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FinnFusion Yearbook 2014

Markus Airila | Antti Hakola (Eds.)

VTT

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Grano Oy, Kuopio 2015

Preface

The year 2014 brought no doubt the most profound change in the history of both European and Finnish fusion research. The European Commission decided to give up the Association structure that had existed for several decades as almost intact. Now during the Horizon 2020 framework, the Euratom Fusion Research program is organised under the EUROfusion Consortium with 29 beneficiaries, practically one per member state, having signed the agreement. Building up the structure and governance procedures of the Consortium took a major effort, and for example, 8 General Assembly meetings to finalise and approve all the rules were organised during the course of the year to get it running smoothly.

The end of the association structure meant also the end of Association Euratom-Tekes era that lasted for 18 years. And this meant also the biggest change ever by far in the Finnish fusion research organisation. The role of Tekes changed from being the signing body of the Association to act as the national funding body of the Finnish fusion research projects. Towards the European Commission and the EUROfusion Consortium, Tekes plays the role of the program owner. Now within the EUROfusion Consortium, VTT is the beneficiary and therefore plays the role of the program manager towards the Commission. The universities carrying out fusion research in Finland are acting as linked third parties to the Consortium. In order to govern this complicated structure, FinnFusion Consortium was established and the consortium agreement was signed among the participating research units in November 2014.

The largest change in the practical research work was the shift from the association baseline support funding to a complete project-based funding. However, the whole Finnish fusion research community, in a broad sense called FinnFusion, can be proud of itself as the total EU-level funding for the FinnFusion projects increased some 20% from 2013 to 2014. This is a very solid proof that our research topics are seen as highly relevant parts of the EUROfusion Consortium workplan to implement the “Roadmap to the realisation of fusion energy to the grid by 2050”.

In 2014, the FinnFusion Consortium participated in several EUROfusion work packages. The largest ones were JET experimental campaigns, JET fusion technology, materials research, plasma facing components, remote maintenance and medium size tokamak work packages. The medium size tokamak work package included in practice several different research topics on the ASDEX Upgrade tokamak. Fusion DEMO work on the balance of plant was a completely new research topic in FinnFusion activities.

EUROfusion also introduced an education work package that allowed us to partly fund 10 PhD students within FinnFusion members. In addition, we have two post-doctoral fellowships funded by the Consortium. FinnFusion also provided three NJOC secondees in JET and one PMU (EUROfusion Program Management Unit) secondee. International collaboration concentrated on tokamak experiments and tokamak edge modelling in the US on DIII-D tokamak under IEA Implementing Agreement with three scientists visiting DIII-D, and two official members were nominated in two different (ITER Tokamak Physics Activity) ITPA groups. For the first time, the annual seminar was organised together with the Swedish and Danish research units in Stockholm in June.

The F4E activities of FinnFusion continued seamlessly from previous years. Aalto University showed with accurate 3D modelling of magnetic fields and related fast particle losses that escaping energetic particles will not pose a threat to the first wall of ITER. As far as remote handling is concerned, year 2014 was characterized by successful demonstrations of divertor handling operations. As a result of the long-term extensive research & development experience of the ITER Divertor Remote Handling systems and equipment, VTT and TUT will be key players in the Assystem consortium where two multifunctional movers and two toroidal movers will be manufactured during five years.

To conclude, I can very proudly write here that the Finnish expertise is very much appreciated and required within the European Fusion program. Now with the fully project-oriented approach of EUROfusion research, the share of the Finnish contribution and overall EU-level funding has increased in 2014. This gives a very solid starting position to FinnFusion towards the coming years of Horizon 2020 both in the EUROfusion Consortium as well as in F4E and ITER. To have achieved all this, I would like to express my most sincere thanks to the scientists and engineers of the Finnish Research Units for their excellent and dedicated work in fusion physics and technology R&D in 2014. And most importantly, I would like to devote the last sentence to Tekes for its indispensable role in acting as the heart of the Association Euratom-Tekes for more than 18 years while lifting Finnish fusion research community from an unknown player back in 1995 to its present status of being a respected leader in many fronts of fusion research.

Tuomas Tala
Head of Research Unit
FinnFusion Consortium

Contents

List of acronyms and names

AFSI	AFSI Fusion Source Integrator
ASCOT	Accelerated Simulation of Charged Particle Orbits in Tori (particle tracing code)
AU	Aalto University, Espoo/Helsinki, Finland
AUG	ASDEX Upgrade (tokamak facility)
BBNBI	Beamlet-based neutral beam injection (simulation code)
CCFE	Culham Centre for Fusion Energy
CEA	Commissariat à l'Énergie Atomique et aux Énergies Alternatives (French Research Unit)
CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (Spanish Research Unit)
CPO	Consistent Physical Object (ITM datastructure)
CRESTA	Collaborative research into exascale systemware, tools & applications
CSC	(Finnish) IT Center for Science
CXRS	Charge-exchange recombination spectroscopy
DIII-D	Tokamak facility at General Atomics, San Diego
DIFFER	Dutch Institute for Fundamental Energy Research
DFT	Density-functional theory
DTP2	Divertor test platform phase 2 (test facility in Tampere)
ECRH	Electron cyclotron resonance heating
EDGE2D	Fluid plasma simulation code
EFDA	European Fusion Development Agreement
EIRENE	Neutral particle simulation code
ELM	Edge localised mode (plasma instability)
ELMFIRE	Gyrokinetic particle-in-cell simulation code
ENEA	Ente per le Nuove tecnologie, l'Energia e l'Ambiente (Italian Research Unit)
EPS	European Physical Society

