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Fusion Yearbook

Association Euratom-Tekes
Annual Report 2011

VTT SCIENCE 7

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Association Euratom-Tekes
Annual Report 2011

Markus Airila & Seppo Karttunen (eds.)

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Cover picture: The new ITER-Like Wall installation was completed at JET in 2011. Ville Takalo, the Operations Resonsible Officer is keeping an eye on the Mascot operator Tim Powell. © EFDA

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Fusion Yearbook
Association Euratom-Tekes Annual Report 2011

[Fuusio-vuosikirja. Euratom-Tekes-assosiaation vuosikertomus 2011]. **Markus Airila & Seppo Karttunen (eds.)** Espoo 2012. VTT Science 7. 173 p. + app. 14 p.

Abstract

This Annual Report summarises the fusion research activities of the Finnish and Estonian Research Units of the Association Euratom-Tekes in 2011. The emphasis of EFDA is in exploiting JET and co-ordinating physics research in the Associations. In addition, emerging technology and goal oriented training (GOT) activities are under EFDA. R&D Grants for the Joint Undertaking “Fusion for Energy” on remote handling for ITER divertor maintenance and MEMS magnetometer development constituted a significant fraction of the total research volume.

The activities of the Research Unit are divided in the fusion physics under the Contract of Association and EFDA. The physics work is carried out at VTT, Aalto University (AU), University of Helsinki and University of Tartu. The research areas of the EFDA Workprogramme within Association Euratom-Tekes are (i) Heat and particle transport and fast particle studies, (ii) Plasma-wall interactions and material transport in SOL region, and (iii) Code development and diagnostics.

Association Euratom-Tekes participated in the EFDA JET Workprogramme 2011, including C28 experiments with the ITER-like wall, diagnostics development and code integration. Two persons were seconded to the JET operating team, one physicist (codes & modelling) and one engineer (remote handling) in preparation of the ITER-like wall. The Association participated also in the 2011 experimental programmes of ASDEX Upgrade at IPP, DIII-D at GA and C-Mod at MIT.

The technology work is carried out at VTT, AU, Tampere University of Technology (TUT) and Lappeenranta University of Technology (LUT) in close collaboration with Finnish industry. Industrial participation is co-ordinated by Tekes. The technology research and development includes the DTP2 facility at VTT Tampere, materials and joining techniques, vessel/in-vessel components, magnetic diagnostics by micromechanical magnetometers for ITER, upgrading of the JET NPA diagnostics, Power Plant Physics and Technology (PPPT) activities, plasma facing materials issues, erosion/re-deposition and material transport studies, development of coating techniques, and in-reactor mechanical testing and characterisation of materials under neutron irradiation.

Association Euratom-Tekes is involved in two GOT projects: GOTiT for theory and modelling and GOTRH for remote handling. GOTRH is coordinated by TUT. In July 2013 AU will organize the EPS Plasma Physics Conference in Espoo.

Keywords nuclear fusion, fusion energy, fusion research, fusion physics, fusion technology, fusion reactors, fusion reactor materials, ITER remote handling, Euratom

Fuusio-vuosikirja
Euratom-Tekes-assosiaation vuosikertomus 2011

[Fusion Yearbook. Association Euratom-Tekes Annual Report 2011]. **Markus Airila & Seppo Karttunen (toim.).** Espoo 2012. VTT Science 7. 173 s. + liitt. 14 s.

Tiivistelmä

Tähän vuosikirjaan on koottu Suomen ja Viron fuusiotutkimusyksiköiden vuoden 2011 tulokset ja saavutukset. Työ on tehty Euratom-Tekes-assosiaation puitteissa. EFDAn painopisteet ovat JET-tokamakin käyttö ja assosiaatioiden fuusiofysiikan tutkimuksen koordinointi. Näiden lisäksi EFDAan kuuluvat uudet teknologiat (emerging technologies) ja uusien asiantuntijoiden koulutus (goal-oriented training, GOT). F4E-organisaation myöntämällä rahoituksella ITERin diverttorin etähuoltojärjestelmän ja MEMS-magnetometrien kehittämiseen on ohjelmassa merkittävä osuus.

Tutkimusyksikön toiminta jakautuu assosiaatiosopimuksen alaiseen fuusiofysiikan tutkimukseen sekä EFDA-työhön. Fysiikan tutkimusta tehdään VTT:llä, Aalto-yliopistossa, Helsingin yliopistossa ja Tarton yliopistossa. Assosiaation työohjelman fysiikkatutkimusalueet ovat (i) Lämmön ja hiukkasten kuljetusilmiöt sekä nopeat hiukkaset, (ii) Plasma-seinämä-vuorovaikutukset ja materiaalien kulkeutuminen kuorintakerroksessa ja (iii) Ohjelmankehitys ja diagnostiikka.

Vuoden 2011 työohjelmassa Euratom-Tekes-assosiaatio osallistui EFDA-JETin koekampanjaan C28, diagnostiikan kehitykseen ja simulointiohjelmien integrointiin. Kaksi tutkijaa toimi JETin käyttöorganisaatiossa; yksi fyysikko (ohjelmistot & mallinnus) ja yksi insinööri (etäkäsittely) ITER-tyyppisen ensiseinän käyttöä valmisteltaessa. Lisäksi assosiaatio osallistui IPP:n ASDEX Upgrade-, GA:n DIII-D- ja MIT:n C-Mod-tokamakin vuoden 2011 koeohjelmiin.

Teknologiatyötä tekevät VTT, Aalto-yliopisto, TTY ja LTY tiiviissä yhteistyössä suomalaisen teollisuuden kanssa. Yritysten osallistumista koordinoi Tekes. Kehitettäviin teknologioihin kuuluvat DTP2-laitteisto VTT:llä Tampereella, materiaalit ja niiden liitostekniikat, tyhjiökammioon liittyvät komponentit, MEMS-pohjaisten diagnostiikkojen kehitys ITERin magneettikenttien mittausta varten, JETin NPA-diagnostiikan päivitys, osallistuminen Power Plant Physics and Technology -tutkimukseen (PPPT), ensiseinämän materiaalit, eroosion, deposition ja materiaalien kulkeutumisen tutkimus sekä pinnoitteiden kehittäminen ja materiaalien mekaaninen testaus ja karakterisointi neutronisäteilytyksen alaisena.

Euratom-Tekes-assosiaatio on mukana kahdessa GOT-hankkeessa: GOTiT (teoria ja mallinnus) ja GOTRH (etäkäsittely), joka alkoi loppuvuonna 2010. GOTRH-hanketta koordinoi TTY. Heinäkuussa 2013 Aalto-yliopisto järjestää EPS:n plasmafysiikan konferenssin Dipolissa Espoossa.

Avainsanat nuclear fusion, fusion energy, fusion research, fusion physics, fusion technology, fusion reactors, fusion reactor materials, ITER remote handling, Euratom

Foreword

In March 2011, the human disaster by the earthquake and tsunami in Japan had a major impact on the Japanese people and society. The infrastructure suffered badly causing among other things delays of the Japanese in-kind contributions to ITER being just a small trouble in the scale of the whole disaster. In Europe, the problem was to find the missing funds for F4E and ITER for the two next year 2012–2013 which are needed to keep the baseline schedule for the project. The decision finally came in December and with that the funds for the accompanying Euratom programme for the next two years. Thus, the year 2011 was critical for ITER in many ways but finally turned out to be positive. At the ITER site in Cadarache the construction work is progressing well as the first buildings and the tokamak building ground are nearly completed.

The Commission proposal for the next framework programme "Horizon 2020" does not follow the recommendation of the independent panel being well below the "Scenario 1". Other feature in the Commission proposal is put ITER outside the budget as a supplementary research programme. Many countries including Finland oppose to this arrangement and would like to see ITER rather inside the Horizon 2020 frame.

In 2011, the emphasis of the Association Euratom-Tekes programme was in the EFDA work programme and in the JET campaign with ITER-like-Wall (ILW). Several tasks of the Task Forces PWI (plasma-wall interactions) and ITM (integrated tokamak modelling) were carried out by the Tekes Association. Both topics are in the core of our research activities. In diagnostics, the NPA upgrade was installed in JET and a F4E Grant for magnetic diagnostics based on micro-mechanical sensors started. Post-mortem analysis of the JET first wall and divertor tiles and related plasma-wall studies continued under JET Technology Task Force.

Two Tekes scientists acted as deputy task force leaders (E2 and FT) for the ILW-experiments. In addition, Tekes provided two JOC secondees, an engineer in the remote handling group and a physicist working modelling and JET code integration and a member to HLST (high level support team for high performance computing). Collaboration with the AUG team at IPP Garching continued in 2011 and has been very important and productive activity for several years. Scientific work at JET and AUG covers transport experiments and modelling, energetic particle physics, NPA diagnostics and plasma-wall and surface studies of divertor tiles. International activities included tokamak experiments in the US and Japan under IEA Implementing Agreement and in two ITPA groups.

Regarding the F4E activities, ITER divertor maintenance development and testing in DTP2 test facility at VTT Tampere has progressed well. Remote handling equipment and operations have been developed and tested, and new tools and methods have been designed. Remote handling will be one of our focus areas in the DEMO design work under the new EFDA department Power Plant Physics and Technology (PPP&T).

I would like to express my most sincere thanks to Tekes and the scientists and engineers of the Finnish and Estonian Research Units their excellent and dedicated work in fusion physics and technology R&D providing in my opinion a valuable contribution to the Euratom Fusion Programme, F4E and ITER.

For me personally, 2011 was the final full year as the Head of Research Unit. My duties as HRU started in March 1995 when the Association Euratom-Tekes was established. I would like to thank also the Commission which played an important and constructive role in the early days of the Tekes Association and helped us to find our role in the Euratom Fusion Programme. We started almost from the scratch but the Finnish programme has established in recent years a firm position in the European Fusion Programme. I have had a privilege to work and establish collaboration with many outstanding colleagues around Europe. I am very confident that my successor Dr. Tuomas Tala will continue and further improve our contribution to European fusion research and ITER.

Seppo Karttunen
Head of Research Unit,
Association Euratom-Tekes

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Appendices

Executive Summary

Overview

Highlights of fusion research carried out by the Association Euratom-Tekes in 2011 are given below. The main activities are experimental work, modelling with related code development and diagnostics related to the main European magnetic fusion facilities JET and AUG. The emphasis in the EFDA work by Tekes was in the Task Forces PWI and ITM. Other EFDA activities in 2011 were carried out within EU Topical Groups, Emerging Technology, Power Plant Physics and Technology as well as in Goal Oriented Training. Significant fraction of Tekes activities was concentrated on work for F4E grants and ITER contracts.

Confinement and transport

Momentum pinch number has been found to have a strong dependence on the inverse density gradient length while the Prandtl number does not haven such a dependence on JET. No q-dependence could be verified. These experimental results are qualitatively consistent with momentum transport theory and gyrokinetic simulations. Similar NBI modulation experiments on AUG show that the Prandtl number is close to one consistent with the strong coupling between ion heat and momentum transport and that there is an inward momentum pinch with a magnitude similar to the ones found on JET and DIII-D. In order to extrapolate the rotation profile to ITER, the density profile must be known. [JET Orders and Notifications, ITPA T&C activity, WP11-TRA-04]

Essential advancement in the applications was found in comparing Elmfire code predictions for poloidal rotation and its velocity oscillations with the Doppler reflectometric experiments. This was thanks to verification of both momentum and energy conservation in the simulations. Experimental TEXTOR parameters for L- and H-mode plasmas were used to initialize Elmfire simulation. In the H-mode simulation, the steep density profile was maintained while for L-mode profiles, strong geodesic acoustic modes were observed together with strongly correlated oscillatory particle flux which leads to profile relaxation. [WP11-TRA-01]

Energetic particle physics

The ASCOT code has been used to simulate the effects of ITER TBMs and ELM control coils on fast ion losses as part of the activities of the ITPA energetic particles topical group. The results suggested intolerable losses, but further analysis revealed this to be due to over-simplified modelling of the magnetic field perturbation. In ASDEX Upgrade, where the fast ion losses due to newly installed in-vessel coils were modelled, artificial stochastization of the magnetic field at the plasma edge was not as much of an issue. The results indicated that the in-vessel coils have a detrimental effect particularly on the confinement of parallel neutral beams. However, they also showed that this effect can be reduced by increasing the total magnetic field. What comes to code development, a model for various MHD mode perturbations (e.g. neoclassical tearing modes and Alfvén eigenmodes) has been implemented on ASCOT. [WP11-DIA-01, WP11-HCD-01]

Power and particle exhaust, plasma-wall interactions

In 2011, we completed the SIMS and optical microscopy analysis of the last set of carbon tiles removed from JET. The results confirm clear erosion on the outer divertor and deposition on the inner divertor. In addition, following the marker injection experiment at the end of C27, ^{13}C deposition profiles on the tiles were determined and the results were simulated with DIVIMP and ERO codes. Also erosion and transport of tungsten was modelled for JET type-I ELMy H-mode plasmas using EDGE2D/EIRENE and DIVIMP. [JET Orders and Notifications]

Simulations of lower single null, ohmic and L-mode plasmas in DIII-D, AUG, and JET with the UEDGE, SOLPS, and EDGE2D/EIRENE codes predict that the flux of neutrals crossing the separatrix is localized close to the divertor x-point. Depending on the strength of radial transport in the far SOL, the calculated fueling profiles also peak at the low field side midplane. The open divertor geometry with horizontal targets in DIII-D is predicted to produce broader fueling profiles than the closed geometries with vertical targets in AUG and JET. Dedicated studies with SOLPS for hydrogen and deuterium L-mode-type plasmas in AUG showed that over a range of both attached and detached divertor plasmas, the heavier the bulk plasma ions, the lower the neutral fuelling. [ITPA DSOL activity]

In ASDEX Upgrade, the full 3D wall geometry was used in impurity migration modelling with ASCOT-PWI, and the predicted strong asymmetry for the deposition of ^{13}C was confirmed in the July 2011 tracer injection experiment. In particular, the ICRH antenna limiters were significant deposition sinks for carbon. The results have a strong influence the estimated overall deposition of impurity elements. PFC erosion and deuterium retention in the outer strike zone and outer midplane of ASDEX Upgrade were investigated using marker tiles and erosion probes, supported with ERO modelling with promising results. For local $^{13}CH_4$ injection experiments, detailed SOLPS5.0-ERO simulations showed that the observed migration pathways of ^{13}C in the W divertor can be considered to be relevant for impurities in general. This observation emphasizes the importance of considering **E x B** drifts for material migration in the divertor region. Uncertainties were identified in the description of the magnetic pre-sheath properties in the integrated plasma/impurity migration simulations. [WP11-PWI-01; WP11-PWI-03; WP11-PWI-04]

Laser induced plasma spectroscopy (LIBS) is being developed for in-situ characterisation of plasma-wall interactions. In 2011, an experimental set-up for LIBS studies of beryllium-containing samples was built at VTT. At University of Tartu, a considerable increase of the recovering distance of LIBS spectra has been achieved and the correlation between LIBS recordings and laser-produced craters were studied. The XRD analysis of samples exposed to Pilot PSI plasma showed that the plasma significantly changes the phase structure of the wall material, which affects, e.g., the sputtering rates. Accelerator Mass Spectrometry (AMS) is developed for tritium depth profile measurements in JET divertor tiles, focusing on efficiency studies of tritium removal by laser ablation from plasma facing surfaces on divertor tiles. High detection sensitivity and adequate spatial resolution have made the detection technique a valuable tool for tritium studies in plasma facing components. [WP11-PWI-03, JW9-FT, JW11-FT]

Systematic MD simulations of different W and C mixtures (W, WC, W_2C) under low-energy (10–300 eV) deuterium (D) irradiation was continued in 2011. Also, in the context of the new ILW-JET, MD simulations of low energy (10–200 eV) Be and D+Be irradiation on W were introduced. [WP11-PWI-05]

Diagnostics

A new detector flange with thin silicon detectors for JET NPA diagnostics was tested and commissioned in 2011. Neutrals from plasma were successfully detected. [JET Orders and Notifications]

To measure the HFS flow of low charge state carbon in the AUG SOL, and to infer the deuteron speed from the measurements, methane was injected and its break-up followed with a spectrometer and fast video cameras. The experimental data, together with ERO simulations, were used to produce radial SOL flow profiles of deuterons and carbon ions. [WP11-PWI-03]

Modelling for ITER, code development and integration

The Association’s participation in EFDA Task Force ITM activities in 2011 covers implementation, integration, verification and validation of ASCOT, Elmfire, SOLPS5.0 and ERO as well as the RFOF module. Now ASCOT and its standalone NBI module are running in a Kepler workflow. In addition, a method was developed to generate 3D wall structures in CPO format from AUG CAD data. Fusion cross section data was implemented in AMNS. [WP11-ITM]-AMNS, WP11-ITM-EDRG, WP11-ITM-IMP3, WP11-ITM-IMP4, WP11-ITM-IMP5]

MHD stability analysis of JET hybrid scenario plasmas has been carried out. In addition, simulations with the EDGE2D/EIRENE edge transport code were matched against experimental data in order to try to establish how the separatrix boundary conditions in JET ELMy H-mode plasmas vary as a function of plasma parameters such as edge safety factor and power. [WP11-ITM-ISM]

Elmfire and ASCOT are supported by the HLST. Recent HLST work includes the development of an orthogonal filtering technique of charge separation to obtain dynamically stable neo-classical equilibrium as well as memory, I/O and HPC-FF support. ASCOT 4, a completely rewritten code version with greatly simplified structure and new features, entered the testing and benchmarking phase. For ERO we developed more fexible handling of complex wall geometries and a set of synthetic spectroscopic diagnostics. [WP09-HPC-HLST, WP11-PWI-03]

Emerging technology and PPPT

VTT's RAMI project has produced general guidelines on how a competent Reliability, Availability, Maintainability and Inspectability (RAMI) approach for technical risk management could be established for the DEMO development process. Applicability of the ITER divertor maintenance scheme to the DEMO divertor was investigated. The remote handling maintenance task is similar to ITER, but the characteristics of DEMO set different requirements for the maintenance procedure and the maintenance devices. [WP11-DAS-RH-02, WP11-DAS-RH-08]

Incremental effects of impurity seeding were studied in the edge plasmas of ASDEX Upgrade and JET in order to predict power exhaust in future fusion reactors. The work in 2011 involved assessment of existing experimental data, planning of new experiments for model validation, and preparation of SOLPS5.0 simulations with both intrinsic and extrinsic impurities. [WP11-PEX-01]

Fusion for Energy and ITER

DTP2 trials included successful CMM/SCEE recoverability tests and second cassette replacement trials subject to cassette misalignments. Control systems of CMM and WHMAN were updated. Design and procurement activities focused on improvement of the second cassette end-effector as well as on design of the diagnostic rack end-effector and the CTM tunnel umbilical. The Remote Handling Control System is used in DTP2 control room for handling the prototypes of ITER divertor maintenance system. In 2011 the necessary analyses and design of the control system were completed, the system was implemented and is entering the demonstration phase. A new modular ITER divertor cassette mock-up was designed. [F4E-GRT-143, ITER/CT/10/4300000179]

Preliminary sensor specifications and environmental constraints for ITER magnetometers were reviewed. New prototype sensors were designed with improvements to radiation hardness and performance, lithography mask drawings were prepared and fabrication of the sensors was started. Sensor enclosure has been designed and simulations of the readout electronics have been started. [F4E-2010-GRT-156]

1. Overview of 2011 Activities

This Annual Report summarises the fusion research activities of the Finnish and Estonian Research Units of the Association Euratom-Tekes in 2011. The Estonian Research Unit was established by the Agreement between Tekes and the University of Tartu in 2007. The emphasis of the new EFDA is in exploiting JET, physics support for ITER and in DEMO activities coordinated by the new EFDA department of Power Plant Pysics and Technology (PPPT). In addition, Tekes Association participated in the Goal Oriented Training (GOT) programme, HPC Implementing Agreement and SERF studies under EFDA. ITER related technology R&D is now under the responsibility of F4E – the European Domestic Agency for ITER (Joint European Undertaking for ITER and the Development of Fusion Energy – Fusion for Energy, Barcelona).

The activities of the Tekes´ Research Unit are divided in the fusion physics under the Contract of Association and EFDA. A New F4E R&D Grant work on magnetic diagnostics started and the running second F4E Grant for ITER divertor maintenance continued in 2011.

The Physics Programme is carried out at VTT Technical Research Centre of Finland, Aalto University (AU), University of Helsinki (UH) and University of Tartu (UT, Estonia). The research areas of the Physics and EFDA Programme are:

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

Association Euratom-Tekes participated actively in the EFDA JET Workprogramme 2011 preparing and participating in the experimental campaign C28. Two persons were seconded to the UKAEA operating team, a physicist in codes & modelling and an engineer in remote handling for installing the ITER-like wall (ILW) in JET. Tekes provided new Deputy TFLs for JET TF E2 and Fusion Technology. Practically all physics activities of the Research Unit are carried out in cooperation with other Associations with the focus on EFDA JET work, physics support for ITER and experimental programme of ASDEX Upgrade (AUG).

Several staff mobility visits of total 642 days took place in 2011. The visits were hosted by the Associations IPP Garching (301 days, MA Art. 1.2.b collaboration), JET/CCFE Culham (103 days), CEA Cadarache (24 days), VTT (21 days), University of Innsbruck (20 days), ENEA Frascati (18 days), Univeristy of Cyprus (18 days), FOM Rijnhuizen (16 days), FZ Jülich (9 days) and ITN Lisbon (5 days). Other staff mobility actions were EFDA meetings (PWI, ITM, FT, TGs; 77 days), ITPA meetings (19 days) and MIT US (11 days) for IEA Large Tokamak experiments. In 2011 Tekes (Aalto University) hosted three meetings eligible for Staff Mobility.

The Technology work is carried out at VTT and Tampere University of Technology (TUT) in close collaboration with Finnish industry. Industrial participation is coordinated by Tekes. The technology research and development is focused on the remote handling, fabrication methods for vessel/in-vessel and TF components plus some activities in ITER and JET diagnostics and JET Technology related to ILW:

- Divertor Test Platform (DTP2) at VTT in Tampere for remote handling of divertor maintenance and development of water hydraulic tools and manipulators and cassette locking systems
- Magnetic diagnostics based on micromechanical sensors (MEMS) for ITER
- Application of powder HIP method for fabrication of ITER vessel/in-vessel and TF components
- Plasma facing materials issues, erosion/re-deposition and material transport studies and developing coating techniques
- In-reactor mechanical testing and characterisation of materials under neutron irradiation
- Modelling of ripple losses and wall loadings for ITER
- Upgrading of the NPA diagnostics for JET
- Feasibility study for micromechanical magnetometers.

The two days Annual Fusion Seminar of the Association Euratom-Tekes was held on M/S Silja Serenade between Helsinki and Stockholm. The invited speaker was Dr. Gianfranco Federici from EFDA presenting the new PPPT programme which will play an increasingly important role in the future activities of the Tekes Association. Guest speakers from the Swedish VR Association Prof. James Drake and Dr. Per Petersson joined the seminar from Stockholm.

Tekes decided to continue the present programme for the next two years 2012–2013 in harmony with the Euratom FP7 extension.

2. Fusion Programme Organisation

2.1 Programme Objectives

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

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

This can be achieved by close collaboration between the Research Unit and Finnish industry, and by strong focusing the R&D effort on a few competitive areas. Active participation in the JET and EFDA Work Programmes and accomplishing ITER technology development Grants by Fusion for Energy provide challenging opportunities for top level science and technology R&D work in research institutes and Finnish industry.

2.2 Association Euratom-Tekes

The Finnish Funding Agency for Technology and Innovation (Tekes) is funding and co-ordinating technological research and development activities in Finland. The Association Euratom-Tekes was established on 13 March 1995 when the Contract of Association between Euratom and Tekes was signed. Other agreements of the European Fusion Programme involving Tekes are the multilateral agreements: European Fusion Development Agreement (EFDA), JET Implementing Agreement (JIA), Staff Mobility Agreement and HPC Implementing Agreement. Tekes and the University of Tartu (Estonia) signed an Agreement in 2007 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 officer in Tekes is Mr. Juha Lindén. The fusion related industrial activities were co-ordinated by Tekes. The Finnish Industry Liaison Officer (ILO) is Mr. Hannu Juuso from Tekes.

2.3 Research Unit

The Finnish Research Unit of the Association Euratom-Tekes consists of several research groups from VTT and universities. The Head of the Research Unit is Mr. Seppo Karttunen from VTT. The following institutes and universities participated in the fusion research during 2011:

1. VTT Technical Research Centre of Finland
    - VTT Materials and Buildings (co-ordination, physics, materials, diagnostics)
    - VTT Industrial Systems (remote handling, beam welding, DTP2)
    - VTT Microtechnologies and Sensors (diagnostics)
2. Aalto University, School for Science
    - Department of Applied Physics
3. University of Helsinki (UH)
    - Accelerator Laboratory (physics, materials)
4. Tampere University of Technology (TUT)
    - Institute of Hydraulics and Automation (remote handling, DTP2).

The Estonian Research Unit of the Association Euratom-Tekes consists of research groups from the University of Tartu. The Head of the Estonian Research Unit is Mr. Madis Kiisk from University of Tartu.

There are three Finnish persons in the ITER IO team, in Cadarache and two Finns in the F4E staff in Barcelona.

2.4 Association Steering Committee

The research activities of the Finnish Association Euratom-Tekes are directed by the Steering Committee, which comprised the following members in 2011:

Chairman 2011	Mr. Juha Lindén, Tekes
Members	Mr. Ruggero Giannella, EU Commission, Research DG
	Mr. Vito Marchese, EU Commission, Research DG
	Mr. Marc Pipeleers, EU Commission, Research DG
	Mr. Pentti Kauppinen, VTT
	Mr. Harri Tuomisto, Fortum Oy
Head of Research Unit	Mr. Seppo Karttunen, VTT
Head of Estonian RU	Mr. Madis Kiisk, UT, Estonia
Finnish ILO	Mr. Hannu Juuso, Tekes
Secretary	Mr. Tuomas Tala, VTT

The Association Steering Committee (ASC) had one meeting in 2011 held in Tartu, Estonia, 17–18 October 2011. Ruggero Giannlella and Marc Pipeleers from the Commission were present and Vito Marchese from the Commission from Brussels and the EFDA Leader Francesco Romanelle from EFDA CSU participated through the video link. All Finnish and Estonian ASC members participated in the meeting.

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 research activities are steered by three Topical Advisory Groups for 1) physics and diagnostics chaired by Seppo Nenonen Oxford Instruments Analytical, 2) for materials research chaired by Ilkka Vuoristo, Luvata Oy and 3) for remote handling systems chaired by Olli Pohls, Hytar Oy. In 2011, the national steering committee consisted from the members of the three advisory groups.

Chairman	Janne Ignatius, CSC
Members	Henrik Immonen, Abilitas Group
	Hannu Juuso, Tekes
	Juhani Keinonen, HY
	Jukka Kolehmainen, Diarc Oy
	Mika Korhonen, Hollming Works Oy
	Risto Kuivanen, VTT
	Juha Lindén, Tekes/ELY
	Pasi Latva-Pukkila, Sandvik Underground Technology
	Timo Laurila, Tekes
	Seppo Nenonen, Oxford Instruments Analytical Oy
	Pertti Pale, PPF Projects
	Olli Pohls, Hytar Oy
	Pentti Pulkkinen, Suomen Akatemia
	Reko Rantamäki, Fortum Oyj
	Solveig Roschier, Tekes
	Rainer Salomaa, Aalto University
	Pekka Siitonen, Metso Powdermet Oy
	Sisko Sipilä, Tekes
	Arto Timperi, Norrhydro Oy
	Pekka Tuunanen, Teknologiateollisuus ry
	Matti Vilenius, TTY/IHA
	Ilkka Vuoristo, Luvata Oy
Head of Research Unit	Seppo Karttunen, VTT
Secretary	Tuomas Tala

The national steering committee had two meetings in 2011.

2.6 Finnish Members in the European Fusion Committees

Euratom Science and Technology Committee (STC)

Rainer Salomaa, Aalto University

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
Juha Lindén, Tekes
Marco Kirm, UT, Estonia
Madis Kiisk, UT, Estonia
EFDA Steering Committee
Juha Lindén, Tekes
Seppo Karttunen, VTT
Madis Kiisk, UT, Estonia

Science and Technology Advisory Committee (STAC)

Jukka Heikkinen, VTT

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

Juha Lindén, 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 ExCo)

Kari Törrönen, Energywave (until September 2011)
Herkko Plit, Fortum (from September 2011)

Other international duties and Finnish representatives in the following fusion committees and expert groups in 2011:

- Seppo Karttunen and Reijo Munther are members of the IEA Fusion Power Co-ordinating Committee (FPCC).
- Jukka Heikkinen, Chairman of the International Programme Committee of the Plasma Edge Theory Workshop (PET).
- Taina Kurki-Suonio is the Chairman of the Local Organisation Committee on the 40th EPS Plasma Physics Conference, Espoo, Finland, July 2013.

- Taina Kurki-Suonio is a member of the International Programme Committee of the 39th EPS Conference on Plasma Physics, Stockholm, Sweden, June 2012.
- Tuomas Tala is a member of the ITPA expert group on transport and confinement. Taina Kurki-Suonio is a member of the ITPA expert group on energetic particles.
- Taina Kurki-Suonio is a member of the Programme Committee of the ASDEX Upgrade project, Max-Planck-Institut für Plasmaphysik.
- Salomon Janhunen is a member of the High Level Support Team for HPC-FF
- Jukka Heikkinen is a Comments Editor of Physica Scripta.
- Markus Airila is the Tekes administrative contact person in EFDA JET matters and representative in EFDA Public Information Network (PIN).
- Hannu Juuso is an Industry Liaison Officer for F4E and Pertti Pale is a consultant for Fusion-Industry matters.
- Harri Tuomisto is a member of the Fusion Industry Innovation Forum Management Board (FIIF MB).

2.7 Public Information Activities

The two days Annual Fusion Seminar of the Association Euratom-Tekes was held on M/S Silja Serenade between Helsinki and Stockholm. The invited speaker was Dr. Gianfranco Federici from EFDA CSU Garching presenting the new PPPT programme which will play an increasingly important role in the future activities of the Tekes Association. Guest speakers from the Swedish VR Association Professor James Drake and Dr. Per Petersson joint the seminar from Stockholm. The number of participants was 65.

Fusion research was a theme in the Seminar organised by the Finnish Nuclear Scociety chaired by Kari Törrönen and Eero Patrakka. Dr. Maurizio Gasparotto gave an overview on ITER construction and Fusion for Energy activities and Dr. Seppo Karttunen presented the highlights of the Euratom-Tekes fusion research.

The Annual Report of the Association Euratom-Tekes, *Fusion Yearbook 2010,* VTT Publications **764** (2011) 177 pp. was published for the Annual Seminar and distributed to Head of Reasearch Units and key persons of the Euratom Associations, EFDA and F4E.

Tuomas Tala gave an interview on the status of Fusion program and ITER for the PRISMA TV-program at VTT (broadcast on 24 March, 2011). Markus Airila gave an interview on JET and its ITER-like wall for Tekniikka & Talous newspaper (published in online version on 5 September, 2011) and for Tiede magazine 10/2011. Seppo Karttunen, Markus Airila and Juha Lindén gave an interview on the development of fusion energy for Energia & Ympäristö magazine 3/2011.

Lecture course "*Introduction to Plasma Physics and Fusion*" by S. Karttunen was given in spring 2011 at the School of Science in the Aalto University.

In 2011 we organized several international meetings:

- Joint Working Session of SEWGs Material Migration and ITER Material Mix on Model Validation, Tervaniemi, Finland, 31 January–2 February, 2011
- ITPA Divertor and Scrape-Off-Layer expert meeting, Dipoli Congress Centre, Espoo, Finland, 16–19 May 2011
- ITM Code Camp, Aalto University, Espoo, Finland, 16–27 May 2011
- Joint meeting of the SEWGs on material migration and ITER material mix of the EFDA TF PWI, Aalto University, Espoo, 19–20 May, 2011.

Aalto University and VTT will host the 40th EPS Conference on Plasma Physics in Finland in July 2013. The venue is Dipole Congress Centre in Otaniemi Campus just a few kilometres from the downtown Helsinki.

2.8 Funding and Research Volume 2011

In 2011, the expenditure of the Association Euratom-Tekes was about € 5.48 million including Staff Mobility actions and F4E & ITER contracts (see Fig 2.1). 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, Aalto, TUT, UH, LUT and UT) and from industry. The total research volume of the 2011 activities was about 50 professional man-years.

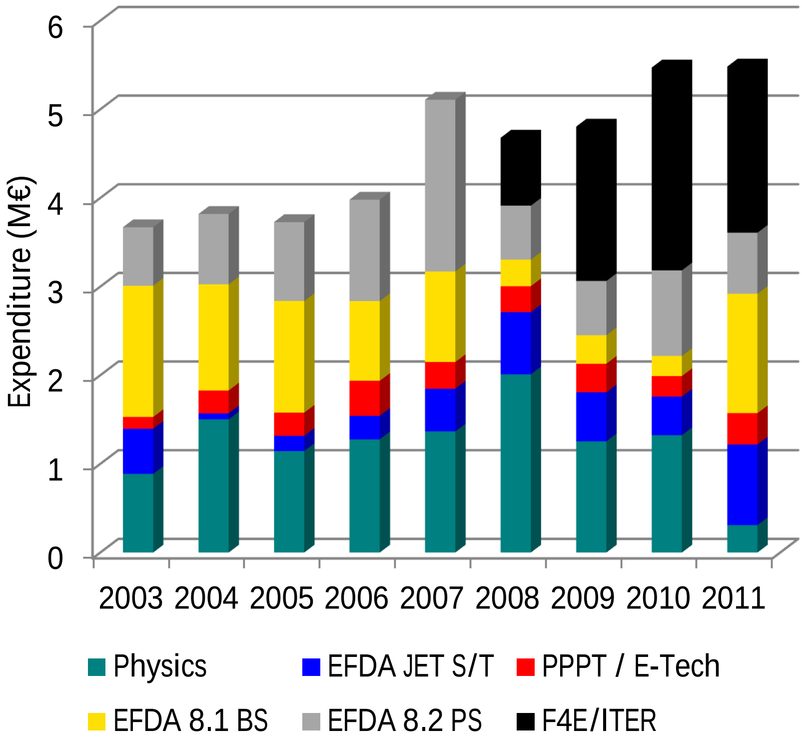


Figure 2.1. Expenditure (in Mio €) of the Association Euratom-Tekes for different physics and technology R&D activities in 2003–2011. The total expenditure was € 5.48 million. The EFDA 8.1 and 8.2 sections cover the participation in ITM and PWI Task Forces, Topical Groups and GOT as well as Staff Mobility.

3. EFDA Fusion Physics and Materials Research

Institute: **VTT Technical Research Centre of Finland**
Research scientists: Dr. Seppo Karttunen (Head of Research Unit), Dr. Leena Aho-Mantila, Dr. Markus Airila, Dr. Antti Hakola, Dr. Jukka Heikkinen (Project Manager), MSc. Seppo Koivuranta, Dr. Jari Likonen (Project Manager), Dr. Tuomas Tala (TFL transport), MSc. Seppo Tähtinen (Project Manager)
Students: Eetu Ahonen, Juuso Karhunen, Paula Sirén

Institute: **Aalto University (AU) School of Science**
Research scientists: Prof. Rainer Salomaa (Head of Laboratory), Dr. Pertti Aarnio, MSc. Otto Asunta, Dr. Mathias Groth (Deputy TFL), MSc. Eero Hirvijoki, MSc. Salomon Janhunen, Dr. Timo Kiviniemi, MSc. Tuomas Korpilo, MSc. Tuomas Koskela, Dr. Taina Kurki-Suonio, MSc. Susan Leerink, Dr. Johnny Lönnroth (JOC Secondee), MSc. Toni Makkonen, MSc. Juho Miettunen, MSc. Antti Salmi, Dr. Marko Santala, Dr. Seppo Sipilä, MSc. Antti Snicker, MSc. Simppa Äkäslompolo
Students: Aaro Järvinen, Toni Kaltiaisenaho, Ville Lindholm, Paavo Niskala

Institute: **University of Helsinki (UH) Accelerator Laboratory**
Research scientists: Dr. Tommy Ahlgren, Dr. Carolina Björkas, Dr. Flyura Djurabekova, Dr. Kalle Heinola, Dr. Krister Henriksson, Prof. Juhani Keinonen (Head of Laboratory), MSc. Ane Lasa, MSc. Andrea Meinander, Dr. Lotta Mether, Prof. Kai Nordlund (Project Manager), Dr. Katharina Vörtler

Companies: Diarc Technology, Oxford Instruments Analytical
Collaborators: UKAEA, IPP Garching, SCK-CEN, University of Tartu, FZ Jülich, EFDA-JET Contributors

3.1 Introduction

The fusion physics work has been performed in close co-operation between VTT Technical Research Centre of Finland and the School for Science and Technology of the Aalto University (AU). Participation in the EFDA JET and EFDA Workprogrammes is the first priority in the fusion physics activities of the Association Euratom-Tekes. Participation in the JET campaign C28 has been very active with 13 scientists being on-site in JET. In addition, further notification work related to the analysis of the results from the last experimental campaigns C26-C27 and in the AUG programme at IPP Garching has continued. JET and AUG work are carried out in co-operation with other Euratom Associations. Main topics were transport and fast particle studies, plasma-wall interactions and diagnostics. One person was seconded to the UKAEA JOC team one for the code development work. The fusion plasma simulation groups at VTT, Aalto University and the University of Helsinki provide an important modelling and support centre in fusion physics, code development & integration and plasma engineering for EFDA, F4E and ITER. In the area of plasma-wall interaction, surface analyses of plasma facing materials and samples supported by computer modelling of erosion and material transport in scrape-off-layer (SOL) are the key points. Advanced coatings, wall diagnostics with smart tiles and plasma processing of materials are carried out in collaboration with industry.

3.2 Energy and Particle Confinement and Transport

3.2.1 NBI modulation Experiments on JET to Study Parametric Dependencies of Momentum Transport

EFDA JET Activity:	JW8-O-TEKE-17 and JW8-N-TEKE-20
Research scientist:	T. Tala, VTT
Collaboration:	EFDA-JET Contributors

Momentum transport and plasma rotation have been studied extensively on many tokamaks in recent years. Both experiments and theory have shown that sheared plasma rotation can stabilise turbulence while the rotation itself has beneficial effects on MHD modes, such as resistive wall modes. In order to be able to predict rotation profile for example in ITER, one needs to know the torque sources and sinks, edge rotation and momentum transport. The topics of this work are the detailed studies of parametric dependencies of momentum transport in JET and then in the following section the first attempts to study momentum transport on AUG and C-Mod (MIT, Boston) tokamaks by means of perturbative methods.

The NBI modulation experiments have been carried out in different types of JET plasmas to study the parametric dependencies of momentum pinch and Prandtl numbers. Most of the plasmas in these scans are in the following parameter regime: low collisionality JET H-mode plasmas at $B_T = 3$ T, $I_p = 1.5$ MA and $n_{e0} \sim 4\times10^{19}$ m^{-3}. Total power levels were up to 15 MW for NBI, including the modulation, and 0–4 MW for ICRH in H minority scheme. Some of the pulses were done with much less power (~4–5 MW) so that they stayed in L-mode. Earlier studies showed that there is no dependence of the pinch number or the Prandtl number on collisionality. Probably the most interesting parametric dependence to be studied is the dependence of the momentum pinch and Prandtl number on the inverse density gradient length R/L_n. There is no simple way to perform a clean R/L_n scan in a tokamak without changing some other dimensionless parameter simultaneously. However, since no dependence of momentum transport coefficients on collisionality was found in the collisionality scan experiment in discussed in the previous section, it is possible to scan R/L_n by varying collisionality and assign the possible changes in momentum transport to be caused by R/L_n rather than collisionality.

The dependence of the Prandtl number on R/L_n is illustrated in Figure 3.1(a). The single value of Pr attached to each shot is based on the average value of Pr between $0.4 < \rho < 0.8$. Also, R/L_n reflects the average value from the same radial range. The large range in R/L_n among the shots has been achieved mainly by varying collisionality, density and the amount of the NBI heating power. It is evident in Figure 3.1(a) that the Prandtl number does not depend on R/L_n as the scatter of the points is uniform. The red points are from linear GS2 simulations using the input data. Consistently with experimental results, the Prandtl number is not found to depend on R/L_n by GS2.

While no dependence of the Prandtl number on R/L_n was found, a clear trend is found for the pinch number. This is illustrated in Figure 3.1(b) where a strong dependence of the pinch number is plotted against R/L_n by the black points. The red points correspond to the GS2 simulations based on the experimental shots. GS2 runs also show an increase in $-Rv_{pinch}/\chi_\phi$ with increasing R/L_n although the trend is much weaker than in the experimental data. Fitting a line through the experimental cloud of points, one obtains the following relation:

$$-\frac{Rv_{pinch}}{\chi_\Phi} \approx \frac{1.2R}{L_n} + 1.4 \tag{1}$$

What is also straightforward to conclude from the dependence above is that without knowing the inverse density gradient length, it will be challenging to estimate the momentum pinch number. When R/L_n ranges from 1 to 3 (typical values in present tokamak plasmas), $-Rv_{pinch}/\chi_\phi$ ranges from 2.6 to 5, resulting in a large difference in rotation peaking. This strong dependence also has consequences to ITER predictions.

A 3-point q-scan was performed on JET by keeping the magnetic field at B = 3.0 T, the variation in q was obtained firstly by increasing I_p from 1.5 MA to 2.5 MA and secondly by adding 3 MW of ICRF heating to delay current diffusion during and after the current ramp-up. The observed weak q-dependence of the pinch number seems larger than the one induced by the difference in R/L_n between the high and low q shots. However, taking into account of the actual error bars as indicated in the plot, no solid conclusion can be drawn about the momentum pinch number dependence on q although the scan may suggest a possible weak dependence.

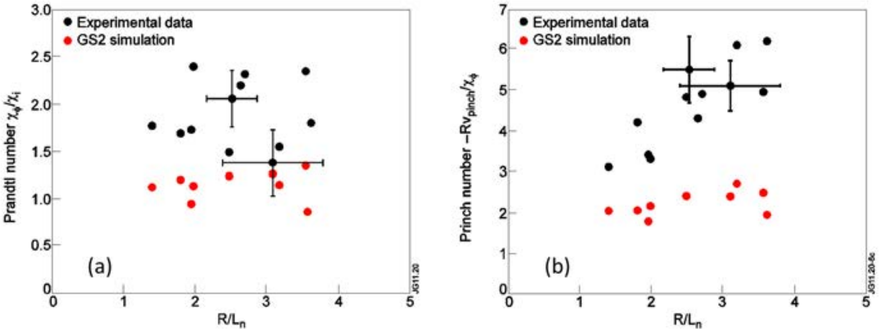


Figure 3.1. (a) Experimental (black dots) and simulated (red dots) Prandtl numbers $P_r = \chi_\phi/\chi_i$, averaged over the range $0.4 < \rho < 0.8$, as a function of the inverse density gradient length R/L_n. (b) As in (a), but for the pinch number.

3.2.2 Momentum transport studies on AUG and C-Mod

ITPA Activity:	ITPA T&C, WP11-TRA-04-01
Research scientist:	T. Tala, VTT
Collaboration:	AUG team, IPP-Garching C-Mod team, MIT

NBI modulation technique to create a periodic rotation perturbation has been also exploited on AUG in the same way as on JET reported in section 3.2.1. Furthermore, the analyses of the data from each tokamak have been performed with JETTO transport code using the time-dependent NBI torque profiles from TRANSP, and are thus based on exactly the same analysis method and tools as the ones used for JET data. A good 10 physics discharges have been obtained during parts of several run days on AUG in 2011 to study momentum transport within the ITPA TC-15 joint experiment. About a factor of 4 variation in collisionality was achieved on AUG by varying the NBI and ECRH power levels. A decent q scan was performed with q_{95} varying from 4 to 6.

To summarise the preliminary scientific outcome, one can conclude that 1) the Prandtl number is close to one consistent with the strong coupling between ion heat and momentum transport as expected with ITG turbulence and 2) there is an inward momentum pinch with a magnitude similar to the ones found on JET and DIII-D. This is illustrated in Figure 3.2. The upper row shows the quality of the fit for the amplitude (left), phase (middle) and steady-state (right) rotation between the experimental simulated data. For this AUG shot 26270, the fit using the Prandtl number (lower row middle) and pinch velocity (lower row right) is within the experimental error bars for most of the radii in amplitude, phase and steady-state profiles. More extensive data analysis is on-going, and also taking into account the possible role of intrinsic torque term.

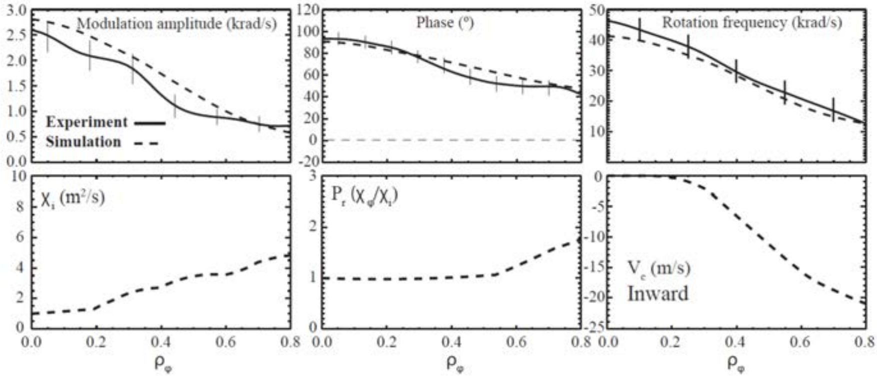


Figure 3.2. Top row: experimental (solid lines) and simulated (dashed lines) rotation modulation amplitude (left), phase (middle) and steady-state profile (right) for discharge 26270. Bottom row: TRANSP calculated thermal ion heat diffusivity (left), best fit Prandtl number (middle) and pinch velocity (right).

More detailed analysis of several shots is planned next year in AUG to exploit all the good physics shots. The preliminary results from the intrinsic torque analysis indicate that in NBI heated plasmas, this component is non-zero and should be taken into account also in the momentum transport studies, thus possibly modifying the Prandtl and pinch number profiles significantly at least under some specific conditions.

One run day was devoted to the ITPA TC-15 experiment on C-Mod in January 2011. The run day consisted on trying 3 different techniques (LHCD modulation, diagnostic NBI modulation (DNBI) and septum sweeping between the upper and lower null configurations (SSEP)) to create a periodic perturbation for the toroidal rotation. LHCD modulation created a suitable rotation perturbation, but the T_e modulation was massive, more than 50 %, thus the plasma is not stationary enough for any meaningful momentum transport analysis. DNBI modulation on the other hand did not perturb the plasma but did not create any observable rotation perturbation either to yield momentum transport coefficients. This technique, however, was not yet fully optimised and could be tried again during another run day. A couple of shots were run with SSEP modulation, i.e. modulating between the upper null and lower null configurations at 8 Hz frequency. It turned out that SSEP modulation can create a non-perturbative rotation modulation on C-Mod. This ITPA experiment will continue on C-Mod in 2012 with an emphasis on the SSEP modulation and possibly ICRH power modulation so that the parametric scans can be performed.

3.2.3 Studies on intrinsic plasma rotation

EFDA task:	WP11-TRA-04
Research scientists:	J. Heikkinen, VTT S. Leerink, AU

The Elmfire code was further developed and tested for full-f gyrokinetic global tokamak plasma simulations with accurate toroidal angular momentum conservation. Gyrokinetic equations of motion, Poisson equation, and energy and momentum conservation laws were derived based on the reduced-phase-space Lagrangian and inverse Kruskal iteration [J.A. Heikkinen and M. Nora, Phys. Plasmas **18**, 022310 (2011)]. The expression of the toroidal angular momentum valid up to second order in gyrokinetic parameter was worked out from this formalism. The resulting angular momentum was studied by Elmfire simulations in the presence of hydrogen plasma relaxation in a small FT-2 tokamak configuration ($a = 8$ cm, $R = 55$ cm, $I = 19$ kA, $B = 2.2$ T) up to plasma energy confinement time scale ($\lesssim 1$ ms). Magnetic ripple was neglected. Special care was taken in identifying the diagnostic radial plasma region for the calculation of the toroidal angular momentum. It was found that in order to evaluate the toroidal angular momentum within a certain radial region, various mechanisms exchanging momentum across the boundaries of this region had to be accounted for, like the ion gyroradius, finite particle size in the PIC simulation method, interpolations adopted, and convection of the particles in and out of the region. Exchange of momentum across the boundary by interpolation and integration algorithms cannot be properly analysed during the simulation so that exact verification of the conservation of the angular momentum is not possible to do in general. However, by specific numeric techniques it was possible to verify the conservation. A specific momentum conservation interpolation algorithm had to be developed. The toroidal angular momentum was found to be conserved within 1–2 % accuracy over the energy confinement time. This verification work has been accepted for publication in Computer Physics Communications. The radial profiles of the toroidal angular momentum were analysed during the relaxation in the simulations performed, but the work is still ongoing.

3.2.4 Thermal ion TF ripple torque and toroidal rotation on Tore Supra

EFDA task:	WP11-TRA-04-01-01
Research scientist:	A. Salmi, VTT
Collaboration:	C. Fenzi, CEA

Tore Supra has large intrinsic toroidal field ripple, thus providing a good platform for studying ripple effects. The motivation of the present study is to see if guiding centre simulations can help to understand the magnitude of momentum sources due to thermal ion and fast ion ripple effects, and whether they are consistent with observed rotation.

To estimate the NBI torque in the presence of ripple, a new NBI module was implemented with Tore Supra geometry. Furthermore, a 3D vacuum ripple map was generated and turned into ASCOT format together with other background data including the radial electric field measurements with Doppler reflectometry. To verify that the implementation of the NBI and the plasma data conversions were successful, code-to-code benchmarking against NEMO and SPOT were performed. Excellent agreement was found for beam parameters without ripple.

The actual physics simulations were then conducted for five discharges of different size where the ripple varied from 0.5 % to 5.5 %. For each discharge, both the thermal ion ripple contribution and the NBI ripple contribution to the total torque were estimated. It was found that the counter-torque from ripple was less in smaller plasmas with smaller ripple for both fast and thermal ions. The torque deposition profile for the smallest ripple plasma is shown in **Figure 3.3**.

