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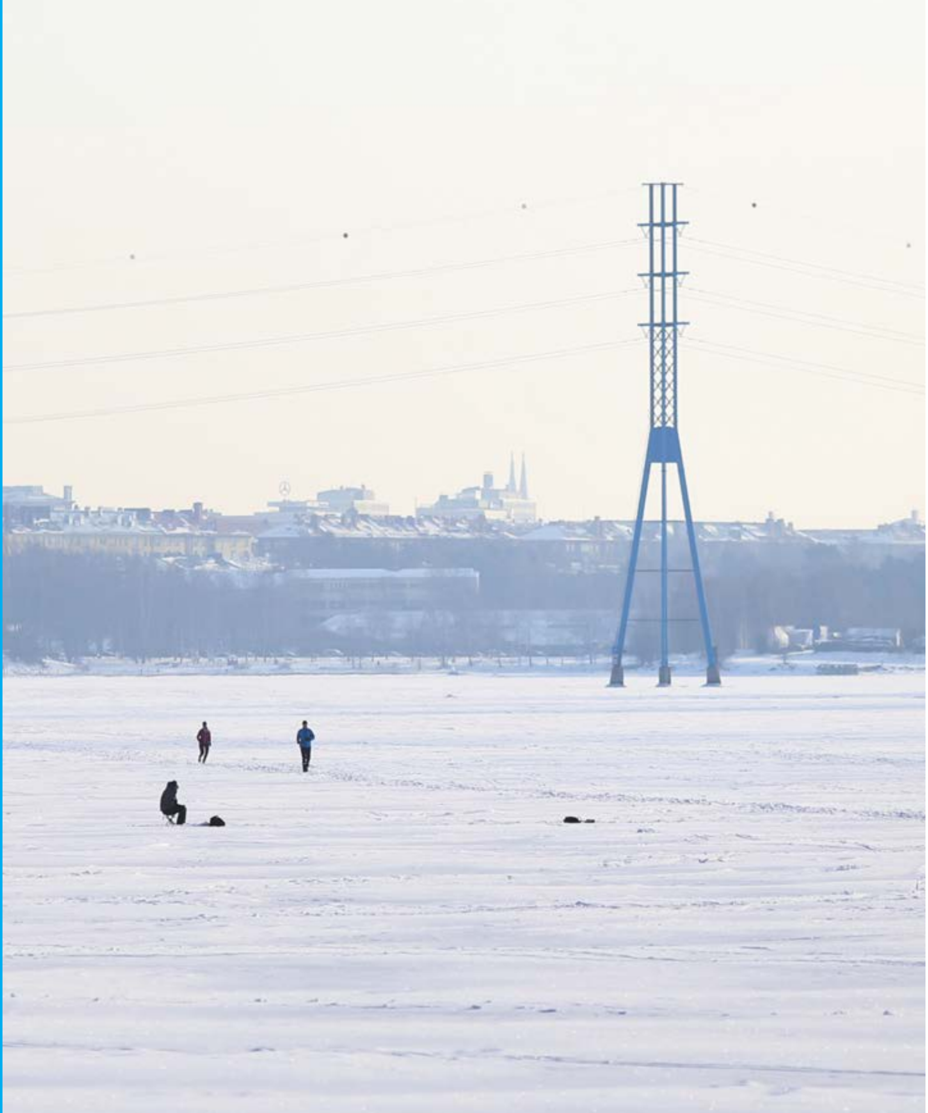

Association Euratom-Tekes

Final summary report 2007–2013

Markus Airila | Tuomas Tala (eds.)

VTT

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Abstract/Tiivistelmä

1. Introduction

1.1 Overview

This report summarizes the scientific and technological highlights of fusion research carried out by the Association Euratom-Tekes in 2007–2013. Detailed reporting is provided in the individual Annual Reports (Appendices A–G). The financial statement has been submitted separately.

The overarching themes of research in the Association were

- Experimental work on JET, ASDEX Upgrade, DIII-D and C-Mod tokamaks, supported by modelling of confinement & transport, fast particles and edge plasma
- Plasma-wall interaction and edge plasma studies with a strong modelling component and supporting code development
- Code integration in the ITM Task Force
- Diagnostic development for JET and ASDEX Upgrade
- Remote handling studies in the DTP2 platform.

Organizationally, the projects were carried out under the following activities of EFDA:

- EFDA JET Workprogrammes
- EFDA JET Fusion Technology Programme
- EFDA JET Enhancements
- Task Force "Integrated Tokamak Modelling"
- Task Force "Plasma-Wall Interaction"
- Topical Groups
- EFDA Technology Programme
- Emerging Technology
- Goal-Oriented Training in Theory
- Goal-Oriented Training in Remote Handling
- EFDA Fellowships
- ITER Physics programme
- Power Plant Physics and Technology programme
- JOC Secondments

- CSU Secondments
- Staff Mobility

At the end of the present report we also review the F4E grants and ITER contracts for information.

Participating institutes were:

- VTT Technical Research Centre of Finland
- Helsinki University of Technology (–2009) / Aalto University (2010–)
- Lappeenranta University of Technology
- Tampere University of Technology
- University of Helsinki
- University of Tartu, Estonia

Figure 1.1. One of the plenary speakers of the 40th EPS Conference on Plasma Physics was Antti Hakola. He reviewed the past 10 years of experiments and modelling on material migration.

1.2 Hosted meetings and conferences

- 2nd German-Finnish workshop on Material Migration in Fusion Devices, 26–27 February 2007, Tervaniemi, Finland.
- 3rd Finnish–German Workshop on Materials Migration in Fusion Devices, Tervaniemi, Finland, 29–30 January 2009.
- 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.

- Integrated Tokamak Modelling 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.
- EFDA TF-PWI Joint Working Session on Integrated Plasma-Wall Modelling, Tervaniemi, Finland, 4–6 February 2013.
- 40th EPS Conference on Plasma Physics, Espoo, 1-5 July 2013. The scientific merits of the Association were notably recognized by the plenary talk of A. Hakola.
- EFDA Steering Committee meeting, Espoo, Finland, 3 July 2013.
- Integrated Tokamak Modelling code camp, Aalto University, Espoo, Finland, 8–19 July 2013.

1.3 Public information activities

The main public information events were

- Inauguration of the DTP2 facility at VTT, Tampere, January 2009
- Fusion Expo, hosted by the Science Centre AHHAA, Tartu, May-July 2013
- 40th EPS Conference on Plasma Physics, Espoo, July 2013.

The Annual Fusion Seminar of the Association was arranged by various institutes (Espoo 2007, M/S Silja Serenade / Stockholm 2008, Pärnu 2009, Tampere 2010, M/S Silja Serenade / Stockholm 2011, Tartu 2012, M/S Silja Serenade / Stockholm 2013). The Annual Report was released in each Annual Seminar. Several general articles and interviews on fusion energy and ITER were published annually. Introductory and advanced university courses on plasma physics and fusion energy were given at Helsinki University of Technology / Aalto University.

1.4 Publications

The Association published 378 refereed journal articles, 407 conference presentations, 116 research reports and 18 general articles. 19 doctoral degrees and 29 master's degrees were completed (see Appendix H).

Figure 1.2. Inauguration of the DTP2 facility at VTT, Tampere, in January 2009.

2. Research highlights

2.1 Confinement and transport

2.1.1 JET, ASDEX Upgrade and DIII-D experiments and analysis

Association Euratom-Tekes carried out several series of transport experiments (intrinsic rotation, momentum transport and particle transport/plasma fuelling) at JET, ASDEX Upgrade and DIII-D during 2007–2013 and had the main responsibility on their analysis. A major long-term undertaking was the development and benchmarking of the gyrokinetic ELMFIRE code that has been presently successfully applied to small tokamaks FT-2 and TEXTOR.

