors made major progress during 2007. 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.

The first phase of the project is to design and build prototypes of the new detectors and identify suitable readout electronics. The detectors were designed and prototype detectors were manufactured during 2007. The detectors use Silicon-on-Insulator (SOI) technology. Modelled electrical potential of the edge and strip regions are shown in Figure 3.8. The thickness of the active part of the detectors has been designed to closely match the ion range achieve best possible background rejection. Initially, thicknesses of 5 and 25 μm have been fabricated. Microscope images of the detectors are shown in Figure 3.9.

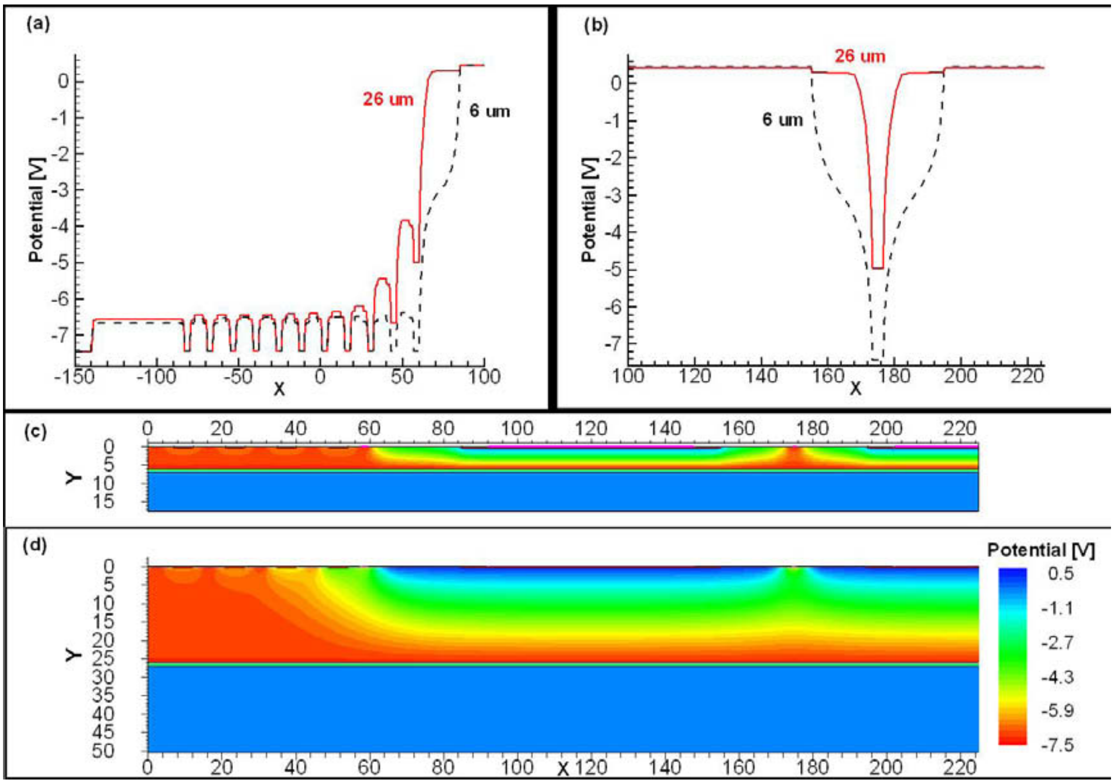


Figure 3.8: A 2D device simulation to illustrate the potential distribution at an bias voltage of -7 V. Top figures, (a) and (b), are horizontal cuts of (c) and (d), taken 50 nm below the surface. The bottom figures, (c) and (d), show the 3 inner most guard rings, the common p-stop grid and one and a half n-strips.

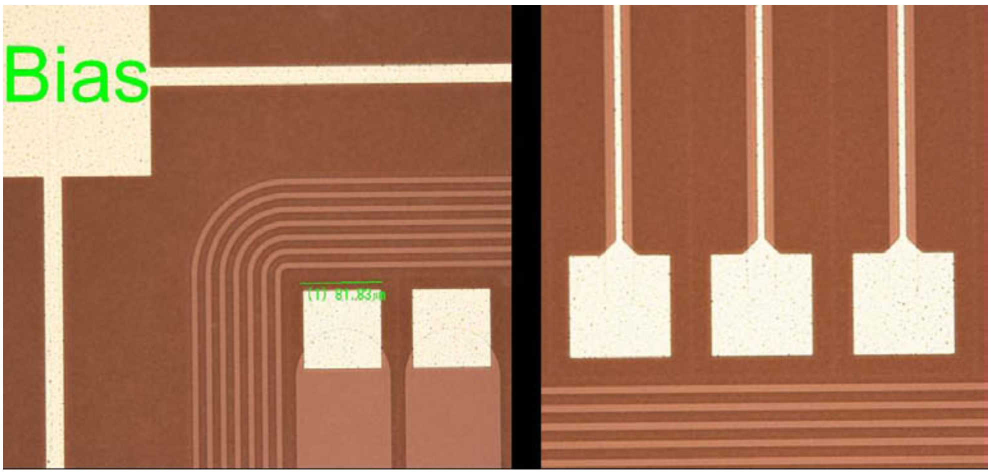


Figure 3.9: (left) Photograph of a corner of a detector with 95 µm wide n-type strips, 2 µm wide p-stops and no aluminum coverage on the strips. The bias ring and guard ring structure are also shown. (right) Photograph showing three 20 µm wide aluminum covered strips and a 5 µm wide p-stop grid surrounding the strips.

Testing of the detectors is ongoing and initial results are very promising. If the testing phase is successful, the diagnostic upgrade will be designed and built to be installed in JET during the EP2 shutdown.

3.2 Participation in the Asdex Upgrade Work Programme 2007 at IPP

3.2.1 Effect of E_r and ripple on edge fast ion distribution

The effect of a radial electric field is generally considered to arise only from its inhomogeneity, but even a constant electric field can have a net effect on NBI-born ions. Another important factor in the behaviour of fast ions is the finite toroidal ripple. Both of these effects have been studied already earlier, but a programming error affecting the particle collisions made the effect of the radial electric field on the fast ion distribution seem insignificant. The set of 8 simulations consisting of all combinations of co- and counter-injection, ripple and radial electric field was resimulated using corrected code and with better statistics. Also the collisionless single-particle orbits of both injection directions and the effect of radial electric field on them were analysed.

Similarly to earlier findings, the fast ion density and its gradient were found to be higher for counter-injection than for co-injection. For co-injection, a population of untrapped particles not present for counter-injection was found to exists at the edge. It was also shown that toroidal ripple reduces the fast ion density and its gradient whereas the radial electric field has the opposite effect (see Figure 3.10). The effect of E_r could be attributed to changes in the orbit width and transition of marginally trapped orbits into untrapped ones for co-injection and the converse for counter-injection. The radial electric field was also found to decrease the asymmetry in the duration of the inner and the outer legs of the trapped particle orbits caused by the monotonically increasing q-profile. The simultaneous presence of both ripple and radial electric field was found to restore the fast ion distribution closer to the ideal case where both of them are absent.

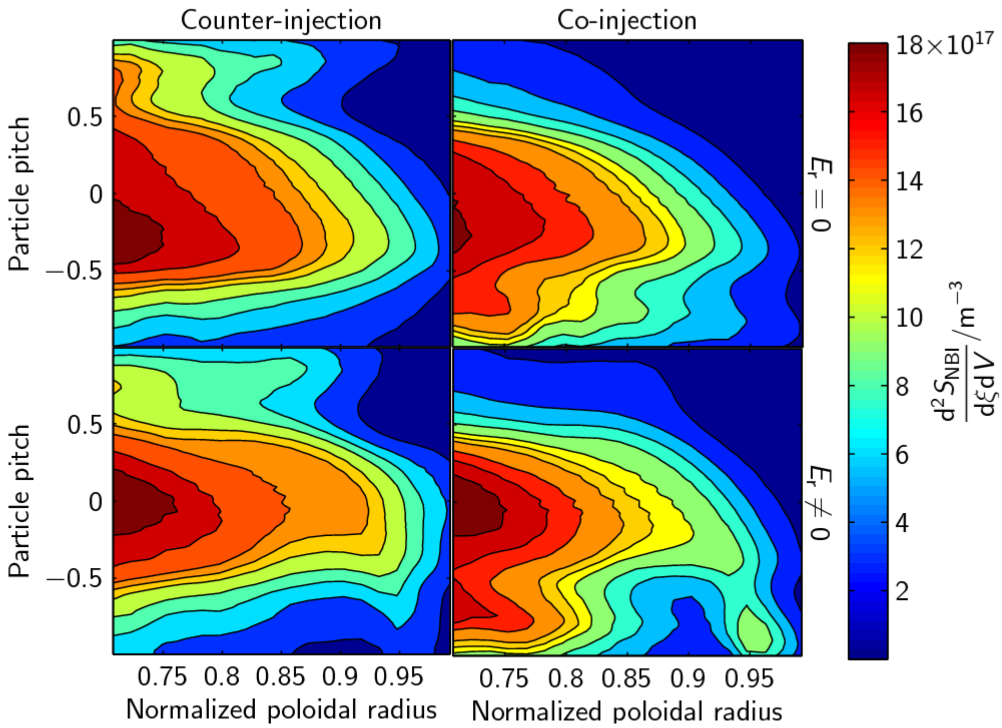


Figure 3.10: Pitch distribution of NBI ions at ASDEX Upgrade edge. Left/right column: counter-/co-injection, top/bottom row: without/with radial electric field.

3.2.2 DD-Fusion triton surface distribution on plasma-facing components

In earlier studies at JT-60U, the surface distribution of tritium has been found to be similar to the flux on high-energy tritons created in DD-fusion reactions. A similar result was obtained for ASDEX Upgrade in 2006 by comparing the ASCOT-simulated triton flux to the tritium surface distribution obtained by photo-stimulated luminescence measurements. Relatively good qualitative agreement was achieved even though only one improved H-mode discharge was simulated.

In 2007, an attempt was made to improve the agreement by choosing a number of different kind of discharges which would represent the whole operational campaign better than the single improved H-mode discharge. In the end, one standard H-mode discharge was simulated. Unfortunately the equilibria of the improved and standard H-mode discharges happened to be very similar with a large clearance to the wall which resulted in similar results for the triton flux. For further studies, a set of discharges with differing equilibria and more representative of the entire campaign has been selected, but not yet simulated.

3.2.3 ELM studies using the fast Neutral Particle Analyser

The addition of a new data acquisition system (DAQ) has enhanced the neutral particle analysers (NPA) of ASDEX Upgrade. The old DAQ had limited capacity for high temporal resolution measurements. The new DAQ shifts the bottleneck to the amplifiers, which cannot handle more than approximately a million neutrals per second.

The new DAQ is in use for both the tilting and the fixed analysers. Detected neutrals are recorded with 50 ns precision. The DAQ system is based on the FEMDAQ – fast economical multichannel data acquisition system. It uses a normal PC to store the data. The storage capacity of the system is limited only by the size of the memory of the PC. After a discharge the data can be downloaded to any workstation. Figure 3.11 shows part of the hardware.

The data analysis and operation of the DAQ was done remotely from Finland during the 2007 campaign. An automated acquisition program is under testing.

The data analysis has focussed on studying edge localised modes, (ELMs), which are recurring weak instabilities in the edge plasma. A significant portion of the plasma energy and particles is lost during the few milliseconds a typical ELM lasts. A typical ELM repetition frequency in ASDEX Upgrade is 100 Hz.

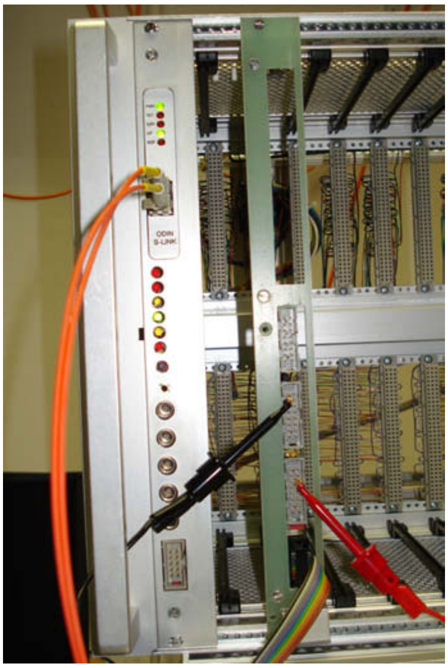


Figure 3.11: The data acquisition system in a test setup. The two boards in the figure can acquire data for one analyser.

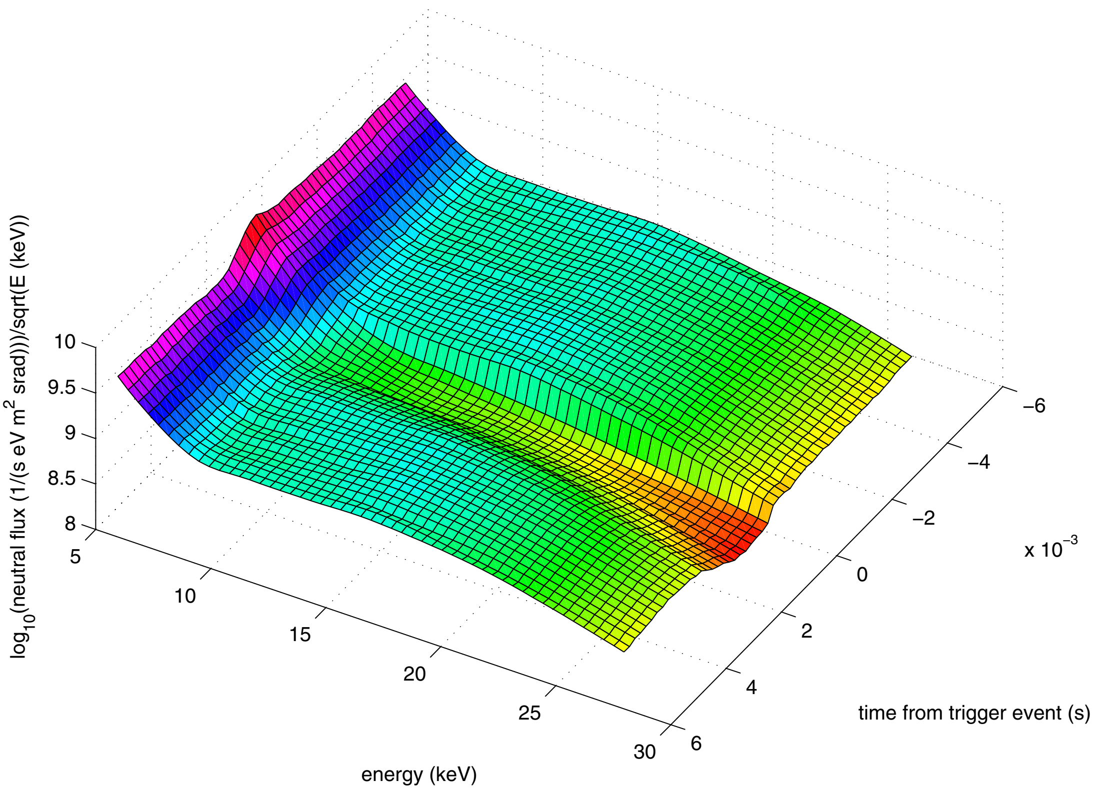


Figure 3.12: The radial electric field stabilises a part of the ripple trapped ions. During the ELMs the field collapses, and the ion population is lost. The figure shows how the diminished ion population emits a weaker flux of neutrals. The flux returns to normal as the field slowly recovers. The figure shows data from the fixed NPA. It is an average of 33 ELMs in ASDEX Upgrade shot #22134.

The research was mostly focussed on the collapse of the radial electric field during the ELM. Figure 3.12 shows a radial electric field measurement. Another topic of research was related to the filamentary structure: It has been observed that the lost plasma particles form plasma tubes, which are aligned roughly with the magnetic field lines. The prospects to measure the properties of the filaments were studied.

3.2.4 Kinetic electrons in the scrape-off layer of ASDEX Upgrade tokamak

Tokamak edge plasma is typically modelled by fluid codes, such as the SOLPS. The fluid picture is built on the assumption of a maxwellian plasma which, for a medium-collisionality scrape-off layer, does not necessarily hold. Of particular concern are the possible kinetic effects resulting from hot, collisionless particles that penetrate from the core plasma to the divertor region.

The presence of kinetic electrons can not be verified by experiments and, thus, the problem was tackled by ASCOT simulations of the ASDEX Upgrade H-mode discharge #17151. Electrons with a Maxwellian energy distribution were launched at several radial locations on the outer plasma midplane and followed to the divertor targets. The particle energies and trajectories were affected by the magnetic geometry, Coulomb collisions with the 2-dimensional plasma background obtained from SOLPS, and the corresponding parallel electric field.

Figure 3.13 shows the distribution of energies at the outer target, as calculated by ASCOT, for two different initial SOL locations. Very close to the separatrix, the target distribution is divided into two components: most electrons thermalise to the target temperature, but there is also a number of electrons impinging on the target with the high midplane energies. Further outside the separatrix, the target distribution resembles more that of the midplane, having no distinct thermal component. The effect of the suprathermal electrons on the target heat load is, however, most significant just outside the separatrix: due to the large temperature drop along the field line, an average energy over four times the local thermal energy is observed at the target.

The results indicate that the thermalisation of SOL electrons is low and, further, depends on the parallel temperature and density profiles in SOL. The observations contradict the assumptions made in the evaluation of the background plasma, suggesting that the fluid model fails to account for some of the crucial edge plasma phenomena. This underlines the importance of considering kinetic effects in modelling the tokamak scrape-off layer.

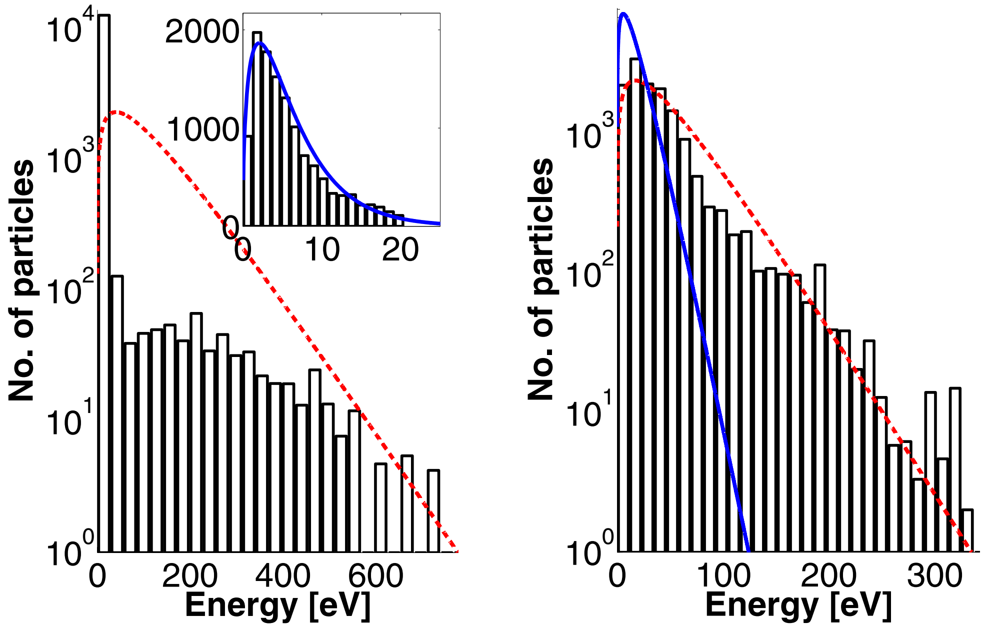


Figure 3.13: Electron energy distributions at the outer divertor plate for initial locations 0.5 mm (a) and 0.5 cm (b) outside the separatrix, for the ASDEX Upgrade H-mode discharge #17151. The number or electrons within each energy bin is represented by a bar. The inset in (a) shows the form of the distribution at lower energies (notice the different scale). The red dashed line and the blue solid line represent the background Maxwell-Boltzmann energy distributions in the initial and final points, respectively.

3.2.5 MHD stability and plasma control

Magnetic equilibrium in tokamaks can be represented as a set of nested magnetic surfaces. MHD instabilities deform these surfaces in case of an ideal MHD mode and create island structures in case of a resistive mode. These modes are typically rotates with different rotation frequencies which screen perturbations from each other. Such a screening effect vanishes when perturbations are coupled. During this coupling stage, a short stochastic phase can appear. The main characteristics of this phase is a strong mixing of the magnetic field lines which destroy magnetic surfaces and strongly increase the radial transport. In spite of the short time duration and small region of stochastization, it can lead to very strong changes in plasma confinement. Studies of fast MHD processes in ASDEX-Upgrade suggest that indeed the stochastization plays an important role in these events. In this paper three such phenomena are discussed: frequently interrupted regime of neoclassical tearing mode (FIR-NTM), minor disruption due to interaction of the (2,1) and (3,1) tearing modes 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 toroidally confined plasma. In this method magnetic field lines are regarded as trajectories of the Hamiltonian system. Practical implementation of this technique requires knowledge of the safety factor and of the MHD perturbations. Determination of the shape and amplitude of the MHD perturbations is a challenging task, because of the large uncertainties in the measurements. We have used combinations of all main MHD diagnostics (magnetic measurements, ECE, Soft X-ray cameras) to deduce these perturbations from experimental data and convert them into the form suitable for the Hamiltonian formalism.

The important parameters for creation of stochastic region are: (i) amplitude of perturbations; (ii) safety factor profile; (iii) number of perturbations with different helicities; (iv) coupling of perturbations.

Frequently Interrupted Regime of Neoclassical tearing mode (FIR-NTM)

During the FIR-NTM the amplitude of the NTM after reaching a certain size suddenly drops to a much smaller value. After this the mode growth starts again. In this way the NTM amplitude never reaches its saturated value. The time in which these amplitude drops occur is very short (about 500 ms), much shorter than the resistive MHD reconnection rate (few 10s of milliseconds in the ASDEX Upgrade). It was shown that this experimental observation can be explained by stochastization of magnetic field lines when the island separatrix is destroyed. We have found that experimental amplitudes of the perturbations are always sufficient to stochastise the magnetic field (condition (i)), but stochastization appears only during the coupling of the modes (condition (iv)). The (1,1) mode, which is needed for a nonlinear coupling between the modes, has a negligible influence on stochastization itself. In this example, stochastization plays a positive role and reduces influence of the NTM on the plasma confinement.

Minor disruption due to the interaction of the (3,1) and (2,1) tearing modes

It was observed in ASDEX Upgrade discharge that series of minor disruptions are accompanied by the interaction of the (3,1) and (2,1) modes. Such a minor disruption leads to temporary deterioration of confinement and flattening of the temperature profile. We have modelled this disruption by using the perturbation amplitude obtained by means of ECE measurements. In this case modes are always coupled (condition (iv)) but stochastization between the resonant surfaces appears only if the amplitude of the (2,1) is higher than a threshold value.

Sawtooth crash

Investigation of sawtooth crashes in ASDEX Upgrade shows that in many cases the magnetic reconnection is not complete, which means that all complete reconnection models are in contradictions with experimental observations. It was shown by means of the mapping technique that amplitudes of the primary (1,1) mode together with its harmonics are sufficient to stochastise the region if the central q is less than 0.85–0.9. This is in good agreement with measurements of the safety factor profile and allows one to explain the existence of the mode after the sawtooth collapse.

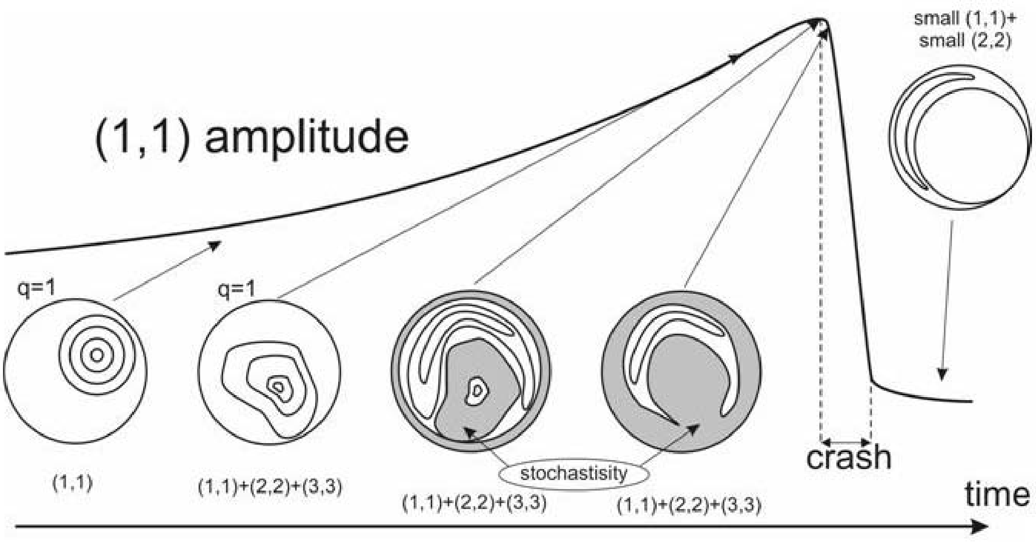


Figure 3.14: The dynamics of the sawtooth crash.

The dynamics of the instability before and during the sawtooth crash was studied by means of spectral analysis and reconstruction of phase trajectories using delay coordinates which are the standard techniques for analyzing stochastic systems and has been used for identification of the transition to chaos in different physical systems. It was demonstrated, on the basis of the soft X-ray and electron cyclotron emission measurements, that during the pre-crash phase, the quasiperiodic transition to stochastic stage occurs. All main features of such a transition are present: (i) MHD oscillations with two incommensurable frequencies develop before the crash (ii) reconstructed trajectories in 2D and 3D phase space demonstrate transition from single frequency behaviour to strongly quasiperiodic regime (iii) typical increase of broad band low frequency noise just before the crash. Moreover, consistent with the most energetically favourable transition from quasi-periodicity to chaos, frequency ratio between two modes is close to the golden mean ratio $G = f_2 / f_1 = \left(\sqrt{5}-1\right)/2 \approx 0.618$, which is the most irrational number. All these results strongly suggest that stochastic reconnection is one of the most probable explanations for the sawtooth crash.

3.2.6 ICRH-generated fast ion studies

Analysis of experiments using ICRF waves on ASDEX Upgrade has continued. In the selected discharges with strong ICRF heating, losses of ICRF-driven fast ions have been measured due to fast ion driven Alfvén eigenmodes and a new mode called the Sierpes mode.

Due to a 60% increase in the electron density n_e in pulse 21136, a decrease of at least 40% is expected in the tail temperature $T_{tail} \propto 1/n_e$ of the ICRF driven fast ion distribution function in the high-energy range of 500 keV and beyond. However, it turns out that even such a large change in T_{tail} is rather difficult to detect with the present set of fast ion diagnostics on ASDEX Upgrade. It is only from the disappearance of the fast-ion-driven toroidal Alfvén eigenmodes during the density ramp that one seems to be able to obtain information on the relevant changes in the fast ion population.

In pulses 22324 and 22325, MHD modes account for less than 1/40 of measured fast ion losses while in other, more typical ASDEX Upgrade discharges MHD modes account for all the measured fast ion losses. Analysis of discharge 22324 with the PION code suggests that prompt losses of ICRF driven fast ions could be responsible for the measured fast ion losses. The next step in the analysis is to calculate the profile of ICRF prompt losses on the wall using three-dimensional modelling e.g. with the FIDO and ASCOT codes, and detailed comparisons of such calculations with the measurements.

Overall, recent experimental observations on ICRF-driven fast ions with hydrogen minority heating were found to be broadly consistent with the theoretical expectations.

The effects of ICRF-induced radial transport of fast ions with toroidally asymmetric ICRF waves were also studied for typical ASDEX Upgrade conditions in preparation for further experiments. It was found that modifications of the fast proton pressure profile can already be achieved by changing the wave direction with the present antennas. The planned new four-strap antennas improve the wave directivity significantly and increase the possibilities to modify the fast ion pressure profiles. The expected differences are similar to and of the same order as those in JET experiments.

3.2.7 Modelling the 2003 AUG divertor puffing experiment

We have modelled the 2003 AUG ^{13}C injection experiment with the ERO code (for background, see Section 3.4.2). In the experiment the deposition at the divertor was measured in detail over a set of tiles downstream of the injection hole. The deposition pattern shows a tail in the downstream direction, characterised by three features: Firstly, virtually all injected ^{13}C was found in the local deposition analysis. Secondly, the areal density of deposited marker carbon decays toroidally with a scale length of 4.5 cm. Thirdly, the deposition tail is noticeably deviated from the magnetic field line direction. It has been proposed that this deviation would be caused by ion E x B drift in the sheath field. Matching these principal results from this experiment provides a challenging test for the ERO code and can significantly help in improving its physics basis.

For puffing experiments with strongly localised re-deposition, toroidal symmetry can not be assumed, and a truly 3-dimensional simulation is called for. This is especially true for the 2003 AUG puffing experiment, which used a single injection hole. To enable simulations of the deposition, we have taken into use the toroidal dimension in the divertor version of ERO. In all previous divertor studies a toroidal symmetry has been assumed and the toroidal dimension has been disabled in the simulations. Our ongoing 3D simulations reproduce almost perfectly the shape of the 2-dimensional ^{13}C distribution, but the deposited fraction is smaller (about 1/8) than in the experiment.

Some simulation parameters are not properly constrained by measurement data, and we must resort to parameter variation to study their effects on carbon migration. This is the case as regards the sticking of hydrocarbons and local electric fields. The background plasma used by ERO does also not match the divertor diagnostics perfectly, which makes it necessary to carry out a sensitivity study with respect to background plasma parameters.

3.3 Theory and Code Development

3.3.1 ELMFIRE code development

Large-scale kinetic simulations of toroidal plasmas based on first principles are called for in studies of such transient transport mechanisms like Low (L) to High (H) confinement barrier formation or Edge Localized Modes (ELM) at the edge plasma, Internal Transport Barrier (ITB) formation in the core plasma, or intermittent turbulence in magnetic fusion devices. Because of rapid or strong restructuring in the particle distribution function f(**x**,**v**,t) and in the EM field, accompanying such transients, full f kinetic calculation is a necessity in such cases.

ELMFIRE is a global gyrokinetic full f particle-in-cell code designed for first principles transport simulation in tokamaks including both neoclassical and turbulent physics. It is based on an implicit gyrokinetic model and a set of guiding-centre equations, field equations, and energy conservation law derived with Lie perturbation method from an appropriate Lagrangian. The guiding-centre motion includes polarization drift, and the coefficient matrix of the Maxwell equations is straightforwardly updated from the simulated f(**x**,**v**,t). Presently, the code is electrostatic with small-amplitude fluctuations having frequencies $\omega << \Omega_i$, where Ω_i is the ion cyclotron frequency. The parallel acceleration of electrons by the electric field is treated implicitly for stability.

The Cyclone Base case has become a standard benchmark case for tokamak plasma turbulence simulations. The case has also been adopted as the standard transport benchmark for the EFDA task-force ITM turbulence project. Several Cyclone Base benchmarks (e.g., linear growth rates) have been obtained [1] with ELMFIRE. Transport evolution of the non-linear benchmark case with different initializations and boundary conditions was studied together with the orbit dynamics of some of the cases. In full f global nonlinear simulation with adiabatic electrons we find that the adiabatic condition has to be modified to correctly evaluate finite ion orbit effects on electrostatic potential with temperature and density profile variations of the plasma.

Experimental benchmarking of the ELMFIRE code is performed in co-operation with the small FT-2 tokamak experiment at the Ioffe Institut in St Petersburg. Correlation lengths and times of density fluctuations as well as poloidal velocity and density fluctuation spectra are compared to experimental results from reflectometer diagnostics. In Figure 3.15, the simulated $E_r \times B$ velocity and total poloidal velocity of fluctuations are shown for typical Ohmic FT-2 parameters. It can be concluded that $E_r \times B$ velocity arising from neoclassical and turbulent mechanisms is the main contributor to the Doppler shift at the inner and outer region of the experiment. At the central region of the simulation, a contribution of mode phase velocity has been found from linear mode analysis, explaining the difference in Figure 3.15. The angular frequencies and growth rates obtained from the ELMFIRE linear mode analysis have been successfully benchmarked against the eigenvalue code GS2. Studies of turbulent coherent burst and their transport are performed with orthogonal wavelet techniques.

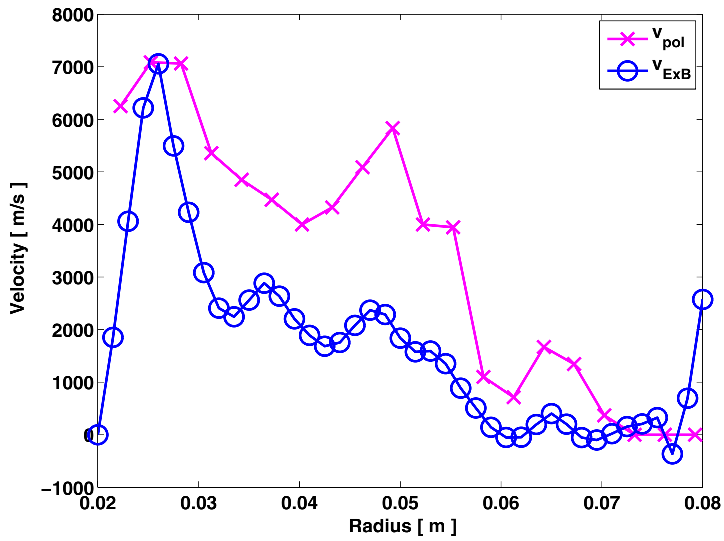


Figure 3.15: The simulated $E_r \times B$ velocity and total poloidal velocity of fluctuations in FT-2.

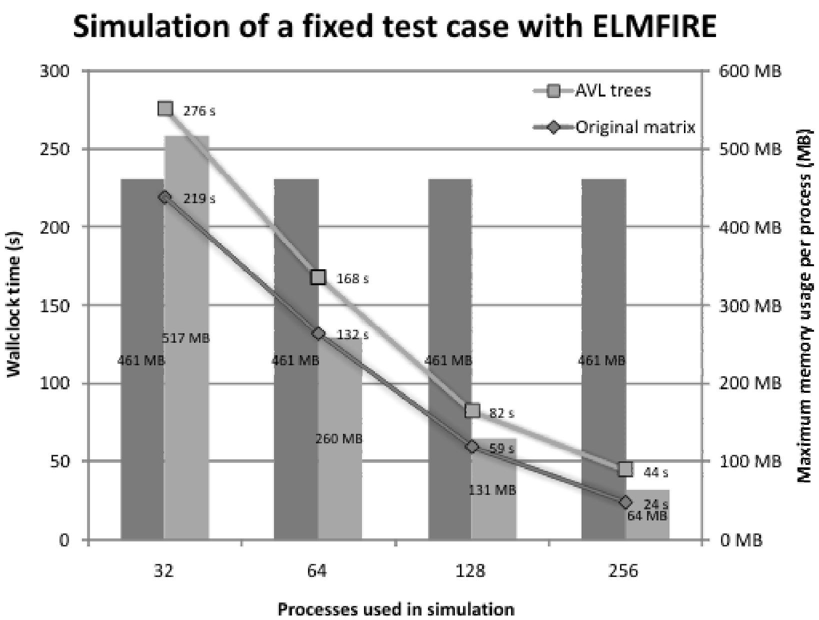


Figure 3.16: Scalability demonstration with data storage using AVL trees.

ELMFIRE parallel scalability has been extended to the multithousand processor range, extending the range of application of ELMFIRE to middle sized tokamaks. This parallel improvement has been possible thanks to the implementation of two techniques, which separately reduce the memory consumption and improve scalability, and whose combined action will take even further the good scalability range. Data storage with AVL trees was implemented for the first time into a gyrokinetic code, reducing the memory consumption and providing theoretically infinite scalability regarding data storage for solving the GK-Poisson equation of the electrostatic potential (see Figure 3.16). Domain decomposition (DD) along the toroidal direction has been integrated in the ELMFIRE code, with reduction of both memory requirements and also communication time. The procedure splits the toroidal system into separate domains in a way that network communication is mostly contained inside every domain, taking up the scalability range by about one order of magnitude.