The scan showed that the ~0.4 Nm of torque injected from the NB was not greatly modified in the smaller plasmas while roughly 60 % of this co-current torque was cancelled due to the ripple effect in the largest plasmas. A similar trend was seen in thermal ion ripple torque (NTV) evaluation. The magnitude of NTV torque was found to be ~1 Nm and below in smaller plasmas and more than 1 Nm in the large plasmas with large ripple in counter-current direction. The estimates agree well qualitatively with the rotation measurements and show that ASCOT estimates of NTV torque are of reasonable magnitude. Further transport analysis is required to link the momentum sources to momentum more quantitatively.

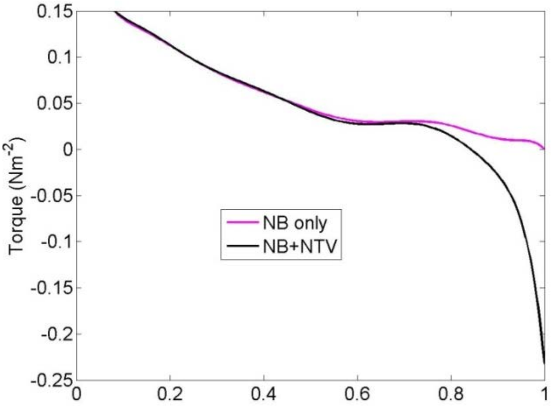


Figure 3.3. Torque profiles for #43304 (δ = 0.5 %) with the diagnostics NB contribution and thermal ions ripple torque (NTV).

3.2.5 Triggering of L-H transition, L-H power threshold and impact of ELM control techniques, role of momentum transport through plasma edge

EFDA task:	WP11-TRA-01
Research scientists:	T. Kiviniemi, S. Janhunen, T. Korpilo, S. Leerink, AU J. Heikkinen, VTT
Collaboration:	Textor Team, FZ Jülich

The parameters and profiles from recent TEXTOR experiments both for H-mode and L-mode plasmas were used to initialize gyrokinetic full-f simulation with Elmfire to see how the radial electric field Er and experimentally observed profiles evolve. In the simulation, it was observed that the L-mode has strong relaxation while the profile in H-mode case is quite well maintained indicating that the present model includes all the physics ingredients which maintain the density profile in H-mode. However, in temperature profiles, no significant difference in qualitative behaviour of the two cases can be seen. Relaxation in L-mode was accompanied by strong geodesic acoustic modes (GAMs). In Figure 3.4, the temporal behavior of the ion heat transport coefficient and particle flux as well as radial electric field and its shear from Elmfire simulation are shown.

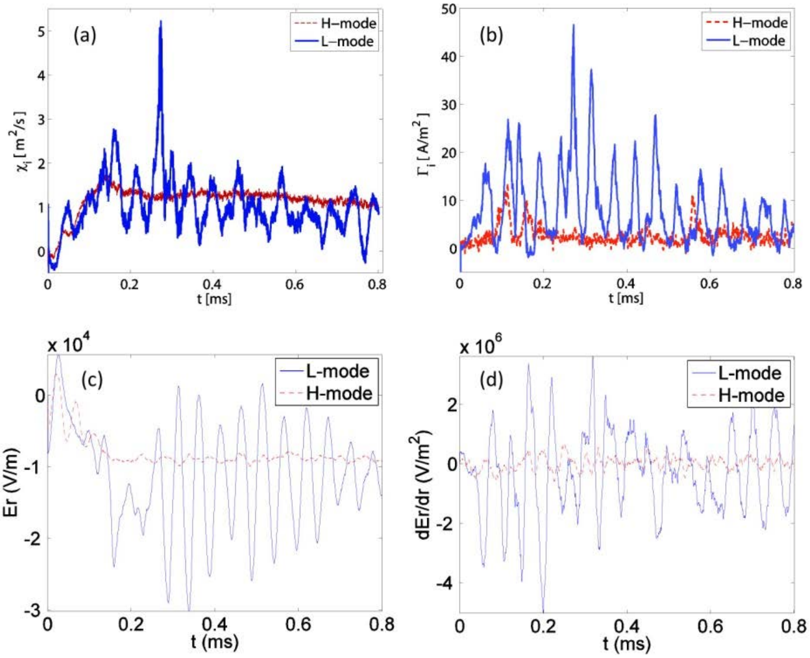


Figure 3.4. Temporal behavior of (a) heat transport coefficient, (b) particle flux as well as (c) radial electric field E_r and (d) its shear is shown for the radial position r = 40.5 cm.

In the figure we can see that the particle flux is strongly correlated to changes in E_r. L-mode case has strong GAMs, and simultaneous strong oscillations in particle flux and heat diffusivity χ are observed while in H-mode case particle flux and oscillations in E_r remain low. In the H-mode case, the average level of χ is close to the χ in L-mode case but oscillation around this mean value are much smaller. Also the particle flux in H-mode case has only some small infrequent peaks while in L-mode case the peaks are much higher and regular. These results are in qualitative agreement with recent experiments in ASDEX Upgrade where the GAM flow shearing was shown to dominate in the turbulent, low mean flow shear L-mode while in high mean flow shear H-mode it was suppressed.

Fourier analysis of the GAM oscillations in Elmfire simulation as a function of radius in L-mode case are shown in Figure 3.5. Here, the simulation data gives about a factor 1.6 higher frequency than the analytic estimate $\omega = 1.4c_s/R$. Here, c_s is the ion sound speed and R is the plasma major radius. However, the experimental fit to the recent AUG data is within the error bars of our simulation as shown in Figure 3.5.

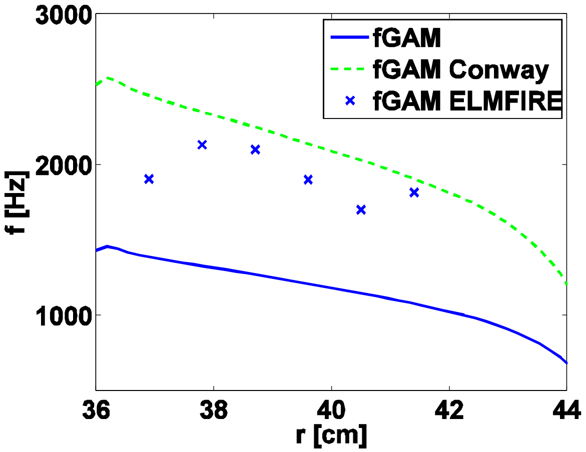


Figure 3.5. Frequency of GAMs in Elmfire simulations compared to two different models.

3.2.6 Impurity transport and transient particle transport experiments at the edge, and related theoretical studies

EFDA task:	WP11-TRA-03
Research scientists:	J. Heikkinen, VTT T. Kiviniemi, AU

The goals of this task were assessment and quantification of the nature of impurity transport (neoclassical or turbulent) in L-mode and H-mode edge, as well as assessment and quantification of the presence and nature of particle convection in the turbulent edge.

Impurity effects on plasma dynamics at the edge plasma conditions were investigated with a full f gyrokinetic (electrostatic) particle code Elmfire. The neoclassical limit was investigated with impurities (O^{6+}) in the collisional regime and main ions (hydrogen) in the plateau region of a small FT-2 tokamak. An excellent agreement of parameter dependence of the radial electric field with the analytical prediction by M. Landreman et al., (Physics of Plasmas **18**, 092507 (2011)) was observed. Similarly, the parallel resistivity was found in excellent agreement with the prediction by Sauter (Physics of Plasmas **6**, 2834 (1999)). And, in excellent agreement the GAM frequency dependence on the impurity content was found with the prediction by W. Guo (Physics of Plasmas **17**, 112510 (2010)). Otherwise the results were reproduced in the presence of turbulence (Ohmic discharge), but the radial electric field was affected by the latter. The heat conductivity coefficient was found to have the same radial profile and magnitude as in experiments (S. Leerink, *Transport timescale investigations of plasma flows in the FT-2 tokamak: measurements and full-f gyrokinetic simulations*, submitted for publication). The result implied the inward convection of the Oxygen impurity in agreement with Landreman, but turbulence was found to modify this result. The work was replicated for TEXTOR in both L- and H-modes. In the H-mode conditions, the simulation maintained the experimental density and temperature profiles. At the inner edge, density shows even slight increase which would indicate that there can be some kind of pinch mechanism involved. In L-mode, strong GAMs are observed with simultaneous occurrence of strong oscillatory particle flux causing particle relaxation (T. Kiviniemi, *Gyrokinetic simulation of edge pedestal in Textor tokamak*, to appear in Contrib. Plasma Phys).

3.2.7 Study of characteristics of Textor turbulence with Elmfire

Research scientists:	T. Kiviniemi, S. Janhunen, T. Korpilo, S. Leerink, AU J. Heikkinen, VTT
Collaboration:	Textor Team, FZ Jülich

Characteristics of TEXTOR turbulence has been studied for two cases, namely experimental L- and H-mode plasmas. In Figure 3.6(a) density fluctuation both for initial noise and for later stages of simulation is calculated as perturbation of density compared to local average which is an average over 10 neighboring poloidal cells. Local average is used to remove the effect of in-out asymmetry on standard deviation within flux surface. Here, "noise level" means the density fluctuation at the beginning of simulation (time step 10, average of L- and H-mode cases) when the fluctuation is assumed to be pure noise. This should be compared to density fluctuation at the end of simulation when turbulence has saturated, which is $\delta n/n$ = 2–8 %. Thus, although the fluctuation level near the edge is much larger than noise, the contribution of noise in the inner plasma is not negligible especially in the H-mode case. In Figure 3.6(b), the poloidal velocity analyzed from correlation of fluctuations is mostly explained by **E** x **B** velocity meaning that there is no significant phase velocity involved in the L-mode case.

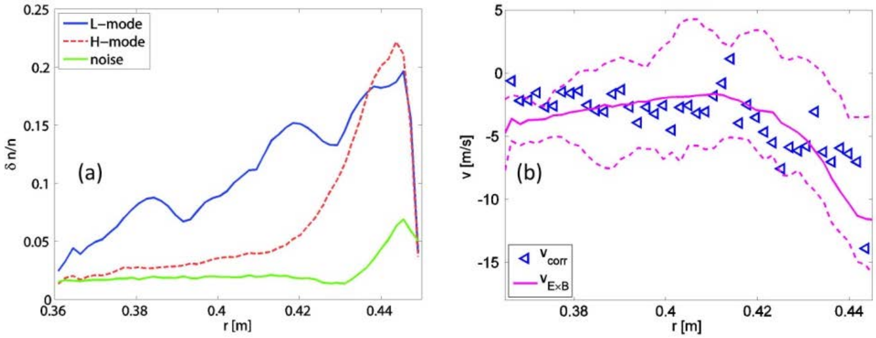


Figure 3.6. (a) Noise level and fluctuation level at saturated turbulence and (b) poloidal velocity from obtained from correlation analysis of turbulence as compared to **E** x **B** velocity.

3.3 Power and Particle Exhaust, Plasma-Wall Interactions

3.3.1 Overview

Research activities in 2011 in the field of power and particle exhaust and plasma-wall interaction cover the co-ordination of JET and ASDEX Upgrade (AUG) experiments, surface analysis of plasma-exposed long-term, tracer injection and erosion samples as well as computer modelling of the scrape-off layer plasma as well as erosion, global and local material migration. The work is supported by code development reported in Section 3.6.

3.3.2 Recycling source and core plasma fuelling in DIII-D, ASDEX-Upgrade, and JET

Research scientists:	M. Groth, V. Lindholm, A. Järvinen, AU
Collaboration:	G. Porter, T. Rognlien, LLNL, USA
	S. Wiesen, D. Harting, JET/FZ Jülich
	D. Coster, M. Wischmeier, IPP Garching
	DIII-D and AUG teams, EFDA-JET contributors

This work was partly funded by Lawrence Livermore National Laboratory in 2011 under subcontract B598086 with Aalto University.

Introduction: Deuterium fueling profiles across the separatrix have been calculated with the edge fluid codes UEDGE, SOLPS, and EDGE2D/EIRENE for lower single null, ohmic and low-confinement plasmas in DIII-D, ASDEX Upgrade, and JET. The poloidal profile of hydrogen (or isotopes thereof) fueling across the separatrix is predicted to impact the pedestal in high-confinement mode (H-mode) plasmas and thus the plasma performance in present and future fusion devices. A cross-machine and cross-code comparison was accomplished to investigate the dependence of the fuelling profile on device dimension, divertor geometry, and upstream density as the primary parameters on the experimental end, and cross-field drifts and fluid versus kinetic neutrals on the code end. The work completed a previous ITPA DSOL proposal (DSOL-16) and was presented as an invited talk at the 2011 EPS conference in Strasbourg, France.

Main results in 2011: Simulations of lower single null, ohmic and L-mode plasmas in DIII-D, AUG, and JET with the UEDGE, SOLPS, and EDGE2D/EIRENE codes predict that the flux of neutrals crossing the separatrix is localized at or close to the divertor x-point. According to neutral fuelling models developed by Mahdavi and Groebner (Mahdavi et al., Physics of Plasmas, 2003), these results would unfavorably scale toward high pedestal densities. Depending on the strength of radial transport in the far SOL, the calculated fueling profiles also peak at the low field side midplane.

The open divertor geometry with horizontal targets in DIII-D is predicted by UEDGE (with fluid neutrals) and SOLPS (kinetic neutral) to produce broader fueling profiles than the closed geometries with vertical targets in AUG and JET, as neutrals are preferentially released toward the main chamber (Figure 3.7/ii). In configurations with wider flux expansion, the peak in the fueling profile occurs poloidally upstream of the divertor x-point, and not directly adjacent to it, consistent with assumption of stronger neutral attenuation at the x-point as the flux expansion is increased. With increasing upstream density, fueling from the HFS divertor x-point region is predicted to increase (UEDGE for all three devices, SOLPS for DIII-D and AUG, Figure 3.8/i) or to remain constant (EDGE2D/EIRENE for JET) (Figure 3.8/ii). The fueling profiles along the high field side SOL are generally broader at high upstream densities than at low upstream density. Fuelling from the low field side divertor x-point region was found to decrease (UEDGE for all three devices, EDGE2D/EIRENE for JET), remain constant (SOLPS for AUG), or increase (SOLPS for DIII-D). Broadening of the fueling profile at the low field side x-point with increasing upstream density is observed with SOLPS for DIII-D, while the narrow fueling profiles right at the LFS x-point are predicted by EDGE2D/EIRENE for JET.

The predicted fueling profiles are a direct consequence of the calculated ion recycling at the target plates, volume recombination within the divertor legs, and the plasma conditions in the divertor legs, in general. Divertor solutions with temperatures at 1 eV at the plate were obtained with all three codes for all three devices. However, the predicted ion currents to the plates generally do not agree with the reduced currents observed experimentally at high upstream density. For high upstream densities in DIII-D, comparison of measured electron density in the low field side divertor against UEDGE and SOLPS simulations indicate that the ionization front remains close to the plate, whereas experimentally it is observed just downstream of the x-point. These fundamental issues remain outstanding and require inclusion of other physics process, such as super-thermal electrons. Inclusion of cross-field drifts results in closer approximation of measured divertor asymmetries (UEDGE for DIII-D and AUG) (Figure 3.7/i), but in other cases it did not significantly change the divertor solutions (SOLPS for AUG). Assuming stronger radial transport in the far SOL, motivated either by matching experimental data or testing a physics model, results in an increase in fueling from the LFS midplane region. Direct measurements of ion fluxes to main chamber surfaces and simulations on grids extending to the main chamber are required to corroborate these predictions.

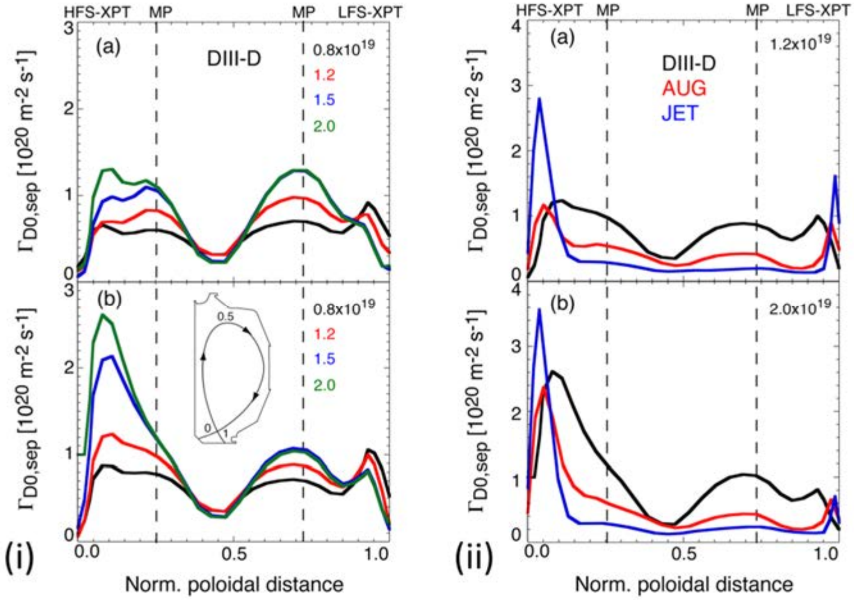


Figure 3.7. (i) Poloidal profiles of the deuterium atomic flux across the separatrix as predicted by UEDGE for DIII-D. The abscissa runs along the separatrix from the HFS x-point to the LFS x-point, as indicated by the insert in (b). The colors correspond to the four electron densities at the separatrix. Results are shown for UEDGE without (a) and with cross-field drifts (b). (ii) Predicted deuterium atomic flux across the separatrix from UEDGE for DIII-D (black), AUG (red), and JET (blue). Results obtained for two different densities are shown: (a) $n_{e,sep,LFS\text{-}mp}$ = 1.2 x 10^{19} m^{-3} (high-recycling divertor conditions), and (b) $n_{e,sep,LFS\text{-}mp}$ = 2.0 x 10^{19} m^{-3} (detached conditions).

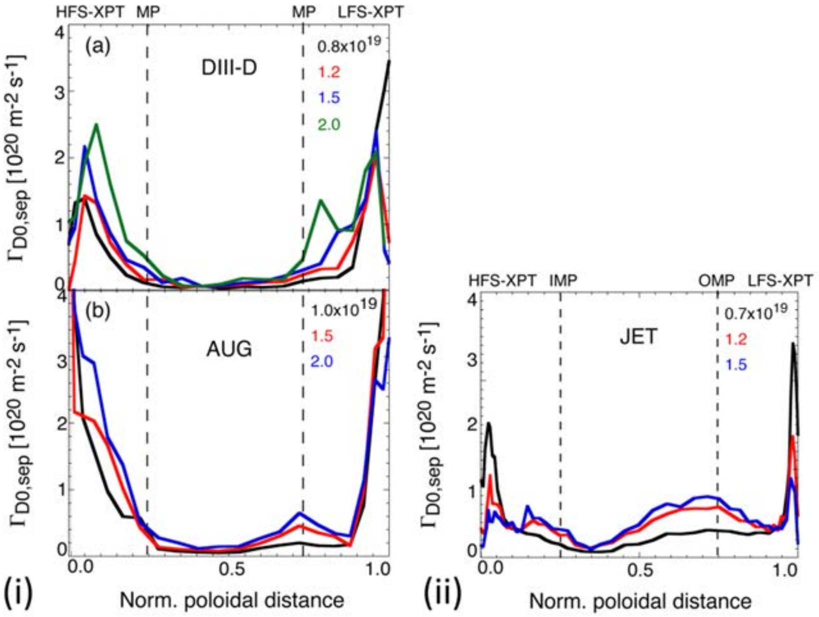


Figure 3.8. (i) Predicted deuterium atomic flux across the separatrix from SOLPS: (a) without cross-field drifts for DIII-D, (b) with cross-field drifts for AUG. (ii) Predicted deuterium atomic flux across the separatrix from EDGE2D/EIRENE for a JET vertical target configuration.

3.3.3 Material transport and erosion/deposition in the JET torus

EFDA-JET task:	JW11-FT-3.68
Research scientists:	J. Likonen, A. Hakola, S. Koivuranta, M. Airila, VTT
Collaboration:	J. Keinonen, K. Mizohata, UH
	P. Coad, A. Widdowson, JET-CCFE
	J. Kolehmainen, T. Haikola, S. Tervakangas, DIARC-Technology

Background: Since 2001 an extensive analysis program has been going on under the JET Task Force Fusion Technology to investigate erosion, material transport and deposition in the JET torus using various surface analysis techniques. Several sets of divertor and wall tiles have been studied in three different divertor geometries: MkII-GB (Gas Box, 1998–2001), MkII-SRP (Septum Replacement Plate, 2001–2004) and MkII-HD (High Delta, 2005–2009). During these different configurations, JET has been operated with CFC as the plasma-facing material. Deposition in the divertor region has been highly asymmetric during each case, with heavy deposition at the inner divertor but just small net erosion at the outer divertor. Analyses of the tiles removed from the vessel during every shutdown form the basis of our knowledge on the plasma-wall interaction mechanisms at JET. The carbon wall was removed during the 2009–2011 shutdown and the CFC tiles were replaced with beryllium tiles in the main chamber wall and with tungsten coated CFC and bulk tungsten (outer divertor only) tiles on the divertor.

Main results in 2011: In 2011, analysis of the carbon tiles has been completed and a set of divertor tiles, removed in 2010, was characterized using Secondary Ion Mass Spectrometry (SIMS) and optical microscopy. In addition, global migration of ^{13}C in the Scrape-Off Layer (SOL) was investigated. The analysed tiles were exposed in different periods (1998–2009, 2004–2009 and 2007–2009).

The analysed outer divertor tiles 7 and 8 exposed in 2004–2009 turned out to be clean indicating that they had clearly been eroded by plasma. The tiles were coated with a carbon marker layer with a thickness of 10 µm before exposure. Surface analyses indicated that the marker layer had completely been eroded so determination of the erosion rate was not possible.

The divertor inner and floor tiles 1, 3, 4 and 6 were exposed either in 1998–2009, 2004–2009 or in 2007–2009. SIMS analyses showed a typical deposition pattern which has been observed after each experimental campaign. Tile 1 (exposed in 2004–2009) had a co-deposited layer on the plasma facing surface with a thickness varying between 18 µm (at the centre of the tile) and 105 µm (on the apron of the tile). The co-deposited layer had a high Be/C ratio near the bottom of the tile and was enriched also in nickel originating from the inconel steel in the JET vessel wall and from internal metal fittings, bolts etc. (see Figure 3.9). Layers rich in metallic impurities have also been found in previous studies. Figure 3.9 also shows an optical microscope image for the same sample. Tiles 3 had thicker co-deposited layers than tile 1 with thickness varying in the range of 40–90 µm. The films had also high Be/C ratio especially near the top of the tile but deuterium content was clearly less than on tile 1. The high Be/C ratio on tiles 1 and 3 may be due to the high delta discharges in 2007–2009 operations.

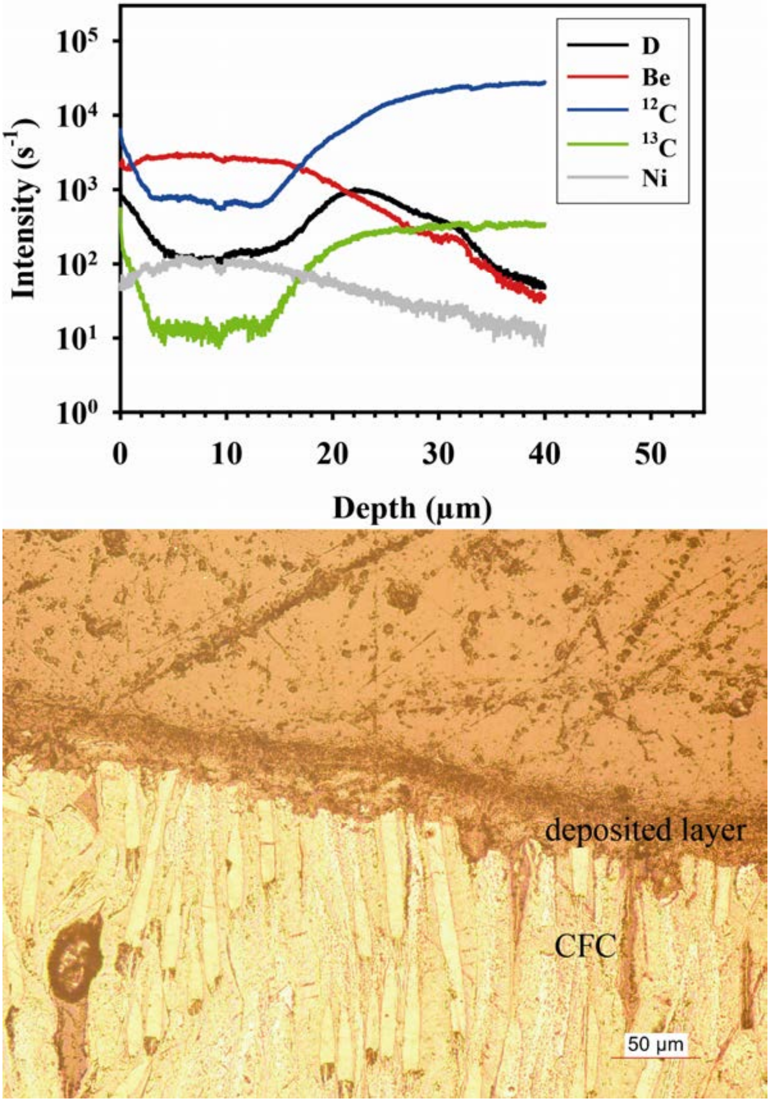


Figure 3.9. SIMS depth profiles (top) and optical microscope image (bottom) for a sample from the bottom of tile 1.

The floor tiles 4 and 6 have always shown very heavy deposition and high deuterium retention especially in the shadowed regions. In 2011, tile 4 exposed in 2004–2009 was analysed. Figure 3.10 shows an optical microscope image from a sample in the shadowed region of tile 4. The thickness of the co-deposited film is ~150 µm. The overall D retention for the 2007–2009 operations will be determined later.

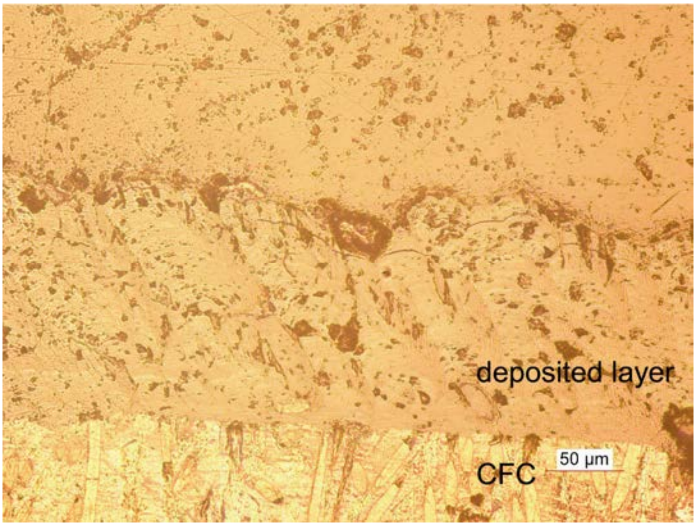


Figure 3.10*.* Optical microscope image for a sample from shadowed area of tile 4.

At the end of the C27 campaign in 2009, Task Force E carried out an experiment to provide specific information on material transport and SOL flows observed at JET. $^{13}CH_4$ was injected into the plasma boundary through 24 holes in a number of outer floor tiles 6 in the last day of discharges using one type of discharge only. ^{13}C deposition pattern was measured both with SIMS and Rutherford backscattering Spectroscopy (RBS). Experimental results for global ^{13}C migration have been reported in 2011. ^{13}C was deposited mainly on tiles 6, 7 and 8, and the amount of ^{13}C on the inner divertor tiles 1, 3 and 4 was clearly smaller.

On tile 6, a local toroidal deposition band with high ^{13}C amount was observed. Local ^{13}C deposition on tile 6 was investigated using the ERO code. Figure 3.11 shows the deposition pattern obtained with ERO. About 37 % of injected ^{13}C is deposited within the simulation volume, whereas 59 % is lost (mostly as neutrals) towards the outer divertor and 4 % towards the X-point. In the experiment, about 16 % of injected ^{13}C was deposited inside the ERO simulation volume. A clear majority of the deposition occurs close to the injection location (on the outer end face of tile 5 and the horizontal part of tile 6). The modelled deposition pattern agrees with the measurements in shape and toroidal decay but is poloidally narrower. This may be due to deposition of ^{13}C that escapes from the simulation volume but returns to the target in reality. The results were presented in an invited talk in the 13th International Workshop on Plasma-Facing Materials and Components for Fusion Applications, Rosenheim, Germany.

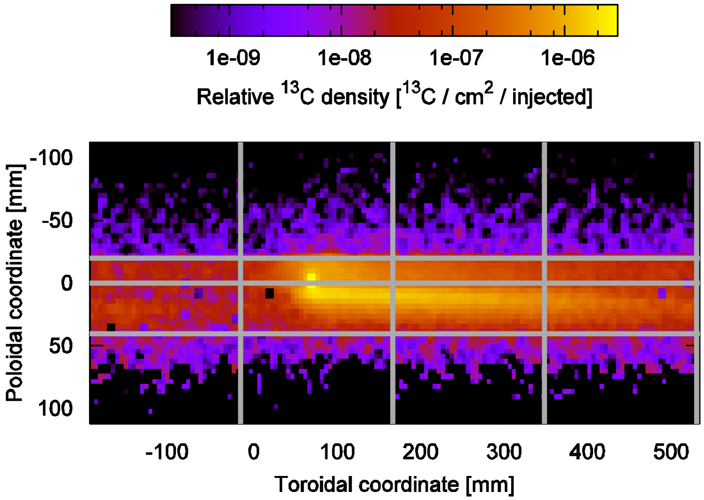


Figure 3.11. Deposition pattern of ^{13}C as simulated with ERO. Tile boundaries and edges are indicated with grey lines. The top row corresponds to the sloping part of tiles 5, the second row to the vertical part of tiles 5, the third row to the horizontal part of tiles 6, and the bottom row to the sloping part of tiles 6.

3.3.4 EDGE2D/EIRENE and DIVIMP simulations of tungsten sputtering and transport in JET ELMy H-mode plasma

Research scientists:	A. Järvinen, M. Groth, J. Lönnroth, AU
Collaboration:	S. Wiesen, JET/FZ Jülich, Germany
	D. Moulton, G. Corrigan, and C. Giroud, JET, CCFE, Culham
	T. Eich, IPP Garching
	J. Strachan, PPPL Princeton,
	P. Belo, IPFN Lisbon,
	S. Jachmich, ERM Brussels

Introduction: The performance of future fusion reactors can be significantly impaired by tungsten contamination. While tungsten impurity is detrimental to the core performance, it is favored as a plasma-facing component (PFC) material due to its low fuel retention and high resistance against physical sputtering in semi-detached plasma conditions. Accordingly, the PFC materials foreseen in the high performance operation of the next major experimental reactor, ITER, consist of beryllium main chamber limiters with full tungsten divertor targets. The leading candidate operation regime for this high performance operation is the type-I ELMy H-mode, which provides both high confinement and beneficial particle exhaust in order to avoid unacceptably high impurity accumulation in the core plasma. Type-I ELMs may, however, have adverse effects to the PFC components for transient heat loads and sputtering, which enhances the risk of unacceptable core contamination. Thus, it is important to understand tungsten contamination process in high performance type-I ELMy H-mode plasmas. To address the issues raised by the ITER PFC materials, the JET tokamak has been refurbished with the ITER like wall with beryllium main chamber limiters and tungsten divertor targets.

In this study, tungsten sputtering and transport are modeled for a high triangularity type-I ELMy H-mode JET plasma. The modeled plasma is based on a JET ITER like wall reference discharge of high triangularity: JPN 76666, $B_{\Phi} = 2.7$ T, $I_p = 2.5$ MA, $P_{in} \sim 16$ MW, $\delta \sim 0.4$, $f_{GW} \sim 0.8$, $f_{ELM} \sim 20$Hz, $\Delta W_{ELM} \sim 200 - 300$ kJ. Tungsten sputtering and transport are modelled by utilizing the quasi-kinetic Monte Carlo code DIVIMP on background plasmas dynamically evolved in time with a 2-D multi-fluid code EDGE2D/EIRENE. Tungsten sputtering due to deuterium and 1 % C^{4+} contamination are taken into account. The carbon contamination represents the presence of light impurities, such as carbon, beryllium, nitrogen, and neon, in the plasma.

Main results in 2011: In this study, the ELMs appear to lead to significantly increased sputtering and leakage of divertor tungsten such that the tungsten core leakage is almost completely determined by the intra-ELM period. Figure 3.12 shows time-traces of target electron density, temperature, core tungsten penetration rate, and integrated tungsten penetrating core per on ELM cycle, as well as contour plots of divertor density and temperature for -0.1 ms, 0.1 ms, 1.1 ms, and 9.9 ms after the ELM onset for a base case ELM with imposed duration of 1 ms, $\Delta W_{ELM} \sim 210$ kJ, and convective to conductive losses fraction of 0.75. At the ELM onset heat burns through a previously cold divertor within the first 0.1 ms after the ELM onset giving target temperatures of a few 100 eV and target density drop by a factor of 3–6. Following the ELM burn-through, approximately around 0.5–1 ms after the ELM onset, the density begins to rise at the targets leading eventually to high recycling target conditions and bringing the target temperatures rapidly down. This effect seems to occur first and more strongly on the inner target than on the outer. Following the high recycling conditions, the target tungsten sputtering decreases and tungsten divertor retention increases, due to greatly enhanced divertor collisionality. Accordingly, after the time window of ~ 0–1 ms after the ELM onset characterized by extremely high tungsten sputtering and leakage, the tungsten sputtering and leakage are strongly suppressed during the following 1–30 ms covering most of the inter-ELM period. Thus, tungsten core contamination of high performance type-I ELMy H-mode plasmas appears to be determined by the balance between the ELM out flushing of tungsten and the ELM caused tungsten core leakage. Assuming sonic SOL transport, SOL temperatures of $T_e \sim 100$ eV, and $T_i \sim 200$ eV and SOL cross-field diffusion coefficient of ~1 m^2/s, an estimated tungsten core confinement time of ~5.5 ms taking into account the ELM flushing can be obtained. Using this confinement time an average core concentration of ~3 x 10^{-6} is obtained for the case presented here.

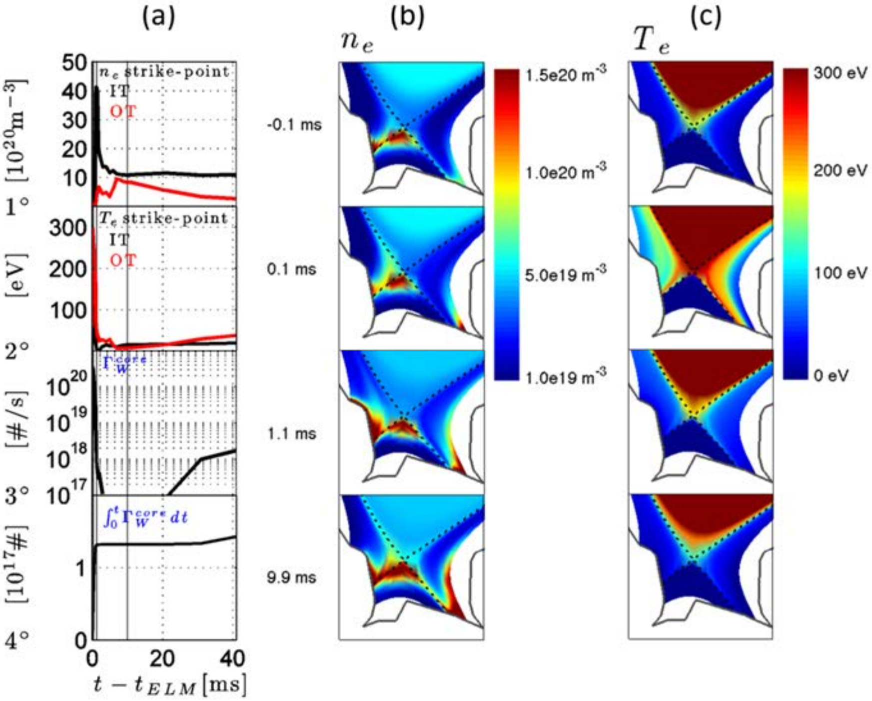


Figure 3.12. a) Time-traces of the base case τ_{ELM} = 1 ms: 1°) Strike-point electron density for inner (red) and outer (black) target, 2°) Strike-point electron temperature for inner (red) and outer (target), 3°) Tungsten core penetration rate, 4°) Integrated amount of tungsten penetrating core per an ELM cycle. b), c) Contour plots of divertor electron density and temperature for -0.1 ms, 0.1 ms, 1.1 ms, and 9.9 ms after the ELM onset.

3.3.5 Material transport and erosion/deposition in ASDEX Upgrade

3.3.5.1 Global migration of ^{13}C in AUG

EFDA task:	WP11-PWI-03-02
Research scientists:	A. Hakola, S. Koivuranta, J. Likonen, VTT M. Groth, T. Kurki-Suonio, V. Lindholm, J. Miettunen, T. Makkonen, AU
Collaboration:	A. Herrmann, K. Krieger, M. Mayer, H. W. Müller, R. Neu, V. Rohde, K. Sugiyama: IPP-Garching T. Haikola, J. Kolehmainen, S. Tervakangas, DIARC-Technology

Studying global migration of impurities in ASDEX Upgrade (AUG) and modelling the obtained results with the ASCOT, DIVIMP, ERO, and SOLPS codes are the main forms of collaboration between Tekes and IPP. To meet these goals, tracer gases have been deliberately injected into the AUG vessel during a number of identical plasma discharges at the end of an experimental campaign and a set of tiles has been removed from the vessel immediately after the experiment for post mortem surface analyses. The deposition profiles of the tracer elements, typically ^{13}C, on the tiles have been determined using Secondary Ion Mass Spectrometry (SIMS) at VTT.

The latest injection experiment was carried out in July 2011. Both ^{13}C-labelled methane ($^{13}CH_4$) and $^{15}N_2$ were simultaneously injected during 11 high-density, lower single null L-mode plasma discharges in hydrogen from one valve at the outer midplane of AUG. Altogether 9.2×10^{22} atoms, with 1:1 ratio for ^{13}C and ^{15}N, ended up in the vessel corresponding to approximately 1 g of each isotope. The shots had the following parameters: $n_e = 5.8 \times 10^{19}$ m^{-3}, $I_p = 0.8$ MA, $B_t = -2.5$ T, $P_{aux} = 1.8$ MW (NBI) + 0.96 MW (ECRH), and flat-top time $\tau = 4.7$ s.

After the experiment, 37 wall tiles from different toroidal and poloidal regions of the torus were removed for SIMS analyses. In late 2011, the measurements were started with 12 tiles, originating from the outer midplane and ICRH antenna limiters, central heat shield, and the divertor region. The obtained surface densities of ^{13}C (in at/cm^2) on the different limiter tiles are collected in Figure 3.13.

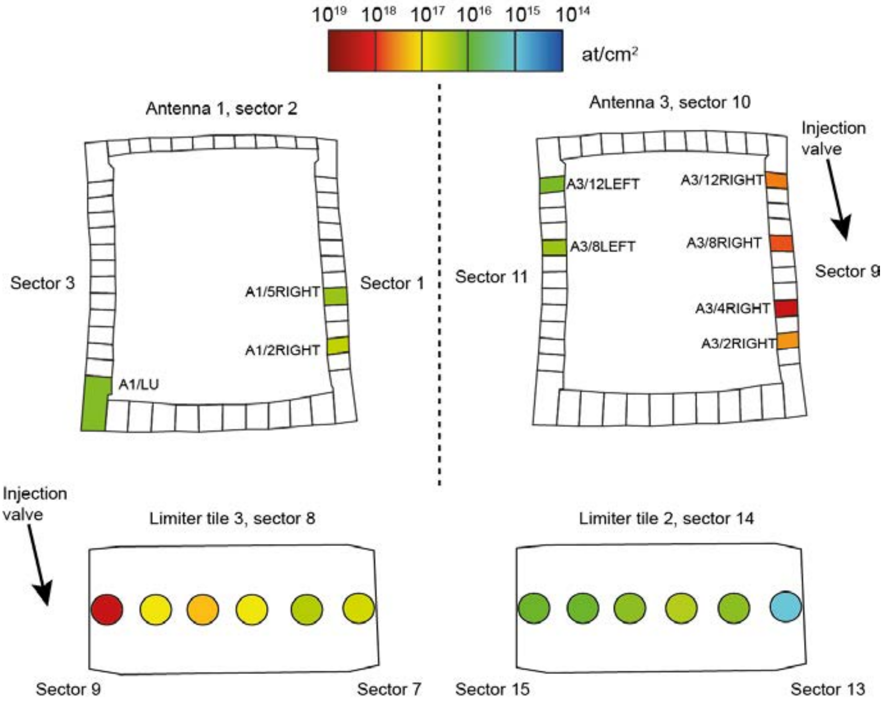


Figure 3.13. Determined surface densities of ^{13}C (in at/cm^2) on the analyzed outer midplane (bottom) and ICRH antenna limiter (top) tiles.

All the tiles shown in Figure 3.13 are strong deposition regions for ^{13}C: the determined surface densities range from 10^{16} to 10^{19} at/cm^2, the deposition being the largest close to the injection valve. These values are 1–2 orders of magnitude higher than what was determined on tungsten-coated tiles after the previous injection experiment in 2007 [A. Hakola et al., Plasma Phys. Control. Fusion **52** (2010) 065006]. Apparently, the selection of tiles for surface analyses was not the most representative one back then. This is supported by the observation that, in accordance with our findings after that experiment, deposition at the inner divertor is small (5×10^{15} at/cm^2). On the other hand, gaps between the limiter tiles contain considerable ^{13}C inventories, up to 10^{16}–10^{17} at/cm^2.

The most interesting result is, however, the toroidally asymmetric deposition pattern of ^{13}C, especially on the ICRH antenna limiters. Deposition on the right-hand and left-hand sides of antenna 3 in sector 10 differ from each other by a factor of 5–50, and similar difference is observed between antennas 1 (in sector 2) and 3. These observations are in a nice agreement with the results from ASCOT simulations, discussed in section 3.3.5.5. We conclude that protruding surface structures at the midplane are significant deposition sinks for carbon – and for other impurities, too. As a consequence, the previously used assumption of toroidally symmetric deposition everywhere in the torus does not seem to hold at the midplane but a full 3D treatment is needed.

3.3.5.2 Retention of deuterium in ASDEX Upgrade

EFDA task:	WP11-PWI-01-02
Research scientists:	A. Hakola, S. Koivuranta, J. Likonen, VTT
Collaboration:	A. Herrmann, K. Krieger, M. Mayer, H. W. Müller, R. Neu, V. Rohde, K. Sugiyama, IPP Garching T. Haikola, J. Kolehmainen, S. Tervakangas, DIARC-Technology

Retention of plasma fuel in the first-wall structures of AUG has been studied with the help of special marker tiles since 2002. The tiles have been produced by DIARC-Technology Inc. and they have been exposed to plasma during a single experimental campaign. The amount of deuterium on them has been determined using Nuclear Reaction Analysis (NRA) at IPP and SIMS at VTT.

In 2011, a set of marker tiles, removed from the outer strike-point region of AUG after the 2007, 2008, and 2010–2011 experimental campaigns, was analysed using NRA and SIMS. The 2007 and 2008 tiles had been equipped with 1.5–5 µm thick poloidal marker stripes of W and Ni as well as with an uncoated poloidal graphite stripe. The results obtained from these tiles were compared with the existing data from the 2009 marker tiles which had had similar stripe configurations. The 2010–2011 tiles, for their part, had 2–4 µm thick W, Mo, Cr, Al, and 5-% Ta-doped W stripes on them. In addition, on some of the tiles W and Mo stripes of different surface roughness had been produced. This way, the effect of substrate material and its roughness on fuel retention could be investigated.

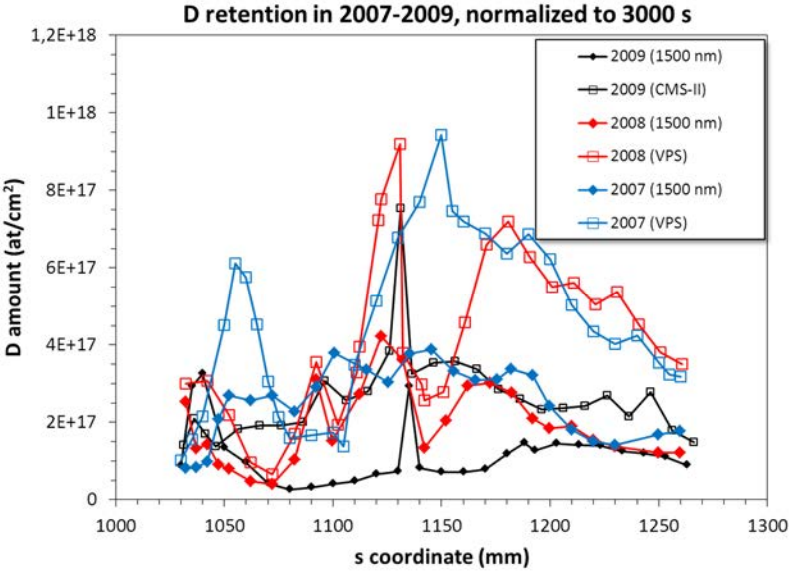


Figure 3.14. Poloidal retention profiles of D in the outer strike-point region of AUG after the 2007–2009 plasma operations. Here CMS-II and VPS stand for the standard W-coated tiles of AUG.

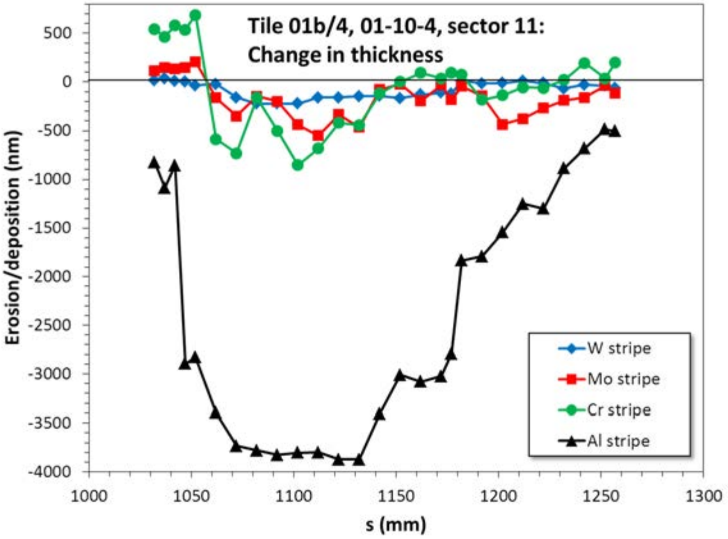


Figure 3.15. Poloidal net erosion profiles for W, Mo, Cr, and Al in the outer strike-point region of AUG after the 2010–2011 plasma operations.

The amount of deuterium was observed to have gradually been decreased from 2007 to 2009 as Figure 3.14 shows. In addition, the marker coatings showed 2–3 times smaller retention than the more porous and rougher coatings on standard AUG wall tiles. Retention on Ni was at least two times smaller than on W, most likely due to a denser surface structure of Ni and the fact that the W coatings are typically heavily oxidized when exposed to ambient air. Considering the 2010–2011 tiles, no noticeable differences could be observed between the different substrate materials. Instead, surface roughness played a large role: the roughest stripes contained the largest deuterium inventories. This can be attributed to rough surfaces showing large surface modifications as a result of plasma exposure such that almost the whole coating has turned into a mixture of carbon and W (or Mo). Retention is typically larger for such mixtures than for pure materials.

3.3.5.3 Campaign-integrated and discharge-resolved erosion processes in ASDEX Upgrade

EFDA tasks:	WP11-PWI-03-01; WP11-PWI-03-02
Research scientists:	A. Hakola, M. Airila, J. Karhunen, S. Koivuranta, J. Likonen, VTT
Collaboration:	A. Herrmann, K. Krieger, M. Mayer, H. W. Müller, R. Neu, V. Rohde, K. Sugiyama, IPP Garching T. Haikola, J. Kolehmainen, S. Tervakangas, DIARC-Technology

Together with fuel retention and migration of materials, erosion of different plasma-facing materials in AUG is an important joint research topic of Tekes and IPP. Also in this front, marker tiles have been used to determine erosion rates for W and various low-Z and high-Z materials during an experimental campaign. The main tools have been Rutherford backscattering spectroscopy (RBS) and NRA at IPP and SIMS at Tekes-VTT. To supplement the campaign-integrated data extracted from the marker tiles, we have recently paid attention also to discharge-resolved erosion processes by exposing marker probes into a pre-selected number of plasma discharges at the outer midplane of AUG. All the probes have been equipped with 50–100 nm thick marker stripes of W, Ni, Al, and C while the substrate material of the probes has been graphite.

In 2011, the work related to erosion studies consisted of two parts: determining erosion for the marker tiles introduced in section 3.3.5.2 and carrying out two new erosion-probe experiments. The results from the marker tiles showed that the campaign-integrated net erosion rate was up to 0.03 nm/s for W and increased exponentially with the charge number of the material, excluding Al which was almost completely eroded. The erosion behaviour of the different markers is presented in Figure 3.15. Also, the rougher the coating was, the smaller was its net erosion. The roughest coatings had suffered from large structural modifications and mixing of elements due to step-by-step erosion of material from plasma-inclined areas and re-deposition in valleys shadowed from direct plasma contact. This enhanced re-deposition explains why the thickness of the coatings had changed less than after the 2007–2009 experimental campaigns, even though the more heating power was available and used during the period 2010–2011.

Considering the erosion-probe studies, the first probe was exposed to four L-mode shots, the other one to a single H-mode shot, all in deuterium. The tip of each probe was approximately at a distance of 35–40 mm from the separatrix during the experiments. For the L-mode probe, the following parameters were used: $n_e = 6 \times 10^{19}$ m^{-3}, $I_p = 1$ MA, $B_t = -2.8$ T, $P_{aux} = 1.4$ MW (NBI), and flat-top time $\tau = 3.7$ s. The corresponding parameters of the H-mode experiments were: $n_e = 6.5 \times 10^{19}$ m^{-3}, $I_p = 0.8$ MA, $B_t = -2.5$ T, $P_{aux} = 7.5$ MW (NBI), and $\tau = 1.5$ s.