ERO	Monte Carlo impurity transport simulation code
ETS	European transport solver (simulation code)
FI	Ferritic insert
FIDA	Fast-ion D-alpha diagnostic
FILD	Fast ion loss diagnostic
FPGA	Field programmable gate array
FZJ	Forschungszentrum Jülich
GAM	Geodesic acoustic mode (plasma instability)
HCD	Heating and current drive
HFS	High-field (inner) side of tokamak
ICRH	Ion cyclotron resonance heating
IFERC	International Fusion Energy Research Centre
ILW	ITER-like wall
IPP	Institut für Plasmaphysik, Garching/Greifswald
ITM	Integrated Tokamak Modelling (predecessor of WP CD)
ITPA	International Tokamak Physics Activity
JET	Joint European Torus (tokamak facility)
JETTO	Transport code
JINTRAC	JET integrated suite of transport codes
JT-60U	Japan Torus 60 Upgrade (tokamak facility)
LIBS	Laser induced breakdown spectroscopy
LFS	Low-field (outer) side of tokamak
LLNL	Lawrence Livermore National Laboratory
LUT	Lappeenranta University of Technology
Magnum-PSI	Linear plasma generator at DIFFER (the Netherlands)
MD	Molecular dynamics (simulation method)
MEE	Ministry of Employment and the Economy (in Finland)
MHD	Magnetohydrodynamics
NBCD	Neutral beam current drive
NBI	Neutral beam injection
NCLASS	Simulation code for neoclassical transport calculation
NJOC	New JET Operating Contract
NPA	Neutral particle analyser
NRA	Nuclear reaction analysis
NTM	Neoclassical tearing mode (plasma instability)
OKMC	Object Kinetic Monte Carlo (material simulation method)

OSM	Onion-skin model (for plasma simulation)
PISCES-B	Linear plasma generator at UCSD, San Diego, US
PMU	Programme Management Unit (of EUROfusion; Garching, Culham)
PRACE	Partnership for Advanced Computing in Europe
RBS	Rutherford backscattering spectroscopy
RH	Remote handling
SIMS	Secondary Ion Mass Spectrometry
SOL	Scrape-off layer
SOLPS	Scrape-off Layer Plasma Simulation (fluid plasma simulation code)
TBM	Tritium breeding module, Test blanket module (in the case of ITER)
Tekes	The Finnish Funding Agency for Innovation
TEXTOR	Tokamak experiment for technology-oriented research (Jülich)
UCSD	University of California, San Diego
UEDGE	Fluid plasma simulation code
UH	University of Helsinki
TUT	Tampere University of Technology
VR	Virtual reality
VTT	VTT Technical Research Centre of Finland Ltd
ÅA	Åbo Akademi University, Turku, Finland

1. FinnFusion Organization

1.1 Programme Objectives

The Finnish Fusion Programme, under the FinnFusion Consortium, 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:

- Develop fusion technology for ITER in collaboration with Finnish industry
- Provide a high-level scientific contribution to the accompanying Euratom Fusion Programme under the EUROfusion Consortium.

This can be achieved by close collaboration between the Research Units and 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 F4E provide challenging opportunities for top level science and technology R&D work in research institutes and Finnish industry.

1.2 EUROFUSION and FinnFusion Consortia

During the Horizon 2020 framework, the Euratom Fusion Research program is organised under the EUROfusion Consortium with 29 beneficiaries, practically one per member state, having signed the agreement during the course of 2014. IPP from Germany acts as the co-ordinator of the Consortium. VTT acts as the beneficiary to EUROfusion in Finland. EUROfusion Consortium prepared a grant application "Implementation of activities described in the Roadmap to Fusion during Horizon 2020 through a Joint programme of the members of the EUROfusion consortium" and it was granted to it in the launch event in Brussels in October 2014. It covers 734 M€ of Euratom funding (including NJOC) for the period 2014–2018 and forms the basis of Euratom Fusion Research program and its funding.

In order to govern the fusion research activities in Finland, FinnFusion Consortium was established and the consortium agreement signed among the participating research units in November 2014. The role of Tekes changed from being the signing body of the Association to act as the national funding body of the Finnish fusion research projects. Towards the European Commission and the EUROfusion Consortium, Tekes plays the role of the program owner. Now within the EUROfusion Consortium, VTT is the beneficiary and therefore plays the role of the program manager towards the Commission. The universities carrying out fusion research in Finland are acting as linked third parties to the Consortium. The FinnFusion organigram is presented in Figure 1.1.