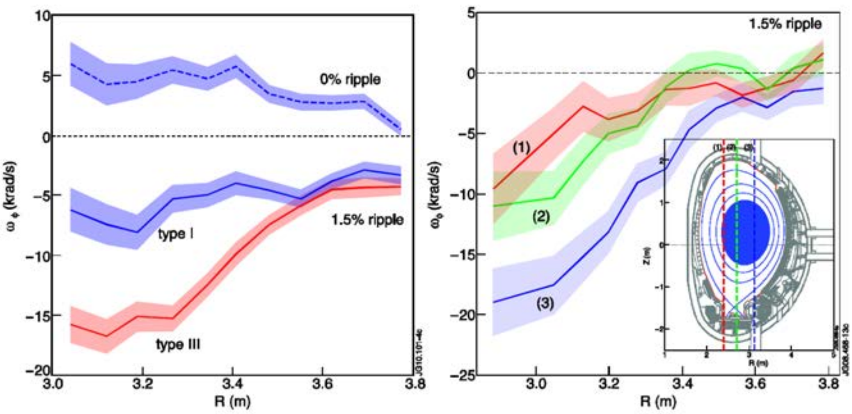


Figure 2.1. (Left frame) Toroidal angular rotation profiles for ICRF heated H-mode plasmas with I_p = 1.5 MA, B_T = 2.2 T, P_{ICRH} = 3 MW for the two ripple levels. Top pulse (dashed blue curve) #74688 with δ = 0.08% and P_{ICRF} = 3.1 MW; bottom pulse (blue and red solid curves) #74686 with δ = 1.5% and P_{ICRF} = 2.9 MW, including both the type I and type III ELM phase. (Right frame) Toroidal angular rotation profiles for L-mode pulses with δ = 1.5%, I_p = 1.5 MA, P_{ICRH} = 2 MW, for three different resonance positions: (1) #77010 with R_{res} = 2.38 m, (2) #77014 with R_{res} = 2.71 m, (3) #77009 with R_{res} = 3.13 m. The resonance positions with respect to the magnetic axis R_0 = 2.95 m are shown in the inset.

Association Euratom-Tekes participated very actively in the JET ripple campaign in 2007–2008. Toroidal magnetic ripple affects significantly the intrinsic plasma rotation on JET. With large ripple, intrinsic rotation becomes counter-current directed over the whole plasma radius. The torque calculation in ASCOT code 8developed by the Association Euratom-Tekes) induced by the fast ion losses due to enhanced ripple has been successfully benchmarked against experimental data from JET. This effect is illustrated in Figure 2.1.

In 2009, DIII-D performed a TBM mock-up experiment where 2–4 best experts from all ITER parties were invited to participate. 2 of the 4 European members were from Tekes. The DIII-D TBM mock-up experiment to simulate ITER Test Blanket Modules (TBM) showed that the plasma rotation is reduced up to 60% with the TBM amplitude 3 times higher than on ITER. The TBM effect on plasma confinement was 10–15% smaller. In 2011, the DIII-D mock-up Test Blanket Module (TBM) experiments with modulated TBM perturbation amplitude were analysed, both with ASCOT code and with JETTO transport code. The observed propagation of the induced rotation perturbation was found to originate from an edge localised counter-current torque source. The magnitude of the torque was estimated to −2.5 Nm for a perturbation that is about 3 times larger than those expected in ITER. Further TBM experiments were performed in 2013 with Tekes scientists leading the experiment on DIII-D. Based on the future analysis of those results, the extrapolation to ITER will be carried out.

In 2006–2007 JET experiments, the NBI modulation technique was pioneered in JET as a tool to study momentum transport. The first major result was to find that there is a significant inward momentum pinch in all NBI heated JET plasmas. And this will have an influence on the prediction of the plasma rotation in ITER. In 2011 within the framework of ITPA work, momentum pinch number was found to have a strong dependence on the inverse density gradient length while the Prandtl number does not have 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, performed in the lead by the Tekes scientists, showed 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 torque sources has to be known.

In 2012–2013, intrinsic torque sources were analysed and experiments were carried out on AUG and JET by introducing a novel method, dedicated 2Hz NBI modulation technique. Dedicated intrinsic torque experiments using a novel 2Hz NBI modulation technique have been performed for the first time in AUG. The analysis method to extract the intrinsic torque from plasma with any arbitrary NBI power has been optimised for the 2Hz NBI modulation technique. A 4-point plasma current scan with q95 ranging from 4 up to 11 was performed. The integrated intrinsic torque increases from 1.5Nm at Ip=0.4MA to 4Nm at Ip=1.0MA. The intrinsic torque profile is quite broad, most of it originating at $\rho>0.5$. The effect of ECRH was studied in two 600 kA H-mode plasmas by injecting ECRH in the latter half of the NBI heated discharge. All the evidence indicates that the experimental data is best reproduced with a combination of off-axis counter-current torque (and possibly a small co-intrinsic torque in the centre at $\rho<0.2$) together with outward convection around the radius where the ECRH power is deposited. The present intrinsic torque profiles have quite large error bars and the profiles will change a bit when taking into account the small time variation in the confinement time due to modulation. Furthermore on this topic, data from selected non-NBI JET discharges have been processed to a state where they can be entered in a European intrinsic rotation database.

JET experiments utilising gas puff modulation technique were executed in 2009 in L-mode and in 2012 to study both the particle transport and the neutral fuelling of the plasma. Particle transport coefficients were extracted from the L-mode plasmas and found to be independent of collisionality. In a single dedicated H-mode discharge in 2011 in C29 campaign the proof-of-principle density modulation in H-mode was observed giving impetus for further studies to be conducted in C31. In 2013, a number of H-mode discharges with D gas puff modulation were executed at JET to study particle sources and transport in the plasma edge region. Clear perturbation in electron density was seen throughout the radius, the effect being the strongest when using the outer midplane inlet possibly due to the narrow SOL. 3-point dimensionless collisionality scan executed very well both L-mode and H-mode. It was possible to keep line integrated density roughly constant when varying I_p from 1.7MA to 2.5MA even with metal-wall-machine. Data will allow some statements on fuelling in ELM non ELM phase, important to address ITER fuelling.

NBI-generated torque and plasma rotation were simulated for AUG, DIII-D and ITER with ASCOT. The toroidal torque on the plasma has two parts: a collisional transfer of toroidal momentum from the beam particles to the plasma, and the **j x B** torque resulting from the finite orbit widths and the radial excursion of the beam ions. In AUG this was analysed for each beam separately, and it was found that the **j x B** torque, particularly that due to the radial current generated by the finite orbit widths of the beam particles, gives a significant contribution to the torque profile. In DIII-D, the torque was calculated in the presence and absence of the mock TBM module. Here the effect of **j x B** was not as dramatic In ITER, the torque was evaluated for both the off- and on-axis beams. The torque values were very similar for both beam dropping to a small negative value inside $\rho = 0.6$ and to a large negative value for $\rho > 0.95$.