In the L-H transition of the edge transport, a transport barrier is created by external heating, which is presently considered an important part of the reactor plasma operation. The study of transport barriers with ELMFIRE includes both neoclassical and turbulence physics. The numerical techniques used are valid even in the plasma edge where the gradients are steep and distributions can significantly deviate from Maxwellian. Extending such a self-consistent simulation from small to medium-size tokamaks is a challenge, but is now possible using AVL and DD methods with present large-scale supercomputing facilities. First results of self-consistent simulation of plasma edge using ASDEX Upgrade parameters have been obtained.

ELMFIRE code development at TKK and VTT was supported by CSC and DEISA computational facilities, by Åbo Akademi through the Tekes FINHPC and by ITM EFDA Task Forces, and by the co-operation between UNED and CIEMAT.

3.3.2 Development of the ASCOT code

3D Wall

A 3-dimensional wall collision model has been developed for ASCOT. This makes it possible to study wall loadings in realistic geometry including e.g. ports, limiters and other toroidally non-axisymmetric structures.

The 3D presentation of the first wall consists of an arbitrary number of different toroidal sector types made of triangular and quadrangular planar elements. A full 360-degree presentation of the wall is created by defining the toroidal angle range and type identifier for each wall sector.

An efficient textbook algorithm is used to detect and record test particle collisions with the wall elements. A special provision has been made to take into account the finite Larmor radius of the test particles. An example of ion hits on the 3D model of ITER's divertor is shown in Figure 3.17.

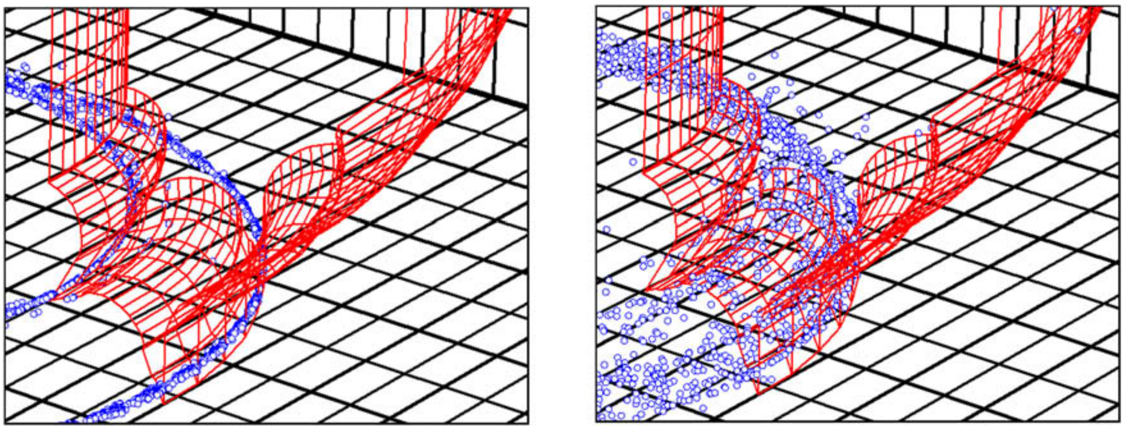


Figure 3.17: Particle hits (blue) in the divertor region of ITER (case #585). Only one 3D wall sector is shown (red). (a) Without charge-exchange (CX) collisions in the scrape-off layer (SOL). (b) With CX collisions in the SOL.

3D magnetic field

A 3-dimensional magnetic field model consisting of at most two sectors defined on an identical grid and a mapping describing how the complete magnetic field of 360 degrees is formed from the sectors was developed for RIPLOS simulations. Two sectors are necessary for representing both the periodic ripple and the local perturbation caused by test blanket modules. The model can be generalized fairly easily for arbitrary number of sectors. Supporting routines for polynomial interpolation in one, two and three dimensions were also developed. The derivatives of the magnetic field are obtained by finite differences and tabulated during preprocessing. If the magnetic field is defined on a non-rectangular region in (R,z), the location of the subgrid used in simulation-time interpolation can also be tabulated. Matlab-routines for processing the original 3D magnetic field data obtained on a finite-element grid from ENEA to a form suitable for ASCOT were also written.

3D neutral particle analyzer model

The project to benchmark ASCOT against experimental results from ASDEX Upgrade tokamak was continued. A new completely 3-dimensional neutral particle analyzer (NPA) model was written. Results are expected in 2008.

Special Issues Related to Open Field Lines and Electrons

The capability of ASCOT to simulate light particles on open field lines was improved in the following ways: (i) More accurate bilinear interpolation of background plasma parameters was introduced. (ii) A self-standing parallel electric field operator was included in the code, to account for e.g. the sheath potential at the divertor targets. (iii) The adjustment of the time step was changed. The bounce time being feasible only above the separatrix, a restriction based on the collision time was introduced to the divertor region. (iv) The order of the Runge-Kutta steps was altered to better account for the large effects of Coulomb collisions on the velocity of a light particle.

Neutral beam injection model

Development of a new neutral beam injection (NBI) model to ASCOT was initiated. The goal is to develop an NBI model that could be used for initializing test particles in realistic geometries of different fusion devices. The initializing is to be done by tracing each neutral starting from outside the plasma, and using Monte Carlo -method for calculating the location in the plasma where the neutral is ionized. The new model will give a more accurate and more detailed test particle distribution compared to the methods currently in use.

Test particle fusion model

The fusion cross-section of two thermal species, deuterium and tritium, has its maximum at around 70 keV. Even though the plasma temperature in fusion devices is substantially lower than that, due to the large amount of thermal ions, thermal fusions take place. Because of their higher energies, fast particles, such as ICRH heated or NBI ions, also have a higher probability to fuse than the thermal particles. Thus, they contribute to the total fusion reaction rate despite being few in number. A module for modelling the fusions between a test particle and a thermal background was created to ASCOT. The model was tested with thermal particles against a parametrised fusion reaction rate calculated from the plasma profiles, and a good correspondence was achieved.

ASCOT – JETTO – EIRENE integration

ASCOT integration with JETTO transport code and EIRENE neutral solver is in progress. The role of ASCOT in the package is to provide more realistic NBI related quantities such as losses, power deposition and fusion reactivity than the Fokker-Planck model currently in use. Once completed the code package will have some new capabilities that do not yet exist among other transport codes and may help to reveal new physics. Technical test of the integrated package have been successful and currently focus is on detailed benchmarking of various components. Whole system is scheduled to be ready by the end of 2008.

3.3.3 Other code development

Development of transport models for ITB and ELM studies

A new ELM modelling scheme has been implemented in the 1.5D core transport code JETTO. The idea behind the scheme is to make use of a comprehensive set of MHD stability results without actually running an MHD stability code on the fly during a transport simulation, which would be a time-consuming, heavy operation. Instead, the scheme makes use of a database with pre-computed results for certain standard reference plasmas (differently shaped pairs of marginally stable normalised pressure gradient and current density profiles) against which the actual simulation plasma is compared. The new module evaluates which pair of database profiles the simulation plasma profiles are closest to in a least-squares sense and then calculates a stability measure based on the closest matching profile pair to determine whether the simulation plasma is stable or not. If the plasma is found to be unstable, the system simulates an ELM by enhancing transport in accordance with the mode structure properties in the database. The new scheme can be used in combination with both the so-called local and theory-motivated ELM modelling schemes, which have already been in use in JETTO previously.

Density pump-out

It has been proposed that the so called “convective cells” or poloidally localised 2D electric fields could be at least partly responsible for the loss of particle confinement (i.e. density pump out) observed in experiments where non-ambipolar losses are expected to be present. These include both toroidal magnetic field ripple experiments (ion loss channel) and resonant magnetic perturbation experiments (electron loss channel). In such experiments poloidally localised losses could lead to the poloidal electric fields.

This problem has been analysed both analytically and using a Monte Carlo based Neo-Classical transport solver XGC-0. In collisionless simulations without the radial electric field it was found that losses are not much affected by the 2D static potential unless the potential is located in X-point region. This is in line with theoretical the understanding showing that losses increase towards the inner target due to the modification of the loss cone. When we turn on the self-consistent radial electric field and collisions the significance of location of the 2D potential becomes much smaller. For the case where we use 500V negative potential (with plasma pedestal temperature 1 keV) the NC loss rate is roughly doubled for both locations. These findings would, in principle, indicate that a 2D potential is a potential candidate for explaining the density pump out. To evaluate the amplitude of the 2D potential and thus the losses that can be sustained one would, however, have to solve the 2D potential self-consistently including the loss mechanisms.

Fusion neutronics

Activity of EFDA in the field of ITER fusion neutronics has been very low in 2007 due to organisational changes, that is, formation of the new legal entity – the ITER International Fusion Energy Organization. We applied for EFDA subtask on evaluation of the shielding capability of the ITER ICRH design (TW6-TPHI-ICHDESREW, part A2.9, Art. 5.1.b) in June, but with no success. Also, taking part to IFMIF fusion neutronics has no longer been possible, as Finland does not belong to the EU donor countries (Germany, Spain, Italy and France) which will carry out the IFMIF research in future. There have been no other suitable tasks related to neutronics. However, despite the lack of neutronics work, 2 original articles have been written by Frej Wasastjerna concerning earlier ITER and IFMIF shielding calculations and published in Annals of Nuclear Energy. Also, Frej Wasastjerna has started writing a doctoral dissertation of his fusion neutronics work: the dissertation is planned to be finished during spring 2008, and will summarise his professional career in fusion neutronics before his retirement. This literary work has been mostly performed with separate VTT funding.

3.4 Plasma Wall Interaction and Surface Studies

3.4.1 Hydrogen migration in high Z plasma-facing materials

Deuterium (D) retention in the implantation induced defects in polycrystalline tungsten (W) has been studied. Deuterium was implanted with different energies and concentrations of retained D were analysed with secondary ion mass spectrometry (SIMS) and nuclear reaction analysis (NRA). Annealings were carried out at four pre-determined temperatures (520... 875 K) corresponding to four different defect types that can trap deuterium. In this study, the quantitative number of each defect type and their concentration profiles produced by 5, 15 and 30 keV D implantation with dose of 5.8×10^{16} cm^{-2} was obtained.

It is clearly seen in Figure 3.18 that the D concentration peak is located deeper in the sample with increasing implantation energy. Also is shown that different D implantation energies create varying amount of defects at various depths. As the incoming D energy increases, the number of trapped D increases and the maximum of the D profiles moves deeper into the sample.

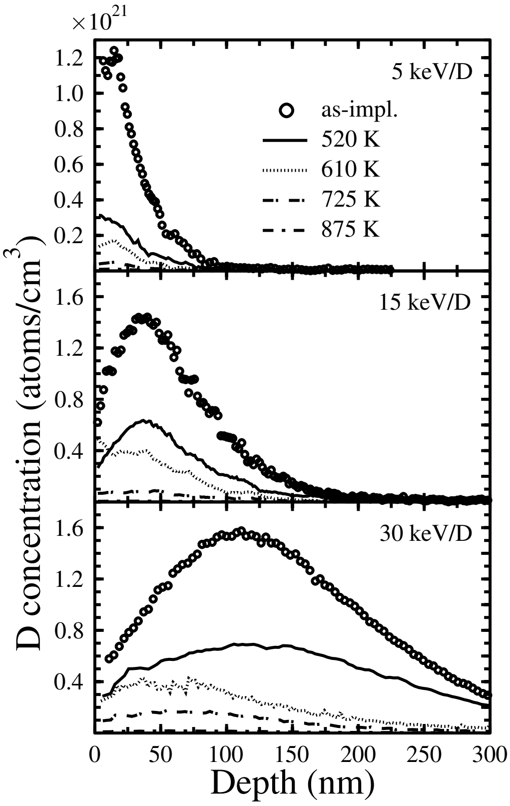


Figure 3.18: D depth profiles measured by SIMS. Increasing implantation energy causes deeper penetration of D into W sample, and growth of the concentrations of D trapping defects. Annealing of the samples reveals the retained D in each defect type.

The amount of retained D after implantation is rapidly decreasing with implantation energy decrease. The main reason to the rapid decrease is the increase of the recombination rate of implantation induced self-interstitials and vacancies with decreasing implantation energy, resulting in a decrease in the number of defects to which D can be trapped. At lower implantation energies these processes happen closer to the surface leading to a high number of the self-interstitials lost to the surface sink.

The first annealing stage (520K) could be partly assigned to the D detrapping from vacancies or vacancy clusters. At 610 and 725 K annealings the D decrease can be connected to the mobilisation of W self-interstitials, e.g. detrapping from interstitial clusters. The final loss of D during the last annealing temperature 875 K could be assigned to mobilisation of vacancies. At this temperature, the recovery studies indicate that almost all implantation induced defects are removed as can be seen from the Figure 3.18.

3.4.2 Modelling of plasma-wall interactions with ERO code

The role of computer modelling is vital when the effects of wall material erosion, migration and re-deposition are investigated. Nowadays a routinely used diagnostics for material migration studies is tracer injection and subsequent surface analysis. These experiments are used to imitate the migration of eroded carbon in the edge plasma. Typically a set of identical plasma discharges with puffing of gaseous tracer methane from a valve is run at the very end of each experimental campaign. The gas molecules dissociate quickly in the plasma, and the carbon ions behave as if they were eroded from the surface in the vicinity of the gas valve. The isotope ^{13}C can then be located in *post mortem* surface analyses of the plasma-facing components. Plasma conditions and the location of the valve can be varied from experiment to experiment. While the technique can accurately deliver both the resulting areal densities and depth profiles of the tracer atoms, it has no time resolution, and only limited information can be obtained about migration pathways by spectroscopy. Leaning on the available measurements, modelling can significantly deepen the understanding of the processes. We use the 3D Monte Carlo impurity transport code ERO, originally developed at IPP and FZJ.

Modelling of local deposition of ^{13}C in AUG and JET divertor puffing experiments was continued in 2007 and will further continue in 2008. The experiments presently under modelling work were performed in H-mode at the end of campaigns in 2003 (AUG) and 2004 (JET). There are surface analysis data available from both experiments. The modelling work done under JET and AUG 2007 workprogrammes is reported in respective sections.

3.5 Non-thermal Low Temperature Plasma Studies

Effort was put in upgrading the present 6.5 kW plasma incineration system at VTT to 120 kW inductive plasma torch (installed at TKK). The new system has operated at 50 kW rf power at 3.4 MHz into the load, and successful incineration of organic waste material at commercial level of burning rate at 27 kW was obtained. Preparations and design for installing the OES diagnostics to the present system were started.

3.6 Research Activities of the Estonian Research Unit

3.6.1 Development of LIPS method for detection of W layers on C substrate

Institute: Gas Discharge Laboratory (GDL), Institute of Physics, University of Tartu

Research Scientists: Matti Laan, Mart Aints, Ants Haljaste, Peeter Paris and Jüri Raud

Main results: The experimental set-up for LIPS measurements was rearranged with purpose to bring out UV spectral region: The spectrometer USB4000 Ocean Optics with enhanced sensitivity in UV and recording in wide spectral region (200–850 nm) was introduced. The focusing lens was replaced by the concave mirror (See Figure 3.19). The spectral response of the whole recording system was accounted.

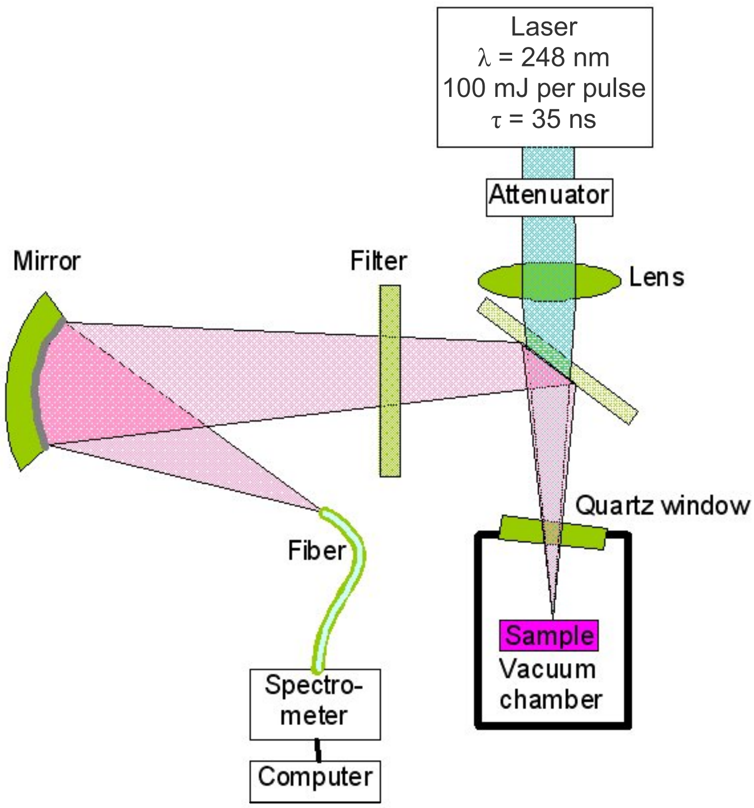


Figure 3.19: Experimental setup.

Carbon samples with tungsten coating of different thickness, prepared by Finnish group, were tested. LIPS spectrum was recorded for every laser shot and changes in spectrum as layers are ablated from the sample surface were observed. An example of obtained spectra is presented Figure 3.20.

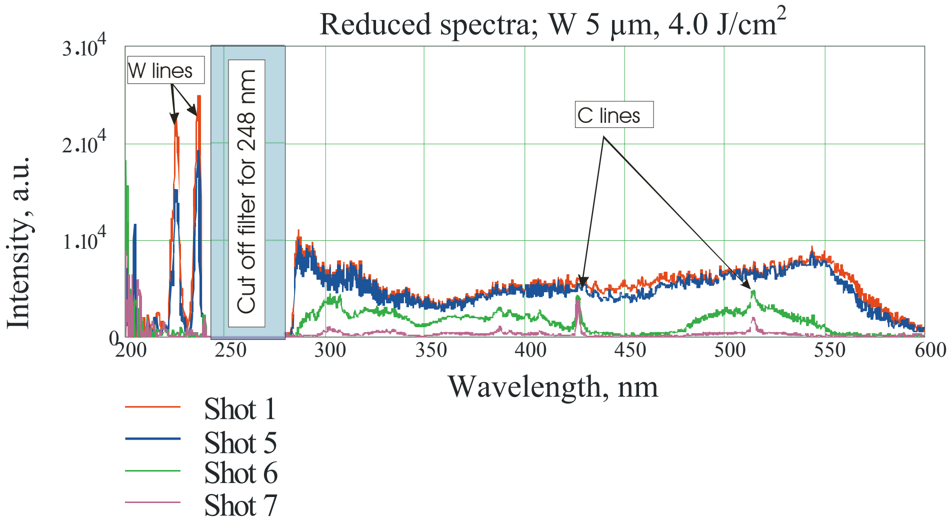


Figure 3.20: Spectrum as a function of laser shot.

At wavelength of 224 and 236 nm there are two intensive lines of tungsten, which disappear after 5th shot for sample with 5 μm tungsten layer. At wavelengths > 280 nm continuous spectrum dominates. After the 5th laser shot carbon lines 427 and 517 nm became detectable. The intensity of characteristic spectral lines as a function of laser shot is presented Figure 3.21. In figure the changes of relative intensity for carbon line 427 nm is given – the intensity at the wavelength 427 nm minus spectrum intensity at the adjacent, without carbon lines region, wavelength 435 nm. The minimum laser fluence necessary to obtain both tungsten and carbon spectra, was 4 J/cm^2. The thickness of tungsten layer ablated by a single shot was about 1 micrometer.

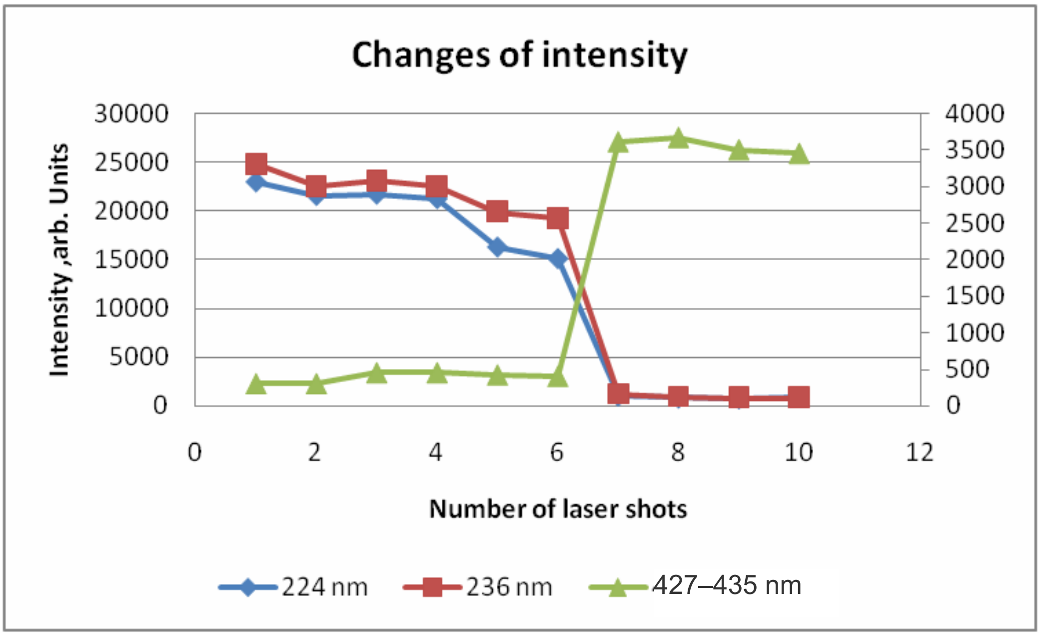


Figure 3.21: Intensity of selected spectral lines as a function of laser shot.

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

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

Main Results 2007: The experimental program connected with the increase of radiation resistance of wide-gap materials (especially metal oxides) has been successfully started. The contribution of hot (non-relaxed) electrons, hot holes as well as of hot recombination between photo-carriers to the excitation of luminescence or the defect creation in Al_2O_3, MgO and LiF crystals (pure, doped or pre-irradiated by swift heavy ions at GSI, Darmstadt) was investigation using several spectral-kinetic methods. Particular attention was paid to the solid-state analogue of the Franck-Hertz effect in the materials doped with certain impurity ions (in particular, Cr^{3+} ions in Al_2O_3). The energy excess of hot conduction electrons is partly spent on the direct excitation of impurity centres or structural defects resulting in impurity luminescence emission or heat release and therefore, in the decreasing of the creation efficiency of nano-size radiation defects. The Franck-Hertz effect can be considered as the luminescent protection against certain non-impact mechanisms of defect creation under the conditions of high excitation density. These non-impact mechanisms of radiation damage, connected with hot electron-hole recombination, should be taken into account even in the materials highly resistant against gamma-irradiation (the formation energy of a Frenkel pair exceeds the energy gap). The probability of hot electron-hole recombination drastically increases under the conditions of high density of electronic excitations, formed, in particular, in the tracks of ~GeV heavy ions.

Taking LiF crystals widely used as a dosimetric material and for the modelling of the processes in Li-containing blanket materials as an example, it was revealed that the creation efficiency of Frenkel defects depends on both the fluence and the flux of 5–10 MeV Au^{198} used to accumulate the same irradiation dose. The similar effect was revealed long ago in classic photographic materials – silver halides. The mechanism of this effect, particularly important for the creation of nano-size intrinsic lithium colloids in a crystal bulk, was suggested and experimentally proved. High density of electronic excitations in the ion tracks provides especially favourable conditions for the formation of temperature-stable aggregates of point defects (F centres) serving as the seeds for nano-size metallic colloids. In the long term the increase of the colloid size leads to mechanical destruction of LiF.

The results are presented as 8 journal papers, 3 oral and 2 poster conference contributions.

3.6.3 Tritium depth profile analysis

Institute: Laboratory of Nuclear Spectroscopy (LNS), University of Tartu
Research 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 the end of 2006 negotiations with Forschungszentrum Rossendorf (FZR) began in order to set up and reassembly a dedicated beam line for tritium depth profile analysis of the inner wall tiles from JET. However, due to FZR precondition to support at least one researcher on site and guarantee the project duration longer than three years, we did not succeed of finding agreement between two parties.

In the second half of 2007, National Institute of Nuclear Engineering, Laboratory of Accelerator Mass Spectrometry was contacted, which showed up an interest to start up collaboration for tritium depth profile measurements by 2008.

3.6.4 Computer modelling on fusion related material and plasma studies

Institute: National Institute Chemical Physics and Biophysics (NICPB), Tallinn, Estonia
Research Scientists: Andi Hektor, Mario Kadastik and Liis Rebane

The fusion research activity at NICPB is focused on two main topics:

a) Power and particle exhaust, plasma-wall interaction
b) Theory and modelling.

The main topic is computer modelling on fusion related material and plasma studies. Our long term plan is to employ the distributed computing (Grid) technology for fusion related modelling.

NICPB has strong competence in distributed computing. The institute has the biggest national scientific computing facility. The institute is a partner in many Grid projects: BalticGrid I and II (supported by EU FP6 and FP7), NorduGrid Neighborhood (supported by the Nordic Ministry Council), Estonian Grid and the CERN computing infrastructure project WLCG (as a Tier2 level computing centre). The BalticGrid project has 10 partners from Estonia, Latvia, Lithuania, Poland, Sweden and Switzerland. The project involves some activities for fusion research with the responsible partners NICPB in Estonia and the Vilnius University in Lithuania.

The fusion activities at NICPB in the framework of Euratom started in 2007. During the first research year we have started three main sub-activities:

1. Modelling tools in fusion related material science in the context of the Grid computing. We have shown that Grid computing is a useful tool for parameter scan type studies in the case. We started some studies to model gas phase chemistry in tokamak plasma.

2. We started to study plasma modelling tools ASCOT and ELMFIRE developed by VTT and TKK, Finland. The plasma modelling codes include many heavily parallel algorithms. Due to the latency of the present Grid systems it is impossible to use the present Grid systems for the real time parallel modelling. However, the Grid is able to provide a solution for some parameter scan type tasks. Also, in the future it can help to build up user friendly data management systems for the large scale plasma modelling programs in Europe (some related activities are planned and coordinated by Euratom).
3. We started to collaborate with some Grid coordination activities at the ITER project (EGEE Fusion VO etc). The ITER project is starting to coordinate the central modelling framework and to distribute the standardized data collections. The Grid technology is clearly needed in the case.

Grid technology for fusion research: First, we studied the present situation of Grid technology for fusion research in the regional and European Grid scale. It was needed to plan the next step: to gridify and support some research applications for fusion on the Grid. Nowadays many competing Grid systems are available after approximately ten years of rapid development. In 2006 the Open Grid Forum (OGF) was formed in a merger of the Global Grid Forum and the Enterprise Grid Alliance. OGF has two main functions: the development of the standards of the Grid and unifying of the different Grid communities over the world.

In the Baltic and Nordic region there are three general purposed Grid systems: EGEE, BalticGrid and NorduGrid. EGEE is the pan-European framework coordinated by CERN using and developing the middleware package gLite. BalticGrid is a regional Grid project to unite the computing facilities in the Baltic Sea region, also using the gLite middleware. The NorduGrid project unites the computing and data resources mainly in the Nordic countries. NorduGrid uses the NorduGrid ARC middleware.

In our studies we used gLite on the BalticGrid infrastructure. The reason is we have well-controlled access to the BalticGrid resources which gives advantages for application testing. In general, it would be rather simple to modify our study for the NorduGrid infrastructure, for example.

In our studies gLite proved itself as a stable development platform for the distributed fusion applications. However, the user friendliness and the stability of gLite should be improved. The main problem is complicated debugging process due to unclear error messages.

Fusion related material modelling on the Grid: Three modelling techniques are used in fusion related material modelling: Molecular Dynamics (MD), quantum mechanical modelling (QM) and Monte Carlo technique (MC). All these techniques involve algorithms which are not inherently parallelizable except MC. The algorithms can be partitioned based on domain decomposition or functional decomposition or a combination. In MD the domain decomposition is complicated as data flow between computing domains is very intensive. QM involves quite different algorithms, but a typical QM computing algorithm can be more effectively decomposed than MD one. The MC methods are inherently parallelizable: computations with different random seeds are entirely independent and they can be distributed between different computational domains.

The computational nodes of the Grid are separated by typical Interent which has quite high latency. The security and Grid layers can increase the latency time up to some minutes. Thus the Grid typically restricts the global domain decomposition for MD or QM. MC which is inherently parallelizable can be a ideal method on Grid systems. Our analysis showed that the gLite package is profitable for all kind of MC applications.

We chose to gridify the cp2k software package to study the gas phase reactions of methane and hydrogen ions in tokamak plasma. In end of 2007 the cp2k software package has been partly gridified on the BalticGrid infrastructure. We start to process to include the application to the official (supported) production level list of the gridified application at the BalticGrid as there is the interest from the different groups in the (Baltic) region to use the cp2k software for modelling of plasma and gas-phase chemistry. The first results from the modelling of the gas phase reactions of methane and hydrogen ions in tokamak environment will be gathered and published in 2008.

Other results: We started to study plasma modelling tools ASCOT and ELMFIRE developed by VTT and TKK, Finland. The plasma modelling codes include the heavily parallel algorithms. Due to the latency of the present Grid systems it is impossible to use the present Grid systems for real time parallel plasma modelling. In general we continue to monitor for the framework of plasma applications coordinated by EFDA. Also, we initiated a fusion interest group at the BalticGrid project to collect and unite the needs of the fusion researcher in the Baltic region.

4. EFDA FUSION TECHNOLOGY PROGRAMME 2007

Association Euratom-Tekes contributes to the EFDA Technology Programme 2007 in the fields of Vessel/In-Vessel, Physics Integration, Tritium Breeding and Materials and System Studies.

4.1 EFDA Technology: Physics Integration

4.1.1 Faraday shield RF modelling and RF sheath dissipation

EDFA 5.1b Contract: TW6-TPHI-ICFS (05-1330)
Principal Investigator: Jukka Heikkinen, Tekes – VTT

The aim of the subtask in the EFDA task TW6-TPHI-ICFS on Faraday shield RF Modelling was to integrate the antenna/Faraday shield coupling model to the ASCOT particle edge transport code for studies of the shield optical transparency. The RF sheath driving potential obtained from the RF electric field map produced with 3D RF code HFSS by IPP for 0pi0pi RF phasing with horizontal screen bars (three bars between septa for each strap box) was interfaced with the ASCOT particle tracking code. Assuming the antenna is completely in a mid-plane port, with the front surface of the Faraday shield being ~ 1 cm behind the first wall, the scrape-off layer ion plasma was modelled with a simple surface-averaged recycling model. Constant Bohm diffusion was assumed for the radial plasma transport in the scrape-off layer. The plasma density was found to be reduced in front of the antenna both in the antenna private region and outside it by the RF induced convective transport. The heat load on the side walls of the antenna private region by RF sheath acceleration along the magnetic field was significantly larger than the heat load on the Faraday shield front by diffusion and convection. A good agreement with the fluid estimate $P = 10^{-15} \cos(|\alpha|) nV(T/\mu)$ W/m^{-2} for the heat flux on the side frame limiters was obtained using the density n and temperature T sampled by ASCOT for the antenna private region. The obtained ASCOT code upgrade for the RF near field effects on the SOL plasma may be useful by simple modifications for general SOL plasma studies including, e.g., gas puffing effects on the control of RF coupling including also the LH grill case.

4.1.2 Ripple studies for ITER

EDFA 5.1b Contract: TW6-TPO-RIPLOS (06-1435)
Principa l Investigator: Taina Kurki-Suonio, Tekes – TKK

The non-axisymmetric nature of the tokamak magnetic field, resulting from the finite number of toroidal field coils, can not be ignored in a fusion device like ITER. This is because the resulting magnetic ripple provides charged particles with a loss channel from the well-confined plasma to the material structures. In a fusion reactor, these particles can be the very high-energy fusion alphas, thus possibly posing a serious threat for the plasma-facing components.

The Tekes contribution to the EFDA task TW6-TPO-RIPLOS consists of the ASCOT simulations of ion losses and the preparatory work needed to allow these simulations in realistic, 3-dimensional ITER background including the 18 toroidal field coils, ferromagnetic inserts (FI), and 1–3 test blanket modules (TBM). In particular, the deliverables were specified to be

1. Setting-up of ASCOT to use 3D magnetic field map and 3D wall provided by EFDA
2. Set up ASCOT-based alpha-particle generation by beam, RF and thermal reactions
3. Technical test of ASCOT-3D and all interfaces on CSC IBMSC and JET JAC
4. Test of the NBI module with 3D wall and the alpha-particle source
5. Simulation of reference Scenarios 2–4. For Scenario 2, three different maps will be studied: no inserts, and two different sets of inserts
6. Modelling of the most dangerous scenario with half-amplitude toroidal field and current and with effects from TBM
7. Modelling of thermal ion losses.

During 2007, Deliverables 1–5 were accomplished. The 3D magnetic background data was obtained from ENEA, and the plasma equilibrium field, together with the plasma profiles, were provided by UKAEA. The ICRH particle sources were provided by VR.

In this work, it was not sufficient to study only the alphas born in thermonuclear reactions. Fusions also occur between the beam ions and the target plasma. Albeit small in number, these reactions could be significant in the edge region, where thermal fusion is low and the wall structures only a small distance away. The first step in evaluating beam-target fusion was to construct a source profile for beam-target fusion. Figure 4.1 shows the comparison of the fusion alpha production model, constructed for evaluating the source strength of the beam-target fusions, to the analytical results in the thermal range. It was found that the alphas from the beam-target fusions are insignificant compared to the thermal fusion.

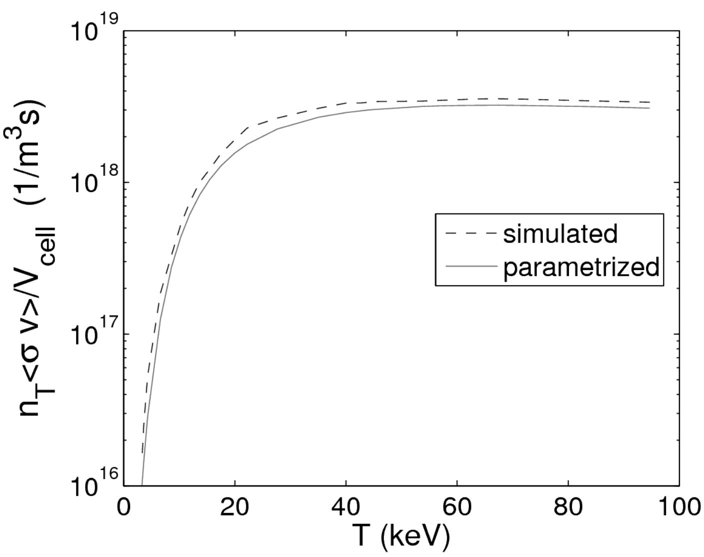


Figure 4.1: Comparison of the fusion alpha production model to analytical results in the thermal range.

ITER Scenario-2 is a standard H-mode scenario, while Scenario-4 corresponds to a more ambitious, advanced scenario plasma. The total power to the walls was found to be less than 1% with FI, for both scenarios 2 and 4. The spatial structure of the wall loads is illustrated in Figure 4.2 for Scenario-2. It is clear that most of the wall load is concentrated onto the toroidal limiters, where the heat fluxes can reach values up to 2 MW/m^2.