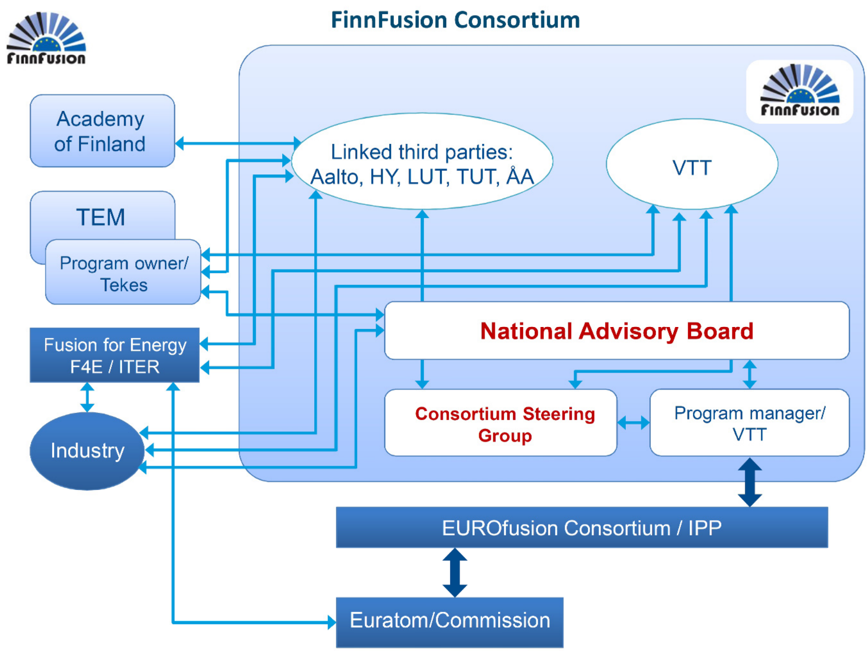

Figure 1.1. Organigram of Finnish Fusion Research Community in 2015–2020.

1.3 Research Unit

The Finnish Research Unit, FinnFusion consists of several research groups from VTT and universities. The Head of the Research Unit is Dr. Tuomas Tala from VTT. The following institutes and universities participated in the fusion research during 2014:

VTT Tech. Research Centre of Finland – Smart industry and energy systems
Activities: Co-ordination, tokamak physics and engineering
Members: Dr. Tuomas Tala (Head of Research Unit), Dr. Leena Aho-Mantila, Dr. Markus Airila, Dr. Antti Hakola, Mrs. Anne Kemppainen (administration), MSc. Seppo Koivuranta, Dr. Jari Likonen

(Project Manager), Dr. Sixten Norrman, Dr. Antti Salmi, MSc. Paula Sirén

Activities: Remote handling, DTP2

Members: Dr. Timo Määttä, MSc. Jorma Järvenpää, MSc. Harri Mäkinen, Lic.Tech. Mikko Siuko, MSc. Hannu Saarinen, MSc. Karoliina Salminen, MSc. Romain Sibois, MSc. Risto Tuominen, MSc. Jukka Väyrynen, Tech. Vesa Hämäläinen

Aalto University, School for Science (AU), Department of Applied Physics

Activities: Physics

Members: Prof. Mathias Groth (Head of Laboratory), MSc. Otto Asunta, Dr. Eero Hirvijoki, MSc. Aaro Järvinen, MSc. Juuso Karhunen, Dr. Timo Kiviniemi, MSc. Tuomas Korpilo, MSc. Tuomas Koskela (NJOC secondee), Dr. Taina Kurki-Suonio, Dr. Susan Leerink, Dr. Johnny Lönnroth (PMU secondee), MSc. Toni Makkonen, MSc. Juho Miettunen, Dr. David Moulton, MSc. Paavo Niskala, Dr. Marko Santala (NJOC secondee), Dr. Seppo Sipilä, Dr. Antti Snicker, MSc. Simppa Äkäslompolo

Students: Thijs Bergmans (ERASMUS), Alejandro Fernandez (ERASMUS), Petteri Heliste, Joona Kontula, Matti Mikkola, Heikki Sillanpää, Konsta Särkimäki, Jari Varje, Henri Ylitie

University of Helsinki (UH), Accelerator Laboratory

Activities: Physics, materials

Members: Dr. Tommy Ahlgren, Dr. Carolina Björkas, MSc. Laura Bukonte, Dr. Flyura Djurabekova, Dr. Kalle Heinola (JOC secondee), Dr. Krister Henriksson, Dr. Pekko Kuopanportti, Dr. Ane Lasa, Dr. Benoît Marchand, Dr. Kenichiro Mizohata, MSc. Morten Nagel, Prof. Kai Nordlund (Project Manager), Dr. Jussi Polvi, Prof. Jyrki Räisänen (Project Manager), MSc. Elnaz Safi, MSc. Andrea Sand, Dr. Vladimir Tuboltsev

Students: Fredrik Granberg, Miika Haataja, Ville Jansson, Aki Lahtinen, Riikka Ruuth, Mohammed Wadi Ullah

Tampere University of Technology (TUT), Inst. of Hydraulics and Automation

Activities: Remote handling, DTP2

Members: MSc. Liisa Aha, MSc. Pekka Alho, MSc. Dario Carfora, Dr. Juha-Pekka Karjalainen, MSc. Ville Lyytikäinen, Prof. Jouni Mattila (Project Manager), MSc. Janne Tuominen, MSc. Mikko Viinikainen

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

1.4 FinnFusion Advisory Board

The FinnFusion Advisory Board gives opinions 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 FinnFusion Advisory Board consists of the Parties and other important Finnish actors in Finnish fusion energy research. The FinnFusion Advisory Board shall enhance the link and information exchange between different research laboratories and industry.