In order to study the impact of plasma rotation and rotational shear on ITBs between JET and JT-60U, a series of discharges with identical plasma profiles (so-called JET – JT-60U identity experiment), but with different plasma rotation were performed by balancing the NBI torque on JT-60U and varying toroidal field ripple on JET. A large variation in Mach numbers was obtained. The Mach number may, however, not be the relevant parameter. Similar values of rotational shear are found in JT-60U and JET. ITBs are always triggered, independently of the rotational shear. Moreover, weak ITBs can always be found in plasmas with reversed magnetic shear. This suggests that overall rotational shear, is not the dominant factor in the triggering of these transport barriers. But strong ITBs only develop in JT-60U and JET plasmas that have sufficient rotational shear in the vicinity of the ITB location. This result indicates that although ITBs may be triggred in ITER, it may be challenging to sustain strong ITBs in ITER where the toroidal rotation gradient may be significantly smaller than that in JET and JT-60U. Also, significant differences were found in the behaviour of the q-profile. Therefore, the influence of plasma geometry on the bootstrap current and further on q-profile evolution was studied using JETTO simulations. The inverse aspect ratio had the largest effect on the bootstrap current: a threefold increase when changing the aspect ratio from 0.2 to 0.4.

2.1.2 Turbulence simulations

The work related to L-H transition included both code development work and simulations with gyrokinetic code ELMFIRE. The main code development effort was to include new scrape-off-layer (SOL) model to ELMFIRE to study edge-core coupling which according to experiments plays an important role in obtaining L-H transition. In simulations including the SOL, some indication of pedestal formation was observed. The main effect seen in the simulation was strong modification of the radial electric field profile within one orbit width from last closed flux surface, simultaneous reduction of heat diffusion coefficient (when compared to runs without the SOL) and formation of edge pedestal in temperature profile. No such pedestal appears in the simulation without the SOL, when other parameters were kept constant. Thus, key ingredient is assumed to be the newly developed scrape-off-layer but more work is needed both to assure the present findings and to test the parametric dependence of the observed phenomenon.

In 2011, 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.

In 2012, multi-scale investigations of drift-wave turbulence and plasma flows were conducted with successful comparisons of measurements and full-f gyrokinetic simulations in FT-2 tokamak for DR spectra, mean equilibrium ExB flows, GAM amplitude and frequency, and transport diffusion coefficients. Investigation of properties of geodesic acoustic modes in TEXTOR using ELMFIRE has continued. Radial eigenmode of GAMs in rough agreement with analytic theory was found and this was observed to create relatively high local rotation shear values. In 2013, a series of ELMFIRE simulations of plasma turbulence for TEXTOR were carried to study parametric dependencies of Geodesic Acoustic Modes. Correlation analysis shows that the radial propagation speed is mainly affected by temperature.

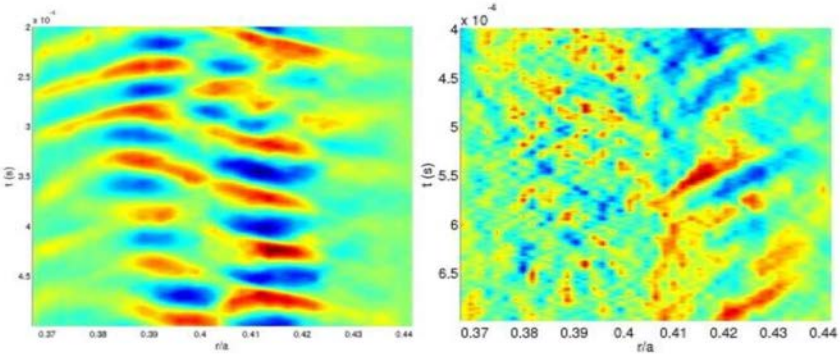


Figure 2.2. (Left) Clear Geodesic Acoustic Mode oscillations in L-mode case are seen in ELMFIRE simulations; (Right) In H-mode case the temporal behavior of E_r is obscure.

2.2 Energetic particle physics

Investigations of fast ions in the Association rely on the in-house developed orbit-following code ASCOT that underwent a major upgrade to version 4 in 2012 and has been applied e.g. to fusion-born alpha particles, fast NBI ions and recently also to impurities (ASCOT-PWI).

ASCOT has a synthetic NPA-diagnostic that allows predicting the NPA signal from a real experiment. A feasibility study was carried out, suggesting that such a diagnostic would be useful in monitoring the population of neutral beam ions intended for driving off-axis current.

In 2010, a scaled mock-up of an ITER TBM module was built and operated on DIII-D. In the experiments, a significant temperature rise was measured on the wall tiles in front of the TBM module when the TBM error field was turned on. The ASCOT code was used to simulate the NBI ion losses due to the TBM module and to determine whether the observed temperature rise could be explained. The TBM mock-up module was found to create a strong local ripple allowing fast ions escape to create a hot spot on the tiles in front of the TBM. However, including limiter structures were found to significantly decrease the fast ion load to the TBM tiles. These results strongly encourage the use of limiters in ITER.

A set of ASCOT simulations was carried out to assess the effect of the newly installed in-vessel coils to the confinement of NBI-generated fast ions in AUG. The coils were found to have little effect on the confinement of perpendicular beams, but to increase the wall load due to parallel beams by a factor of 2–3. However, since the absolute contribution from the parallel beams is insignificant compare to perpendicular beams, this causes no alarm as far as the integrity of the wall components is concerned.

In 2011 ASCOT was 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.

In 2012 the full orbit following capability of ASCOT was utilized to study the effect of TBMs on fast ion confinement. A good agreement with the results of the OFMC and SPIRAL codes as well as with recent DIII-D experimental results was found. ASCOT was also used to assess the effect of changes in neutral beams and plasma impurities on neutral beam ion losses in JET-ILW. Losses from the upgraded neutral beams were found to be slightly reduced, and the plasma heating profiles were found to decrease slightly at plasma mid-radius and shift towards the axis and the edge. The effect of tungsten impurity on beam power deposition was found to be very small when the impurity density was assumed constant on flux surfaces.

In 2013 ASCOT was applied to study the effects of NTMs on energetic ion confinement in the 15 MA H-mode scenario of ITER. An amplitude scan over the NTM magnitude revealed that the fusion alpha particle heat load to the wall structures would stay safely within the design limits. Alfvén eigenmodes in the 9 MA hybrid scenario were, however, observed to cause significant redistribution. ASCOT has also been used in modelling the fusion product activation probe experiment in AUG. The probe orientation was found to be less than optimal, as most of the fusion products were filtered by the graphite cap of the probe.

2.3 Plasma-wall interactions

2.3.1 Overview

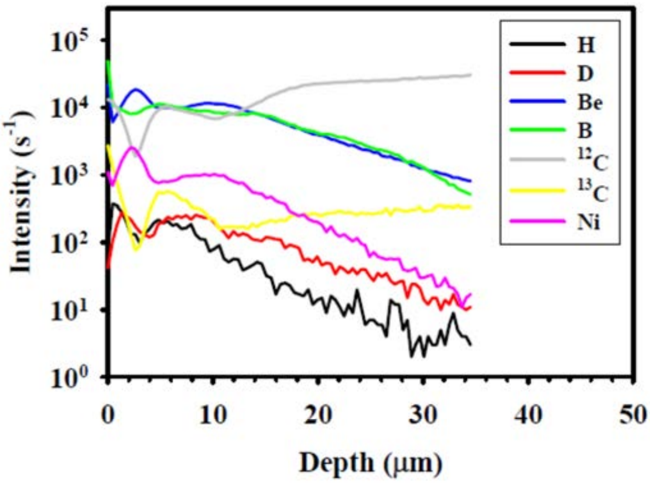
The Association has long-term traditions in plasma-wall interaction research, in particular surface analyses of plasma-exposed samples, and from 2004 onwards a new strategy has been implemented that enhances strongly also the modelling activity in this area. During 2007–2013 the activity has significantly expanded and covers presently

- a major role in coordinating and executing edge/PWI related experiments in JET and ASDEX Upgrade
- surface analyses and cleaning techniques of plasma-exposed samples

- integrated high-performance computing encompassing the edge plasma, impurity transport and atomistic plasma-surface interactions as well as code development.