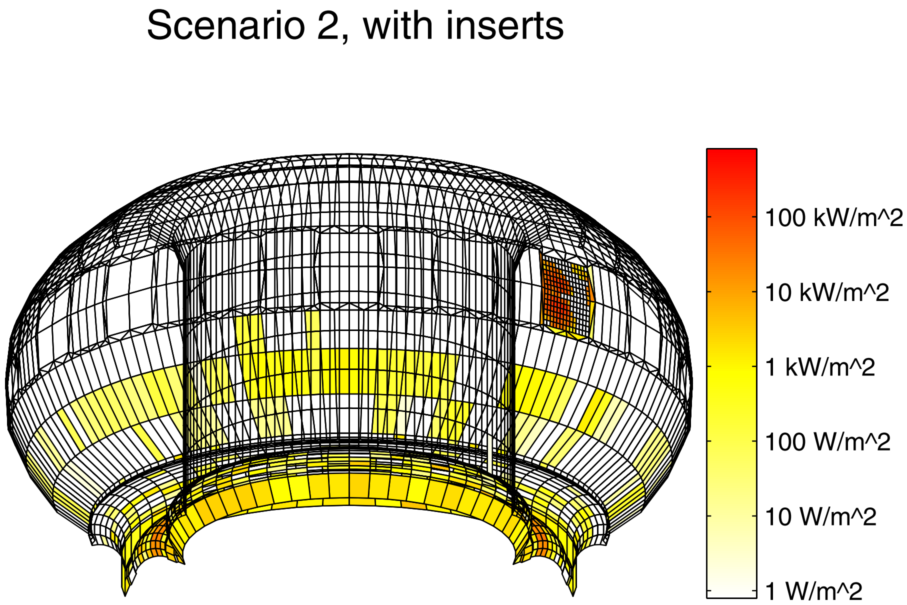


Figure 4.2: Wall load distributions for Scenario-2 (ASCOT simulation).

Simulations with TBM's revealed unexpected physics due to the extent to which they distorted the magnetic structures: island-like structures were found to be formed near rational-q surfaces as the field lines form helical tubes. Close to the separatrix, even an ergodic region was observed. Clearly, the confinement of fusion alphas is significantly degraded, but quantitative estimates can only be obtained once the physics related to these islands and ergodic regions is understood at a fundamental level.

4.1.3 Fast ions effects on ITER diagnostics

EFDA 5.1a Task: TW6-TPDS-DIADEV-1
Principal Investigator: Ville Hynönen, Tekes – TKK

The aim of the DIADEV task (TW6-TPDS-DIADEV) was to investigate the extent to which the fast ions generated by auxiliary heating – neutral beams and ICRF heating – influence possible ITER diagnostics. Tekes contribution to the task involved ASCOT simulations of the fast ions generated by neutral beams.

The 4D slowing-down distribution of NBI ions in (R,z, v_{par},v_{perp}) and the neutron emission profile from beam-target fusion reactions in (R,z) were simulated for ITER neutral beams (E_0 = 1 MeV, 16.5 MW on-axis & 16.5 MW off-axis) in Scenarios 2 (H-mode) and 4 (Steady-State). The neutron emissivities from the fusion fusion reactions for both scenarios are illustrated in Figure 4.3. There was partial synergy with the TW6-TPO-RIPLOS project in which Tekes was also involved. The input data, including the equilibrium magnetic field, the plasma profiles and the NBI input data, were obtained through RIPLOS project. However, no Scenario 4 equilibrium was available at the time, so the Scenario 2 equilibrium was used in all the simulations. Since in reality the low magnetic shear in Scenario 4 translates into small poloidal magnetic field, the fast ion orbits should be wider in this scenario. This was not realized in the simulations because the Scenario 2 equilibrium was used.

The total production rate of neutrons obtained was $3.1 \times 10^{18}\ s^{-1}$ for Scenario 2, corresponding to a fusion power of about 8.7 MW. The corresponding numbers for the Scenario 4 are $3.5 \times 10^{18}\ s^{-1}$ and 9.9 MW. For comparison, the fusion power from thermal reactions is 470 MW for both scenarios, evaluated from the density and temperature profiles used in the simulations. The total number of NBI ions in the 4D distributions were $N = 1.25 \times 10^{20}$ for the Scenario 2 and $N = 2.16 \times 10^{20}$ for the Scenario 4. These agreed quite well with the corresponding numbers obtained in Fokker–Planck simulations by Association Euratom-ÖAW also participating in the task. The ÖAW results were $N = 1.38 \times 10^{20}$ for the Scenario 2 and 2.39×10^{20} for the Scenario 4.

The simulated neutron emissivities and 4D distributions were delivered to the other parties of the task to be used as input for further modelling.

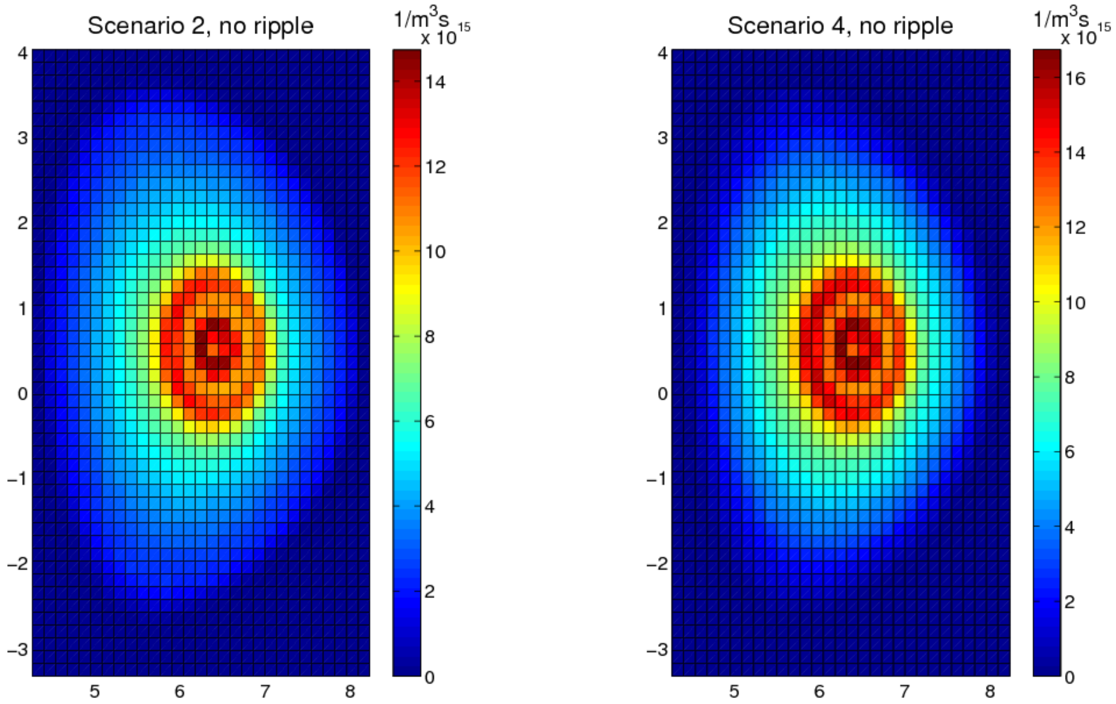


Figure 4.3: Neutron emissivities in the poloidal cross-section from beam-target fusion reactions obtained for scenarios 2 and 4 in ASCOT simulations.

4.1.4 Development of micromechanical magnetometer for ITER

EFDA 5.1a Task: TW6-TPDS-DIADEV-2
Research scientists: A. Kärkkäinen and 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. Several prototypes of micromechanical magnetometers have actually been developed for measuring e.g. the geomagnetic field. VTT's 3D magnetometer on single chip is one of the best efforts in this field.

The feasibility study for a MEMS magnetometer to ITER was done 1.4.2006–28.2.2007. The main emphasis of the study was on the magnetometer stability and life time in ITER environment, especially considering the neutron flux and operation temperature.

Goal: The goal of year 2007 for the magnetometer project was to complete the feasibility study, design new sensors according to the ITER specifications and start the manufacturing of the MEMS components. All of these goals were achieved although the manufacturing of the MEMS components was delayed until the beginning of the 2008 because of the lack of project financial resources.

Main Results in 2007: Scientific literature on the radiation effects to the mechanical characteristics of silicon or MEMS devices is very limited. Although radiation damage in silicon semiconductor detectors have been studied tens of years, these studies have mainly concentrated on the electrical properties of silicon. No published data about the effect of radiation on Young modulus was available. Charging of the dielectric layers of the MEMS components was reported by several references.

We irradiated MEMS accelerometers and magnetometers in the FiR research reactor at VTT for 0.5 h 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. 12 accelerometers (bulk micromachined, manufactured by VTI) and 7 magnetometers (SOI structures, manufactured by VTT) were characterized before and after the irradiation. The focus was on observing possible changes in the spring constant or charging of the MEMS components.

The components survived the radiation test without changes in their mechanical or electrical characteristics. These results are reported in Research Report VTT-R-06467-07: Feasibility study of a MEMS magnetometer for ITER diagnostics, delivered 10.9.2007.

The redesign of the magnetometer included scaling up the measurement range of the magnetic field, simplifying the manufacturing process, and reselection of the electrode metal. The scaling of the magnetic field amplitude from 10 µT to 2 T was done by reducing the excitation coil turns to one and by lowering excitation current. Also no vacuum encapsulation is needed resulting to a low Q value and hence an increased bandwidth. The readout electronics is simplified and its stability is improved by using off-resonance excitation.

Conclusion and further work: As a summary, the current research results confirm that the VTT 3D MEMS magnetometer looks as a prominent candidate for ITER static magnetic field monitoring. The manufacturing of the redesigned magnetometer started in January 2008 and the sensors are expected to be ready in July 2008. The readout electronics development is ongoing and the laboratory measurements of the magnetometer could start in the autumn.

4.1.5 Diagnostics support

EDFA 5.1b Contract: TW6-TPDS-DIASUP (06-1435)
Principal Investigator: Jukka Heikkinen, Tekes – VTT

Tekes participated in the EFDA Task DIASUP for defining the procurement practices for the ITER diagnostics port-plug. This was jointly done by Prizztech Oy, VTT, TKK, and FMI (Finnish Meteorological Institute) based on their experiences in corresponding activities within CERN, ESA, and JET. The main contribution was in proposing the details in the management structures for EU procurements issued by ITER. To ensure timely deliverables, it was found desirable to have a special technical centre for system integration, job allocation and for resolving critical design problems.

4.1.6 Characterisation of AUG wall tiles and plasma facing components with surface analytical techniques

EFDA 5.1a Task: TW6-TPP-CARTIL
Research Scientists: E. Vainonen-Ahlgren, J. Likonen and T. Renvall, Tekes – VTT
V. Rohde and M. Mayer, IPP Garching
J. Kolehmainen and S. Tervakangas, DIARC Technology Inc.

Background: Understanding the balance of erosion and re-deposition in a divertor with an ITER-like plasma facing components (PFC) arrangement (metallic first wall and carbon divertor) operating in ITER-relevant plasmas (Type I ELMy H-modes and ITER-relevant alternatives) is very important in order to predict material migration from the main wall to the divertor, and vice versa, and the expected size and localisation of the retained tritium in ITER.

Goals: The purpose of the studies was to carry out post-mortem analysis of specially prepared tiles/samples (with markers) installed in various areas of the vacuum vessel of ASDEX Upgrade tokamak (AUG), for long operating periods or for controlled plasma exposures. The emphasis of the analysis is on the mixed material layers formation and composition and on results of experiments dedicated to understanding of the erosion/re-deposition balance (such as ^{13}C puffing experiments). Influence of the glow discharge on the layers deposited on the tiles during the campaign was also investigated.

Main results in 2007: At the end of the 2004/2005 campaign, a glow discharge cleaning experiment was performed at ASDEX Upgrade. The main idea was to remove possible hydrocarbon films deposited on the walls during the campaign. The whole first wall served as a cathode. Mixture of He and O_2 with composition of 98 and 2%, respectively, was used for the experiment. A set of the tiles was removed after the glow discharge. For the study following tiles were chosen: three inner heat shield tiles (from the top, middle and bottom positions) and tiles from the inner and outer upper divertor.

At the heat shield the W-coated tiles had co-deposited layers containing mainly of boron and carbon with thickness of about 1 µm. Glow discharge treatment changed the composition and thickness but didn't remove the co-deposited layer. The co-deposited layers at the upper divertor have quite similar composition as the layers at the heat shield. Glow discharge treatment decreased the amount of boron and carbon only slightly.

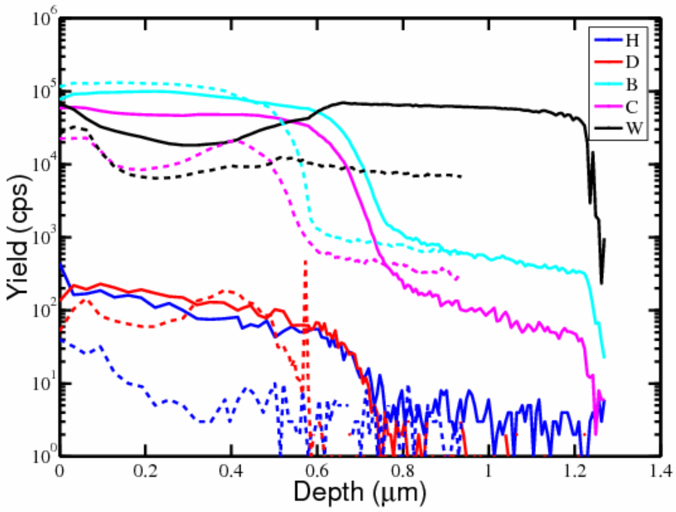


Figure 4.4: SIMS depth profiles measured at the bottom of the inner upper divertor before (dashed line) and after (solid line) glow discharge treatment.

The main purpose of the glow discharge experiment was to remove the conducting hydrocarbon films deposited on the first walls during the campaign. However, some of the tiles were covered with insulating boron layers due to boronisation of the vessel. Clearly these layers were not removed by the glow discharge, but it changed the structure of the layers considerably.

4.1.7 Improvement of surface processes modelling in the ERO code for advanced description of mixed material formation in ITER reference scenarios

EDFA 5.1b Contract: TW6-TPP-ERITERB (06-1389)
Principal Investigator: Markus Airila, Tekes – TKK

In all fusion plasma devices eroded material is transported and re-deposited on other locations, possibly far away from the point of origin. In a device such as ITER, where more than one element is present, the formation of compound materials is highly probable. The properties of these compounds can differ significantly from the originally installed material. In a highly demanding and diverse environment in fusion reactors, it is likely that the newly formed compound cannot meet the challenge posed by the surroundings, leading to a failure or deterioration of operation.

The 3D Monte Carlo impurity transport code ERO is used to model erosion, local impurity migration and deposition in limiter and divertor tokamaks as well as linear plasma simulators. The code consists of two main parts: a plasma-surface interaction part and an impurity transport part. Both parts use several models and external data from different sources to include all relevant physics. While the plasma transport part has been found to yield a reasonably realistic description of molecular, atomic and ion transport in the plasma, the simple surface model is insufficient for accurate description of material mixing. Presently, a surface model based on the binary-collision approximation

(BCA) is also available, but it cannot handle chemical effects that become important at low impact energies.

During the task TW6-TPP-ERITERB the low-impact-energy range of the data set of ERO was supplemented by sputtering data (for carbon incident on a carbon surface) calculated by Molecular Dynamics (MD). Also reflection data for normal incidence were obtained; showing considerable difference to the BCA based data set at low energies. The MD sputtering data can be reasonably well fitted using the Bohdansky formula for the sputtering yield as a function of incident energy, containing two fitting coefficients Q (magnitude of sputtering yield) and E_{th} (threshold energy). The values of the coefficients change from 0.75 to 0.642 and 7.42 eV to 8.56 eV, respectively. A previously modelled case for ITER divertor was simulated with the new sputtering data. Since these data are rather similar to the old data set, the modelling results also remain similar. However, the use of MD reflection data (when it extensively covers different angles of incidence) would potentially affect the results much more.

The new sputtering data were made available in the CVS repository where the up-to-date version of ERO is stored. A method was also elaborated for direct coupling of ERO and the MD code HCPARCAS, developed by K. Nordlund at UH. A library of numerical MD samples representing different amorphous carbon surfaces and particles was generated for bombardment simulations. Since the directly coupled code could be applied only to very short-time simulations, it was not used.

4.1.8 Molecular dynamics simulations of mixed material formation at the ITER divertor

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

Interatomic potential for Fe-He: Helium present in iron, and in metals and materials in general, affects and usually deteriorates the structural and mechanical properties. He in iron is known to affect vacancy mobility and cause bubble formation, void swelling, high temperature embrittlement and blistering. The steel in fusion reactors will be subject to 14 MeV neutron irradiation which produces helium through transmutation reactions. The presence of helium could affect radiation damage in steel, by binding strongly to vacancies or helium-vacancy clustering, thus possibly affecting the recombination of damage.

To be able to study the effect of He on radiation damage in Fe using molecular dynamics simulations, we have developed a new interatomic potential. Focusing on He defect formation and migration in the iron matrix. The potential was fitted to literature *ab initio* data. We have, in contrast with Fe-He potentials in the literature, shown that a pair potential is capable of describing the correct order of stability of interstitials. While not fitted to configurations with He-He interaction, the potential describes He_nV_m clusters in good agreement with available *ab initio* data.

Tested with several somewhat different iron potentials, the Fe-He potential performs well, especially for those intended for radiation damage simulations. Together a Cr-He potential under development all needed interactions are soon available to simulate the effect of helium on damage production in iron-chromium alloys, as well as the pure elements.

Inter-atomic potential for BeC: Knowing the interplay between the fuel plasma and the reactor components, such as the first wall and the divertor, is a critical issue for the construction of fusion reactors. The atom-level mechanisms behind e.g. erosion and re-deposition, and the behaviour of the resulting mixed materials, are, however, not easily accessible to experiments. Hence, computational methods, including molecular dynamics (MD) simulations, are needed.

The interactions in a system of particles are within MD described by an inter-atomic potential. The study of reactor processes requires models for the mixed interaction between the first wall and the divertor materials beryllium and carbon. As a first step, we have constructed a Tersoff-like bond order potential for the pure beryllium system that is fitted to several properties of the ground structure. The potential is also able to reproduce the experimentally observed melting point and structures of different co-ordinations, as calculated with the help of the density-functional theory (DFT).

The bond order formalism was also used in the development of the inter-atomic potential for the Be-C system. As in the pure beryllium potential construction process, DFT-data of several different structures were included in the fitting database. In its current form, the potential can reproduce the only observed Be-C phase, the antifluorite Be_2C structure. The absence of experimental data makes the assessment of the potential difficult, but at least the high melting point characteristic of Be_2C is reproduced. When compared to DFT data, the bulk modulus and the elastic constants are also relatively well reproduced.

4.2 EFDA Technology: Vessel/In-Vessel

4.2.1 Host activities in connection with the DTP2 test facility

EDFA Art. 5.1b Contract: TW6-TVR-DTP2OP
Principal Investigators: Jorma Järvenpää, Arto Timperi and Risto Tuominen, Tekes – VTT and Jouni Mattila, Tekes – TUT/IHA

Objectives: The Divertor Exchange is a critical operation in ITER reactor service and maintenance. Since the beginning of 2005 Euratom Tekes association has put a significant effort to establish the DTP2 platform to study and develop the divertor exchange procedures. This achievement is a joint-venture of TUT and VTT.

This task relates to technical support and project work to be performed in relation to the development and operation of the DTP2 test facility. The major components for this facility are currently being constructed by industry under EFDA contract and the integrated facility will be hosted and operated by the Finnish Fusion Association Tekes.

The purpose of this task is as follows:

a) To provide technical support to EFDA-CSU during the final stages of procurement (factory and site acceptance testing) of the prototype remote handling equipment for DTP2 (Cassette Multifunctional Mover (CMM) and Second Cassette End-Effector (SCEE)).

b) To carry out the integration and commissioning of the CMM & SCEE with the CMM control system hardware and software.

c) To develop and execute an RH-trials programme based on second cassette replacement operations to:

   - Establish whether the prototype CMM design will allow second cassette transport, installation and removal in an effective manner and within safe operational limits
   - Determine workable safety and alarm thresholds for the CMM & SCEE axes
   - Validate the nominal RH operating procedures proposed for ITER.

d) To carry out an FMEA study to assess reliability of the prototype CMM and SCEE system according to current industrial practise.

Deliverable 1: To lay project management plan.

Deliverable 2: To plan and realize the integrated DTP2 architecture, infrastructure and proposed trials program up to the end of 2007.

Deliverable 3: To report on the integration and commissioning of the DTP2 sub-systems.

Deliverable 4: To detail procedures for a formal set of DTP2 RH trials to demonstrate and verify the second cassette replacement process.

Deliverable 5: To perform and report on the FMEA analysis on the prototype CMM and SCEE including recommendations (where applicable) for design improvements to increase system reliability.

Deliverable 6: To report on the preparation and execution of a set of DTP2 RH trials based on the procedures mentioned at Deliverable 4 above.

Deliverable 7: To collect final summary report on DTP2 related activities executed during 2007.

How they will be performed: For the large extend, the work for the above deliverables is performed in the DTP2 laboratory and in a close contact to all the team members and the facility (including TUT/IHA). This is necessary in order to understand the constraints and to get the best possible result of the work. The theories and developments have to be tested on the shop floor continuously.

Deliverable 1: To determine the DTP2 ”floor level” management plans for DTP2, in order to provide the best practices for 2007 operations. This part of the work is done together by the joint partner TUT/IHA. The work of this task is divided between several performers and it is important that all the sub-tasks have the responsible task managers, team members and clear time schedules for the different phases.

Deliverable 2: To finalize the DTP2 test surrounding before the actual start up of the testing and trials. In this sub-task the architecture of the test surrounding will be specified, i.e. control room, test stand and control cables. Drawings of the test facility will be generated and the structures will be realized according to the plans. In addition, the preliminary proposals for the test runs will be generated. This part of the work is also done together by the joint partner TUT/IHA.

Deliverable 3: TUT/IHA has designed the control software for CMM/SCEE mover and the control components are delivered from Spain. In this sub-task the control system will be integrated as a workable complete system. Also this part of the work is also done together by the joint partner TUT/IHA.

Deliverable 4: In this sub-task the detailed test programme for the CMM/SCEE is developed. The test-programme should cover well all the expected functions of the mover. In this task the control system will be fine tuned, to perform the divertor exchange by the CMM/SCEE movers. This part of the work is also done together by the joint partner TTY/IHA.

Deliverable 5: To guarantee the reliability of CMM/SCEE mover, the FMEA-analysis will be done for the control system, components and the sub-systems. According to the results the improvement proposals will be generated to make the systems reliable for the ITER surrounding. This part of the work is done mainly VTT.

Deliverable 6: To perform the tests. The test runs will be performed according the programme developed in the deliverable 4. The tests are performed together with VTT and TUT/IHA experts in a close contact with EFDA personnel. The main objective of the test runs is to develop the reliability of CMM/SCEE mover and to find out the possible problems in its operation. Important issue is also to develop the control procedures so that Remote Handling operation in ITER can be performed. This part of the work is also done together by the joint partner TTY/IHA.

Deliverable 7: In this sub-task the results of the test runs and the development work of the RH operations during the year, will be collected and reported.

The main results of 2007:

<u>Deliverable 2:</u> Finalizing and building up the DRM test surrounding was continued. The Divertor cassette manufactured by Gradel in Luxemburg was transported into the VTT test hall in April 2007. VTT designed lifting and handling equipments for the cassette.

Electrical cabinets for controlling the CMM/SCEE Mover were manufactured in Spain by Procon Systems S.A. The cabinets were transported to VTT in February 2007. During the inspection some manufacturing faults were discovered in the cabinets. These faults were repaired by VTT. During the first tests of the cabinets there were problems discovered in the host computer. Problems were so serious that in the end the computer had to be changed.

Occupational safety in test surroundings is an important part of this work. For this purpose the safety plan was created. DTP2 test platform is surrounded by the protection fence which includes gates. The gates are locked and connected to the control system. If the gate will be opened during the test trial it causes the emergency stop for the whole system.

The electrical cabinets made by Procon Systems were assembled at the test platform. In the test hall the cable trays were mounted on the wall and cables from cabinets to control room were lined on the cable trays.

CMM/SCEE Mover main controls are located in the control room which is built on the mezzanine in the hall. The Control room of DTP2 was realized together with TUT/IHA. TUT/IHA created and developed the visualization and the viewing system of the control room.

Figure 4.5: DTP2 Divertor Region Mock-up stage 1.

Deliverable 3: The control software for CMM/SCEE Mover is developed by TUT/IHA. The electrical cabinets are taken into use and the electrical components in the cabinets tested. All tests have been performed by the help of virtual model of the CMM/SCEE Mover. CMM/SCEE Mover delivery is delayed very badly, already over a year. For that reason the functional tests for the Mover have been impossible to be performed.

Deliverable 4: The test programme for the first test trials of the CMM/SCEE Mover was prepared. The program consists of tuning of the regulators and transducers. The program contains also a longer time test program so that Mover is valid to the ITER surrounding. In the test program all Mover functions are tested in practice. The first tests will be performed on the test rig and at the later stage on the DTP2 test platform by driving Mover from Control room using the remote handling operation.

Deliverable 5: Reliability and safety of the control system, components and subsystems are the essential properties for CMM/SCEE Mover. VTT has performed CMM/SCEE Mover FMECA Analysis. In the analysis, it was systemically discovered failure modes of the components and how failures effect to the system operation. In the analysis, many critical points were discovered and many of these findings were included in the development work of the control software. The analysis provides valuable information for trials. There are many critical operations and failures which have to be tested in the trials.

Main problem during the analysis process was lack of documentation. Telstar Industrial the manufacturer of CMM/SCEE has not yet delivered final documentation and in analysis used documentation was insufficient.

Deliverable 6: The original objective of the task was trials of the CMM/SCEE Mover. Telstar Industrial the manufacturer of the Mover could not get it ready in time. Original delivery date was April 2007. The current latest expected delivery date is in May 2008.

Instead of the original task VTT and TUT/IHA have participated designing and controlling manufacturing of the mover. We have assisted EFDA in these tasks. During the design process inspecting has been applied 3D virtual modelling.

4.2.2 Development of DTP2 subsystems and tooling in support of remote handling trials

EFDA Art. 5.1a Task: TW6-TVR-DTP2DEV
Principal Investigator: Jouni Mattila, Tekes – TUT/IHA

Objectives: This task addresses development work of essential subsystems and tooling needed to support the remote handling trials which will be carried out in the new DTP2 once commissioning of the main RH equipment has been completed. Remote handling of the trials will be done from the control room presented in the figure below.

Figure 4.6: DTP2 control room.

Subsystems of the DTP2 control room comprise:

- Design, development and implementation of a viewing system which will provide the control room operators with clear views of both the environment and the tasks being carried out. This will require assessment of the requirements, design of the functional hardware based on realistic ITER constraints, software to provide an efficient operator interface, procurement and installation of all hardware, and final testing of the overall system. For compatibility with commercial radiation-hard cameras, the cameras to be used must provide a standard CCIR video signal.
- Design, development and implementation of a graphical visualization system to provide the operator with computer-generated views of the operating environment using virtual reality techniques. This will involve assessment of the general requirements, carrying out a market survey of commercial VR-type software and hardware products, selection and procurement of a suitable system, and development of the RHE and environmental models necessary.

- Design, development and construction of a radiation-hard, water-hydraulic jack to enable testing and validation of the ITER reference cassette locking system. This jack will need to fit into the very limited space available in the cassette body, whilst providing a force of up to 500 kN. Although it must incorporate its own (separate) hydraulic power unit, there is no requirement at this stage for the jack to be remotely handled.

Deliverables:

Deliverable 1: Project Management Plan summarising the task content by means of a work breakdown structure, a time plan scheduling these tasks, and details of the personnel resources to be employed in each task.

Deliverable 2: Report outlining the requirements, hardware design, procurement of components, design and implementation of operator interface and testing of the RH viewing system for the DTP2.

Deliverable 3: Report describing the requirements, results of market survey, procurement of hardware and application software, development of models and operator interface and testing of the RH graphical visualisation system for the DTP2 based on VR techniques.

Deliverable 4: Report on the design, procurement of components and construction of a water-hydraulic jack suitable for testing of the ITER reference cassette locking system concept.

Deliverable 5: Compilation of Final Versions of deliverables 2, 3 and 4.

Main Results in 2007:

Deliverable 2: Design for the DTP2 Control room and the viewing system hardware are finalized. Hardware items (including video matrix) are mostly provided and installed by Avack Ltd.

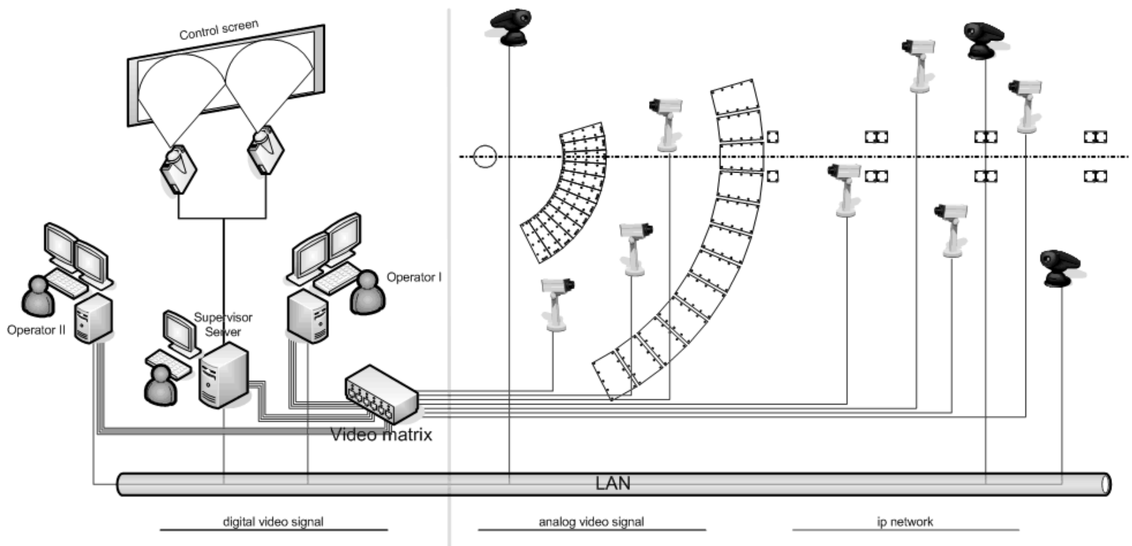


Figure 4.7: Viewing system hardware.

IHA is responsible of the single operator's control of the viewing system. Therefore IHAView software program was implemented for providing user interface for basic video camera controlling and various augmented reality tools, supporting decision making process in teleoperating robots (e.g. machine vision).

IHAView is meant to be a part of general purpose viewing system, supporting surveillance, but also being capable as a complex real-time image analysis and augmented reality platform. IHAView works on Microsoft Windows XP platform and requires specific hardware bundled with software. This includes framegrapper cards with suitable drivers, a joystick, and supported cameras. IHAView has been tested against the defined requirements and the test results were acceptable.

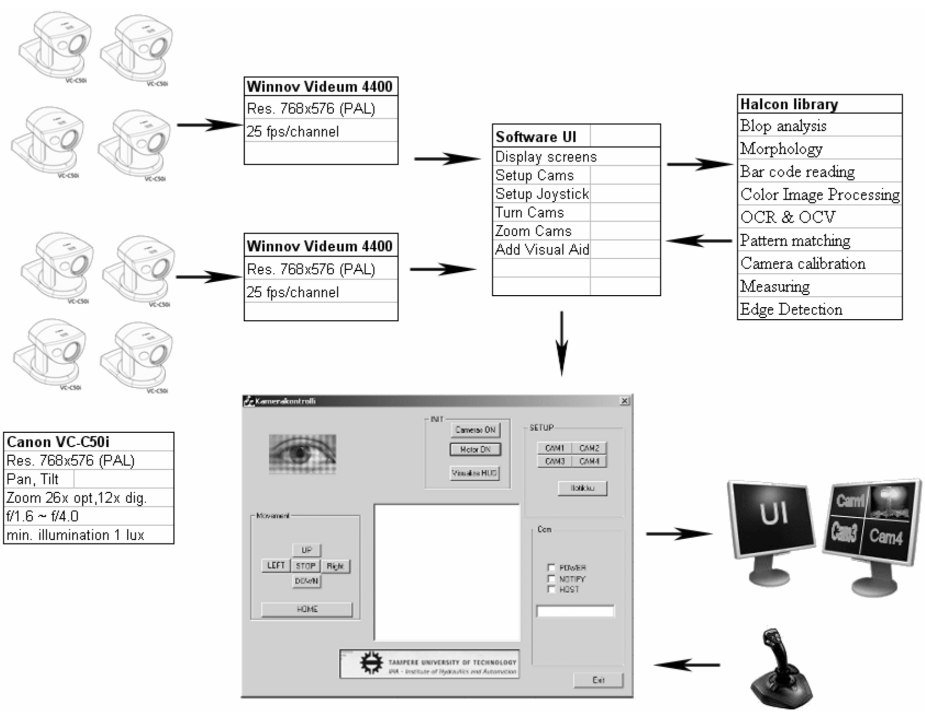


Figure 4.8: Interface design of the IHAView software.

Deliverable 3: Visualization system requirements were defined and the market survey for available visualization systems was carried out. The conclusion of the market survey was that the most suitable Visualization systems for DTP2 control room purposes would be Virtools or IHA3D. Even though there were quite a few requirements Virtools did not cover, it has means for program basically any feature the user wants. Virtools is expensive software to be purchased within this project and it is not entirely open source code software. At the same time the IHA3D is free of cost for IHA, and the source code is open for development. IHA3D already fulfilled most of the requirements and therefore can be used in the DTP2 control room without any additional work. For these reasons the IHA3D was selected to be the DTP2 visualization system.

IHA3D is a visualization environment developed at TUT/IHA and it works on Windows© platforms. It has a built-in editor which allows the user to create virtual robot models and configure robot characteristics. The built-in editor also allows creating complex robot behaviour such as closed structures (e.g. correctly working cylinders). IHA3D allows almost real-time visualization of created robots from multiple viewpoints by using OpenGL 3D graphics. Created robot models can be controlled via incoming network connections. The virtual robot can for example receive its current joint values from a simulation model or even from the real robot. In addition IHA3D allows sending important model information via outgoing network connections. IHA3D supports various control mechanisms e.g. haptic devices. It also incorporates fast collision warning and detection algorithms. These algorithms allow the user to observe when virtual robot is about to collide or is colliding. This information can be shown on the screen but it can also be sent to a target computer by using outgoing network connections.

CAD models of the DTP2 devices are imported into the visualization system. IHA3D has been tested against the defined requirements and the test results were acceptable.

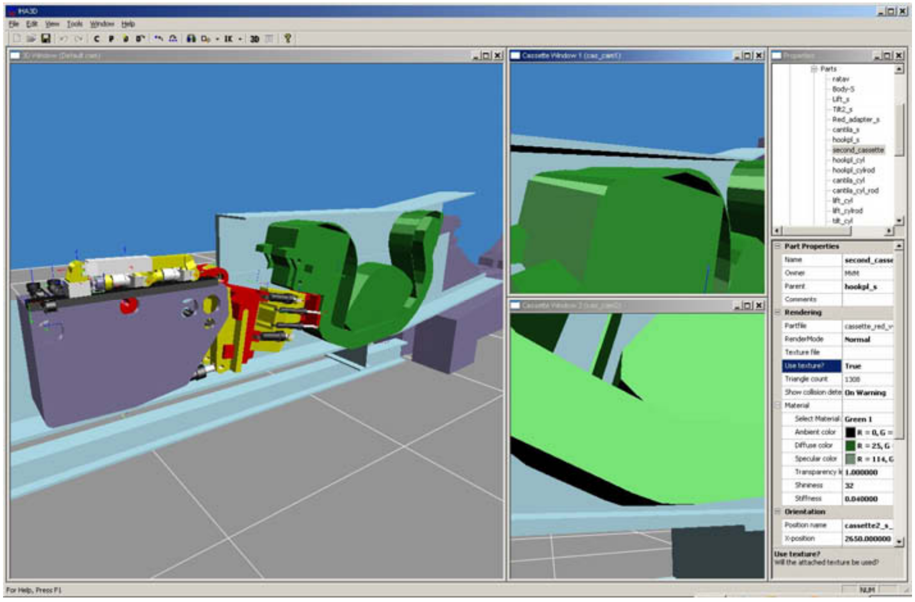


Figure 4.9: Visualization system IHA3D.