Our results show that the erosion rate decreases strongly with increasing atomic number: while for the L-mode probe the erosion rate of W is 0.2 nm/s, the obtained erosion rates of Ni, Al, and C are 7–20 times higher. Due to ELMs, an enhanced erosion rate of 1 nm/s was observed for W in the H-mode experiment, the other materials showing up to 40 times larger erosion than in the L-mode experiment. ERO modelling of the L-mode experiment was initiated in late 2011 by varying the decay lengths of the background plasma parameters n_e, T_e, and T_i and the concentration of light and heavy impurities in the plasma. So far, the most promising results have been obtained with carbon concentrations of approximately 0.5 % and the decay lengths being around 20–30 mm.

For erosion studies during the 2012 campaign of AUG, 22 new marker tiles have been produced by DIARC-Technology Inc. All the tiles were made of graphite and coated either with a 2 µm thick P92 steel coating or 1.5–2 µm thick W and Ni marker stripes. The tiles have been mounted in the central heat shield and the upper divertor of AUG.

3.3.5.4 Modelling of local erosion and deposition of W

EFDA task:	WP11-PWI-04-03
Research scientists:	L. Aho-Mantila, M. Airila, VTT
Collaboration:	K. Krieger, K. Schmidt, Z. Yang, IPP Garching

ASDEX Upgrade carried out an experiment to verify the existence of prompt redeposition. Graphite samples with W and Mo markers were exposed to plasma using the divertor manipulator. Downstream from the marker in the bare graphite surface part of the sample the surface had a shallow groove. According to an analytical model of erosion-redeposition on a rough surface, only promptly redeposited material is expected to be deposited inside the groove. The toroidal fall-off length would mainly depend on the magnetic field angle, the ionisation mean free paths of Mo and W and their gyro radii.

Erosion and deposition on the W/Mo probes was modelled with ERO. In the model the probe surface (26 x 50 mm) has a plasma-wetted part (15 mm toroidally) at an angle of 3 degrees with respect to B and a plasma-shadowed part (11 mm toroidally) recessed by 0 to 0.5 mm. The plasma is assumed to be uniform with $n_e = 5 \times 10^{19}$ m^{-3}, $T_e = T_i = 20$ eV, M = 1 and 0.5 % of C^{4+} impurities.

Figure 3.16 shows gross erosion and deposition (with promptly deposited fraction indicated) as well as net erosion along the probe. Modelled gross erosion of W plasma-wetted surface is about 0.8 nm/s and the corresponding net erosion 0.2–0.3 nm/s. Almost all W ions that are re-deposited on the plasma-wetted surface are promptly re-deposited ones. In the shadowed area the re-deposition rate is about 0.05 nm/s. Promptly re-deposited fraction of W is dominant in the area closest to the plasma-wetted surface but becomes negligible at the opposite edge.

Modelled gross erosion of Mo plasma-wetted surface is about 3.5 nm/s and corresponding net erosion 1–2 nm/s. In the shadowed area the re-deposition rate of W is about 0.2 nm/s. The role of prompt re-deposition is very similar as in the case of tungsten.

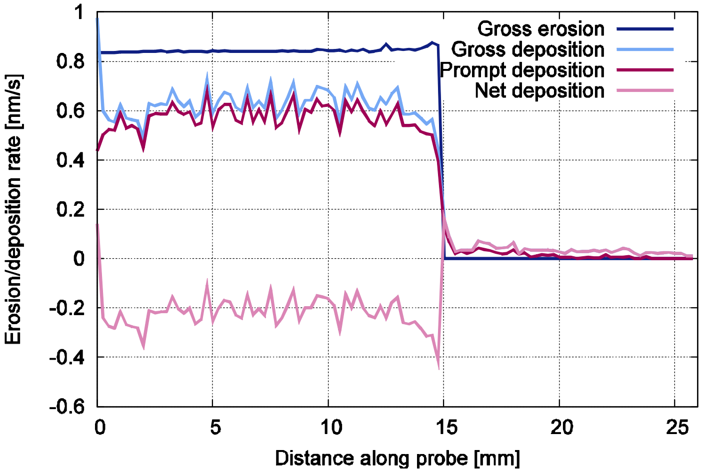


Figure 3.16. Erosion/deposition balance of W along the toroidal dimension of the probe.

3.3.5.5 ASCOT simulations of ^{13}C transport in ASDEX Upgrade

EFDA task:	WP11-PWI-03-03-02
Research scientists:	J. Miettunen, T. Kurki-Suonio, T. Makkonen, M. Groth, E. Hirvijoki, S. Äkäslompolo, AU A. Hakola, J. Likonen, VTT
Collaboration:	K. Krieger, ASDEX Upgrade Team, IPP Garching

In 2007, the migration of carbon in ASDEX Upgrade (AUG) was studied by methane ($^{13}CH_4$) injection. The total amount of deposited ^{13}C was estimated by assuming toroidally symmetric deposition. Remarkably, the total number of deposited atoms was observed to be less than 10 % of the number of injected atoms.

The experiment has been simulated with the 3D orbit-following Monte Carlo code ASCOT using both a realistic 3D wall geometry of AUG and a 3D magnetic field with toroidal ripple. As shown in Figure 3.17, the simulations indicate that the non-axisymmetric wall geometry causes notable toroidal asymmetry in the deposition profile in the outer (low-field side) midplane region, which can provide a partial explanation for the missing carbon inferred from post-mortem analysis of ^{13}C deposition. Using a simple estimation, it was concluded that, in this particular case, assuming toroidally symmetric deposition would cause 30 % of the injected ^{13}C not to be accounted for. In the divertor and the heat shield regions, it was observed that the deposition profile is rather closely toroidally symmetric.

The effect of reflection from wall surfaces was studied with a simple model that uses a constant sticking coefficient. In the model, each time a test particle encounters a wall surface, it is reflected back into the plasma with a predefined, constant probability. The particles are reflected as neutrals with their energy corresponding to their impact energy and with a random direction of velocity. It was observed that, even with a low sticking coefficient, local re-deposition of the reflected particles was dominant and the 2D deposition pattern only became slightly more diffuse, in particular around the protruding wall structures near the outer midplane. The result can be considered to give a qualitative indication of the effect of erosion of deposited particles on the deposition pattern. This and the performed sensitivity analysis of the simulation parameters proved that the observed features of the toroidal profile, strong asymmetry near the outer midplane and symmetry in other regions, remain unchanged over a wide range of different simulation parameters.

A new $^{13}CH_4$ injection experiment was conducted on ASDEX Upgrade in 2011. For the experiment, predictive ASCOT modelling was carried out using a new 3D wall geometry that takes into account even the most recent changes in AUG such as structures due to resonant magnetic perturbation coils. Strong toroidal asymmetry was observed in the simulation results, similarly as presented here. Preliminary experimental results have shown confirmation of the predicted effect of non-axisymmetric wall geometry. In the first analyzed samples, strong ^{13}C deposition peaks were observed on ICRH antenna structures as well as on wall tiles next to the injection port with ^{13}C surface densities reaching 10^{17}–10^{18} at/cm^2. Significant asymmetry in deposition was also noticed between antennas separated toroidally by 180 degrees.

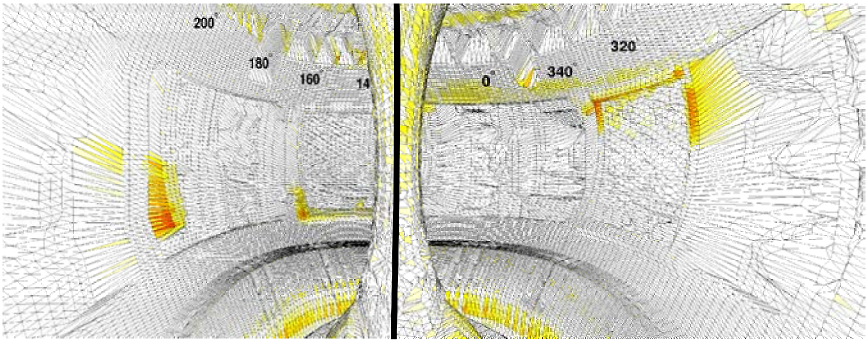


Figure 3.17. Deposition of ^{13}C in the 2007 experiment on ASDEX Upgrade as calculated by ASCOT. Highest deposition can be observed on protruding wall structures such as port and ICRH limiters.

3.3.5.6 SOLPS simulations of the SOL in the 2011 ^{13}C experiment in AUG

Research scientists:	V. Lindholm, M. Groth, AU A. Hakola, VTT
Collaboration:	D. Coster, M. Wischmeier, IPP Garching

Introduction: Today's plasma devices are being run with either hydrogen (H) or deuterium (D) plasmas, or a mixture of both. It is not always clear how the choice of plasma species impacts the properties of a shot. At ASDEX Upgrade in Garching, Germany, ^{13}C gas injection experiments have been performed to ascertain the impurity transport patterns in the device. These two experiments, performed in 2007 and 2011 by A. Hakola et al., were run with different bulk plasma species; in 2007 deuterium was used, in 2011 it was hydrogen. Since the aim was to investigate large-scale carbon transport, it was not a primary goal of these experiments to determine differences due to the main plasma species differences. The two experiments can, therefore, only be said to have been performed with roughly similar parameters, not identical.

Principal results in 2011: While attempting to simulate the 2007 and 2011 ^{13}C experiments using SOLPS (especially the 2011 experiment), it was possible to simulate the exact same case with both hydrogen and deuterium. At the time of writing, little time has been used to try to exactly replicate either experiment. Instead, a case sufficiently close to both experiments was developed, whose parameters are still being refined. Running this case with both hydrogen and deuterium, it has been possible to investigate whether the choice of plasma species produces macroscopic effects in properties pertinent to impurity migration. In practice, this means comparing divertor profiles, neutral penetration and plasma flow profiles, which was performed over a number of cases in a parameter scan of the outer midplane electron density at the separatrix.

Since the outer midplane (OMP) density was the free variable, it was trivial to obtain a match for measured OMP data. However, cases matching the OMP data did not match the data measured at the inner and outer targets (IT and OT). Other cases in the density scan did produce better matches to the targets. This is a documented problem with 2D fluid codes. For the OT density, the simulation produced lower values further away from the peak, which may be a side effect of the grid which does not extend as far as the measured data; conceivably the boundary conditions impact the exact values.

Similarly, it was possible to get a fairly good match to OMP electron temperature, but at the OT the profiles were quite different. The 2011 profile did exhibit an anomalous second peak, which is not usually seen. Looking at the reference shot, the peak is absent, suggesting some temporary anomaly. Again, however, a large part of the profile is unaccounted for, since the grid still does not contain all the measured points. Possibly the profiles would match better with a larger grid.

Neutral penetration is shown by SOLPS to depend significantly on the plasma species (Figure 3.18). Heavier bulk plasma ions constrict the neutrals more, leading to fewer neutrals crossing the separatrix. The absolute difference increases with plasma density, although percentage-wise it is practically constant.

Finally, the flow profiles produced by SOLPS have been examined. There is a stagnation point at the OMP, and a smaller one slightly above the inner midplane. No probe data for the flow profiles exists, but it is at least clear that in the SOLPS simulations they are not affected by the plasma species in any major way. In other words: according to SOLPS, the plasma species should not have a large impact on impurity migration. Factors, such as plasma density, input power etc. are more likely to affect the outcome.

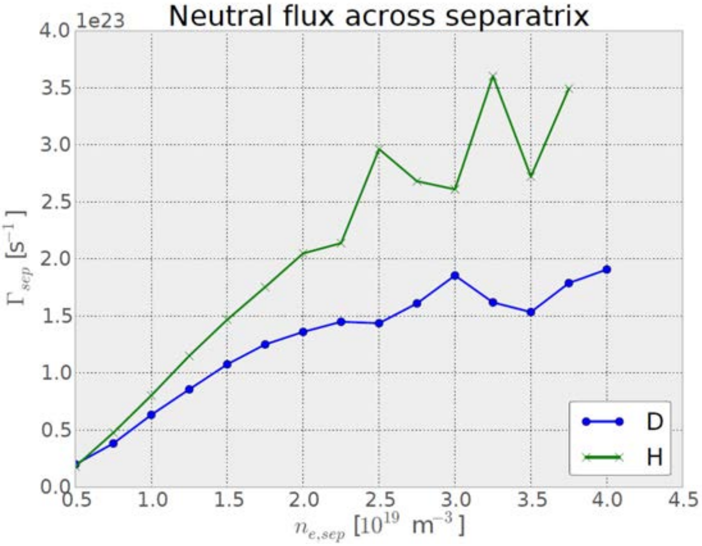


Figure 3.18. Total core plasma fuelling by hydrogen and deuterium neutrals.

3.3.5.7 SOLPS and ERO modelling of local erosion and re-deposition in the outer W divertor of AUG

EFDA task:	WP11-PWI-04
Research scientist:	L. Aho-Mantila, VTT
Collaboration:	M. Wischmeier, K. Krieger, ASDEX Upgrade Team, IPP Garching A. Kirschner, D. Borodin, FZ Jülich

Introduction: A series of $^{13}CH_4$ injection experiments have been performed in the 2007–2009 ASDEX Upgrade campaigns to investigate carbon migration in well-diagnosed, attached L-mode plasmas in forward and reversed magnetic field configurations. The tracer was injected into several locations in the outer divertor plasma, and well-resolved 2D patterns of local ^{13}C deposition were obtained using post-mortem ion-beam measurements. The experiments have been modelled using the SOLPS5.0 code package to calculate the divertor conditions and the ERO code to calculate the tracer trajectories and the re-deposition and re-erosion of ^{13}C at the target.

Main results in 2011: The analyses made in 2010 using the SOLPS5.0-ERO simulations were complemented in 2011 with detailed investigations of local re-deposition processes of various hydrocarbon species on a tungsten-coated divertor surface. The local deposition patterns observed on the divertor tiles were found to result from carbon ions which travelled primarily outside the magnetic presheath region, see Figure 3.19. As transport in neutral state was of smaller significance for the deposition patterns, the observed local ^{13}C migration pathways could be considered to be relevant for impurities in general. The ions were subject to **E** x **B** drifts and experienced friction with the divertor plasma.

Hydrocarbons were transported mainly within the magnetic presheath and contributed to the local re-deposition efficiency. The modelled re-deposition efficiency was, thus, found to be sensitive to the assumptions made regarding the sticking probability of hydrocarbons. However, uncertainties were identified regarding the properties of the magnetic presheath, in particular near tile edges, which prevented validation of the sticking assumptions.

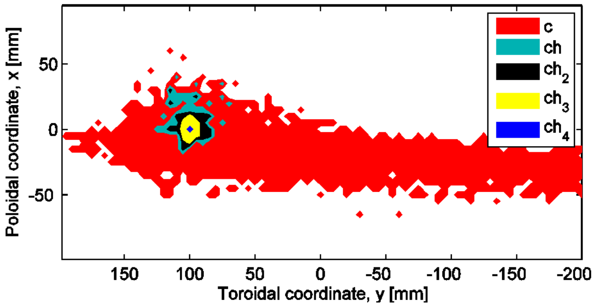


Figure 3.19. Distribution of various hydrocarbon molecules and carbon returning to the divertor surface from methane injection, according to the SOLPS5.0-ERO modelling.

3.3.6 Development of data analysis and interpretation tools for spectroscopic flow measurements in ASDEX Upgrade

EFDA task:	WP11-PWI-03-02
Research scientists:	T. Makkonen, M. Groth, T. Kurki-Suonio, AU M. Airila, VTT
Collaboration:	T. Pütterich, A. Janzer. T. Lunt, H.W. Mueller, E. Viezzer, ASDEX Upgrade Team, IPP Garching

To infer the background deuterium flow in the HFS SOL in AUG, methane was injected and the ensuing carbon plume followed spectroscopically and with a fast video camera. These measurements provided radial profiles of the flow velocity of CIII (465 nm) and the spatial extent of singly (CII 515 nm) and doubly ionized carbon. The experimental technique and first measurements are documented in section 3.7.2. To interpret the obtained carbon emission data and to attempt inferring the deuterium flow, the 3-D Monte Carlo impurity code ERO was utilized.

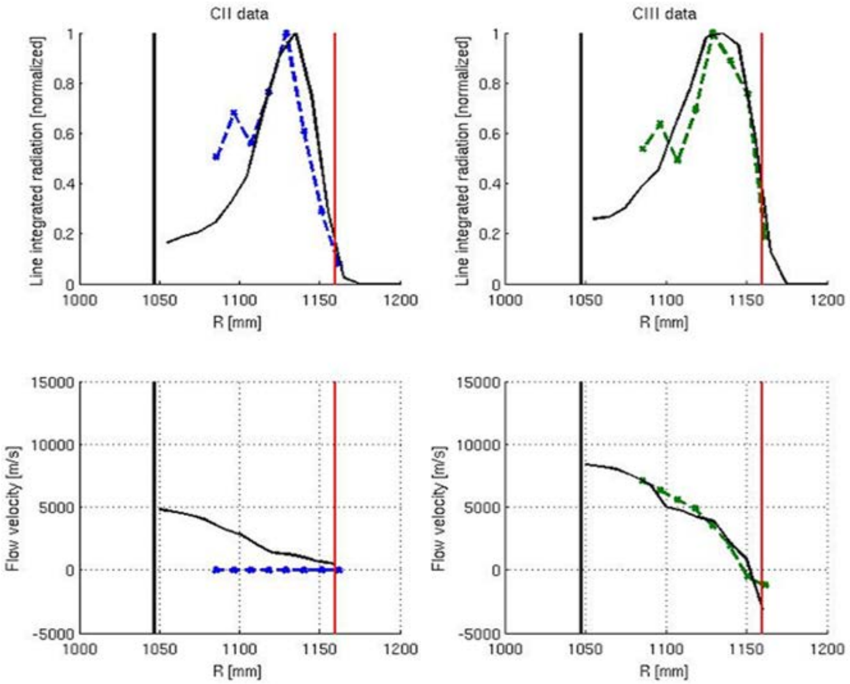


Figure 3.20. Radial profiles of measured CII and CIII data (dashed lines) and ERO simulations (solid lines). (a) Line integrated emissivity from CII. (b) Line integrated emissivity from CIII. (c) CII flow velocity. It should be noted that Doppler shift of CII has not been calculated and is plotted as zero here for comparison. (d) CIII flow velocity. The vertical black line is the central column and the vertical red lines are the separatrix.

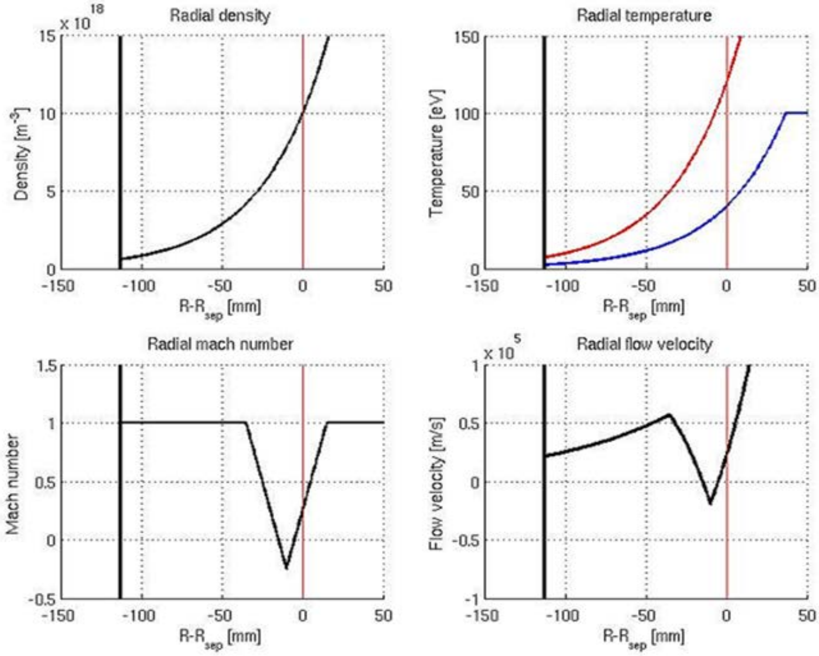


Figure 3.21. Deuterium background plasma parameters adjusted in ERO to obtain the match to the measured profiles shown in Figure 3.20. (a) – (b) – (c) – (d).

Simulations of the measured CII and CIII velocities were carried out with the intent of matching the experimental data for inter-ELM periods by modifying the plasma parameters at the injection location until a match is found. This is done using realistic profiles for density, temperature, and flow velocity. We were able to match the experimental data using these assumptions. The comparison between experimental data and ERO simulations is shown in Figure 3.20.

To obtain a match to the experimental profiles, we had to assume a dip in the background deuterium flow velocity close to the separatrix. This is a physically interesting result as it indicates strong shear close to the separatrix. The used plasma background is shown in Figure 3.21. The plasma background had an exponentially decaying density and temperature profile. The density at the separatrix was assumed to be 10^{19} m^{-3} in line with measurements at the outer midplane. The electron temperature was assumed to be 40 eV at the separatrix; the same order of magnitude is in the HFS. The ion temperature was assumed 3 times higher – a typical value for the upstream SOL. The deuterium background flow was assumed to be at a Mach number equal unity across the entire SOL with the exception of a dip close to the separatrix. The gradient length scale for density and temperature was 4 cm.

3.3.7 Erosion of materials exposed to plasma discharges in Pilot-PSI

EFDA tasks:	WP11-PWI-03-04; WP11-ETS-DTM-01-05
Research scientists:	A. Hakola, J. Likonen, VTT P. Paris, M. Aints, M. Laan, A. Lissovski, University of Tartu
Collaboration:	K. Bystrov, G. de Temmerman, DIFFER T. Haikola, J. Kolehmainen, S. Tervakangas, DIARC-Technology

The research units Tekes–VTT and Tekes–University of Tartu have collaborated with the DIFFER Institute (formerly FOM Institute for Plasma Physics Rijnhuizen) in the field of plasma-surface interactions since 2008. The main research theme is studying erosion of ITER-relevant materials when exposed to plasma in the linear devices Pilot-PSI and Magnum-PSI. For the experiments, test samples consisting of a few µm thick coatings have been produced by DIARC-Technology Inc.

In 2011, the work concentrated on determining erosion and changes in the surface structure of samples exposed in 2010 and carrying out a new set of plasma-exposure experiments in Pilot-PSI. This section gives an overview of the SIMS analyses of the 2010 samples, while the other analyses are discussed in detail in section 4.1.2.

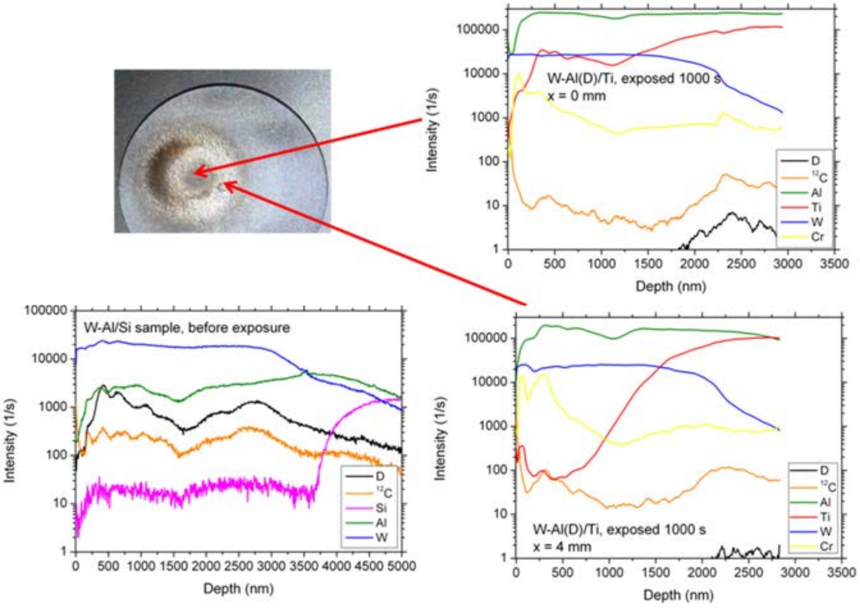


Figure 3.22. SIMS depth profiles measured from a W-Al(D) sample before and after its plasma exposure. The analysis points have been located at the center of the plasma spot and 4 mm to the right of it. The sample was exposed during 1000 s and using a bias voltage of –40 V. The surface temperature was approximately 600°C during the experiments.

Particularly, mixed W-Al samples exposed to plasma in 2010 show a complicated spot-to-spot erosion pattern on their coatings. Depending on the sample and its thickness, net erosion ranges from 500 nm to 3.0 μm but is rather constant throughout the exposed region as Figure 3.22 shows. No simple dependence on the experimental conditions could be observed except that higher ion energies seem to lead to a more inhomogeneous erosion profile. Another interesting observation is that close to the center of the plasma spot the remaining film has been completely mixed with the substrate material. Based on Laser-Induced Breakdown Spectroscopy (LIBS), Scanning Electron Microscopy (SEM), and X-ray diffraction measurements (see section 4.1.2), surface modifications and changes in the crystal structure play the largest role in the erosion of the coatings.

Considering the new experiments, the first set of samples had 3-μm thick diamond-like carbon (DLC) or mixed W-Al-C (5% of W, 47% of Al, 47% of C) coatings on W. Two of the DLC samples had Balinit® coatings and contained hydrogen while DIARC-Technology had been responsible for producing the other samples with different doping levels of deuterium. These samples were exposed to hydrogen plasmas with electron densities in the range of $2–3\times10^{20}$ m^{-3}, electron temperatures around 1 eV, and fluences of the order of $10^{23}–10^{24}$ $m^{-2}s^{-1}$. A 0.4-T magnetic field was used, the biasing voltage was -40 V, and the exposure time ranged from 20–120 s. The maximum sample temperature was 300–500°C. The DIARC DLC samples showed large chemical erosion while the Balinit coatings were much more durable: the net erosion was a factor of 2 smaller in terms of the measured mass loss (1 mg vs. 2 mg).

The other set of samples, produced by DIARC-Technology Inc. and the Romanian MedC Association, consisted of D-doped W-Al coatings with different W:Al ratios. The thickness of these samples was 2–4 μm and they were produced on Mo. The nominal W:Al ratios of the samples were 85:15, 75:25, and 60:40. For these samples, hydrogen plasmas with neon to enhance erosion were used. The plasma parameters and other experimental conditions were almost the same as for the DLC samples but the exposure time was now longer (260–520 s) and the maximum surface temperature higher (500–600°C). The Al content of the samples as well as the substrate material seemed to have large impacts on the observed erosion/re-deposition and surface-modification patterns as well as on the measured surface temperatures; this we attribute to differences in the thermal conductivities and melting points of the different materials. The determined mass loss of each sample varied from 0.1 mg to 0.2 mg.

3.3.8 LIBS setup for studying beryllium-containing samples

EFDA tasks:	WP11-PWI-03-04
Research scientists:	A. Hakola, J. Karhunen, VTT M. Aints, A. Lissovski, P. Paris, University of Tartu

In 2011, an experimental set-up for LIBS studies of beryllium-containing samples was built in the beryllium- and tritium-handling facilities of Tekes-VTT. This system will enable erosion and retention studies of different samples having beryllium as one of their constituents. In the initial phase, the necessary samples will be provided by the Romanian MedC Association, and some of them will be implanted with D at IPP or exposed to plasma discharges in the linear plasma device Pisces B. Later on, wall tiles removed from JET will be analysed in the system.

The set-up consists of a vacuum chamber, the necessary vacuum pumps and gauges, a pulsed Nd:YAG laser (λ = 1064 nm, τ = 5 ns), an optical system to guide the laser beam on the sample, and a spectrometer to record the spectrum of light that the laser pulses will produce as a result of their interaction with the target. A photograph of the system can be seen in Figure 3.23.

The functionality of the system has now been tested and the experiments with the first beryllium samples are scheduled for the summer 2012. In addition, a new spectrometer has been purchased to enable gated recording of emission spectra at a temporal resolution of a few ns and at spectral resolution down to 0.1 nm.

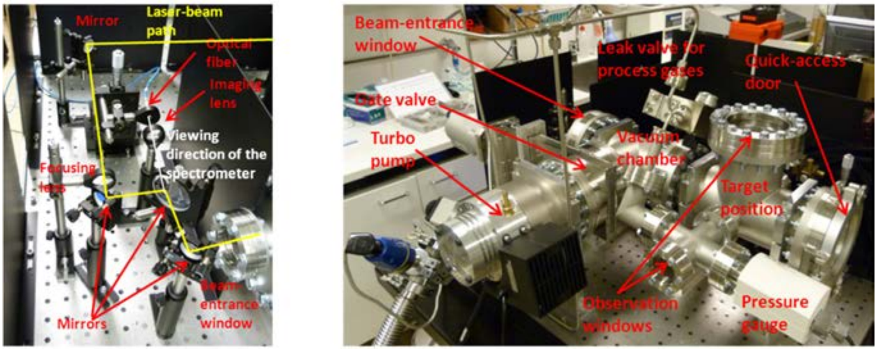


Figure 3.23. Right: photograph of the LIBS system built for analyzing beryllium-containing samples. Left: detailed view of the optical set-up of the LIBS system.

3.4 Energetic Particle Physics

3.4.1 Fast ion experiments with the FILD and other diagnostics

EFDA task:	EFDA-WP11-DIA-01-02-01
Research Scientist:	S. Äkäslompolo
Collaboration:	Manuel García-Muñoz, ASDEX Upgrade team, IPP Garching

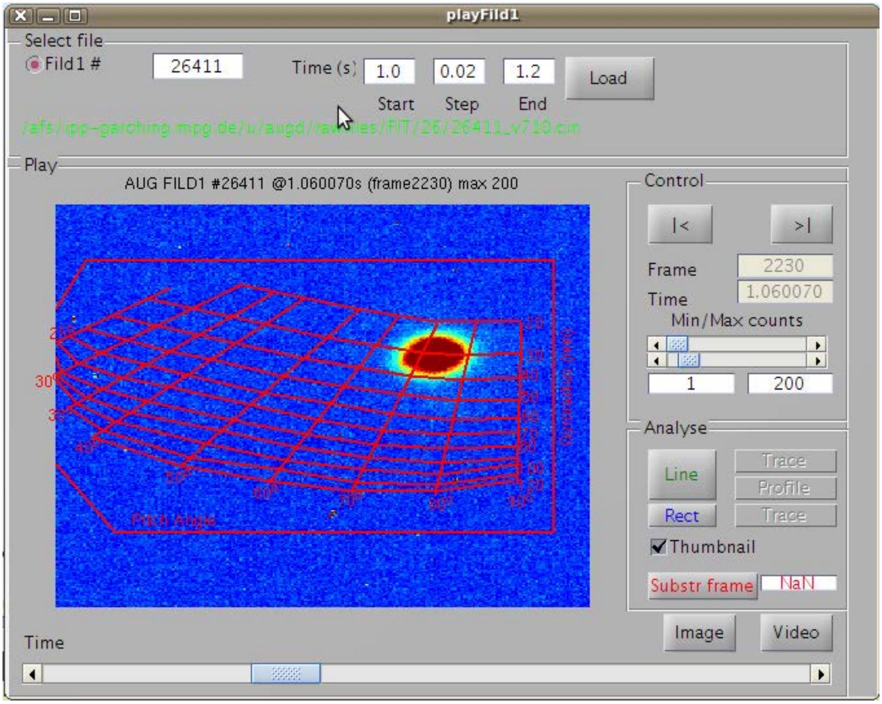
The visit to Garching, Germany, was part of the European experimental programme carried out at ASDEX Upgrade tokamak.

Fast ions or suprathermal ions have a far higher energy than the thermal bulk of the plasma. The fast ions are mostly born during non-inductive heating of the plasma. Because of their high energy, the fast ions have a potential to quickly erode the plasma facing components. On the other hand, it is believed that the fast ions play a significant role in high performance plasma operational modes. Magnetohydrodynamic (MHD) instabilities of the plasma can drive fast ions from the plasma. Such instabilities include the Edge Localized Mode (ELM).

In ASDEX Upgrade, fast ions can be measured with a number of diagnostics. In this plan, the fast ion loss detector (FILD) is used in concert with other fast ion diagnostics, especially the neutral particle analyser (NPA). The goal is to gain further understanding of the behavior of fast ions during ELMs and the effect of the resonant magnetic perturbation (RMP) from ELM mitigation coils to the fast ions.

S. Äkäslompolo has established collaboration with Dr. García-Muñoz, who is the fast ion diagnostician at AUG. In recent years, Äkäslompolo has assisted him in setting up the diagnostics and operating them during an exceptionally taxing time period: annually, for a few weeks, an extra FILD probe is attached to the midplane manipulator of AUG, and a large number of fast-ion-dedicated discharges are performed. In addition to helping during the experiments, Äkäslompolo provides theoretical fast ion distributions with the ASCOT code.

The three-week visit was deemed a success. The ELM measurements were successful. Interesting new data was acquired about fast ion losses during ELMs. Also other MHD modes were measured. The data acquisition (DAQ) and data analysis software were updated (see Figure 3.24) and new code was written. Äkäslompolo’s main tasks were updating the FILD1 probe data acquisition software, creating data analysis tools for the fast camera films produced by FILD1, checking the possibility of using thermometry for comparisons with ASCOT simulations, monitoring the heat load on FILD probes during experiments, learning NPA raw data postprocessing methods, and finding causes for unsuccessful fast camera measurements. The measurements for the studies described in section 3.4.2 were made during the visit.



● Fild1 # 26411

Time (s) 1.0 Start, 0.02 Step, 1.2 End

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AUG FILD1 #26411 @1.060070s (frame2230) max 200

Frame 2230

Time 1.060070

Min/Max counts 1 200

☑ Thumbnail

Substr frame NaN

Figure 3.24. A screen capture from the fast camera data-analysis software developed during the expedition.

3.4.2 Effect of ELM mitigation coils in AUG on NBI ion confinement

EFDA task:	EFDA-WP11-DIA-01-02-01
Research scientists:	O. Asunta, S. Äkäslompolo, T. Kurki-Suonio, AU
Collaboration:	M. García-Muñoz, ASDEX Upgrade Team

Mitigation of edge localized modes (ELMs) is vital for successful high-confinement mode (H-mode) operation of ITER. One suggested method for ELM mitigation is using magnetic field perturbations. To study this method, eight in-vessel saddle coils have been installed on ASDEX Upgrade (AUG). Their effect on fast ion wall loads was studied with the fast particle following Monte Carlo code ASCOT. Neutral beam injected (NBI) particles were simulated in two AUG discharges both in the presence and in the absence of the magnetic field perturbation induced by the in-vessel coils.

In one of the discharges (#26476) three neutral beams were applied individually, making it a useful basis for investigating the effect of the coils on different beams. However, no ELM mitigation was observed in #26476, probably due to the low plasma density. Therefore, another discharge (#26895), demonstrating clear ELM mitigation, was also studied. The magnetic perturbation due to the in-vessel coils has a significant effect on the fast particle confinement (see Figure 3.25), but only when the total magnetic field is low. When the total magnetic field was high, the perturbation did not increase the losses, but merely resulted in redistribution of the wall power loads. Hence, it seems to be possible to achieve ELM mitigation using in-vessel coils, while still avoiding increased fast ion losses, by simply using a strong magnetic field.

In the same simulations, data from ASCOT synthetic diagnostic was compared with experimental Fast Ion Lost Detector (FILD) measurements. Preliminary results show a reasonable correspondence, but more work is needed in order to better isolate the effect of the in-vessel coils on the measured FILD signal.

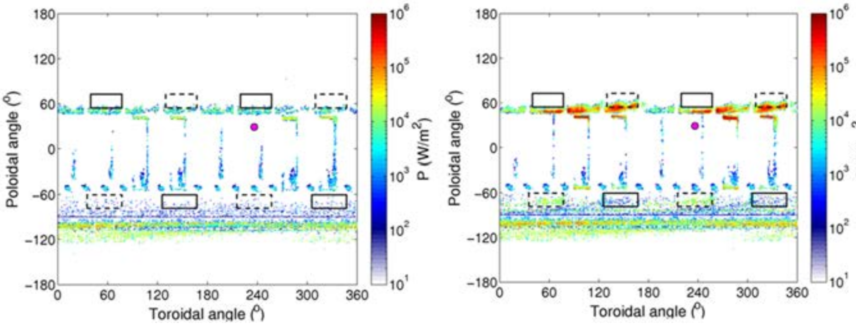


Figure 3.25. Simulated fast ion wall loads for beam Q6 in #26476 when I_{coil} = 0.0 kA (left) and when I_{coil} = 0.95 kA (right). The FILD, located at around 235 deg in toroidal and 30 deg in poloidal angle, is marked with a magenta circle, whereas the in-vessel coils are drawn as squares with solid (negative current) and dashed (positive current) black line.

3.4.3 ASCOT simulations of off-axis current drive

EFDA task:	WP11-HCD-01-04-01-01
Research scientist:	O. Asunta, AU
Collaboration:	R. Akers, M. Romanelli, G. Corrigan, CCFE

Modelling the off-axis current drive in Mega Amp Spherical Tokamak (MAST) turned out to be more complicated than expected. The work on getting the required data from MAST database to the Jet Integrated TRAnsport Code (JINTRAC) is still in progress. In principle ASCOT is ready for the current drive simulations, but some more improvements, such as including the effect of rotation and self-collisions between neutral beam injected (NBI) particles, should still be made to improve the reliability of the simulations.

3.5 Theory and Modelling for ITER

3.5.1 Support to predictive scenario modelling for future devices

EFDA task:	WP11-ITM-ISM
Research scientist:	J. Lönnroth

The ITER Scenario Modelling (ISM) group within Task Force Integrated Tokamak Modelling (ITM) carries out modelling activities in preparation for future tokamak devices, primarily ITER. The work includes modelling of both actual ITER plasmas and of plasmas from present tokamaks deemed to be interesting with ITER operation in mind in one way or another. The contribution of Tekes to this work in 2011 has mainly been focused on MHD stability analysis of hybrid scenario JET plasmas. This remains work in progress and continues in 2012, when enough analysis should have been carried out in order for general conclusions to be drawn from the work.

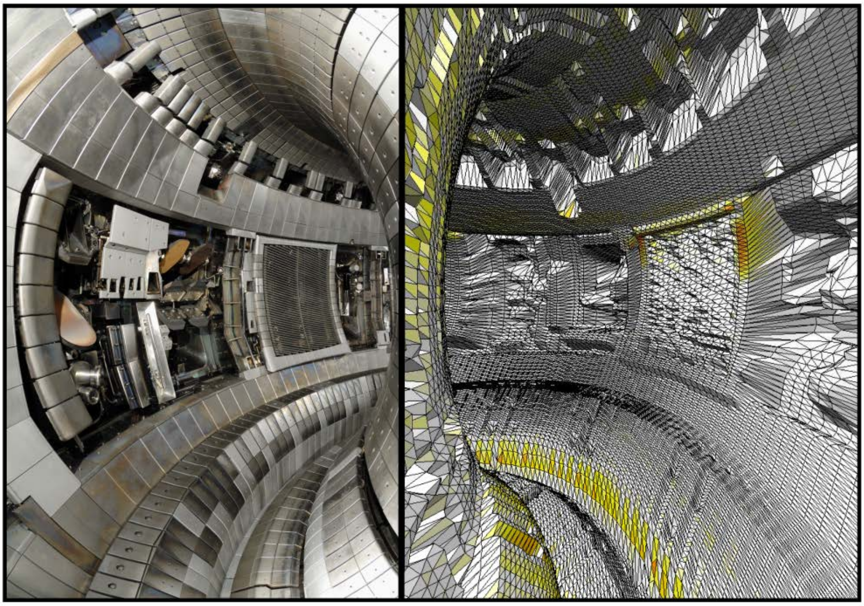


Figure 3.26. On the left is a photograph of the ASDEX Upgrade vessel, and on the right the defeatured 3D wall. The color depicts simulated particle flux to the wall.

3.5.2 Defeaturing the 3D first wall

EFDA tasks:	WP11-ITM-EDRG-ACT1-T03; WP11-ITM-EDRG-ACT1-T02
Research Scientists:	S. Äkäslompolo, T. Koskela, AU
Collaboration:	T. Lunt, H.-J. Klingshirn, IPP Garching

ASDEX Upgrade 2011 CAD data has been converted into a three-dimensional gas-tight wall mesh at Tekes – Aalto University. The method is based on ray-tracing a dense rectangular grid of radial rays in toroidal-poloidal space. The resulting mesh can then be smoothed to reduce the amount of data and to remove anomalies. The final mesh (as illustrated in Figure 3.26) can then be converted into wall data in CPOs or other formats understood by simulation codes (Figure 3.27). Such wall descriptions were successfully used in simulations of ^{13}C injection experiments. The first steps in similar activities for the JET ITER-like wall have been taken.

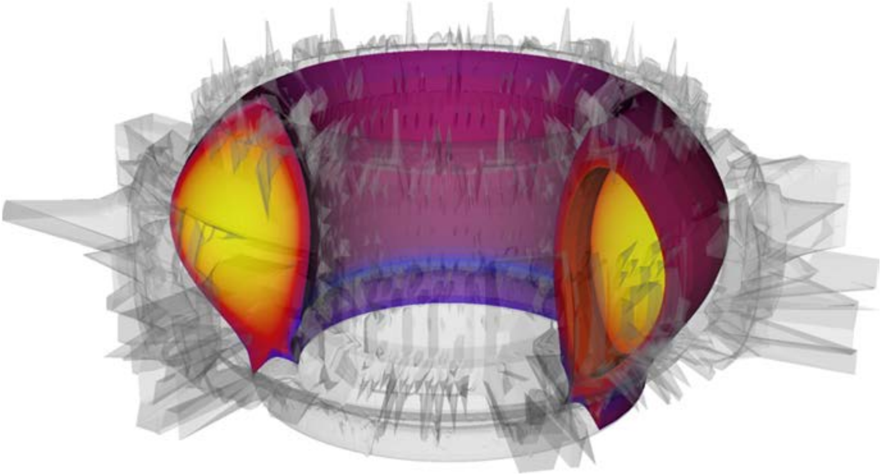


Figure 3.27. The AUG wall, coupled to a SOLPS plasma solution via CPOs.

3.5.3 Assessing the effect of TBMs and ELM mitigation coils on fast ion confinement and wall power loads in ITER

Research scientists:	T. Kurki-Suonio, O. Asunta, T. Koskela, A. Snicker, S. Sipilä, S. Äkäslompolo, AU

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

The 5D Monte Carlo orbit-following code ASCOT is well suited for studies of fast ion wall load profiles, and has previously been applied to ITER scenarios under the assumption that the fast ion transport is dominated by neoclassical effects, resulting in a modest fast ion population at the edge.

The finite number (18 in ITER) and limited toroidal extent of the Toroidal Field (TF) coils cause a periodic variation of the magnetic field strength, the so-called toroidal ripple. At the separatrix, the ripple strength can be up to 1.1 %. Such ripple can cause significant fast particle leakage, leading to very localized power loads on the walls. Therefore, ferromagnetic inserts (FIs) will be embedded in the double wall structure of the ITER vacuum vessel, reducing the ripple to 0.6 %. Unfortunately, in ITER the field at the edge is further perturbed by the test blanket modules (TBMs), made of ferromagnetic material. TBMs cause poloidally and toroidally localized perturbations to the magnetic field. In addition, the in-vessel coils, found effective for ELM mitigation, cause a field modulation at their own periodicity. An example of the combined effect of different perturbations on the magnetic field structure is shown in Figure 3.28. Recent simulation results suggest strongly increased loss of NBI power with the ELM coils.

The effect of TBMs on the magnetic field is read into ASCOT from ITER database. In order to include the effect of the ELM coils in ASCOT simulations, unless it becomes available from database, the field modulation the coils cause must be evaluated. For this purpose, a new code called BioSaw has been written. The code solves the vacuum magnetic field caused by a coil with given dimensions and parameters from the Biot-Savart law.

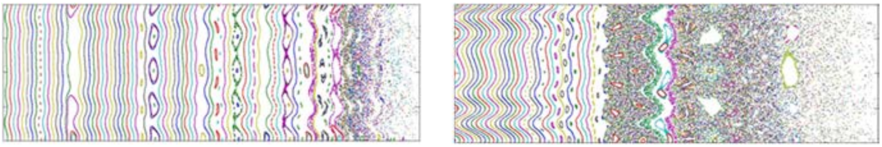


Figure 3.28. Poincare plots of the field lines in ITER plasma using two different equilibria available for ITER studies. On the left, the field lines remain well confined, leading to NBI power losses of about 3 %, while on the right the stochastic region extends deep into the plasma, leading to power losses of almost 30 %.

3.5.4 Upgrading ASCOT code for ITER modelling

Research scientists:	A. Snicker, E. Hirvijoki, AU
Collaboration:	E. Poli, P. Lauber, M. Schneller, IPP Garching

A model for various MHD mode perturbations has been developed for the guiding-center orbit-following code ASCOT. The model can treat both stationary MHD modes (neoclassical tearing modes, NTM) and rotating modes (Alfvén eigenmodes, AE). It is based on a vector presentation of the equations of motion, and is applicable in an arbitrary coordinate system, thus allowing simulations all the way to the wall. Figure 3.29 illustrates the island structures as they appear for ions in ASCOT simulations.

3.5.5 Preparing Elmfire for integrated modelling of ITER

Research scientists:	J. Heikkinen, VTT
	S. Janhunen, T. Kiviniemi, T. Korpilo, S. Leerink, AU

Elmfire is a global electrostatic full-f gyrokinetic particle-in-cell code for turbulent tokamak plasma studies having the full capapbility to deal with kinetic electrons and binary momentum and energy conserving collisions among the charged particles. Further description and status of its development are described elsewhere in this yearbook. On the way of its path towards simulating ITER tokamak plasma, various unresolved problems have to be settled. On the physics side, the code has to be made to cover the scrape-off-layer and to deal with electromagnetic turbulence. This will require an unstructured grid and efficiency considerations of the related interpolations and sampling methods with special consideration of the X-point features. Electromagnetism in full-f code is difficult to introduce as it at the same time requires the advancing of the magnetic background in response to the evolving plasma currents. It has not yet been realized whether this feature is practical to be included. Adding these physical ingrediences, as they undoubtedly lead to significantly larger memory and CPU consumption, were postponed for good reasons. Their introduction will be reconsidered during the ongoing EU Large-scale integrating project (ICT Call 7) CRESTA (Collaborative Research into Exascale Systemware, Tools and Applications), where one goal is to provide Elmfire with the necessary features to run efficiently in the coming exascale supercomputers. To promote the integration of Elmfire with the other fusion codes, strong effort within the ITM Task Force has been made in unifying the I/O subroutines and operations. It is premature to consider running Elmfire together with other fusion codes (MHD or fluid transport codes).

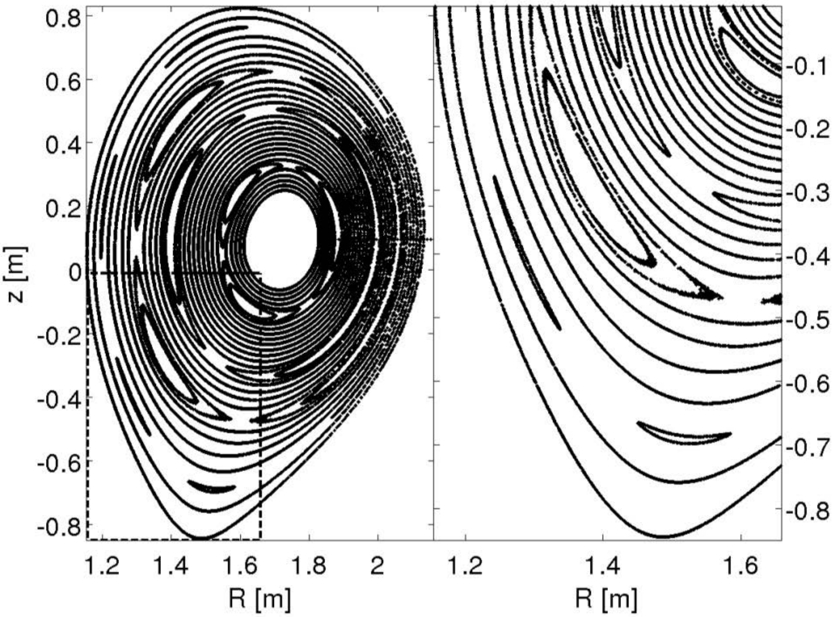


Figure 3.29. Island structures as seen by ions in ASCOT simulations.

3.5.6 Modelling of material mixing for extrapolation to ITER

EFDA task: WP11-PWI-05-03
Research scientists: K. Nordlund, C. Björkas, A. Meinander, A. Lasa, K. Vörtler, UH

According to the actual design, current and future tokamak-like fusion reactors include beryllium (Be), carbon (C), and tungsten (W) as the plasma-facing materials. Due to sputtering and consequent redeposition, during reactor operation, also mixtures of all these elements will form. Hence it is important to understand the different atom-level mechanisms in these materials.

In 2011, we performed a systematic comparison of W and different tungsten carbides (WC and W_2C) under low-energy deuterium (D) irradiation, We studied the D reflection and structural changes in the three materials, the C sputtering yields and mechanisms in the tungsten carbides and the effect of the temperature in these processes.

For this study, we constructed a crystalline W cell consisting of 3000 atoms and irradiated its (100) surface with 10, 30, 50, 100, 200, 300 and 1000 eV D ions, at 300 and 600 K. The tungsten carbides cells consisted of 2400 atoms. Both crystalline and amorphous tungsten carbides were studied. The D impact energies were 10, 20, 30, 50 and 100 eV. In all the cases, we performed 3000 cumulative bombardments for each energy. The impact point of the cell and the bombarding deuterium ion was randomized by shifting the cell in the x and y direction after every run while keeping the deuterium initial position constant, in the middle of the xy-plane and 5 Å above the cell surface.

We found that no W was sputtered. Regarding the D trapping, the D in W is present mainly in atomic form, causing deformation of the W lattice where the D atoms are located. In contrast, the D in WC and W_2C is trapped forming small molecules and the change in the structure of the materials is larger. The C sputtering yield strongly depends on the C content of the first few layers. This sputtering yield increases due to Swift Chemical Sputtering in the range of 30–50 eV D impacts, causing also molecule sputtering. The C sputtering yields are used as input for plasma simulations with the ERO code and the D trapping profiles obtained in our simulations are taken by Rate Equation codes to calculate the D diffusion in the W-based materials.