2.3.2 Erosion, material migration and deposition in JET

Erosion, material migration and deposition in the JET torus were investigated in several extensive analysis campaigns of CFC and ILW first-wall tiles removed during shutdowns. A general finding is that the inner divertor tiles show a net deposition pattern whereas the outer divertor is an erosion region.



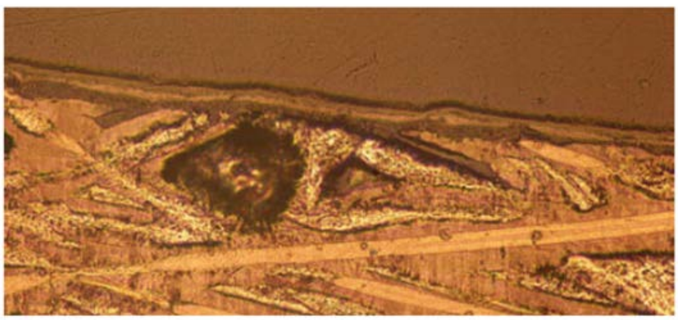


Figure 2.3. SIMS depth profile (top) and optical microscope picture (bottom) from bottom of inner divertor tile 1 removed in the 2007 shutdown of JET.

In 2010–12, surface analyses with SIMS and optical microscopy were carried out for last carbon tiles from JET campaign C27. The results confirm clear erosion on the outer divertor and deposition on the inner divertor. Heavy deposition was found in the shadowed areas of the floor tiles. Complex, yet regular erosion/deposition patterns were observed on inner wall guard limiters, outer poloidal limiters and the upper dump plate ICRH antenna. It was estimated that the deuterium retention by all divertor tiles during 2007–09 is about 2%, which is the same as the D retention observed during 2001–2004. In addition, global ^{13}C migration was investigated. $^{13}CH_4$ methane was puffed at the end of 2009 campaign and the ^{13}C deposition pattern on the divertor tiles was determined and the results were simulated with DIVIMP and ERO codes. The highest ^{13}C amounts were found near the puffing location. Also erosion and transport of tungsten was modelled for JET type-I ELMy H-mode plasmas using EDGE2D-EIRENE and DIVIMP. A significant part of the work in 2013 was devoted to the first *post mortem* analysis of the JET ILW divertor tiles. Migration of material towards the inner divertor had decreased and the fuel retention reduced by a factor of 10 compared to the carbon-wall era of JET. The thickest layers (up to 15 µm) were observed on the apron region of Tile 1, mainly containing Be and hardly any C or D. Finally, migration of ^{13}C impurities, originating from the outer divertor, was modelled using EDGE2D-EIRENE, ERO, and DIVIMP. Transport via the main chamber to the inner divertor played an important role and re-erosion further modified the primary deposition patterns.

Studies to compare two different tritium retention measurements were performed for JET divertor tiles. Both full combustion (FC) and accelerator mass spectrometry (AMS) proved to measure tritium efficiently and accurately in the plasma facing materials. Due to their inherent differences the two methods are, however, most useful in combination, especially when high and low tritium activities have to be measured.

Euratom-Tekes played the main role in the coordination and execution of experiments of JET C29–30, and in providing edge modelling expertise. Experiments included divertor detachment and impurity seeding in L-mode as well as the campaign C30c aiming at steady-state wall conditions before the removal of long-term samples. EDGE2D-EIRENE was used to assess the impact of the wall materials on the scrape-off layer and divertor performance, showing a 30–50% reduction in radiated power and a corresponding increase in conducted power to the target plates, consistent with experiments in 2009 and 2011. EDGE2D/EIRENE H-mode simulations show that ELMs lead to transient sheath-limited phases in the SOL, enhancing W sputtering and penetration into the core. SOLPS simulations of JET L-mode plasmas show that drifts are the primary cause for in-out asymmetries in divertor temperature, density and impurity radiation. Finally, simulations of ^{10}Be migration with ASCOT revealed a possible Be impurity transport path from the limiter to the core and the scrape-off layer in a sequence of an inner-wall limited and an Ohmic diverted plasma scenario.

2.3.3 Erosion, material migration and deposition in ASDEX Upgrade

In 2010 erosion of tungsten and nickel were studied in AUG with the help of marker tiles, produced by Diarc-Technology Inc. For nickel the amount of erosion was larger by a factor of 5–10, indicating that steel might not be a suitable plasma-facing material in ITER, especially not in the divertor region most heavily affected by plasma.

First wall erosion studies in ASDEX Upgrade continued in 2012. Campaign-integrated erosion profiles of dedicated markers of varying roughness were determined and they showed that rough coatings were eroded 4–8 times slower than smooth layers. Also, ERO simulations of erosion probe data exposed to AUG L-mode plasmas reproduced the measured erosion of W, C, and Ni markers. In H-mode a satisfactory agreement was achieved for W only.

The first-wall studies in AUG were continued in 2013 by determining campaign-integrated erosion/deposition profiles at the top and inner wall structures of the vessel. Both regions were net deposition zones for W. At the outer midplane, the exposure of a marker probe to low-power H-mode plasmas indicated strong net erosion even for W. Modelling work focused on injected ^{13}C and ^{15}N impurities from the outer midplane. Complementary use of SOLPS, ERO, and ASCOT indicated asymmetric deposition in wall structures close to the source, in accordance with experimental results. The deposition patterns were strongly affected by plasma flows, magnetic configuration, and SOL density. The SOL flows were further investigated by synthetically reproducing the measured spectroscopic signals of injected impurities at the high-field side of the vessel using ERO.

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.

2.3.4 Modelling of divertor and scrape-off layer physics

Validation of fluid codes EDGE2D-EIRENE and SOLPS was carried out by simulating the scrape-off layer plasma conditions in well-diagnosed JET and AUG discharges, and comparing experimental and predicted profiles. The SOL plasmas produced by these codes are instrumental, since they provide the necessary basis for detailed trace-impurity simulations with DIVIMP, ERO, and ASCOT.

- For JET, EDGE2D-Eirene simulations reproduce the total power to the high field side target obtained in an upstream density scan reasonably well, but underestimate the total radiated power by a factor-of-two when using the

Roth-2003 chemical sputtering yields for carbon. While in the simulations the plasma temperature falls below 2 eV at the highest upstream densities, the particle currents to both low field side and high field side do not drop to zero as observed in experiments.

- For AUG, magnetic field reversal was observed to considerably change the redeposition of ^{13}C injected into the outer divertor scrape-off layer. SOLPS5.0-ERO simulations show that the differences can be attributed to the combination of the **E x B** drift reversal directly influencing the transport of carbon and changes in local plasma conditions due to the drift reversal.

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. In 2013, fluid code simulations explained (i) the reduced ion current around the outer strike point during transition from high-recycling to partially detached divertor within 50%, and (ii) experimentally observed radiation peak around the outer X-point in N_2- and Ne-seeded H-mode plasmas.