Chairman	Janne Ignatius, CSC
Members	Henrik Immonen, Abilitas
	Arto Timperi, Comatec
	Jukka Kolehmainen, Diarc
	Leena Jylhä, Finnuclear
	Kristiina Söderholm, Fortum
	Mika Korhonen, Hollming Works
	Olli Pohls, Hytar
	Ben Karlemo, Luvata
	Jarmo Lehtonen, Metso Minerals
	Vesa Kyllönen, National Instruments Finland
	Pertti Pale, PPF Consulting
	Antti Väihkönen, Academy of Finland
	Janne Uotila, Sandvik
	Veera Sylvius, Space Systems Finland
	Juha Linden, Tekes
	Hannu Juuso, Tekes
	Timo Laurila, Tekes
	Arto Kotipelto, Tekes
	Kari Koskela, Tekes
	Herkko Plit, MEE
	Liisa Heikinheimo, TVO
	Timo Vanttola, VTT
	Riikka Virkkunen, VTT
	Timo Määttä, VTT
	Mathias Groth, Aalto
	Kai Nordlund, UH
	Jouni Mattila, TUT
	Heikki Handroos, LUT
	Jan Westerholm, ÅA
Co-ordinator	Tuomas Tala, VTT
Secretary	Markus Airila, VTT

The FinnFusion advisory board had two meetings in 2014.

1.5 Finnish Members in the European Fusion Committees

1.5.1 Euratom Science and Technology Committee (STC)

- Rainer Salomaa, Aalto University

1.5.2 Euratom Programme Committee, Fusion configuration

- Tuomas Tala, VTT
- Arto Kotipelto, Tekes

1.5.3 EUROFUSION General Assembly

- Tuomas Tala, VTT

1.5.4 EUROFUSION Science and Technology Advisory Committee (STAC)

- Kai Nordlund, UH
- Mikko Siuko, VTT

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

- Kari Koskela, Tekes
- Tuomas Tala, VTT

1.5.6 Executive Committee for the Joint European Undertaking for ITER and the Development of Fusion Energy, "Fusion for Energy" (F4E ExCo)

- Herkko Plit, Ministry of Employment and the Economy

1.5.7 Other international duties and Finnish representatives in the following fusion committees and expert groups in 2014

- Taina Kurki-Suonio is a member of the ITPA expert group on energetic particles. Tuomas Tala is a member of the ITPA expert group on transport and confinement.
- Reijo Munther is a member of the IEA Fusion Power Co-ordinating Committee (FPCC).

- Tuomas Korpilo was a member of the High Level Support Team until 31 December 2014.
- Markus Airila is the VTT representative in EUROfusion Communications Network (FuseCOM).
- Hannu Juuso is an Industry Liaison Officer (ILO) for F4E, Timo Määttä is the European Fusion Laboratory Liaison Officer (EFLO) 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).
- Harri Tuomisto is a member in the DEMO stakeholders group.
- Taina Kurki-Suonio and Tuomas Tala are members of the Committee for Nuclear Energy Research Strategy in Finland, set by the Ministry of Employment and The Economy.
- Taina Kurki-Suonio is appointed as an affiliated professor in physics, in particular plasma physics (2014–2016) at Chalmers University of Technology, Gothenburg, Sweden.
- Kai Nordlund is a member of the international committee of the COSIRES Conference (Computer Simulation of Radiation Effects in Solids).

2. JET Work Programme 2014

2.1 WP JET1: JET Experiments and Analysis; EFDA-JET experimental campaigns C31–34

Research scientists: M. Groth, A. Järvinen, T. Koskela, D. Moulton, M. Santala, AU
K. Heinola, A. Lasa, E. Safi, UH
M. Airila, J. Likonen, A. Salmi, P. Sirén, T. Tala, VTT

2.1.1 Investigations of seeded and intrinsic impurities in SOL

In line with previous campaigns, FinnFusion was in C31–34 strongly involved in experiments encompassing the areas of divertor detachment in different geometries, effect of seeded impurities on radiation and detachment, as well as PFC erosion and material migration. These issues were additionally addressed during *edge modelling meetings*. FinnFusion staff led two primary experiments to elucidate divertor detachment: (a) comparison of horizontal and vertical outer divertor configurations and (b) comparison of deuterium and hydrogen.

EDGE2D-EIRENE simulations of nitrogen-seeded ELMy H-mode plasmas show that nitrogen is a very suitable divertor radiation for typical JET divertor conditions with electron temperatures in the range of 30 eV. The simulations predict transition to detachment assisted by nitrogen at the outer divertor when more than 45–50% of the power crossing the separatrix is radiated in the divertor. Whereas nitrogen radiation is concentrated in the divertor chamber in JET, neon radiation is predicted and measured to occur partially in the confined plasma. Therefore, neon injection is predicted to reduce the power crossing the separatrix in partially detached divertor operation in JET.

EDGE2D-EIRENE simulations were also used as plasma backgrounds to model the migration of eroded beryllium to the divertor. Consistently with post mortem analyses the simulations show that the migration pattern on the inner divertor is mainly determined by the magnetic geometry and less sensitive to variations in plasma conditions.

2.1.2 Core transport studies

Tekes (i) coordinated the planning and execution of experiments on intrinsic torque and particle transport utilising NBI and gas modulations; (ii) studied the redistribution of NBI ions and heating due to a poloidally asymmetric heavy impurity distribution by integrated JETTO/ASCOT simulations; and (iii) analysed the local transport at L-H transition with JINTRAC and NCLASS.