We are also examining the mysterious formation of a highly underdense fuzz on W surfaces during prolonged He bombardment. This effect, observed experimentally at the PISCES-B plasma machine in San Diego, could potentially even become a showstopper for ITER, and hence it is crucial to understand it. Figure 3.30 shows initial MD simulation results, which shows that prolonged He bombardment can lead to growth of W surfaces and formation of a bubble network in it. This is likely the first stage of the W fuzz formation.

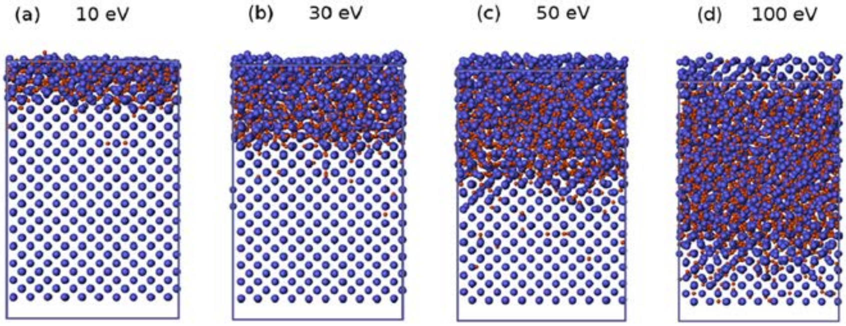


Figure 3.30. Bubble formation and surface growth during prolonged (3000 impacts) He bombardment of W.

3.6 Code Development and Integration

3.6.1 Code implementation, integration, verification and validation

3.6.1.1 Kepler / test workflows / benchmarking and validation

EFDA tasks:	WP11-ITM-IMP5-ACT1; WP11-ITM-IMP5-ACT3
Research scientists:	O. Asunta, E. Hirvijoki, S. Sipilä, A. Snicker, AU

During 2011, the neutral beam injection (NBI) module of ASCOT was turned into a stand-alone Kepler actor called BBNBI. Furthermore, this actor was adapted to version 4.09a of ITM data structures and included in a Kepler workflow. The test workflow, presented in Figure 3.31, initializes the necessary (but at the time unavailable) limiter and NBI structures before proceeding to the BBNBI actor that generates an ensemble of NBI test particles. The results are plotted and the produced test particle ensemble (in a consistent physical object or CPO called *distsource*) is forwarded as input to ASCOT. Including BBNBI in the IMP5HCD workflow producing e.g. heat and particle source information for the European Transport Solver (ETS), the heart of ITM, is a work in progress due to problems with the Universal Access Layer (UAL) of the Kepler environment. Benchmarking against other codes using Kepler is foreseen in the near future.

An ASCOT Kepler actor using UAL version 4.09a has been created, with embedded code-specific inputs and using CPO's for other input/output. Distribution CPO output has been added. The actor has been tested to run successfully in a Kepler test workflow on the EFDA Gateway platform. Documentation for code users has been written and is in the process of being embedded in the Kepler actor. Benchmarking ASCOT against other orbit-following codes and validation against experimental results in Kepler environment has not commenced, as no other orbit-following code and no suitable experimental data is available in Kepler environment.

The SOFI code has been adopted to use UAL version 4.09a. It has been tested as a standalone version, and the code is ready for the creation of a Kepler actor. The current version of the source code can be found in the SVN repository. The first version of code documentation for developers is accessible in the repository.

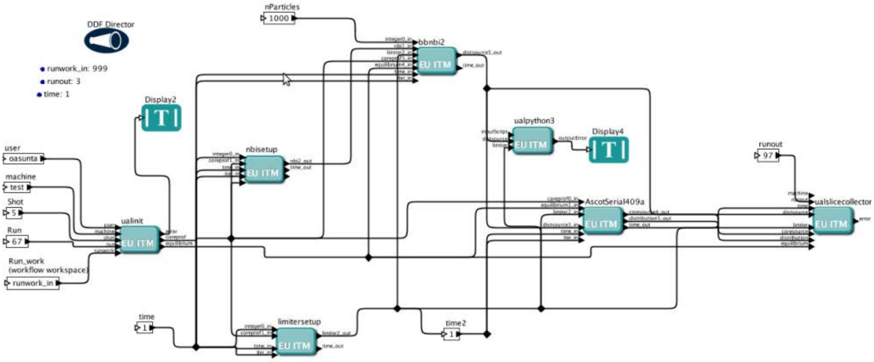


Figure 3.31. Kepler workflow for testing BBNBI and ASCOT. The workflow also includes actors needed for generating the input needed by BBNBI and ASCOT because, for the time being, data from experimental devices is not yet available.

3.6.1.2 Kepler workflows and interfacing with HPC-FF

EFDA task:	WP11-ITM-IMP4-ACT2
Research scientists:	S. Janhunen, T. Korpilo, AU

Data inputs from CPOs (coreprof & coretransp) are now available to the Elmfire code, including density, temperature and current profiles. The current profile implementation has been tested with a previously well known FT-2 test case, and the results have been found to agree with earlier results for analytical current profile.

The code runs on HPC-FF. As outstanding issues, HDF5 outputs are not finished, and will be worked on in 2012. The background magnetic field remains cocentric circular.

We have participated in the ITM WS/CC in Cyprus, which was found to be very productive in terms of finishing the current profile upgrade and renewing commitment to the IMP#4 project.

3.6.1.3 Integration and validation of edge codes

EFDA task:	WP11-ITM-IMP3-ACT2
Research scientists:	L. Aho-Mantila, M. Airila, VTT

Implementation of CPO handling in ERO was continued. The 2010 developed preprocessor for CPO fluid plasma data (edge/fluid) input was upgraded to use data version 4.09a. The public version of ERO that is available in CVS can handle the outer divertor target representing its geometry as two straight segments. A fitting procedure was added to the pre-processor for automatic definition of the target based on the fluid grid target boundary shape. The developed pre-processor produces a plasma background file needed by ERO for divertor simulations. Once completely tested, the pre-processor and ERO will constitute a Kepler actor.

For validation of edge codes, extensive SOLPS5.0-ERO modelling was performed for low-density AUG L-mode discharges in forward and reversed B_t and I_p. The results with drifts included were thoroughly benchmarked against all available diagnostic measurements. The measured local carbon migration pathways were reproduced in SOLPS5.0-ERO simulations. The magnetic pre-sheath was identified as the most uncertain region in these integrated simulations, and verification of the magnetic pre-sheath model using detailed PIC simulations is recommended.

3.6.1.4 Cross verification of linear and neoclassical codes on specified standard cases

EFDA task: WP11-ITM-IMP4-ACT3
Research scientists: J. Heikkinen, VTT
S. Janhunen, T. Kiviniemi, T. Korpilo, S. Leerink, AU

The Elmfire code has been improved with respect to neoclassical calculations, so that $m \neq 0$ modes for $n = 0$ mode are now included (previously only the flux-surface average was included). This has been found to be important especially with respect to finding an equilibrium distribution function that is stable (with respect to GAM oscillations), while the equilibrium E_r is found to be more or less unaffected.

We have investigated a case with impurities and found considerable difference with respect to the equilibrium E_r compared to Hazeltine-Hinton, which is not reproduced by the NEOCLASS code but is expected [Landreman et al., Phys. Plasmas **18**, 092507 (2011)]. We therefore can conclude that Elmfire can be utilized also in obtaining the neo-classical equilibrium for a multi-species (up to 3) plasma. This could be the point of easiest impact of Elmfire on the IMP#4 project in 2012.

The results in given in this subsection of the report are worked on to be published in the beginning of 2012. Two papers are expected: methods paper for the filtering, and a paper on the physical implications thereof.

3.6.1.5 Integration of turbulence codes

EFDA task: WP11-ITM-IMP4-ACT1
Research scientists: S. Janhunen, T. Korpilo, S. Leerink, AU

While the Elmfire code has been now prepared (see section 3.6.1.2) as to make it possible for the benchmark case to be run, we need to access additional HPC-FF resources to be able to run it. The considerable increase of $1/\rho^{*2}$ from our FT-2 and TEXTOR cases makes this case difficult for turbulence runs. However, as a first test, we are considering the possibility of obtaining a NC equilibrium for this test case (see section 3.6.1.4) as a first step.

Some improvements in the Elmfire (such as improved energy conservation properties from time stepping with velocity Verlet) have been made with respect to conservation properties during this reporting period.

3.6.2 Developing a code for modelling ICRH including synergy with NBI

EFDA task:	WP11-ITM-IMP5-ACT4-01
Research scientist:	A. Salmi, AU
Collaboration:	T. Johnson, KTH

The Integrated Tokamak Modelling (ITM) provides a framework for European scientists to collaborate for advancing modelling capability in areas where it is seen most important. One of such tasks is the development of a code capable of simulating ICRH together with synergy from NBI using guiding centre codes. To this aim, the ASCOT code has been modified to allow consistent simulations with the new RFOF module. RFOF is the ITM Monte Carlo module for ICRF heating with orbit following codes. The main achievements for 2011 were:

- The ASCOT main program has been altered to allow time dependent operation within a Kepler workflow.
- New code and functionality has been implemented to allow dynamic particle reweighting and control for better performance.
- MPI operation between ASCOT/RFOF has been implemented and initial tests appear promising.
- A basic concept for the data flow in future integration of wave code into the mix has been discussed. The current solution favors passing the waves CPO unaltered through the orbit follower to the RFOF module. For time-dependent RF heating waveforms, another CPO type may also be needed
- Input namelists for RFOF have been converted into XML and merged into ASCOT XML input file to make the code parameters accessible through Kepler.

To summarise, RFOF has been integrated with orbit following MC code ASCOT and run successfully on the EFDA Gateway platform. The proof-of-principle is demonstrated in Figure 3.32. A fast ion tail distribution develops and an expected amount of power is absorbed. More detailed validation of the model is, however, needed. Parallel processing capability is implemented and performs well in initial tests outside the Kepler environment. The time scale acceleration scheme for axisymmetric simulations is completed and tested for a user-defined acceleration level. Overall, good progress has been made, and detailed validation simulations can now begin.

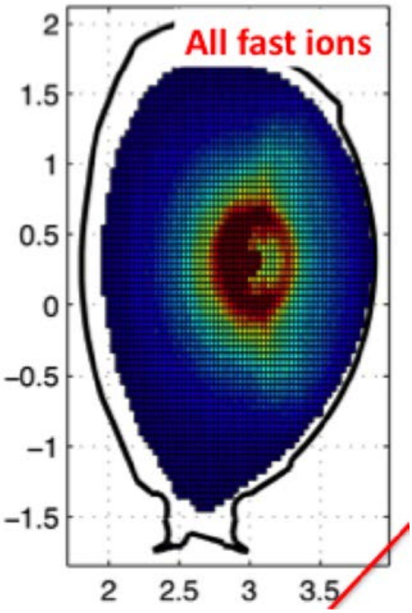


Figure 3.32. Fast ion energy content with ASCOT+RFOF demonstrating a successful proof-of-principle simulation.

3.6.3 Contributions to fusion product modeling in ITM

EFDA tasks:	WP11-ITM-AMNS-ACT1; WP11-ITM-EDRG-ACT3; WP11-ITM-IMP5-ACT6
Research scientists:	S. Äkäslompolo, O. Asunta, E. Hirvijoki, AU

ITM code development and integration tasks related to fusion products and other fast ions have spanned the whole path from birth to diagnostics. The ASCOT code plays a central part, as it can produce fast ion slowing down distributions which can then be used as input to further calculations. In addition, models developed for ASCOT have been re-used in new modular ITM tools.

The fusion cross sections, thermal reactivities and beam-target reactivities for D(d,n)^{3}He, D(d,p)T, T(d,n)^{4}He and ^{3}He(d,p)^{4}He reactions have been made available to other ITM collaborators via the Atomic, Molecular, Nuclear and Surface data (AMNS) database. Work for providing beam-beam cross sections is on-going due to unexplained discrepancy in results.

The AFSI Fusion Source Integrator code has been written, to provide the fusion reaction rates on a given plasma scenario. It involves developing tools that calculate nuclear reactions from both Maxwellian and non-Maxwellian distribution functions of the reactants. Some issues including above mentioned discrepancy compared to NUBEAM/TRANSP and CPO implementation still remain. The issues are foreseen to be fixed in early 2012 and new features added in 2012.

There has been progress towards implementing an NPA synthetic diagnostic, but the first results are expected only in early 2012. When the NPA model is complete, a neutron and gamma diagnostic model can be build with a relatively small effort on top of the NPA code base.

3.6.4 High Level Support Team Activities (HLST)

3.6.4.1 HLST support for Elmfire

EFDA task: WP09-HPC-HLST
Research scientist: S. Janhunen, AU

Elmfire is a gyrokinetic particle code with electrostatic perturbations. It includes electrostatic perturbations and up to three species calculated from the polarization response. This introduces some restrictions on filtering techniques that can be applied to the potential and numerical stability of time-stepping algorithms. We have worked on an orthogonal filtering technique of the charge separation to obtain dynamically stable neo-classical equilibrium, and have found a numerically stable alternative (2nd order) time stepping algorithm (velocity Verlet) to the original (symplectic Euler) 1st order technique. Elmfire is running well on the HPC-FF infrastructure, and some problems have been identified and corrected. Earlier in the year we (with the Elmfire code) were experiencing some trouble on HPC-FF as regards running with high number of processors. The problems were identified to be related to the PETSc library.

We have implemented a new Fourier filtering technique for neo-classical initialization of the code, where only long wavelength toroidal modes (≠ 0 and = 0) are included in the initial simulation period. This simple technique may be utilized for proper evaluation of the neo-classical equilibrium without turbulence first, and then continue the run with full mode spectrum allowing turbulence. This technique is expected to reduce the computing effort needed for runs where the feedback between turbulence and collisional physics in saturation state is needed.

3.6.4.2 HLST support for ASCOT

EFDA task: WP09-HPC-HLST
Research scientist: Simppa Äkäslompolo, AU

The ASCOT group received HLST support for implementing fast file I/O using the HDF5 library. Other topics for which support was received include shared memory segments for shared memory, solving MPI problems and general help in exploiting HPC-FF.

3.6.5 Development of the ASCOT code

Research scientists:	E. Hirvijoki, O. Asunta, T. Koskela, J. Miettunen, S. Sipilä, A. Snicker, S. Äkäslompolo, AU
Collaboration:	U. Tigerstedt, J. Westerholm, Åbo Akademi N. Hariharan, HLST

The ASCOT code has been under constant development for 20 years. In the process, the code structure has become increasingly complicated and difficult to maintain. In order to remedy this situation, a completely rewritten version is under development. Identified by version number 4, the new ASCOT code has been written making extensive use of FORTRAN 90/95 features. The code structure has been greatly improved and simplified, and the old interpolation routines have been replaced by a fast and reliable spline package. The new version is in the testing and benchmarking phase.

3.6.6 Elmfire gyrokinetic transport code development

Research scientists:	J. Heikkinen, VTT S. Janhunen, T. Kiviniemi, S. Leerink, AU

Elmfire is a 5D gyrokinetic full-f particle code for edge and global simulations of plasmas. Here, direct implicit solution method for ion polarization drift and electron parallel response is used and even plasma edge in the scrape-off-layer zone (SOL) can be simulated. Various complicated ingredients have been added to Elmfire to improve its compatibility with real experimental conditions and to prepare it for simulations in large tokamaks. Impurity ion species are included and neutral ionization model as a particle source and recycling of lost particles on the limiters are adopted. A Monte Carlo binary collision model (among all particle species) and loop voltage sustain the kinetic plasma equilibrium. Extensive diagnostics of plasma parameters and a complete Fourier analysis package for the mode evolution, including statistical analysis of a variety of transport quantities, facilitates extracting physical effects from the wealth of data. Advanced filtering methods are adopted to suppress the inherent noise in statistical sampling of the coefficient matrix and the charge separation.

Code is essentially a particle-in-cell code and solution of fields from 3D data requires sparse matrix inversion for which several different iterative solvers and preconditioners have been tested over the years. The present set of libraries that can be used in the code are at least IBM (PESSL, BLACS, GSL) and x86-64 (PETSc, ACML, FFTW). In the present version of the code parallelization is purely MPI based. Hybrid MPI/OpenMP version of the code is in progress, but is not expected to be used for this proposal.

When compared to other European codes, Elmfire is quite unique. It is gyrokinetic with kinetic electrons being thus more accurate than gyrofluid codes and gyrokinetic codes which assume adiabatic electrons. It also solves whole distribution of ions and electrons thus being full-f, unlike most other gyrokinetic codes which use so-called delta-f approximation. Delta-f codes are powerful for small deviations from background distribution and very suitable for snapshot transport analysis and linear mode analysis needing only some 10–100 particles per cell. However, for strongly perturbed plasma with strong transients or long time scale transport in core or edge plasmas, only full-f gyrokinetic method is truly warranted. Full-f approach makes the code able to simulate also neoclassical physics. Especially in edge plasmas, where wall losses and recycling together with strong gradients affect the distributions, use of fluid and delta-f kinetic approaches are questionable. However, the drawback of using full-f gyrokinetic approach is that at least 1000 particles per cell for an acceptable noise level are needed, which makes the simulations heavy.

Elmfire is computationally very demanding due to its integrated full-f algorithm. Because of this particularity, the code has been adapted for parallel computing using the MPI communication library. Large number of simulations particles is needed for good statistics regarding the actual particle behaviour. The process of advancing the markers according to the equations of motion require proportionally large amount of CPU-time. This process can however be parallelized almost perfectly. The electrostatic field is calculated via a fixed grid, whose values are needed in the equations of motion of particle markers. The storage of those values and specially the matrix of implicit interactions between markers and E-field take most memory, which has to be stored in RAM, posing a limitation to system size. Elmfire has been prepared to run on parallel machines, taking special care of the scalability and efficient usage of resources. It has already been optimized and used in all representative computers of the CSC. Used processors are Power4 (IBM eServer 1600), IBM PowerPC 770, and AMD Opteron (HP ProLiant DL145, and Cray XT4). It has been also optimized for Intel processors. The code has been tuned with pre-processor instructions to use the most optimized mathematical libraries, depending on the running architecture. The efficiency of I/O subsystem has also been taken care of with the introduction of MPI-IO collective calls that will provide efficient disk writing even in the massively parallel case. Presently, Elmfire can read tokamak data in CPO.

Preparatory access for CURIE for scaling tests has been supported but the porting and scaling tests are not yet finished. It is foreseen these tests are finished by the end of March 2012. In Jugene, Elmfire scaling tests have been successfully done even up to 131,072 processors. At the same time, Elmfire code has been adopted as one of the few high performance codes as a test bed for the European exascaling project CRESTA. It is expected that within this project running outside EFDA, Elmfire can be provided with the necessary applied mathematics and computer science elements required for simulation of the ITER tokamak plasma. These elements include an unstructured grid, aggressive domain decomposition and openMPI features for memory handling, real-time visualization tools, and use of graphic processors.

3.6.7 Development of the ERO code

EFDA tasks:	WP11-PWI-03-02; WP11-PWI-03-03
Research scientists:	E. Ahonen, M. Airila, VTT T. Makkonen, M. Groth, AU
Collaboration:	J. Lento, J. Tarus, CSC – IT Centre for Science J. Westerholm, E. Yurtesen, Åbo Akademi University D. Borodin, A. Kirschner, FZ Jülich

Divertor geometry definition in ERO was upgraded. The code supports now more complex divertor geometries which can be defined in the input file. In addition, handling of fluid code generated plasma backgrounds was improved. The upgrades were made available to all ERO users in the CVS repository of FZJ. In addition, the performance of ERO was profiled and necessary optimization actions identified in collaboration with CSC and Åbo Akademi University.

A set of new synthetic diagnostics were adapted in ERO to aid the interpretation of the experiment reported in section 3.7.2, including the spectrometer views and a synthetic fast camera view allowing any viewing angle and nonlinear distortions. In addition to the synthetic diagnostics, routines to initialize the ERO simulations based on AUG experimental data have been implemented. Data from the toroidal magnetic field and the magnetic equilibrium reconstruction from the Cliste code are used to obtain the magnetic field close to the injection location.

3.6.8 Development of a 3D equilibrium solver

Research scientists:	E. Hirvijoki, S. Janhunen, T. Koskela, A. Snicker, S. Äkäslompolo, AU
Collaboration:	S. Ilvonen, CSC – IT Center for Science

A simple summation of an axisymmetric plasma equilibrium and a fully 3D external magnetic field may result in excessive stochastization of the magnetic field structure. This happens because the result of the summation no longer fulfills the equilibrium conditions. In order to address this issue, a project to construct a truly 3D equilibrium with FEM has been initiated together with CSC – IT Center for Science within the SimITER Consortium of the Academy of Finland.

The chosen method assumes an axisymmetric initial state that is perturbed with an external 3D magnetic field. The force balance equation is solved with the finite element method, thus relaxing many of the approximations required by more traditional approaches. A Picard-Lindelöf iteration process is used to obtain the new equilibrium state. The plasma profiles are assumed static and mapped as functions of toroidal flux. Figure 3.33 illustrates the poloidal magnetic field calculated by this method. So far, several elements of the numerical solver have been implemented and partially tested. The current focus is on combining the developed blocks with the FEM code ELMER.

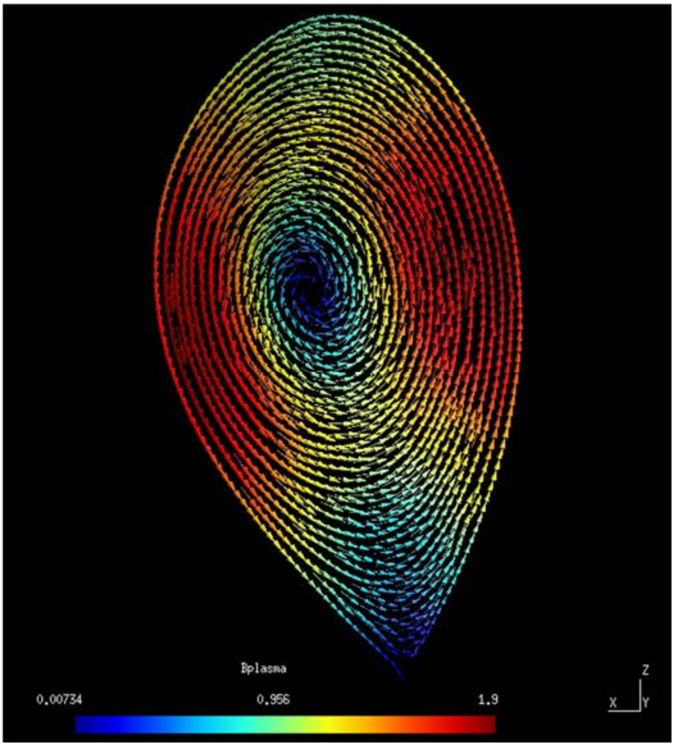


Figure 3.33. The magnetic flux density induced by the plasma current as calculated with the ELMER-based equilibrium solver.

3.6.9 Use of computing resources

Elmfire is computationally very demanding due to its integrated full-f algorithm. The ASCOT and Elmfire groups used approximately 2.5 million CPUh of CSC supercomputer resources in 2011. During 2011 about 8000 node-hours/month of computing time was available for the ASCOT group on HPC-FF.

The computing cluster of the Aalto University School of Science, Triton, is the smaller brother of CSC's Vuori: a Linux cluster with 230+ compute nodes with 12 CPU cores each plus additional resources for GPU computing and several nodes with 1TB of RAM. All the nodes are interconnected through InfiniBand. It is very well suited for mid-range simulations with ASCOT and various other computations.

The combined workstations of the Fusion and Plasma Physics and Fission and Radiation Physics Group research groups in Aalto University form a High Throughput Computing (HTC) platform implemented with the Condor software. Most smaller ASCOT simulations can be run quickly and efficiently with the spare processors of the workstations. The cluster has been used for over 83 CPU-years of computing since the founding of the cluster in early 2010.

3.7 Plasma Diagnostics

3.7.1 Testing and commissioning of JET NPA diagnostics upgrade

EFDA JET Activity:	JW6-OEP-TEKE-13; JW6-NEP-TEKE-17
Research scientist:	M. Santala, AU
Collaboration:	CCFE, VTT Microelectronics, Ioffe Institute

Neutral particle analysers (NPAs) detect atoms (i.e., 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 original diagnostic hardware as well as all data collection electronics has been supplied to JET by Ioffe Institute, St. Petersburg.

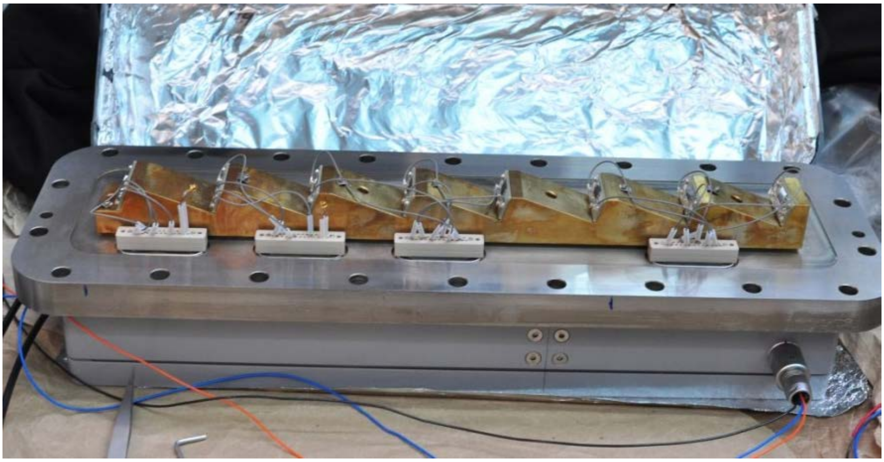


Figure 3.34. Completed diagnostic flange undergoing testing at JET. The vacuum side with detectors mounted on monolithic detector support is shown. The grey box on the air-side of the flange houses the new preamplifier electronics.

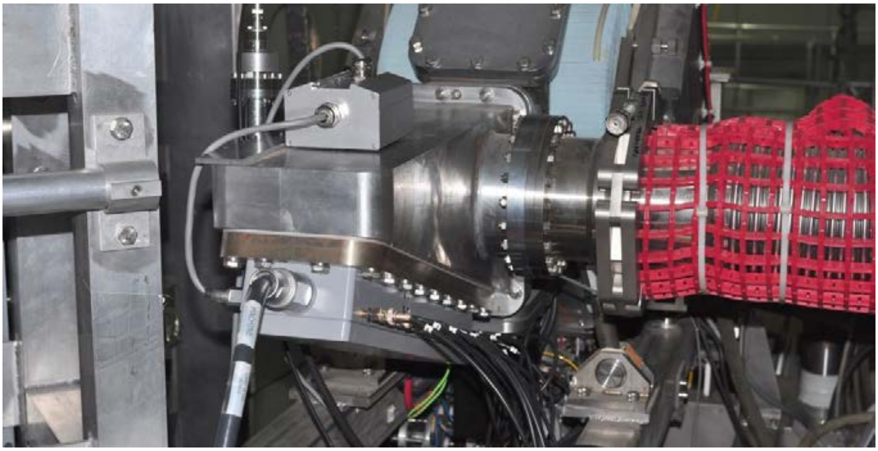


Figure 3.35. The new flange as installed on the JET machine. The KF1 magnet is shown on background and vacuum pumps are to the right. The thick cable connecting to the end of the preamplifier box carries all the signals and the various coaxial cables connecting to the side of the box are for detector bias supply and monitoring.

During 2011, new detector flange with thin silicon detectors for the KF1 diagnostic has been manufactured, installed and initially commissioned. Previously, thin CsI(Tl) detectors coupled to photomultipliers were used to detect the ions in the NPAs. These detectors had slow response due to CsI(Tl), their background sensitivity was relatively high and energy resolution was poor. A major drawback for fusion plasma diagnostic was that it was not possible to distinguish between alphas and deuterons in a single detector. These detectors have now been replaced with newly developed thin silicon detectors using SOI technology.

The new flange was initially assembled and tested at JET (Figure 3.34). This demonstrated the functionality of the entire data acquisition chain using flashing LED and an alpha source to excite the detectors and the new data acquisition electronics to read them and record the acquired data on a computer. The new flange was installed on JET (Figure 3.35) and installation of data acquisition electronics and cabling continued by CCFE during summer. As JET experimental campaign started in autumn the diagnostic was ready for commissioning.

Despite the various operating difficulties of the JET machine itself, neutrals from plasma were successfully detected by the new diagnostic setup towards the end of 2011. However, there have been issues with noise in the detector signals. The work continues with development of new software for the analysis of the entirely new raw data: previously, ion events were detected in hardware but now the raw detector signals are recorded and the detection of ions is carried out in software. This allows much more elaborate post-processing if errors are detected or algorithms are improved (e.g. pile-up processing). Instead of less than 1 MB of data per pulse, the diagnostic is now producing about 1.5 GB.

3.7.2 Develop a spectroscopic flow measurement for SOL region

EFDA task: WP11-PWI-03-02

Research scientists: T. Makkonen, M. Groth, T. Kurki-Suonio, AU
M. Airila, VTT

Collaboration: T. Pütterich, A. Janzer. T. Lunt, H.W. Mueller, E. Viezzer,
ASDEX Upgrade Team, IPP Garching

To study the deuterium flow in the high field side SOL, methane was injected from the high field side midplane in AUG, and the carbon velocities were measured by Doppler spectroscopy as well as the emission distribution of low charge state carbon ions imaged with a fast video camera. Methane was injected from a valve located in the central column in sector 1, 13 cm above the midplane (Figure 3.36). Radially, the injection was viewed by 8 spectroscopic lines of sight. These lines of sight are assumed parallel to the magnetic field and crossed the poloidal plane of the injection at different R coordinates.

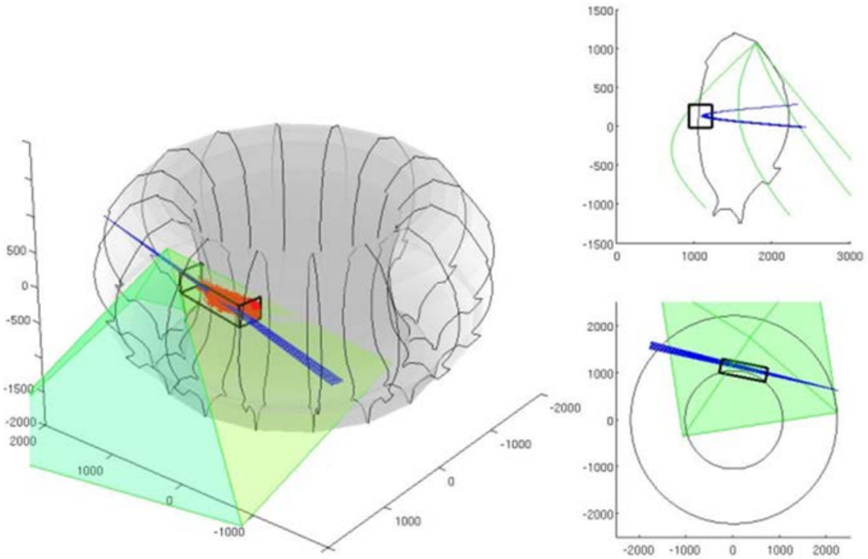


Figure 3.36. The experimental setup. Left: 3D view. Top right. View in the poloidal plane of the injection. Bottom right: view from above. All units are in mm. The thin black lines are the AUG first wall contours. The thick black box is the ERO simulation box. The red data in the 3D picture is a simulated carbon cloud. The blue lines are the used spectroscopic lines of sight. The green triangle and lines is the vertical fast camera view.

Doppler spectroscopy measurements were performed for singly and doubly ionized carbon: CII (515 nm) and CIII (465 nm). A fast video camera situated in the center of sector 1, above the injection, looking downwards towards the injection location was used to record images of CII and CIII emission of the same wavelength as the spectrometer at the injection location. The imaging system is complemented by a tangentially viewing fast camera.

The measured CII emission displays relatively little Doppler shift indicating that CII may not be equilibrated with the background flow. CIII, on the other hand, displayed a clear Doppler shift varying in time and radius. Several IDL routines were developed by Aalto University and VTT for AUG to analyze the spectroscopic data automatically and calculate the Doppler shift and temperature of CIII.

Measured flow profiles are shown in Figure 3.37. In L-mode the measured CIII flow was observed at a magnitude of 2 km/s in the direction of the direction of the low field side divertor in the SOL close to the separatrix. Inside the separatrix, the flow is in the opposite direction. In contrast, in H-mode plasmas during intra-ELM periods, the CIII flow was observed towards the high field side divertor, at velocities of the order 6 to 10 km/s in the far scrape-off layer. The velocities relax to 2–4 km/s in the direction away from the high field side divertor during inter-ELM periods. A local minimum in the flow velocity is observed close to the separatrix. It should be noted, however, that the spectroscopic lines of sight measure along their entire path length, and thus the observed profile are convoluted. We are extending this method for using nitrogen gas as N_2 is more preferred by AUG operations.

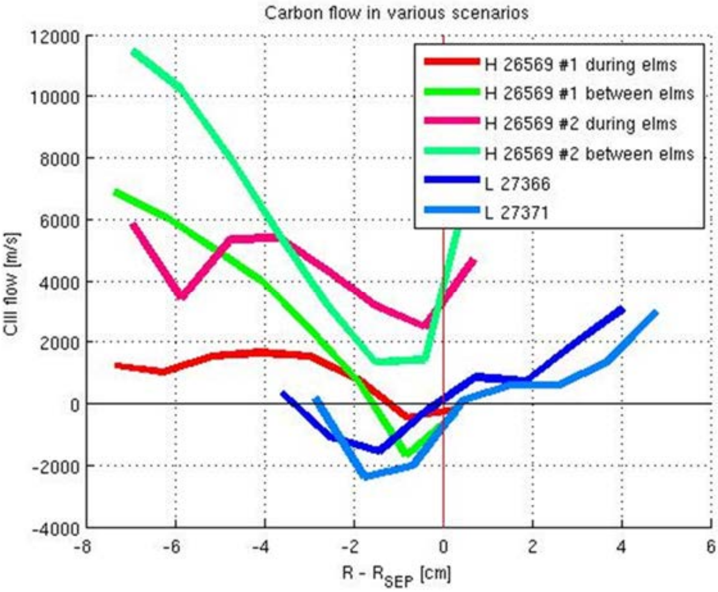


Figure 3.37. Radial profiles of CIII flow in the HFS SOL for L-mode and ELMy H-mode plasmas. Positive velocities denote flow in the direction of the HFS lower divertor. Discharge 26569 had several flat top phases with varying triangularity. #1 and #2 refer to two different phases where phase #2 had a higher triangularity.

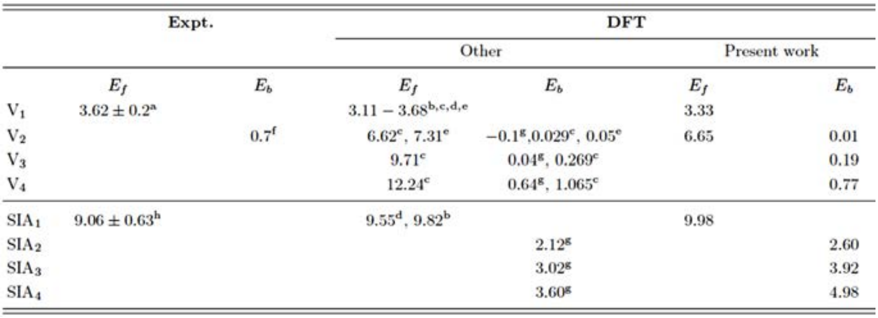
3.8 Emerging Technology and Power Plant Physics & Technology

3.8.1 Hydrogen migration in high Z plasma-facing materials

EFDA tasks:	WP10-MAT-WWALLOY-06
Research scientists:	K. Nordlund, K. Heinola, T. Ahlgren, M. Hakala, UH

The stability of small vacancy and interstitial clusters in tungsten were studied with first-principles calculations. The binding and the formation energies of the clusters increases with the cluster size. The di-vacancy binding energy was found to be nearly null but attractive, see Table 3.1.

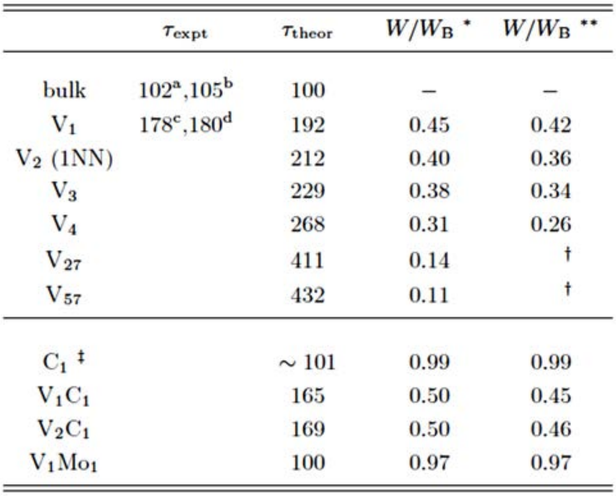
Table 3.1. The DFT calculated formation (*E*f) and binding (*E*b) energies for V*n* and SIAn systems with 1 ≤ *n* ≤ 4. Results are compared with experimental and other DFT results. Units eV.



	Expt.		**DFT**			
			Other		Present work	
	E_f	E_b	E_f	E_b	E_f	E_b
V_1	3.62 ± 0.2^{a}		$3.11 - 3.68^{b,c,d,e}$		3.33	
V_2		0.7^{f}	6.62^{c}, 7.31^{e}	-0.1^{g},0.029^{c}, 0.05^{e}	6.65	0.01
V_3			9.71^{c}	0.04^{g}, 0.269^{c}		0.19
V_4			12.24^{c}	0.64^{g}, 1.065^{c}		0.77
SIA_1	9.06 ± 0.63^{h}		9.55^{d}, 9.82^{b}		9.98	
SIA_2				2.12^{g}		2.60
SIA_3				3.02^{g}		3.92
SIA_4				3.60^{g}		4.98

The experimental Positron Annihilation Spectroscopy (PAS) method is a powerful tool for the detection of open volume defects in solid materials. However, the lifetime of positrons in different defects is needed in order to identify the defect. Numerical calculations of the positron lifetimes and Doppler broadening of annihilation radiation were performed employing the program Doppler. For positron lifetimes the electron density is obtained from the VASP calculation. The electron density is constructed by a superposition of atomic orbitals. The positron wave function is calculated in a 128 atoms super-cell on a real-space grid using potentials derived by density functional theory (DFT) methods. From the overlap of electron and positron densities, the annihilation rate for each orbital is calculated. The electron momentum distribution probed by positrons is then obtained by summing up each electron state weighted by the calculated partial annihilation ratio. Table 3.2 shows a comparison between experimental and calculated positron lifetimes.

Table 3.2. Theoretical and experimental β^+ lifetimes (ps) in W. Also included the calculated line-shape parameter values W/W_B with and without the effect of valence electrons.



	τ_{expt}	τ_{theor}	W/W_B *	W/W_B **
bulk	102[a],105[b]	100	–	–
V_1	178[c],180[d]	192	0.45	0.42
V_2 (1NN)		212	0.40	0.36
V_3		229	0.38	0.34
V_4		268	0.31	0.26
V_{27}		411	0.14	†
V_{57}		432	0.11	†
C_1 ‡		~ 101	0.99	0.99
V_1C_1		165	0.50	0.45
V_2C_1		169	0.50	0.46
V_1Mo_1		100	0.97	0.97

3.8.2 Radiation damage in structural materials

EFDA task:	WP10-MAT-REMEV-04-02
Research scientists:	K. Nordlund, C. Björkas, A. Meinander, K. Henriksson, K. Vörtler, UH
Collaboration:	SCK-CEN, CCFE

Ferritic/martensitic steels are considered candidate structural materials for fusion reactors, as they are known to be resistant to swelling and defect accumulation due to irradiation compared to other steels. The EFDA MAT-REMEV task is leading a systematic international effort to understand and predict radiation damage in steels with a multi-scale approach, including density functional theory, Molecular dynamics (MD) and Monte Carlo simulations. MD simulations are well suited for the length and time scales of primary damage formation due to collision cascades. Modeling stainless steels with up to dozens of different elements was until recently out of reach for MD simulations. To overcome this, we developed in 2008–2010 the first interatomic potential that can model stainless steel.

Using this new potential, which correctly reproduces the mechanical and thermodynamic properties of most Fe and Cr carbides as well as simple C and Cr defects in Fe, we have studied the combined effect of Cr and C on primary cascade damage in bcc-Fe (ferrite), including concentrations of C up to 5 at.%. Although the equilibrium solubility level of C in ferrite at 300 K is of the order of 10−12 wt% [8], non-equilibrium systems may contain higher concentrations.

Hence, it is of interest to explore how higher concentrations affect the behaviour of radiation damage cascades.

The evolution of cascades was studied by analysing snapshots taken at 0.1 ps intervals for the first 2 ps, and at longer intervals for the rest of the run. From the time development of defects shown in Figure 3.38, one can see that the cascades develop and recombine, as is usual for metals. In particular, recombination can be seen to occur with the same time profile at all levels of C included in this study, although the remaining defects are more numerous at higher concentrations.

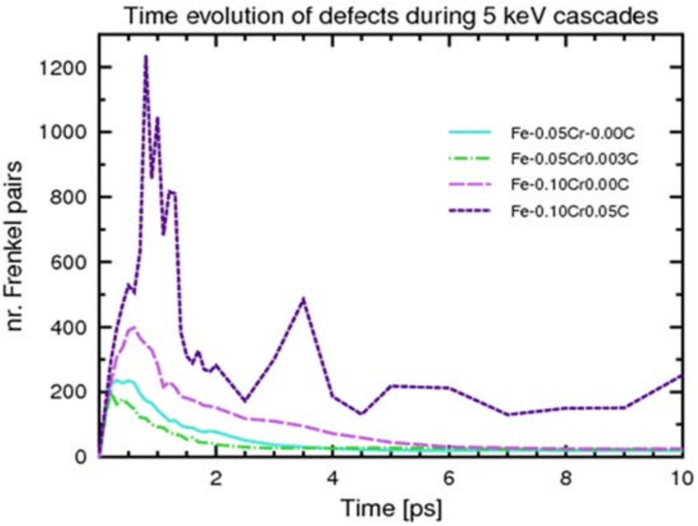


Figure 3.38. The number of Frenkel pairs occuring during a selection of 5 keV cascades as a function of time. Defects are calculated from single cascades.

The production of defects in binary FeCr with 5 % Cr was in line with results using earlier potentials for the binary system. However, with the new potential a clear increase (about a factor of three) in defect numbers with increasing Cr concentration was seen in 5 keV cascades, contrary to previous results, which showed no increase in defects up to 15 % Cr.

The addition of C in octahedral positions for concentrations up to 1 at.% had no significant effect on the number of defects, in agreement with previous results for the binary FeC system. There was no amorphization of the metal up to 1 at.% C, although C in solution is thermodynamically unstable at these concentrations, and in the longer term ought to form cementite precipitates. This, however, does not fully destabilize the lattice, as can be seen from the strong recombination in Figure 3.38. However, at concentrations above 1 at.% of C there was a clear and fairly strong increase in defect numbers, since the bcc lattice destabilizes locally. The binary FeC system showed no increase with increasing C concentration.

No clear effect of C concentration on the number of surviving Frenkel pairs, nor on defect clustering, was observed. Neither did the presence of C affect the Cr concentration in defects. However, the content of C in defects was found to be clearly above stoichiometric levels for all concentrations of C, both for vacancies and SIAs. This supports earlier results for the binary FeC system. The level of C content in defects relative to the stoichiometry was the same for all C concentrations, within the statistical uncertainties. A possible effect of Cr concentration could be seen on the C content in both vacancies and SIAs, (see Figure 3.39), with a lower C content in vacancies and higher in SIAs at 5 % Cr compared to 10 % Cr.

3.8.3 Divertor plasma edge modelling studies

EFDA task:	WP11-PEX-01-ACT1
Research scientist:	L. Aho-Mantila, VTT
Collaboration:	C. Lowry, EFDA JET CSU M. Wischmeier, IPP Garching X. Bonnin, LSPM – CNRS ASDEX Upgrade Team and JET-EFDA Contributors

Introduction: The objective of this task was to study incremental effects of impurity seeding in the edge plasma, in order to make reliable predictions of power exhaust in future fusion reactors. For this purpose, we have initialized the validation of L-mode radiative SOL and divertor plasma models against experimental data from the full-metal devices ASDEX Upgrade and JET. In 2011 the work focused on assessment of available experimental data from the two devices and on preparation of SOLPS5.0 simulations of L-mode discharges with and without N seeding.

Main results in 2011: At ASDEX Upgrade with all-W plasma-facing components, only few L-mode discharges were identified to be suitable for model benchmarking. When N_2 was injected into a low-density discharge, the outer divertor plasma was observed to cool down from the original 25 eV to as low as 5 eV, with the level of cooling dependent on the level of impurity seeding. At JET, no impurity seeding studies were made with the all-metal wall prior to late 2011. Therefore, new experimental proposals with N_2 seeding were made for both machines for model validation purposes.

In parallel to the assessment of experimental data, we started the preparation of SOLPS5.0 simulations for ASDEX Upgrade and JET. The main part of the work focused on setting up the multi-species simulations that include N in addition to the more usual intrinsic impurities C and He. 2D simulation grids with various resolutions were created according to the magnetic equilibrium in the ASDEX Upgrade discharges. Furthermore, a new vessel geometry corresponding to the actual ASDEX Upgrade wall was incorporated in the simulations. With this setup, the first plasma solutions were derived with various levels of N injection. The work will continue in 2012 with detailed comparison to experimental data.

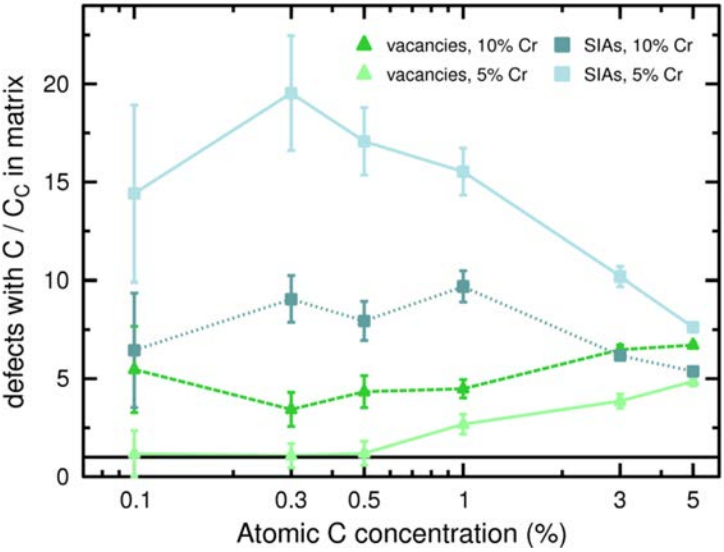


Figure 3.39. Fraction of vacancy and SIA defects with C within nearest neighbour distance, divided by concentration of C in matrix. Results from 5 keV cascade simulations in Fe with 5 % and 10 % Cr. The error bars are 1 errors of the average.

3.8.4 Outlines for the definition of RAMI guidelines for DEMO systems

EFDA task:	WP11-DAS-RH-08-ENEA/TEKES
Research scientists:	R. Tuominen, M. Siuko, VTT
Collaboration:	T. Pinna, ENEA

The objective specified for this task was to describe a roadmap for the application of the Reliability, Availability, Maintainability and Inspectability (RAMI) approach and to provide the first outline of associated guidelines for DEMO major systems. The task was performed in co-operation by ENEA in Italy and VTT.

Demonstration Power Plant (DEMO) will be a prototype fusion reactor designed to prove the capability to produce electrical power in a commercially acceptable way. Compared to the previous fusion facilities, which have been aimed solely on investigation and development of the necessary technologies, much higher requirements on plant availability for continuous power production will be obvious for the DEMO facility. In order to support design decisions and build up the confidence that such requirements will be achieved in the final installation, a systematic RAMI assurance approach, starting from the pre-conceptual and conceptual design phases, to support the system development is seen a necessity.

The task has produced general guidelines on how a competent RAMI approach for technical risk management could be established for the DEMO development process. In addition, some specific initial guidelines on critical functions in the

DEMO major systems have been outlined. The experience gained in the existing fusion devices and in other relevant fields of technology should be converged and considered when setting up the RAMI processes for DEMO. In the EFDA Working Program for the year 2012 a dedicated task has been issued under Design Tools and Methods (DTM), in which the RAMI processes for DEMO will be elaborated in more detail.

3.8.5 Applicability of the ITER divertor maintenance scheme to the DEMO divertor

EFDA Grant Contract:	WP11-DAS-RH-02-TEKES/ENEA
Research scientists:	J. Järvenpää, M. Siuko, VTT
Collaboration:	C. Labate, ENEA

DEMO, as well as ITER, is a tokamak-type fusion device. Based on the previous PPCS work, the main divertor design principle is similar; toroidal shape, divertor cassettes and maintenance ports for the divertor.

In ITER, divertor plasma facing components are combined as cassettes to make replacement and handling easier. The same principle is proposed to be applied also in DEMO. The main differences are:

- DEMO availability (thus fast maintenance = short down-time) is in key role.
- The neutron loading during the reactor operation in DEMO is considerably higher than in ITER.

The two differences make DEMO maintenance more challenging than in ITER, including also optimisation of methods and logistics. The heavy neutron load affects the material properties of reactor components. For example, the divertor cooling pipes cannot be re-welded after use and have to be replaced. Due to the high level of activation, the divertor cassette temperature will rise when the tokamak cooling system is disconnected, therefore a maintenance cooling system will have to be arranged during the transportation in the transport cask. On the other hand, the maintenance task is similar to ITER, but the characteristics told above set very different requirements for the maintenance procedure and the maintenance devices.

4. Activities of the Estonian Research Unit

4.1 LIBS for in-situ determination of erosion/deposition of first-wall materials

EFDA task:	WP11-PWI-03-04
Research scientists:	M. Laan, M. Aints, A. Lissovski, P. Paris, University of Tartu A. Hakola, J. Karhunen, J. Likonen, VTT
Collaboration:	H. Mändar, I. Jõgi, University of Tartu T. Haikola, J. Kolehmainen, S. Tervakangas, DIARC-Technology K. Bystrov, G. de Temmerman, DIFFER, Netherlands

4.1.1 LIBS development

In 2011, instead of the previously used KrF laser, a Nd:YAG laser (QuantelYG981E) was applied for LIBS studies. The new laser has a considerably better beam quality which allows better reproducibility for recording LIBS spectra. From the viewpoint of damage thresholds of different optical components the laser wavelength 1064 nm appeared to be the best. The design of the optical set-up allowed the increase of the collinear recovering distance to 1.5 m. The new system was applied to studying the properties of 2 and 5 µm thick W-Al (60 % W, 22 % Al) coatings on Ti substrates, prepared by DIARC-Technology Inc.The recorded LIBS profiles were observed to qualitatively match with the profiles recorded by SIMS at Tekes-VTT.