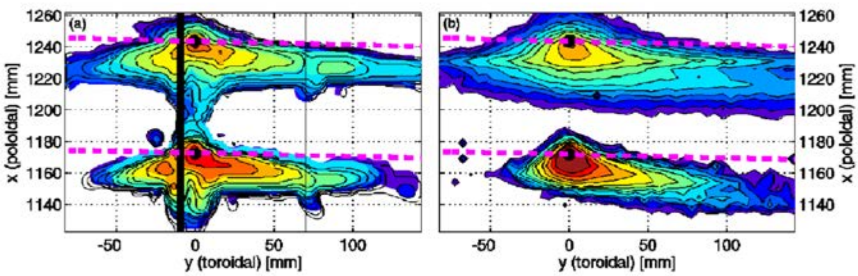


Figure 2.4. Local ^{13}C deposition patterns measured with nuclear reaction analysis (a) and simulated with the ERO code, using background plasma parameters from SOLPS simulations (b). Magnetic field lines are drawn with the dashed magenta lines. The vertical black lines in (a) represent the tile gaps. Data from the local tracer injection experiment of ASDEX Upgrade in 2007.

2.3.5 Arc-discharge and plasma sputtering methods for PFC cleaning

Cleaning of deposited layers from plasma facing surfaces is a key safety issue in ITER. The feasibility of an arc-discharge based technique in removing deposited layers from the wall structures of ITER was investigated. Arc-discharge and plasma-sputtering methods were developed for this purpose. The arc-discharge technique proved to be fast but the resulting surfaces were relatively rough and showed signs of local melting. In contrast, the plasma sputtering approach resulted in smooth surfaces and excellent cleaning efficiency.

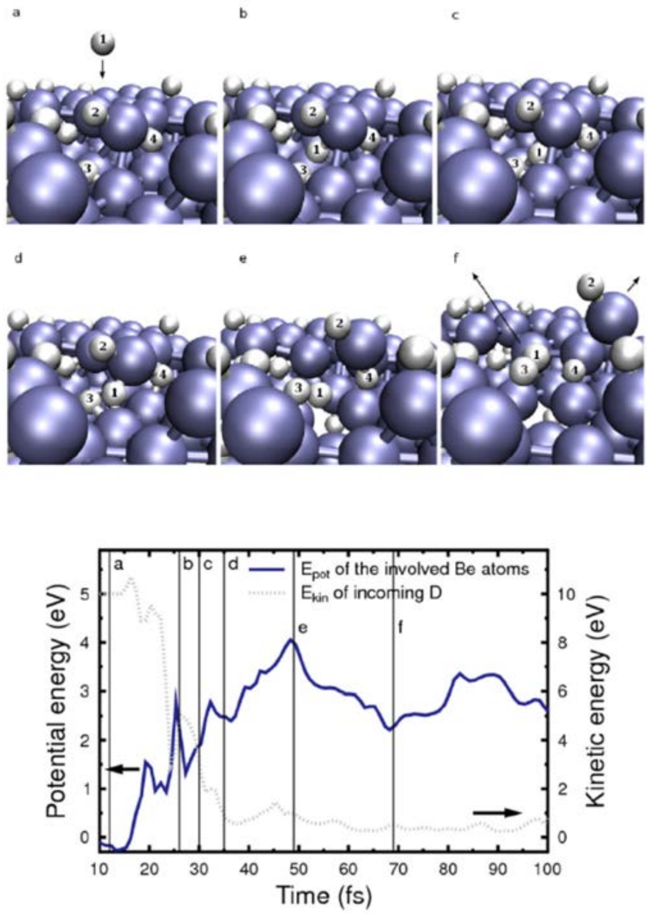


Figure 2.5. An illustration of a sputtering event in Molecular Dynamics. The upper part of the figure shows snapshots of the situation at six different times during the process. The D ions are represented by the small light grey spheres and the Be atoms are the larger dark spheres. The graph in the lower part illustrates the kinetic energy of the incoming D ion (dotted line) and the potential energy of the Be atoms that are initially bonded with the sputtered Be atom (solid line). The initial potential energy of these is chosen as zero level energy. The times corresponding to the snapshots are indicated with vertical lines in the graph and the arrows in the last snapshot (f) show in which direction the sputtered D_2 and BeD molecules are moving.

2.3.6 Modelling of plasma-facing materials

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.

Tungsten fuzz formation mechanisms were investigated in 2012 with MD simulations, reproducing the experimentally found $t^{1/2}$ dependence of the fuzz layer thickness growth. Bubble formation and rupture are the key events in this fuzz formation onset. Formation and properties of mixed Be-W layers were investigated with MD simulations. Be was preferentially sputtered by plasma particles while W was sputtered by Be. The D atoms were retained in or clustered under growing surface layers. Experimentally, fuel retention was studied by exposing Be-W films into PISCES-B plasmas. The roles of porosity of Be-W mixtures as well as vacancies and helium in W were found to be significant for D retention.

2.4 Diagnostics

During 2010, Phase II to upgrade the KF1 diagnostic was launched. The work concentrated on detailed design and procurement of the components necessary for the upgrade. Tekes has provided the detectors bonded to PCBs, the torus hall electronics and 8-channel bias power supply. A new detector flange with thin silicon detectors for JET NPA diagnostics was tested and commissioned in 2011 and the performance was demonstrated during spring 2012 experimental campaign of JET. In 2013, the diagnostics activities focused on the operation of NPAs. The high-energy NPA was not fully utilized in order to limit the formation of fast ion tails in the plasma. In contrast, the low-energy NPA was actively used in RF heating and RF wall conditioning experiments. In addition, plans were made for upgrading the diagnostics during the following shutdown to make it compatible with DT campaign and ensure operational reliability. An impact assessment was also carried out to relocate NPA in Oct 8, adjacent to the NBI injector. The second important research topic was the JET neutron calibration exercise. The neutron measurements were consistent with the previous calibration done in the 1980's.

Irradiation tests of micromechanical magnetometer sensors were carried out. Neutron fluence of 10^{17} n/cm^2 was found to damage the sensor glass cap. Cadmium shielding improved sensor radiation hardness but glass has to be replaced by silicon in the next-generation sensors. First measurements with 30 m long cables indicate that the specified magnetic field resolution can be met. Magnetic diagnostics work continued as a F4E Grant from 2011.

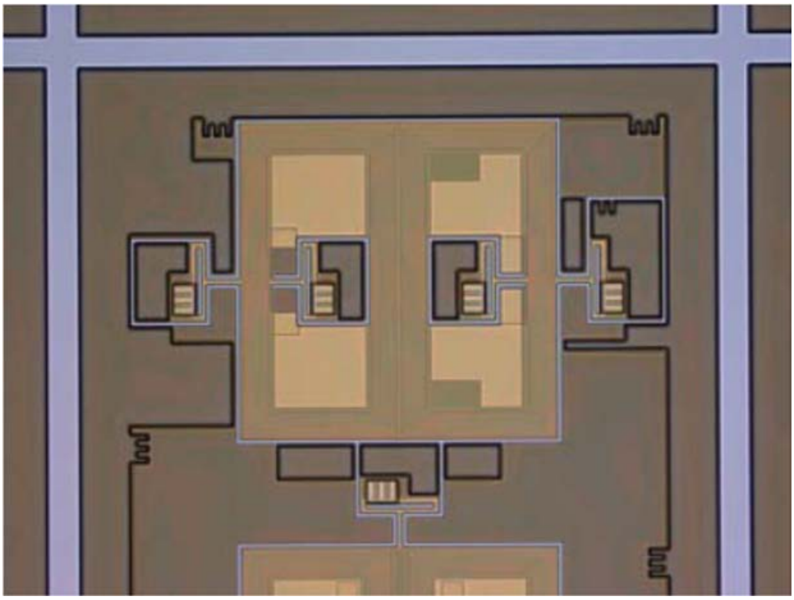


Figure 2.6. Microscope image of a micromechanical magnetometer before vacuum encapsulation (design from 2008).