Intrinsic torque and gas modulation experiments were successfully completed fulfilling nearly everything on the agenda and yielded large amount of quasi-stationary high quality MHD free data for detailed analysis. A particular experimental observation from the dimensionless collisionality scan (factor of 5 in nu*) shows a clear increase in density peaking with decreasing nu* consistent with earlier JET database studies but opposite to recent DIII-D results where nu* variation of 2 was shown not to affect peaking at all. The rho* scaling of intrinsic torque experiment (also ITPA TC-17) featured a dimensionless rho* scan with the largest possible rho* on JET (at B_T=1.3T) in effort get an identity match against AUG and DIII-D. This was indeed achieved on both machines while also extending the rho* range in a multi-machine rho* scan.

Simulated NBI ion distributions are in agreement with the vertical neutron camera measurements that show a broadening in the 2.5 MeV neutron profile when tungsten peaks on the outboard side of the plasma. Furthermore, the losses of NBI ions due to 3D magnetic fields were simulated in the M13–44 experiments. Vacuum field modelling by ASCOT shows the losses due to the n = 1 toroidal variation, corresponding to the waveform used in the EFCCs.

Experimental and NCLASS predictions and sensitivity were compared for heat fluxes, n_e, n_{imp}, T and E_r at L-H transition for different divertor configurations.

2.1.3 Support for JET neutral particle analysers

For the KF1, the 2014 campaigns were particularly successful. For the first time with the recently upgraded thin silicon detectors, intense ion tails were observed in several sessions with combined RF and NBI heating during C33 campaign. Both hydrogen and deuteron tails were seen and cross-contamination between the two masses was demonstrated to be low.

Particular highlights were the measurements of 2nd harmonic heated H tails in H majority plasmas without other auxiliary heating. It was demonstrated that significant ion tails can be generated with low plasma density or high RF power. These H tails were correlated with increasing machine wall temperatures. In an experiment on minority-heated ^{3}He in hydrogen, KF1 was the only diagnostic to observe a weak but consistent ^{3}He tail which decreased with X[^{3}He], demonstrating the onset of mode-conversion regime. In an experiment on fusion product studies (M13-45), 3rd harmonic heated deuterons interacted with varying concentrations of thermal ^{3}He in bulk plasma. KF1 measured very strong D tails which were well-correlated with TOFOR measurements. Furthermore, it is under investigation if KF1 also measured fusion product alphas in pulses with high X[^{3}He].

In 2013, KR2 was utilised in experiment on ICRF optimisation in H mode (M13-16). The results demonstrated that, with the RF power available, it was not possible to generate fast ion tails in such high density plasmas. There was much demand for KR2 also for the C33 H campaign, especially during isotope exchange. However, KR2 could not be operated as DMV2 continued to occupy the KR2 port on the machine.

2.2 WP JET2: Plasma-facing components

Research scientists: K. Heinola, K. Mizohata, UH
M. Airila, A. Hakola, S. Koivuranta, J. Likonen, VTT

JET operated with an all-carbon wall (JET-C) until October 2009 and during the shutdown in 2009–2011 all the carbon-based plasma facing components (PFC) were replaced with the ITER-like wall (JET-ILW). The divertor tiles of JET-ILW are made of tungsten-coated carbon fibre composites (CFC), except the load bearing tiles in the outer divertor which are made of solid tungsten. Limiters in the main chamber are manufactured from solid beryllium.

The JET2 programme focused on post-mortem analysis of wall components and in-vessel erosion-deposition probes (EDP) in 2014 and VTT used Secondary Ion Mass Spectrometry (SIMS), Thermal Desorption Spectrometry (TDS) and tile profiling for the analysis of wall components. The latter two techniques are available at CCFE. Samples from the divertor tiles exposed in 2011–2012 were analysed with SIMS for erosion and deposition under TF-FT task in 2013 and in 2014 the fuel retention in the same samples was investigated. The results are collected in Figure 2.1. On the inner vertical divertor tiles the highest deuterium amount is on top of tile 1, which has the highest deposition, and the deuterium amount decreases towards the bottom of the tile. On tile 3 the deuterium amount is somewhat higher than at the bottom of tile 1. The shadowed area of inner floor tile 4 has similar deuterium amount as the top of tile 1. The outer divertor tiles 6, 7 and 8 have clearly smaller deuterium amounts than the inner divertor tiles. SIMS results for deuterium retention was compared with TDS and Ion Beam Analysis (IBA) and there is a good agreement between the different techniques. Post-mortem analysis show that the deuterium retention at JET with the ITER-like wall has decreased by a factor of ~18.

Tile 0 (HFGC) exposed in 2011–2012 was available for post-mortem analyses only in 2014. Samples were cut for various analysis techniques using coring technique at VTT. In addition, cross-sectional samples for microscopy were prepared. SIMS analyses were made both from plasma-exposed and shadowed areas. In the case of shadowed area the samples have a thin surface peak for impurities (D, C, Ni, Mo). The samples from plasma exposed area have a co-deposited layer with a thickness in the range of 2–8 µm. The co-deposited layer contains impurities D, C, Be, Ni and Mo. Be has penetrated into the W and Mo layers. D amount in the shadowed areas is in the range of 10^{17} cm^{-2} whereas in the plasma exposed area the D amounts are clearly higher, in the range of 10^{18} cm^{-2}.

Larger scale erosion and deposition have been measured with the tile profiler after each major shutdown. Tiles have been measured both before the installation and after the experimental campaign and comparing the results before and after the experiments, erosion/deposition can be determined. In 2014, new divertor and limiter tiles for the 2014–2015 shut-down were measured with the tile profiler.