The research concentrated on the dependence of the LIBS spectra on the number of laser shots striking a particular position on the target as well as the radial profiles of the laser-produced craters. For the latter purpose, profilometer measurements of laser-produced craters were carried out. In the case of uncoated Ti samples there was a satisfactory correlation between the measured profiles and those predicted by the ablation model (see Figure 4.1) in spite of the influence of surface roughness. Similar study of samples with W-Al and W coatings on Ti substrate showed that craters were surrounded by collars whose height was even larger than the depth of the actual crater. A probable reason of this complicated structure is considerably different melting temperatures of the coating and the substrate.

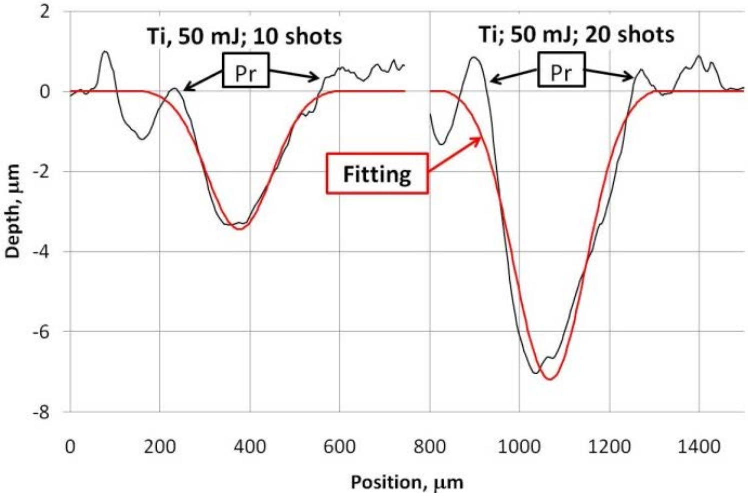


Figure 4.1. Laser-produced crater profiles on uncoated Ti samples.

First steps were made to develop another laser-based diagnostic method – laser induced ablation spectroscopy (LIAS). In this case ablation is combined with gas discharge plasma. The study showed that ablated elements radiate during a considerably longer time interval which could improve the signal to background ratio. Besides, LIBS spectra are recorded at lower values of the laser fluence.

In addition, a new LIBS system for erosion and retention studies of beryllium-containing samples was built in the beryllium- and tritium-handling facilities of Tekes-VTT. This setup is discussed in detail in section 3.3.8.

4.1.2 Properties of samples exposed to plasma in Pilot-PSI

First results of the post-mortem analyses of samples exposed to Pilot-PSI plasma in 2010 were presented in the Annual report 2010 (pp.44–45 and pp. 86–89). In 2011, LIBS profiles of unexposed and exposed areas of 5-μm thick W(60 %)-Al(30 %) coatings on Ti substrate were compared. The comparison showed that as a result of plasma exposure, the initially steep interface between the coating and the substrate becomes broader (see Figure 4.2). This finding indicates that plasma flux causes a remarkable mixing of materials. Another, more unexpected effect was the decrease of the intensities of various spectral lines. This finding could indicate that plasma action changes the phase composition of the sample material, thus changing the ablation rate. XRD studies of samples supported the assumption (see Figure 4.3): exposure to plasma caused a remarkable narrowing of the W line, i.e., a growth of crystallites took place. SIMS results of the same W-Al samples analysed here are presented in section 3.3.7 as well as a description of new experiments carried out in Pilot-PSI in late 2011.

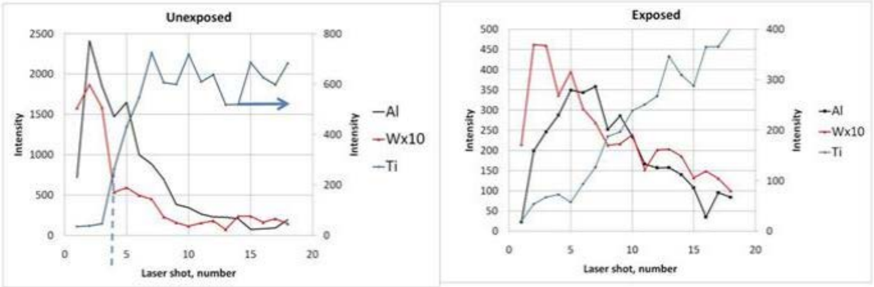


Figure 4.2. Comparison of LIBS profiles of unexposed and exposed areas of 5-μm thick W(60%)-Al(30%) coatings on Ti substrate.

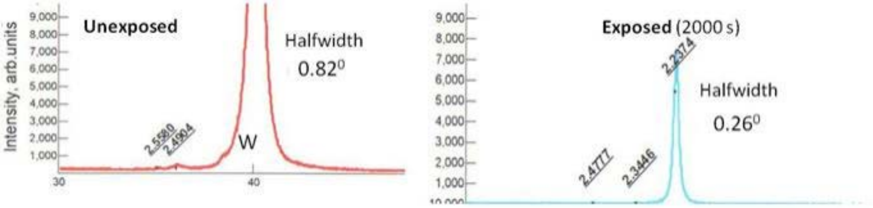


Figure 4.3. The intensity and width of the W line change with exposure. Left: unexposed; Right:exposed for 2000 s.

4.2 Tritium depth profile measurements of JET divertor tiles by AMS

EFDA tasks:	JET JW9-FT-3.50, JW11-FT-1.19
Research scientists	M. Kiisk, UT
	J. Likonen, VTT
Collaboration	C. Stan-Sion, M. Enachescu, M. Dogaru, MEdC
	G.Gizane, AEUL

Background: Accelerator mass spectrometry (AMS) is a highly sensitive analysing method that provides complementary information to other conventional methods used to analyse or diagnose fusion experiments, but is the only method capable to determine ultra-low concentrations of Tritium in different substrates. AMS is able to scan the depth of the material and deliver the depth profile information of the T concentration. By measuring the depth of the implanted Tritium into the bulk of pure materials (e.g. C, W, Be) it determines the energy of the incident particles and therefore, can be applied as an efficient diagnose tool for fusion experiments in Tokamaks (ASDEX, JET). In this way, AMS is able to characterize the plasma confinement and stability, the quality of neutral beam injector and its perturbing interaction produced on the plasma confinement.

The research work has been carried out as a continuation of the JET fusion technology task JW9-FT-3.50, in which the main goals were to set-up the T-AMS system and perform T depth profile AMS test experiments for the selected divertor tiles from JET as well. In 2011, this work was united with the tritium research done by full combustion technique (FCM), which is carried out by the University of Latvia, association Euratom-AEUL. The united work was done under JET Fusion Technology task JW11-FT-1.19 with the title “AMS and FCM measurements of tritium in laser cleaned tiles and tritium depth profiles in JET divertor tiles”.

Specific objectives: The main goals of the work in 2011 were the following:

- Continuation of AMS measurements on selected JET divertor tiles
- AMS depth-profile measurements of the set of disks cut from tile 14 IN G3B from campaigns between 2001 and 2004 for comparison with FCM results
- Manufacturing new standard samples with specific procedure for tritium AMS and FCM measurement calibrations
- Cross comparison of AMS and FCM measurements of the newly produced standard samples.

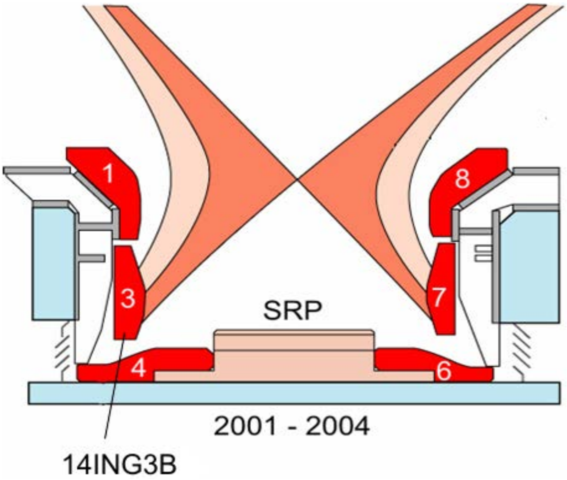


Figure 4.4. JET divertor used during campaign 2001–2004.

Results: The task was concentrated for studies on tile 14 IN G3B exposed in 2001–2004. The divertor configuration for the 2001–2004 operations is shown in Figure 4.4. The half of the tile’s plasma facing surface was detritiated by Laser ablation. In Figure 4.5, the drilled sample positions of each cylinder are indicated. Cylinders drilled from the right hand side (7f, 3f, 1f etc.) of the tile have the surface of their first slice cleaned by laser ablation. The purpose of the exercise was to compare detritiated and non-detritiated surface areas as well to compare the two measurement techniques. However, it is important that samples to compare have the same poloidal location; otherwise sharp poloidal distribution of the tritium retention in the divertor will influence results.

Each cylinder was divided in two semi-cylinders (see Figure 4.5), one for FCM and the other for AMS. Each semi-cylinder was cut into 1 mm thick slices (see Figure 4.6). For AMS and FCM measurements cylinders 6e and 4e were prepared from non-treated and 1f, 3f, 7f from laser treated area.

The calibration of the AMS and FCM measurements was done by standard samples. However, since there are no commercially available standard graphite samples, the standards are home made. The procedure for sample preparation can be found in [C. Stan-Sion et al., UPB. Sci. Bull A **66** (2004) 1]. Three standards with activity concentrations 50, 100 and 200 Bq/g, were prepared. Figure 4.7 illustrates the homogeneity of the T in the standard sample, since measurement time is proportional with the depth from sample surface.

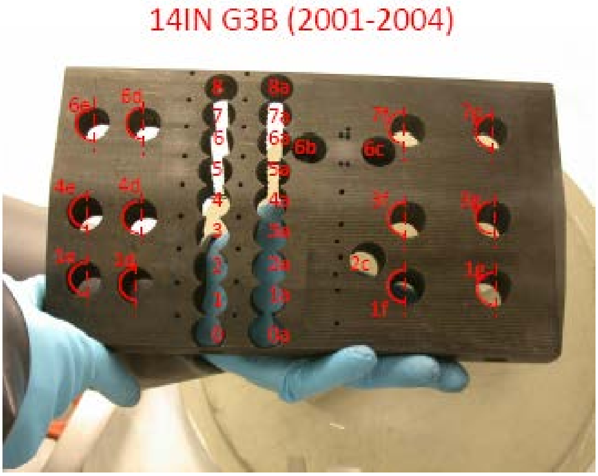


Figure 4.5. The tile 14 IN G3B exposed in 2001–2004 and the drilled sample locations used in tritium analyses.

The results of obtained values measured by AMS and FCM for standard samples have been presented in Table 4.1. The results indicate good correspondence between the two measurement techniques.

In order to compare the concentration measurements performed by the Full Combustion Method (FCM) and by the Accelerated Mass Spectrometry (AMS) several aspects of the two methods have to be considered and evaluated.

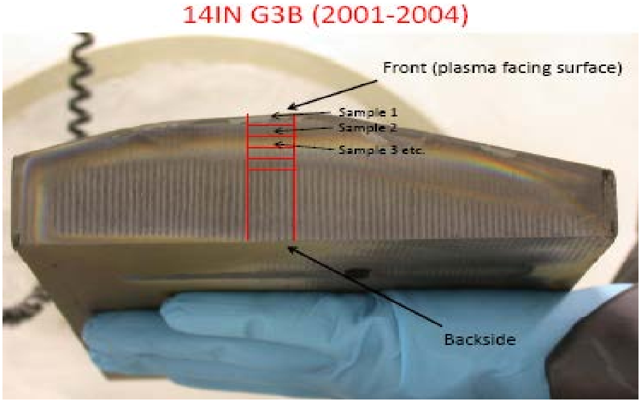


Figure 4.6. Schematics of slices cuts for the drilled samples in tile 14IN G3B.

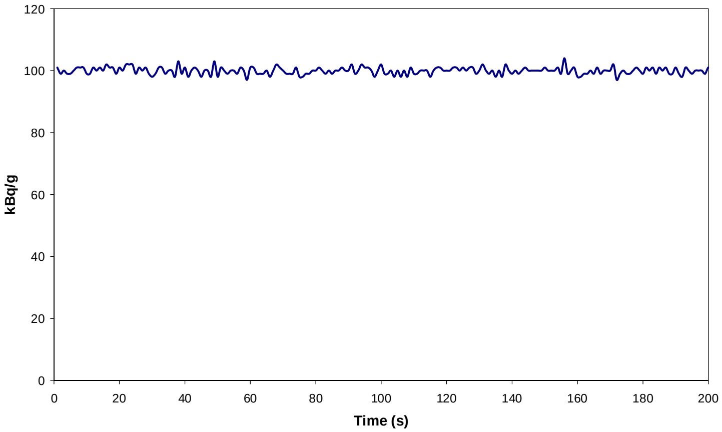


Figure 4.7. Standard samples measured by AMS. The tritium concentration the standard sample is 100 Bq/g.

Table 4.1. Results of measurements for standard samples.

Standard no.	Value (Bq/g)	
	AMS	FCM
1	48±5	52±7
2	103±11	110±12
3	197±15	218±14

Major difference between AMS and FCM comes from the fact that in FCM, in order to measure the contained T concentration, the entire mass of the sample to be analyzed is practically pulverized. In this way, the measured value is actually an averaged value of the T concentration over the entire mass of the sample. AMS, however, is performing depth profiling of the concentration of T in the bulk of the sample by sputtering with a focused sub-mm ^{133}Cs beam into the sample. As the sputter beam advances into the bulk, it registers T atoms as a function of sample depth for about every 20 nm.

Finally, for the inter-comparison, the evaluation of an average over the AMS depth profile is necessary. In this respect, two factors have to be precisely determined. The depth of the AMS sputtering procedure and the dimensions (thickness) of the slices should be identical for both AMS and FCM analyses.

Both parameters are subject for errors and it can be expected that slicing accuracy of the samples may not be sufficient. Additional factor is that original surface of a tile has a curvature and possesses convex shape and therefore, cannot be cut with parallel surfaces.

Figure 4.8 presents T activity concentrations for 5 first slices from the plasma facing side of the tile 14IN G3B for locations 7f, 6e. As can be seen, deviations between the two methods are larger in the case of non-treated surface sample. However, overall agreement is relatively good, considering that the effects discussed above which influence the comparison of the results from the two measurement technique, have not been thoroughly studied and estimated.

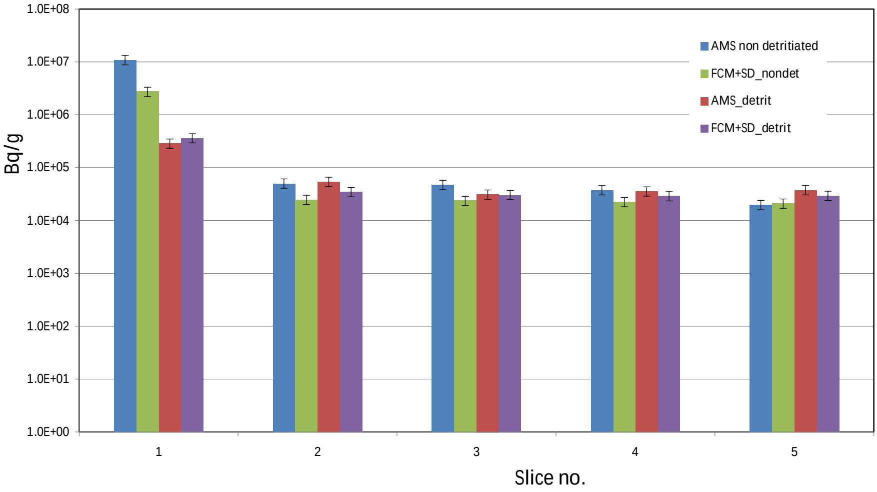


Figure 4.8. Inter-comparison of the AMS and FCM measurements for cylinders 7f and 6e.

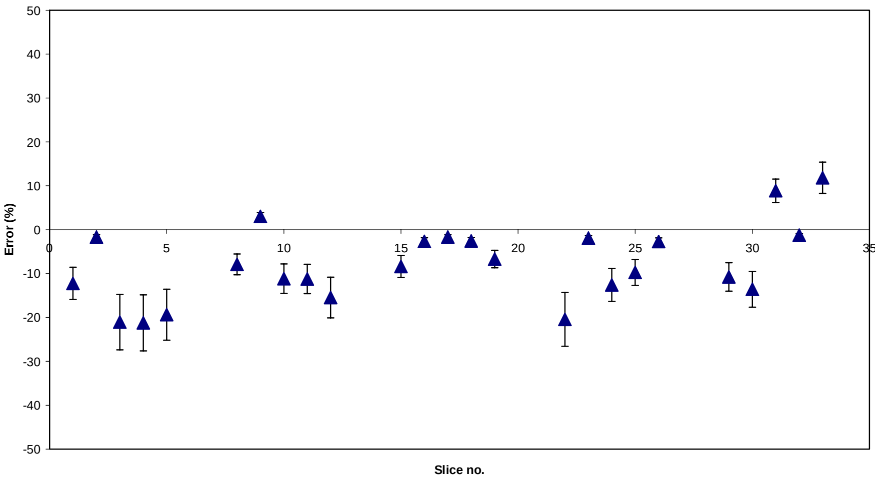


Figure 4.9. Relative deviations in the inter-comparison of FCM and AMS measurements of tritium concentrations.

Figure 4.9 presents relative deviations between the results from AMS and FCM. As can be seen, the general trend shows that errors are systematic (with two exceptions) and not larger than 20 %.

Most of the values differ about 10 %. The larger error values were exclusively obtained for the surface slices. At this point only qualitative reasoning for the deviation can be presented. As mentioned above, the curvature of the plasma facing surface and non-identical sample preparation for the two measurement techniques is expected to contribute the most. Another possible effect may be cross contamination, which may occure during slicing of the samples. However the influences of these effects are still to be done.

The work will be continued in 2012 within JET FT task JW12-FT-1.20.

5. JOC Secondments, Staff Mobility and Training

Several staff mobility visits of total 642 days took place in 2011. The visits were hosted by the Associations IPP Garching (301 days, MA Art. 1.2.b collaboration), JET/CCFE Culham (103 days), CEA Cadarache (24 days), VTT (21 days), University of Innsbruck (20 days), ENEA Frascati (18 days), Univeristy of Cyprus (18 days), FOM Rijnhuizen (16 days), FZ Jülich (9 days) and ITN Lisbon (5 days). Other staff mobility actions were EFDA meetings (PWI, ITM, FT, TGs; 77 days), ITPA meetings (19 days) and MIT US (11 days) for IEA Large Tokamak experiments. In 2011 Tekes (Aalto University) hosted three meetings eligible for Staff Mobility.

One physicist and one engineer were seconded to the CCFE JET Operating Team, Johnny Lönnroth (code development and modelling) and Ville Takalo (RH).

5.1 CCFE JOC secondments

5.1.1 JET remote handling for ILW experiment

JOC secondee:	V. Takalo, TUT/IHA
Period:	1 January–31 March 2011

Ville Takalo is a remote handling expert from IHA/TUT seconded in CCFE Engineering Department Remote Handling Group at JET. The EP2 2010–2011 shutdown converted the wall to be more ITER like with new design, new materials, new diagnostic and enhanced power. Majority in-vessel work is carried out remotely and work comprises over 8000 components to be handled remotely. During the EP2 shutdown Ville Takalo acts as Remote Handling Operations Responsible Officer.

5.1.2 JET code development and modelling

JOC secondee: J. Lönnroth, AU
Period: 1 January–31 December 2011

J. Lönnroth has been responsible officer for maintaining, developing and providing customer support for the Finnish Monte Carlo guiding centre following code ASCOT at JET under the auspices of the JET operating contract.

The Tekes contribution of the modelling work done under S/T Orders under the auspices of the JET Operating Contract has in 2011 focused on trying to establish the separatrix boundary conditions (temperature and density) as a function of parameters such as edge safety factor q95 and power by matching EDGE2D/EIRENE simulations with experimental data.

In predictive transport modelling, the separatrix density and temperature specified as boundary conditions can strongly influence the simulation results, such as confinement and ELM behaviour. This becomes a concern, as the combined uncertainty in magnetic reconstruction and diagnostic position results in an uncertainty in the mapping of the density and temperature profiles in JET of at least 1 cm. Given the strong gradients in the edge pedestal of H-mode plasmas, with scale lengths comparable to the uncertainty in the mapping, this translates into considerable uncertainty in the separatrix density and temperature.

The quasi-stationary inter-ELM H-mode phases of a number of well-diagnosed JET plasmas have been modelled with the two-dimensional edge transport code EDGE2D/EIRENE. In the EDGE2D/EIRENE coupling, EDGE2D solves the fluid equations for the conservation of energy, particles and momentum, whereas the kinetic neutral Monte Carlo code EIRENE provides the source terms of the fluid equations due to plasma-neutral interactions. By adjusting the model parameters for perpendicular transport in the core, edge transport barrier and scrape-off layer regions of the simulation domain, the EDGE2D/EIRENE simulations have been matched with experimental data. Specifically, the simulations have been compared against high-resolution Thompson scattering data for the electron temperature and density at the outer midplane and against infrared camera (IR) and Langmuir probe data for the divertor heat and particle loads.

The study highlights several aspects and difficulties of the technique of matching experimental data for the edge plasma region with fluid code simulations: Without a constraint on the downstream temperature profile, the upstream separatrix temperature remains poorly constrained and a large number of edge density and temperature solutions remain possible, since matching the IR data profile provides a constraint for the pressure, but not for the electron temperature and electron density separately. The inclusion of target diagnostic data does further constrain the edge density and temperature profiles. Adding a constraint on the downstream temperature profile greatly reduces the possible solutions and leads to a separatrix electron temperature of the order of 150 eV at the outer midplane in JET ELMy H-mode plasmas with relatively high midplane separatrix density.

5.2 Staff Mobility visits and reports

5.2.1 Framework agreement between Associations Tekes and IPP: Energetic Particle Physics

Names of seconded persons:	O. Asunta, T. Koskela, T. Kurki-Suonio, A. Snicker, S. Äkäslompolo
Sending Institution:	Aalto University
Host Institution:	IPP Garching

The framework agreement 2011 was implemented according to the research plan below.

For several years now Association Euratom-Tekes/Aalto University (previously: Helsinki Univ. of Technology) has been active in investigating the distribution and dynamics of NBI-generated fast ions in ASDEX Upgrade both numerically and experimentally.

Simppa Äkäslompolo was instrumental in the upgrading the NPA data acquisition system and after the retirement of Ulrich Fahrbach has a significant responsibility in making sure the enhanced capabilities of the NPA system are optimally utilized. Äkäslompolo also has also rewritten part of the DAQ system for FILD. He is involved in planning an active NPA fast ion diagnostic together with Drs. Ryter and Garcia-Munoz and did the 3D wall reconstruction (WP10-ITM-EDRG-ACT3) with Dr. Lunt. This spring Äkäslompolo will be participating in the fast ion experiments with two simultaneous FILD probes, and another visit later in the year is foreseen.

Tuomas Koskela has expertise in simulating fast ion physics in complicated tokamak geometries: he has simulated ITER scenarios with TBMs and, more recently, the TBM mock-up experiments carried out in DIII-D. While we have already simulated the effect of the B-coils on NBI-ions and did not find alarmingly large or intense hot spots, the situation with ICRH-generated ions in MeV range could be more serious. One 2-week long visit would be needed for Koskela to learn about ICRH ion distribution in AUG.

Taina Kurki-Suonio coordinates the fast ion collaboration between Tekes and IPP. The goal is “ASCOT Upgrade”, a comprehensive fast ion code to be used to model fast ion experiments not only in ASDEX Upgrade also in ITER. She has been active in investigating the role of fast ions in the pedestal region, particularly in the context of the quiescent H-mode. The work is strongly coupled to the experiments and, therefore, three 2–3 week visits per year has been found necessary.

Otto Asunta has developed a new, ab initio NBI launcher for ASCOT for more realistic modelling of NBI-born fast ions. Asunta has benchmarked the ASCOT launcher to FAFNER and, together with Dr. Tardini, is benchmarking it against NUBEAM. It appears adapting ADAS is necessary – like it was done for FAFNER. This collaboration requires at least one 2-week visit to IPP.

Antti Snicker has already implemented a numerical model for drift islands into ASCOT in order to study the effect of, e.g., NTMs on fast ion confinement. During a 3-month long visit he and Dr. Poli are trying to generalize this model for non-axisymmetric systems. Together with Dr. Lauber he is also developing models for various fast ion related MHD modes, such as different Alfven eigenmodes.

5.2.2 Framework agreement between Associations Tekes and IPP: Power and Particle Exhaust

Names of seconded persons:	L. Aho-Mantila, M. Groth, A. Hakola, S. Koivuranta, T. Kurki-Suonio, T. Makkonen, J. Miettunen
Sending Institution:	Aalto University, VTT
Host Institution:	IPP Garching

The framework agreement 2011 was implemented according to the research plan below.

Association Euratom-TEKES has been active in investigating erosion, deposition, and carbon transport in ASDEX Upgrade for several years. For the erosion and deposition studies, special marker coatings have been prepared on selected divertor and main-chamber tiles, and each coated set of tiles has been exposed to plasma during a whole experimental campaign. The erosion of the coatings and the composition of layers deposited on them have been determined using post-mortem ion-beam techniques such as Nuclear Reaction Analysis (NRA), Rutherford Backscattering (RBS), and Secondary Ion Mass Spectrometry (SIMS). The migration of carbon, for its part, has been investigated with the help of ^{13}C injection experiments and subsequent SIMS analysis of wall tiles. Since 2008 we have initiated modelling efforts to analyze both the SOL plasma and the migration of the ^{13}C impurities in it.

Leena Aho-Mantila investigates scrape-off layer physics and impurity transport by modelling experiments carried out in ASDEX Upgrade. She is doing SOLPS code-experiment validation work in collaboration with Dr. Marco Wischmeier and Dr. David Coster’s edge physics group. In addition to the SOL characterization experiments, she is also the TEKES responsible officer for the local ^{13}C injection experiments and participates in tungsten erosion studies. In order to carry out the simulation work, take part in the experiments and analyse the resulting experimental data, Aho-Mantila travels several times a year to IPP for 2–4 weeks at a time.

Mathias Groth participates in the ASDEX Upgrade programme by utilizing AUG data for the validation of edge fluid codes such as SOLPS and UEDGE (ITPA DSOL proposal 22) and for SOLPS/DIVIMP simulations of ^{13}C experiments.

Antti Hakola is in charge of NRA, RBS, and SIMS analyses of various plasma-facing components such as the marker tiles discussed above, marker probes attached to the midplane manipulator, and silicon samples mounted in remote areas. Hakola is also the TEKES responsible officer for the global ^{13}C injection experiments. All this research is done is collaboration with Drs. Volker Rohde, Rudolf Neu, Karl Krieger, and Matej Mayer, and requires several weeks of stay at IPP annually.

Seppo Koivuranta is doing NRA and RBS measurements of marker tiles at IPP together with Dr. Hakola. Koivuranta is also doing the necessary data analysis of the measured spectra. Typically he makes one or two 2-week visits per year to IPP.

Toni Makkonen continues carbon transport simulations with the OEDGE code under the supervision of Dr. Karl Krieger. In addition, based on simulation and measurement results from 2010, he has proposed new kind of flow and impurity measurements to be carried out during the experimental campaign 2011. Two approaches are pursued: spectroscopic measurements under the supervision of Dr. Thomas Pütterich and video diagnostics under the supervision of Dr. Tilmann Lunt. Three to four 2-week-long visits to IPP are needed for this work.

Juho Miettunen, together with Dr. Taina Kurki-suonio, has enhanced the Monte Carlo –based orbit-following code ASCOT, normally used for fast ion studies, so that it could be applied for impurity tracing in the SOL. ASCOT is not based on fluid approach and, thus, naturally avoids many shortcomings of, say, DIVIMP. This approach has appeared very promising and, after the completion of Miettunen’s Master’s Thesis, he should learn to evaluate and extract experimental data from AUG and get networked with the relevant researchers at IPP. One or two 2-week visits are foreseen for this purpose in 2011.

5.2.3 MHD modes in ASCOT code

Name of seconded person:	A. Snicker
Sending Institution:	Aalto University
Host Institution:	IPP Garching
Dates of secondment / mission	1 January–29 March 2011

5.2.3.1 Work plan / milestones

ASCOT is a guiding centre orbit following code used for computational studies of mainly fast ion physics in tokamaks. It has the inside track relative to other similar codes thanks to its moder features, e.g. realistic 3D magnetic field structure, realistic 3D wall design, pitch/energy collision operators and inclusion of finite Larmor radius effects. It describes very accurately neoclassical physics and has been a tool for a various studies during its lifetime.

During recent years ASCOT has been a vital part in understanding the fast ion distribution, e.g. plasma heating, and fast ion caused wall loads in ITER. However, ASCOT together with the other similar codes, as far as we know, does not take into account a couple of important non-neoclassical issues that comes with ITER tokamak. ASCOT development for a few years aims to solve at least following issues:

- Anomalous diffusion caused by microturbulence, certainly present in ITER
- ITER will not be MHD-quiescent
    - Large scale magnetic perturbations, i.e. magnetic islands, caused by, e.g. NTM's
    - Large number of fusion born alpha-particles will induce rich spectrum of Alfvénic eigenmodes (AE's).

Microturbulence motivated anomalous diffusion coefficient is already included in ASCOT and detailed studies will be reported in future. The purpose of the visit is to proceed work with a magnetic island model within ASCOT. The model has already been implemented and used for preliminary simulations of fast ion wall loads in ITER. The main goal is to benchmark the model to earlier experiments/simulations of ASDEX Upgrade (AUG) and continue studies with ITER. Main improvement will be inclusion of magnetic ripple, since so far model has been able to simulate axisymmetric magnetic fields. In case of ITER, the ripple will certainly be an important factor.

Moreover, this visit will support further collaboration between IPP Garching and Aalto University. It also provides a possibility to attend weekly AUG seminars, contributing to visitors PhD studies.

5.2.3.2 Report

The benchmark exercise was accomplished. As the results, a bit surprisingly, disagreed, more work is still needed to fully understand why the different codes produce different results for fast ion losses. The work to extend the island model to non-axisymmetric backgrounds was found to be more difficult than was thought. However, a numerical model was created and it is now under a various tests.

During the stay a solid interaction to the experiments was created by attending to AUG Monday-meetings. These meetings revealed a couple of interesting discharges that can be used to further validate our island model. A first version of a numerical model for Alfvénic modes were discussed with Dr. Lauber and Dr. Pinches.

5.2.4 Momentum and Particle transport, Joint ITPA Experiment TC-15 between JET, DIII-D, NSTX, C-Mod and ASDEX-U

Name of seconded person:	T. Tala
Sending Institution:	VTT
Host Institution:	IPP Garching
Dates of secondment / mission:	30 January–8 February 2011

5.2.4.1 Work plan / milestones

Tuomas Tala is the spokesperson of ITPA TC-15 Joint Experiment and he will act as a scientific co-ordinator of ITPA TC-15 experiment on ASDEX-U together with Dr. McDermott, as he has already done on DIII-D, JET and C-Mod. This is a joint ITPA experiment TC-15 (between JET, DIII-D, NSTX, ASDEX-U and C-Mod) where the main objective is to clarify the parametric dependencies of momentum pinch on several plasma parameters that are known to play a key role. The main dependence to be studied is the collisionality, the other ones being q-profile and density gradient length R/L_n. These parametric dependencies of the pinch terms must be known in order to make reliable extrapolations for ITER toroidal rotation profiles, in particular its peaking. In addition to the momentum pinch, the corresponding dependencies of the momentum diffusion coefficients on these plasma parameters will be obtained.

After having completed this ITPA experiment also on C-Mod and ASDEX-U, it will be possible to draw pretty solid conclusions on momentum transport at least with respect to parametric dependencies, for example in view of ITER. Based on this multi-tokamak approach, a very wide parameter range will have been scanned in such a way that much more reliable extrapolation and predictions to ITER can be performed.

5.2.4.2 Report

10 physics discharges were obtained on these AUG experiments during the visit to study momentum transport and non-NBI torque. As many of the shots were executed in two phases with different plasma parameters, effectively more data points have been achieved. Collisionality, R/L_n and q scans were included in the run plan. About a factor of 4 variation in collisionality was achieved on AUG by varying the NBI and ECRH power levels. However, this collisionality scan could not be performed in the same way as on DIII-D and JET where all the other dimensionless parameters were simultaneously kept fixed. Changing R/L_n turned out to be really challenging on AUG, only a very narrow range of R/L_n variation was achieved. More experimental shots are needed to complete the scan and these are planned later in spring 2011. The most important conclusion from this set of experiments is that NBI modulation is a feasible method to study momentum transport and intrinsic rotation on AUG.

5.2.5 Ion-beam analysis of ASDEX Upgrade tiles, probes, and samples

Name of seconded person:	A. Hakola
Sending Institution:	VTT
Host Institution:	IPP Garching
Dates of secondment / mission:	6–19 February 2011

5.2.5.1 Work plan / milestones:

1. analyzing erosion probes with RBS and a set of marker tiles with NRA
2. making preparations for the coming probe-exposure and ^{13}C injection experiments in AUG.

5.2.5.2 Report

Since 2002, erosion of first-wall components, deposition of the eroded material and retention of the plasma fuel on them, and migration of material in the torus have been addressed with the help of special marker tiles and probes produced by the Finnish coating company DIARC-Technology. To determine erosion, the thicknesses of the marker layers are measured before and after their plasma exposure, whereas for the deposition studies the depth profiles of different elements and the total amount of each of them on the coatings are evaluated. The analyses are done using secondary ion mass spectrometry (SIMS) at VTT and Rutherford backscattering spectroscopy (RBS) and nuclear reaction analysis (NRA) at IPP.

Milestone #1: During the present visit, altogether six graphite probes, coated by DIARC-Technology for discharge-resolved erosion studies during the 2011 and 2012 experimental campaigns of ASDEX Upgrade, were analyzed using RBS. These measurements provide the necessary pre-exposure data such that erosion of the marker stripes on the probes can be determined. This requires re-analysis of the same probes after they have been exposed to plasma and comparing the two obtained RBS data sets with each other.

All the probes have been equipped with four 5-mm wide, 30–50-mm long, and 50–100-nm thick marker stripes. The distance between any two of the stripes is approximately 5 mm on an oval-shaped surface, tilted by 45° from the horizontal reference plan. The materials of the marker stripes are carbon (in the form of diamond-like carbon, DLC, with a thin intermediate layer of tungsten), aluminium, nickel, and tungsten.

The RBS analyses were performed in the accelerator lab of IPP. The measurements were made in the Bombardino analysis chamber using 3.0-MeV protons. The step between adjacent measurement points along each marker stripe was 5 mm. For two of the probes, additional RBS analyses with 2.0-MeV $^4He^+$ ions were carried out. These analyses were performed on approximately the same locations as the proton measurements. The ^4He measurements will make it easier to study erosion of especially the aluminium and carbon stripes.

In addition to the probes, four outer strike-point tiles (type Bgr. 1) originating from the 2007 and 2008 (2+2) experimental campaigns of ASDEX Upgrade, were measured using NRA. One of the 2007 as well as one of the 2008 tiles had an uncoated poloidal stripe (width 20 mm) and a toroidal Ni stripe (width 10 mm, thickness 5 µm) on them. The remaining areas on these tiles had been coated with a 1.5-µm thick W layer. The two other tiles had 10-mm wide poloidal Ni (thickness also 5 µm) and W (thickness 500 nm) stripes next to each other and a 5-µm thick toroidal Ni stripe on top of everything. The remaining parts of these two tiles had a 1.5-µm thick W coating.

The tiles were analyzed in the Bombardino chamber using 2.5-MeV 3He+ ions. The deuterium, carbon, and boron content of the samples were determined from the measured NRA spectra and the results were compared with the corresponding data from the 2009 marker tiles and from the VPS W-coated Bgr. 1 tiles of the 2007 and 2008 campaigns. Preliminary results indicate that particularly the D profiles for the marker and VPS tiles show significant differences in the erosion-dominated zones of the tiles.

All the planned measurements were carried out and the analysis of the obtained RBS and NRA spectra has been started. This milestone was thus reached.

Milestone #2: During the visit, discussions with the ASDEX Upgrade team were carried out concerning the coming probe-exposure and ^{13}C experiments and their schedule later in this spring and in the summer. Also the number and locations of the tiles that will be removed from the vessel after the ^{13}C experiment were discussed. Furthermore, preliminary plans about producing new coatings on divertor and main-chamber tiles of ASDEX Upgrade for the 2012 experimental campaign were made. This milestone was reached.

5.2.6 Fast ion experiments, with the FILD and other diagnostics.

Name of seconded person:	S. Äkäslompolo
Sending Institution:	Aalto University
Host Institution:	IPP Garching
Dates of secondment / mission:	14 February–4 March 2011

5.2.6.1 Work plan / milestones

The proposed visit is part of the European experimental programme carried out at ASDEX Upgrade tokamak and part of the proposal EFDA-WP11-DIA-01-02-01/TEKES.

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

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

In ASDEX Upgrade fast ions can be measured with a number of diagnostics. We use the fast ion loss detector (FILD) in concert with other fast ion diagnostics, especially the neutral particle analyser (NPA). The goal is to gain further understanding of the behaviour of the fast ions during ELMs and the effect of the resonant magnetic perturbation (RMP) from ELM mitigation coils to the fast ions.

We have an established collaboration with Dr. Garcia-Munoz, who is the fast ion diagnostician at AUG. During last years I have assisted him in setting up the diagnostics and operating them during the exceptionally taxing time frame: Annually for a few weeks an extra FILD probe is attached to the midplane manipulator of AUG, and a large number of fast ion dedicated discharges are performed. In addition to help during the experiments, I provide theoretical fast ion distributions with the ASCOT code. ASCOT is guiding centre following plasma simulation code developed in Helsinki.

5.2.6.2 Goals

1. During the first week set up and calibrate the diagnostics as well as do scenario development.
2. Perform the actual experiments during the last two weeks. The experiments should include at least the ELM and RMP studies.

5.2.6.3 Report

The ELM measurements were succesful. Interesting new data was obtained about fast ion losses during ELMs. Also other MHD modes were measured. The data acquisition (DAQ) and data analysis software were updated and newly written.

The main tasks of preparing the diagnostic hardware and software were quite succesful. The following directly measurement related tasks took significant fraction of my time (in no particular order):

- Update FILD1-probe data acquisition system
- Create a data analysis tools for the fast camera films
- Check possibility of comparing thermometry with ASCOT simulations
- Monitor heat load on FILD-probes during experiments
- Learn NPA raw data postprocessing methods
- Find causes for unsuccesfull fast camera measurements.

Other tasks that I was able to work on:

- HLST: Two dinner meetings with Nitya Hariharan and Antti Snicker took place, where some loose ends of past collaboration were tied. A short meeting with Roman Hatzky, regarding FIPC licence, took also place.

- A discussion with Dr. Coster about ITM-AMNS-ACT1-01 took place. This enabled our research group to immediately start working on the project.
- A short meeting with Dr. Lunt related to WP11-ITM-EDRG-ACT1-02 took place. Further work include converting a new 3D-wall of AUG for ASCOT. Also some aspects of the previous wall were clarified.
- A working session with Benedict Geiger solved problems related to data transfer between the ASCOT code and the FIDASIM codes.

5.2.7 JET tiles analysis using tile profiler

Name of seconded person:	J. Likonen
Sending Institution:	VTT
Host Institution:	JET/CCFE
Dates of secondment / mission:	15–22 February 2011

5.2.7.1 Work plan / milestones

1. Participation in the JET tiles analysis under the FT task JW11-FT-3.68 using tile profiler
2. evaluation and comparison of SIMS and ion beam results.

5.2.7.2 Report

The main aim of the visit was to measure a divertor and inner wall guard limiter tile using a surface profiler developed at JET. 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. In 2010 several new divertor, IWGL and OPL tiles were measured with the tile profiler before installation of the tiles. During this visit one divertor tile (tile 6) and one inner wall guard limiter (IWGL) tile were measured with the tile profiler. Both tiles had been exposed in 2004–2009.

During this visit RBS spectra from divertor tile 6 were simulated with WiNDF program. This tile was removed from the torus after the ^{13}C puffing experiment which was made in 2009. Puffing was made through a hole in this tile. There is a local ^{13}C deposition band located poloidally near the puffing hole. RBS analyses were made in a toroidal direction and highest ^{13}C amounts were observed near the puffing location. Comparison with the SIMS results will be made later in 2011.

5.2.8 Spectroscopic and video measurements of tokamak impurities (1)

Name of seconded person:	T. Makkonen
Sending Institution:	Aalto University
Host Institution:	IPP Garching
Dates of secondment / mission:	20–26 February 2011

5.2.8.1 Work plan / milestones

Understanding impurity transport is crucial for future fusion reactor design. Impurity transport in the scrape off layer (SOL) of current tokamaks is dominated by the parallel background plasma flow in typical scenarios. Unfortunately, there are not many measurements of the flow profile in the SOL, and current fluid code results do not always seem to be consistent with these measurements.

Further work in this field is needed. It has been envisioned to do a flow measurement at the high field side in ASDEX Upgrade using spectroscopic and/or video diagnostics. Using spectroscopic measurement, the Doppler shift of impurity radiation lines can be used to deduce the impurity flow velocity. As for the video measurements, the time evolution or steady state of an impurity cloud produced by a gas injection can be compared against simulations in order to deduce the background flow velocity.

During the last visit, the experimental capabilities in ASDEX Upgrade were mapped out. During this visit, I wish to start preparing actual experiments and get to know the data acquisition software for the diagnostics in question. Also, results developing video viewing software is presented.

The key person for this visit are Dr. Lunt and Dr. Pütterich.

5.2.8.2 Report

During the visit, diagnostics capabilities of the ASDEX Upgrade tokamak were mapped out and the experimental dates were decided for the experiment. Also, the details of the actual experiment were worked out. The experiment would consist of injecting methane and following the ensuing CII (C+1) and CIII (C+2) clouds with a spectrometer with 8 lines-of-sight and a fast video camera.

In addition, work was started to develop tools for analysing the observed CII and CIII spectra in order to deduce the Doppler shift corresponding to the flow velocity. In normal CXRS measurements, the radiation of hydrogen like ions are looked at. In this case, the structure caused by the Zeeman splitting is more complicated.

Progress made on previously started video analysis software was reported to AUG and discussed.

5.2.9 NPA flange assembly (1)

Name of seconded person:	M. Santala
Sending Institution:	Aalto University
Host Institution:	EFDA-JET
Dates of secondment / mission:	7–18 March 2011

5.2.9.1 Work plan / milestones

The purpose of the visit is to deliver the custom electronics and detectors for the NPA upgrade to JET, assemble the detector flange and test the complete assembly. The electronics for the NPA upgrade has been manufactured at home institute, and the detectors have been bonded to the PCBs. Futhermore, an 8-channel bias power supply has been designed and built. CCFE has manufactured the flange with casing for the electronics as well as the support for the detectors.

During the visit, all the torus hall components will be assembled in a lab at JET. The basic functionality of the completed flange will be tested using an alpha source and a LED as signal source. At the end of the mobility visit, it is expected to have the new detector flange has been assembled and tested. It is expected to be ready for installation on the machine.

5.2.9.2 Report

The detector PCBs, preamplifier PCBs and the bias power supply were delivered to JET at the beginning of the visit, and CCFE had the flange and the associated mechanics ready. The final assembly proceeded slower than anticipated predominantly due to various issues with the necessary internal cabling. Some mechanical inconsistencies were also discovered. The testing has been completed during the following Secondment – planned in conjunction of the visit under Mobility – and the flange is ready for installation on the machine.

5.2.10 Spectroscopic and video measurements of tokamak impurities (2)

Name of seconded person:	T. Makkonen
Sending Institution:	Aalto University
Host Institution:	IPP Garching
Dates of secondment / mission:	14–19 March 2011

5.2.10.1 Work plan / milestones

Understanding impurity transport is crucial for future fusion reactor design. Impurity transport in the scrape off layer (SOL) of current tokamaks is dominated by the parallel background plasma flow in typical scenarios. Unfortunately, there are not many measurements of the flow profile in the SOL, and current fluid code results do not always seem to be consistent with these measurements.

Further work in this field is needed. It has been envisioned to do a flow measurement at the high field side in ASDEX Upgrade using spectroscopic and/or video diagnostics. Using spectroscopic measurement, the Doppler shift of impurity radiation lines can be used to deduce the impurity flow velocity. As for the video measurements, the time evolution or steady state of an impurity cloud produced by a gas injection can be compared against simulations in order to deduce the background flow velocity.

During previous visits, diagnostic capabilities of ASDEX Upgrade were mapped out and preliminary plans for these measurements were carried out. The experimental dates have now been decided and the purpose of this visit is to help with the experiments.

The key person for this visit are Dr. Lunt, Dr. Pütterich, and Dr. Janzer.

5.2.10.2 Report

The experiments were carried out during the visit and they were succesful. Methane was injected from valve T3 located in the high field side of ASDEX Upgarde and the ensuing carbon cloud followed with a fast video camera and a spectrometer. The fast video camera was able to observe a CII (C+1) and a CIII (C+2) cloud and so did the spectrometer.

Development of analysis software started during my last visit was continued.

The data and the analysis of it will be presented at the PSI 2012 conference in Aachen, Germany.

5.2.11 JET edge modelling meeting – Multi-scale approach to hydrogen retention in W

Name of seconded person:	K. Heinola
Sending Institution:	University of Helsinki
Host Institution:	EFDA-JET
Dates of secondment / mission:	21–25 March 2011

5.2.11.1 Work plan / milestones

1. Model the effect of ELMs (H-mode JET shot #76666) to the hydrogen retention and out-diffusion from W.
2. Prepare Multi-scale simulations for L mode shot (#78647) and perform first-principles calculations for hydrogen trapping to impurities in W.

5.2.11.2 Report

1. During the visit, the Multi-scale calculations showed the dynamical change in the hydrogen reflection coefficient on W during ELMs. Due to the residual hydrogen out-diffusion from the W bulk, the reflection was found to be over 100% for nearly ~5 ms after the ELM. No further speculation was done, since the material physics regarding to the transient hydrogen supersaturation in W during ELM is missing. After the shot, hydrogen was found to be leaking out of W within time window of tens of seconds. Work is ongoing to study the effect of hydrogen supersaturation to the formation of hydrogen trapping to W point defects.
2. Experimental JET data on ILW reference plasma #78647 will be used as an input to the Multi-scale calculations to study the hydrogen retention on W divertor. This data comprises of energy and number of incoming particles as well as the W surface temperature. Moreover, results from ERO code for predicting impurities migrating to the divertor area will be used in the future Multi-scale calculations. During the secondment the first Multi-scale calculations based on the experimental data were initiated.

5.2.12 JET edge modelling meeting – DIVIMP, EDGE2D/EIRENE, and TIM/EIRENE simulations and benchmark

Name of seconded person:	A. Järvinen
Sending Institution:	Aalto University
Host Institution:	EFDA-JET
Dates of secondment / mission:	21–25 March 2011

5.2.12.1 Work plan / milestones

1. Agree with S. Wiesen about the details of DIVIMP simulations.
2. Agree with J. Seebacher and M. Groth about the EDGE2D/EIRENE cases to be used in DIVIMP and EIRENE-TIM simulations.
3. Agree with J. Seebacher and M. Groth about the details of the benchmark process.

5.2.12.2 Report

During the meeting, the details of the DIVIMP simulations corresponding to the S.Wiesen’s JINTRAC study were agreed. Within these constraints, the DIVIMP simulations required for the EPS 2011 contributions and for S.Wiesen’s invited talk were conducted successfully. The benchmark project between DIVIMP, EDGE2D/EIRENE, and TIM/EIRENE was advanced by agreeing about the required EDGE2D/EIRENE catalogue cases and about the parameters to be compared between the codes.

5.2.13 JET edge modelling meeting – Coordination and EDGE2D/EIRENE modelling

Name of seconded person:	M. Groth
Sending Institution:	Aalto University
Host Institution:	EFDA-JET
Dates of secondment / mission:	21 March–1 April 2011

5.2.13.1 Work plan / milestones

1. Organise and lead the edge modelling meeting.
2. Continue EDGE2D/EIRENE modelling of JET pulse 78647 and 78658 for EPS11; process cases for neutral fuelling profile (D. Harting, S. Wiesen).
3. Continue EDGE2D/EIRENE modelling of JET pulse 78647 and trace-carbon and trace-tungsten injection for comparison to DIVIMP and TIM-EIRENE (A. Järvinen, J. Seebacher).
4. Continue EDGE2D/EIRENE modelling of JET pulse 78647: pure-Be and mixed Be/W cases in support of ERO modelling of hydrogen retention.
5. Participate in TFE1/E2 manning meeting for JET ILW campaign 2011–12.

5.2.13.2 Report

As part of my assignment as JET deputy task force leader I organised a two-week long edge modelling meeting at JET. This meeting brought together approximately 20 scientists with expertise in fluid and kinetic edge modelling, as well as turbulence modelling, molecular dynamics and density functional theory, and computational techniques. The focus of the work was on two sets of JET plasmas: well-diagnosed L-mode at three different densities, and type-I ELMy H-mode. Both plasmas are foreseen as JET ITER-like wall reference discharges. Splitting up in smaller groups, each group worked on a specific task, which was subsequently discussed within the entire group at the end of week 1 and week 2. Various other projects were supported through these activities, including the A. Järvinen’s thesis.

5.2.14 JET edge modelling meeting – Carbon and beryllium migration

Name of seconded person:	M. Airila
Sending Institution:	VTT
Host Institution:	EFDA-JET
Dates of secondment / mission:	28 March–1 April 2011

5.2.14.1 Work plan / milestones

1. Model the 2009 ^{13}C injection experiment with the ERO code.
2. Start preparing a model for beryllium migration in ILW experiments.