Laser induced breakdown 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.

Development of LIBS for in-situ characterisation of plasma-wall interactions continued in 2012. ITER-relevant Be-W samples were studied and the quantitative composition of an unknown sample could be determined with better than 5% accuracy, as compared with the standard post mortem analyses.

Association Euratom-Tekes participated in the development of a novel scrape-off layer flow diagnostic for ASDEX upgrade. To measure the high-field side scrape-off layer flow of low charge state carbon, 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. The spectroscopic measurement detects low-charge-state carbon originating from methane injection, and modelling is necessary in the interpretation of partly equilibrated particle velocities.

In 2012, the AUG fast ion measurement campaign was supported by participating in setting up the Fast Ion Loss Diagnostic probe and the activation probe of AUG. To this end, ASCOT was expanded to calculate neutron and other particle fluxes onto the probes and preparatory simulations were completed.

2.5 Theory and modelling for ITER; code development and integration

2.5.1 Development of ASCOT

The domestic Monte Carlo based orbit following code ASCOT has been developed to the point that it is currently probably the most comprehensive fast ion simulation tool in the world: it features 3D magnetic backgrounds and wall structures and now offers not only guiding centre formalism but also full orbit following. In addition, ASCOT is equipped with theory-based models for both turbulent transport of fast ions and slowly rotating islands, such as NTMs. Furthermore, ASCOT has now been refurbished to include atomic physics as well as background plasma rotation/flow, so that it suits studies of impurities in the energy range of 1–100 eV in the open field lines of the scrape-off-layer and halo regions.
ASCOT was extended to a new tool for impurity transport studies. ASCOT allows routine simulations with full 3D features in both magnetic background and wall structures. ASCOT simulations of the ASDEX Upgrade 2007 ^{13}C puffing experiments revealed the importance of including realistic wall structures in particular in determining the deposition patterns. Comprehensive code-code and code-theory comparisons of the basic models used in ASCOT, SOLPS and OEDGE were carried out to identify principal differences in their predictions of SOL properties and material transport. For instance, OEDGE and ASCOT agree in their ^{13}C migration predictions if the temperature gradient force is disabled in OEDGE.

A major effort was the complete rewriting the ASCOT code from scratch, using most modern programming standards, into a new version. ASCOT4 is now used for production runs alongside with the old ASCOT. A method was developed for combining time-dependent MHD modes and realistic 3D magnetic field, at the same time allowing orbit-following up to the first wall in either guiding-center or full-orbit formalism.

2.5.2 Development of ELMFIRE

ELMFIRE is a full-f nonlinear global gyrokinetic transport code for electrostatic simulations for tokamak plasma. In 2010, effort was taken to extend the simulation region to the scrape-off layer. At the same time, the principles of the ambient gyrokinetic equations, energy and momentum conservation laws as solved by ELMFIRE and based on Dirac's constrained Hamiltonian and inverse Kruskal iteration were finalized and published. The incorporation of the SOL into the gyrokinetic edge calculations had numerous beneficial effects; density and heat pile-up at the separatrix observed with the earlier ELMFIRE version due to profile relaxation by turbulent transport was prevented and fluent particle and heat exchange between the edge and SOL was produced. This provided a remarkable result (not found with the earlier version without the SOL) of pedestal formation, and by sufficient core heating an onset of strong shearing of the radial electric field with the concomitant reduction of turbulence across the pedestal.

2.5.3 Development of ERO

ERO is a 3D Monte Carlo impurity transport and plasma-wall interaction code originally developed at IPP Garching and FZ Jülich. Association Euratom-Tekes has taken a significant developer role since 2004.

We developed more flexible handling of complex wall geometries and a set of synthetic spectroscopic diagnostics. Moreover, the surface model of ERO was upgraded to deal with the ITER-relevant Be/W/C issues. ITER-relevant material mixing was investigated by generating sputtering and reflection data with MD for several Be/W/C compounds and implementing the data into ERO. In first simulations for ITER and JET the effect of new data on plasma-wall interactions remains modest.

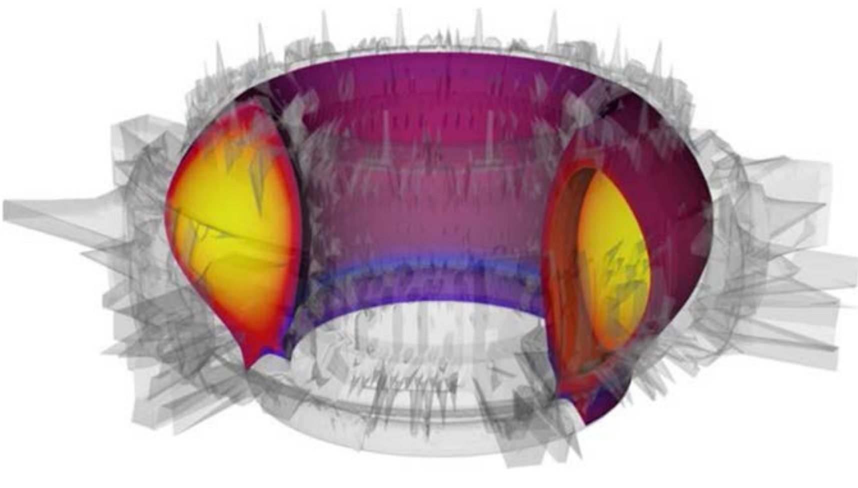


Figure 2.7. The AUG wall, coupled to a SOLPS plasma solution via CPOs.

2.5.4 Code integration in ITM Task Force and SimITER consortium

Work towards a highly standardized and sophisticated computing environment was carried out within EFDA Task Force ITM. The Association's participation in these activities in covers implementation, integration, verification and validation of ASCOT, Elmfire, SOLPS5.0, ERO, BBNBI 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. The most important recent milestone was the successful parallel runs of both ASCOT4 and an earlier version ASCOT3.5 in the Kepler environment. In addition to ASCOT, the integration of BBNBI and ERO codes was carried out by adapting them to use Consistent Physical Objects (CPOs) in their input and output operations, allowing the inclusion of these codes as modules in a Kepler simulation workflow. The development work included upgrades along with the development of the ITM datastructure.

The four-year Academy of Finland SimITER project was running in 2010–2013 as a consortium formed by Aalto University, University of Helsinki, Åbo Akademi University, VTT and CSC. Significant progress was achieved in improving the computational efficiency of ASCOT, ERO and PARCAS by implementing modern optimization and programming practices (e.g. GPGPU) and novel multi-scale modelling methods. On the physics side, methodology was developed for accurate 3D magnetic field and first wall modelling. Recent theory work include a proper diffusion operator for anomalous transport, rotating MHD modes in real tokamak geometry, NBCD model for ITER and a guiding-center-consistent Coulomb collision operator. MD simulations, for their part, explained the mechanisms behind molecular sputtering of beryllium and tungsten fuzz formation, and produced new Be/W/C data for the ERO code to account for material mixing and potential chemical effects. Gyrokinetic modelling with Elmfire was extended towards the first wall by implementing toroidal limiters.

2.5.5 Fast particles under 3D magnetic fields and MHD instabilities

ITER plasmas cannot be expected to be MHD quiescent. In particular, ITER is expected to be prone to neoclassical tearing modes (NTM) that exhibit slowly rotating island structures. We simulated the thermonuclear alphas in ITER Scenario-2 for four different cases: pure neoclassical transport, with only a (2,1) island added, with only a (3,2) island added, and including both a (2,1) and a (3,2) island. All NTM's were found to increase the peak power load, and the effect is strongest for the (2,1) mode that is closer to the plasma edge. The increase in power load is about a factor of two.