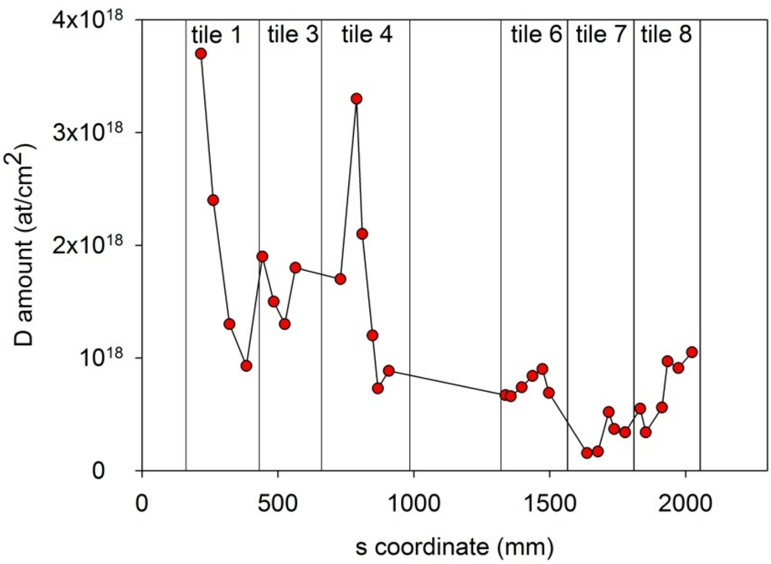

Figure 2.1. Deuterium amount on the ILW divertor tiles exposed in 2011–2012 measured with SIMS.

2.3 WP JET4: Enhancements

Research scientist: M. Santala, AU

WP JET4 work package consists of a number diagnostic enhancement projects. Several of them were launched under EFDA, with some EUROfusion elements added and some of them are pure EUROfusion projects. The FinnFusion-led project in WP JET4 is ISU2 (Isotope Separator Upgrade 2) to upgrade JET low energy neutral particle analyser (NPA) with custom silicon detectors and new data acquisition hardware and software. This project was initiated as an EFDA project but it also has a large EUROfusion component. ISU2 is carried out in collaboration with FinnFusion, VR (Sweden) and JET operator.

In the ISU2 project, the main activity in 2014 was the procurement of new batch of silicon detectors. The procurement was first sent to a tender process, won by

Advacam Ltd, a company operating at Micronova, Espoo. Although the design was based on the previous set of detectors designed and manufactured for the JET high energy NPA, several design changes were implemented to better fit the needs of the low energy NPA. Detector size was scaled down from 7 by 10 mm to 7 by 7 mm and the detectors have 32 strips at 220 μm pitch. The detector structure was also optimised for low energies by having the thinnest possible surface layers. The detectors were completed in December and initial testing carried out at Micronova cleanroom facility. The tests demonstrated that the reverse leakage current of the detectors is generally very low at the anticipated bias voltage.

The detectors in low energy NPA are laid out in a tight 3D array designed for tubular photomultiplier-based detectors. To minimise the impact on the functionality and calibration of the NPA this geometry must be closely mimicked with the new detectors. This poses challenges for the silicon detectors which naturally would be mounted on flat PCBs. A prototype design was created with narrow "detector PCBs" connected at right angle to "readout PCBs" with all readout electronics.

A conceptual design of the overall data acquisition electronics was made, illustrated in Figure 2.2. In addition to the in-vacuum electronics, the design of the vacuum interface and airside electronics are essential. The airside electronics will consist of a microcontroller-based control and monitoring module and several FPGA modules for processing the readout data and transmitting it to JET diagnostic hall and CODAS systems. It is foreseen to use direct Ethernet connection for data transmission, needing only simple PC-based hardware at the CODAS end.

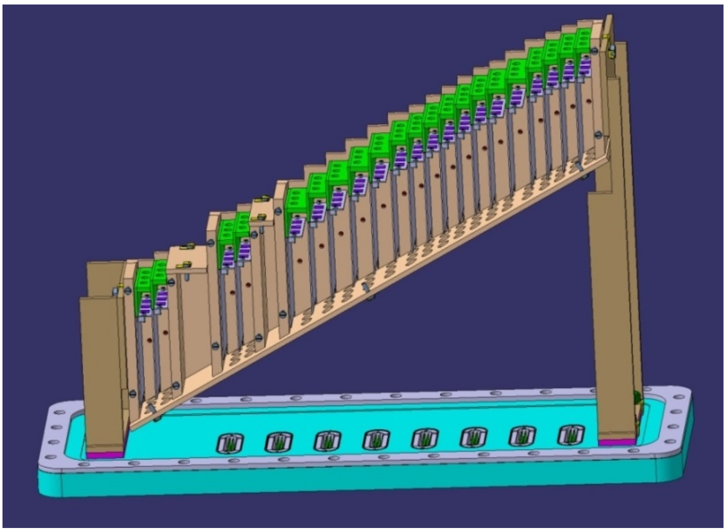

Figure 2.2. In-vacuum mechanics and vacuum flange as modelled by JET design office.

3. ITER Physics Workprogramme 2014

3.1 WP MST1: Medium-size tokamak campaigns

Research scientists: J. Karhunen, A. Snicker, T. Kurki-Suonio, AU
B. Marchand, UH
L. Aho-Mantila, A. Hakola, A. Salmi, T. Tala, VTT

Eight scientists from Finland participated in the MST1 campaign on ASDEX Upgrade tokamak in 2014. The topics covered transport physics, plasma-wall-interaction, edge and divertor physics, fast ion physics and diagnostics work. The work included leading and executing experiments, several kinds of modelling of experimental data and diagnostics upgrades.