Deliverable 4: During the Second Cassette installation sequence, the water-hydraulic jack is transported on the top of the Cassette Multi-functional Mover (CMM) to the Divertor area. The CMM Manipulator is then taking the Jack from the tool rack and it introduces the Jack into a Cassette slot of reduced dimensions. Many geometric, interface and functional requirements arise during this installation sequence. Such requirements were not specified in the Technical Specifications file. The gathering of these requirements was possible thanks to an iteration process, in which Virtual Reality (VR) tools were employed. The flow chart in Figure 4.10 shows the iterative process employed during the design of the water hydraulic Jack. The process started from a concept design, whose 3D graphics were imported to a virtual scenario containing all parts involved in the Jack transportation and installation. DELMIA v5 software was employed to a) reproduce the installation sequence of the Jack design, b) detect any collisions with the environment and c) plan the optimal trajectory path for transporting the Jack from the tool rack to the Cassette slot. All these VR studies led to a new set of requirements of the Jack. From these requirements a new Jack design was conceived and then tested again in DELMIA. This iteration was repeated several times until an optimal Jack design, fulfilling all requirements, was obtained.

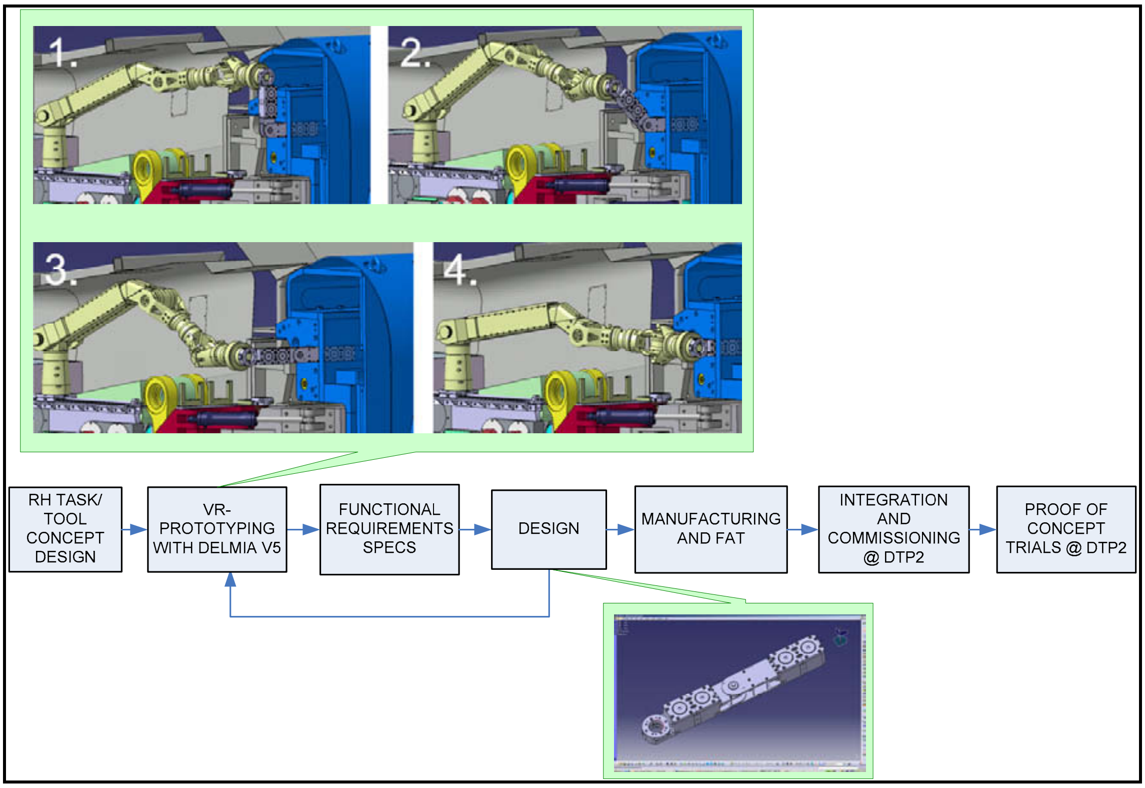


Figure 4.10: Design process of the water-hydraulic jack, with divertor cassette installation process verification using VR.

During the VR installation sequence verification, some of the geometrical requirements demanded that the total length of the jack had to be reduced considerably. On the other hand, interface requirements within the Cassette slot required longer length of the Jack. This problem could be solved by dividing the Jack body in two parts and linked by a passive rotational joint with friction brakes. This design solution allows the Jack to be stored and transported in *L*-shape (jack parts rotated 90 degrees) and then inserted in the slot with a straight shape.

The main specifications of the Jack are explained in Figure 4.11. The jack can provide a hydraulic force of 540 kN (functional requirement) by means of four pistons which have a stoke of 46 mm (interface requirement). Body and cylinder blocks were machined and assembled at IHA premises.

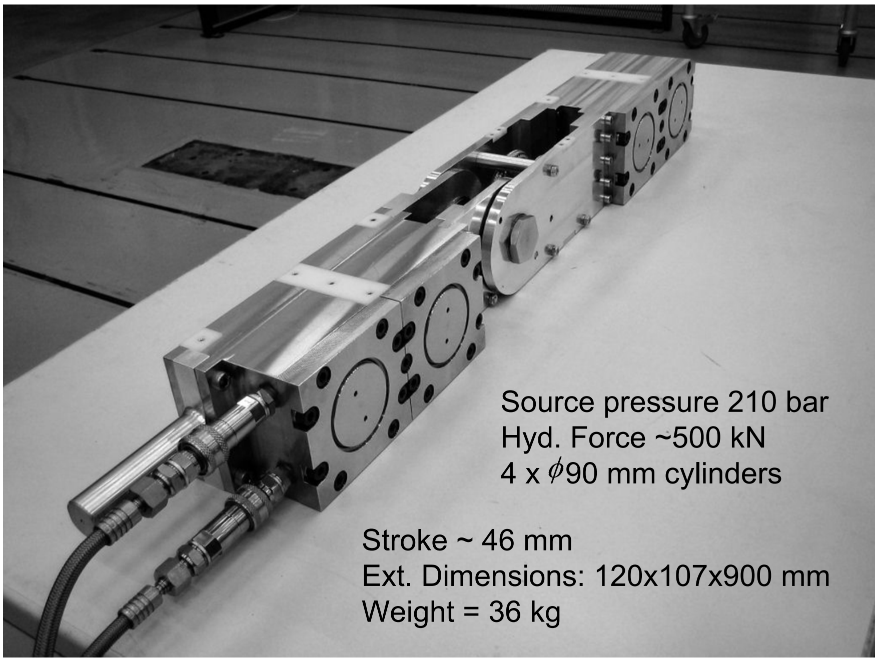


Figure 4.11: Cross-section of the water hydraulic jack employed to lock/unlock Divertor Cassettes.

The Jack and its hydraulic power unit had to conform to the provisions laid out in the Machine Directive 98/37/EC (CE-marking) due to ITER Safety and Regulatory requirements. IHA and VTT took the proper actions and produced the required documentation so that an EC Declaration of Conformity could be issued.

The Jack was tested at the Divertor Test Platform (DPT2) facility, which includes full scale mock-ups of Divertor Region and Divertor Cassette. The main purpose of the jack test was to validate the ITER reference cassette locking system concept, in which the Jack applies a compression force of 340 kN, provoking 19 mm compression deformation of the Cassette. The tests were carried out successfully, fulfilling all design requirements and validating the cassette locking system concept.

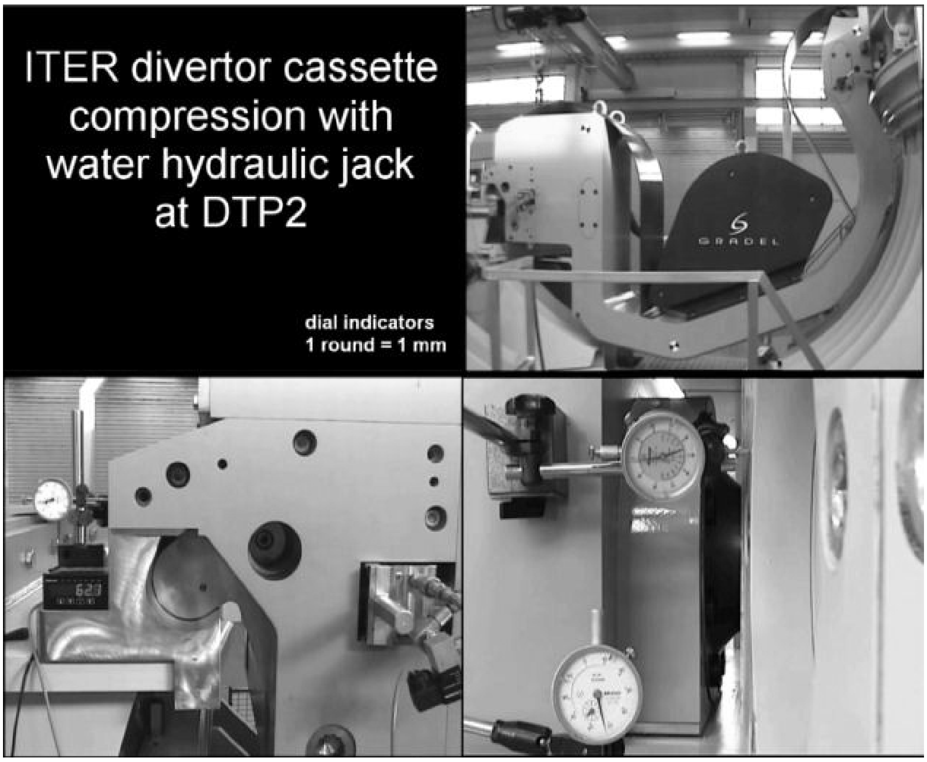


Figure 4.12: Tests at DTP2 site, where the Jack compresses and uncompresses the Divertor Cassette against the toroidal Divertor rails.

4.2.3 Software development and modelling of the CMM system

EFDA Art. 5.1a Task: TW6-TVR-CMMHLC
Principal Investigator: Jouni Mattila, Tekes – TUT/IHA

Objectives:

1. To produce the high level control software, which interfaced with the low level software produced in TW5 will enable the real CMM/SCEE prototype to perform its functions.
2. To consider the findings of the Hazard and Operability Analysis (HAZOP), a DTP2 Safety Study performed by VTT (EFDA 05/1314, deliverable 2), when writing the Functional Requirements Specification of the CMM/SCEE control system.

Deliverables:

Deliverable 1: Project Management Plan summarising the task content, a time plan scheduling these tasks, details of the personnel resources, and a summary of the stakeholders and their interests.

Deliverable 2: Functional Requirements Specification, itemising each function that will be required of the final CMM/SCEE system.

Deliverable 3: Design Description Document including Technical Design Specification, the overall software architecture and its mapping into proposed system hardware, implementation and software revision control system.

Deliverable 4: Test Report that demonstrates rational and practical procedure for testing the software and system as a whole with respect to functional requirements set, usability to trained operators and overall reliability and robustness to non-normal events.

Deliverable 5: Final report.

Main results in 2007: The project had duration of one year, starting in July 2006. Since CMM/SCEE system was expected to arrive to the DTP2 early 2007 the high level controller (HLC) software development was done iteratively meaning that the HLC development was divided into iterations each adding more functionality and features to the software program. The first iteration of the software implements the very basic functionality and communication with the virtual model. The second iteration adds features communicating with the CCS hardware. Within this task (TW6-TVR-CMMHLC) both the first and the second iteration of the program were released. Next iteration of the HLC will be done within another task (TW6-TVR-DTP2OP2).

Deliverables 1, 2 and 3 were delivered to EFDA in 2006. Early 2007 the first iteration of the HLC was released. Testing was done successfully according to the written test plan (Deliverable 4).

Since the CMM/SCEE deliver to the DTP2 was delayed until 2008 the second iteration of the HLC, which functions with the CCS hardware, was implemented within this task. It also meant that the deliverable 2 (FRS) was updated and the deliverables 3 (DDD) and 4 (Test document) were partly rewritten. The final report including updated versions of all the required documentation was delivered in October 2007.

4.2.4 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 and
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:

1. Implementation of a safety system for hands-on testing of the CMM system
2. CMM/SCEE system 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.

Deliverables:

Deliverable 1: A Project Management Plan (PMP) showing the breakdown of responsibilities between various contributing parties and a project time schedule (indicating main milestones and interim progress reviews by EFDA-CSU).

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 should consist of final integration and commissioning of the CMM/SCEE system. However, the arrival of the CMM to the DTP2 is delayed due to circumstances beyond IHA's control. The final integration and commissioning of CMM/SCEE cannot therefore be done within this task. Instead, Deliverable 3 will include subtasks related to final Integration and Commissioning of HLC and CCS (available hardware at DTP2) and Test Plans for the integration and commissioning of the CMM/SCEE.

- Subtask 1: CMM HLC software version 2.5 release
- Subtask 2: DTP2 test preparation
- Subtask 3: I&C supportive software development.

Main results in 2007:

Deliverable 2: Flexible safety system has been designed and it will be ready before the end of March 2008 by VTT.

Deliverable 3: DTP2 Controlling system software CMM HLC version 2.5 (subtask 1 of the deliverable 3) has been implemented. It includes more functionality and features into the HLC software by covering the following requirements.

- CAN and OPC connections between the Host PC and the MSC are implemented.
- The device can be operated in Cartesian space.
- Status of the axes can be changed by the operator controlling the CMM. The Cantilever Arm and Hook Plate can be set to passive state. All axes can be set to the enabled or locked state.
- More safety alarms and functions are implemented. A priority of the functions and signals are defined.

Most part of the subtasks 2 and 3 (of the deliverable 3) will be developed in early year 2008, but the following work has been issued already.

- The Graphical User Interface (GUI) for Tuning the LLC (MSC's) is designed, implemented and tested.

- LLC integration with the HLC. The communication modules between the LLC and HLC. Communication protocols are studied and the most suitable will be used for implementing the communication between MSC's and the Host PC.

4.2.5 EFDA quality assurance exercise

EFDA QA-pilot project for DTP2
Principal Investigators: Jouni Mattila, Tekes – TUT/IHA and
Jorma Järvenpää, Tekes – VTT

Introduction: A Quality Assurance (QA) system is needed to comply with ITER requirements and with the safety and licensing requirements which regulate the activities in support for ITER. A QA system is also needed to improve work process and efficiency, and to enable the Association to better compete with others.

F4E objective is to implement a QA programme in the European Fusion Associations:

- Quality system has to be prepared in each Association to provide the guidelines for their internal work.
- All Associations will be asked to provide their Quality Plan on the basis of the management specs EFDA/F4E will provide.
- EU DA contract awarding for ITER tasks will require a mandatory QA approach.

Objectives: The EFDA Task TW6-TVR-DTP2DEV 'Development of DTP2 subsystems and tooling in support of remote handling trials' was selected by EFDA as one of 3 pilot projects aimed to develop a Quality Assurance (QA) framework for the TW6-TVR-DTP2DEV task. This volunteer work was prepared by IHA and VTT. It was supervised, controlled and reviewed by EFDA Quality Representative (QR).

Deliverables:

- To produce a Quality Plan for the EFDA Task TW6-TVR-DTP2DEV.

Main results:

This QA exercise was prepared by IHA and VTT, under the supervision of EFDA Quality Representative. The main results of this QA exercise have been:

- The understanding of the Technical and Management Specification documents, which in the future are going to be the basis of a call for tender/interest to Associations.
- The formulation of a response to previous documents in terms of a **Quality Plan**, where the plans schedules and explanation of the disposals to comply with the Management Specifications requirements have been assembled.
- Compliance with the QA system has led us to implement Document Management and Product Lifecycle Management tools.
- With this exercise, mechanisms to control ongoing and future work with EFDA/F4E, and consistent with Quality Assurance requirements, have been learnt.

Results of the QA exercise and the Quality Plan prepared by IHA and VTT were presented in a “QA meeting with EU Associations” during November 2007 at Fusion For Energy premises. The main remarks made during these presentations were:

- Associations involved in the exercise remarked that the exercise was very useful and that, even if it required additional resources, it was worth doing it.
- EFDA QR expressed that IHA had a very good involvement and VTT provided good support during the QA exercise. EFDA QR also stated that the Quality Plan presented by IHA/VTT was very good and developed.
- EFDA RO said “Certainly I would be very happy as an EFDA or ITER RO to receive a QP of this clarity at the start of a project and look forward to the future when it becomes the norm”.

4.2.6 Design and development towards a parallel water hydraulic intersector weld/cut robot IWR

EFDA Art 5.1a Task: TW5-TVV-IWRFS
Researchers: Heikki Handroos, Huapeng Wu and Pekka Pessi
Tekes – LUT/IMVE

Introduction: Within the task TW3-TVV-ROBASS; Upgrade Robot to Include Water Hydraulics and a Linear Track, which was completed early 2008 and TW5-TVV-IWRFS; Demonstration of IWR Operational Feasibility the parallel Intersector Weld/Cut, which is on-going task 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 cleanliness 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. In addition to the abovementioned tasks an Underlying Technology task Virtual Prototyping of Manufacturing Operations of IWR (VIRIWR) was completed in 2007. Within the task a high quality animation video describing the key operations of IWR during the first assembly of VV was produced. By this video the manufacturing scenarios were evaluated and checked.

The structure of IWR providing 10 degrees of freedom: Figure 4.13 shows the assembly of IWR. The water hydraulic 6-DOF robot 1 is mounted on a steel carriage 2 which is driven by two separate servo motors including cyclo gears 4. The carriage moves along the track by employing rack and pinion drive. A water hydraulic bearing force compensation system 3 is maintaining constant contact force between bearing wheels and rails. Since the radius of the track is varying the distance between the upper and lower wheel must vary in order to prevent damage. To be able to operate in the both sides of the track slewing bearing 7 with rotational drive unit 5 is introduced. To enlarge the work envelope of IWR an additional linear drive unit with bearings 6 will be used.

Hydraulically driven tilting mechanism of the hexapod frame 8 is also needed to reach the lower areas of the work space.

All ten degrees of freedom cannot be active during the operations of the robot. They are mainly used for moving the hexapod robot in appropriate positions to avoid workspace boundaries. The rotation table 7 is equipped by water hydraulic clamping system 10 in order to improve the stiffness while machining.

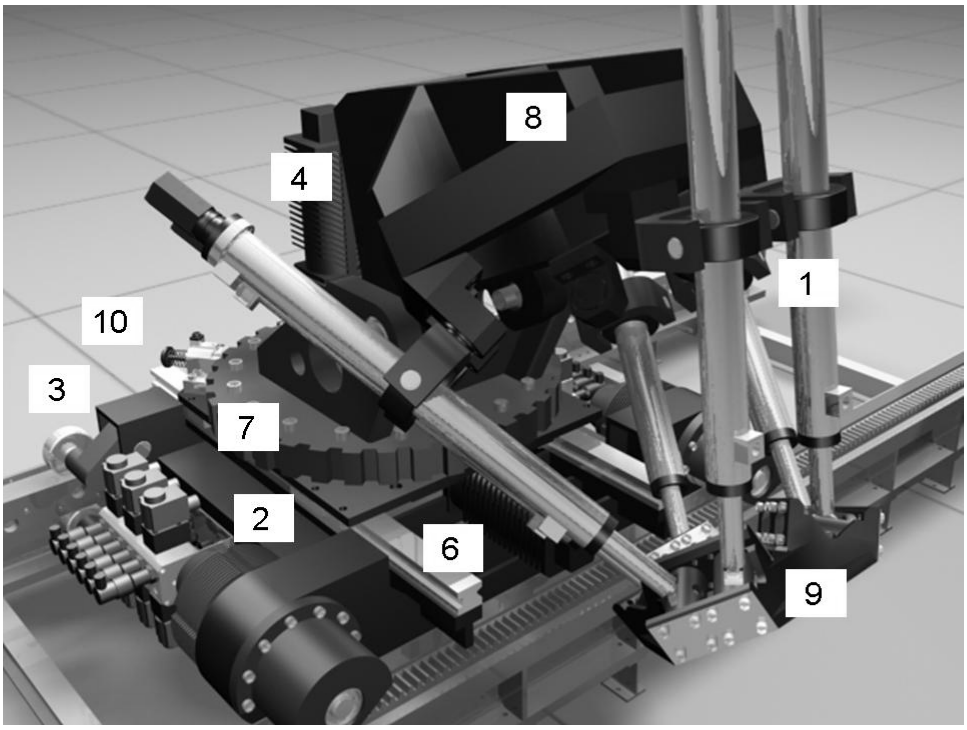


Figure 4.13: IWR construction.

The experimental prototype of IWR: Figure 4.14 illustrates the experimental prototype of 10-DOF IWR set up in laboratory of IMVE, 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 2 µm 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 IMVE. 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.

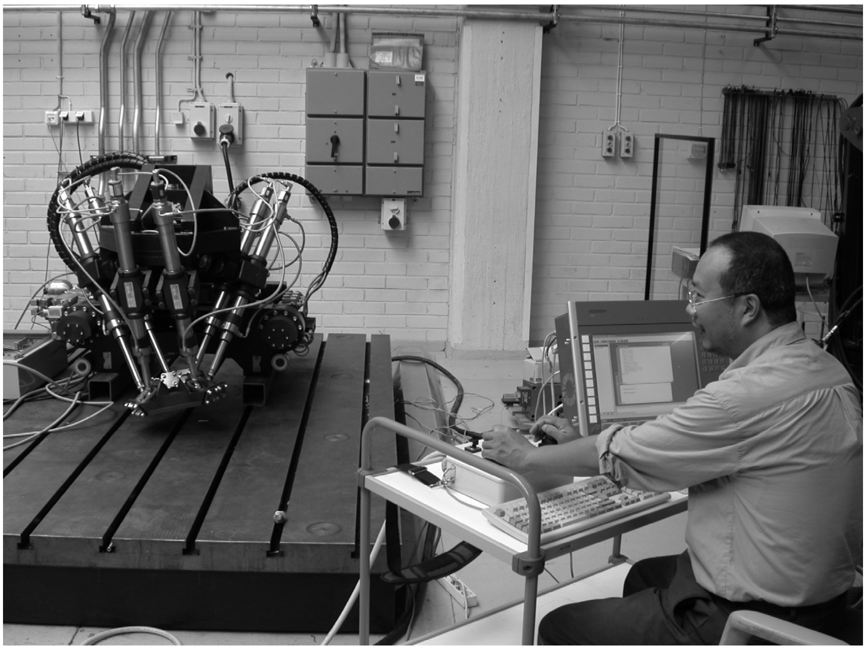


Figure 4.14: Experimental IWR prototype.

The virtual manufacturing tests of IWR: Figure 4.15 illustrates IWR at work on VV Poloidal Section Model Mock-Up. The CAD-drawings of VV provided by EFDA were converted into SolidWorks format. These drawings in conjunction with the drawings of the parts of experimental IWR were used in building high quality video of the main manufacturing operations of IWR during the first assembly of VV. 3ds MAX-program which is developed for professional animation video building was used as the main tool. The highlights of the video include

- Mounting of the robot tracks on the inner surfaces of the VV sectors
- IWR on a track in the inner surface of a sector
- IWR carrying out narrow gap TIG-welding of a splice plate and sector
- IWR carrying out cutting of defected seam
- The individual motions provided by IWR
- IWR moving on a track assembled on the poloidal segment model mock-up.

The produced animation video gave an important view to the general problems associated with the assembly of VV and the important advantages of the developed IWR over commercially available industrial robots.

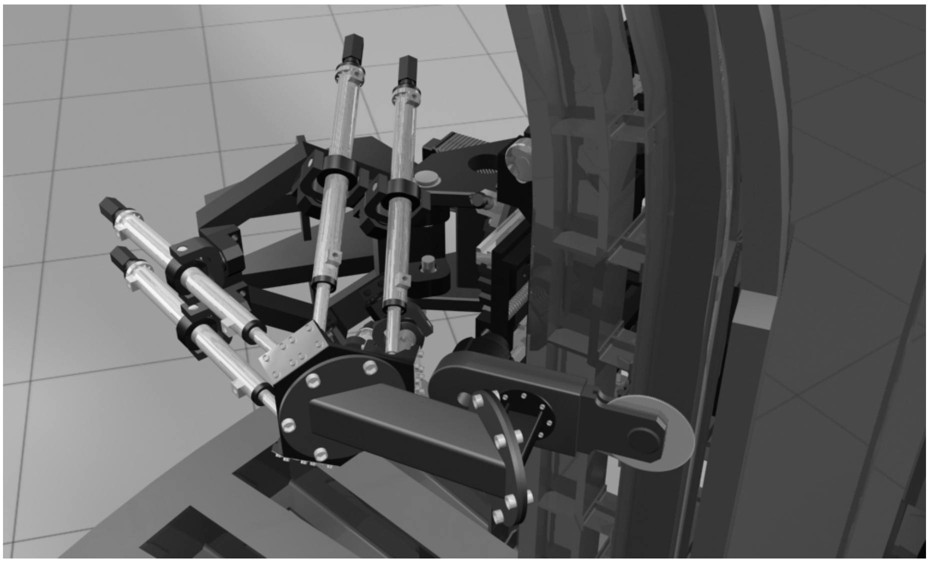


Figure 4.15: Virtual prototype of IWR carrying out cutting.

4.2.7 IHYB – Industrialisation and weld quality issues of high productive laser\arc hybrid for thick section welding of ITER grade SS material

EDFA Art. 5.1b Contract: TW6-TVA-IHYB
Researchers: Veli Kujanpää and Miikka Karhu, Tekes – VTT

Introduction: 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. It is found that if the ratio of so called chromium and nickel equivalent (Cr_{eq}/Ni_{eq}) in weld metal is below a certain level, e.g. 1.5, the susceptibility for solidification cracking is much higher than in welds where chromium and nickel equivalent ratio is e.g. above 1.5. The critical ratio is also depending on the solidification rate such that at the higher solidification rates the critical ratio is slightly increased. The impurities, especially sulphur and phosphorus also play a role in the susceptibility of hot cracking. If the impurity content is very low, below 0.01%, the susceptibility is much decreased.

The hot cracking susceptibility is also dependent on the level of strains affected by the rigidity of the structure. If the structure is very rigid, the strains causing hot cracking develop much easier.

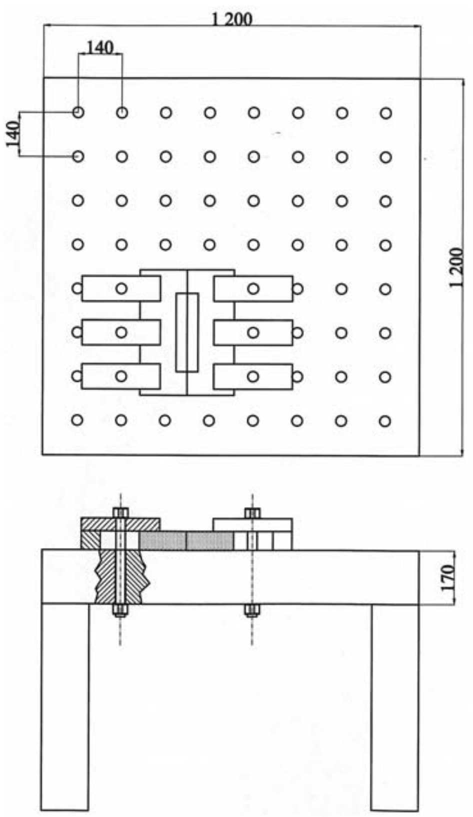
For the above reasons the ordinary austenitic stainless steel composition is often balanced such that usually ordinary AISI316L or AISI316LN composition is on the safe composition range, i.e. the ratio of chromium and nickel equivalents is over 1.5.

When we calculate the corresponding ratio of chromium and nickel equivalents in ITER grade austenitic stainless steel AISI316LN ITER, we find that its composition is about 1.2 to 1.5, depending on the variation of the element content, which marks risk of hot cracking.

Objectives: In respect of ITER assembly work the multi pass hybrid welding with reasonable quality level suitable towards industrialisation is aimed.

The main objective of this work is to get an overview of quality aspects of laser and hybrid laser welding, especially hot cracking susceptibility of ITER grade stainless steel material. Important aspects 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 a view of suitable filler metal for ITER VV application both in sector welding and assembly.

Preliminary results: The test system was first developed and tested. It consists of rigid 170 mm thick table and clamping system for that, Figure 4.16. In clamping system, thick high strength bolts were used to minimize all angular distortions. The test piece used was planned to be rigid as it self and simulate the rigidity of assembly welds, Figure 4.17. The weld thickness was 20 mm. The material was ITER Grade 316 L(N) austenitic stainless steel with original thickness of 60 mm. The ratio of chromium and nickel equivalents is 1.49 and sulphur content was 0.0001%. The experimental set-up is shown in Figure 4.18. 3 kW Nd:YAG laser with GMA torch as hybrid welding system was used with KUKA 15 kg robot.



– 170 mm thick steel table
– Grid of Ø 33 mm holes
- Clamp holders and M30 ultra high strength screws tighten with dial torque wrench at certain tightness (~250kN /screw)
- Simulates rigid structure

→ minimizes angular distortion

Figure 4.16: Hot cracking test system used in the experiments.

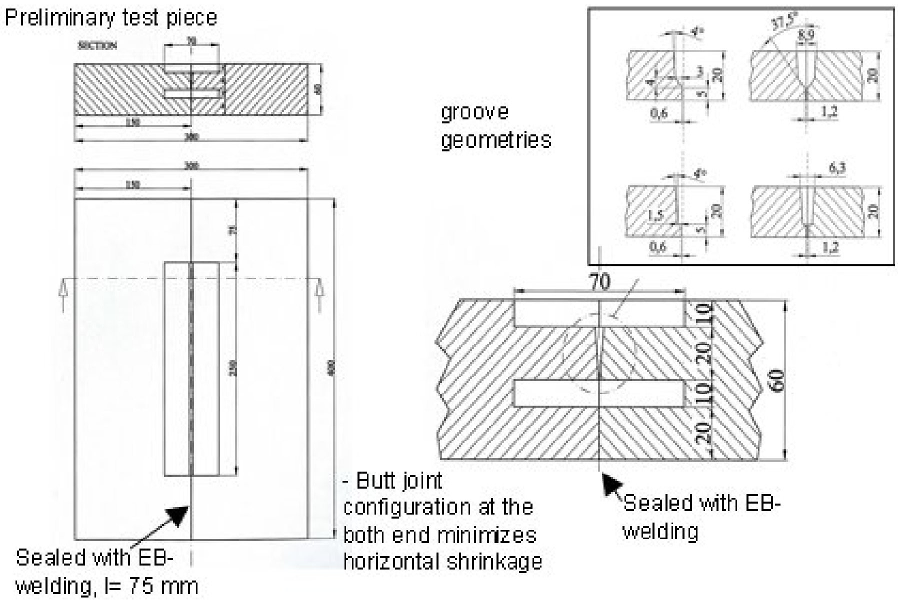


Figure 4.17: Test piece used in hot cracking tests.

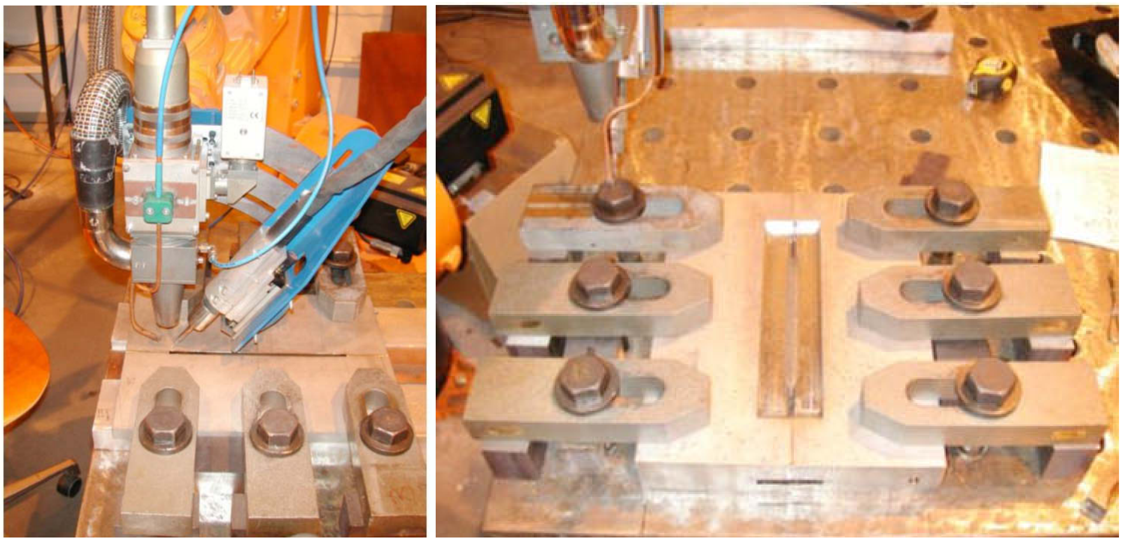


Figure 4.18: The experimental set-up.

The welds were made with multi-pass technique; typically 6–7 passes were needed to fill the groove. Hot cracking was occurred mostly in second and third pass, Figure 4.19. According to preliminary results, hot cracking can occur in these rigid weld arrangements. The amount of it depends on groove design and welding parameters, but in all welds it occurs at least in some extent. Further tests will show the total amount of cracking level and the dependence of susceptibility on welding parameters and arrangements.

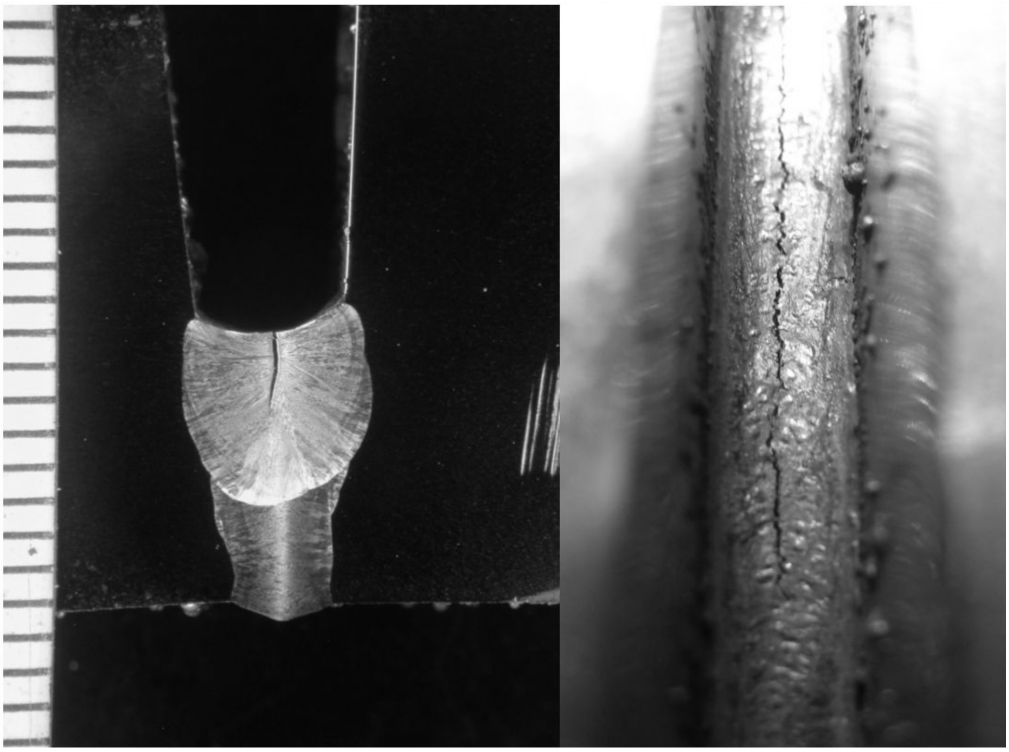


Figure 4.19: Second pass showing continuous hot crack.