5.2.14.2 Report

1. During the visit, ERO simulations were set up for local ^{13}C migration in the 2009 injection experiment and the results will be presented together with surface analyses at the PFMC conference. The simulations suffer from inadequate Langmuir Probe data from the divertor floor; therefore the plasma profiles must be extrapolated over some distance, which brings uncertainty into the simulation. This issue is investigated with parameter variations with respect to density and temperature, and in some cases the simulated deposition profile matches well the measured one.
2. M. Groth has carried out EDGE2D/Eirene fluid modelling for ILW reference plasmas which will be used as plasma backgrounds in ERO to investigate local migration of eroded beryllium. The import of these plasma backgrounds into ERO was initiated.

5.2.15 Analysis of JET tiles using ion beam techniques

Name of seconded person:	J. Likonen
Sending Institution:	VTT
Host Institution:	ITN, Lisbon, Portugal
Dates of secondment / mission:	28 March–1 April 2011

5.2.15.1 Work plan / milestones

- Participation in the analysis of JET tiles using ion beam techniques under the FT task JW11-FT-3.68.

5.2.15.2 Report

The main aim of the visit was to analyse samples from JET divertor tiles 6. Samples were cut from four different tiles 6 at Tekes. The aim in the ion beam analyses was to determine local ^{13}C deposition pattern which was formed during the last operational day at JET in 2009. During that experiment, $^{13}CH_4$ was puffed through divertor tiles 6. Visual inspection of the tiles indicated that there was a strong local toroidal deposition pattern in downstream direction of the plasma. During the visit, samples from two different tiles 6 were analysed with RBS, ERDA and NRA technique. RBS results agree with visual inspection; there is strong toroidal deposition pattern close to the puffing hole.

RBS spectra will be simulated for ^{13}C amount using Windf program developed partly at ITN by Dr. N. Barradas. Dr. Barradas setup Windf programme for the geometry of the ion beam facility. He made some preliminary simulations of some of the RBS spectra.

5.2.16 Edge physics in AUG

Name of seconded person:	T. Kurki-Suonio
Sending Institution:	Aalto University
Host Institution:	IPP Garching
Dates of secondment / mission:	29 March–5 April 2011

5.2.16.1 Work plan / milestones

1. Prepare for the reversed-current experiments with focus on QHM
2. Prepare for the ASCOT simulations of trace-element experiments to take place in the end of the campaign.

5.2.16.2 Report

1. With Dr. Suttrop we discussed how to utilize the recently installed B-coils to carry out control experiments on QHM operation. The DIII-D group claims that the key factor is the edge rotation that should be controllable with the B-coils. Also, with the reversed Ip/BT experiments we wish to find out how easy, if possible at all, it is to achieve QHM operation in a tokamak with full-W walls.
2. Preliminary ASCOT simulations of impurity transport in the ASDEX Upgrade, using the full 3D features of the tokamak wall, indicate that 3D effects play a role. It was decided that predictive simulations should be carried out for this year's trace-element experiments. In the absence of a realistic erosion model, a finite sticking coefficient will be used to mock the processes that erode the deposited impurity from a PFC.

5.2.17 Exposing erosion probes to plasma discharges in ASDEX Upgrade

Name of seconded person:	A. Hakola
Sending institution:	VTT
Host institution:	IPP Garching
Dates of mission:	3–9 April 2011

5.2.17.1 Work plan / milestones

1. Exposing 1–3 erosion probes to AUG plasma
2. Making preparations for reference measurements of ne and Te and for the coming ^{13}C experiment in July 2011.

5.2.17.2 Report

So far, particularly erosion has been investigated by analysing the tiles or probes after they have been exposed to numerous plasma discharges with varying configurations and parameters during a whole experimental campaign. In contrast, information on the erosion process during a limited number of discharges is largely missing. To address this issue, six graphite probe heads were coated with different marker materials by DIARC-Technology in 2010 to be exposed to 1–5 plasma shots each during the 2011 and 2012 experimental campaigns of AUG. After the exposure, the erosion of the different marker materials will be determined using Rutherford Backscattering Spectroscopy (RBS).

Milestone #1: During the present visit, two of the probes were mounted on a midplane manipulator of AUG for their plasma exposure. All the probes had been equipped with four 5-mm wide, 30–50-mm long, and 50–100-nm thick marker stripes. The distance between any two of the stripes is approximately 5 mm on an oval-shaped surface, tilted by 45° from the horizontal reference plan. The materials of the marker stripes are carbon (in the form of diamond-like carbon, DLC, with a thin intermediate layer of tungsten), aluminium, nickel, and tungsten.

The probes were attached to the manipulator such that the marker stripes were facing the magnetic field lines with the 45° angle of incidence and with magnetic connection towards the lower divertor. During the discharges, the tip of each probe was moved by some 20–25 mm outside the limiter shadow, approximately to a distance of 40–45 mm from the separatrix.

The first probe was exposed to L-mode discharges in deuterium. The relevant ASDEX Upgrade discharges were #26725-26728, and the most important plasma parameters were I_p = 1 MA, B_t = -2.8 T, $n_e = 6\times10^{19}$ m^{-3}, and P_{aux} = 1.4 MW (of NBI power). A reference discharge (#26724) without the probe was also performed with strike-point scans enabled. In addition to the standard diagnostics, a fast IR camera was looking at the probe to record the temperature distribution at its surface. Visual inspection after the experiment showed that the stripes had survived well from their plasma treatment. The most noticeable effect was that the

DLC stripe had changed color from bluish to gray indicating either its erosion or redeposition on the surface.

The second probe was exposed to H-mode discharges in deuterium. While the main motivation of the L-mode experiment is to model the obtained results with the ERO code, the goal of the H-mode experiments is to study the effect of fast ions on erosion. This time the relevant ASDEX Upgrade discharge was #26748 (reference shot with strike-point scans #26747) with I_p = 0.8 MA, B_t = -2.5 T, n_e = 6.5×10^{19} m^{-3}, and P_{aux} = 7.5 MW (of NBI power). At around 2 s, the probe was glowing heavily and at 2.45 s the discharge was abruptly stopped. IR images indicated that the marker stripes at the probe tip were gone but survived closer to the far edge of the probe. After visual inspection the situation did not seem so gloomy anymore. The first 5–10 mm of the Al stripe was gone but for the other 3 stripes there was first an erosion region next to the tip of the probe, then a deposition zone and finally more or less intact area the farthest away from the plasma.

The erosion measurements of the marker stripes will be carried out during a later mobility visit, most likely in July. All the planned experiments were carried out so this milestone was reached.

Milestone #2: During the visit, the coming ^{13}C experiments were discussed with the ASDEX Upgrade team. If the machine is working properly, most likely the experiment will take place in the last week of July 2011. Also reference measurements of n_e and T_e at the midplane (related to the L-mode experiment) may be carried out around the time of that experiment. This milestone was reached.

5.2.18 Modelling the scrape-off layer and local migration of carbon in ASDEX Upgrade

Name of seconded person:	L. Aho-Mantila
Sending Institution:	VTT
Host Institution:	IPP Garching
Dates of secondment / mission	3–16 April 2011

5.2.18.1 Work plan / milestones

The main purpose of this visit is to discuss the outcome of past modelling projects related to AUG experiments and summarize the results from the PhD work carried out within the last four years. Plans for future code development and benchmarking efforts will be discussed with experts from the theory department of IPP. Future experiments will be prepared and their modelling will be discussed with the experts from the experimental department.

Goals:

1. Discussion of the benchmarking of SOLPS-ERO simulations against AUG experimental data. In particular, the status of SOLPS modelling of the SOL

of AUG and plans to further investigate the issues in code validation will be discussed. (M. Wischmeier, D. Coster, A. Chankin)

2. Discussion of the recently submitted paper on SOLPS-ERO modelling (U. Stroth)
3. Analysis of spectroscopic data from the C13 injection experiments in 2007–2009 (S. Potzel, R. Dux)
4. Preparation of AUG experiments with flow measurements (H.W. Müller, M. Wischmeir)
5. Planning the modelling of tungsten erosion in AUG (K. Krieger, T. Lunt).

5.2.18.2 Report

SOLPS5.0 modelling of the scrape-off layer in AUG low-density discharges was discussed. It was agreed that in 2011 the focus will be on comparing the pedestal and outer midplane SOL in L- and I-mode discharges and on studying the parallel ion flows in forward and reversed field (goal 1). Experimental data for code benchmarking exists in both topics.

New L-mode discharges with flow measurements in forward and reversed field were scheduled for July 2011 (goal 4). The discharges are hoped to provide more diagnostics data and steadier discharge conditions for code-experiment benchmarking compared to earlier data obtained in 2007–2009. The H-mode threshold appears to be lower in the present AUG campaign compared to earlier campaigns, which may make it more difficult to obtain the desired L-mode conditions. Relevant discharges in this campaign will be studied for detailed planning of the experiments.

An experiment studying prompt re-deposition using the divertor manipulator was discussed (proposal by Dr. Krieger, modelling by L. Aho-Mantila using SOLPS-ERO, goal 5). The manipulator will be equipped with a graphite head that contains a marker layer of one of the heavier materials (W, Mo, Re, Au), depending on the availability of the relevant ionization and sputtering data for modelling. Plasma conditions similar to earlier ^{13}C injection experiments will be sought for, in order to compare the local re-deposition between carbon and high-Z materials.

Spectroscopic calibration and geometry of the lines-of-sights viewing the $^{13}CH_4$ puffs in the earlier campaigns were verified (goal 3). The data appears to be suitable for code-experiment benchmarking.

Fruitful discussions of the recently submitted paper on SOLPS-ERO modelling took place with Dr. Stroth (goal 2).

The milestones of this visit were completed.

5.2.19 Momentum and Particle transport, Joint ITPA Experiment TC-15 between JET, DIII-D, NSTX, C-Mod and ASDEX-U

Name of seconded person:	T. Tala
Sending Institution:	VTT
Host Institution:	IPP Garching
Dates of secondment / mission:	11–16 April 2011

5.2.19.1 Work plan / milestones

T. Tala is the spokesperson of ITPA TC-15 Joint Experiment and he will act as a scientific co-ordinator of ITPA TC-15 experiment on ASDEX-U together with Dr. McDermott, as he has already done on DIII-D, JET and C-Mod. This is a joint ITPA experiment TC-15 (between JET, DIII-D, NSTX, ASDEX-U and C-Mod) with the main objective to clarify the parametric dependencies of momentum pinch on plasma parameters that are known to play a key role. The main dependence to be studied is collisionality, the other ones being q-profile and density gradient length R/L_n. These parametric dependencies of the pinch terms must be known in order to make reliable extrapolations for ITER toroidal rotation profiles, in particular its peaking. In addition to the momentum pinch, the corresponding dependencies of the momentum diffusion coefficients on these plasma parameters will be obtained.

The first part of the experiment was carried out in January-February 2011 on AUG. About half of the planned program was finished as planned. Now in this second round, the main emphasis is on reaching the low collisionality end of the scan, therefore, this set of the experiment is scheduled right after the boronisation. The other emphasis is on high beta part of the experiment, but this may require another run day as the high beta scenario development during this campaign is not yet finished on AUG.

After having completed this ITPA experiment also on C-Mod and ASDEX-U, it will be possible to draw pretty solid conclusions on momentum transport at least with respect to parametric dependencies, for example in view of ITER. Based on this multi-tokamak approach, a very wide parameter range will have been scanned allowing much more reliable extrapolation and predictions to ITER.

5.2.19.2 Report

A good 10 physics discharges have been obtained during parts of several run days on AUG in 2011 to study momentum transport and non-NBI torque. As many of the shots were executed in two phases with different plasma parameters, effectively almost 20 data points have been achieved. Collisionality, R/Ln and q scans were included in the run plan. About a factor of 4 variation in collisionality was achieved on AUG by varying the NBI and ECRH power levels. However, this collisionality scan could not be performed in the same way as on DIII-D and JET where all the other dimensionless parameters were simultaneously kept fixed.

Changing R/Ln turned out to be really challenging on AUG, only a very narrow range of R/Ln variation was achieved. A decent q scan was performed with q95 varying from 4 to 6. NBI torque has been calculated with TRANSP for all the shots and the analysis of these experiments is on-going using the same methodology (implemented in the JETTO transport code) and tools as for JET and DIII-D plasmas. A new optimisation routine to calculate the Prandtl and pinch number has been developed in this project; it automatically finds the Prandtl and pinch number profiles that reproduces the experimental amplitude, phase and steady-state with minimal errors. Furthermore, a new technique to exploit the NBI modulation phase to extract the intrinsic torque was developed. By having two free parameters, the momentum confinement time and non-NBI (intrinsic) torque, one can fit the full time evolution of total momentum at each radii over several modulation cycles and thereby find the profile of the intrinsic torque.

To summarise the preliminary scientific outcome, one can conclude that 1) the Prandtl number is close to one consistent with the strong coupling between ion heat and momentum transport as expected with ITG turbulence and 2) there is an inward momentum pinch with a magnitude similar to the ones found on JET and DIII-D also within this TC-15 joint experiment. The preliminary results from the intrinsic torque analysis indicate that in NBI heated plasmas, this component is non-zero and should be taken into account also in the momentum transport studies, thus possibly modifying the Prandtl and pinch number profiles significantly at least under some specific conditions.

5.2.20 NPA flange assembly (2)

Name of seconded person:	M. Santala
Sending Institution:	Aalto University
Host Institution:	EFDA-JET
Dates of secondment / mission:	22 May–4 June 2011

5.2.20.1 Work plan / milestones

The purpose of the visit is to finalise the installation of NPA upgrade electronics and the necessary interconnects as well as carry out offline tests of the upgrade. The main aim of the tests is to demonstrate that the newly installed hardware functions as planned on the machine. Ultimately, some data should be collected using the new DAQ electronics while exciting the new detectors by pulsed LEDs. Some troubleshooting work is envisaged as well. Early observations suggest that the noise levels on the signal lines are higher than expected. Furthermore, some issues have been discovered with wiring pinout. At the end of the mobility visit, it is expected to have all essential hardware installed and basic functional tests complete. It is envisaged to have demonstrated the operation of the full electronics chain in real JET conditions.

5.2.20.2 Report

During the visit the installation of main data acquisition hardware was completed. Tests were carried out to acquire data with the new setup. Using pulsed LEDs built onto the new detector flange, it was demonstrated that the all the elements in the upgrade basically function as installed on the JET machine. Some unanticipated noise issues were discovered. The noise was reduced drastically by adding impedance-matching termination resistors to monitoring signals, however, some noise still remained.

5.2.21 Collaborative modelling of impurity migration in the divertor of ASDEX Upgrade

Name of seconded person:	L. Aho-Mantila
Sending Institution:	VTT
Host Institution:	FZ Jülich
Dates of secondment / mission:	14–22 June 2011

5.2.21.1 Work plan / milestones

The ERO code has been used to model carbon migration in the divertor of ASDEX Upgrade, for interpreting results obtained from ^{13}C injection experiments. In the scope of the present visit, we will discuss the outcome of these simulations and their further benchmarking against the experiments, and initialize new modeling projects. Goals:

1. Discuss possibilities to model the detailed tile shaping and its influence on the magnetic presheath in the divertor. We plan to use the 3D-GAPS code by D. Matveev *et al* for these investigations.
2. Compare the modelled and measured spectroscopic signals. Discussions with D. Borodin, A. Kirschner and S. Brezinsek.
3. Compare the results obtained when using two different surface models in the simulations: ERO-HMM and ERO-SDTrimSP. Support is needed from the ERO modellers at FZJ when using the coupled ERO-SDTrimSP code package.
4. Discuss possibilities to model prompt re-deposition of various high-Z materials in future ASDEX Upgrade experiments with the ERO team.

5.2.21.2 Report

The visit focused mainly in preparations for the EPS conference. I discussed the modelling results and the possibilities to further improve the analysis with the ERO team. Instead of performing detailed spectroscopic analysis (goal 2), the density of the methane cloud was modelled and presented in the EPS paper. The clouds were observed to travel in the direction of **E x B** drift, which was in line with the spectroscopic data. Dr. Kirschner provided me a working setup for SDTrimSP runs and described the input data (goal 3). However, due to the limited time, we were not able to get the AUG cases working yet.

Inclusion of effects from detailed tile shaping was discussed with D. Matveev and B. Berberich. It turned out that 3D PIC simulations of the electric field in the tile shadow are computationally very demanding. However, future versions of the relevant PIC codes might be able to tackle this problem. I provided them the required input parameters, and we agreed to have another look at this problem in the future. The set-up for simulations of future prompt re-deposition experiments was discussed. Dr. Borodin advised me how to best include the necessary material geometry in the simulations.

In addition to the above planned topics, I had a chance to discuss issues related to the de-excitation of hydrocarbon molecules with Prof. Janev. Furthermore, Dr. Kirschner gave useful comments on my doctoral dissertation and described the status of ERO modelling among collaborators.

5.2.22 JET tiles analysis using tile profiler (2)

Name of seconded person:	J. Likonen
Sending Institution:	VTT
Host Institution:	JET/CCFE
Dates of secondment / mission:	28 June–22 July 2011

5.2.22.1 Work plan / milestones

1. Participation in the JET tiles analysis under the FT task JW11-FT-3.68 using tile profiler
2. evaluation and comparison of SIMS and ion beam results.

5.2.22.2 Report

Milestone #1: Main aim of the visit was to evaluate the data obtained with the tile profile (). 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. In principle this can be done very easily, but the measuring probe has been changed couple of times since 2007. It has turned out that the properties of the new probe differ somewhat from the original one. This was observed when one test tile was measured with the new probe. This means that the results before and after exposure cannot be directly compared with each other. Therefore the data for exposed tiles has to be manipulated. A software called V-Stars has been used for this purpose. With this program it is possible to make linear transformations (e.g. translations of the coordinates and rotations) such that the data for exposed tiles is reasonable when compared with the data before exposure. Basically the software produces qualitative pattern for erosion and deposition. In order to get quantitative results, the V-Stars results have to be compared with post-mortem surface analyses (e.g. with SIMS and optical microscopy). During this visit V-Stars calculations were made for some divertor tiles.

Milestone #2: During the last day of the C27 campaign in 2009, pure $^{13}CH_4$ was injected into the torus from the outer divertor. All divertor tiles have been analysed with ion beam techniques and SIMS (milestone 2) but data analysis is still in progress. Analysis of the RBS spectra was continued during the visit using WiNDF program that has been developed at the Univ. of Surrey in England and IST in Portugal.

5.2.23 Modelling the scrape-off layer and local migration of carbon in ASDEX Upgrade

Name of seconded person:	L. Aho-Mantila
Sending Institution:	VTT
Host Institution:	IPP Garching
Dates of secondment / mission:	3–29 July 2011

5.2.23.1 Work plan / milestones

The purpose of this visit is to plan and coordinate experiments at ASDEX Upgrade, analyze experimental data and discuss the related modeling of the plasma boundary together with the local experts. The physics topics to be investigated in particular are the local re-deposition of low- and high-Z impurities on the outer divertor tiles, the mechanisms driving parallel ion flows in the scrape-off layer, and divertor power exhaust in impurity-seeded discharges. Goals:

1. Plan and coordinate discharges in forward and reversed magnetic field, with measurements of the parallel ion flows and radial electric field in the scrape-off layer. The experiments will be modeled using the SOLPS5.0 code package. For this purpose, a good diagnostics coverage of the divertor and main SOL, and a magnetic geometry suitable for generating a wide computational grid must be sought for.

2. Participate in planning a ^{13}C-injection experiment at the end of the experimental campaign. Discuss the schedule for post-mortem analyses of a special divertor tile used for investigating the effects of surface roughness on carbon deposition.

3. Continue SOLPS5.0 modelling of the AUG scrape-off layer, focusing on comparisons between L- and I-mode phases observed in discharges carried out in earlier campaigns.
4. Discuss ERO modelling of prompt re-deposition of high-Z impurities, in comparison with experiments carried out using the divertor manipulator in AUG.

5.2.23.2 Report

Discharges in reversed magnetic field were carefully planned for measuring parallel ion flows and radial electric field in the scrape-off layer (goal 1). Based on earlier density ramp-up experiments, three different density levels were chosen in order to obtain various, steady divertor recycling regimes. Unfortunately, technical problems during the reversed B_t/I_p campaign prevented us from performing these experiments, and they had to be postponed for the 2012 campaign. Due to the limited available experimental time, also the forward field discharges were postponed.

In the absence of new experimental data on SOL flows, data from earlier campaigns was discussed in further detail. In particular, several questions made by the referees of an extensive manuscript were addressed. The analysis of flow and E_r measurements from reciprocating Langmuir probes was assessed. It was concluded that in forward field, the Langmuir probe analysis agrees well with Doppler reflectometry measurements. They are also in satisfactory agreement with the E_r calculated in SOLPS5.0 simulations. Measurements of flow velocities were confirmed to be trustworthy in both field directions, and it could be concluded that the simulations agree with the flow measurements only in reversed field. The analysis of E_r in I-mode plasmas (goal 3) suggested that further insight into the role of parallel ion flows on divertor conditions could be gained, if flow measurements could be carried out in I-mode. New experiments will be proposed for the 2012 campaign for this purpose.

In the course of the visit, we found that the special tile used for surface roughness measurements was positioned too far away from the divertor valves to obtain sufficient deposits from divertor ^{13}C injection. Therefore, at the end of the campaign, ^{13}C was injected only from the outer midplane. Post-mortem analyses will show whether sufficient deposition was obtained on the marker tile (goal 2).

At the end of the campaign, Dr. Karl Krieger performed an experiment investigating prompt re-deposition of W using the divertor manipulator. The experiments are considered suitable for ERO modelling, although several features such as ELMs and impurity-seeding have to be considered. First results are expected before December 2011.

In addition to the original goals, plans for the modelling of impurity-seeded discharges were discussed.

5.2.24 Energetic ions in AUG

Name of seconded person:	T. Kurki-Suonio
Sending Institution:	Aalto University
Host Institution:	IPP-MPG
Dates of secondment / mission:	4–15 July 2011

5.2.24.1 Work plan / milestones

1. Prepare for the ‘confined alpha simulation’ experiment
2. participate in the reversed-current experiments to be carried out this time.

5.2.24.2 Report

1. Preparing for the Confined Alphas experiments: CTS currently works beautifully but is not measuring fast ions due to spurious signals the origin of which remains obscure. Fernando Meo is working on the problem, but while it remains unsolved, no Confined Alpha experiments are foreseen since CTS there a major role there.

2. The reversed I_p/B_T experiments failed due to a major fuse blowing up repeatedly. Thus no QHM experiments could be carried out and it remains uncertain how easy, if possible at all, it is to achieve QHM operation with full-W walls.

In addition, Dr. Garcia-Munoz has found a really interesting feature in the FILD signal showing evidence for fast ions playing a role in triggering ELMs. I spent a major part of the second week data mining to find how generic this feature is, and if the frequency correlates with any magnetic signal. Will be studied in more detail on Thursday and Friday. Need to check also other shots, e.g., what about shots with pure ECRH? This was a low-q discharge, does that play a role? The envelope of fast ion oscillations takes place at the frequency of 1–2kHz. Could that somehow resonate with precession frequency?

Attended IPP colloqium and the following discussions with Dr. Zittel on energy issues (by invitation of Prof. S. Günter).

5.2.25 Spectroscopic and video measurements of tokamak impurities (3)

Name of seconded person:	T. Makkonen
Sending Institution:	Aalto University
Host Institution:	IPP Garching
Dates of secondment / mission:	7–20 July 2011

5.2.25.1 Work plan / milestones

Understanding impurity transport is crucial for future fusion reactor design. Impurity transport in the scrape off layer (SOL) of current tokamaks is dominated by the parallel background plasma flow in typical scenarios. Unfortunately, there are not many measurements of the flow profile in the SOL, and current fluid code results do not always seem to be consistent with these measurements.

During March, methane was injected at the high field side of ASDEX Upgrade and the time evolution and shape of the pursuing CII / CIII clouds were followed using spectroscopic measurements and fast video cameras. This was the first measurement of its kind. Carbon flow towards the inner divertor was observed.

During my visit I wish to participate in the reversed Ip/Bt campaign. Injecting methane at the HFS would allow testing how the reversed Ip/Bt affects the flow in the SOL. Also, further development of analysis software and tools related to high field side methane injection will be carried out.

The key person for this visit are Dr. Pütterich and Dr. Lunt.

5.2.25.2 Report

Unfortunately, ASDEX Upgrade suffered from several technical failures during the reversed Ip/Bt campaign and no data was gathered from this configuration. However, the presented method was used to gather data from L-mode discharges and from new H-mode discharges. During the last visit, data was gathered only from H-mode discharges.

After the previous visit, the data analysis software was finished, and now reported to AUG during this visit. Work was started planning new experiments.

Preliminary efforts to model the methane injections were started.

5.2.26 Material migration studies in ASDEX Upgrade and ion-beam analysis of probes exposed to ASDEX Upgrade plasmas

Name of seconded person:	A. Hakola
Sending Institution:	VTT
Host Institution:	IPP Garching
Dates of secondment / mission:	13–30 July 2011

5.2.26.1 Work plan / milestones

1. Participating in the planning and realization of a new ^{13}C injection experiment in AUG
2. analysing two marker probes using RBS and determining erosion of the marker stripes on the probe heads
3. participating in the kick-off meeting of the Dust and Tritium Management activities under the EFDA Emerging Technologies programme.

5.2.26.2 Report

This visit was part of active collaboration between the Finnish research unit VTT (under Euratom-Tekes) and Max-Planck-Institut für Plasmaphysik (IPP) in the field of plasma-wall interactions. Our joint projects are closely connected to the research done in ASDEX Upgrade (AUG). Particular focus areas are studying erosion of first-wall components, deposition of the eroded material and impurities, retention of the plasma fuel, and migration of material in the AUG torus.

These issues are addressed with the help of special marker tiles and probes produced by the Finnish coating company DIARC-Technology Inc. To determine erosion, the thicknesses of the marker layers are measured before and after their plasma exposure. Deposition, for its part, is investigated by evaluating surface densities and depth profiles for each element of interest on the coatings. The analyses are done using secondary ion mass spectrometry (SIMS) at VTT and Rutherford backscattering spectroscopy (RBS) and nuclear reaction analysis (NRA) at IPP.

Since 2003, Tekes and IPP have studied global migration of carbon by injecting $^{13}CH_4$ tracer into AUG torus during identical plasma discharges at the very end of experimental campaigns. After each such experiment, a selected number of wall tiles – both marker tiles and standard W-coated AUG tiles – have been removed from the vessel for SIMS, RBS, and NRA analyses. The poloidal ^{13}C distribution on these tiles has been determined, resulting in a large database for ASCOT, DIVIMP, and ERO simulations. So far, four ^{13}C injection experiments have been carried out with the latest in 2007. That experiment, however, raised several questions which were the ultimate reason for proposing a new injection experiment at the end of the 2011 experimental campaign.

Milestone #1: During the present visit, a global ^{13}C injection experiment was carried out in AUG. This time, both $^{13}CH_4$ and another tracer gas $^{15}N_2$ were simultaneously injected from one valve at the outer midplane during 11 high-density, lower-single null L-mode discharges (AUG shots #27382–#27392). The most important plasma parameters were I_p = 800 kA, B_t = -2.5 T, n_e = 5.8 × 10^{19} m^{-3}, P_{aux} = 1.8 MW + 0.7 MW (NBI + ECRH), and injection rate 1.8 × 10^{21} s^{-1} (1:1 ratio for nitrogen and carbon atoms). Altogether approximately 4.6 × 10^{22} ^{13}C atoms or 1 g of ^{13}C was injected during the experiment.

In the previous experimental day, set-up shots (#27366 and #27371) with 5–15-cm strike-point scans were performed. During these shots $^{12}CH_4$ was also puffed into the torus from one valve at the high-field-side midplane for flow-velocity measurements, n_e and T_e measurements at the divertor legs were made, and midplane manipulator with a reciprocating probe head was used to extract n_e, T_e, and flow velocity distributions at the outer midplane.

In addition to the actual experiment, tiles to be removed from the vessel during the coming shutdown and new marker tiles to be coated for the 2012 experimental campaign were discussed with the AUG team.

The ^{13}C experiment was successfully realized and this milestone was thus reached.

Milestone #2: Another main goal of the visit was to analyse using RBS two marker probes, exposed to L- and H-mode AUG plasma discharges, respectively, in April 2011. Since the probes had already been analysed before their plasma treatment, the present measurements made it possible to evaluate erosion of their marker coatings.

Both the probes were made of graphite and coated with 5-mm wide, 30–50-mm long, and 50–100-nm thick marker stripes. The materials of the marker stripes were carbon (in the form of diamond-like carbon, DLC, with a thin intermediate layer of tungsten), aluminium, nickel, and tungsten. The RBS analyses were performed in the accelerator lab of IPP using 3.0-MeV protons (both probes) and 2.0-MeV $^4He^+$ ions (only the L-mode probe). The step between adjacent measurement points along each marker stripe was 3–5 mm.

Both the L-mode probe and the H-mode probe showed the largest erosion at the tip of the probe (closest to plasma during the discharges). Proton measurements generally suggested larger erosion and steeper erosion profiles than helium measurements. The only exception was the DLC layer, for which protons only told the “average” erosion. In addition, the helium measurements gave more reliable data on the erosion of aluminium and DLC stripes than the proton measurements. Different materials showed also very different erosion behavior: tungsten was eroded by up to 2–3 nm, nickel up to 20 nm (L-mode) or 70 nm (H-mode), aluminium up to 30 nm (L-mode) or >100 nm (H-mode), and DLC up to 50–60 nm. In the H-mode case, the whole Al and Ni layers had vanished at the tip of the probe.

In addition to the probe measurements, a number of 4-μm thick, D-doped W-Al films on silicon with three different W:Al ratios were measured using RBS (3.0-MeV protons) and NRA ($^3He^+$ ions, energy varied from 690 keV to 4.0 MeV). This way, the elemental composition as well as the deuterium content of the samples could be identified.

All the planned measurements were carried out and analysis of the obtained RBS spectra was finished. This milestone was thus reached.

Milestone #3: In 14–15 July, EFDA organized a kick-off meeting on Dust and Tritium Management activities under the Emerging Technologies programme. I participated in the meeting and gave a talk on "Arc-discharge cleaning of plasma-facing components". Good contacts were established and new ideas for future work were raised. This milestone was reached.

5.2.27 Participation in the ^{13}C injection experiment in AUG

Name of seconded person:	J. Likonen
Sending Institution:	VTT
Host Institution:	IPP Garching
Dates of secondment / mission:	28–29 July 2011

5.2.27.1 Work plan / milestones

1. Participation in the ^{13}C injection experiment in AUG.

5.2.27.2 Report

During the present visit, a global ^{13}C injection experiment was carried out in AUG. This time, both $^{13}CH_4$ and $^{15}N_2$ were simultaneously injected from one valve at the outer midplane during 11 high-density, lower-single null L-mode discharges. Altogether approximately 4.6×10^{22} ^{13}C atoms or 1 g of ^{13}C was injected during the experiment. In addition to the actual experiment, tiles to be removed from the vessel during the coming shutdown and new marker tiles to be coated for the 2012 experimental campaign were discussed with the AUG team. The ^{13}C experiment was successfully realized and this milestone was thus reached.

5.2.28 LIBS measurements of test samples

Name of seconded person:	P. Paris
Sending Institution:	University of Tartu
Host Institution:	VTT
Dates of secondment / mission:	15–17 August 2011

5.2.28.1 Work plan / milestones

1. Building up beryllium-compatible LIBS recording optical system
2. recording first preliminary LIBS spectra.

5.2.28.2 Report

The visit was devoted to LIBS studies of ITER-relevant materials with the further aim to use LIBS for in-situ testing of fusion reactor walls. During the visit the goal was to build up the beryllium-compatible LIBS system (milestone 1) and do the first preliminary test records of LIBS spectra with Nd:YAG laser available at VTT (milestone 2). The experiments described here are part of the EFDA PWI tasks WP10-PWI-04-04-01/TEKES/BS and WP10-PWI-04-04-02/TEKES/BS.

Milestone #1: During my visit the main optical layout of the LIBS measurement system was build up in the Be handling facilities at VTT. An Ocean Optics spectrometer from Tartu research unit integrated into the experimental LIBS setup. The setup consists of a Nd:YAG laser (λ = 1064 nm) producing 5–7-ns long pulses typically with energies up to 50 mJ, the necessary delivering, focusing and imaging optics, fibre coupling for the spectrometer, and a vacuum chamber with a base pressure of 10^{-8} mbar. After carefully aligning the whole setup, a series of measurements were made with different samples. Experiments were conducted for brass, titanium, molybdenum and tungsten-aluminium coating on titanium and molybdenum substrates. The whole set-up showed feasibility for LIBS measurements.

Milestone #2: LIBS system was tested varying the laser fluency to optimize the recording regimes. Spectra were recorded in both directions: collinearly to the laser beam and perpendicularly to the normal of the target surface from the side windows were done. After measurements the spectral lines were identified on spectra for each type of sample and compared with results obtained with results of more accurate Mechelle spectrometer in Tartu. At the end of my visit the Ocean Optics spectrometer was replaced by an Oriel spectrometer, which spectral resolution is comparable with Mechelle one. Shot to shot registration of spectral lines with good spectral resolution was demonstrated.

Both milestones were reached.

5.2.29 LIBS measurements of test samples

Name of seconded person:	A. Lissovski
Sending Institution:	University of Tartu
Host Institution:	VTT
Dates of secondment / mission:	15–31 August 2011

5.2.29.1 Work plan / milestones

1. Building up beryllium-compatible LIBS recording optical system
2. recording first preliminary LIBS spectra.

5.2.29.2 Report

The development work has been aimed making LIBS a suitable tool for in situ determination of erosion/deposition of plasma-facing components in ITER. Until now there are absent LIBS measurement data for such ITER relevant mixed materials which containing Be. The importance of studying true beryllium samples has been stressed many times. Aluminum used often in plasma studies instead of Be is not at all good proxy because of quite different properties in interaction with the laser beam and also because of complex chemistry of beryllium.

Be needs special care in handling, special facilities. The research unit of VTT has been done most of preparation for the new beryllium-compatible LIBS chamber in their facilities. All needed optical details and components for the LIBS recording system have been acquired. According to the cooperation plans between research units of VTT and the University of Tartu, people from Tartu having competence in this field will build up the LIBS system. Samples will prepared in mutual cooperation by our Romanian partner Cristian Lungu.

During the visit the goal is to build up the Be-compatible LIBS system and do first preliminary test records of LIBS spectra with Nd-YAG laser available at VTT. Test will be made varying the laser fluency to optimize the recording regimes.

Milestones #1 and #2: During my visit an Ocean Optics spectrometer was taken into use and integrated into the experimental LIBS setup. The setup now consists of a Nd:YAG laser (λ = 1064 nm) producing 5–7 ns long pulses typically with energies up to 50 mJ, the necessary focusing and imaging optics, fiber coupling for the spectrometer, and a vacuum chamber with a base pressure of 10^{-8} mbar. After carefully aligning the whole setup, a series of measurements were made with different marker samples. Experiments were conducted for brass, titanium, molybdenum and tungsten-aluminium coating on titanium and molybdenum substrates. Spectra were recorded parallel to the laser beam but also perpendicular measurements from the side windows were done. Ten craters during each experiment were produced, each with seven or eight shots. Spectrum was recorded after every shot. After measurements the spectral lines were identified on spectra for each type of sample and compared with results obtained with more accurate Mechelle spectrometer in Tartu.

The Ocean Optics spectrometer was replaced by an Oriel spectrometer, which spectral resolution is comparable with Mechelle one. The method for registration of narrow spectral lines with good spectral resolution with dependence on laser shot number was demonstrated. Both milestones were reached.

5.2.30 ITM General Meeting and a short visit to ASDEX Upgrade

Name of seconded person:	S. Äkäslompolo
Sending Institution:	Aalto University
Host Institution:	EFDA CSU + IPP Garching
Dates of secondment / mission:	12–21 September 2011

5.2.30.1 Work plan / milestones

1. Participation in the ITM general meeting
2. Discussions with ASDEX Upgrade/IPP staff related to ongoing modelling work of ASDEX Upgrad fast ions. Continuation of whatever work was commenced with IPP staff during the meeting.

5.2.30.2 Report

I participated in the following training sessions on Monday and Tuesday morning: *ITM tools and methods (basic)*, *ITM Workflows in Kepler – ISE*, and *GRID/HPC workflows*. During the actual meeting I participated in all plenary sessions and in EDRG and IMP5 parallel sessions.

In addition to numerous smaller issues that I was able resolve during the meeting, a major undertaking (in the context of work during coffee breaks and evenings) was with Jorge Ferreira: He helped me to evaluate the fusion cross sections in the code TRANSP to resolve conflicting benchmarking results between TRANSP and ASCOT. This work was not finished, but was signicantly progressed.

During the three days following the meeting, I worked with IPP staff:

- Giovanni Tardini (The above TRANSP/ASCOT comparisons, future neutron spectroscopy simulation plans)
- Ulrich Fahrbach (detailed NPA geometry for ITM work)
- David Coster (Nuclear reaction rates to the ITM AMNS framework)
- Manuel Garcia-Munoz (Past and future AUG fast ion simulations)
- Wolfgang Treuter and Karl Behler (Remote AUG data access).

5.2.31 Thermal ion ripple torque evaluation in Tore Supra tokamak

Name of seconded person:	T. Tala
Sending Institution:	VTT
Host Institution:	CEA Cadarache
Dates of secondment / mission:	3–4 October 2011

5.2.31.1 Work plan / milestones

This visit will be the official start of this collaboration that will be carried out C. Fenzi, R. Dumont and M. Schneider from CEA and Antti Salmi and Tuomas Tala from Tekes. ASCOT simulations will be performed for a set of OH and ICRH L-mode plasma discharges. In particular, the ripple-induced torque will be estimated and compared with experimental observations, and ASCOT results will be benchmarked with those from local codes (EVE and SPOT) developed at Cadarache.

5.2.31.2 Report

It was a good kick-off visit for this collaboration. Antti Salmi will be the main person carrying out the work and he will report more extensively the outcome of this mobility visit at CEA to initiate this work.

5.2.32 Energetic ions in AUG

Name of seconded person:	T. Kurki-Suonio
Sending Institution:	Aalto University
Host Institution:	IPP Garching
Dates of secondment / mission:	30 October–12 November 2011

5.2.32.1 Work plan / milestones

1. Discuss and decide on the future direction of the PWI studies on AUG
2. The effect of B-coils on NBI ions – is it as small as indicated by preliminary ASCOT simulations?

5.2.32.2 Report

In discussions with Drs. Kallenbach and Krieger it was agreed that since carbon appears to be loosing importance as a reactor first wall material, the major simulation effort as far as impurity transport is concerned should now be given to beryllium. Nonetheless, the trace-impurity experiments at AUG will still be fully analyzed also numerically.

By the time of my visit a Japanese group had stirred some unrest with simulation results indicating that the ELM-mitigation coils in ITER would lead to an up to 30% power loss of NBI ions. However, the phenomenal success of the AUG B-coils in mitigating the ELMS while totally failing to affect the edge rotation seems to indicate that the magnetic perturbations are well shielded by the plasma and, thus, do not penetrate very deep. However, the DIII-D group has reported contradictory results and, therefore, the shielding issue remains the major problem to be solved before reliable predictions on the effect of ELM-mitigation coils on fast ion confinement can be given. Our simulation results thus far have been carried out taking into account also the change in density that follows the activation of the coils. However, Dr. Wolfrum pointed out that our case study had been on an 'anomalous' case, where the density got lower with the coil activation. The study thus has to be repeated.

5.2.33 Atomistic simulations of material mixing in ILW-JET

Name of seconded person:	A. Lasa
Sending Institution:	University of Helsinki
Host Institution:	EFDA-JET
Dates of secondment / mission:	14–24 November 2011

5.2.33.1 Work plan / milestones

During the Edge Modelling Meeting, I will work on atomistic simulations of Be deposition on W, consequent material mixing and the effect of Be as impurity

5.2.33.2 Report

During the visit, we studied different W-Be-D systems by means of Molecular Dynamics (MD) method, an appropriate tool for atomistic simulations. We first tested a new Be-W potential [C. Björkas *et al., J. Phys.: Condens. Matter,* **22** 352206 (2010)] for MD, to ensure it can be used for in our study-case: low-energy Be and Be plus D irradiation on W. To describe the W-W interaction in the W-Be-D system, we tried two different potentials: the one presented in [N. Juslin *et al., J. Appl. Phys.*, **98**, 123520 (2005)] and a potential that improves the defect energies of Juslin's potential [T. Alhgren *et al., J. Appl. Phys*. **107**, 033516 (2010)]. Better results were obtained with the latter combination, thus using it in the following work.

We started the simulations of cumulative, low-energy, Be and Be plus D impacts on W, aiming study the Be deposition on W and the effect of Be as impurity on the D retention in W. The Be and D impact energies were estimated based on the ILW-JET data for the plasma temperature near by the divertor, concluding that the most significant energies are in the 10–200 eV range. The W substrate temperature in our simulations was chosen based on the divertor temperature in ILW-

JET experiments. The Be and D depth profiles, sputtering and reflection, energy and angular distribution of the sputtered species, molecule formation and other material mixing properties will be analysed. The results will be used by impurity transport codes (ERO) and rate equation theory codes (RE). This work will be presented in PSI 2012, as well as in later Modelling Meetings.

5.2.34 Ion-beam analysis of ASDEX Upgrade marker tiles

Name of seconded person:	A. Hakola
Sending Institution:	VTT
Host Institution:	IPP Garching
Dates of secondment / mission:	20–25 November 2011

Name of seconded person:	S. Koivuranta
Dates of secondment / mission:	27 November–2 December 2011

5.2.34.1 Work plan / milestones

1. RBS measurements of marker tiles at IPP.

5.2.34.2 Report

Since 2002, erosion of first-wall components, deposition of the eroded material and retention of the plasma fuel on them, and migration of material in the torus have been addressed with the help of special marker tiles and probes produced by the Finnish coating company DIARC-Technology. To determine erosion, the thicknesses of the marker layers are measured before and after their plasma exposure, whereas for the deposition studies the depth profiles of different elements and the total amount of each of them on the coatings are evaluated. The analyses are done using secondary ion mass spectrometry (SIMS) at VTT and Rutherford backscattering spectroscopy (RBS) and nuclear reaction analysis (NRA) at IPP.

During the present visit, altogether 11 new marker tiles were analyzed using RBS. The measurements had been scheduled to be made just before mounting the tiles into the ASDEX Upgrade torus where they will be exposed to plasma discharges during the 2012 experimental campaign. The same tiles will be reanalyzed with RBS after the campaign and the erosion of the marker coatings will be determined by comparing the two obtained RBS data sets.

Eight of the analysed tiles formed a complete poloidal set at the upper divertor, while the three other tiles originated from the central heat-shield column of the ASDEX Upgrade torus. Six of the upper-divertor tiles had 1.5–2-μm thick, equally wide poloidal W and Ni marker stripes on them; the remaining two upper-divertor tiles had four poloidal markers on them: 1.5–2-μm thick W, Ni, Mo, and Cr stripes. Considering the heat-shield tiles, two of them were equipped with a 1.5–2-μm thick coating of P92 steel. The last tile, for its part, had been coated with toroidal W and Ni markers (thickness 1.5–2 μm) of equal width.

The RBS analyses of the tiles were carried out in the accelerator lab of IPP. The measurements were made in the Bombardino analysis chamber using protons with an energy of 3 MeV. The step between adjacent measurement points along each marker stripe or region was 20–30 mm.

All the planned measurements were carried out and the milestone was therefore reached.

5.2.35 Comparison of SOLPS modelling of AUG and JET, vertical target configuration, D and H plasmas

Name of seconded person:	V. Lindholm
Sending Institution:	Aalto University
Host Institution:	EFDA-JET
Dates of secondment / mission:	5–9 December 2011

5.2.35.1 Work plan / milestones

The main purpose of this visit is to attend the Edge Modelling Meeting coordinated by Mathias Groth, both for listening to talks and meeting people in the Edge Modelling community. Additionally, the plan is to discuss my SOLPS modelling work with M. Groth, which is related to both JET and AUG.

5.2.35.2 Report

I attended the modelling meeting and got to know some of the people that I have only communicated with via e-mail. I had discussions with Mathias Groth on SOLPS modelling issues and differences between AUG and JET. The existing models were refined. My main area of interest was the target and flow profiles in AUG and JET, which is planned to carry over into the modelling of the ^{13}C experiment performed at AUG by Antti Hakola et al.

5.2.36 Exposing mixed-material test samples to Pilot-PSI plasmas

Name of seconded person: A. Hakola
Sending institution: VTT
Host institution: FOM Rijnhuizen
Dates of Secondment / mission: 7–14 December 2011

Name of seconded person: P. Paris
Sending Institution: University of Tartu
Dates of secondment / mission: 7–14 December 2011

5.2.36.1 Work plan / milestones

1. Exposing test samples (W-Al, DLC, and/or W-Al-C) to Pilot-PSI plasmas
2. Discussing the integration of a LIBS system into Magnum-PSI as well as the results obtained after the 2010 Pilot-PSI experiments with the FOM people.

5.2.36.2 Report

This visit was related to the active collaboration between the FOM Institute for Plasma Physics Rijnhuizen and Tekes (research units VTT and University of Tartu) in the field of plasma-surface interactions. The main research themes within this collaboration are studying erosion/re-deposition of ITER-relevant materials when exposed to high-flux plasma discharges and developing laser induced breakdown spectroscopy (LIBS) an *in situ* diagnostics tool for ITER.

The experiments described here are part of the EFDA PWI tasks WP11-PWI-03-04-01/TEKES/BS and WP11-PWI-03-04-02/TEKES/BS and the EFDA ETS DTM tasks WP11-ETS-DTM-01-05-01/TEKES/BS and WP11-ETS-DTM-01-05-02/TEKES/PS.

Milestone #1: During the visit, altogether 14 test samples were exposed to plasma discharges in Pilot-PSI. The first 7 samples were related to the EFDA ETS DTM tasks and consisted of 3-μm thick diamond-like carbon (DLC, 6 samples) or mixed W-Al-C (1 sample) coatings on 25-mm diameter and 2-mm thick tungsten disks. The approximate composition of the mixed sample, produced by DIARC-Technology Inc., was 5 % of W, 47 % of Al, 47 % of carbon (in the form of DLC), and 1 % of D. Two of the DLC samples had Balinit® coatings and were slightly doped with hydrogen while DIARC-Technology had been responsible for producing the other DLC coatings with two different doping levels of deuterium. Before and after plasma exposure the samples were weighted using a Mettler Toledo microbalance to estimate net erosion of their coatings.

The samples were exposed to hydrogen plasmas with electron densities in the range of $2–3\times10^{20}$ m^{-3}, electron temperatures around 1 eV, and fluences of the order of $10^{23}–10^{24}$ m^{-2}s^{-1}. A 0.4-T magnetic field was used, the biasing voltage was

-40 V (corresponding to the maximum ion energy on the sample surface), and the exposure times ranged from 20–120 s; the longest exposure times corresponded to samples where the measured ion saturation currents were the lowest. The plasma jet had an approximately Gaussian shape with a diameter of 10–15 mm so that the exposed area showed a smoothly varying temperature profile with the maximum occurring close to the centre of the sample. This maximum was kept at a low level (300–500°C), excluding two samples were the temperature accidentally jumped to 1000°C and the coating was largely damaged. However, due to the extremely good thermal conductivity of DLC, large (chemical) erosion was observed for every sample. The Balinit coatings were much more durable than the DIARC coatings: the net erosion was a factor of 2 smaller in terms of the measured mass loss (1 mg vs. 2 mg).

The remaining 7 samples were W-Al coatings with different W:Al ratios in the film matrix. Three of the samples were produced by DIARC-Technology Inc. These samples had 4-μm thick coatings on 30-mm diameter and 2.5 mm thick molybdenum disks. All the samples were doped with deuterium (~1%), and their nominal W:Al ratios were 85:15, 75:25, and 60:40. The last 4 samples were produced by the Romanian MedC Association (C. Lungu) with the same specifications as above. However, the W-Al coating was now only 2 μm thick: between the substrate and the W-Al film there was a 0.5-μm thick W layer and on top a 1-μm thick Al layer. Molybdenum was the substrate material for three of the samples; the last sample had been prepared on stainless steel.

For the W-Al samples, hydrogen plasmas with neon to enhance erosion were used. The plasma parameters and other experimental conditions were almost the same as for the DLC samples but the exposure time was now longer (from 260 s to 520 s) and the maximum surface temperature higher (500–600°C). The Al content of the samples as well as the substrate material seemed to have large impacts on the observed erosion/re-deposition and surface-modification patterns as well as on the measured surface temperatures; this we attribute to differences in the thermal conductivities and melting points of the different materials. The determined mass loss of each sample varied from 0.1 mg to 0.2 mg.

All the planned experiments were carried out and the samples will now be analyzed using SEM, XRD, SIMS, and LIBS. Also the plasma-exposed spot on the samples will be investigated with a profilometer. This milestone was reached.

Milestone #2: A LIBS diagnostics is being installed in Magnum-PSI in early 2012. During the visit possible forms of collaboration in this front were discussed. A particularly interesting topic is exposing a set of samples in Magnum and immediately after exposure carry out extensive LIBS measurements across the whole surface. In addition, a presentation of the results obtained from samples exposed in Pilot-PSI in 2010 was given in a meeting of the PSI group of FOM. This milestone was reached.

5.2.37 NPA noise tests

Name of seconded person:	M. Santala
Sending Institution:	Aalto University
Host Institution:	EFDA-JET
Dates of secondment / mission:	10–14 December 2011

5.2.37.1 Work plan / milestones

This visit is in connection to a secondment to JET. The purpose is to continue troubleshooting the noise issues with the new detectors. During weekend, LED wiring will be disconnected from the preamps in order to prevent any noise ingress from LED wiring. The results will be tested with plasma operation after weekend.

5.2.37.2 Report

The visit continued a preceding secondment. During weekend quiet hours a visit was made to the JET torus hall and diagnostic LED wiring was disconnected from the preamplifier PCBs.

The following week NPA signals were recorded during JET operations. Although slight changes in noise were seen, the work on LED wiring did not solve the main noise issues.

5.3 Euratom and EFDA fusion training scheme

5.3.1 EFDA goal-oriented training I fusion theory and modelling – GOTiT

EFDA GOT:	WP08-GOT-GOTiT
Project Coordinator:	J. Mattila, TUT
TEKES Trainees:	L. Aho-Mantila, VTT O. Asunta, S. Janhunen, S. Leerink, AU
TEKES Mentors:	J. Heikkinen, VTT T. Kurki-Suonio, AU

The EFDA Goal Oriented Training in Theory (GOTiT) activities were concluded in 2011. The monthly e-seminar series was coordinated by Tekes (T. Kurki-Suonio and S. Leerink) and consisted of the following presentations:

- 22 February: Nicolay J. Hammer, (trainee, HLST Garching): ‘Performance Tuning Using Vectorization’.
- 26 May: Ian Chapman, (trainee, CCFE): ‘Modeling the Stability of Resistive Wall Modes’.