One AUG experiment, *The scaling of intrinsic torque with respect to ρ* (characterising the turbulence scale length in a tokamak), pedestal gradient and ECRH power*, with VTT as the leader will be reported here in detail. Significant amount of time was devoted to this experiment, more than 30 plasma discharges on AUG in 2014.

An international database within the International Tokamak Physics Activity (ITPA) framework has been constructed for scaling the so-called intrinsic rotation to future devices. Initial estimates from this database project a large intrinsic velocity (~300 km/s) for ITER. However, this database did not distinguish between convective, diffusive, and core/edge localized residual stress contributions to the momentum flux, which can change dramatically depending on the plasma parameters and operating conditions. For example, recent experiments at JET have shown very small intrinsic velocities that can even go counter depending on the level of magnetic field ripple. These results are at odds with the original ITPA database scaling.

As our understanding of momentum transport has evolved, it has become clear that although a velocity prediction is ultimately what is desired for ITER, other torques on the plasma, as well as the need to distinguish between velocity and angular momentum, makes it difficult to make further progress on understanding intrinsic rotation generation without looking at the underlying drive mechanisms. Therefore, the necessary extension of the work on intrinsic rotation is to characterize the “intrinsic torque” associated with its generation. The term “intrinsic torque” is composed of all the other torque but the Neutral Beam Injection (NBI) components.

Intrinsic rotation has been and will be studied extensively on several different tokamaks, including ASDEX-Upgrade. However, in the intrinsic rotation studies the limitation is typically that only very small levels of NBI power (for diagnostics purposes) can be used such that the measured rotation remains intrinsic. Thus, the plasma scenarios are somewhat restrictive. On the other hand, the intrinsic torque derived from slow NBI modulation (2–4Hz) can be applied to any plasma with any amount of NBI power. Therefore, it is particularly suitable to high power H-mode plasma (with large edge gradient) scenarios.

In stationary plasma discharges, it is impossible to distinguish between diffusive, convective and intrinsic source components. However, through the use of modulation techniques it is possible to identify these fluxes separately. This new intrinsic torque optimised technique employs a 2-Hz on-axis NBI power modulation of ±0.625MW above a baseline NBI power level of at least 3MW, often significantly higher. This results in a ~10% modulation in the observed rotation, which is an ideal situation as the signal is clear. Time traces of the most important parameters are illustrated in Figure 3.1. The beam modulation creates a visible modulation in the angular momentum.

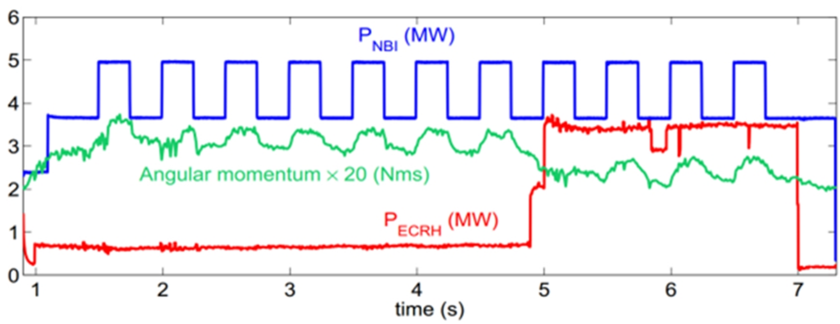

Figure 3.1. Time traces of ASDEX-Upgrade discharge number 29215.

The analysis of the intrinsic torque used in this paper adapts the shell peeling technique that was validated in DIII-D experiments at General Atomics in the US, with co- and counter-beams cancelling each other for regular beam driven plasmas. Here NBI torque modulation is used to induce a roughly 5% perturbation in toroidal rotation while avoiding significant time dependent changes in turbulence and thus momentum transport. The analysis is based on the momentum balance equation

$$\frac{\partial L}{\partial t} = T_{NBI} + T_{intr} - \frac{L}{\tau_\phi}, \quad (1)$$

where $L(\rho,t)$ is the angular momentum defined as $\int^{\rho} mn(\rho,t)\langle v_\phi(\rho,t)R\rangle dV$, T is the total torque composed of the NBI driven torque $T_{NBI}(\rho,t)$ and the time-independent plasma intrinsic torque $T_{intr}(\rho)$. T_{intr} is expected to originate primarily from residual stress as discussed earlier although in practice it is not possible to separate the other possible torques that may be present. $\tau_\phi(\rho)$ is assumed to be time-independent momentum confinement time. Here, T_{NBI} and L are considered to be the known quantities; the angular momentum L is calculated based on the experimental measurements of plasma rotation, density and equilibrium and $T_{NBI}(\rho,t)$ is the time-dependent NBI torque. The unknowns $T_{intr}(\rho)$ and $\tau_\phi(\rho)$ are solved using a non-linear optimization algorithm that iterates these parameters until the calculated angular momentum best fits the experimentally measured angular momentum in a χ^2 sense.