4.2.8 Irradiation of CuCrZr/SS and CuCrZr/Be joints at 300ºC produced under different blanket manufacturing conditions

EFDA Art. 5.1a Task: TW6-TVM-NAJT
Principal Investigator: Seppo Tähtinen, Tekes – VTT

In previous tasks HIP joints between CuCrZr alloy and stainless steel have been irradiated and tested at 150°C at a dose level of 0.3 dpa. It has been noted that both manufacturing as well as irradiation conditions affect both the joint strength and the strength of the base materials CuCrZr and stainless steel. The aim of this task is to measure the effect of irradiation to a dose level of 0.3 dpa on the joint and the base material strength when the irradiation and test temperature is 300°C. Approx 90 specimens will be irradiated, 30 each at doses of 0.001, 0.01 and 0.1 dpa with an irradiation temperature of 300°C, in inert gas. There will be for each dose 18 mini charpy specimens (27 mm x 4 mm x 3 mm) and 12 tensile specimens (39 mm x 5 mm x 1 mm). Since material samples will also be available containing joints between Be and CuCrZr, it is also proposed to include some of these joints in the irradiation and testing campaign. The joint specimens will consist of a mixture of Be/CuCrZr and CuCrZr/SS joints and the tensile test specimens will include SS and Cu specimens. The final loading matrix will be agreed with EFDA and TBD. All the data generated shall be entered into a database supplied by EFDA.

Main Results in 2007: Material procurement and technical specifications were finalised. Due to delays in manufacturing procedure specimen preparation and irradiation are planned for year 2008.

4.2.9 Modification of ITER materials documents and assessment of materials data

EFDA Art. 5.1b Contract: TW6-TVM-LIP (06-1474)
Principal Investigator: Seppo Tähtinen, Tekes – VTT

Over the past few years the ITER MPH files have been systematically updated with the support of EFDA. This has been performed in parallel with the development of a database to ensure the traceability of the data used for the assessment of the material properties. This task constitutes a continuation of these activities, concentrating on MPH files that have not yet been completely revised or written. In particular this task should concentrate on the joints between SS/CuCrZr.

The current design of ITER utilises CuCrZr alloys in the first wall and divertor structures. The function of copper alloy is mainly to dissipate heat produced by plasma operation and disruptions. The copper alloy is not designed to provide structural support for the first wall however, both heat dissipation and structural support is expected for the divertor cassette. The anticipated temperatures range for copper alloys in the first wall and divertor is from 100°C to about 350°C.

Main Results 2007: Fracture toughness behaviour of HIP joint specimens seems to be dominated by the strength mismatch of the CuCrZr alloy and stainless steel. Those HIP joint specimens which have experienced relatively high cooling rate and optimum aging heat treatment have subsequently low strength mismatch (CuCrZr have either higher or lower yield strength that stainless steel) and show relatively low fracture toughness values. On the other hand, those HIP joint specimens which have experienced slow cooling rate or over aging heat treatment have larger strength mismatch (CuCrZr have substantially lower yield strength that stainless steel) and show relatively high fracture toughness values.

Post-irradiation experiments have demonstrated that neutron irradiation results in increase of yield strength already at low doses and at higher doses a yield drop phenomenon with almost complete loss of work hardening ability and reduction of uniform elongation are observed. All these irradiation related phenomena are more pronounced in case copper alloys than those in stainless steel.

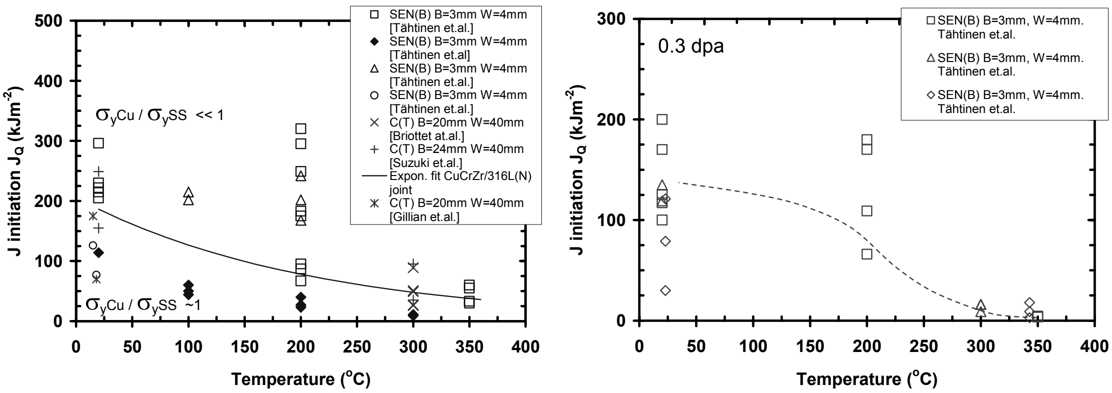


Figure 4.20: Fracture toughness values of CuCrZr/316L joints in temperature range between 20 and 350°C (a) in unirradiated and (b) irradiated conditions.

4.2.10 In reactor tensile testing of copper and CuCrZr alloy

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

Results on in-reactor tensile tests carried out recently (TV2-TVV-SITU) and their analysis (see Risø Report No. RISØ-R-1481 (EN), October 2004, 46 pages, VTT Report No. BTUO76-031127, 2004) have shown that during the in-reactor tensile tests, both copper and CuCrZr alloy deform uniformly and a homogeneous fashion. These experiments have shown no sign of yield drop and plastic instability (i.e. low temperature embrittlement) during deformation as commonly observed during post-irradiation tensile testing. Microstructural evidence obtained in the in-reactor tensile tested specimens together with the measured stress-strain behaviour suggest, however, that the ductility and lifetime of specimens tested under these conditions are strongly dependent on the stress level reached in the specimen at relatively low dose and strain levels. This stress level seems to determine the initiation and density of cleared channels. The dislocation activity in these channels and their evolution as a function of dose and strain appears to control the ductility and lifetime of specimens. The present experiments have been designed to determine the dependence of cleared channel formation on the stress, strain and dose levels. Both copper and CuCrZr alloy specimens will be investigated at the reactor ambient temperature (i.e. ~60°C. These experiments will be carried out in the BR-2 reactor at Mol and in collaboration with Risø (Denmark) and SCK.CEN (Belgium).

Main Results in 2007: Tensile loading modules were manufactures and delivered to SCK-CEN and installed in the irradiation rigs Due to technical delays in BR2 reactor operation in-reactor tests have been delayed to March 2008.

4.2.11 Manufacture of CuCrZr/316L SS mock-ups by powder HIP

EFDA Art. 5.1a Task: TW5-TVB-PHCSMU
Principal Investigator: Seppo Tähtinen, Tekes – VTT

Two fabrication routes are being considered for the fabrication of the Cu alloy/316L(N)-IG Stainless Steel (SS) bi-metallic structure for the production of First Wall (FW) panels for ITER: solid Hot Isostatic Pressing (HIP) and powder HIP. The powder HIP fabrication consists of a first HIP cycle at 1100°C and 140 MPa for 4 hours to consolidate the 316L(N)-IG SS powder backing plate with an embedded 316L(N)-IG SS tube gallery. A second HIP cycle at 1040°C and 140 MPa for 2 hours is then performed for consolidating and joining the CuCrZr alloy powder to form the heat sink layer. The fabrication route was briefly studied during the ITER Engineering Design Activities. The objective of this task is therefore to check that the improved joining conditions parameters developed for the solid HIP fabrication route can also be applied to the powder HIP route, and offer a competitive alternative fabrication route.

Main Results in 2007: Material procurement and technical specifications were finalised. Two HIP cycles were carried out for CuCrZr alloy, e.g., 1040°C/105 Mpa/3 h + 1040°C/0.5 h/fast cooling (100°C/min) + ageing 580°C/2 h and 980°C/105 Mpa/3 h + 980°C/0.5 h/fast cooling (100°C/min) + ageing 580°C/2 h. The results of the first HIP cycles indicated that tensile strength of powder CuCrZr alloy increased with increasing HIP temperature. Yield strength of powder HIPed CuCrZr alloy was 175 MPa. Due to delays in manufacturing procedure next HIP cycles are planned for first quarter of 2008.

4.2.12 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

The copper alloys in ITER are used due to their good heat conduction properties in the first wall and divertor components. Copper alloys are bonded in between stainless steel structure material and Beryllium or CfC armour materials. The joint interfaces are subject to thermal and mechanical loads under neutron irradiation. In the present manufacturing rules there is no clear quality or strength criteria for the Cu/SS or SS/SS joint interfaces. Particularly the strength of CuCrZr alloy is very sensitive to heat treatments during manufacturing cycle and consequently also the strength of Cu/SS joints.

Main results 2007: Tensile and fracture toughness specimens were irradiated to different dose levels of 0.001, 0.01 and 0.1 dpa and tested at the irradiation temperature of 150°C. The final analysis of the test results are in progress.

4.3 EFDA Technology: Tritium Breeding and Materials

4.3.1 Structural materials: Rules for design, In-reactor tensile tests of Fe and FeCr alloys

EFDA Art. 5.1a Task: TW5-TTMS-005
Principal Investigator: Seppo Tähtinen, Tekes – VTT

In view of the fact that mechanical property changes are driven directly by microstructural changes, it is quite possible, however, that the mechanical response of structural materials in a fusion or fission reactor exposed simultaneously to an intense flux of energetic neutrons and external and internal stresses may be entirely different from those commonly observed during post-irradiation tests. In fact, the in-reactor tensile tests performed recently on pure copper and CuCrZr alloy have demonstrated that indeed the deformation behaviour observed in the in-reactor tests is substantially different from that commonly observed in post-irradiation tests. However, since the damage accumulations during irradiation as well as dynamic behaviour of dislocations are likely to be different in bcc iron alloys from that in fcc copper alloys, it is important to investigate the in-reactor deformation behaviour of bcc iron and Fe-Cr alloy. The results of these investigations would be valuable not only from technological points of view but would also provide useful and realistic guidelines for understanding and modelling the deformation behaviour of bcc materials under the condition of dynamic deformation and damage production in reactor environment.

Main results 2007: It is rather interesting to note that the magnitude of the pre-yield dose does not affect the level of the maximum post-yield flow stress in Fe-Cr alloy. This is just opposite to what was observed in the case of pure copper where the maximum flow stress was found to be strongly dependent on the magnitude of pre-yield dose. Furthermore, unlike in the case of pure copper, the pre-yield dose does not have any effect on the uniform elongation of Fe-Cr alloy during in-reactor deformation. The variation of irradiation induced increase in the flow stress, $\Delta\sigma_f$, with strain (dose) clearly shows that the irradiation makes very small contribution to the post-yield flow stress in the specimen with a pre-yield dose of 1.0 x 10^{-2} dpa. The results on the specimen with a pre-yield dose of 1.1 x 10^{-3} dpa illustrate, on the other hand, that the irradiation causes significant contribution to the increase in the post-yield flow stress.

The results on the mechanical performance of the in-reactor tensile tested pure iron specimen are substantially different from that observed in the case of Fe-Cr alloy. For instance, in the post-yield plastic flow regime, the hardening rate (σ_f vs. ε) in pure iron with the pre-yield dose of 2.7 x 10^{-4} dpa is much lower than that in Fe-Cr alloy with a pre-yield dose of 1.1 x 10^{-3} dpa. Furthermore, both the level of hardening and the level of $\Delta\sigma_f$ saturate at a considerably lower strain (dose) value in pure iron than that in the case of Fe-Cr alloy. It is somewhat surprising that both the uniform elongation and total elongation are much lower in the case of pure iron even when the level of maximum hardening is much lower in pure iron than that in Fe-Cr alloy.

In the case of Fe-Cr alloy, the yield stress increases with increasing pre-yield dose. The increase in the post-yield flow stress, σ_f, with increasing strain (dose) is faster in the specimen with lower pre-yield dose. Furthermore, the strain (dose) dependence of $\Delta\sigma_f$ is also noticeably stronger in the specimen with lower pre-yield dose than that in the specimen with higher pre-yield dose. In should be pointed out that these effects are qualitatively very similar to what has been reported earlier for the in-reactor tensile tested pure copper.

One of the striking features of the microstructural evolution during the in-reactor tensile deformation is the lack of cleared channel formation both in Fe-Cr alloy and pure iron. The post-irradiation tensile tested specimens of Fe-Cr and pure iron do exhibit the phenomenon of yield drop yet no cleared channels could be found in these specimens. An equally interesting feature exhibited by the in-reactor deformed Fe-Cr specimen is that the deformation during in-reactor test occurs in a completely homogeneous manner without any indication of flow localization. A typical micrograph presented shows a relatively low density of almost uniformly distributed straight dislocation lines parallel to the traces of three {011} planes lying in the [111] zone axis. There is no indication of dislocation segregation in the form of cells and dislocation walls.

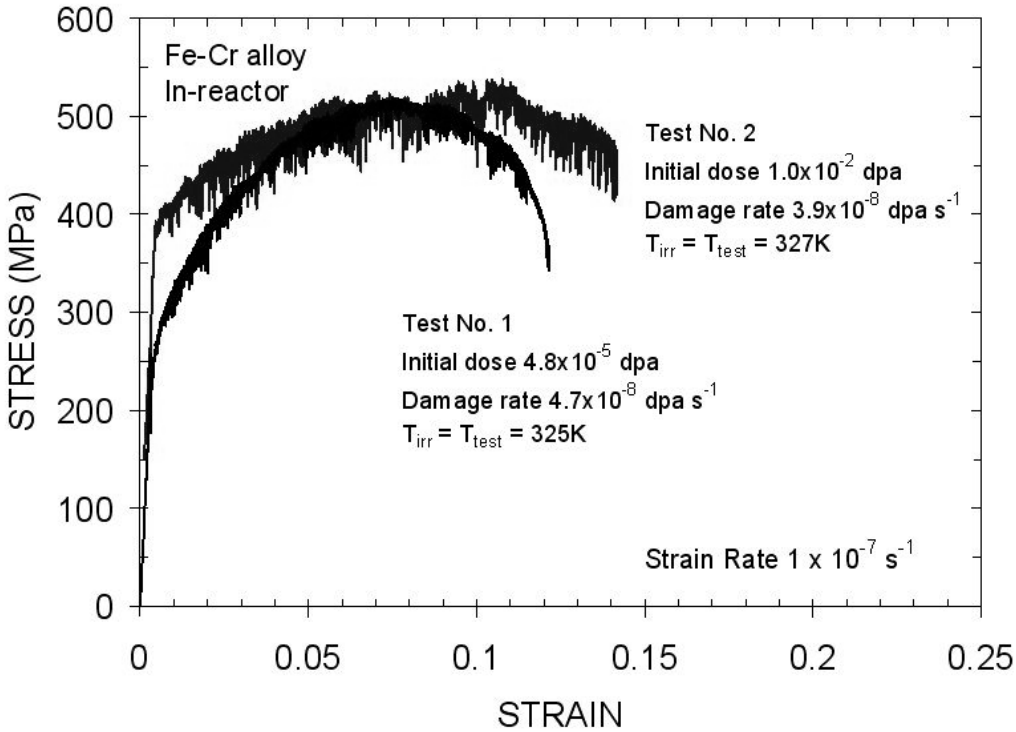


Figure 4.21: Stress-strain curves of Fe-Cr alloy tensile tested in in-reactor condition at 325 and 327 K.

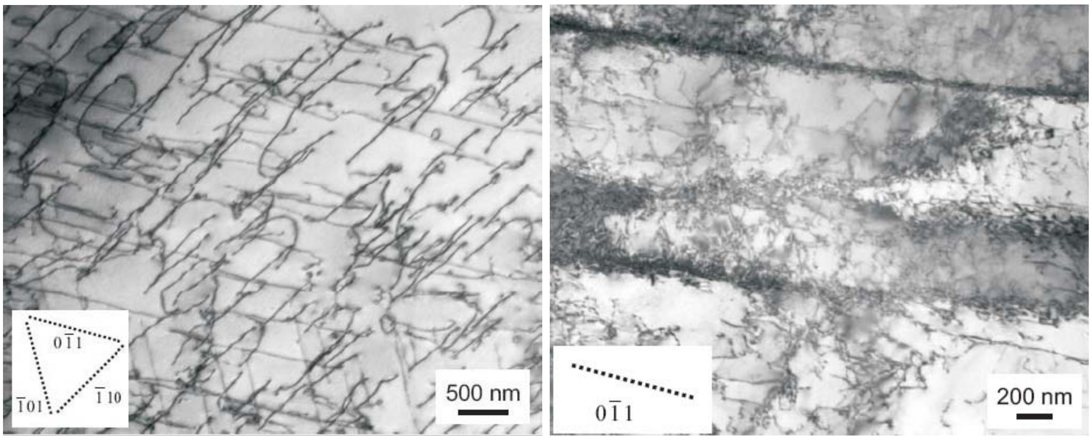


Figure 4.22: Dislocation microstructure in the FeCr alloy specimens used in the in-reactor tests (a) no. 1 tensile tested to a total strain level of 12.0% and to a dose level of 7.8 x 10-2 dpa and (b) no. 2 tensile tested to a total strain level of 14.3% and to a dose level of 6.5 x 10-2 dpa with a strain rate of 1.0 x 10-7 s-1.

4.3.2 Radiation damage in EUROFER: FeCrHe thermodynamics

EFDA Art. 5.1a Task: TW6-TTMS – 007/13a
Principal Investigator: Kai Nordlund, Tekes – UH

Fe-Cr alloys are the basic model materials for ferritic/martensitic (FM) steels that are candidate structural materials for advanced near-future fission and fusion reactors. High-Cr FM steels (both reduced activation and oxidedispersed strengthened) typically contain from 7 to 14 at.% Cr, while the content of the other alloying elements generally does not exceed 1–2%. The choice of these steels is governed by their superior resistance to neutron irradiation, in terms of low damage accumulation and swelling, compared to e.g. austenitic steels. Nonetheless, in future nuclear systems it is expected that core structural materials will be subject to severe irradiation and environmental conditions during their reactor life-time. A quantitative understanding of the mechanisms leading to the change of properties of these steels after long-term exposure to irradiation is therefore recognized to be of high importance for a safe design and operation of innovative nuclear systems. A great deal of understanding can be achieved by studying simpler model systems such as, in the case of high-Cr steels, Fe-Cr alloys.

The degradation of material properties under irradiation is a multi-scale phenomenon, meaning that different physical processes take place on different time and space levels. Nowadays, it is widely accepted that a multi-scale modelling approach provides a practical framework to tackle this problem. In this framework, Molecular Dynamics (MD) techniques are a unique tool to study the primary damage state due to displacement cascades induced by high energy particles (such as neutrons, ions, electrons, etc.). Over the last decade MD simulations have been widely used to assess the primary damage state in pure bcc Fe, some Fe-based systems, and also Fe-Cr alloys, mostly in Fe-10Cr alloys. Although different inter-atomic potentials have been used, the following two conclusions were drawn about the effect of Cr on the primary damage state in Fe-Cr alloys. Firstly, the presence of Cr hardly affects the number of formed Frenkel pairs and their distribution in clusters. Secondly, self interstitial atoms (SIAs) and their clusters were observed to be enriched by Cr atoms, due to the presence of sufficiently high binding energy between a Cr atom and a SIA (in both <110> and <111> configurations).

It should be mentioned, however, that most of the previously exploited potentials suffer from an incorrect description of the mixing enthalpy and SIA properties, concerning the available data obtained from first principle calculations. Thus, the application of the previously existing potentials to Fe-Cr alloys with other Cr concentration (C_{Cr}) than 10% would not be justified. The study of alloys with other C_{Cr} (both less and more than 10%) is, however, of practical interest, since there exists a change in the heat of mixing from negative to positive at about 10%. Consequently, if C_{Cr} exceeds 10% in binary Fe-Cr alloys (as well in FM steels), a separation of the alpha to alpha prime phase occurs, resulting in the formation of fine-dispersed nanometer size matrix-coherent Cr-rich precipitates. On the other hand, in alloys with $C_{Cr} < 10\%$ a tendency towards ordering of Cr atoms was experimentally detected. Note that both of these processes take place in the region of temperatures potentially important for technological applications (above 500K). Moreover, phase transformation can be accelerated due to self diffusion via radiation-induced defects and direct in-cascade atomic redistribution under irradiation.

We have studied the primary damage state in Fe-Cr binary alloys with different Cr content, addressing the following issues:

1. Is it still true, that the presence of Cr does not affect the number of formed Frenkel pairs and their clustering in Fe-5Cr and Fe-15Cr alloys?
2. Is the in-cascade ballistic mixing sufficient to induce, within the short imeframe of the cascade, Cr atom redistribution as dictated by the acting thermodynamic forces (i.e. the heat of mixing of the corresponding alloy)?

3. May cascades dissolve pre-existing Cr precipitates, contribute to their growth or in any way modify them? Do precipitates somehow affect the primary damage state due to the cascades initiated near them?

To address issues (i) and (ii), displacement cascades were simulated in Fe-5Cr and Fe-15Cr alloys, where Cr atoms were distributed randomly. The evolution of cascades in Fe-10Cr alloys containing Cr-rich precipitates was studied as well to address issue (iii). The simulations were carried out using two versions of the two-band potential, fitted to different sets of heat of mixing obtained from DFT. Thus, we also examined the effect of the mixing enthalpy, to which the potentials were fitted, on the primary damage state in Fe-5Cr and Fe-15Cr alloys.

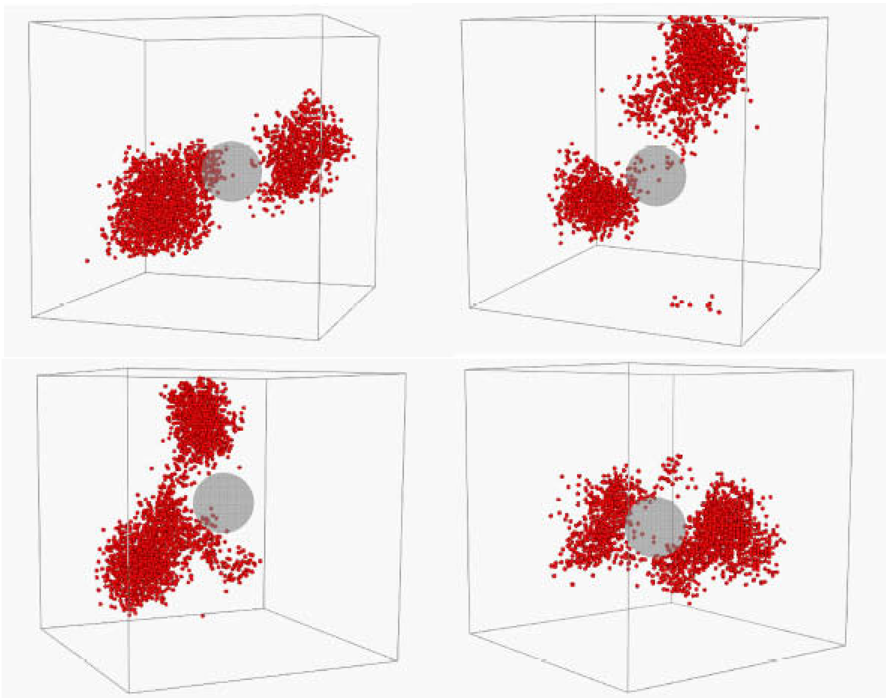


Figure 4.23: The appearance at peak time of four typical 20 keV cascades with a Cr precipitate present. Small red balls indicate positions of interstitials, while the gray sphere in the centre of the box shows the position (and size) of the precipitate.

The following conclusions can be drawn based on the results obtained:

i) The variation of the chromium concentration has no effect on the amount of survived Frenkel pairs nor on the distribution of defects in clusters as compared to results obtained in pure Fe. The only noticeable effect of the Cr content on the cascade-induced defects was seen in the enrichment of Cr in survived SIAs, depending on the PKA energy and the potential applied.

ii) The analysis of the SRO parameter in matrices subject to 5 keV cascades revealed ordering in Fe-5Cr (negative SRO) and segregation in Fe-15Cr (positive SRO) alloys.

iii) The comparative study of cascades in Fe-10Cr matrices with and without Cr-rich precipitates, shows that the number of survived defects does not change by the presence of the precipitates. The pre-existing 5 nm precipitates were not dissolved by 20 keV cascades. The estimated clustered fractions of SIAs and vacancies were found to be the same in matrices with and without the precipitates. Furthermore, SIAs and SIA clusters initially formed inside the precipitates were observed to migrate from the precipitates towards the precipitate-matrix interface. It can therefore be concluded that the main effect of the precipitate on the primary damage state limited in time (about few tens of ps) is expressed in the increase of interstitials defects attached to the precipitate-matrix interface.

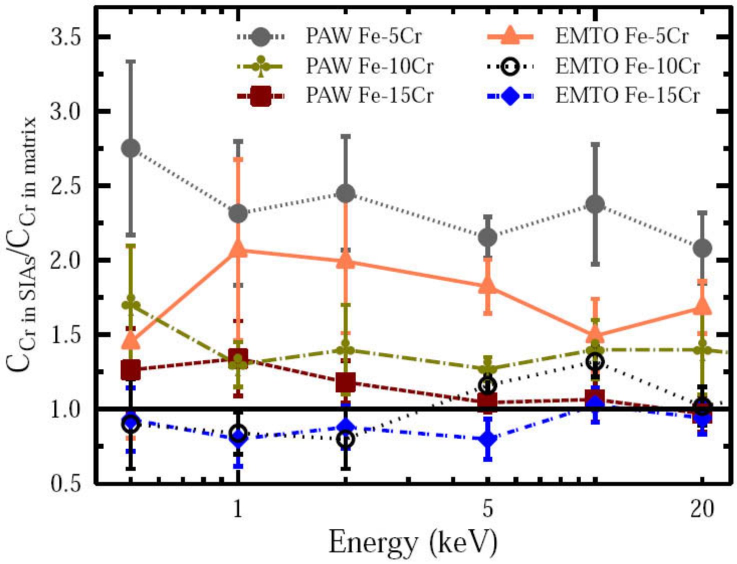


Figure 4.24: Ratio of the Cr content in SIAs over the Cr content in the Fe-Cr matrix obtained by cascade simulations. The error bars give the 1 standard error of the average.

4.4 EFDA Technology – System Studies

4.4.1 Global TIMES modelling – EFDA-TIMES industry update

EFDA Art. 5.1a Task: TW6-TRE-ETMIND
Principal Investigator: Antti Lehtilä, Tekes – VTT

The project has been carried out under the EFDA programme for Socio-economic Research on Fusion (SERF). Since end of 2004 the EFDA and the Associations have been developing a multi-region global long-term energy modelling framework called EFDA-TIMES-model, starting from an initial version developed by an external consortium via an Article 7 contract. The initial version showed many needs for revisions, updates and improvements, which have been ongoing by the Associations participating in the model development. The seven groups participating in the EFDA-TIMES work programme have been IPP (Garching), CIEMAT (Madrid), OEAW (Graz), UKAEA (Culham), ENEA (Rome), Risoe (Roskilde), and VTT (Espoo). The TIMES modelling tools have been developed under the IEA ETSAP Programme, with VTT actively contributing.

In 2006, the EFDA-TIMES Steering Group decided to initiate a set of separate tasks for the update an improvement of all main sectors in the model. One of the necessary tasks was to thoroughly review and improve the industry sector of the model, based on the results of previous investigations (e.g. Tekes – VTT task deliverable TW5-TRE-FESO/A). Accomplishing this challenging task was the goal of the VTT project.

The model updating tasks were to be carried out in line with the following guidelines:

- The quality assurance guidelines set up by the EFDA-TIMES Steering Group (e.g. regarding data sources and documentation) should be executed;
- The proper inclusion of the revised data into the master version of the EFDA-TIMES framework should be assured in co-operation with the team responsible for managing the master version;
- Regular communication should be had with the EFDA-TIMES Steering group and EFDA RO;
- Communication also with the groups responsible for updating the electricity sector and resource assumptions, to ensure proper handling of linkages.

Under this general framework, the review and update of the industrial sector subsystem covered the following important sub-tasks:

- The RES structure of the industrial sectors and the structure of the database templates were simplified where deemed appropriate;
- The Base Year calibration was revised on the basis of recent IEA statistics;
- The Base Year calibration was completely revised on the basis of adopting a hybrid approach, incorporating both fully-incorporated industrial process technologies and generic energy service technologies;
- The technology characterization of new technologies were almost completely revised, on the basis of the hybrid approach adopted, incorporating both process technologies and energy service technologies;
- The correct linkage between the upstream sector and the iron and steel industries was established;
- The original so-called dynamic emission factors were removed and replaced by more accurate static emission factors on the appropriate flows into the sectoral fuel technologies;
- All user constraints and market share constraints were reviewed and updated;
- The industrial load curve representation of the model was reviewed and updated;
- The demand driver sensitivities and efficiency projections were reviewed and updated.

The database updates have been thoroughly documented both in the final report and in the Excel database template files. The data have been collected almost exclusively form recognized public sources (scientific papers and reports), in accordance with the EFDA guidelines. As a result, the data sources are now much more transparent. In addition, efforts have been made to assemble the data estimates and projections in a harmonized and balanced way, in order to avoid biased model behavior.

In summary, the sub-model for the industrial sectors was very thoroughly updated during the project with respect to both the RES structure and the data for new technologies and demands. According to the test runs with the updated model, the hybrid approach adopted works well and produces considerably more credible results than the earlier versions of the model.

According to the publication policies adopted by the EFDA-TIMES Model Steering Group, publications by the individual research teams are not endorsed at this stage. However, joint conference papers have been submitted to the 2008 International Energy Workshop in Paris and to the SOFT conference in Rostock, September 2008.

5. UNDERLYING TECHNOLOGY

5.1 ITER relevant teleoperation development and experimentation with water hydraulic manipulator

5.1.1 Relevant teleoperation development and experimentation

Improved position control of WHMAN – main results in 2007: In 2006 a 3-DOF ZYZ wrist was manufactured and tested successfully to develop 5-DOF WHMAN (Water Hydraulic Manipulator). A photograph of 5-DOF WHMAN is shown in Figure 5.1. In 2007 the research was directed to evaluate and enhance the performance of this new developed WHMAN. A variation of position control strategies were tested with 5-DOF WHMAN. The aim of the research was to investigate the best possible solution for the position control of newly developed vane actuators along with the planar arm.

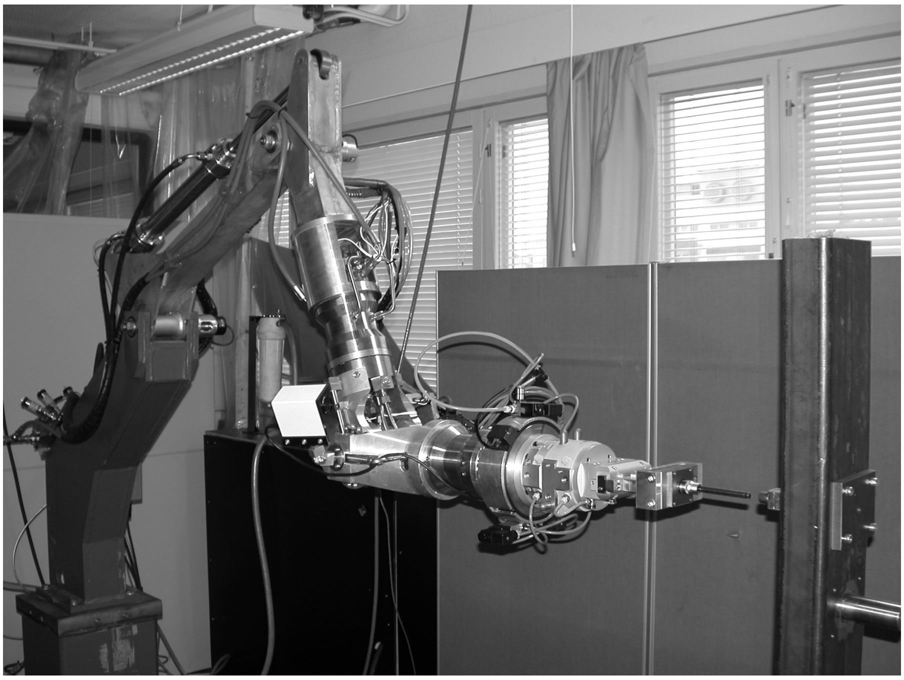


Figure 5.1: 5-DOF WHMAN with a wrench tool.

The best position tracking was obtained by using so called state feedback controllers based on the pole placement technique. The target was set to achieve the end point positioning accuracy of ±2 mm and $\pm 1^{o}$. In worst case scenario this end point position accuracy is guaranteed when the joints positioning accuracy is less than $\pm 0.054^{o}$. The controller was found stable and robust in whole motion range of WHMAN, which shows the possible application of state feedback controllers in multi-DOF hydraulic manipulators.

In Figure 5.2 the position tracking plots shows the position tracking performance of the manipulator in Cartesian space.

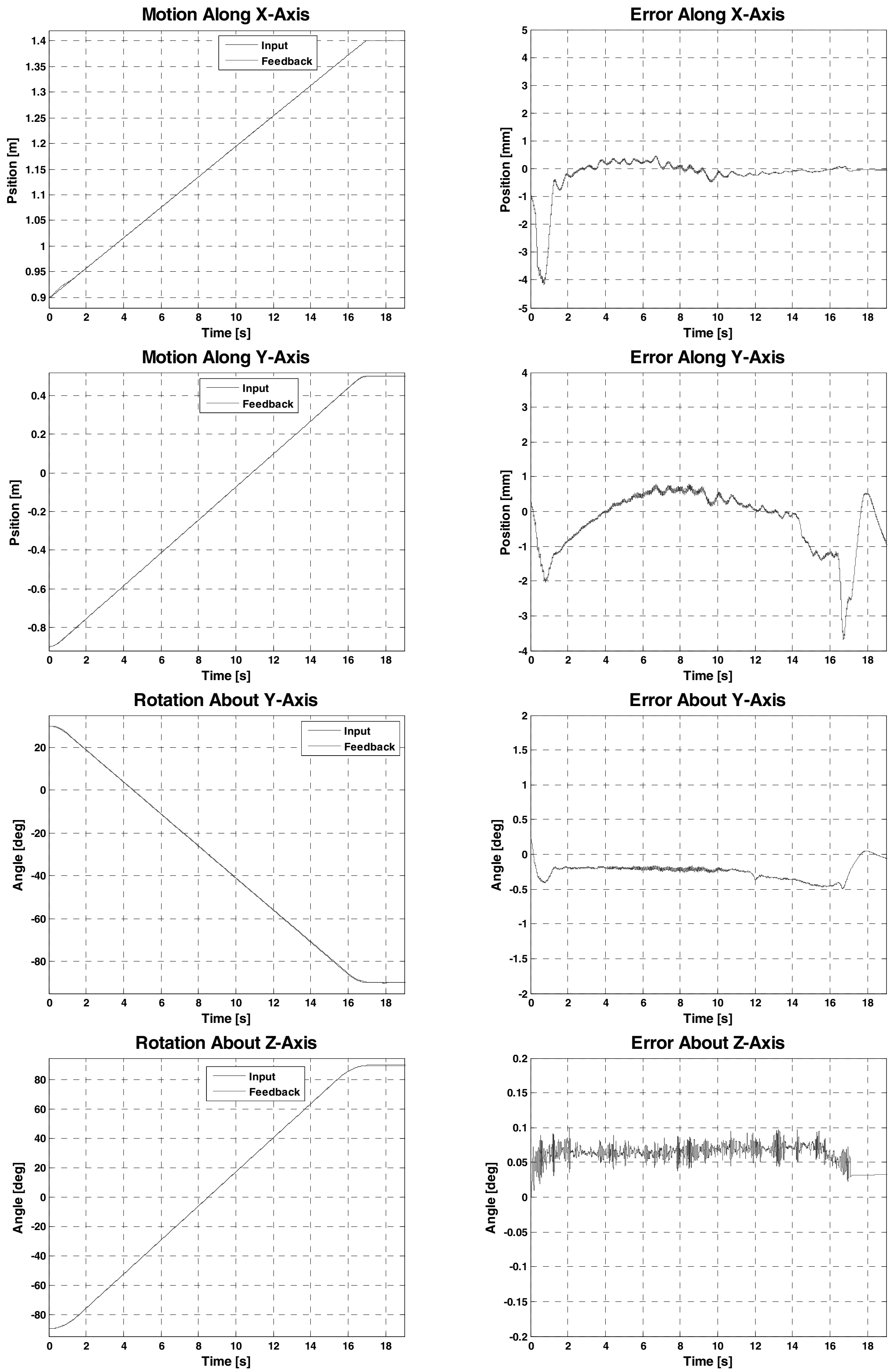


Figure 5.2: Tracking response when manipulator is moved along both vertical and horizontal axes.