- 6 July: Yann Frauel, (trainee, CEA): ‘Recent Additions in the Tools of the ITM Platform’.
- 6 July: Tobias Goerler, IPP: ‘Global and (Coupled) Local Gyrokinetic Investigations of Plasma Microturbulence’.
- 7 September: Qaisar Mukhtar, (trainee, KTH): ‘Monte Carlo Operators Describing Coulomb Collisions in Toroidal Plasma’.
- 5 October: Thomas Johnson, (trainee, KTH): ‘Heating and Current Drive Modelling in the ITM’.
- 5 October: Samuli Saarelma, (trainee, UKEA): ‘Global Gyrokinetic Turbulence Simulations of MAST Plasmas’.
- 2 November: Lars-Göran Höök, (trainee, KTH): ‘Reducing Noise in Quasi-Linear Particle Simulations’.
- 2 November: Otto Asunta (trainee, Aalto): ‘Fast Ion Wall Loads in ASDEX Upgrade in the Presence of Magnetic Perturbations due to ELM Mitigation Coils’.

One GOTiT high-level intense course, Resonant and Non-Resonant Interactions in Beam-Plasma Systems and Magnetic Fusion Plasmas, was organized in Frascati, Italy, 13–17 June 2011. The course was attended by three of our trainees. Extensive lecture material was prepared and distributed by the organizing association (ENEA).

5.3.2 EFDA goal oriented training in remote handling – GOTRH

EFDA GOT:	WP10-GOT-GOTRH
Project Coordinator:	J. Mattila, TUT
TEKES Trainees:	P. Alho, J. Väyrynen, TUT R. Sibois, VTT
TEKES Mentors:	J. Mattila, TUT K. Salminen, VTT

5.3.2.1 Objectives

The aim of the EFDA’s European Goal Oriented Training programme on Remote Handling (RH), “GOT RH”, is to train engineers for activities to support the ITER project and the long-term fusion programme in European associations, the work of associates, Fusion for Energy, and the ITER organization and industry.

The principal objective is to implement a structured, remote handling system *design and development oriented training task* that is carried out in a multidisciplinary systems engineering framework through the use of ITER / Fusion for Energy task-related and quality assurance processes and the available documents, document templates, and ITER-relevant software products. Special emphasis is placed on a top-down engineering approach with multidisciplinary consideration of design requirements related to reliability, availability, maintainability, and inspectability (cf. RAMI approach). Within this SE framework, each GOT RH trainee will work within the context of a multi-site collaborative design team on a RH system design task, facilitated by mentors with ITER remote handling and general engineering experience. The activity will increase the coherence in European RH activities, networking in training activities, the transfer of knowledge and will connect engineering from other disciplines (viz. plug engineering) to the remote handling community. The GOT RH project serves as a practical level project for increasing the coherence within RH context of collaborative training project between 5 participating European associations.

ITER will consist of around 10 million parts (roughly 10 times more than the largest airplane in production) and hundreds of systems with thousands of interfaces among them to be identified and controlled. A key requirement for the success of such a large project is adopting a systematic and standardized approach to ensure the consistency of the design with the required performance. In its own part, the science and technology objective of this project is to develop common standards and tools for ITER design and development activities. Common standards and tools are necessary to guide ITER development while ensuring that ITER is properly designed to make it affordable to build, operate and maintain.

GOT RH project has five EURATOM partners with 10 trainees:

- Association Euratom-Tekes, Finland (3)
- Association Euratom-CEA, France (2)
- Association Euratom-FOM, Netherlands (2)
- Association Euratom-KIT, Germany (1)
- Association Euratom-CIEMAT, Spain (2).

The EFDA GOT project is coordinated by Prof. Jouni Mattila (TUT) from the association Euratom-Tekes. EFDA Responsible Officer is Jon Harman.

5.3.2.2 Main results in 2011

Jukka Väyrynen is the TUT trainee working on the work package (WP) 1.3 in GOT RH. Topic of the WP1 is remote handling procedures and tools. The goal of this particular project (*WP1.3: RAMI requirements assessment of ITER remote handling equipment components for their future procurement and life-cycle management*) is to study the ITER RH equipment RAMI requirements and evaluate a set of equipment against the requirements through qualitative and quantitative methods. Furthermore, based on the evaluation, the goal is to create a scheme with which the RAMI requirements could be met, and based on the concept scheme, to create a process for building reliability in further ITER RH equipment development.

A concept for the design process – or design framework – was developed, and preliminary verification of the model has been performed by analysing the design process of a prototype-state device (WHMAN) by “designing” the device again but incorporating the new methods and processes suggested by the design framework. While the purpose of the design process is not to analyse ready (more or less) systems, with this method the obvious fallbacks and failures in the design process can be weeded out. In addition, this study could provide new insight on the prototype device. Furthermore, during the framework tests new ideas on what information could be extracted from the model emerged and were included in the documentation generated based on the tests.

As the framework was used on a pre-existing device, all the design process features could not be verified. For a preliminary test, however, this was deemed not to be an issue. It is hoped, however, that this issue will be remedied in the future. The current scope for further studies would include analysing the results and implementing additions and corrections if need for such arise in addition to the aforementioned field-test during real design process.

Pekka Alho is the TUT trainee working on the WP2.1. Focus of the WP2 is software and control systems. The main research objective for this project (WP2.1: Fault tolerant device control system architectures for ITER RH system) is development of a fault tolerant and dependable architecture for ITER remote handling systems. The architecture must not only fulfil the strict functional and non-functional requirements set by the ITER environment but also balance the cost efficiency aspects of the fault tolerant designs, according to the As Low As Reasonably Practicable (ALARP) principle.

The implementation of the project is proceeding as defined by the GOT RH task process, which includes documentation such as system requirements document and conceptual control system design architecture. Control system architecture development is in the prototyping phase where different solutions are tested on an open source real time operating system used to control a commercial industrial manipulator. Next steps will include a design description document and updates to the RH system requirements and architecture based on the research efforts.

Romain Sibois is the VTT trainee working on the WP 1.5. The objective of this project (WP1.5: Verification and Validation (V&V) of ITER RH System Requirement using Digital Mock-ups) is to enhance verification and validation methods, models and processes during the early design phases of ITER Remote Handling equipment. The project aims to find out and utilize the most useful and efficient V&V approach to fulfil the requirements of the concept design towards reducing physical testing and replacing some aspects by virtual testing and verification.

A concept of the enhanced V&V approach has been performed and related requirements have been documented in the system requirements document as required by the GOT RH task process. The conceptual design phase is still proceeding and will be documented in the conceptual design document. The model verification will be performed by applying the developed concept method on selected test cases related to ITER RH equipment.

6. Fusion for Energy and ITER Activities

6.1 Divertor RH design updates and DTP2 Phase 2 testing

F4E Contract:	F4E-GRT-143
Research scientists:	M. Siuko, J. Järvenpää, VTT J. Mattila, TUT/IHA

6.1.1 Objectives

The main objectives of the activities foreseen in this Grant are:

- To continue the campaign of operational CMM and WHMAN trials started in the previous Contract (F4E-2008-GRT-MS-RH-01) and to assess the performance and robustness of the RH equipment when performing under non-nominal operating conditions.
- To identify, implement and test a series of modifications and upgrades to the RH equipment and its Control System as a result of the experiences acquired in previous Trials campaigns and in order to add new functionalities required for the execution of further RH Trials with new RH equipment.

The Grant F4E-GRT-143 started in September 2010 and will be finished in May 2012. The grant is divided in three tasks:

1. DTP2 trials and control system updates
2. Design and procurement activities
3. Development of RH Control system using DTP2 platform.

6.1.2 Grant description and main results in 2011

The Grant started in the end of 2010, and the work was mainly carried out in 2011. Some testing and reporting is still to be done in 2012. Detailed descriptions of activities and results for each task during 2011 are explained in the next chapters.

6.1.2.1 Task 1

Task 1 is divided in five subtasks.

Subtask 1.1 – CMM/SCEE recoverability tests

The handling test of the second cassette has been completed within the tests dealing with 2008–2010 Grant. In the continuation of the testing, an experimental campaign was done aiming at demonstrating the possibility to recover the Cassette Multifunctional Mover/Second Cassette End-Effector (CMM/SCEE) from the vacuum vessel in case of component failure or malfunction.

The campaign was focused on those faults that will probably prevent the CMM to exit the vacuum vessel following the standard procedure. Based on the FMECA analysis in the previous grant, a set of most severe failure modes were assessed and assigned to specific Recovery Scenarios and corresponding Recovery Methods were outlined for them in test plan. The same plan also specified the plan to investigate rescue ability of the CMM in the case that the Radial Drive unit is disengaged and CMM is dragged back (Figure 6.1).

The following failure mode cases were selected to be tested empirically:

1. Recovery servo lines, CMM/SCEE hydraulic quick connector: Replacing part of existing piping of at least one joint is done. The effect of different kind of leakage to the system and capability to recover with the aid of implemented redundancy were observed.
2. Recovery servo valve: Disconnecting a connection (power, earth or shield) to a solenoid or a servo valve in order to simulate failure either in a solenoid valve, or valve cablings. The effect of failure to the system and capability to recover with the aid of the implemented redundancy were observed. At least one solenoid and one servo valve were tested.
3. Redundancy by other Radial Drive (RD) motor: Electrical connections to one of the RD motors/brakes are disconnected. The effect of failure to the system and capability to recover with the aid of the implemented redundancy are observed.
4. Tachometer on RD motor 2: RD tachometer cable/cables is/are disconnected. The effect of failure to the system and capability to recover with the aid of the implemented redundancy were observed.

Subtask 1.2 – Second Cassette replacement trials subject to cassette misalignments

The purpose of the cassette misalignment tests was to test robustness of cassette removal process and capability of CMM/SCEE to lift the cassette subject to different kinds of misalignment situations. Test procedure and variations on cassette position after releasing the cassette from locking position were investigated in advance during cassette location survey. For the misalignment test the measuring system was developed such that motion of the cassette could be monitored continuously by utilizing data acquisition of 8 LVDT sensors. New measuring arrangement provided to be useful as it produced new knowledge about cassette behaviour (Figure 6.2). According to the tests it can be said that robustness of the CMM/SCEE prototype against cassette misalignments is excellent. It seems, that picking of the cassette is possible from whatever position or orientation the cassette is having after it has been fully unlocked.

Figure 6.1. Rescue operation of CMM/SCEE + Divertor cassette using pulling device, which is installed to the end of the radial rails.

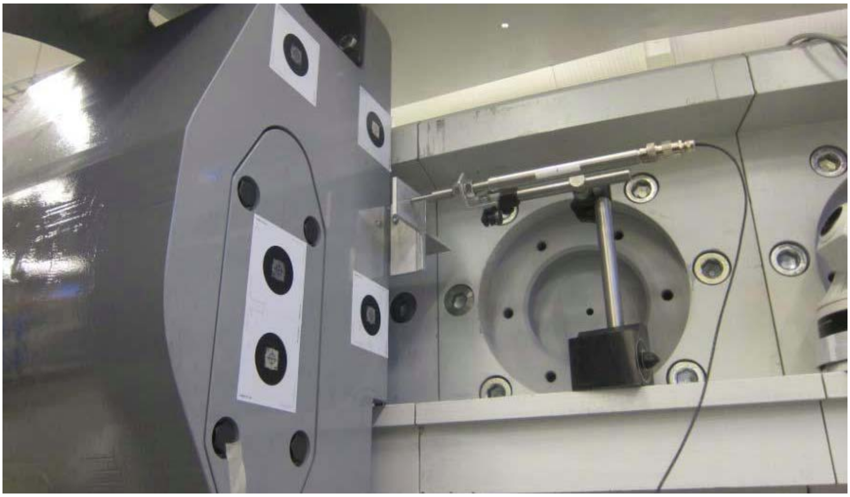


Figure 6.2. Sensor at the tip of the cassette for measuring cassette position.

Subtask 1.3 – Full replacement sequence of second cassette

This sub-task included preparations to execute the full replacement sequence of the second cassette. Full replacement sequence means that CMM and WHMAN are working together on Divertor region mock-up. Preparations were done to both WHMAN and CMM.

Subtask 1.4 – CMM and WHMAN Control system software updates

The control system software of both CMM and WHMAN were updated and further developed based on the experiences and the developed new requirements of the trials at DTP2.

Subtask 1.5 – WHMAN Trials

Recent WHMAN activities have included kinematic calibration, performance evaluation and Cassette Locking System (CLS) testing outlined in the test plan, which was submitted in the beginning of the grant. Series of tests to assess the performance of WHMAN were done on WHMAN test stand (Figure 6.3).

WHMAN trials have included calibration, accuracy and repeatability analysis of WHMAN, operational testing with the CLS mock-up, and locking of Second Cassette in DRM with the developed WHMAN CLS RH processes and tools. These developed new WHMAN CLS tools are modified Water Hydraulic Jack, Pin Tool and Wrench Tool. The developed WHMAN tool mock-ups were verified against the design requirements and existing CLS Task Description requirements utilizing virtual mock-ups of WHMAN, CMM/SCEE, Gradel Cassette and DRM.

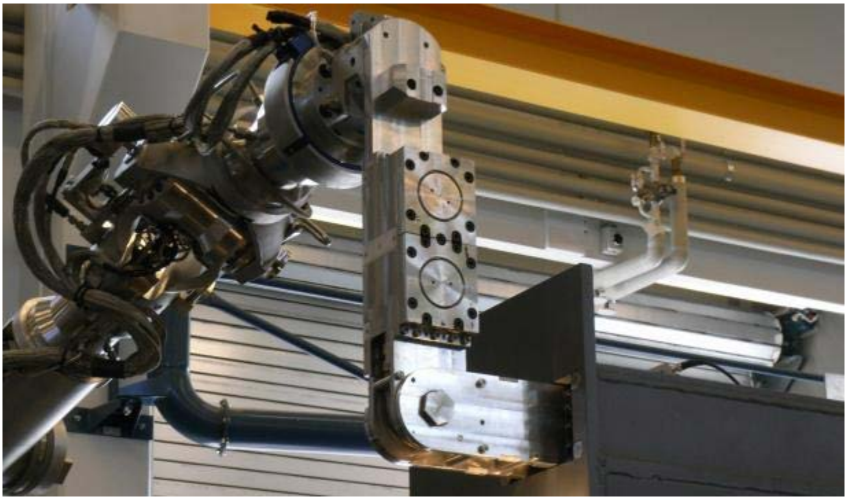


Figure 6.3. WHMAN inserting the jack tool into the cassette CLS mock-up slot (2 mm gaps) on WHMAN test stand.

6.1.2.2 Task 2

Task 2 is divided in four subtasks.

Subtask 2.1 – Second Cassette End-Effector (SCEE) improvements

The objective of sub-task 2.1 was to conduct a refurbishment of the SCEE to solve the issues found during the DTP2 test campaign, and consequently to improve the reliability of the results obtained in the Divertor RH test campaigns being carried out at DTP2.

Main focus is the improvement of the bearing and resolver solution of SCEE joints. Interfaces between the Second Cassette End-Effector, Divertor Cassette Mock-up and CMM have been analysed and improvements presented. As a result for the analysis part, refurbishment of the SCEE can be done, and the main goal is to reduce the clearance of the CRO and HRO joint bearings and improve reliability of the rotation angle measurement in the CRO and HRO joint. Based on the analysis and modification plan, detailed manufacturing drawings and calculations for selected solutions have been done. Implementation phases after the modification plans are disassembly, machining and assembly. SCEE has been disassembled and sent for machining in the end of 2011 and is ready in the beginning of 2012.

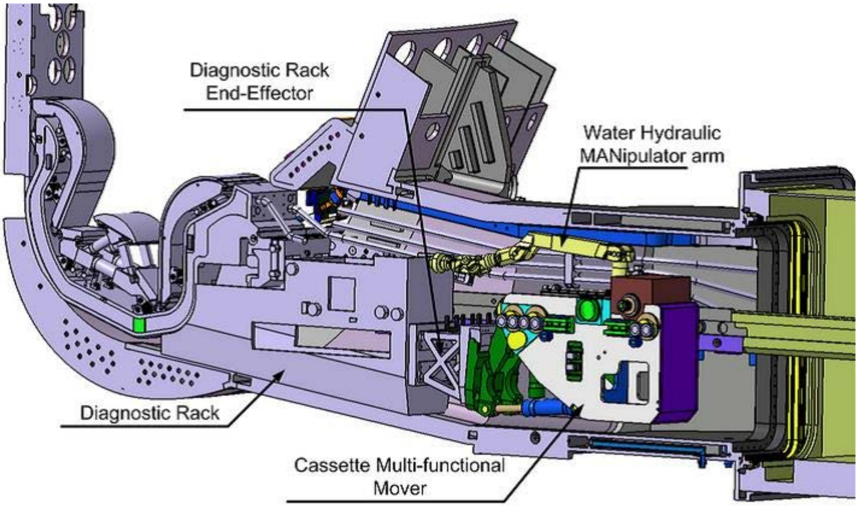


Figure 6.4. The installation and extraction of the Diagnostic Rack is carried out by using the Diagnostic Rack End-Effector during ITER plant maintenance.

Subtask 2.2 – Concept design of the Diagnostic Rack end-effector

CMM is equipped with additional end-effector tools to allow handling of different types of targets. CMM tools consist of; Central, Second and Standard Cassette End-Effectors, CTM Umbilical End-Effector, Diagnostic Rack End-Effector and Primary Closure Plate End-Effector. Sub-task 2.2 had the focus on the Diagnostic Rack End-Effector (DREE) concept development (Figure 6.4). End-Effector needs to have an appropriate interface for the Diagnostic Rack (DR) and for the CMM. When performing maintenance operations DREE is used as a passive component for enabling the CMM to carry and to position the DR to the vacuum vessel.

The task included the development of System Requirements Document (SRD) and Design Description Document (DDD) for DREE. These design documents apply not only to the End-Effector, but also to the means and equipment required to perform the installation and extraction sequences of the Diagnostic Rack. DDD presents a concept design of the DREE, which was developed based on the SRD and Task Definition of DREE. In addition to concept design description, operation sequence of the Diagnostic Rack installation using DREE was developed. Also preliminary structural analyses of DREE were developed and the results were used for initial sizing of the structure. Recoverability considerations of the DREE were as well developed.

Subtask 2.3 – Concept design of the CTM tunnel Umbilical and its End-Effector

Sub-task 2.3 focused on the CTM tunnel Umbilical (UMB) and CTM Umbilical End-Effector (UMBEE), which is used to handle CTM tunnel umbilical (Figure 6.5). CTM Umbilical needs to have an appropriate interface for the End-Effector and for the vacuum vessel. When performing maintenance operations CTM Umbilical provides electric and hydraulic power for the CTM. End-Effector needs to have an appropriate interface for the CTM Umbilical and for the CMM. When performing maintenance operations UMBEE is used for enabling the CMM to carry and to position the Umbilical to the vacuum vessel.

The task included System Requirements Document (SRD) and Design Description Document (DDD) for both UMB and UMBEE. DDD presents a concept design of the UMB and UMBEE, which were developed based on the SRDs and Task Definitions. In addition to concept design description, operation sequence of UMB installation using UMBEE was developed. Also preliminary structural analyses of UMB and UMBEE were developed and the results were used for initial sizing of the structure. Recoverability considerations of the UMB and UMBEE were as well developed.

Subtask 2.4 – Management of requirements

Sub-task 2.4 has been started in the end of 2011 and will be continued in 2012. The task includes studying utilisation of the software tools, and investigating the suitability of using standardized system engineering processes.

6.1.2.3 Task 3

Task 3 is divided in four subtasks.

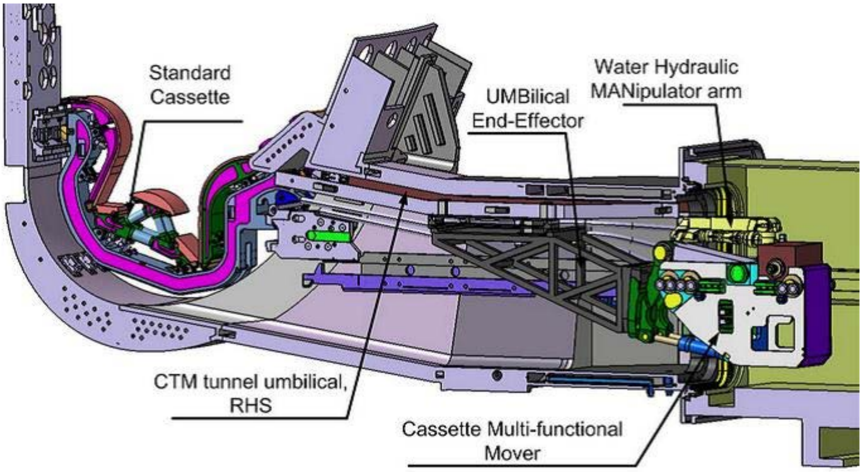


Figure 6.5. The installation and extraction of Umbilical is carried out by using the Umbilical End-Effector during ITER plant maintenance.

Subtask 3.1 – Analysis and Design

The Remote Handling Control System (RHCS) is used in the DTP2 control room for handling the prototypes of ITER Divertor maintenance devices. The analysis and design phase of the Task 3 explained the architecture of the RHCS and the RHCS requirements defined by ITER and F4E. Some requirements were also developed by the DTP2 development team. The document created in this sub-task described each of the sub-systems in RHCS and discussed how each of the sub-systems will be developed during the implementation phase. The defined sub-systems are:

- Operation management system
- Command and Control
- Input device
- Virtual Reality
- Structural Simulator
- Equipment controller
- Remote Diagnostics
- Viewing
- Computer Assisted Teleoperation.

The operation management system is used for planning and instructing the execution of RH operations. The Command & Control system is a GUI application that is used for controlling a RH Equipment by connecting to its Equipment Controller. Input device consists of control system development for an input device controller and related real-time network interfaces. The Virtual Reality system is designed to assist remote handling operators and operations engineers in execution of RH operations. The function of the structural simulator is to ensure that the virtual representations of the RH equipment are closely aligned with the actual RH equipment. Remote Diagnostics includes condition monitoring, which detects the faults in the components of remote handling equipment during the operation. Optimal visual feedback is essential for all manual interactions within the RH environment, it helps to perform man-in-the-loop remote operations and the Viewing system is responsible for this. Computer Assisted Teleoperation is a software subsystem designed for assisting the operator in haptic RH tasks.

Subtask 3.2 – Implementation

This sub-task included implementation of the sub-systems as defined in the Implementation plan, which was written in the analysis and design sub-task. Implementation of the 9 sub-systems was leading to the Interim Report on progress of the control system implementation. Interim report clarified the design and the properties of the DTP2 control systems. It was divided into eight appendices that described the individual systems. In the demonstration phase there will be a demonstration called “Integrated Operations”, which aims to demonstrate the interoperability of the various systems in action. Requirements of the control systems were also described in the Interim report and the status of the development was reflected on the requirements. Architecture and properties of the systems were reported and future development plans illustrated.

Demonstration plans for each task were also completed in this sub-task.

Subtask 3.3 – Demonstration

Demonstration phase includes demonstrations of:

- Integrated Operations
- Accurate Virtual Reality
- Condition Monitoring
- Optimized Viewing
- Standard Controller

The demonstration phase has started in the beginning of 2012.

Subtask 3.4 – Reporting

The reporting phase will be done in 2012.

6.2 Modular divertor cassette mock-up for ITER

ITER Contract:	ITER/CT/10/4300000179
Research scientists:	J. Järvenpää, H. Mäkinen, VTT

Aims of these projects are:

- Design of a new modular divertor cassette mock-up
- Procurement (manufacturing) new modular divertor cassette mock-up
- Testing of the new locking system operation.

First, requirements for the divertor cassette mock-up design were collected. Based on ITER divertor cassette design, modular concept for divertor cassette mock-up was sketchedand the detailed design process was started. Main design drivers for the detailed design process were modular structure allowing updates, external geometry of the ITER divertor cassette, weight, location of the center of gravity and the stiffness of the ITER divertor cassette.

During detailed design process of the divertor cassette still some modification proposal for ITER cassette design were presented. These proposals were accepted by ITER. Modifications were included in the design of the new cassette mock-up. Structure of the divertor cassette mock-up is simplified so that manufacturing cost can be reduced.

The stiffness of the divertor cassette mock-up body and ITER cassette body was compared using Finite Element Method (FEM). After the iteration process stiffness and external geometry fulfilled the requirements and manufacturing drawings were produced and reviewed by IO. Detailed design process of the new divertor cassette mock-up is ready. The main components of the new divertor cassette mock-up are shown in Figure 6.6. The technical details of the new cassette mock-up are: length 3293 mm, height 2467 mm, width 775 mm, weight 9000 kg and stiffness of the cassette body 19 kN/mm. The procurement and test phase of the project will be carried out during 2012.

6.3 R&D/design of sensors for the ITER magnetics diagnostic: design of the outer-vessel steady-state discrete sensor system

F4E Grant:	F4E-2010-GRT-156
Research scientists:	J. Kyynäräinen, H. Rimminen, J. Saarilahti, VTT

Background: Magnetic diagnostics on tokamaks provide local measurements of the magnetic field and large-area measurements of magnetic flux close to the surface of the plasma. Combinations of these measurements are processed to determine a variety of plasma parameters, such as its position, shape or the electrical current it carries, in both static and a range of dynamic conditions. Some of the plasma parameters are determined in real time for plasma control applications while others are determined off line for physics studies. The subject of this grant is to develop detailed designs for a steady-state discrete magnetics sensor system including sensor assemblies to be installed on the outer vessel of the ITER tokamak, to provide measurements of the plasma equilibrium field.

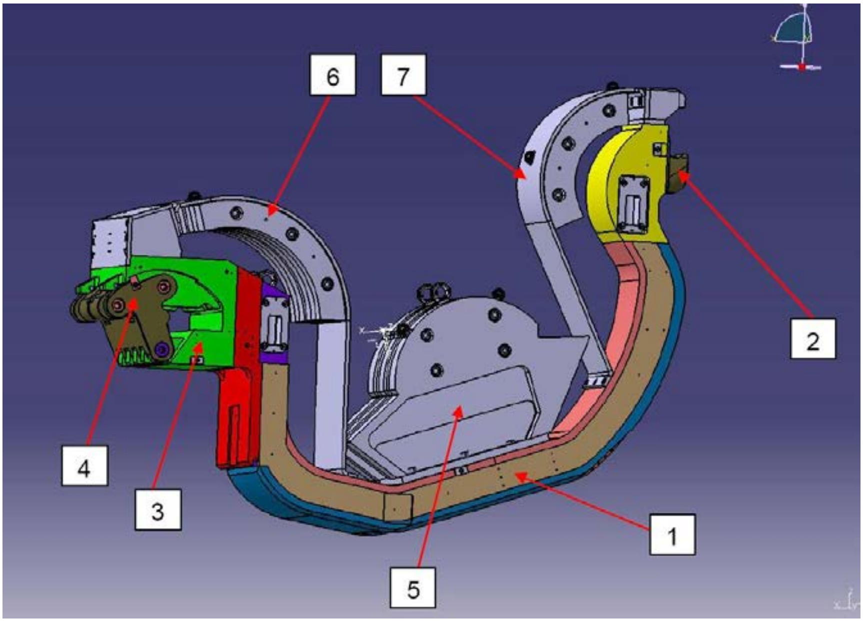


Figure 6.6. Main components of the new divertor cassette mock-up. 1. Cassette body. 2. Inboard hook. 3. Knuckle. 4. Outboard locking system. 5. Dome. 6. Outer vertical target mock-up. 7. Inner vertical target mock-up.

Goals: R&D and design activities to detail designs for steady-state discrete magnetics sensor system, aimed at measuring the equilibrium field outside the tokamak vessel (Figure 6.7). The detailed designs and associated documentation shall be developed to a level consistent with the requirements for an F4E Preliminary and Detailed Design Reviews. The designs shall aim at meeting the performance, reliability and operating life requirement targets. Grant duration is 26 months.

Progress in 2011: The grant was signed on 11 March 2011 and the kick-off meeting was held on 30 March 2011. Preliminary sensor specifications were adapted for Outer-Vessel Inductive Sensors for steady-state sensors, taking into account previous R&D to generate an F4E-approved revised set of preliminary specifications for the sensors to be designed. Review Environmental constraints and compatibility requirements, proposed by ITER IO, were reviewed and minor changes were recommended to F4E for an appropriate set of environmental constraints to be used for the sensor design.

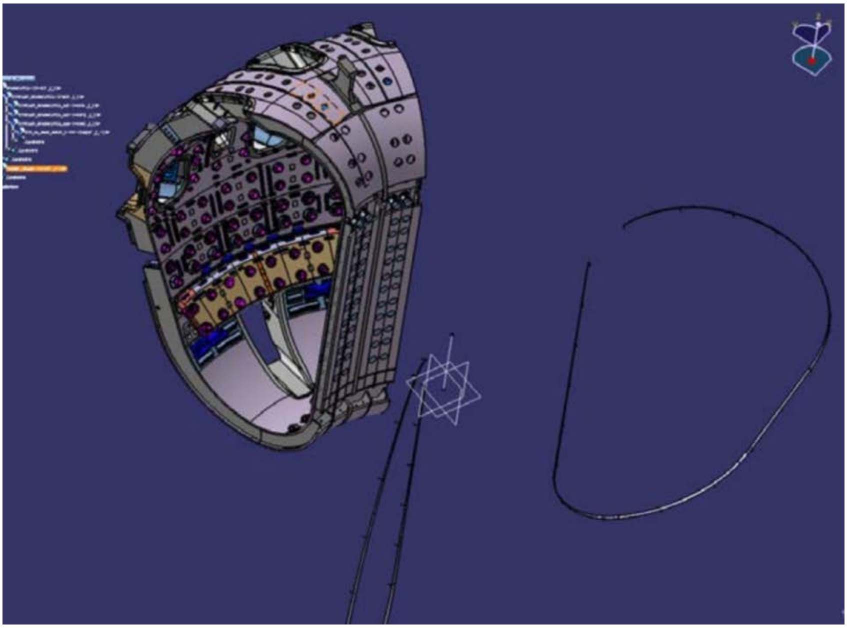


Figure 6.7. View of the steady state sensors on the vacuum vessel sectors 2, 5 and 8. The grey bands are the looms formed by the sensor tails.

New prototype magnetometer sensors were designed and mask drawings were prepared (Figure 6.8). Seven different sensors layouts were designed. Main improvements and modifications of the new sensors, as compared to the sensors tested in EFDA WP10-DIA-03-02, are the following.

1. The borosilicate glass capping wafer will be replaced by a silicon capping wafer. Silicon does not suffer from neutron-induced dimensional changes. In addition, helium generation and diffusion rates will be much smaller than in borosilicate glass.
2. Wafer bonding order will be reversed in a way that the device wafer/capping wafer will be done first. This enables characterization of the sensors in a vacuum chamber prior bonding of the
3. Gold-silicon eutectic bonding will be used to bond the bottom wafer.
4. The mechanical compliance will be larger, the excitation coil will have multiple turns and the overall sensor area will be larger, thus increasing the sensitivity.
5. Additional metal layer will be deposited on top of the excitation coil. It will serve as a ground plane to reduce the direct electrostatic excitation which causes nonlinearity.

Fabrication of the sensors was started in December 2011.

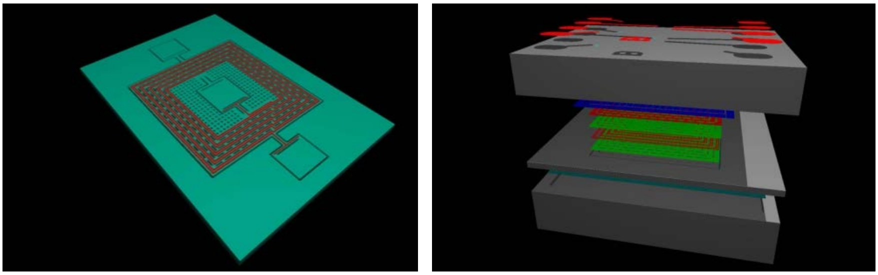


Figure 6.8. Exploded views of the MEMS magnetometer die.

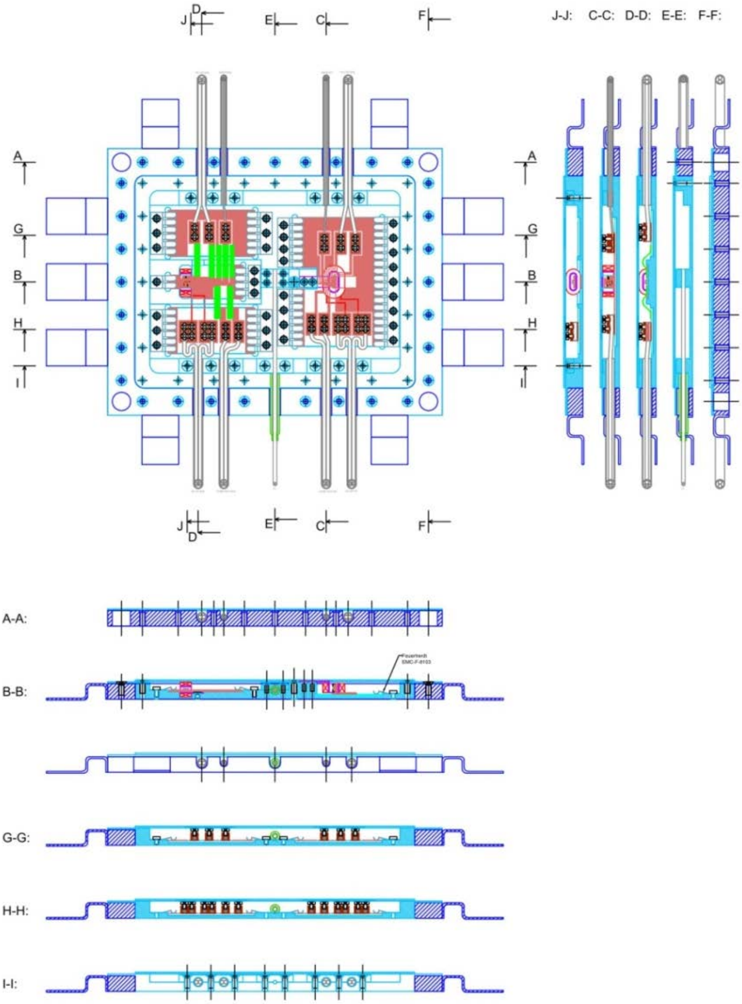


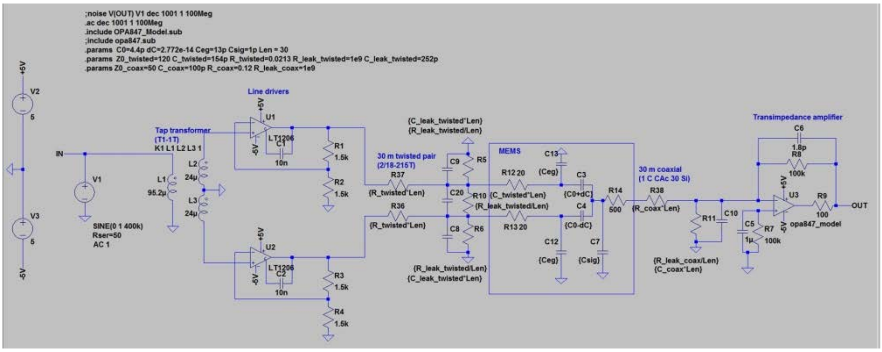
Figure 6.9. CAD drawing of the sensor enclosure housing one magnetometer for the poloidal field direction and one for the radial direction.

Stainless steel sensor enclosure has been designed to fit in the 11 mm narrow gap between the vacuum vessel outer surface and the thermal radiation shield (Figure 6.9). The sensors will be glued to aluminium nitride based DBC substrates using cyanate ester based adhesive and electrical contacts will be made using gold wire bonding. To ensure reliability, cables will be laser or electron beam welded to the substrates. The enclosures will be friction welded to the vacuum vessel outer surface.

The radiation hardness of the sensors will be tested in VTT's Triga Mk2 pool reactor. Test substrates have been designed for the irradiation and a preliminary irradiation plan proposed to F4E. Irradiations will be carried out

Simulations of the readout electronics have been started (Figure 6.10). The challenge in the design is that the radiation level at the sensors locations is too high for preamplifiers to survive and up to 30 m long cables will be needed between the sensors and the front-end electronics. The baseline design is based on connecting the sensors sense electrodes in a half-bridge configuration and reading the signal using a transimpedance amplifier to reduce the effect of the cable capacitance.

The sensors will be operated below the mechanical resonance frequency to reduce sensitivity to possible radiation-induced gas generation inside the sensor die vacuum cavity. Simulations show that a magnetic flux density resolution of about 3 mT is feasible for a 20 Hz measurement bandwidth. This nearly meets the specifications. Tests will be needed to measure the performance in a more reliable way since many effects like cross-axis sensitivity and temperature sensitivity cannot be simulated accurately.



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```

Figure 6.10. Simulation model of the readout electronics.

7. Other Activities

7.1 Conferences, workshops and meetings

M. Aints, A. Hakola, S. Karttunen, M. Kiisk, M. Laan, J. Likonen, A. Lissovski and P. Paris participated in a meeting between collaborative researches groups from VTT and University of Tartu within Euratom-Tekes association, Tallinn, Estonia, 19–20 January 2011.

T. Ahlgren, L. Aho-Mantila, M. Airila, A. Hakola, K. Heinola, A. Järvinen, T. Kurki-Suonio, A. Lasa, J. Likonen, T. Makkonen, A. Meinander, J. Miettunen, K. Nordlund and K. Vörtler participated in a Joint Working Session of SEWGs Material Migration and ITER Material Mix on Model Validation, Tervaniemi, Tervakoski, 31 January–2 February 2011. In addition there were 18 participants from abroad. Local organization by M. Airila and T. Kurki-Suonio.

L. Aho-Mantila, M. Airila, O. Asunta, A, Hakola, K. Heinola, E. Hirvijoki, T. Koskela, T. Kurki-Suonio, A. Lasa, A. Meinander, J. Miettunen, K. Nordlund, A. Salmi, S. Sipilä, A. Snicker and K. Vörtler participated in the SimITER Boot Camp, Tervaniemi, Finland, 2 February 2011.

T. Tala participated in the EPS program committee meeting, Strasbourg, France, 14–15 March 2011.

K. Heinola participated in EFDA Fusion Materials Topical Group Monitoring Meeting on MAT-W&WALLOY, Garching, Germany, 9–10 February 2011.

O. Asunta and S. Sipilä participated in the ITM Code Camp, Cadarache, France, 14–18 March 2011.

M. Airila (28 March–1 April), M. Groth, K. Heinola (21–25 March) and A. Järvinen (21–25 March) participated in JET Edge Modelling Meeting, Culham, UK, 21 March–1 April 2011.

M. Aints, A. Hakola, E. Hirvijoki, T. Kiviniemi, T. Koskela, T. Kurki-Suonio, A. Lissovski, T. Makkonen, A. Meinander, J. Miettunen, S. Sipilä and S. Äkäslompolo participated in the XLV Annual Conference of the Finnish Physical Society and the Second Nordic Physics Meeting, 29–31 March 2011, Helsinki, Finland.

T. Tala participated in the 6th ITPA Transport and Confinement meeting, San Diego, US, 4–5 April 2011.

T. Tala participated in the EU-US Transport Task Force Workshop TTF, San Diego, US, 6–9 April 2011.

M. Airila, O. Asunta, S. Janhunen, T. Korpilo, T. Koskela, T. Kurki-Suonio, S. Leerink, A. Meinander and S. Äkäslompolo participated in the LASTU Annual Seminar, Gustavelund, Tuusula, Finland, 7–8 April 2011.

M. Siuko and J. Järvenpää participated in the ITER Divertor meeting, Cadarache, France, 13–14 April 2011.

T. Tala participated in the CCE-FU Workshop on European fusion roadmap for FP8 and beyond, IPP Garching, Germany, 13–15 April 2011.

P. Peussa, J. Mattila and P. Pale participated in the F4E hosts Remote Handling Information Day, Barcelona, Spain, 18 April 2011

A. Hakola, J. Kolehmainen, M. Laan, J. Likonen and S. Tervakangas participated in the collaboration meeting DIARC-VTT-University of Tartu in Helsinki, 19 April 2011.

M. Airila participated in the 1st General Planning Meeting of the EFDA ITER Physics Work Programme, Garching, Germany, 5–6 May 2011.

C. Björkas, A. Hakola, A. Järvinen, A. Lasa J. Likonen and A. Meinander participated and presented a poster in the 13th International Workshop on Plasma-Facing Materials Components for Fusion Applications, Rosenheim, Germany, 9–13 May 2011.

L. Aho-Mantila, M. Airila, M. Groth, A. Hakola, K. Heinola, T. Kurki-Suonio, J. Likonen participated in 15th ITPA Meeting on SOL/Divertor Physics, Espoo, Finland, 16–19 May 2011. Oral talks were given by L. Aho-Mantila, K. Heinola and A. Hakola. The meeting was organized by Aalto University and VTT at Dipoli Congress Centre under the SimITER research project. The meeting was attended by more than 60 participants.

K. Salminen and R. Sibois participated European Nuclear Society – Young Generation Network the European Nuclear Young Generation Forum (ENYGF) in 2011, Prague, Czech Republic, 17–21 May 2011

M. Airila, A. Hakola, M. Laan, A. Lasa and P. Paris participated in the Joint Meeting of the EFDA PWI SEWGs on Material Migration and ITER Material Mix, Espoo, 19–20 May 2011. The meeting was organized by VTT and Aalto University under the SimITER research project at Aalto University.

L. Aho-Mantila, M. Airila, O. Asunta, E. Hirvijoki, A. Salmi, S. Sipilä, A. Snicker and S. Äkäslompolo participated in the ITM Code Camp, Espoo, Finland, 16–27 May 2011.

O. Asunta participated in the JET E1/E2 Task Force meeting, Culham, UK, 19 May 2011 (remote presentation).

K. Heinola participated in EFDA Fusion Materials Topical Group Monitoring Meeting on MAT-W&WALLOY, Frascati, Italy, 6–7 June 2011 and presented an oral talk.

65 participants in the Euratom-Tekes Annual Fusion Seminar, Silja Serenade, 7–9 June 2011. The invited speaker was Dr. Gianfranco Federici, EFDA CSU Garching, and guest speakers Professor James Drake and Dr. Per Petersson, Association Euratom-VR, Sweden. Researchers of Association Euratom-Tekes gave several presentations on fusion physics and technology.

K. Nordlund chaired the first OECD Nuclear Energy Agency (NEA) working group meeting on primary radiation damage (PRD), Paris, France 10 June 2011.

O. Asunta, E. Hirvijoki and A. Snicker participated in the GOTiT course on Resonant and Non-Resonant Interactions in Beam-Plasma Systems and Magnetic Fusion Plasmas, Frascati, Italy, 13–17 June 2011.

M. Laan participated on the JET Fusion Technology 1st semi-annual monitoring meeting teleconference, 16 June 2011.

M. Airila participated in the Annual Meeting of the EFDA Public Information Network, Greifswald, Germany, 16–17 June 2011.

A. Hakola participated in the Joint Meeting of the EFDA PWI SEWGs on Fuel Retention and Dust, Garching, Germany, 20–22 June 2011.

L. Aho-Mantila, O. Asunta, A. Järvinen, T. Kiviniemi, T. Korpilo, T. Kurki-Suonio and T. Tala participated in the 38th EPS Conference on Plasma Physics, Strasbourg, France, 27 June–1 July 2011.

J. Lönnroth visited FOM Institute for Plasma Physics Rijnhuizen, Niuwegein, The Netherlands, participating in a Task Force Integrated Tokamak Modelling (ITM), ITER Scenario Modelling Group (ISM) working session, 4–8 July 2011.

A. Lasa participated in the 48th Culham Plasma Physics Summer School, Culham, UK, 11–22 July 2011.

A. Hakola participated in the Kick-Off Meeting of the EFDA Emerging Technologies – Dust and Tritium Management Programme, Garching, Germany, 14–15 July 2011.

M. Laan participated in Kick off Meeting Technologies – Dust and Tritium management in IPP Garching, Germany, 14–15 July 2011.

K. Piip participated in summer school “Plasma Wall Interaction in Fusion Devices: Physics and Technology” in Erice, Italy, 17–24 July 2011.

A. Meinander participated in the PRACE Summer School: Taking the Most Out of Supercomputers, Helsinki, Finland, 29 August–1 September 2011.

C. Björkas participated in the 10th Carolus Magnus Summer School, Weert, the Netherlands, 4–16 September 2011.

O. Asunta and T. Kurki-Suonio participated in the 12th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems, Austin, Texas, U.S.A., 7–10 September 2011.

10 participants from Diarc, VTT and University of Tartu participated in the collaboration meeting of VTT-Diarc-University of Tartu, Tallinn, Estonia, 9 September 2011.

O. Asunta and T. Kurki-Suonio participated in the ITPA Energetic Particle Physics Topical Group Meeting, Austin, Texas, U.S.A., 12–13 September 2011.

J. Lönnroth participated in the 13th International Workshop on Plasma Edge Theory in Fusion Devices, South Lake Tahoe, California, USA, 19–21 September 2011.

R. Sibois participated Karlsruhe International Summer School on Fusion Technology, Karlsruhe, Germany, 19–30 September 2011.

K. Nordlund chaired the second OECD Nuclear Energy Agency (NEA) working group meeting on primary radiation damage (PRD) Paris, France, 29–30 September 2011.

J. Järvenpää participated in the Remote Handling DEMO meeting in EFDA, Garching, Germany, 5 October 2011

A. Hakola visited IPP Greifswald, Germany, 13–14 October 2011.

C. Björkas participated in the ICRFM conference, Charleston, SC, USA, 16–20 October 2011.

A. Hakola participated in the 2nd General Planning Meeting of the EFDA ITER Physics Work Programme, Garching, Germany, 27–28 October 2011.

L. Aho-Mantila, A. Hakola and T. Kurki-Suonio participated in the Annual ASDEX Upgrade Program Seminar, Ringberg, Germany, 7–11 November 2011.

A. Hakola participated in the 10th Annual Meeting of the EFDA PWI Task Force, Bratislava, Slovakia, 28–30 November 2011.

O. Asunta, E. Hirvijoki and A. Snicker participated in the ITM Code Camp, Innsbruck, Austria, 5–9 December 2011.

A. Salmi and T. Kurki-Suonio participated in the 19th European Fusion Physics Workshop, Seebad, Heringsdorf, Germany, 4–6 December 2011.

A. Snicker participated in the ITM Code Camp, Nicosia, Cyprus, 9–15 October 2011.

T. Koskela, T. Kurki-Suonio and S. Äkäslompolo participated in the 5th ITER International Summer School on MHD and Energetic Particles, Aix-en-Provence, France, 20–24 June 2011.

S. Äkäslompolo participated in the ITM General Meeting, Garching, Germany, 12–16 September 2011. M. Kiisk participated in a meeting between collaborative researches groups from VTT, MedC and AEUL, Riga, Latvia, 4 October 2011.

T. Tala participated in the 7th ITPA Transport and Confinement meeting, Cadarache, France, 5–7 October 2011.

K. Vörtler participated in the 15th International Conference on Fusion Reactor Materials (ICFRM15), Charleston, South Carolina, USA, 16–22 October 2011.

T. Tala participated in the Tekes Association steering Committee, Tartu, Estonia, 17–18 October 2011.

C. Björkas participated in the conference “The Finlandssvenska fysik- och kemidagarna”, Silja Symphony, 19–21 November 2011 and presented an invited talk.

K. Nordlund participated in the MAT-REMEV monitoring meeting, Garching, Germany, 21–23 November 2011.

M. Aints, M. Laan and A. Lissovski participated in Intermediate Video Meeting on Emerging Technologies – Dust and Tritium Management, 7. December 2011.

T. Määttä, P. Peussa, J. Mattila and P. Pale participated in the ITER Business Forum Manosque, France, 7–8 December 2011.

M. Kiisk participated in EFDA JET Task Force Fusion Technology 2011 Annual Monitoring and 2012 Kick-off meeting, EFDA-JET, Culham, UK, 12–14 December 2011.

K. Nordlund participated in IAEA meetings on plasma-wall interactions, Vienna, Austria, 12–16 December 2011.

K. Heinola participated in EFDA PPP&T Task Planning Meeting on Task Area #5: Materials R&D and Material Engineering Database Activities, Garching, Germany, 15–17 December 2011.

7.1 Visits

J. Lönnroth was seconded to EFDA-JET, Culham, UK, 1 January–31 December 2011.

A. Salmi was seconded to EFDA-JET, Culham, UK, 31 January – 25 February 2011.

M. Groth was seconded to EFDA-JET, Culham, UK, 13–17 June 2011.

K. Heinola visited the University of Lille, France, 25–30 June 2011.

M. Groth was seconded to EFDA-JET, Culham, UK, 1 August–31 December 2011.

A. Salmi visited CEA, Cadarache, France, 2–15 October 2011.

T. Tala visited Tore Supra, CEA, France, 3–4 October 2011.

O. Asunta was seconded to EFDA-JET, Culham, UK, 7 November–2 December 2011.

T. Tala was seconded to EFDA-JET, Culham, UK, 14–25 November 2011.

L. Aho-Mantila, M. Airila, M. Groth, K. Heinola, A. Järvinen (23 October–9 December), A. Lasa (14–24 November) and V. Lindholm (5–9 December) participated in the JET edge modelling meeting in JET, Culham, UK, 14 November–9 December 2011.

A. Salmi was seconded to EFDA-JET, Culham, UK, 21–25 November 2011.

T. Tala was seconded to EFDA-JET, Culham, UK, 5–9 December 2011.

A. Salmi visited IPP Greifswald, Germany, 7 December 2011.

7.2 Visitors

B. Levesy and J.-P. Martins from ITER, Cadarache, France visited VTT (DTP2) on 19 January 2011.

S. Esque, L. Semeraro, R. Ranz, from F4E, Barcelona, Spain and D. Hamilton from ITER, Cadarache, France and F. Crisanti from ENEA, Italy visited VTT (DTP2) on 2–3 February 2011.

Dr. Marco Wischmeier from IPP Garching, Germany, visited VTT on 3 February 2011.