The large Larmor radius of energetic ions can affect both their radial transport in a non-axisymmetric magnetic background and the location where they collide with the vessel wall. With its added full orbit capability, ASCOT was applied to study these effects for thermonuclear alphas in ITER Scenario-4 which is especially vulnerable to ripple losses. In the full-orbit simulations, it was found that ripple-related full orbit transport mechanisms affect the wall load distribution for both the unmitigated ripple case.

Sawtooth control remains an important unresolved issue for the ITER Scenario 2 operation. Such ELMy H-mode plasmas are expected to be unstable to the internal kink mode. In order to study the stabilizing effect of fast particles, populations of fusion-born alpha particles and neutral beam injected (NBI) particles in ITER were simulated with ASCOT. Conclusion was that maintaining the $q = 1$ surface close to the magnetic axis would make sawtooth control easier to achieve.

The neutral beam current drive (NBCD) was simulated for both ITER and AUG. In ITER, both on- and off-axis 1 MeV beams were simulated in Scenario-2. The on-axis beam produced a strong centrally peaked current density profile reaching the value of about 1 MA/m^2 in the centre, while the off-axis beam produced a broad maximum in the region of $0.2 < \rho < 0.4$. The simulations were carried out both with and without the turbulent diffusion. The only observable difference in the distributions was a slight outward shift of the maximum in the driven current, but this change is so small that it is certainly within experimental uncertainty.

2.5.6 High-level support team (HLST) activities

Elmfire and ASCOT were 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.

With the full f gyrokinetic global Elmfire code, a detailed agreement with mean equilibrium $\mathbf{E} \times \mathbf{B}$ flows, oscillating fine-scale zonal flows and turbulence spectra observed by a set of sophisticated microwave back-scattering techniques as well as a good fit of the thermal diffusivity data were demonstrated.

Supporting numerical work included the derivation and implementation of an interpolation algorithm for momentum conservation in gyrokinetic PIC codes and enhanced memory handling of coefficient matrix construction in Elmfire. Elmfire is being modified in hybrid form including openMP and MPI features.

2.6 Power plant physics and technology

2.6.1 Remote maintenance

The divertor test platform DTP2 was installed in Tampere in 2007 and provided the basis of extensive investigations on remote maintenance during the whole reporting period.

Remote Maintenance concepts were developed for replacing divertor cassettes and cooling pipes in DEMO. The reactor design of DEMO is proposed to have 16 toroidal field coils and 16 ports in between. By designing the divertor to consist of

48 cassettes (3 per port) the need for a separate in-vessel cassette carrier is eliminated, which leads to a much simpler maintenance procedure and logistics than in ITER. A conceptual telescopic radial mover has been designed and proposed. A common set of tools and methods are required in order to support the analysis of the DEMO plant and systems from the RAMI perspectives. 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. The study produced recommendations on the establishing of an effective RAMI management process for the DEMO development work.

2.6.2 Power exhaust in DEMO

The Association has been active in power exhaust studies within the PPPT programme from the very beginning. Power exhaust studies aim at building a database of documented plasma experiments and validated simulations, the design of DEMO exhaust scenarios being a particular motivation. In 2011, 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 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. In 2012, N_2 seeded discharges were characterized in ASDEX Upgrade and JET in order to build an experimental basis for power exhaust predictions and the associated model validation. SOLPS simulations were prepared to describe these experiments, yielding radiation patterns and divertor in-out asymmetries qualitatively similar to those observed in the experiments. In 2013, scans of the edge plasma properties with different power dissipation levels by radiating impurities were performed using SOLPS5.0 and compared to experimental trends in N-seeded discharges in AUG and JET. N seeding allows achieving divertor radiation of ~60% of input power.

2.7 Emerging technology – materials research

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 new developed potential is now used to simulate different possible compounds involved in stainless steels subjected to irradiation. Initial results show that even low-energy recoils in cementite can produce substantial amounts of damage. This is because cementite is a ceramic compound, where damage recombination in a cascade is not as pronounced as in pure metals such as ferrite or austenite Fe.

The formation and migration of vacancies in W was investigated with MD and DFT. The results show that vacancy formation close to W surface and in bulk is mainly driven by the H concentration, whereas temperature plays a strong role in the mobility of vacancies.

Utilizing our Fe-Cr-C interatomic potential finalized in 2013, the effects of carbide precipitates on the mobility of dislocations in steels were studied. Significantly large critical stresses to initiate dislocation movement at low temperatures were observed. MD simulations were used to investigate 150 keV collision cascades in bulk W. The results showed that vacancy clusters form mostly as low density areas at the center of previously liquid areas. The probability of cascade collapse was increased by slowing down the cooling rate of the heat spike.

2.8 Fusion for Energy and ITER

2.8.1 ITER divertor maintenance development

In support of Fusion for Energy (F4E), activities at VTT and TUT continued for ITER divertor maintenance development and testing at the DTP2 test facility in Tampere. Remote handling equipment and operations have been developed and tested, and new tools and methods have been designed. Second cassette operations with Cassette Multifunctional Mover (CMM) have been performed fully remotely from the control room using virtual models. Supervisory and control systems have been upgraded so that the CMM operations can be safely performed from the control room. Water hydraulic manipulator (WHMAN) to provide assistance to CMM during Second Cassette installation and removal operations was further developed and tested on top of CMM during last year. Conceptual design of Cassette Toroidal Mover (CTM) and Divertor region mock-up extension were finished during 2010.

ITER IO contract work on the Divertor Cassette locking system was completed. A new cassette inner attachment was manufactured and its behaviour during locking and unlocking was tested on DTP2. A new version of the cassette outer locking system is under development and will be manufactured and tested during 2011.

DTP2 trials in 2011 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.

The F4E grant GRT-401 continued a long series of tests and development work of ITER divertor remote maintenance on the DTP2 platform. In 2013 RH-trials on the exchange of the central and the second divertor cassette were repeated, since the divertor cassette and its locking system have been modified substantially after the first tests. To keep the DTP2 platform and systems in operation and updated for the next phase, some refurbishment work was carried out.

In the ITER contract ITER/CT/12/4300000674, the divertor cassette mock-up design was upgraded using several testing phases including a heat treatment. Already the first test led to design modifications of the locking mechanism. After heat treatment, the tight clearances of latches were affected by the heat treatment so that turning the knuckle was no more possible. As a result, the mechanism requires modifications.

Figure 2.8. Cassette locking system after heat treatment in a vacuum furnace.

2.8.2 Development of MEMS magnetometers for ITER

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.

In 2012, manufacturing of a new MEMS magnetic field sensor continued, and processed silicon wafers were completed for wafer bonding. Sensor enclosure was designed and 3D modelled. Several prototype versions of the readout electronics were constructed and measurements were carried out with existing sensors up to 1.1 T flux density. Measured resolution in laboratory environment meets the specifications.

Fabrication of MEMS magnetic field sensors and the design of a stainless steel enclosure continued under the F4E grant GRT-156. FEM simulations were used to find mechanical and thermal stresses due to electromagnetic loads, radiation and temperature excursions. Laboratory tests with previous generation sensors and prototype readout electronics meet the specified resolution of about 2 mT.

2.8.3 Fast particle losses due to 3D magnetic perturbations in ITER

The effect of 3D magnetic field perturbations on fast particle losses in ITER was investigated using ASCOT. Simulations suggest that the total power load to the wall depends strongly on the NTM perturbation amplitude, but remains below the design limits of the wall materials. No additional hot spots on the walls were observed.