Quantitative evaluation of WHMAN teleoperation system – main results in 2007: The main purpose of the WHMAN is to perform the remote handling tasks in the diverter region of ITER. Therefore the evaluation of teleoperation capabilities of WHMAN is crucial. The general architecture of the teleoperation system is shown in Figure 5.3.

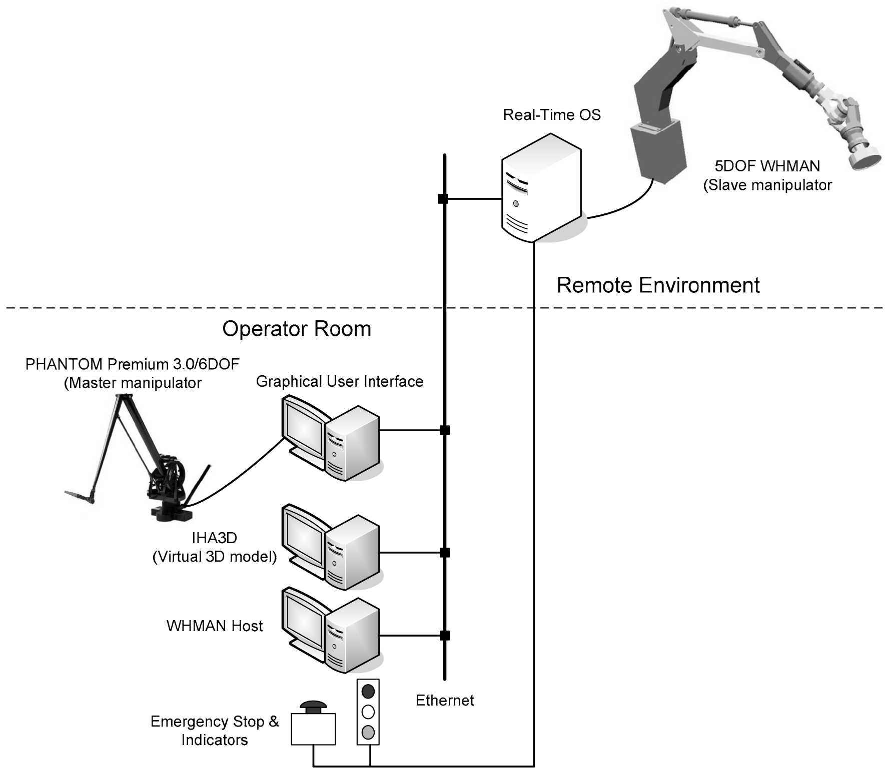


Figure 5.3: Teleoperation system architecture.

The WHMAN is employed as the slave manipulator to carry out the tasks in the remote environment. The PHANTOM Premium 3.0/6DOF which is a commercial haptic device is used as the master manipulator. The device provides force feedback in three translational degrees of freedom and torque feedback in three rotational degrees of freedom. The Ethernet was chosen as the communication medium because of its wide availability and long familiarity in the industrial world. The control signals are exchanged between the system components by using UDP (User Datagram Protocol).

A previously established criterion was chosen for the quantitative evaluation of teleoperation performance. According to this criterion the performance of a master-slave system can be experimentally evaluated by operating them under two basic conditions:

1. Unconstrained movement: Slave is moved freely in its environment. F_s being the forces acting on the slave manipulator, this condition can be established as:

   $F_s = 0.$

2. Hard Contact: Slave is made to contact and apply force against an infinitely hard surface. X_s being the displacement of slave manipulator, this condition can be established as:

   $\Delta X_s = 0.$

The above two tests results in four parameters which are obtained from the two port representation matrices of a teleoperation system. Evaluation parameters and there desired values are summarized in table below.

Table 5.1: Evaluation parameters.

Test Condition	Parameters		Desired Value
Unconstrained Movement	Free motion impedance	**(h_{11})**	$\rightarrow 0$
	Position tracking	**(h_{21})**	$\rightarrow 1$
Hard Contact	Force tracking	**(F_{12})**	$\rightarrow$ - 0.002
	Maximum transmittable impedance	**(Z_{11})**	$\rightarrow \infty$

During the experiment the master manipulator is operated by the operator randomly; first in free motion region of slave and then slave against the hard contact surface. The position and force data from master and slave is acquired for a time period of 60 seconds. Figure 5.4 and Figure *5.5* show the plots for these parameters for different axes of motion and rotation. All axes provide good conformance of position and force tracking.

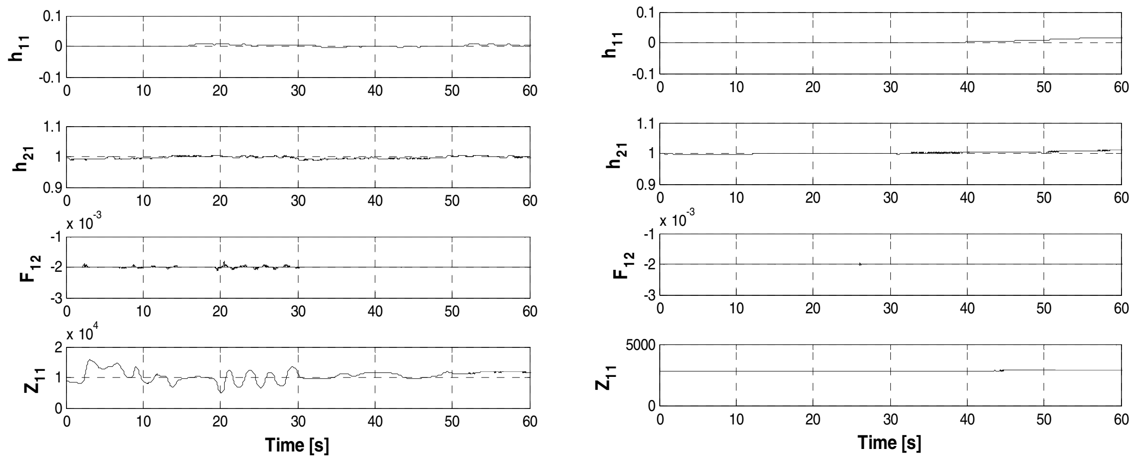


Figure 5.4: Evaluation parameters along planar axes.

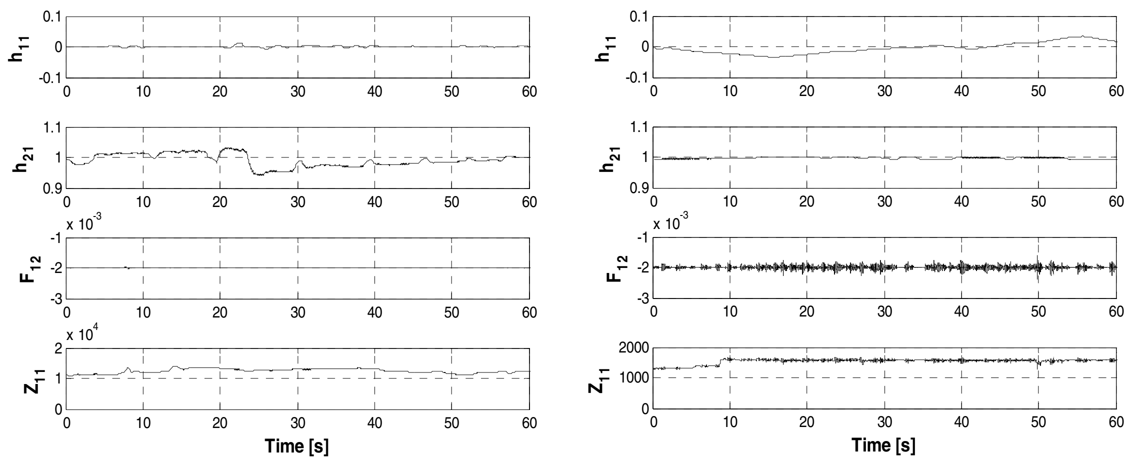


Figure 5.5: Evaluation parameters about rotation axes.

5.1.2 Improved manipulator task viewing, task visualization and GUI systems

Improved manipulator task visualization system – main results in 2007: IHA3D is a modeling software, developed at IHA/TUT, using MFC and OpenGL (Open Graphic Library) to run under the Windows® platform. Figure 5.6 demonstrates the implemented virtual model. The software communicates with the rest of the system over the Ethernet. The objects developed in the CAD software can be loaded by IHA3D to create the virtual environment. A frame is attached to each object to define its position and orientation in the environment with respect to one global frame.

Another purpose of IHA3D is to provide a simulated virtual environment. This feature is helpful for planning, practicing and simulating a task in the virtual environment before the operator performs the task in the actual environment. In this way a great number of errors and unpredictable situations can be avoided during the performance of the task. Trajectory points can be defined by the operator and can be tested beforehand. The operator can move and rotate his/her point of view to monitor the operation closely in a way providing access to innumerable cameras. These trajectory points can be stored in a file for later use with WHMAN during the task execution.

IHA3D provides information about the collisions of the object in the environment in the following ways:

- By changing the color of colliding objects on the screen.
- 0/1 digital online information over the Ethernet.
- IHA3D also provides the online location of the objects in the environment. Together with the collision information, this data can later be plotted to locate the exact collision points.
- By providing an online force vector depending on the depth of collisions which can be used to regenerate forces on Phantom during practicing a task.

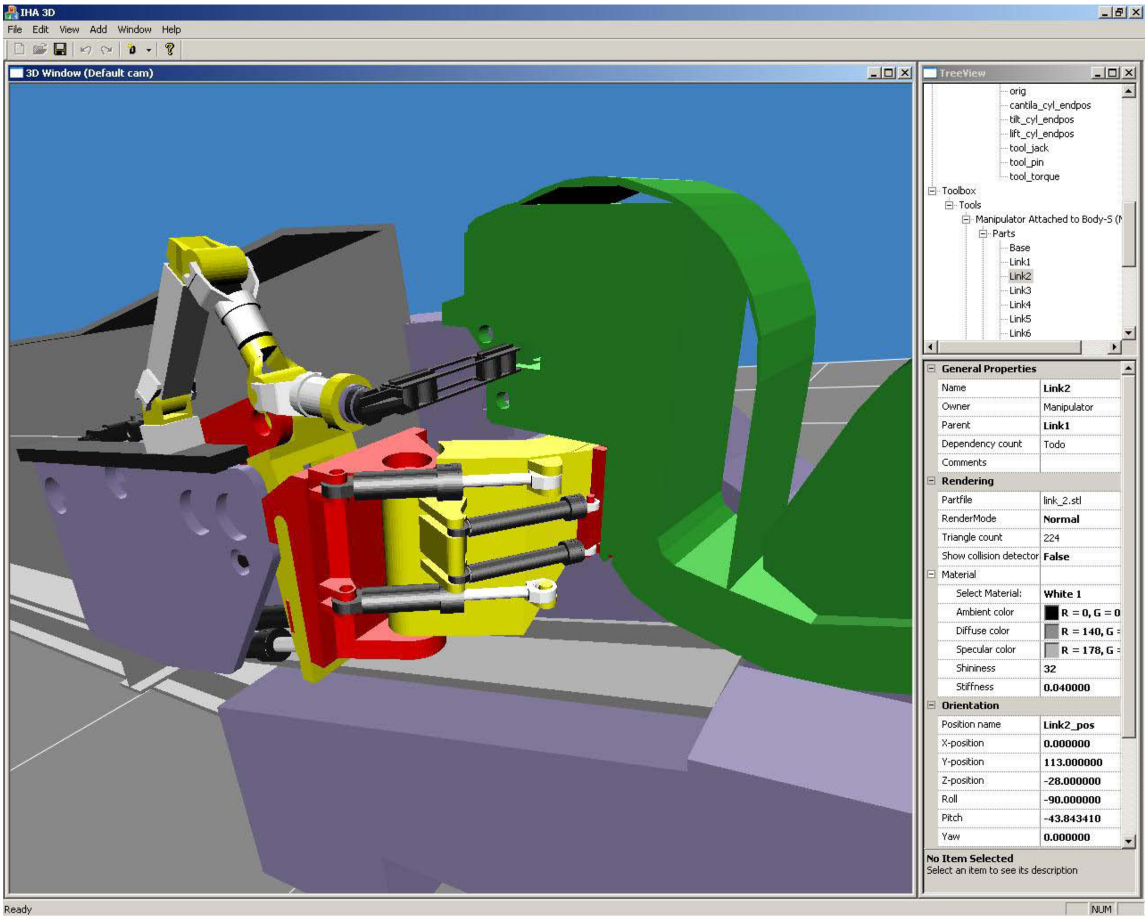


Figure 5.6: Virtual model of 5DOF WHMAN.

Improved manipulator task vision system – main results in 2007: Since the WHMAN is supposed to perform its tasks inside the divertor region, it is important to test the remote handling capabilities of WHMAN teleoperation system when the manipulator is not in the direct vision of the operator. To realize the scenario the cameras were placed around and on WHMAN and the videos were transmitted to a separate room so that the operator can only monitor the operation of WHMAN from the video feedback. In addition to live video feedback a virtual model of the manipulator and environment was available for operator's assistance. Picture in Figure 5.7 shows the live video feedback of manipulator operation and the virtual model replicating the operation.

Figure 5.7: Remote user interface for the WHMAN operator.

Improved GUI for task control and planning – main results in 2007: The removal and installation of divertor cassettes involve the operations from both CMM (Cassette Multifunctional Mover) and WHMAN inside the tunnel. The CMM-HLC (High Level Controller) has been developed using the graphical language of LabView™. Hence, a decision was taken to use the same development platform for the development of WHMAN-HLC. Similar software and hardware was setup and step by step transformation of all the operations and functions of WHMAN was done. The future benefits of these developments are:

- Less training time for the operators as both systems use the similar user interfaces.
- Faster development, since much functionality of CMM-HLC and WHMAN-HLC are common, such as joystick control or trajectory motion.
- Since both CMM and WHMAN have to function together, the interfacing of two controllers will be simplified.
- Reduced maintenance and inventory cost as many similar components are used in the hardware.

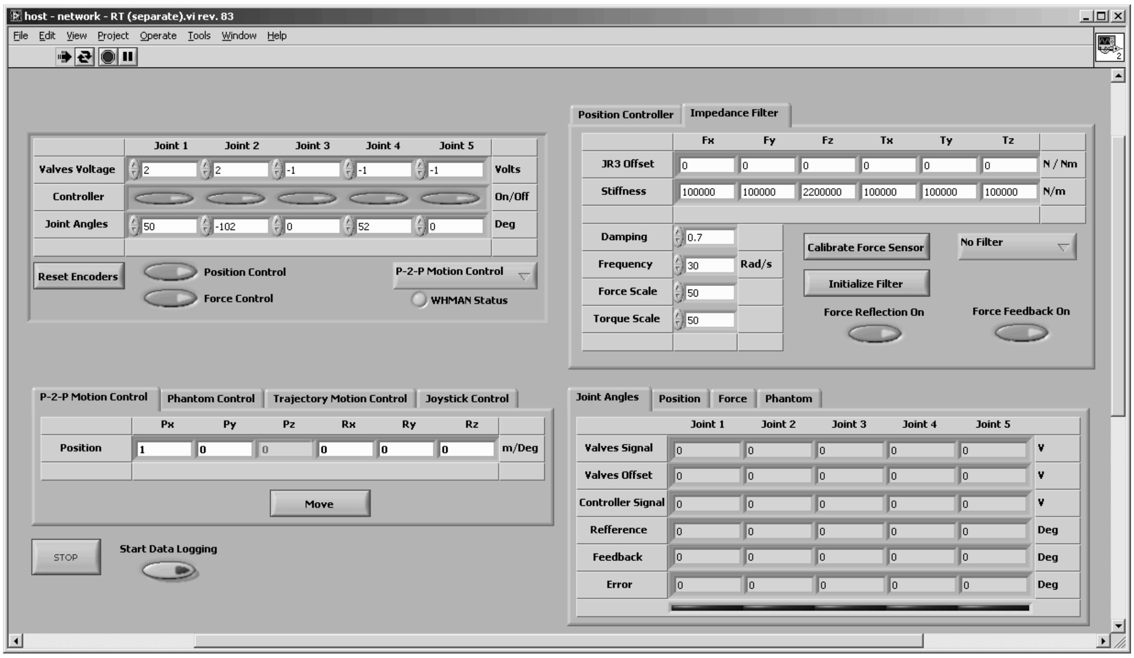


Figure 5.8: GUI of WHMAN-HLC.

Figure 5.8 shows the graphical user interface. Currently the next version of HLC is under development with goals of including advance functionalities for better remote handling task control and planning. Improved safety features and interlocks will also be included in the future versions of WHMAN-HLC.

5.1.3 Robustness and fail-safe considerations

Among the main principles for the good maintenance of a fusion reactor, safety-related principles are of extreme importance. These principles state that:

- The maintenance equipment must be retrievable
- The maintenance task must be accomplished safely and reliably.

The achievement of such principles relies strongly in the definition of safety requirements and FMEA (Failure mode and effect analysis) studies during the early phases of remote handling equipment design. With FMEA, critical failure modes are identified and the possibility to detect them is investigated. The cause and the severity of failure modes are analyzed and specific requirements for the components involved are assigned. The ultimate goal is to provide recommendations to mitigate failure modes and assign severities.

In the activity presented here, FMEA studies of the hydraulic manipulator have not been carried out yet, but they are planned to be conducted in the future. Instead, the most severe single-failure modes have been identified. In order to make our system fail-safe and fault-tolerant against these single-failures, the following provision, related to mechanical and hydraulic design of the manipulator, have been taken into account.

Fail-safe servo valve block

To achieve in a development of a fail-safe water hydraulic manipulator arm, a careful investigation of a redundant servo valve system was performed. At the first prototype phase each of the vane actuators are equipped with one servo valve and two pressure sensors. A servo valve failure can cause a lost of control and prevent or interrupt a remote handling operation. Because RH equipment will have to be fault-tolerant and fail-safe a further development of the manifold was needed. The current version of the manifold can be seen in Figure 5.9.

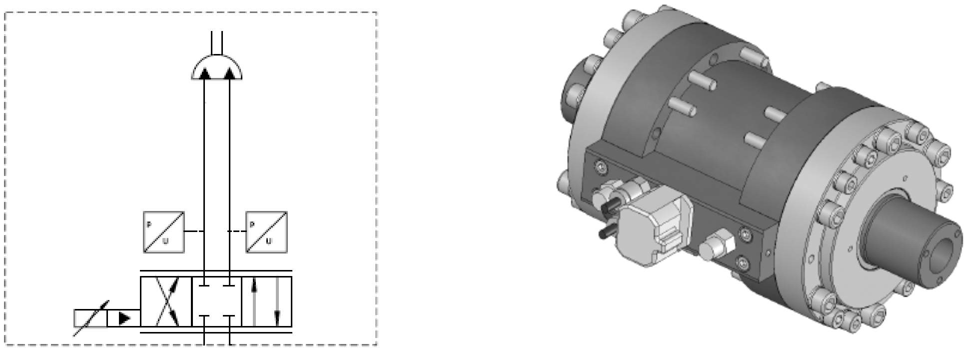


Figure 5.9: Current version of servo valve manifold.

A fail-safe manipulator should not cause any harm after a single point failure. To accomplish this goal the manifold was modified to accommodate two servo valves, two pressure sensors, two pilot on/off valves and four lock valves. Construction of the manifold can be seen from Figure 5.10. With this configuration, the servovalve block not only becomes fail-safe but also fault-tolerant.

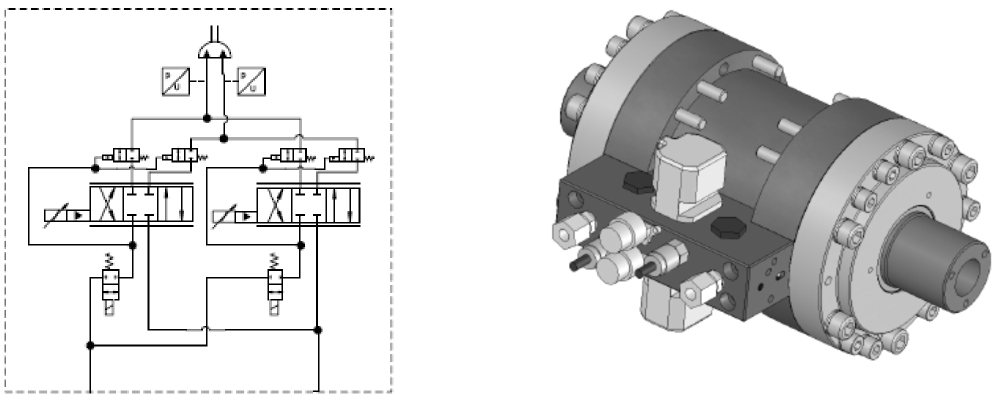


Figure 5.10: Proposed fail-safe servo valve manifold.

The used servo valve will be chosen with a solenoid on/off valve. The on/off valve simultaneously opens the lock valves of the currently used servo valve and allows the vane actuator to be operated. If a failure of the servo valve occurs, it can be isolated from the hydraulic circuit and the manipulator will be operated with a second valve. All of these functions can be implemented in the current version of the vane actuator by modifying the valve manifold. To achieve a compact manifold design, a preliminary design of the lock valve was done. The lock valve is a hydraulic pilot on/off valve, constructed from radiation tolerant materials. In Figure 5.11 is presented the cutaway view of the designed valve. Lock valve is operated by applying a pressure on the top of the diaphragm, resulting in a force that will open the orifice of the valve.

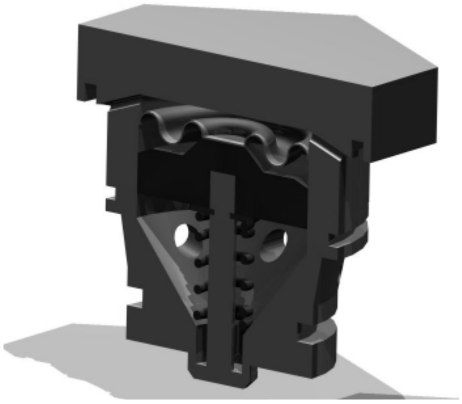


Figure 5.11: Cross section of the pilot lock valve.

Safety vane brakes

To prevent the damage that the manipulator arm can cause, to the environment or to itself, when pressure or electric power is lost, WHMAN will include a safety brakes. Brakes are located at the shoulder and at the elbow-joints. Brakes will lock when the pressure level of the system is too low, or when the brake control valve is turned off. The brake is designed to hold 80% of the vane actuator maximum torque, so the vane actuator can be driven against the brake in case of a brake failure. By doing do, a recovery of the manipulator is possible.

The designed prototype is a band-type brake. The construction of the brake is simple and the overall dimensions and the weight are small compared to other types of brake constructions. The construction also utilizes the dimension of the vane actuator in the best possible way; the braking action is performed in the most outer diameter of the actuator, resulting in a good torque to size relationship. Belt type brake needs small actuation force because the movement of the friction drum is amplifying the braking action.

Brake is constructed from three major parts; the friction drum, the belt and the cylinder block, as shown in Figure 5.12 (left).

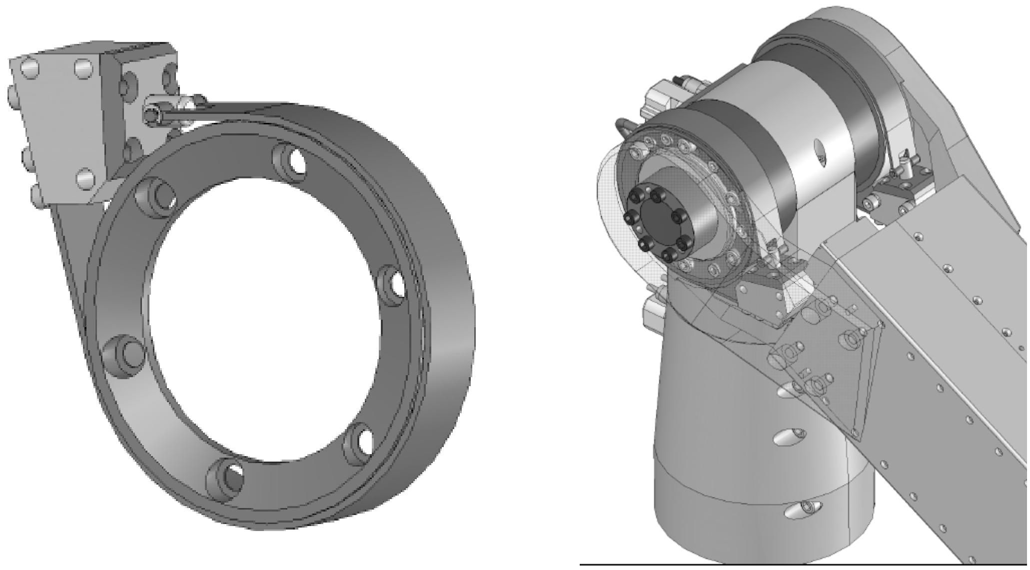


Figure 5.12: Vane brake pars (right). Vane brake assembled into the shoulder joint of the manipulator (left).

The friction lining will be attached to the aluminum drum by adhesive or by surface coating. The drum is made from aluminum alloy to ensure the lightweight construction and a good heat conducting capability. The belt and the cylinder block will be constructed of acid proof stainless steel. The shoulder will be equipped with two identical brakes; the assembly is shown in Figure 5.12 (right). Each capable of producing 1600 Nm braking torque.

Limit switches

When the manipulator is used in RH, there is no direct visual feedback of its movements. The position of each joint has to be known very accurately and the joint position should not be lost in a power failure. Each rotational joint of the manipulator is equipped with an absolute resolver and the prismatic joint is equipped with an LVDT-type sensor. Although chosen sensors are robust and absolute, we have to consider the possibility of a sensor failure. The failure of a joint sensor could lead to a degraded operation of the manipulator, since information on the absolute position of the joint would be lost. Adding a redundant resolver to each axis is not feasible due to the additional wiring involved and the limited size of the manipulator umbilical.

In order to make the system fault-tolerant against this failure, the introduction of electrical limit switches have been considered.

Limit switches will be placed at the both ends of the movement range in each joint. If a resolver or a LVDT-sensor fails, a limit switch would provide two known positions for the joint. With this information a recovery of the equipment could be feasible.

6. STAFF MOBILITY ACTIONS, JOC SECONDMENTS AND EFDA CSU

Several staff mobility visits of total 801 days took place in 2007. The visits were hosted by the Associations IPP Garching (541 days), UKAEA Culham (51 days), FZK Karlsruhe (30 days), FZJ Jülich (58 days) and task force (PWI, ITM, E, H, FT) meetings (44 days). Tekes (University of Helsinki) hosted two staff mobility visits by Andi Hektor (77 days), from NICPB, Tallinn, Estonia.

Regarding the EFDA JET activities Association Euratom-Tekes is participating in the Task Forces activities S1/S2, H, E, T, D and FT. S/T Order/Notifications work will continue in the JET Workprogramme 2007 including secondments and scientific coordination for the JET experimental campaigns C17–C19 in 2007. Tuomas Tala is a Task Force Leader for Task Force T (transport).

One physicist was seconded to the UKAEA JET Operating Team, Antti Salmi (code development and modelling). Four engineers were seconded to the EFDA CSU Garching in 2007, Tommi Jokinen (Assembly), Pertti Pale (Project Control), Hannu Rajainmäki (Magnets) and Mikko Siuko (Remote Handling).

6.1 Staff Mobility Visits in 2007

6.1.1 ASCOT analysis of fusion tritium distribution on plasma-facing surfaces in ASDEX Upgrade

Name of seconded person:	Ville Hynönen
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP-Garching
Dates of secondment / Mission:	6 May – 2 June 2007

Work Plan / milestones: The Monte Carlo -based orbit following code ASCOT has been used to evaluate the surface distribution of tritons born from beam-plasma and thermal plasma DD-reactions. The simulation results were compared to experimental Photo-Stimulated Luminescence measurements. However, only one improved H-mode discharge was simulated and it is unlikely to represent the whole experimental campaign accurately. To obtain better match between the simulations and the experiment, a more detailed study comprised of a number of different discharges is necessary.

1) In collaboration with Sugiyama and Dux decide a suitable set of discharges representative of one experimental campaign.
2) Perform ASCOT simulations for the set of discharges. The relative weights of the discharges based on their frequency during one campaign will then be used to compose an overall surface distribution from the simulation result of individual discharges.
3) Together with Sugiyama, compare the composite simulation results to the experimental measurements.
4) If there is enough time, continue the investigation of DIOL radial currents and the corresponding poloidal torque started on my previous mobility visit to IPP.

This includes evaluating how big of a contribution such torque could make on the radial electric field and comparing H-mode and QHM conditions both with and without magnetic ripple.

Report:

1) The shots from experimental campaign 2002/2003 were scanned through together with Dux, T. Kurki-Suonio, Sips and Sugiyama. Sips provided a set of 9 candidate discharges representing the most frequent discharge types during the campaign. This set was further reduced by eliminating

   - Improved H-mode discharges (simulated earlier)
   - One discharge with only RF heating (FAFNER code can't produce triton source rate profiles for RF-heated discharges)
   - Discharges not likely to produce a lot of tritons during the campaign (too infrequently occurring or low temperature/density).

   In the end we were left with several different Standard H-mode discharges (different beams, plasma current…).

2) Two Standard H-mode cases were selected for the simulations, but one of them had to be dropped because there were not enough measurements to get good plasma profiles. Triton source rate input for ASCOT was obtained from FAFNER simulations and ASCOT simulation was completed successfully. However, the results turned out to be very similar to results obtained earlier for the Improved H-mode case. Therefore adding the two results would not have provided any new information.

3) Both the old and new simulation results are qualitatively in good agreement with measurement results.

4) An attempt was made to continue the investigation DIOL currents, but two problems surfaced: the definition for orbit-loss current used in the ASCOT code does not match the definition used in Shaing & Crume theory [1]. Therefore changes in the code are required before the poloidal torque and the resulting poloidal rotation can be solved using the theory. Also the edge collisionality in the QH-mode discharge under consideration seemed to be too low (<1) in order to apply the theory. Discussing the problem with Wolfrum we learned that generally the collisionality exceeds unity in ASDEX Upgrade discharges, but in QH-mode discharges collisionality can indeed be very low. Partial reason for the seemingly too low collisionality might be that the impurities had not been taken into account. This has not yet been verified, but it is possible that the Shaing & Crume theory can't be applied for this problem.

Additional tasks: The numerical energy drifts and the related problem of 3D magnetic field (i.e., with toroidal ripple) interpolation were discussed with D. Coster and Strumberger. There are no easy solutions: the interpolated magnetic field can be made smoother by using more enhanced methods, but this would slow down the simulation. Or the orbit integration can be changed so that energy is forced to stay constant in the absence of collisions, but then the numerical drift is probably transferred to the orbit of the particle. The problem becomes worse when simulating very high energy particles, such as fusion alphas (3.5 MeV), because the orbits remain unchanged for long time. This allows any numerical inaccuracies caused by irregularities in the magnetic background to accumulate much more than for lower-energy particles. In axisymmetric simulations this can be overcome by accelerating the collisional time scales, but this is not possible in the presence of toroidal ripple, because the orbits no longer close in poloidal cross section.

W. Suttrop kindly instructed how PED shotfiles are created from experimental data. The AUGPED program written by Dr. Horton is used for this purpose. Furthermore, the PED shotfiles can be converted to MDSplus trees, which can then be used to create ASCOT plasma and magnetic background input files. Earlier it was always necessary to ask someone from IPP to do the preliminary steps up to the MDSplus tree for us, but now we can do it ourselves.

[1] K.C. Shaing and E.C. Crume, Jr., Phys. Rev. Lett. **63** (1989) 2369–2372.

6.1.2 Benchmarking ASCOT against NPA measurements

Name of seconded person:	Taina Kurki-Suonio
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP-Garching
Dates of secondment / Mission:	13–26 May 2007

Work Plan / milestones:

1) NPA measurements: together with Fahrbach and W. Suttrop, compare the simulated fluxes obtained with the improved NPA model against the experimental ones to uncover the origin of discrepancies. The order of magnitude now is in reasonable agreement with experiments, but there are curious differences in shape that need to be understood – both in experimental and simulated spectra. Participate in the planning of the ELM-resolved NPA measurements, if timely.
2) In collaboration with V. Hynönen and W. Suttrop, investigate the DIOL radial currents and the corresponding poloidal torque due to NBI, and evaluate how big of a poloidal rotation it could drive. Compare H-mode and QHM conditions.
3) Assist Wolfrum in investigating the L-H transition conditions in the B_T ramp-down experiments.
4) Discuss the new ASCOT-calculated divertor load results with Kallenbach to assess their relevance to the edge plasma operation.

Report: 1st task: The agreement between the neutral spectra measured in dedicated discharges in 2005 and those simulated by ASCOT's new NPA model were found to be astonishingly good considering the simplifications of the model (e.g., 1-D neutral profile). However, for the CD beams the simulated results still deviate from the measured spectra. This will be further investigated.

2nd task: The simulation of the poloidal rotation driven by neutral beam ions was found to be hampered by too low an edge collisionality, which was calculated to be well below unity for all cases under inspection. However, according to AUG databases the collisionality generally exceeds unity. This discrepancy was resolved in discussions with Dr. Wolfrum: we need to include the effect of impurities. Unfortunately, for the most interesting QHM case the collisionality is indeed less than one due to the low density. Therefore it is not clear if our present method for evaluating the poloidal rotation is applicable.

3rd task: With Wolfrum and Reich we studied the characteristics of the L-H transition in the B_T ramp-down experiments. To me the rapidity of the changes seemed to imply that the fresh NB-injected ions play a role. It was decided that the B_T ramp-down experiments should be repeated with pure ECRH to verify/disprove this hypothesis.

4th task: This task was postponed to my second visit later this summer.

Significant part of my visit was spent on discussing the results of ASCOT simulations carried out for kinetic electrons in the AUG SOL. D. Coster and Chankin participated in this effort. The results had indicated that electrons from the outer midplane could explain the discrepancies observed between Langmuir probe and IR measurements at the outer divertor. However, I had growing suspicions that the guiding-center MC simulations might not the ideal tool for this. Our discussions led to further studies that have now shown that the fast electrons arriving at the plate in the simulations arise from the SOL bulk.

Also the problems arising when simulating non-axisymmetric tokamak plasmas with ASCOT were extensively discussed with D. Coster and Strumberger: we had observed violation of energy conservation for the fast NBI-ions in ASCOT simulations of AUG plasmas when the effect of ripple was included. It was found that this is a fundamental problem related to fast particles: due to their low collisionality their orbits remain unchanged for long times and, thus, any irregularities in the magnetic background accumulate and can cause numerical changes in the particle quantities that exceed the random changes due to collisions. This sets unprecedented requirements for the smoothness of the magnetic background.