M. Merola, A. Martin, V. Komarov, T. Jokinen, S. Griffit from ITER, Cadarache, France visited VTT (DTP2) on 15 February 2011.

A. Satonen from Finnish parliament visited VTT (DTP2) on 30 March 2011.

M. Fabianec from Hausler AG Duggingen, Swizerland visited VTT (DTP2) on 31 March 2011.

L. Johansson from National Instruments in Sweden visited VTT (DTP2) on 11 April 2011.

H. Desmedt from European Commission visited VTT (DTP2) on 2–3 May 2011.

Guests from University of Naples, Italy, visited VTT (DTP2) on 2–3 May 2011.

An ITM code camp was organized by Tekes – Aalto University at Aalto University, Espoo, 16–27 May 2011, attended by 25 participants from various Associations.

A. Tan and colleagues from Workplace Safety and Health Institute, Singapore visited VTT (DTP2) on 6 June 2011.

S. Esque and R. Ranz, from F4E, Barcelona, Spain, visited VTT (DTP2) on 15–16 June 2011.

S. Esque, M. Popescu, C. Annino and R. Ranz, from F4E, Barcelona, Spain visited VTT (DTP2) on 23–24 August 2011.

C. Shapardonov embassy of Canada visited VTT (DTP2) on 1 September 2011.

S. Esque, R. Ranz, C. Van Hille from F4E, Spain and J. Palmer and D. Hamilton from ITER France visited VTT (DTP2) on 6–7 October 2011.

E. Marenkov visited the University of Helsinki 15 October–15 December 2011 and worked on the topic of D penetration in carbon materials.

P. Grammatikopoulos visited the University of Helsinki 15 October–15 December 2011 as an HPC-Europa visitor, working on the topic of dissolution of Cr clusters in Fe, and gave a talk on dislocation mobility in metals.

Professor J. Watton from University of Cardiff, England visited VTT (DTP2) on 4 November 2011.

Professor W. Fundamenski from CCFE, Culham, UK, visited Aalto University on 4 November 2011 and acted as the opponent of L. Aho-Mantila.

Dr. R. Pitts from ITER Organization, Cadarache, France, visited VTT on 4 November 2011 and gave a general presentation "ITER Status and Challenges" to an audience of over 90.

Dr. M. Wischmeier from IPP Garching, Germany, visited VTT on 4 November 2011.

Professor M. Ferre from Universidad Politécnica de Madrid visited VTT (DTP2) on 5 November 2011.

7.3 Other activities

T. Tala gave an interview on the status of Fusion program and ITER for the PRISMA TV-program at VTT (broadcast on 24 March 2011).

Lecture course "Introduction to Plasma Physics and Fusion" by S. Karttunen was given in spring 2011 at the School of Science in Aalto University.

A media event was organized for Finnish journalists at VTT (DTP2), 21 June 2011. DTP2 was one of the main attractions.

L. Aho-Mantila was awarded an IOP Poster Prize for the best posters at the 38th EPS conference on Plasma Physics, Strasbourg, France, 27 June–1 July 2011.

M. Airila gave an interview on JET and its ITER-like wall for Tekniikka & Talous newspaper (published in online version on 5 September, 2011).

M. Airila gave an interview on JET and its ITER-like wall for Tiede magazine 10/2011.

S. Karttunen, M. Airila and J. Lindén gave an interview on the development of fusion energy for Energia & Ympäristö magazine 3/2011.

8. Publications 2011

8.1 Fusion Physics and Plasma Engineering

8.1.1 Publications in scientific journals

1. S.A. Norris, J. Samela, C.S. Madi, M.P. Brenner, L. Bukonte, M. Backman, F. Djurabekova, K. Nordlund and M.J. Aziz, MD-Predicted Phase diagrams for Pattern Formation, Nature communications **2** (2011) 276.
2. P. Mantica, C. Challis, A.G. Peeters, D. Strintzi, T. Tala, M. Tsalas, P.C. de Vries, B. Baiocchi, M. Baruzzo, M.N.A. Beurskens, J.P.S. Bizarro, P. Buratti, J. Citrin, G. Colyer, F. Crisanti, A.C.A. Figueiredo, X. Garbet, C. Giroud, N. Hawkes, J. Hobirk, F. Imbeaux, E. Joffrin, T. Johnson, E. Lerche, J. Mailloux, V. Naulin, A. Salmi, C. Sozzi, G. Staebler, D. Van Eester, T.W. Versloot, J. Weiland and JET-EFDA contributors, A Key to Improved Ion Core Confinement in the JET Tokamak: Ion Stiffness Mitigation due to Combined Plasma Rotation and Low Magnetic Shear, Physical Review Letters **107** (2011) 135004.
3. J. Lönnroth, V. Parail, D.C. McDonald, S. Saarelma, E. de la Luna, M. Beurskens and JET-EFDA contributors, Dependence of pedestal performance on the characteristics of the H-mode pedestal, Nuclear Fusion **51** (2011) 013003.
4. M. Valisa, L. Carraro, I. Predebon, M.E. Puiatti, C. Angioni, I. Coffey, C. Giroud, L. Lauro Taroni, B. Alper, M. Baruzzo, P. Belo, daSilva, P. Buratti, L. Garzotti, D. Van Eester, E. Lerche, P. Mantica, V. Naulin, T. Tala, M. Tsalas and JET-EFDA contributors, Metal impurity transport control in JET H-mode plasmas with central ion cyclotron radiofrequency power injection, Nuclear Fusion **51** (2011) 033002.
5. C. Perez von Thun, A. Perona, T. Johnson, M. Reich, S. Sharapov, V. Kiptily, M. Cecconello, A. Salmi, V. Goloborod`ko, S. Pinches, M. García-Muñoz, D. Darrow, M. Brix, I. Voitsekhovitch, and JET EFDA contributors, Numerical simulation of fast ion loss detector measurements for fishbones on JET, Nuclear Fusion **51** (2011) 053003.
6. K. Kamiya, Y. Sakamoto, G. Matsunaga, A. Kojima, H. Urano, N. Oyama, Y. Koide, Y. Kamada, K. Ida, T. Kurki-Suonio and the JT-60 Team. Spatio-temporal structure of the edge radial electric field during H-mode in JT-60U. Nuclear Fusion **51** (2011) 053009.
7. K. Shinohara, T. Kurki-Suonio, D. Spong, O. Asunta, K. Tani, E. Strumberger, S. Briguglio, T. Koskela, G. Vlad, S. Günter, G. Kramer, S. Putvinski, K. Hamamatsu, Effects of complex symmetry-breakings on alpha particle power loads on first wall structures and equilibrium in ITER, Nuclear Fusion **51** (2011) 063028.

8. X. Litaudon, Y. Sakamoto, P.C. de Vries, A. Salmi, T. Tala, C. Angioni, S. Benkadda, M.N.A. Beurskens, C. Bourdelle, M. Brix, K. Crombé, T. Fujita, S. Futatani, X. Garbet, C. Giroud, N.C. Hawkes, N. Hayashi, G.T. Hoang, D. Hogeweij, G. Matsunaga, T. Nakano, N. Oyama, V. Parail, K. Shinohara, T. Suzuki, M. Takechi, H. Takenaga, T. Takizuka, H. Urano, I. Voitsekhovitch, M. Yoshida, ITPA Transport Group, the JT-60U team and JET EFDA contributors, Core Transport Properties in JT-60U and JET Identity Plasmas, Nuclear Fusion, **51** (2011) 073020.
9. F. Imbeaux, J. Citrin, J. Hobirk, G.M.D. Hogeweij, F. Köchl, V.M. Leonov, S. Miyamoto, Y. Nakamura, V. Parail, G. Pereverzev, A. Polevoi, I. Voitsekhovitch, V. Basiuk, R. Budny, T. Casper, J. Fereira, A. Fukuyama, J. Garcia, Y.V. Gribov, N. Hayashi, M. Honda, I.H. Hutchinson, G. Jackson, A.A. Kavin, C.E. Kessel, R.R. Khayrutdinov, C. Labate, X. Litaudon, P.J. Lomas, J. Lönnroth, T. Luce, V.E. Lukash, M. Mattei, D. Mikkelsen, I. Nunes, Y. Peysson, P. Politzer, M. Schneider, G. Sips, G. Tardini, S.M. Wolfe, V.E. Zhogolev, ASDEX Upgrade Team, C-Mod Team, DIII-D Team, JET-EFDA contributors, JT-60U Team, Tore Supra Team, contributors of the EU-ITM ITER Scenario Modelling group, ITPA ‘Integrated Operation Scenarios’ group members and experts and ITPA ‘Transport and Confinement’ group members and experts, Current ramps in tokamaks: from present experiments to ITER scenarios, Nuclear. Fusion **51** (2011) 083026.
10. T. Kurki-Suonio, O. Asunta, T. Koskela, A. Snicker, T. Hauff, F. Jenko, E. Poli, and S. Sipilä, Fast Ion power loads on ITER First Wall Structures in the Presence of NTMs and microturbulence,, Nuclear Fusion **51** (2011) 083041.
11. A.G. Peeters, C. Angioni, A. Bortolon, Y. Camenen, F.J. Casson, B. Duval, L. Fiederspiel, W.A. Hornsby, Y. Idomura, N. Kluy, P. Mantica, F.I. Parra, A.P. Snodin, G. Szepesi, D. Strintzi, T. Tala, G. Tardini, P. de Vries and J. Weiland, Overview of toroidal momentum transport, Nuclear Fusion **51** (2011) 094027.
12. M. Garcia-Munoz, I.G.J. Classen, B. Geiger, W.W. Heidbrink, M.A. Van Zeeland, S. Äkäslompolo, R. Bilato, V. Bobkov, M. Brambilla, G.D. Conway, S. da Graça, V. Igochine, Ph. Lauber, N. Luhmann, M. Maraschek, F. Meo, H. Park, M. Schneller, G. Tardini, ASDEX Upgrade Team, Fast-ion transport induced by Alfvén eigenmodes in the ASDEX Upgrade tokamak, Nuclear Fusion **51** (2011) 103013.
13. M.J. Schaffer, J.A. Snipes, P. Gohil, P. de Vries, T.E. Evans, M.E. Fenstermacher, X. Gao, A.M. Garofalo, D.A. Gates, C.M. Greenfield, W.W. Heidbrink, G.J. Kramer, R.J. La Haye, S. Liu, A. Loarte, M.F.F. Nave, T.H. Osborne, N. Oyama, J-K. Park, N. Ramasubramanian, H. Reimerdes, G. Saibene, A. Salmi, K. Shinohara, D.A. Spong, W.M. Solomon, T. Tala, Y.B. Zhu, J.A. Boedo, V. Chuyanov, E.J. Doyle, M. Jakubowski, H. Jhang, R.M. Nazikian, V.D. Pustovitov, O. Schmitz, R. Srinivasan, T.S. Taylor, M.R. Wade, K-I. You, L. Zeng, and the DIII-D Team, ITER Test Blanket Module Error Field Simulation Experiments at DIII-D, Nuclear Fusion **51** (2011) 103028.
14. G. Kramer, B. Budny, R. Ellis, M. Gorelenkova, W. Heidbrink, T. Kurki-Suonio, R. Nazikian, A. Salmi, M. Schaffer, K. Shinohara, J. Snipes, D. Spong, T. Koskela, and M. Van Zeeland, Fast-ion effects during test blanket module simulation experiments in DIII-D, Nuclear Fusion **51** (2011) 103029.
15. H. Urano, G. Saibene, N. Oyama, V. Parail, P. de Vries, R. Sartori, Y. Kamada, K. Kamiya, A. Loarte, J. Lönnroth, Y. Sakamoto, A. Salmi, K. Shinohara, H. Takenaga, M. Yoshida, The JT-60 Team and JET EFDA Contributors, Edge pedestal characteristics in JET and JT-60U tokamaks under variable toroidal field ripple, Nuclear Fusion **51** (2011) 113004.
16. T. Tala, A. Salmi, C. Angioni, F.J. Casson, G. Corrigan, J. Ferreira, C. Giroud, P. Mantica, V. Naulin, A.G. Peeters, W.M. Solomon, D. Strintzi, M. Tsalas, T.W. Versloot, P.C. de Vries, K.-D. Zastrow and JET-EFDA contributors, Parametric Dependencies of Momentum Pinch and Prandtl Number in JET, Nuclear Fusion **51** (2011) 123002.

17. T.W. Versloot, P.C. de Vries, C. Giroud, M. Brix, M.G. von Hellermann, P.J. Lomas, D. Moulton, M.O' Mullane, I. Nunes, A. Salmi, T. Tala, I. Voitsekhovich, K.-D. Zastrow and JET EFDA contributors, Momentum Losses by Charge Exchange with Neutral Particles in H-mode Discharges at JET, Plasma Physics and Controlled Fusion, **53** (2011) 065017.

18. A.T. Salmi, T. Tala, G. Corrigan, C. Giroud, J. Ferreira, J. Lönnroth, P. Mantica, V. Parail, M. Tsalas, T.W. Versloot, P.C. de Vries, K.-D. Zastrow and JET EFDA contributors, NBI Torque in Presence of Magnetic Field Ripple: Experiments and Modelling for JET, Plasma Physics and Controlled Fusion, **53** (2011) 085005.

19. D. Moseev, F. Meo, S.B. Korsholm, T. Koskela, M. Albergante, O. Asunta, H. Bindslev, A. Bürger, V. Furtula, M. Yu Kantor, F. Leipold, P.K. Michelsen, S.K. Nielsen, M. Salewski, O. Schmitz, M .Stejner, E. Westerhof and the TEXTOR team, Comparison of measured and simulated fast ion velocity distributions in the TEXTOR tokamak,, Plasma Physics and Controlled Fusion **53** (2011) 105004.

20. H. Nordman, A. Skyman, P. Strand, C. Giroud, F. Jenko, F. Merz, V. Naulin, T. Tala and the JET-EFDA Contributors, Fluid and gyrokinetic simulations of impurity transport at JET, Plasma Physics and Controlled Fusion **53** (2011) 105005.

21. I. Chapman, J. Graves, T. Johnson, O. Asunta, P. Bonoli, M. Choi, E. Jaeger, M. Jucker, and O. Sauter, Sawtooth control in ITER using ion cyclotron resonance heating, Plasma Physics and Controlled Fusion **53** (2011) 124003.

22. R.M. McDermott, C. Angioni, R. Dux, E. Fable, T. Pütterich, F. Ryter, A. Salmi, T. Tala, G. Tardini, E. Viezzer and the ASDEX Upgrade Team, Core Momentum and Particle Transport in the ASDEX Upgrade Tokamak, Plasma Physics and Controlled Fusion **53** (2011) 124013.

23. M. Groth, G.D. Porter, T.D. Rognlien, S. Wiesen, M. Wischmeier, D.P. Coster, T. Eich, M.E. Fenstermacher, C. Fuchs, R.A. Groebner, D.Harting, A. Herrmann, A. Huber, Jachmich, A. Kallenbach, C.J. Lasnier, A.W. Leonard, A. Meigs, H.W. Müller, M.E. Rensink, D.L. Rudakov, J.G. Watkins, E. Wolfrum, and the DIII-D and ASDEX Upgrade Teams, and JET EFDA Contributors: Poloidal distribution of recycling sources and core plasma fueling in DIII-D, ASDEX-Upgrade and JET L-mode plasmas, Plasma Physics and Controlled Fusion 53 (2011) 124017.

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25. J.A. Heikkinen and M. Nora, Gyrokinetic Equations and Full f Solution Method Based on Dirac's Constrained Hamiltonian and Inverse Kruskal Iteration, Physics of Plasmas **18** (2011) 022310.

26. M.A. Van Zeeland, W.W. Heidbrink, R.K. Fisher, M. Garcia-Munoz, G. Kramer, D.C. Pace, R.B. White, S. Aekaeslompolo, M.E. Austin, J. Boom, I.G.J. Classen, S. da Grasa, B. Geiger, M. Gorelenkova, N.N. Gorelenkov, A.W. Hyatt, N. Luhmann, M. Maraschek, G.R. McKee, C. Muscatello, R. Nazikian, H. Park, S. Sharapov, B.J. Tobias, Y. Zhu, ASDEX Upgrade Team, Measurements and Modeling of Alfven Eigenmode Induced Fast-Ion Transport and Loss in DIII-D and ASDEX Upgrade, Physics of Plasmas **18** (2011) 056114.

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28. M. Mehine, C. Björkas, K. Vörtler, K .Nordlund and M.I. Airila, Modelling the erosion of beryllium carbide surfaces, Journal of Nuclear Materials, **414** (2011) 1.
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8.1.2 Conference articles – physics and plasma engineering

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60. L. Aho-Mantila, M. Wischmeier, A. Kirschner, D. Borodin, K. Krieger and the ASDEX Upgrade Team, Effect of field reversal on carbon migration in the outer divertor of ASDEX Upgrade, 38th European Physical Society Conference on Plasma Physics, Strasbourg, France, June 27–July 1, 2011, Paper P1.061.

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62. T. Tala, A. Salmi, P. Mantica, C. Angioni, G. Corrigan, P.C. de Vries, C. Giroud, J. Ferreira, J. Lönnroth, V. Naulin, A.G. Peeters, W. Solomon, D. Strintzi, M. Tsalas, T.W. Versloot, J. Weiland, K.-D. Zastrow and JET-EFDA contributors, NBI Modulation Experiments to Study Momentum Transport and Magnetic Field Induced Ripple Torque on JET, 38th European Physical Society Conference on Plasma Physics, Strasbourg, France, June 27–July 1, 2011, Paper P1.139
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82. T. Kurki-Suonio, O. Asunta, T. Koskela S. Sipilä, A. Snicker and S. Äkäslompolo, Orbit-following fusion alpha wall load simulations for ITER including full orbit effects, 12th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems, Austin, Texas, US, September 7–10, 2011, Paper O-17 (2011).
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84. S. Sipilä, A. Snicker and T. Kurki-Suonio, Orbit-following fusion alpha simulations for ITER including full orbit effects, XLV Annual Conference of the Finnish Physical Society and the Second Nordic Physics Meeting, Helsinki, March 29–31, 2011, Paper C4.3.
85. S. Janhunen, J.A. Heikkinen, T. Kiviniemi, T. Korpilo, and S. Leerink, Simulation of electrostatic drift-wave turbulence in tokamaks with the gyrokinetic code Elmfire, XLV Annual Conference of the Finnish Physical Society and the Second Nordic Physics Meeting, Helsinki, March 29–31, 2011, Paper C4.4.
86. S. Äkäslompolo, Messing up a perfectly smooth magnetic field configuration in a tokamak, XLV Annual Conference of the Finnish Physical Society and the Second Nordic Physics Meeting, Helsinki, March 29–31, 2011, Paper P1.13.
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89. T. Kurki-Suonio, O. Asunta, T. Koskela, J. Miettunen, S. Sipilä and S. Äkäslompolo. Fusion Energy and Critical Wall Issues for ITER. XLV Annual Conference of the Finnish Physical Society and the Second Nordic Physics Meeting, Helsinki, March 29–31, 2011, Paper P2.9.
90. J. Miettunen, T. Kurki-Suonio, M. Groth, A. Hakola, E. Hirvijoki, K. Krieger, J. Likonen, T. Makkonen, S. Äkäslompolo and the ASDEX Upgrade Team, Kinetic modelling of impurity transport in tokamaks, XLV Annual Conference of the Finnish Physical Society and the Second Nordic Physics Meeting, Helsinki, March 29–31, 2011, Paper P2.74.
91. T. Koskela, O. Asunta, E. Hirvijoki, T. Kurki-Suonio, S. Sipilä, A. Snicker, and S. Äkäslompolo, Symmetry and fast ion confinement issues in tokamaks, XLV Annual Conference of the Finnish Physical Society and the Second Nordic Physics Meeting, Helsinki, March 29–31, 2011, Paper P2.113.
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93. T. Kiviniemi, J. Heikkinen, S. Janhunen, S. Leerink, T. Korpilo, Gyrokinetic transport barrier simulations for Textor, XLV Annual Conference of the Finnish Physical Society and the Second Nordic Physics Meeting, Helsinki, March 29–31, 2011, Paper P2.116.

94. E. Hirvijoki. Is it Worth Re-Coding an Old Work Horse? XLV Annual Conference of the Finnish Physical Society and the Second Nordic Physics Meeting, Helsinki, March 29–31, 2011, Paper P2.127.

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8.2 Fusion technology

8.2.1 Publications in scientific journals

96. F. Djurabekova, S. Parviainen, A. Pohjonen, and K. Nordlund, Atomistic modeling of metal surfaces under electric fields: Direct coupling of electric fields to a molecular dynamics algorithm, Phys. Rev. E **83** (2011) 026704.

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100. S. Parviainen, F. Djurabekova, H. Timko, and K. Nordlund, Implementation of electronic processes into molecular dynamics simulations of nanoscale metal tips under electric fields, Comput. Mater. Sci. **50** (2011) 2075.

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8.2.2 Research reports – fusion technology

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107. J. Kyynräinen and H. Rimminen, Final Report of EFDA WP10-DIA-03-02 MEMS Magnetometers, VTT-R-01790-11 (2011).
108. J. Kyynäräinen, Proposal for revised sensor specifications and environmental constraints (F4E_D_GRT-156_DX1) (2011).
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111. H. Saarinen, J. Järvenpää, R. Tiusanen. CMM/SCEE Recoverability Test Plan. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 96 p.
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113. J. Karjalainen, V. Hämäläinen, H. Saarinen, H. Mäkinen. 2nd Cassette replacements with misalignments, test plan. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 33 p.
114. H. Saarinen, J. Karjalainen, V. Hämäläinen. Cassette Location Tests. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 25 p.
115. J. Tuominen, A. Muhammad, H. Saarinen. WHMAN performance assessment plan. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 49 p.
116. H. Mäkinen. SCEE Design Modifications Plan. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 82 p.
117. P. Valkama, P. Kinnunen. System Requirements Document SRD Diagnostic Rack End-Effector. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 47 p.
118. P. Valkama, P. Kinnunen. System Requirements Document SRD Umbilical. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 47 p.
119. P. Valkama, P. Kinnunen. System Requirements Document SRD Umbilical End-Effector. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 46 p.
120. L. Aha, M. Saarinen. Implementation plan. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 67 p.
121. J. Tuominen, Z. Ziaei, P. Kinnunen, J. Koivumäki, V. Lyytikäinen, M. Viinikainen. WHMAN Trials on Test Stand. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 269 p.
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123. P. Valkama, P. Kinnunen. Design Description Document, CTM Umbilical. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 50 p.

124. P. Valkama, P. Kinnunen. Design Description Document, Umbilical End-Effector. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 36 p.

125. M. Saarinen, L. Aha, J. Kortelainen, T. Niemeläinen, L. Heikkilä, T. Nurminen, H. Saarinen, J. Karjalainen, A. Muhammad, J. Alanen, T. Vaarala, S. Rantala. Interim Report. Divertor RH design updates and DTP2 Phase 2 Testing. Tampere 2011. 145 p.

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8.3 Doctoral and graduate theses

127. L. Aho-Mantila, Divertor plasma conditions and their effect on carbon migration in the ASDEX Upgrade tokamak, Doctoral dissertation, Aalto University School of Science, Espoo 2011. VTT Publications **773.**

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129. H. Timko, Modelling vacuum arcs: from plasma initiation to surface interactions, Doctoral dissertation, University of Helsinki, 2011. Report Series in Physics, HU-P-D **188.**

130. A. Muhammad, Impedance control of redundant manipulators, Doctoral dissertation, Tampere University of Technology, 2011.

131. J. Miettunen, Kinetic modelling of ^{13}C transport in the ASDEX Upgrade tokamak with the ASCOT code, M.Sc Thesis, Aalto University School of Science, Espoo 2011.

8.4 Publications of Estonian Research Unit

8.4.1 Publications in scientific journals

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8.4.2 Conference articles

133. P. Paris, M. Laan, M. Aints and A. Lissovski,, Discharge-assisted LIBS and ablation-induced current pulses, 6th Euro Mediterranean Symposium on Laser-Induced Breakdown Spectroscopy, Cesme Izmir, 11–15 September 2011, p. 150.

8.4.3 Research reports

134. M. Laan, M. Aints, A. Hakola, M. Kiisk, J. Likonen and P. Paris, Final Report JW10 –FT-1.17 Development of the in-situ diagnostics for the characterisation of deposited layers and/or coatings, European Fusion Development Agreement (EFDA), JET Task Force Fusion Technology, United Kingdom (2011).

Appendix A: Introduction to Fusion Energy

A.1 Energy Demand Is Increasing

Most projections show world energy demand doubling or trebling in the next 50 years. This derives from fast population growth and rapid economic development. Energy sources that are not yet fully tapped include biomass, hydropower, geothermal, 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.

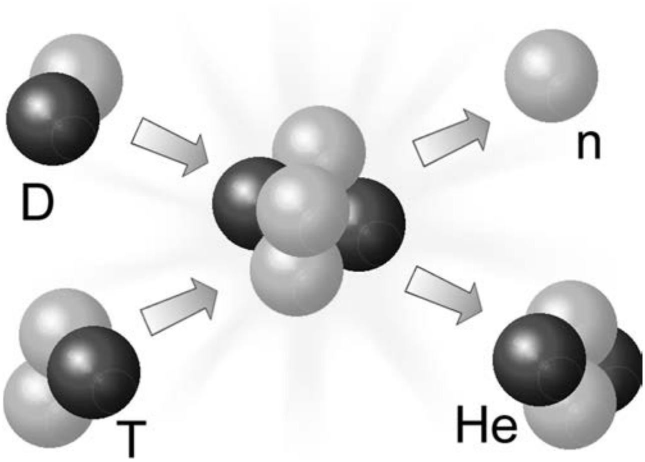

Figure A.1. In a fusion reaction, Deuterium (D) and Tritium (T) fuse together forming a Helium nucleus (^{4}He) and releasing a large amount of energy which is mostly carried by a neutron (n).

A.2 What Is Fusion Energy?

Fusion is the energy source of the sun and other stars, and all life on Earth is based on fusion energy. The fuels burned in a fusion reactor are hydrogen isotopes, deuterium and tritium. Deuterium resources are practically unlimited, and tritium can be produced from lithium, which is abundant. The fusion reactions occur only at very high temperatures. For the deuterium-tritium reaction, fuel 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.

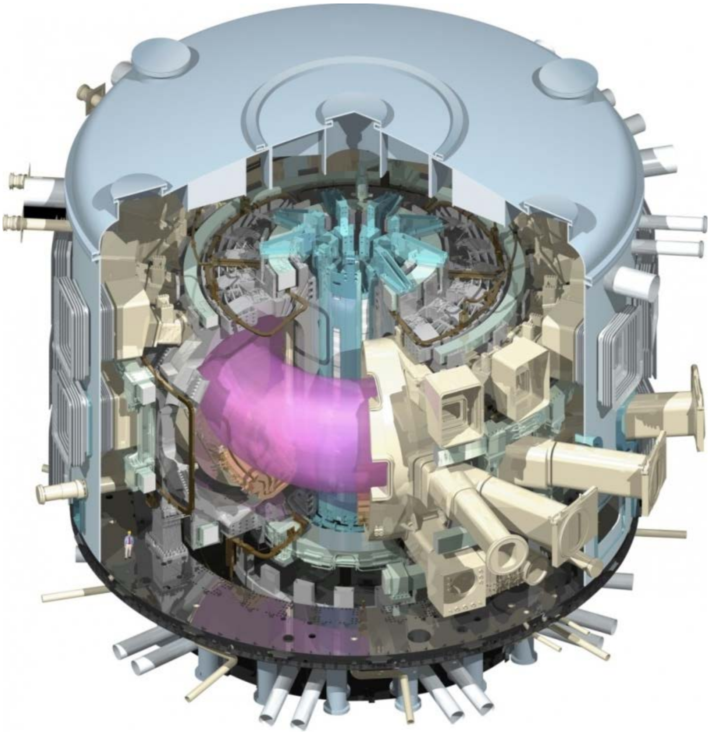

Figure A.2. A design model for the experimental fusion reactor ITER, which is under construction in Europe (Cadarache, France) as world wide collaboration.

A.3 The European Fusion Programme

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

Euratom Fusion Associations are the backbone of the European Fusion Programme. There are 27 Associations from the EU countries and Switzerland. The multilateral European Fusion Development Agreement (EFDA) between all Associations and Euratom takes care of overall physics co-ordination in Europe, facilitates the joint exploitation of the JET facilities and 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 2007 and came fully operational in 2008. The main task of “Fusion for Energy” is to provide European in-kind contributions for ITER including component and system procurements, services and technology R&D for ITER. In addition, “Fusion for Energy” manages DEMO design activities and the European Broader Approach activities in collaboration with Japan.

A.4 ITER International Fusion Energy Organisation

To advance significantly beyond the present generation of fusion devices, a next step device, enabling the investigation of burning plasma in near-reactor conditions, is needed. This will be done in the global ITER project (“iter” is “way” in Latin), which is the joint project of EU, Japan, Russian Federation, United States, China, India and South Korea. The ITER parties agreed in 2005 to site ITER in Europe (Cadarache, France) and the ITER International agreement was signed by the parties in Elysée Palace hosted by the President of France Jacques Chirac, Paris, on 21 November 2006. ITER started as an international legal entity from 27 November 2007. The director general of ITER is Osamu Motojima and head of the ITER project is Remmelt Haange. At the end of 2011 the project staff was about 500 persons. The total number of personnel will be close to 600.

Figure A.3. Construction is now finished on the first building atop the ITER platform: the Poloidal Field Coils Winding Facility. Photo: F4E January 2012.

Appendix B: Institutes and Companies

B.1 Research Institutes and Companies

Tekes – The Finnish Funding Agency for Technology and Innovation
Kyllikinportti 2, Länsi-Pasila
P.O. Box 69, FI-00101 Helsinki, Finland
tel. +358 10 191 480; fax: +358 9694 9196
www.tekes.fi

Juha Linden	juha.linden@tekes.fi
Kari Koskela	kari.koskela@tekes.fi
Hannu Juuso	hannu.juuso@tekes.fi

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

Units of VTT Technical Research Centre of Finland:

VTT Materials for Power Engineering
Otakaari 3A, Espoo and Kemistintie 3, Espoo
P.O. Box 1000, FI-02044 VTT, Finland
tel. +358 20 722 111; fax: +358 20 722 6390
www.vtt.fi

Tuomas Tala	tuomas.tala@vtt.fi
Jukka Heikkinen	jukka.heikkinen@vtt.fi
Jari Likonen	jari.likonen@vtt.fi
Seppo Tähtinen	seppo.tahtinen@vtt.fi

VTT Production Systems
Tuotantokatu 2
P.O.Box 17021, FI-53851 Lappeenranta, Finland
tel. +358 20 722 111; fax: +358 20 722 2893

Veli Kujanpää	veli.kujanpaa@vtt.fi

VTT System Engineering
Tekniikankatu 1
P.O. Box 1300, FI-33101 Tampere, Finland
tel. +358 20 722 111; fax: +358 20 722 3495

Jorma Järvenpää	jorma.jarvenpaa@vtt.fi
Mikko Siuko	mikko.siuko@vtt.fi

VTT Sensors
Tietotie 3, Espoo
P.O. Box 1000, FI-02044 VTT, Finland
tel. +358 20 722 111; fax: +358 20 722 7012
Jukka Kyynäräinen jukka.kyynarainen@vtt.fi

Aalto University (AU)
School of Science
Department of Applied Physics
P. O. Box 14100, FI-00076 AALTO, Finland
tel. +358 9 4511; fax: +358 9 451 3195
physics.aalto.fi
Rainer Salomaa rainer.salomaa@tkk.fi
Taina Kurki-Suonio taina.kurki-suonio@tkk.fi

Tampere University of Technology (TUT)
Institute of Hydraulics and Automation
Korkeakoulunkatu 2, P.O. Box 589, FI-33101 Tampere, Finland
tel. +358 3115 2111; fax: +358 3115 2240
www.iha.tut.fi
Matti Vilenius matti.vilenius@tut.fi
Jouni Mattila jouni.mattila@tut.fi

Lappeenranta University of Technology (LUT)
Laboratory of Machine Automation
Skinnarilankatu 34, P.O.Box 20, FI-53851 Lappeenranta, Finland
tel. + 358 5 621 11; fax: +358 5 621 2350
www.lut.fi
Heikki Handroos heikki.handroos@lut.fi

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

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

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

B.4 Industrial Companies

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

Company: **Adwatec Oy**
Technology: Water cooling systems for high power electronics (low, medium and high voltage).
Contact: Adwatec Oy, Artturintie 14H, FI-36220 Tampere, Finland
Tel. +358 3 389 0860; fax. +358 3 389 0861
www.adwatec.com
Arto Verronen, arto.verronen@adwatec.com

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

Company: **CLS-Engineering Oy**
Technology: Preliminary engineering, implementation, engineering, field and electrification engineering, manufacturing of automation cabinets and switchgear, programming, installation, testing, and maintenance services.
Contact: CLS-Engineering Oy, Hakunintie 21, FI-26100 Rauma, Finland
Tel. +358 201 549 400; fax. +358 201 549 401
www.cls-engineering.fi
Tom Holmström, tom.holmstrom@cls-engineering.fi

Company: **Comatec Group (Engineering bureau Comatec Ltd)**
Technology: Engineering design for machinery and industrial equipment. Mobile machinery, production equipment, transportation equipment as well as pressure equipment and boiler plant engineering. Our offering comprises of concept services, project design and management services, design services and expert services.
Contact: Comatec Group, Kalevantie 7C, FI-33100 Tampere, Finland
Tel. +358 29 000 2000
www.comatec.fi
Miikka Riittinen, miikka.riittinen@comatec.fi

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

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

Company: **DIARC-Technology Oy**
Technology: Carbon and refractory metal coatings for plasma facing components. Deuterium doped coatings for hydrogen migration and erosion studies in thermonuclear fusion machines. Plasmacleaning techniques for first wall components.
Contact: DIARC-Technology, Kattilalaaksontie 1, FI-02330 Espoo, Finland
Tel. +358 10 271 2030; fax +358 10 271 2049
www.diarc.fi
Jukka Kolehmainen, jukka.kolehmainen@diarc.fi

Company: **Elektrobit Microwave Oy**
Technology: Product development, test solutions and manufacturing for microwave and RF- technologies, high-tech solutions ranging from space equipment to commercial telecommunication systems.
Contact: Teollisuustie 9A, FI-02700 Kauniainen, Finland
Tel. +358 40 344 2000, Fax +358 9 5055 547
www.elektrobit.com
Marko.Koski, marko.koski@elektrobit.com

Company: **Elomatic Oy**
Technology: Design and other services for manufactures of machinery and equipment. We are involved in our customer's R&D – projects, in product design and in production development.
Contact: Elomatic Oy, Kangasvuorentie 10, FI-40320 Jyväskylä, Finland
Tel. +358 14 446 7111; Fax +358 14 446 7123
www.elomatic.com
Timo Martikainen, timo.martikainen@elomatic.com

Company: **Etteplan Oyj**
Technology: Etteplan is a specialist in industrial equipment engineering and technical product information solutions and services. Our customers are global leaders in their fields and operate in areas like the automotive, aerospace and defence industries as well as the electricity generation and power transmission sectors, and material flow management.
Contact: Terveystie 18, FI-15860 Hollola, Finland
Tel: +358 10 307 1010

Company: **Fortum Power & Heat Oy**
Technology: Nuclear Engineering.
Contact: Power Solutions, Piispanportti 10, Espoo, FI-00048 Fortum, Finland
Tel. + 358 10 4511; fax. +358 10 453 2770
www.fortum.com
Herkko Plit, herkko.plit@fortum.com

Company: **Hollming Works Oy**
Technology: Mechanical engineering, fabrication of heavy steel and stainless steel structures, design for manufacturing.
Contact: Puunaulakatu 3, P.O.Box 96, FI-28101 Pori, Finland
Tel. +358 20 486 5040; fax +358 20 486 5041
www.hollmingworks.com
Mika Korhonen, mika.korhonen@hollmingworks.com

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

Company: **Instrumentti-Mattila Oy**
Technology: Designs and manufacturing of vacuum technology devices.
Contact: Valpperintie 263, FI-21270 Nousiainen, Finland
Tel +358-2-4353611, Fax +358-2-431 8744
www.instrumentti-mattila.fi
Veikko Mattila, veikko.mattila@instrumentti-mattila.fi

Company: **Japrotek Oy Ab**
Technology: Design and manufacturing of stainless steel and titanium process equipment such as columns, reactors and heat exchangers.
Contact: Japrotek Oy Ab, P.O.Box 12, FI-68601, Pietarsaari, Finland
Tel +358-20 1880 511, Fax +358-20 1880 415
www.vaahto.fi
Ulf Sarelin ulf.sarelin@vaahto.fi

Company: **Jutron Oy**
Technology: Versatile electronics manufacturing services.
Contact: Jutron Oy, Konekuja 2, FI-90630 Oulu , Finland
Tel +358-8-555 1100 , Fax +358-8-555 1110
www.jutron.fi
Keijo Meriläinen, keijo.merilainen@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, FI-38701 Kankaanpää, Finland
Tel. +358 20 486 5034; fax +358 20 486 5035
www.hollmingworks.com
Jarmo Huttunen, jarmo.huttunen@hollmingworks.com

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

Company: **Luvata Pori Oy**
Technology: Superconducting strands and copper products.
Contact: Luvata Pori Oy, Kuparitie, P.O Box 60, FI-28101 Pori, Finland
Tel. +358 2 626 6111; fax +358 2 626 5314
Ben Karlemo, ben.karlemo@luvata.com

Company: **Mansner Oy Precision Mechanics**
Technology: Precision mechanics: milling, turning, welding, and assembling. From stainless steels to copper.
Contact: Mansner Oy, Yrittäjäntie 73, FI-03620 Karkkila, Finland
Tel. +358 20 7862 367; fax +358 20 7862 363
www.mansner.com
Sami Mansner, sami.mansner@mansner.fi

Company: **Marimils Oy**
Technology: Evacuation guiding systems and emergency lighting.
Contact: Marimils Oy, Pohjantähdentie 17, FI-01451 Vantaa, Finland
Tel. +358 207 508 615; Fax. +358 207 508 601
www.marimils.com
Juha Huovilainen, juha.huovilainen@marimils.fi

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

Company: **Metso Oyj**
Metso Engineered Materials and Components
Technology: Steel castings, special stainless steels, powder metallurgy, component technology/ engineering, design, production and installation.
Contact: Metso Engineered Materials and Components, P.O.Box 306,
FI-33101 Tampere, Finland
Tel. +358 20 484 120; fax +358 20 484 121
www.metsomaterialstechnology.com
Jari Liimatainen, jari.liimatainen@metso.com

Company: **Oxford Instruments Analytical**
Technology: Plasma diagnostics, vacuum windows.
Contact: Nihtisillankuja, P.O. Box 85, FI-02631 Espoo, Finland
Tel:+358 9 329411, Fax: +358 9 23941300
www.oxford-instruments.com
Seppo Nenonen , seppo.nenonen@oxinst.fi

Company: **Patria Oyj**
Technology: Defence and space electronics hardware and engineering.
Contact: Patria Oyj, Kaivokatu 10, FI-00100 Helsinki, Finland
Tel +358-2-435 3611, Fax +358-2-431 8744
www.patria.fi
Tapani Nippala, tapani.nippala@patria.fi

Company: **Platom Oy**
Technology: UF$_6$ handling equipment, process modelling and radioactive waste management.
Contact: Platom Oy, Jääkärinkatu 33, FI-50130 Mikkeli, Finland
Tel. +358 44 5504 300; fax +358 15 369 270
www.platom.fi
Miika Puukko, miika.puukko@platom.fi

Company: **Powernet Oy**
Technology: Design and manufacturing of custom design power supplies, AC/DC, DC/DC, DC/AC in power ranges from 100–3200W.
Contact: Powernet Oy, Martinkyläntie 43, FI-01720 Vantaa, Finland
Tel. +358-10-2890-700; fax. +358-10-2890-793
Harry Lilja, harry.lilja@powernet.fi

Company: **PPF Projects Oy**
Service: Tekes Industrial Activation Project, ITER.
Contact. Kaunismäentie 7B, FI-28800 Pori, Finland
Tel. +358 50 40 79 799, +358 2 648 2030
fusion.ppf.fi
Pertti Pale, pertti.pale@ppf.fi

Company: **Prizztech Oy**
Role: Industry activation and support.
Contact: Pohjoisranta 11D, PL 18, FI-28101 Pori, Finland
Tel. +358 44 710 5336
www.prizz.fi
Leena Jylhä, leena.jylha@prizz.fi

Company: **Pöyry Finland Oy**
Technology: Global consulting and engineering expert within the Pöyry Group serving the energy sector. Core areas: nuclear energy, hydropower, oil & gas, renewable energy, power & heat, transmission & distribution.
Contact: P.O.Box 93, Tekniikantie 4 A, FI-02151 Espoo, Finland
Tel. +358 10 3311
www.poyry.com
Miko Olkkonen, miko.olkkonen@poyry.com

Company: **Rados Technology Oy**
Technology: Dosimetry, waste & contamination and environmental monitoring.
Contact: Rados Technology Oy, P.O.Box 506, FI-20101 Turku, Finland
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Company: **Rejlers Oy**
Technology: Services for industry, energy, building & property and infra customers. Core expertise: electricity and automation, mechanical engineering, plant engineering, FE modelling and analysis. Also more comprehensive project deliveries as turn-key basis.
Contact: Rejlers Oy, P.O.Box 194, FI-50101 Mikkeli, Finland
Tel: +358 20 7520 700; Fax. +358 20 7520 701
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Seppo Sorri, seppo.sorri@rejlers.fi

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

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

Company: **Space Systems Finland Ltd.**
Technology: Safety critical systems development; safety assessments and qualification of systems for use in nuclear power plants.
Contact: Space Systems Finland Ltd, Kappelitie 6 B, FI-02200 Espoo, Finland
Tel. +358 9 6132 8600; fax +358 9 6132 8699
www.ssf.fi
Timo Latvala, timo.latvala@ssf.fi

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

Company: **SWECO Industry Oy**
Technology: Consulting and engineering company operating world-wide, providing consulting, engineering and project management services for industrial customers in plant investments, product development and production.
Contact: Valimotie 9, P.O. Box 75, FI-00381 HELSINKI, Finland
Tel. +358 20 752 6000
Kari Harsunen, kari.harsunen@sweco.fi

Company: **Tampereen Keskustekniikka Oy**
Technology: Product development, design, production, marketing, and sales of switchgear and controlgear assemblies.
Contact: Hyllilänkatu 15, P.O.Box 11, FI-33731 Tampere, Finland
Tel. +358-3-233 8331
www.keskustekniikka.fi
Reijo Anttila, reijo.anttila@keskustekniikka.fi

Company: **Tankki Oy**
Technology: Production and engineering of stainless steel tanks and vessels for use in different types of industrial installations.
Contact: Oikotie 2, FI-63700 Ähtäri, Finland
Tel. +358 6 510 1111, Fax +358 6 510 1200
Jukka Lehto, jukka.lehto@tankki.fi

Company: **TVO Nuclear Services Oy**
Technology: Nuclear power technologies; service, maintenance, radiation protection and safety.
Contact: Olkiluoto, FI-27160 Eurajoki,
Tel. + 358 2 83 811; Fax. +358 2 8381 2109
www.tvons.fi
Mikko Leppälä, mikko.leppala@tvo.fi

Company: **TP-Konepajat Oy / Arelmek Oy**
Technology: Heavy welded and machined products, DTP2 structure.
Contact: TP-Konepajat Oy / Arelmek Oy, PL 23, FI-33701 Tampere, Finland
Tel. +358 40 8318001
www.tpyhtio.fi
Jorma Turkki, jorma.turkki@tpyhtio.fi

Company: **Oy Woikoski Ab**
Technology: Production, development, applications and distribution of gases and liquid helium..
Contact: Voikoski, P.O.Box 1, FI-45371 Valkeala, Finland
Tel. +358-15-7700700 Fax. +358-15-7700720
www.woikoski.fi
Kalevi Korjala, kalevi.korjala@woikoski.fi

Company: **ÅF-Consult Oy**
Technology: Design, engineering, consulting and project management services in the field of power generation and district heating. EPCM services.
Contact: FI-02600 Espoo, Finland
Tel +358 40 348 5511, Fax. +358 9 3487 0810
www.afconsult.com
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Title	**Fusion Yearbook** **Association Euratom-Tekes Annual Report 2011**
Author(s)	Markus Airila & Seppo Karttunen (eds.)
Abstract	This Annual Report summarises the fusion research activities of the Finnish and Estonian Research Units of the Association Euratom-Tekes in 2011. The emphasis of EFDA is in exploiting JET and co-ordinating physics research in the Associations. In addition, emerging technology and goal oriented training (GOT) activities are under EFDA. R&D Grants for the Joint Undertaking “Fusion for Energy” on remote handling for ITER divertor maintenance and MEMS magnetometer development constituted a significant fraction of the total research volume. The activities of the Research Unit are divided in the fusion physics under the Contract of Association and EFDA. The physics work is carried out at VTT, Aalto University (AU), University of Helsinki and University of Tartu. The research areas of the EFDA Workprogramme within Association Euratom-Tekes are: • Heat and particle transport and fast particle studies • Plasma-wall interactions and material transport in SOL region • Code development and diagnostics. Association Euratom-Tekes participated in the EFDA JET Workprogramme 2011, including C28 experiments with the ITER-like wall, diagnostics development and code integration. Two persons were seconded to the JET operating team, one physicist (codes & modelling) and one engineer (remote handling) in preparation of the ITER-like wall. The Association participated also in the 2011 experimental programmes of ASDEX Upgrade at IPP, DIII-D at GA and C-Mod at MIT. The technology work is carried out at VTT, AU, Tampere University of Technology (TUT) and Lappeenranta University of Technology (LUT) in close collaboration with Finnish industry. Industrial participation is co-ordinated by Tekes. The technology research and development is focused on • Divertor Test Platform (DTP2) at VTT in Tampere for remote handling of divertor maintenance and development of water hydraulic tools and manipulators • Materials and joining techniques • Vessel/in-vessel components • Magnetic diagnostics by micromechanical magnetometers for ITER • Upgrading of the JET NPA diagnostics • Power Plant Physics and Technology (PPPT) activities • Plasma facing materials issues, erosion/re-deposition and material transport studies and developing coating techniques • In-reactor mechanical testing and characterisation of materials under neutron irradiation. Association Euratom-Tekes is involved in two GOT projects: GOTiT for theory and modelling and GOTRH for remote handling. GOTRH is coordinated by TUT. In July 2013 AU will organize the EPS Plasma Physics Conference in Dipoli, Espoo.
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Nimeke	**Fusion Yearbook** **Association Euratom-Tekes Annual Report 2011**
Tekijä(t)	Markus Airila & Seppo Karttunen (toim.)
Tiivistelmä	Tähän vuosikirjaan on koottu Suomen ja Viron fuusiotutkimusyksiköiden vuoden 2011 tulokset ja saavutukset. Työ on tehty Euratom-Tekes-assosiaation puitteissa. EFDAn painopisteet ovat JET-tokamakin käyttö ja assosiaatioiden fuusiofysiikan tutkimuksen koordinointi. Näiden lisäksi EFDAan kuuluvat uudet teknologiat (emerging technologies) ja uusien asiantuntijoiden koulutus (goal-oriented training, GOT). ”Fusion for Energy” -organisaation myöntämällä tutkimusrahoituksella ITERin diverttorin etähuoltojärjestelmän ja MEMS-magnetometrien kehittämiseen on assosiaation ohjelmassa merkittävä osuus. Tutkimusyksikön toiminta jakautuu assosiaatiosopimuksen alaiseen fuusiofysiikan tutkimukseen sekä EFDA-työhön. Fysiikan tutkimusta tehdään VTT:llä, Aalto-yliopistossa, Helsingin yliopistossa ja Tarton yliopistossa. Assosiaation työohjelman fysiikkatutkimusalueet ovat • Lämmön ja hiukkasten kuljetusilmiöt sekä nopeat hiukkaset • Plasma-seinämä-vuorovaikutukset ja materiaalien kulkeutuminen kuorintakerroksessa • Ohjelmankehitys ja diagnostiikka. Vuoden 2011 työohjelmassa Euratom-Tekes-assosiaatio osallistui EFDA-JETin koekampanjaan C28, jossa otettiin käyttöön uusi ITER-tyyppisellä ensiseinä, diagnostiikan kehitykseen ja simulointiohjelmien integrointiin. Kaksi tutkijaa toimi JETin käyttöorganisaatiossa; yksi fyysikko (ohjelmistot & mallinnus) ja yksi insinööri (etäkäsittely) ITER-tyyppisen ensiseinän käyttöä valmisteltaessa. Lisäksi assosiaatio osallistui IPP:n ASDEX Upgrade-, GA:n DIII-D- ja MIT:n C-Mod-tokamakin vuoden 2011 koeohjelmiin. Teknologiatyötä tehdään VTT:llä, Aalto-yliopistossa, Tampereen teknillisessä yliopistossa ja Lappeenrannan teknillisessä yliopistossa tiiviissä yhteistyössä suomalaisen teollisuuden kanssa. Yritysten osallistumista koordinoi Tekes. Teknologioiden kehittämisen painopistealueina ovat • Divertor Test Platform -laitteisto DTP2 VTT:llä Tampereella diverttorin etähuollon testaukseen ja koulutukseen; vesihydrauliikkaa käyttävien työkalujen ja manipulaattorien kehitys • Materiaalit ja niiden liitostekniikat • Tyhjiökammioon liittyvät komponentit • MEMS-pohjaisten diagnostiikkojen kehitys ITERin magneettikenttien mittausta varten • JETin NPA-diagnostiikan päivitys • Osallistuminen Power Plant Physics and Technology -tutkimukseen (PPPT) • Ensiseinämän materiaalit, eroosion, deposition ja materiaalien kulkeutumisen tutkimus sekä pinnoitteiden kehittäminen • Materiaalien mekaaninen testaus ja karakterisointi neutronisäteilytyksen alaisena. Euratom-Tekes-assosiaatio mukana kahdessa GOT-hankkeessa: GOTiT (teoria ja mallinnus) ja GOTRH (etäkäsittely), joka alkoi loppuvuonna 2010. GOTRH-hanketta koordinoi TTY. Heinäkuussa 2013 Aalto-yliopisto järjestää EPS:n plasmafysiikan konferenssin Dipolissa Espoossa.
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Association Euratom-Tekes Annual Report 2011

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