Simulations of the effect of TAEs indicate that the alpha particle wall power load will stay at the MHD-quiescent level but that alpha particles are quite strongly redistributed in the core plasma. The inclusion of the magnetic perturbation of ELM control coils (so far without plasma response) in the simulations made the magnetic field stochastic deep inside the pedestal.

Solving the magnetization of ferromagnetic components in ITER constitutes a major part of the F4E grant GRT-379, which assesses the impact various magnetic perturbations on the confinement of energetic ions and on the wall power loads. In 2013, all the relevant components, including coils, the first wall, together with the TBM's and FI's, were imported from ITER as CAD drawings and reconstructed to be compatible with COMSOL. A numerically smooth and accurate scheme to evaluate the perturbation field due to the magnetized components was devised.

Appendix A: Fusion Yearbook – Association Euratom-Tekes Annual Report 2007

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Appendix G: Fusion Yearbook – Association Euratom-Tekes Annual Report 2013

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Appendix H: Publication data 2007–2013 for Association Euratom-Tekes

	Refereed articles						Conference articles			Technical reports			Theses	
	Physics		Technology		Estonia									
	Published	Submitted	Published	Submitted	Published	Submitted	Physics	Technology	Estonia	Physics	Technology	General arti-cles	Doctoral	Master's
2007	20	19	30	10	3	5	33	24	9	0	7	5	0	4
2008	29	14	19	12	6	1	52	16	3	0	6	6	3	7
2009	38	26	9	0	3	1	28	11	11	0	1	3	3	6
2010	37	23	1	3	1	2	54	18	1	0	56	4	1	4
2011	50	7	7	3	1	0	48	0	1	0	22	0	4	1
2012	31	29	1	4	0	2	42	6	3	0	19	0	4	4
2013	44	8	28	12	0	0	24	23	0	0	5	0	4	3
Total	**249**	**126**	**95**	**44**	**14**	**11**	**281**	**98**	**28**	**0**	**116**	**18**	**19**	**29**

Refereed articles	378
Conference articles	407
Technical reports	116
General articles	18
Doctoral theses	19
Master's theses	29

Series title and number

VTT Technology 214

Title	**Association Euratom-Tekes** Final summary report 2007–2013
Author(s)	Markus Airila & Tuomas Tala (eds.)
Abstract	This report summarises the fusion research activities of the Finnish and Estonian Research Units of the Association Euratom-Tekes in 2007–2013. The emphasis of the work coordinated by EFDA was in ITER Physics, PPPT and the ITM Task Force. Other EFDA activities were carried out within Goal Oriented Training and EFDA Fellowship. In addition, a significant fraction of Tekes activities was directed to F4E grants and ITER contracts. Fusion physics work was carried out at VTT, Aalto University (AU), University of Helsinki (UH) and University of Tartu (UT). The main activities were plasma experiments in collaboration with tokamak laboratories, modelling and code development, and diagnostics related to the main European fusion facilities JET and AUG. In particular, Association Euratom-Tekes focused on (i) Heat and particle transport and fast particle studies, (ii) Plasma-wall interactions and material transport in the scrape-off layer, and (iii) Development of simulation codes and their integration into the ITM environment. The Association participated in the EFDA JET Workprogrammes, including experiments with the carbon wall and the ITER-like wall, edge and core modelling, diagnostics development and code integration. The Association participated also in the experimental programmes of ASDEX Upgrade at IPP and the analysis of DIII-D and C-Mod data. Technology work was carried out at VTT, AU and Tampere University of Technology (TUT) in close collaboration with Finnish industry. Industrial participation was coordinated by Tekes. The technology research and development includes the DTP2 facility at VTT in Tampere, materials and joining techniques, vessel/in-vessel components, magnetic diagnostics for ITER by micromechanical magnetometers, 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 development of coating techniques. Association Euratom-Tekes was involved in Goal-Oriented Training in Remote Handling project, coordinated by Tampere University of Technology.
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Julkaisun sarja ja numero

VTT Technology 214

Nimeke	**Euratom-Tekes-assosiaatio** Yhteenvetoraportti 2007–2013
Tekijä(t)	Markus Airila & Tuomas Tala (toim.)
Tiivistelmä	Tähän yhteenvetoraporttiin on koottu Suomen ja Viron fuusiotutkimusyksiköiden vuosien 2007–2013 tärkeimmät tulokset ja saavutukset. Työ on tehty Euratom-Tekes-assosiaation puitteissa. EFDAn koordinoima työ keskittyi ITERin fysiikkaan, DEMOn fysiikkaan ja tekniikkaan (power plant physics and technology, PPPT) ja integroituun mallinnukseen (integrated tokamak modelling, ITM). EFDA-työtä tehtiin uusien asiantuntijoiden koulutuksessa (goal oriented training in remote handling, GOTRH, ja EFDA Fellowship). Tampereen teknillinen yliopisto oli koordinointivastuussa GOTRH-projektissa. F4E-organisaation myöntämällä rahoituksella ja ITER-sopimuksilla oli ohjelmassa merkittävä osuus. Fysiikan tutkimusta tehtiin VTT:llä, Aalto-yliopistossa, Helsingin yliopistossa sekä Tarton yliopistossa, ja se keskittyi plasmakokeisiin yhteistyössä tokamak-laboratorioiden kanssa ja niiden mallinnukseen. Assosiaation erityisiä painopistealueita olivat (i) Lämmön ja hiukkasten kuljetus ja nopeiden hiukkasten fysiikka, (ii) Plasma–seinämä-vuorovaikutukset ja materiaalien kulkeutuminen kuorintakerroksessa sekä (iii) Simulointiohjelmistojen kehitys ja integrointi ITM-ympäristöön. Euratom-Tekes-assosiaatio osallistui EFDA-JETin koekampanjoihin, reuna- ja sydänplasman mallinnukseen, diagnostiikan kehitykseen ja simulointiohjelmien integrointiin. Lisäksi assosiaatio osallistui ASDEX Upgrade -tokamakin koeohjelmiin sekä DIII-D- ja C-Mod-tokamakien tulosten analysointiin. Teknologiatyötä tekivät VTT, Aalto-yliopisto ja LTY tiiviissä yhteistyössä suomalaisen teollisuuden kanssa. Yritysten osallistumista koordinoi Tekes. Kehitettyihin 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 PPPT-tutkimukseen, ensiseinämän materiaalit, eroosion, deposition ja materiaalien kulkeutumisen tutkimus sekä pinnoitteiden kehittäminen.
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Association Euratom-Tekes
Final summary report 2007–2013

This report summarises the fusion research activities of the Finnish and Estonian Research Units of the Association Euratom-Tekes in 2007–2013.

Fusion physics work was carried out at VTT, Aalto University, University of Helsinki and University of Tartu. The main activities were plasma experiments in collaboration with tokamak laboratories, modelling with related code development, and diagnostics. The Association participated in EFDA JET Workprogrammes, edge and core modelling, diagnostics development and code integration, as well as in the experiments of ASDEX Upgrade at IPP and the analysis of DIII-D and C-Mod data.

Technology work was carried out at VTT, Aalto University and Tampere University of Technology in close collaboration with Finnish industry. Industrial participation was coordinated by Tekes. R&D included the DTP2 facility at VTT, materials and joining techniques, vessel/in-vessel components, magnetic diagnostics for ITER by micromechanical magnetometers, upgrading of the JET NPA diagnostics, Power Plant Physics and Technology activities, plasma facing materials issues, material transport studies and development of coating techniques.

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