Together with V. Hynönen and Sips and Sugiyama we scanned through the shots from the experimental campaign 2002/03 to find representative shots for the tritium simulations. An improved H-mode has already been simulated, and the results correspond well to the measured tritium surface distributions. However, in order to try to reproduce even the finer details of the distributions, different configurations from the campaign have to be simulated.

6.1.3 Manufacturing and installation of highly time-resolved data acquisition system for neutral particle analysis at ASDEX Upgrade

Name of seconded person:	Simppa Jämsä
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP-Garching
Dates of secondment / Mission:	28 May 2007 – 7 June 2007

Work Plan / milestones: Neutral particle analyser (NPA) measures the flux of neutral particles emitted from the plasma. The measurement is mass and energy resolved.

The time resolution is currently poor since, before the experiment, a number of time intervals, bins, needs to be set. This results in only a few data samples with relatively long averaging times, which makes the analysis of short events, such as ELMs, difficult. The plan is to replace the current data acquisition (DAQ) hardware by a fully time resolved model, where each detected particle is recorded. The first physics study is proposed to be the comparison of fast particle losses during and in between ELMs, which is believed to play a role in tungsten sputtering.

During my mobility visit I wish to accomplish the following tasks:

(a) Manufacture and install the new DAQ hardware for the NPA of AUG.
(b) Adapt the DAQ-software for the new hardware.
(c) Familiarise myself with the operation of the experiment during operational days.

Report: Generally: the tight time schedule of the visit induced intensive working schedule. With the extremely competent people at AUG most of the tasks were completed to a satisfactory level. The rest of the work can be done remotely or easily by the staff at AUG. The most important people I worked with at AUG were W. Suttrop, Fahrbach and Banhierl.

I wish to report the following of the respective objectives:

(a) Manufacture and install the new DAQ hardware for the NPA of AUG.

The design of the hardware was finalised. One of the two required copies of the hardware was manufactured and tested. It was installed and test acquisitions were recorded. The manufacturing and installation of the second copy should be straight forward and will shortly be done by the staff at AUG.

(b) Adapt the DAQ-software for the new hardware.

A first version of the software was written and tested. A final version will be written and installed remotely.

(c) Familiarise myself with the operation of the experiment during operational days.

I spent more than one and a half days of my visit working in the control room of AUG experimental operation and my understanding of the operations increased significantly.

6.1.4 ^{13}C puffing experiment and analysis of JET tiles

Name of seconded person:	Jari Likonen
Sending Institution:	VTT Technical Research Centre of Finland
Host Institution:	EFDA JET / UKAEA
Dates of secondment / Mission:	2–4 April 2007 and 2–20 July 2007

Work Plan / milestones (April visit):

- participation in the ^{13}C puffing experiment.

Work Plan / milestones (July visit):

- mechanical measurements of selected wall tiles prior to the installation during 2007 shutdown
- evaluation and comparison of SIMS, TOF-ERDA and RBS results
- determination of erosion/deposition pattern at divertor tiles exposed in 2004–2007
- study ^{13}C migration in SOL.

Report (April): Main aim of the visit was to participate in the ^{13}C puffing experiment. An impurity injection experiment was performed on the last day of the C18 programme, when ^{13}C was injected from the outer mid-plane during H-mode discharges. Aim is to study the effect of ELMs on ^{13}C transport. The divertor tiles and other wall tiles will be examined for traces of ^{13}C under TF-FT task in 2008, as data for further modelling studies aiming to establish a picture of transport around the torus and during ELMs.

Report (July): Main aim of the visit was to measure a set of divertor and limiter tiles using a surface profiler developed at JET (milestone 1). The purpose of the measurements is to measure the surface profile of the tile before installation at JET. The tiles will be exposed at JET typically for few years and after this the tiles will be removed and the tile measurements will be repeated. By comparing the results before and after plasma exposure, erosion/deposition pattern can be determined. New software for the tile profiler system has been developed and tested in 2006–2007 at JET. The software works now and the system meets mechanical specifications. Major source of error is the tile mounting. A measurement routine has been set up. In total 10 unexposed divertor tiles and 4 outer poloidal limiter tiles were measured during the staff mobility visit.

Divertor tiles exposed in 2004–2007 (Milestone 3) were not yet available during the staff mobility visit and thus no analyses of these tiles were made.

Tungsten coated marker tiles made at Tekes in 2001 were removed in 2004 shutdown. During the staff mobility visit outer divertor tile 7 was analysed with ion beam techniques at the Univ. of Brighton. RBS spectra will be simulated using SIMNRA program later and the coating thicknesses and compositions will be calculated (Milestones 2, 4). Tile 7 is very interesting because of the ^{13}C migration studies. ^{13}C was puffed in 2004 from the outer divertor between tiles 7 and 8. Tile 7 has been analysed earlier both with RBS and SIMS and previous analyses show that there is high amount of ^{13}C near the top of the tile. Analyses were now extended and RBS/NRA measurements were made on a larger scale in order to map ^{13}C distribution on tile 7. Further samples from tile 8 will be analysed in order to study toroidal symmetry of the ^{13}C distribution.

6.1.5 Simulation of mode competition in the ITER coaxial gyrotron cavity

Name of seconded person:	Olgierd Dumbrajs,
Sending Institution:	Helsinki University of Technology
Host Institution:	FZK-Karlsruhe
Dates of secondment / Mission:	1–30 June 2007

Work Plan / milestones:

i) mode competition studies in the FZK coaxial cavity gyrotron
ii) comparison of codes developed at FZK and Helsinki University of Technology
iii) investigation of possibilities to tune mechanically a coaxial cavity gyrotron.

Report: I was able to comply with the milestones.

Three reports for the Joint 32nd International Conference on Infrared and Millimeter Waves, and 15th International Conference on Terahertz Electronics, 3rd – 7th September, 2007, Cardiff, UK, were prepared:

1. Mode Competition in the 170 GHz Coaxial Gyrotron Cavity for ITER
2. Investigations on an Experimental 170 GHz Coaxial Cavity Gyrotron
3. Wideband Continuous Frequency Tunable Coaxial Gyrotron Oscillators.

Computer codes developed at the Helsinki University of Technology have been installed on the computers of the Forschungszentrum Karlsruhe. The corresponding talks were given at the conference and the papers have been submitted to scientific journals.

6.1.6 Hysteresis in enhanced transport (crash) with respect to sawtooth amplitude

Name of seconded person:	Olgierd Dumbrajs, Tekes – TKK
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP-Garching
Dates of secondment / Mission:	1 July – 31 August 2007

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: The topic of research "Hysteresis in enhanced transport (crash) with respect to sawtooth amplitude" was initiated. In particular a hidden variable (temperature gradient) has been found and equations leading to hysteresis have been derived. In addition three articles have been prepared for publication:

1. O. Dumbrajs, V. Igochine, H. Zohm and ASDEX Upgrade Team, *Diffusion in a stochastic magnetic field in ASDEX Upgrade*, Nuclear Fusion **48** (2008) 024011, 7 p.
2. 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, 9 p.
3. V. Igochine, O. Dumbrajs, H. Zohm and ASDEX Upgrade Team, *Transition from quasiperiodicity to chaos during sawtooth crash*, Nuclear Fusion (in print).

During the next secondment to IPP Garching in spring 2008 detailed studies of hysteresis are planned with particular emphasis on finding a correct source term.

Research activities: All the milestones (except milestone 3) for this visit were achieved.

6.1.7 Analysis of the JET divertor tiles

Name of seconded person:	Antti Hakola
Sending Institution:	Helsinki University of Technology
Host Institution:	EFDA JET / UKAEA
Dates of secondment / Mission:	2–27 July 2007

Work Plan / milestones:

- mechanical measurements of selected wall tiles prior to the installation during 2007 shutdown
- evaluation and analysis of RBS results of removed tiles
- linking my experience with lasers into cleaning and analysis of various surfaces.

Report: The main aim of the visit was to characterise a set of divertor and limiter tiles using a surface profilometer developed at JET (Milestone 1). 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 according to the guidelines reported during the present visit. By comparing the results before and after plasma exposure, erosion/deposition pattern can be determined. New software for the tile-profiler system was developed and tested in 2006–2007 at JET. The software has provided the possibility to perform both dynamic and static repeatability studies; here dynamic stands for different operators mounting the tile in the measurement device whereas static means that the same measurement is performed several times in a row without remounting the tile. A proper measurement routine has been set up which has almost completely eliminated one of the main sources of error. In total, 10 unexposed divertor and 4 outer poloidal limiter tiles were measured during the staff mobility visit.

Tungsten coated marker tiles made at Tekes in 2001 were removed in 2004 shutdown. During the staff mobility visit, RBS spectra measured earlier from some of these tiles were analyzed using SIMNRA program, and the coating thicknesses and compositions were calculated (Milestone 2). Particularly, the amount of ^{13}C was determined to provide information for migration studies. J. Likonen made extended RBS/NRA measurements of tiles 7 and 8 during his staff mobility visit, and the results of these measurements will be analysed during the coming months.

Due to the hectic measurement period, holiday season, and extreme weather conditions in the UK in July, Milestone 3 could only be partially achieved. However, preliminary discussions with people responsible for laser cleaning were made in the beginning of the staff mobility visit.

6.1.8 Benchmarking ASCOT against NPA measurements

Name of seconded person:	Taina Kurki-Suonio
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP-Garching
Dates of secondment / Mission:	8–28 July 2007

Work Plan / milestones:

1) NPA measurements: together with S. Jämsä and Fahrbach and W. Suttrop participate in the processing of the ELM-resolved NPA measurements. These measurements are carried out with the new NPA data acquisition system installed by Jämsä in June 2007.
2) Bring into conclusion the study on the importance of kinetic electrons on the local conditions near the outer divertor target. This work will be carried out in collaboration with D. Coster and Chankin.
3) Discuss the new ASCOT-calculated divertor load results with Kallenbach to assess their relevance to the edge plasma operation.
4) Go through the database of the 2002/03 campaign to find the most prominent magnetic configurations with different locations for the X- and strike points. Choose the most relevant configurations to be used in ASCOT simulations of the tritium wall distribution.

Report: 1st task: the new data acquisition system of AUG's NPA was operating well, and together with S. Jämsä, who is in charge of collecting the data now, we compared the measured fluxes across ELMs to various other diagnostics. In particular, we wanted to find a signal that could be used as the trigger for the ELM start time. As a result, work was started with Dr. Marachek on constructing an 'ELM hunter' which, by combining the information from various diagnostics, would serve as a trigger for an imminent ELM.

2nd task: Together with D. Coster and Chankin, the latest results from the kinetic electron simulations were reviewed, and it was concluded that they provide overwhelming evidence for the fact that no significant contribution on the divertor loads can be attributed to energetic electrons emerging from the core plasma. The outline for a paper reporting these findings was made, and the paper will be written by the end of September.

3rd task: With Kallenbach and Eich we reviewed a fairly recent paper by Hahn et al. (PoP 12 (2005) 102501) where simulations of bulk ions under the combined effect of increased ELM-time diffusion and radial electric field were able to well reproduce the measured divertor load characteristics on AUG. Plans were made on repeating these simulations using the ASCOT code and scrutinizing the assumptions made in the published work.

4th task: Together with Sugiyama we analyzed the two already simulated pulses to find a reason why they produced so similar tritium loads on the walls. We realized that we had too much focused on the plasma performance and too little on the geometry. Both of the simulated pulses had R_{aus} that was quite small compared to the majority of the pulses during the 2002/03 campaign. With the help of Sips we were able to identify a third pulse, with R_{aus}-value more characteristic of the campaign and with good performance. It is to be expected that ASCOT simulations of this pulse will produce different wall load profiles, hopefully further improving the agreement between measurements and modelling.

6.1.9 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-Garching
Dates of secondment / Mission:	11 August – 8 September 2007

Work Plan / milestones: The topic of the visit is two-fold: (A) to bring to conclusion the work done in modelling scrape-off layer electrons with the ASCOT code and (B) to initialize the graduate studies that concentrate on modelling of plasma-surface interaction and impurity migration with the ERO code. Both tasks involve simulations with ASDEX Upgrade plasma background.

(A) Suprathermal electrons arriving from the plasma core to the divertor plates affect the divertor plasma properties. Non-Maxwellian electron energy distribution may have a significant effect on the plasma sheath and divertor power loads, particularly in the H-mode scenario with low collisionality in the scrape-off layer. A measure of the thermalisation of electrons in a realistic plasma background can be given via numerical simulations with the orbit-following Monte Carlo code ASCOT. Electron simulations on open field lines are cpu-intensive and demand new features from the ASCOT code, the main adaptation of which has been in core ion simulations.

(B) Carbon layers built-up by eroded and re-deposited carbon are found to enhance tritium retention in tokamak chamber wall. In ASDEX Upgrade, ^{13}C methane puffing experiments have been conducted in which the deposition of carbon on the chamber wall has been investigated by ion beam analysis at IPP and by modelling with the ERO code at Helsinki University of Technology. The post-mortem analyses of the wall tiles show that the main deposition of carbon occurs in a direction that deviates from that of the local magnetic field. In the ongoing modelling this deviation – possibly caused by electric fields – is presently not reproduced. Thus ERO should be supplemented with a suitable model for the electric field caused by the gas puffing.

Goals:

1. ASCOT simulations shall be fine-tuned to give realistic, quantitative results. A paper is written in collaboration with D. Coster and Chankin.
2. Basis should be formed for more detailed ERO modelling of methane puffing experiments in ASDEX Upgrade tokamak, and possible topics of graduate studies involving ERO modelling are discussed (K. Krieger, Pugno, Kallenbach and W. Rohde).

Report: The results obtained with ASCOT electron simulations in AUG SOL were discussed with D. Coster and Chankin. Detailed investigation of the mechanisms affecting the target energy distributions was done in order to explain the qualitatively different results obtained at different radial locations in SOL. This included performing the ASCOT simulations with

1. a minimum energy limit set for each particle as a simulation end criterium, in order to exclude the contribution of thermalised electrons to the target energy distributions
2. suprathermal initial ensembles, in order to estimate the critical energy limit for collisionless propagation of the electrons
3. varying initial poloidal location, in order to determine where prompt kinetic losses could be significant.

The plasma parameters along the simulated field lines were also extracted from ASCOT and their effect on the target energy distributions was contemplated. As a consequence, the interpolation routine employed in ASCOT to determine the background plasma parameters was found insufficient for the present modelling purposes. A refined interpolation was implemented to the code. Some of the simulations were performed with IPP computers but, for some reason, parallel computing was found not to succeed. During the mobility visit, reasons for this were not found. Important conclusions could be made based on the research done at IPP. In addition, D. Coster and Chankin presented valuable suggestions for the structure of the paper.

The status of ERO simulations and the recent modelling results were discussed with Pugno. The importance of considering the effect of an electric field on carbon migration was reviewed and the implementation of the electric field in ERO simulations was proposed as a future work. Collaboration with D. Coster and Neuhauser was suggested.

Due to the ongoing holiday season and the time-consuming work done with the ASCOT simulations, however, a wider discussion of the future ERO work was not achieved.

Additional tasks: Chankin proposed investigation of the electron energy distribution at the outer SOL mid-plane, motivated by inconsistencies observed between Langmuir probe and laser measurements (Müller). This was left as possible future work with ASCOT.

6.1.10 Gyrokinetic modelling of electromagnetic plasma turbulence

Name of seconded person:	Markus Nora
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP-Garching
Dates of secondment / Mission:	11 August – 8 September 2007

Work Plan / milestones: In tokamak plasmas, the quality of confinement is mainly determined by the level of turbulence driven transport. Since the direct measurement of the turbulence and its evolution is so far impossible, numerical simulations are used to get insight into the mechanisms which cause and affect turbulence. For long, electrostatic versions of gyrokinetic codes were assumed to give reasonable explanations but nowadays it has become a common opinion that electromagnetic effects are also needed.

ELMFIRE code is a gyrokinetic global full-f PIC code developed as a joint project between VTT and TKK. At the moment, inclusion of the fluctuations of the magnetic field is one of the major tasks regarding the development of the physics in the code. Despite the constantly increasing computational resources, it is necessary to use certain simplifications in describing the physical system. Thus, the applied numerical schemes and the trade-off between physics and computational feasibility are crucial issues in order for the simulation results to be tenable.

Goals: Concluding the required modifications for the electromagnetic upgrade of the ELMFIRE code in collaboration with B. Scott.

Report: The physical and numerical aspects of the electromagnetic plasma dynamics were discussed with B. Scott. The interplay of the quick-moving electrons and the fluctuating magnetic field was considered in terms of fluid equations and a proper set of physical effects required to achieve a stable system was formulated. One of the major conclusions was that a better agreement between the currents determined by the particles and the magnetic field is required before the time evolution of the magnetic field can be included to ELMFIRE. Thus the development of the present computational geometry to a more flexible one is the following stepping stone towards electromagnetism and has been set to high priority in the future work.

Another salient topic of the visit was the theoretical background of ELMFIRE which has so far based on the Krylov-Boholiubov averaging. It was pointed out, that a derivation based on the Lagrangian theory and Lie-transformations would be more apparent to other members of the fusion community and would guarantee energy conservation. Dr. Scott's advice on this subject was most valuable and the work is already in progress.

In addition to the intended goals, a comparison of numerical methods against the ORB5 code was done with Bottino. Since ORB5 is also a gyrokinetic PIC code, a more thorough comparison of results, which goes beyond the common linear mode analysis of turbulence codes, was also planned.

6.1.11 NPA measurements and energetic ions in AUG

Name of seconded person:	Taina Kurki-Suonio.
Sending Institution:	Helsinki University of Technology
Host Institution:	IPP-Garching
Dates of secondment / Mission:	19 October – 1 November 2007

Work Plan / milestones:

1) NPA measurements: together with Fahrbach and W. Suttrop make more detailed plans for the ELM-resolved NPA measurements. These measurements are carried out with the new NPA data acquisition system installed by the above in June 2007.
2) Discuss the new ASCOT-calculated divertor load results with Kallenbach and Eich to assess their relevance to the measured divertor load asymmetries and pinpoint the dominant physics behind them.
3) In collaboration with the experimental group I also wish to participate in planning the possible reversed-current campaign with reduced heating power.

Report: 1^{st} task: the new data acquisition system of AUG's NPA has been operating well. With Fahrbach and W. Suttrop we made plans for the ELM-resolved NPA measurements. In the first stage, we shall monitor the high-energy (tens of keV) channels across ELMs to see if the behaviour of the ripple-blocked NBI ions could be used to deduce the time constant for the restoration of the edge radial electric field after and ELM. In a meeting where also H. Zohm was present, it was decided that the new NPA measurements will be used together with the FILD in determining the nature of filaments related to ELMs.

2^{nd} task: Kallenbach and Eich gave me a review of the latest findings on the divertor load profiles during ELMs and the associated in-out asymmetry. The simulation plan was revised accordingly.

Together with D. Coster and Chankin, the latest results from the kinetic electron simulations were reviewed, and it was concluded that they provide overwhelming evidence for the fact that no significant contribution on the divertor loads can be attributed to energetic electrons emerging from the core plasma. The outline for a paper reporting these findings was made, and the paper will be written by the end of September.

3^{rd} task: The reversed-current shots are likely to be part of the experimental campaign in 2008 thus facilitating new studies of the QH-mode and the related MHD activity. Both the fast NPA and FILD measurements will play a crucial role in determining the significance of the fast ion population for the edge stability in these shots.

Additional, unforeseen tasks:

4^{th} task: In a meeting with S. Günter and E. Strumberger we discussed the redistribution of fast ions due to microturbulence on one hand and magnetic islands on the other. S. Günter and E. Strumberger already have preliminary results on the direct orbit losses due to magnetic islands and in later phases ASCOT could be used to get more comprehensive results. The anomalous processes related to micro-turbulence were further addressed in discussions with B. Scott.

5th task: The preparation of the EFDA Goal Oriented Training (GOT) task was in its most hectic phase during my visit, and I was drawn to the process by D. Coster and Konz.

6th task: With K. Krieger we made plans for restarting the DIVIMP simulations of ^{13}C-puffing experiments at TKK.

7. OTHER ACTIVITIES

7.1 Conferences, Workshops and Meetings

S. Karttunen and R. Salomaa participated in the Symposium "Starting 7th Framework Programme", Dipoli, Espoo, 11–12 January 2007.

A. Lehtilä participated in the Energy Modelling Experts Workshop, Garching, Germany, 22–24 January 2007.

A. Lehtilä participated in the EFDA-TIMES Model Steering Group Meeting, Garching, Germany, 28 January 2008.

A. Lehtilä participated in the EFDA SERF Workshop and EFDA-TIMES Model Steering Group Meeting, Garching, Germany, 7–8 February, 2007.

S. Karttunen participated in the Launching P7 Conference for Information Multipliers, Brussels, Belgium, 7–8 February 2007.

A. Timperi participated in the Industrial Liaison Officer Network Meeting in Saariselkä, Finland, 7–9 February 2007.

K. Nordlund participated in EU Project FERROCROMO Planning Meeting, Brussels, Belgium, 16 February 2007.

N. Juslin participated in the International Conference TMS 2007, Orlando, FL, USA, 25 February – 1 March 2007.

S. Karttunen participated in the IEA Fusion Power Coordinating Committee Meeting, Paris, France, 27–28 February 2007.

The Laboratory of Advanced Energy Systems of Helsinki University of Technology (Markus Airila and Taina Kurki-Suonio) arranged the 2nd German-Finnish workshop on Material Migration in Fusion Devices, taking place 26–27 February 2007 in Tervaniemi, Tervakoski, Finland. The meeting attracted 20 participants from TKK, VTT, UH, IPP and FZJ.

T. Ahlgren, L. Aho-Mantila, C. Björkas, A. Hakola, K. Heinola, V. Hynönen, K. Nordlund, R. Salomaa and K. Vörtler participated in the Second Finnish Workshop on Material Migration in Fusion Devices, Tervaniemi, Finland, 26–27 February 2007.

S. Tähtinen participated in the Workshop on Coordination/Support Actions (CSA) on Material Research, EFDA CSU, Germany, 2 March 2007.

Tekes FUSION Tecnology Programme 2003–2006, Summary Seminar, Espoo, Finland, 8–9 March 2007. Keynote speaker was Dr. Maurizio Gasparotto, from EFDA CSU Garching (EFDA Associate Leader for Technology). Seminar attracted about 100 participants.

L. Aho-Mantila, M. Nora and T. Ikonen participated in Physics Days 2007 – Physics Crossing Borders, the 41st Annual Meeting of the Finnish Physical Society, Tallinn, Estonia, 15–17 March 2007.

C. Björkas, N. Juslin and K. Nordlund participated in the Joint International Topical Meeting on Mathematics and Supercomputing in Nuclear Applications (M&C + SNA), Monterey, CA, USA, 15–19 March 2007.

K. Rantamäki and M. Santala participated in the Task Force H Meeting, Ringberg, Germany, 16–18 April 2007.

S. Karttunen participated in the Ad-Hoc-Group Meeting on new EFDA and CoA, Brussels, Belgium, 20 March 2007.

S. Karttunen participated in the Information Meeting on the Joint European Undertaking for ITER and the Development of Fusion Energy, Brussels, Belgium, 21 March 2007.

K. Rantamäki participated in the Women in Nuclear Global – 15th Annual Meeting, Bali, Indonesia, 21–27 April 2007.

K. Rantamäki participated in the17th Topical Conference on Radio Frequency Power in Plasmas, Clearwater, Florida, USA, 7–9 May 2007.

S. Karttunen participated in the Meeting of Heads of Research Unit on new EFDA and CoA, Brussels, Belgium, 20 May 2007.

N. Juslin participated in the 11th workshop on Multi-scale Modelling of FeCr Alloys for Nuclear Applications in Forschungszentrum Karlsruhe, Germany, 6–9 May 2007.

A. Salmi participated in the 11th International Workshop in Plasma Edge Theory in Fusion Devices (11th PET), Takayama, Japan, 23–25 May 2007.

C. Björkas and K. Nordlund participated in the TW6-TPP-BeTunCMOD Kick-Off Meeting, Garching, Germany, 24–25 May 2007.

A. Salmi participated in the Satellite Meeting of PET-11 at National Institute for Fusion Science, Japan, 28–30 May 2007.

R. Salomaa participated in the 13th International Conference on Emerging Nuclear Energy Systems, Istanbul, 3–8 June 2007, gave two oral talks, chaired one session, and served as a member of the organising committee.

S. Karttunen and J. Linden participated in the 34th EFDA Steering Committee Meeting hosted by the Association Euratom-Tekes, Dipoli, Espoo, Finland, 4–5 June 2007.

A. Timperi and K. Salminen participated in the PREFIT Workshop on Remote Hnadliong in Oxford on 5–6 June 2007.

H. Wu and H. Handroos "Calibration of a parallel robot using differential evolution algorithm", Smart Systems 2007, Seinäjoki, Finland, 6 June 2007.

K. Nordlund participated in the EFDA Meeting, Oxford, UK, 13–16 June 2007.

V. Kujanpää participated International Conference on Lasers in Manufacturing (LIM2007), Munich, Germany, 16–21 June 2007.

V. Kujanpää participated European Laser Institute Board Meeting, Munich, Germany, 21 June 2007.

H. Wu, H. Handroos and P. Pessi participated in the 22nd IEEE/NPSS Symposium on Fusion Engineering, Albuquerque, New Mexico, USA, 17–21 June 2007.

A. Timperi parcitipated in the Powergen Conference, Milan, Italy, 26–27 June 2007.

V. Hynönen and T. Kiviniemi participated in the 34th EPS Conference on Plasma Physics, Warsaw, Poland, 2–6 July 2007.

V. Kujanpää participated International Institute of Welding Annual Meeting, Dubrovnik, Croatia, 1–6 July 2007.

L. Aho-Mantila participated in the 44th Culham Plasma Physics Summer School, Oxford, UK, 9–20 July 2007.

A. Lehtilä participated in the EFDA-TIMES Model Steering Group Meeting, Garching, Germany, 13 July 2007.

J. Raud, participated in the International Conference on Phenomena in Ionized Gases (ICPIG), 15–20 July 2007 in Prague, Czech Republic.

S. Karttunen and A. Timperi participated in the EFDA Fusion Programme Workshop in Garching, Germany, 18–20 July 2007.

T. Ekholm participated in the International Energy Workshop, Stanford, USA, 25–27 July 2007.

V. Kujanpää, M. Karhu and several others participated Nordic Conference of Laser Materials Processing (NOLAMP11) in Lappeenranta, Finland, 20–22 August 2007. V. Kujanpää was the general chairman of the conference.

A. Hakola, A. Hektor, V. Hynönen, S. Karttunen, M. Kiisk, M. Kirm, M. Laan, J. Likonen, A. Lushchik, K. Nordlund, R. Salomaa, S. Tähtinen and E. Vainonen-Ahlgren participated in the 2nd Annual Finnish-Estonian Fusion Seminar, Tallinn, Estonia, 22–23 August 2007.

V. Kujanpää participated in the International Conference of Welding (JOIN07), Lappeenranta, Finland, 22–24 August 2007.

S. Karttunen, J. Keinonen and R. Salomaa participated in the Symposium ”Energy – A Challenge for Physics”, organised by the Finnish Physical Society, Helsinki, Finland, 31 August 2007.

O. Dumbrajs participated in the Joint 32nd International Conference on Infrared and Millimeter Waves and 15th International Conference on Terahertz Electronics, Cardiff, UK, 3–7 September 2007.

S. Tähtinen participated in the EFDA Project Planning Meeting, EFDA CSU, Germany, 21 September 2007.

K. Heinola participated in the 18th International Conference on Ion Beam Analysis (IBA 2007) held in Hyderabad, India, 23–28 September 2007.

S. Karttunen participated in the EFDA Fusion Programme Workshop in Cadarache, France, Germany, 8–10 October 2007.

C. Björkas participated in the TW7-TTMS-007 Monitoring Meeting, Nice, France, 17 October 2007.

K. Nordlund participated in the EFDA Plasma Wall Interaction Task Force meeting, Austria, 17–19 October 2007.

V. Kujanpää participated in the International Conference of Lasers and Electro-Optics, Orlando, Florida, U.S.A., 29 October – 2 November 2007.

J. Kyynäräinen, MEMS magnetometer for ITER diagnostics summary on feasibility study and irradiation tests, ITER Magnetics Meeting, Lausanne, Switzerland, 12–14 November 2007.

A. Lehtilä participated in the VEDA-TIMES Workshop, Garching, Germany, 26–28 November 2007.

S. Tähtinen participated in the Meeting on collaboration issues between VTT/SCK, EFDA CSU, Germany, 27 November 2007.

J. Järvenpää participated in the QA-meeting at "Fusion for Energy", Barcelona, Spain, 27–28 November 2007.

M. Laan participated in the 15th European Fusion Physics Workshop, 3–5 December 2007, Prague, Czech Republic.

VTT and IHA organised European Remote Handling Working Group meeting in Tampere on 4–5 December 2007. There were 23 participants from seven Associations and representatives from ITER IO and remote participation from "Fusion for Energy".

N. Juslin participated in the 12th workshop on Multi-scale Modelling of FeCr Alloys for Nuclear Applications at EDF, Paris, France, 4–7 December 2007.

N. Juslin participated in the international conference Towards Reality in Nanoscale Materials, Levi, Finland, 9–13 December 2007.

C. Björkas, K. Nordlund, K. Vörtler and S. Tähtinen participated in the International Conference on Fusion Reactor Materials, Nice, France, 10–14 December 2007.

S. Karttunen and A. Timperi participated in the ITER International Business Forum, Nice, France, 10–14 December 2007.

R. Salomaa and K. Rantamäki participated in the 15th Finnish-Russian Symposium on Physics of Hot Plasmas, Espoo, Finland, 10–11 December 2007.

S. Tähtinen participated in the EFDA CSU Monitoring meeting on Modelling, Nice, France, 17 December 2007.

S. Karttunen and L. Ewart participated in the IPR Workshop, Barcelona, Spain, 19 December 2007.

7.2 Visits

K. Rantamäki visited EFDA-JET, Culham Science Centre, Abingdon, UK 1 January – 6 March 2007.

A. Salmi visited EFDA-JET, Culham Science Centre, Abingdon, UK 1 January – 31 December 2007.

M. Santala visited EFDA-JET under S/T Secondment, 2 January – 4 April 2007.

K. Salminen visited Oxford Technologies and JET, under PREFIT Programme, April – September 2007.

A. Salmi visited NYU, Courant Institute, USA, 9 April – 4 May 2007.

V. Kujanpää visited Institute of Laser Physics, St. Petersburg, Russian Federation, 23–24 April 2007.

O. Dumbrajs visited Forschungszentrum Karlsruhe, Germany, 1 June – 30 June 2007.

T. Ikonen visited FZJ Jülich, Germany, 20 May – 16 June 2007.

A. Hakola visited EFDA-JET, Culham Science Centre, Abingdon, UK, 1–28 July 2007.

O. Dumbrajs visited IPP Garching, Germany, 1 July – 31 August 2007.

J. Lönnroth visited EFDA CSU Garching, Germany 16–20 July 2007.

T. Jokinen visited Institute of Mechatronics and Virtual Engineering (EFDA-IMVE), LUT, Lappeenranta, 21 August 2007.

L. Aho-Mantila visited IPP Garching, Germany, 11 August – 8 September 2007.

M. Nora visited IPP Garching, Germany, 11 August – 8 September 2007.

A. Timperi visited CERN, Switzerland, 21 August 2007.

O. Dumbrajs worked as a visiting Professor at University of Fukui, Fukui, Japan, 1 October – 31 December.

A. Timperi visited EFDA CSU, Garching, Germany, 4–5 October 2007.

S. Karttunen visited CEA Cadarache, France, 8–10 October 2007.

S. Karttunen visited University of Latvia, Riga, Latvia, 25–26 October 2007.

V. Kujanpää visited Central University of Florida, Orlando, Florida, USA, 2 November 2007.

V. Kujanpää visited Luleå University of Technology, Luleå, Sweden, 19 November 2007.

V. Kujanpää and I. Vanttaja visited Laser Zentrum Hannover, Hannover, Germany, 28 November 2007.

J. Järvenpää visited Telstar Industrial S.L, Barcelona, Spain, 29 November 2007.

7.3 Visitors

J. Palmer from EFDA CSU, Garching visited VTT and Tampere University of Technology on 6–7 February 2007 and 21–22 August 2007.

V. Rohde from IPP Garching visited VTT Otaniemi, 28 February 2007.

I. Miyamoto from the Osaka University visited VTT Lappeenranta, 20 April 2007.

P. Coad from JET/UKAEA visited VTT Otaniemi, 22–29 April 2007.

P. Baker from the Laser Institute of America, visited VTT Lappeenranta, 25 June 2007.

H. Irie, from Japan Welding Technology Centre, H. Hasegawa, M. Suzuki, Y. Anzo and M. Sato, from Japan Welding Engineering Society, M. Tanaka and M. Ushio from Joining and Welding Research Institute, Osaka University, visited Lappeenranta University of Technology and VTT Lappeenranta, 29 June 2007.

140 international scientists and industrial partners visited Lappeenranta University of Technology and VTT Lappeenranta during Nordic Conference of Laser Materials Processing, 20–22 August 2007.

D. Rodriques from EFDA CSU Garching visited VTT and Tampere University of Technology, 21–22 August 2007.

M. Irving from EFDA CSU, Garching visited VTT and Tampere University of Technology on 20–21 February 2007, 19 September 2007.

A. Romeiro from the University of Vigo, visited Lappeenranta University of Technology and VTT Lappeenranta, 14 August – 14 September 2007.

A.A. Andreev from the Vavilov Institute, St. Petersburg, visited Helsinki University of Technology, 1 October – 31 December 2007.

S. Dudarev from UKAEA, Culham, UK, visited University of Helsinki, 29 October – 7 November 2007.

C. Varandas, I. Ribeiro, T. de Almeida from IST Portugal visited VTT Tampere and DTP2, 17–18 October 2007.

C. Ibbot, M. Pipeleers and D. Bartlett from the Commission participated in the Association Steering Committee meeting, Tampere, Finland, 17 October 2007.

O. Burdo from Kiev Institute for Nuclear Research visited Helsinki University of Technology, 9–17 December 2007.

A. Tesini and J. Palmer from ITER IO and 10 remote handling experts from 7 Euratom Associations visited VTT and DTP2 facility during the RH Working Group Meeting, Tampere, Finland, 4–5 December 2007.

8. PUBLICATIONS 2007

8.1 Fusion Physics and Plasma Engineering

8.1.1 Publications in scientific journals

1. S.J. Janhunen, F. Ogando, J.A. Heikkinen, T.P. Kiviniemi and S. Leerink, "Collisional dynamics of Er in turbulent plasmas in toroidal geometry", Nuclear Fusion **47** (2007) 875–879.

2. T. Tala, Y. Andrew, K. Crombé, P.C. de Vries, X. Garbet, N. Hawkes, H. Nordman, K. Rantamäki, P. Strand, A. Thyagaraja, J. Weiland, E. Asp, Y. Baranov, C. Challis, G. Corrigan, A. Eriksson, C. Giroud, M.-D. Hua, I. Jenkins, H.C.M. Knoops, X. Litaudon, P. Mantica, V. Naulin, V. Parail, K.-D. Zastrow and JET-EFDA contributors, "Toroidal and Poloidal Momentum Transport Studies in JET", Nuclear Fusion **47** (2007) 1012–1023.

3. X. Litaudon, J.P.S. Bizarro, C.D. Challis, F. Crisanti, P.C. De Vries, P. Lomas, F.G. Rimini, T.J.J Tala, R. Akers, Y. Andrew, G. Arnoux, J.F Artaud, Yu.F. Baranov, M. Beurskens, M. Brix, R. Cesario, E. De La Luna, W. Fundamenski, C. Giroud, N.C. Hawkes, A. Huber, E. Joffrin, R.A Pitts, E. Rachlew, S.D.A Reyes-Cortes, S. Sharapov, K.D. Zastrow, O. Zimmermann and the JET EFDA contributors, "Prospects for Steady-State Scenarios on JET", Nuclear Fusion 47 (2007) 1285–1292.

4. V. Hynönen, T. Kurki-Suonio, W. Suttrop, R. Dux, K. Sugiyama and the ASDEX Upgrade Team, "Surface loads and edge fast ion distribution for co- and counter-injection in ASDEX Upgrade", Plasma Physics and Controlled Fusion **49** (2007) 151–174.

5. G. Counsell, P. Coad, C. Grisola, C. Hopf, W. Jacob, A. Kirschner, A. Kreter, K. Krieger, J. Likonen, V. Philipps, J. Roth, M. Rubel, E. Salancon, A. Semerok, FL. Tabares, A. Widdowson and JET-EFDA Contributors, "Tritium Retention in Next Step Devices and the Requirements for Mitigation and Removal Techniques", Plasma Physics and Controlled Fusion **48** (2007) B189.

6. V. Hynönen and T. Kurki-Suonio, "Erratum on surface loads and edge fast ion distribution for co- and counter-injection in ASDEX Upgrade", Plasma Physics and Controlled Fusion **49** (2007) 1345–1347.

7. J. Lönnroth, V. Parail, V. Hynönen, T. Johnson, T. Kiviniemi, N. Oyama, M. Beurskens, D. Howell, G. Saibene, P. de Vries, T. Hatae, Y. Kamada, S. Konovalov, A. Loarte, K. Shinohara, K. Tobita, H. Urano and JET EFDA Contributors, "Effects of ripple-induced ion thermal transport on H-mode plasma performance", Plasma Physics and Controlled Fusion **49** (2997) 273–295.

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8.2 Fusion Technology

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8.2.2 Conference articles – fusion technology

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26. S. Tähtinen, P. Moilanen, B.N Singh, P. Jacquet, J. Dekeyser, M. Li, J.F. Stubbins and D.J. Edwards, "In-reactor Creep-fatigue Deformation Behaviour of CuCrZr alloy", ICFRM-13, Nice, France, 10–14 December 2007.

27. B.N Singh, X. Huang, S. Tähtinen, P. Moilanen, P. Jacquet and J. Dekeyser, "In-reactor Deformation Behaviour during Uniaxial Tensile Tests of Pure Iron and Fe-Cr Alloy", ICFRM-13, Nice, France, 10–14 December 2007.

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8.2.3 Research reports

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8.3 General Articles

1. O. Asunta, "Fuusioalfojen käyttäytyminen 'advanced scenario'-plasmoissa", ATS Ydintekniikka **36** (2007) 1, p. 29 (in Finnish).

2. T. Ikonen, "Molekyylidynaaminen pintamalli fuusioplasmojen epäpuhtaussimuloin-neille", ATS Ydintekniikka **36** (2007) 2, p. 29 (in Finnish).

3. L. Aho-Mantila, "Terminen tasapaino tokamak plasman kuorintakerroksessa", ATS Ydintekniikka **36** (2007) 3 (in Finnish).

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5. Taina Kurki-Suonio, "Mistä kilovatteja kuntopyörään vuonna 2020?", Polysteekki, Teknillisen korkeakoulun aikakauslehti 1/2007, p. 3 (in Finnish).

8.4 Doctoral and Graduate Theses

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2. A. Nieminen, "Verifying of position accuracy for ITER-maintenance robot", TUT/IHA, Tampere, Finland, 2007, 78 p. (Master's Thesis at Tampere University of Technology, in Finnish).

3. L. Aho-Mantila, “Monte Carlo Modeling of Fast Electron Effects in the Divertor Region”, Espoo 2007, 72 p. (Master’s Thesis at Helsinki University of Technology).

4. T. Ikonen, “Molecular Dynamics based surface model for the impurity transport code ERO”, Espoo 2007, 75 p. (Master’s Thesis at Helsinki University of Technology).

8.5 Publications of Estonian Research Unit

8.5.1 Publications in scientific journals

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4. A. Lushchik, I. Kudryavtseva, P. Liblik, Ch. Lushchik, A.I. Nepomnyashchikh, K. Schwartz and E. Vasil'chenko, “Electronic and ionic processes in LiF:Mg,Ti and LiF single crystals”, submitted for publication in Radiat. Meas. 2007.

5. I. Kudryavtseva, A. Lushchik, A.I. Nepomnyashchikh, F. Savikhin, E. Vasil'chenko and J. Lisovskaya, “Excitation of thermo- and photostimulated luminescence by VUV radiation and ions in LiF:Mg,Ti single crystals”, submitted for publication in Phys. Solid State 2007.

6. A. Lushchik, Ch. Lushchik, K. Schwartz, E. Vasil'chenko, T. Kärner, I. Kudryavtseva, V. Isakhanyan and A. Shugai, “Stabilization and annealing of interstitials formed by radiation in binary metal oxides and fluorides”, submitted for publication in Nucl. Instr. and Meth. B 2007.

7. V.N. Makhov, A. Lushchik, Ch.B. Lushchik, M. Kirm, E. Vasil'chenko, S. Vielhauer, V.V. Harutunyan and E. Aleksanyan, “Luminescence and radiation defects in electron-irradiated Al_2O_3 and Al_2O_3:Cr”, submitted for publication in Nucl. Instr. and Meth. B 2007.

8. K. Schwartz, A. Lushchik, Ch. Lushchik, E. Vasil'chenko, R. Papaleo, D. deSouza, M. Sorokin, A. Volkov, K.-O. Voss, C. Trautmann and R. Neumann, “Color center creation in LiF crystals irradiated with 5-MeV Au ions”, submitted for publication in Nucl. Instr. and Meth. B 2007.

8.5.2 Conference articles

1. P. Paris, M. Laan, M. Aints and T. Plank, “Analysis of Current Pulses Induced by Laser Ablation”, Proceedings of the XLI Annual Conference of the Finnish Physical Society: XLI Annual Conference of the Finnish Physical Society; Tallinn, Estonia; March 15–17, 2007. (Ed.) Vainio, R.; Pomoell, J.; Louhivuori, M. Helsinki: University of Helsinki, 2007, 338.

2. P. Paris, J.A. Heikkinen, J. Järvinen and A. Tiitta, “Optical emission spectroscopic measurements of gas temperature in inductive rf discharge”, Proceedings of the XLI Annual Conference of the Finnish Physical Society: XLI Annual Conference of the Finnish Physical Society; Tallinn, Estonia; March 15–17, 2007. (Ed.) Vainio, R.; Pomoell, J.; Louhivuori, M. Helsinki: University of Helsinki, 2007, 284.

3. A. Lushchik, I. Kudryavtseva, P. Liblik, Ch. Lushchik, A.I. Nepomnyashchikh, K. Schwartz and E. Vasil'chenko, “Electronic and ionic processes in LiF:Mg,Ti and LiF single crystals”, 15th International Conference on Solid State Dosimetry (SSD-15), Delft, the Netherlands, July 8–13, 2007 (oral).

4. I. Kudryavtseva, A. Lushchik, A.I. Nepomnyashchikh, F. Savikhin, E. Vasil'chenko, J. Lisovskaya, “Excitation of thermo- and photostimulated luminescence by VUV radiation and ions in LiF:Mg,Ti single crystals”, XIII Feofilov symposium on spectroscopy of crystals doped by rare earth and transition metal ions, Irkutsk, Russia, July 9–13, 2007.

5. J. Raud and M. Laan, “Production of N_2^+ in PC of HF discharge in He/N_2 mixture”, XXVIII International Conference on Phenomena in Ionized Gases, July 15–20, 2007, Prague, Czech Republic.

6. A. Lushchik, Ch. Lushchik, K. Schwartz, E. Vasil'chenko, T. Kärner, I. Kudryavtseva, V. Isakhanyan and A. Shugai, “Stabilization and annealing of interstitials formed by radiation in binary metal oxides and fluorides”, 14th International Conference on Radiation Effects in Insulators (REI-2007), Caen, France, August 28 – September 1, 2007(oral).

7. K. Schwartz, A. Lushchik, Ch. Lushchik, E. Vasil'chenko, R. Papaleo, D. deSouza, M. Sorokin, A. Volkov, K.-O. Voss, C. Trautmann and R. Neumann, “Color center creation in LiF crystals irradiated with 5-MeV Au ions”, 14th International Conference on Radiation Effects in Insulators (REI-2007), Caen, France, August 28 – September 1, 2007(oral).

8. V.N. Makhov, A. Lushchik, Ch.B. Lushchik, M. Kirm, E. Vasil'chenko, S. Vielhauer, V.V. Harutunyan and E. Aleksanyan, “Luminescence and radiation defects in electron-irradiated Al_2O_3 and Al_2O_3:Cr”, 14th International Conference on Radiation Effects in Insulators (REI-2007), Caen, France, August 28 – September 1, 2007.

9. M. Laan, P. Paris, T. Plank and M. Aints, “Laser spectroscopy of diagnostics tiles for erosion”, 2nd Annual Finnish-Estonian Fusion Seminar, Tallinn, Estonia, oral report (2007).

APPENDIX A. SUMMARY TABLES OF PHYSICS AND EFDA TECHNOLOGY ACTIVITY

Tekes contributions to EFDA JET and AUG Experiments in 2007

Experiment / Device	**Tekes Contributions**	**Remarks**
EFDA JET Joint European Torus	**Tekes Staff at UKAEA/JET** • *Tuomas Tala*, Task Force Leader (T), scientific co-ordinator • *Antti Salmi*, JOC secondee, codes/data analysis, (H,T) • *Karin Rantamäki*, scientific co-ordinator (H) • *Ville Hynönen (T), Timo Kiviniemi (T), Jari Likonen (E), Johnny Lönnroth (T), Marko Santala (D)*	
	Tekes contributions to experimental campaigns C18-C19	<u>Task Force</u>
	• Determination of parametric dependences of ITG and TEM (T-3.3.2)	T
	• Exploration of beam modulation as a tool for viscosity and heat transport measurements, including modelling of momentum transport	T
	• Preparations and analysis of results from the TF ripple campaign	T
	• Material transport in SOL by means of tracer (C13) techniques (E-1.3.6)	E, FT
	• ITER relevant coupling of LH waves in advanced tokamak regimes (H-1.6.1)	H
	• JET EP2 diagnostics – upgrading NPA diagnostics	T
	• Predictive transport modelling for ITER	D
IPP: **AUG**	• Effect of E_r and ripple on edge fast ion distribution • Effect of anomalous transport and E_r on divertor load asymmetry • DD-Fusion triton surface distribution on plasma-facing components • ELM studies using the fast neutral particle analyser • Kinetic electrons in the scrape-off layer of ASDEX Upgrade tokamak • MHD stability and plasma control • ICRH-generated fast ion studies • Modelling the 2003 AUG divertor puffing experiment	Staff Mobility

Tekes Activities in EFDA Technology in 2007

Task Reference	Task Area / Task Title	tot/ps
	Physics Integration / JET Technology	**k€**
TW6-TPDS-DIADEV	Fast ions effects on ITER diagnostics	30
TW6-TPDS-DIADEV	Development of micromechanical magnetometer for ITER	50
TW6-TPDS-DIASUP	Diagnostics support (Art. 5.1b Contract)	45
TW6-TPP-CARTIL	Characterisation of AUG wall tiles and plasma facing components with surface analytical techniques	150/60
TW6-TPHI-ICFS	Faraday shield RF modelling and RF sheath dissipation (Art. 5.1b Contract)	50
JW6-FT- 3.32	Material transport, erosion / re-deposition in JET torus	190/150
JW5-TA-EP-BEW-02	Development of W-coatings for JET divertor tiles (Art 5.1b Contract)	60
JW5-EP-DIAGN	Upgrading of the NPA diagnostics system (S/T Order)	80
TW6-TPO-RIPLOS	Ripple studies for ITER (Art 5.1b Contract)	228
TW6-TPP-ERITERB	Improvement of surface processes modelling in the ERO code for advanced description of mixed material formation in ITER reference scenarios (Art. 5.1b Contract)	25
TW6-TPP-BETUNCMOD	Molecular dynamics simulations of mixed material formation at the ITER divertor	255
	Vessel / In-Vessel	
TW5-TVM-SITU2	In reactor tensile testing of copper and CuCrZr alloy	125/40
TW5-TVB-PHCSMU	Manufacture of CuCrZr / 316L SS mock-ups by powder HIPing	130/100
TW6-TVM-NAJT	Irradiation of CuCrZr/SS and CuCrZr/Be joints at 300ºC produced under different blanket manufacturing conditions	150
TW6-TVM-LIP	Modification of ITER materials documents and assessment of materials data (Art. 5.1b Contract)	30
TW5-TVR-CMMHLC	Software development and modelling of the CMM system	300
TW6-TVR-DTPTA	Host activities in connection to DTP2 test facility (Art. 5.1b Contract)	600
TW6-TVR-DTP2OP	– Host activities in connection with the DTP2 test facility – Implementation of a DTP2 safety system for testing, and final CMM/SCEE integration and commissioning (Art. 5.1b Contract)	398
TW6-TVR-DTP2DEV	– Development of DTP2 subsystems and tooling in support of remote handling trials – EFDA QA-pilot exercise	220/100
TW5-TVV-IWRFS	Design and development towards a parallel water hydraulic intersector weld/cut robot IWR	400
TW6-TVA-IHYB	Industrialisation and weld quality issues of high productive laser\arc hybrid for thick section welding of ITER grade SS material (Art. 5.1b Contract)	150
Underlying Tech	ITER relevant teleoperation development and experimentation with water hydraulic manipulator	150
	Tritium Breeding and Materials	
TW5-TTMS-005	Structural materials: Rules for design, fabrication and inspection, in-reactor tensile tests of Fe and FeCr alloys	178
TW6-TTMS-07/13a	Radiation damage in EUROFER: FeCrHe thermodynamics	50
	System Studies	
TW6-TRE-ETMIND	Global TIMES modelling – EFDA-TIMES industry update	58
	EFDA CSU Secondments	
EFDA CSU Garching Secondments	Tommi Jokinen, Assembly Pertti Pale, Administration / project control Hannu Rajainmäki, Magnets Mikko Siuko, Remote Handling	

APPENDIX B.   INTRODUCTION TO FUSION

B.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.

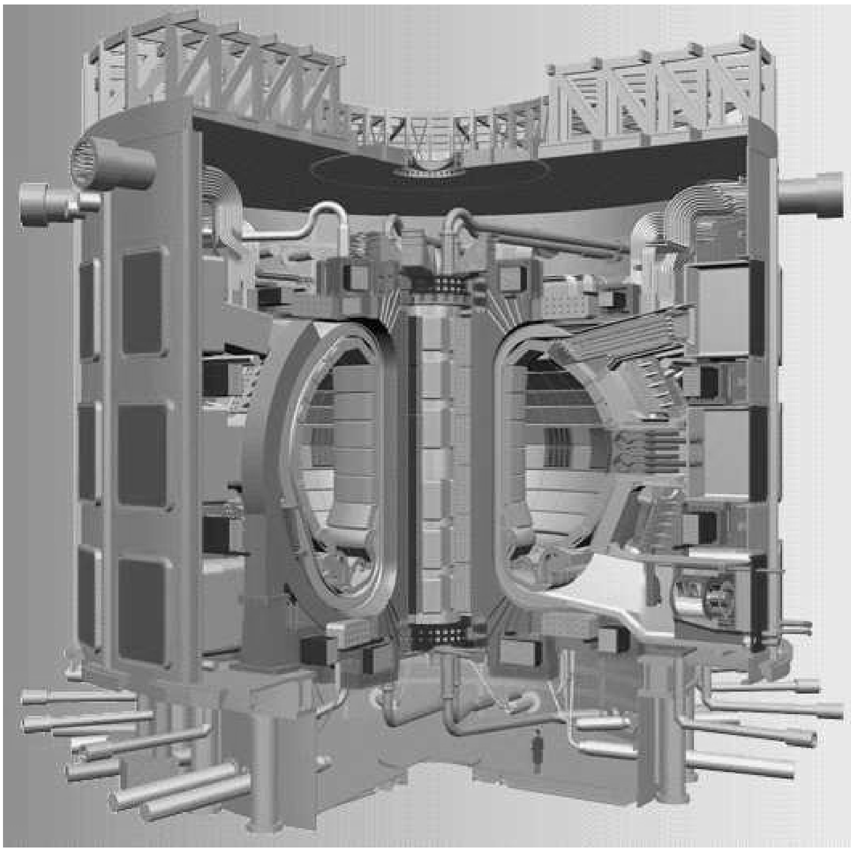

Figure B1: A design model for the experimental fusion reactor ITER, which will be constructed in Europe (Cadarache, France) as a world wide collaboration.

B.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.

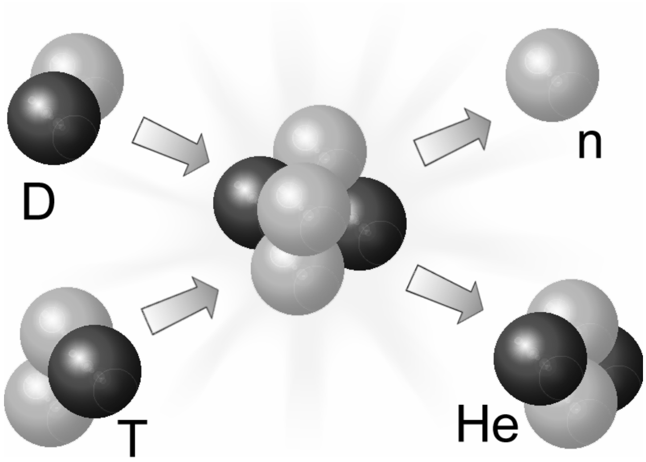

Figure B2: In a fusion reaction, deuterium (D) and tritium (T) fuse together forming a helium nucleus (^{4}He) and releasing a large amount of energy which is mostly carried by the neutron (n).

B.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 27 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. “Fusion for Energy” manages the European Broader Approach activities in collaboration with Japan.

B.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. Project staff exceeds 250 and will soon reach 300. The total number of personnel will be close to 600.

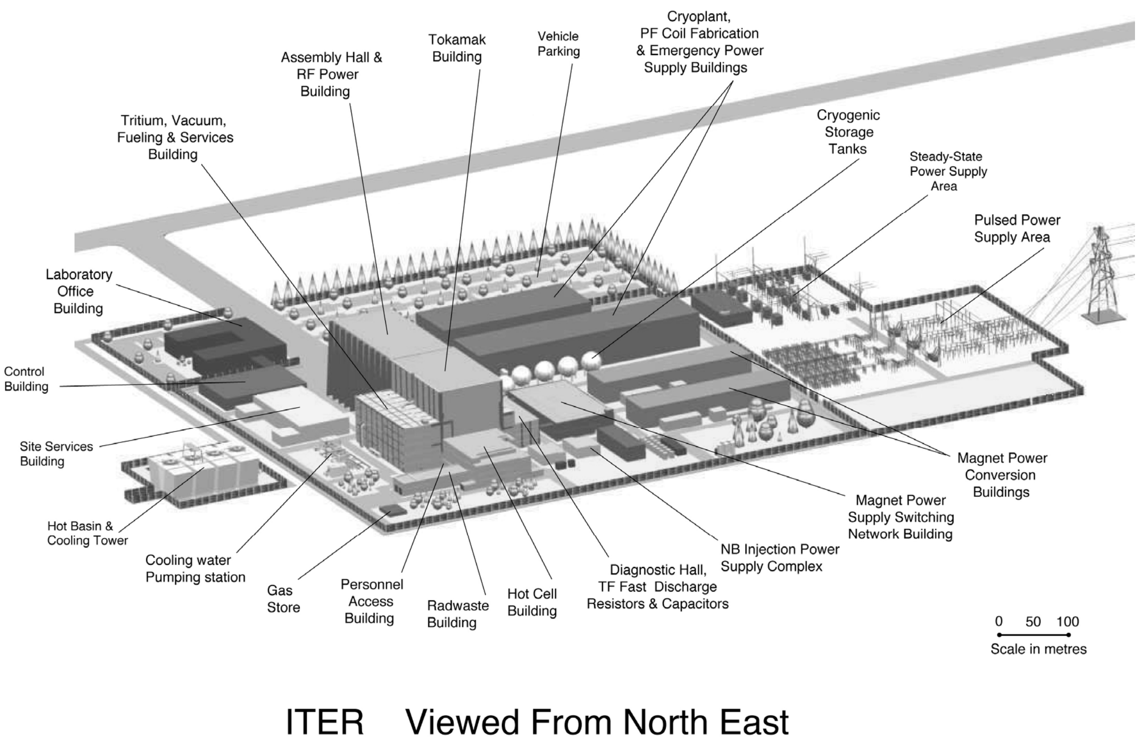

Figure B3: Lay-out of the ITER site and buildings at Cadarache.

APPENDIX C. INSTITUTES AND COMPANIES

C.1 Research Institutes and Companies

Tekes – The Finnish Funding Agency for Technology and Innovation
Kyllikinportti 2, Länsi-Pasila
P.O. Box 69, FIN-00101 Helsinki, Finland
Tel. +358 105 2151; Fax. +358 105 215903
www.tekes.fi
Juha Linden juha.linden(at)tekes.fi

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

VTT, Technical Research Centre of Finland

VTT Materials Performance
Otakaari 3A, Espoo
P.O. Box 1000, FIN-02044 VTT, Finland
Tel. +358 20 722 111; Fax. +358 20 722 6390
www.vtt.fi
Seppo Karttunen seppo.karttunen(at)vtt.fi

VTT Materials Performance
Kemistintie 3, Espoo
P.O. Box 1000, FIN-02044 VTT, Finland
Tel. +358 20 722 111; Fax. +358 20 722 7002
Seppo Tähtinen seppo.tahtinen(at)vtt.fi

VTT Production Systems
Tuotantokatu 2
P.O. Box 17021, FIN-53851 Lappeenranta, Finland
Tel. +358 20 722 111; Fax. +358 20 722 2893
Veli Kujanpää veli.kujanpaa(at)vtt.fi

VTT System Engineering
Tekniikankatu 1
P.O. Box 1300, FIN-33101 Tampere, Finland
Tel. +358 20 722 111; Fax. +358 20 722 3495
Jorma Järvenpää jorma.jarvenpaa(at)vtt.fi
Arto Timperi arto.timperi(at)vtt.fi

VTT Nuclear Energy
Otakaari 3A, Espoo
P.O. Box 1000, FIN-02044 VTT, Finland
Tel. +358 20 722 111; Fax. +358 20 722 6390
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VTT Energy Systems
P.O. Box 1000, FIN-02044 VTT, Finland
Tel. +358 20 722 111; Fax. +358 20 722 7026
Antti Lehtilä antti.lehtila(at)vtt.fi

VTT Sensors
Tietotie 3, Espoo
P.O. Box 1000, FIN-02044 VTT, Finland
Tel. +358 20 722 111; Fax. +358 20 722 7012
Jukka Kyynäinen jukka.kyynarainen(at)vtt.fi

Helsinki University of Technology (TKK)

Helsinki University of Technology
Advanced Energy Systems
P. O. Box 4100, FIN-02015 TKK, Finland
Tel. +358 9 4511; Fax. +358 9 451 3195
www.tkk.fi
Rainer Salomaa rainer.salomaa(at)tkk.fi

Helsinki University of Technology
Automation Technology
P. O. Box 3000, FIN-02015 TKK, Finland
Tel. +358 9 4511; Fax. +358 9 451 3308
www.tkk.fi
Aarne Halme aarne.halme(at)tkk.fi

Tampere University of Technology (TUT)

Tampere University of Technology
Institute of Hydraulics and Automation
Korkeakoulunkatu 2, P.O. Box 589, FIN-33101 Tampere, Finland
Tel. +358 3115 2111; Fax. +358 3115 2240
www.iha.tut.fi
Matti Vilenius matti.vilenius(at)tut.fi

Tampere University of Technology
Laboratory of Electromagnetics
Korkeakoulunkatu 2, P.O. Box 589, FIN-33101 Tampere, Finland
Tel. +358 3115 3602; Fax. +358 3115 2160
www.tut.fi
Risto Mikkonen risto.mikkonen(at)tut.fi

Lappeenranta University of Technology (LUT)

Laboratory of Machine Automation
Skinnarilankatu 34, P.O. Box 20, FIN-53851 Lappeenranta, Finland
Tel. +358 5 621 11; Fax. +358 5 621 2350
www.lut.fi
Heikki Handroos heikki.handroos(at)lut.fi

University of Helsinki (UH)
Accelerator Laboratory
P.O. Box 43, FIN-00014 University of Helsinki, Finland
Tel. +358 9 191 40005; Fax. +358 9 191 40042
www.beam.helsinki.fi
Juhani Keinonen juhani.keinonen(at)helsinki.fi
Kai Nordlund kai.nordlund(at)helsinki.fi

C.3 Estonian Research Unit of the Association Euratom-Tekes

University of Tartu
Institute of Physics
Riia 142
51014 Tartu, Estonia
Tel. +372 742 8493; Fax. +372 738 3033
www.fi.tartu.ee
Madis Kiisk madis.kiisk(at)fi.tartu.ee
Marco Kirm marco.kirm(at)ut.ee

National Institute of Chemical Physics and Biophysics
Akadeemia tee 23,
12618 Tallinn, Estonia
Tel. +372 639 8300; Fax. +372 670 3662
www.kbfi.ee
Andi Hektor andi.hektor(at)cern.ch

C.4 Industrial Companies

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

Company:	**Adwatec Oy**
Technology:	Remote handling, water hydraulics, actuators and drives
Contact:	Adwatec Oy, Polunmäenkatu 39 H 9, FIN-33720 Tampere, Finland Tel. +358 3 389 0860; Fax. +358 3 389 0861 www.adwatec.com Arto Verronen rto.verronen(at)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, FIN-01800 Klaukkala, Finland Tel. +358 9 878 01244; Fax. +358 9 878 01200 www.aspocomp.com Markku Palmu markku.palmu(at)aspocomp.com

Company	**Creanex Oy**
Technology:	Remote handling, teleoperation and walking platforms
Contact:	Creanex Oy, Nuolialantie 62, FIN-33900 Tampere, Finland Fax. +358 33683 244, GSM +358 50 311 0300 www.creanex.com Timo Mustonen timo.mustonen(at)creanex.com
Company:	**Delfoi Oy**
Technology:	Telerobotics, task level programming
Contact:	Delfoi Oy, Vänrikinkuja 2, FIN-02600 Espoo, Finland Tel. +358 9 4300 70; Fax. +358 9 4300 7277 www.delfoi.com Heikki Aalto heikki.aalto(at)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, FIN-02200 Espoo, Finland Tel. +358 9 2517 6130; Fax. +358 9 2517 6140 www.diarc.fi Jukka Kolehmainen jukka.kolehmainen(at)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, FIN-02151 Espoo, Finland Tel. +358 46911; Fax. +358 9 469 1981 www.poyry.com Vilho Salovaara vilho.salovaara(at)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, FIN - 02700 Kauniainen, Finland Tel. +358 40 344 2000; Fax. +358 9 5055 547 www.elektrobit.com Marko.Koski marko.koski(at)elektrobit.com
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, FIN-01601 Vantaa, Finland Tel. +358 40 348 5511: Fax. +358 9 3487 0810 www.enprima.com Jarmo Raussi jarmo.raussi(at)enprima.com

Company: **Finpro**
Role: Industry activation and support
Contact: Finpro, P.O. Box 358,
Porkkalankatu 1, FIN-00181 Helsinki, FIN-28600 Pori, Finland
Tel. +358 204 6951; Fax. +358 204 695200
www.finpro.fi
Pekka Tolonen pekka.tolonen(at)finpro.fi

Company: **Fortum Nuclear Services Oy**
Technology: Nuclear Engineering
Contact: Fortum Nuclear Services Oy, Keilaniementie 1, Espoo,
FIN-00048 Fortum, Finland
Tel. +358 10 4511; Fax. +358 10 453 3403
www.fortum.com
Herkko Plit herkko.plit(at)fortum.com

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

Company: **Hollming Works Oy**
Technology: Mechanical engineering, fabrication of heavy stainless steel structures
Contact: Puunaulakatu 3, P.O. Box 96, FIN-28101 Pori, Finland
Tel. +358 20 486 5040; Fax. +358 20 486 5041
www.hollmingworks.com
Jari Mattila jari.mattila(at)hollmingworks.com

Company: **Hytar Oy**
Technology: Remote handling, water hydraulics
Contact: Hytar Oy, Ilmailukatu 13, P.O. Box 534, FIN-33101 Tampere, Finland
Tel. +358 3 389 9340; Fax. +358 3 389 9341
Olli Pohls olli.pohls(at)avs-yhtiot.fi

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

Company: **Japrotek Oy**
Technology: Designs and manufacturing of stainless steel process equipment such as columns, reactors and heat exchangers
Contact: Japrotek Oy, P.O. Box 12, FIN-68601, Pietarsaari, Finland
Tel. +358 20 1880 511; Fax. +358 20 1880 415
www.vaahtogroup.fi
Ulf Sarelin ulf.sarelin(at)vaahtogroup.fi

Company:	**Jutron Oy**
Technology:	Versatile electronics manufacturing services
Contact:	Jutron Oy, Konekuja 2, FIN-90630 Oulu, Finland Tel. +358 8 555 1100; Fax. +358 8 555 1110 www.jutron.fi Keijo Meriläinen keijo.merilainen(at)jutron.fi

Company:	**Kankaanpää Works Oy**
Technology:	Mechanical engineering, fabrication of heavy stainless steel structures including 3D cold forming of stainless steel
Contact:	Kankaanpää Works Oy, P.O. Box 56, FIN-38701 Kankaanpää, Finland Tel. +358 20 486 5034; Fax. +358 20 486 5035 www.hollmingworks.com Jarmo Huttunen jarmo.huttunen(at)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, FIN-15801, Lahti, Finland Tel. +358 3 899 11; Fax. +358 3 899 417 www.kempower.fi Petri Korhonen petri.korhonen(at)kempower.fi

Company:	**Luvata Oy**
Technology:	Superconducting strands and copper products
Contact:	Luvata Oy, Kuparitie, P.O Box 60, FIN-28101 Pori, Finland Tel. +358 2 626 6111; Fax. +358 2 626 5314 Ben Karlemo ben.karlemo(at)outokumpu.com

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

Company:	**Marioff Corporation Oy**
Technology:	Mist fire protection systems
Contact:	Marioff Corporation Oy, P.O. Box 25, FIN-01511 Vantaa, Finland Tel. +358 9 8708 5342; Fax. +358 9 8708 5399 www.hi-fog.com Pekka Saari pekka.saari(at)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, FIN-33541 Tampere, Finland
Tel. +358 20 484 120; Fax. +358 20 484 121
www.metsopowdermet.com
Jari Liimatainen jari.liimatainen(at)metso.com

Company: **Oxford Instruments Analytical**
Technology: Plasma diagnostics, vacuum windows
Contact: Nihtisillankuja, P.O. Box 85, FIN-02631 Espoo, Finland
Tel. +358 9 329411; Fax. +358 9 23941300
www.oxford-instruments.com
Heikki Sipilä heikki.sipila(at)oxinst.fi

Company: **Patria Oyj**
Technology: Defence and space electronics hardware and engineering
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Company: **PI-Rauma Oy**
Technology: Computer aided engineering with CATIA
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www.pi-rauma.fi
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Company: **Platom Oy**
Technology: Remote handling, thermal cutting tools and radioactive waste handling
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www.platom.fi
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Company: **PPF Products Oy**
Service: Industry activation and support
Contact. Portaantie 548, FIN-31340 Porras, Finland
Tel. +358 3 434 1970; Fax. +358 50 40 79 799
Pertti Pale pertti.pale(at)surffi.net

Company: **Prizztech Oy**
Role: Industry activation and support
Contact: Teknologiakeskus Pripoli, Tiedepuisto 4, FIN-28600 Pori, Finland
Tel. +358 2 620 5330; Fax. +358 2 620 5399
www.prizz.fi
Jouko Koivula jouko.koivula(at)prizz.fi

Company: **Rados Technology Oy**
Technology: Dosimetry, waste & contamination monitoring and environmental monitoring
Contact: Rados Technology Oy, P.O. Box 506, FIN-20101 Turku, Finland
Tel. +358 2 4684 600; Fax. +358 2 4684 601
www.rados.fi
Erik Lehtonen erik.lehtonen(at)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, FIN-05840 Hyvinkää, Finland
Tel. +358 19 2660 600; Fax. +358 19 2660 601
www.rejlers.fi
Jouni Vidqvist jouni.vidqvist(at)rejlers.fi

Company: **Rocla Oyj**
Technology: Heavy Automated guided vehicles
Contact: Rocla Oyj, P.O. Box 88, FIN- 04401 Järvenpää, Finland
Tel. +358 9 271 471; Fax. +358 9 271 47 430
www.rocla.fi
Pekka Joensuu pekka.joensuu(at)rocla.com

Company: **Selmic Oy**
Technology: Microelectronics design and manufacturing, packaging technologies and contract manufacturing services
Contact: Selmic Oy, Vanha Porvoontie 229, FIN-01380 Vantaa, Finland
Tel. +358 9 2706 3911; Fax. +358 9 2705 2602
www.selmic.com
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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, FIN-68601 Pietarsaari, Finland
Tel. +358 6 781 7500; Fax. +358 6 781 7510
www.solving.fi
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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, FIN-01601 Vantaa, Finland
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Company: **Tampereen Keskustekniikka Oy**
Technology: Product development, design, production, marketing, and sales of switchgear and controlgear assemblies
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Tel. +358 3 233 8331
www.keskustekniikka.fi
Reijo Anttila reijo.anttila(at)keskustekniikka.fi

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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Technology: Nuclear power technologies; service, maintenance, radiation protection and safety
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www.tvo.fi
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Company: **TP-Konepaja Oy / Arelmek Oy**
Technology: Heavy welded and machined products, DTP2 structure
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Tel. +358 40 8318001
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Company: **Woikoski Oy**
Technology: Production, development, applications and distribution of gases and liquid helium
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FUSION YEARBOOK

Association Euratom-Tekes. Annual Report 2007

Abstract

This report summarises the activities and results of the fusion energy research carried out by the Research Unit of the Association Euratom-Tekes in 2007. Fusion research covers both physics and technology. Approximately one third of research volume is in physics and two thirds in technology. The University of Tartu joined the Tekes Association in 2007 and Estonia provides now a contribution to the European Fusion Programme in plasma-wall studies and wall diagnostics.

Our highest priority in the fusion physics work is a participation in the EFDA JET work programmes and experimental campaigns. The main emphasis of the work is in simulations of tokamak transport experiments by predictive integrated codes, modelling of radio-frequency heating experiments and fast particles studies. The supporting theoretical work on turbulent transport and edge plasmas and related code development has proceeded well, too. Plasma-wall studies including coatings and material transport in the scrape-off-layer provide another important contribution to the JET programme. Upgrading of the JET neutral particle analyser (NPA) and development of micromechanical magnetometer are the main diagnostics activities of the Association Euratom-Tekes.

The work of the Tekes Association in ITER technology was strongly focused into vessel/in-vessel materials and remote handling studies and was partly carried out in close collaboration with Finnish industry. The main activity was to prepare hosting of the ITER divertor test platform (DTP2) at VTT. The basic DTP2 steel structure was completed, control systems are tested and one full size cassette mock-up is delivered by industry. The test runs will start as soon as the multifunctional mover is ready and arrives at VTT. Other activities in remote maintenance systems include water hydraulic manipulators and tools for the ITER divertor maintenance and virtual modelling of remote handling operations. Advanced fabrication methods for ITER vacuum vessel as well as prototyping of intersector welding and cutting robot may provide considerable savings in VV manufacturing. A second domain of fusion technology covers research and characterisation of first wall materials, in-reactor mechanical testing of reactor materials under neutron irradiation, studies of joining and welding methods. Some effort was devoted to simulations of radiation damage mechanisms in FeCr. Socio-economic studies dealt with global energy modelling issues.

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