The effect of the q-profile on the intrinsic rotation was studied by performing a plasma current scan ranging from 400 kA to 1 MA while keeping the toroidal magnetic field constant at B_t = 2.5 T. This resulted in q_{95} variation by almost a factor of 3 ranging from about 4 to 11. However, since the plasma density in the tungsten walled AUG is strongly linked to plasma current via the Greenwald density, it is practically impossible to change the q_{95} value without changing plasma density. Therefore, more heating was applied in the high current, high density discharges to keep the collisionality υ_{eff} as constant as possible (υ_{eff} difference remained below 30%). The resulting integrated intrinsic torque profiles from this 4-point q-scan are shown in Figure 3.2. While the associated uncertainties remain large, there is a clear trend indicating that the intrinsic torque increases with increasing plasma current. Note that while this set of data was intended primarily as a q-scan, it also effectively forms a pedestal height scan where the 1-MA pulse has about two times higher pedestal top density than the 0.4-MA discharge. Also, the pedestal temperature is some 20–30% higher in the 1-MA discharge than in the 0.4-MA discharge. It is therefore likely that both the q and the pedestal height contribute to the derived torque changes. The experimental evidence from C-Mod tokamak (located at MIT, US) also indicates that density and temperature pedestals may have a different impact on intrinsic torque drive.

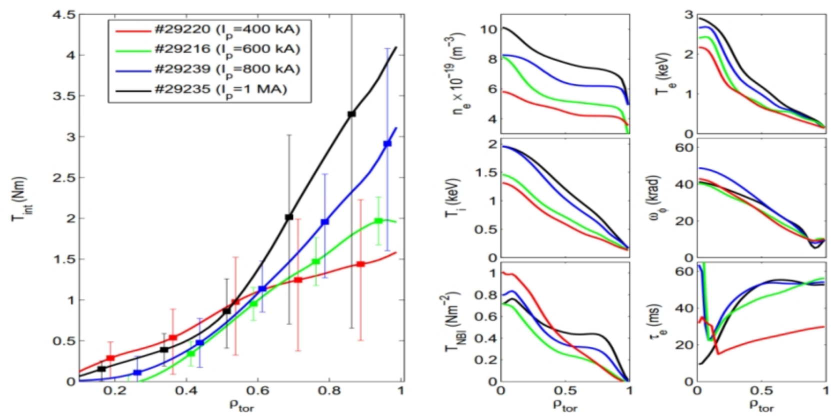

Figure 3.2. Volume integrated intrinsic torque profiles (left frame) and the most important time averaged plasma profiles in the 4-point q-scan.

While the experiments suggest that q-profile and/or pedestal height have an influence on intrinsic torque in AUG, the scaling of intrinsic torque to larger devices like ITER remains open. Therefore, multi-machine experiments, within the framework of ITPA, are planned to study ρ^* scaling of core intrinsic torque and the pedestal scaling of edge intrinsic torque. JET and DIII-D have dedicated time now after the AUG experiment in their experimental programs so that a proper, dimensionless multi-machine ρ^* scaling experiment can be completed and ITER extrapolation performed. These experiments will also produce data for momentum transport studies so that a much more solid ground to predict the ITER rotation is achieved.

3.2 WP PFC: Preparation of efficient PFC operation for ITER and DEMO

Research scientists: M. Groth, J. Karhunen, AU
T. Ahlgren, C. Björkas, K. Heinola, A. Lahtinen, A. Lasa, K. Nordlund, J. Räisänen, UH
M. Airila, A. Hakola, VTT

In 2014, the WP PFC activities were carried out under two different subprojects: **SP4** on modelling the plasma background as well as plasma-surface interaction and transport of particles in the edge plasma and **SP5** on experimental investigations of erosion and deposition processes in ASDEX Upgrade (AUG) and on the development of Laser-Induced Breakdown Spectroscopy (LIBS) for ITER purposes.

3.2.1 Erosion and prompt re-deposition of tungsten in ASDEX Upgrade

One of the largest tasks in the Work Package was investigating erosion and prompt re-deposition of tungsten in AUG. The experiment itself was carried under WP MST1 but all the *pre* and *post* analyses as well as modelling the outcomes of the experiment were left for WP PFC.

In the experiment, W-coated graphite probes were exposed to identical, low-density and high-temperature L-mode plasmas (AUG shots #31238–31251) in the vicinity of the outer strike point of AUG by using the upgraded divertor manipulator (DIM-II). The overall exposure time was ~80 s, after which the probes were removed from the vessel for analyses.

According to Figure 3.3c, the probes consisted of a poloidal W marker (thickness approximately 20 nm), a shallow (depth 0.2 mm) uncoated trench magnetically downstream of the W marker, and finally an inclined Mo marker (thickness ~20 nm) toroidally next to the trench; with this configuration, promptly re-deposited W atoms at the bottom of the trench could be protected from further plasma exposure.

Before and after the experiment the probes were measured using Rutherford Backscattering Spectroscopy (RBS). The measurements were carried out in the poloidal direction along each of the three markers and the obtained RBS spectra were fitted using the SIMNRA program. This way, the poloidal composition and thickness profiles of the different markers were obtained.

Our results show that closest to the strike point, the W markers had been eroded by 7–10 nm, while in the peripheral regions the net erosion was 3–5 nm (see Figure 3.3a). These correspond to net erosion rates of 0.04–0.13 nm/s, which are consistent with the reported long-term data in A. Hakola *et al.*, Journal of Nuclear Materials, http://dx.doi.org/10.1016/j.jnucmat.2014.11.034. The corresponding re-depositions on the bottom of the trench are 3–5 nm and 1–2 nm, i.e., ~30% of the eroded W atoms would be promptly re-deposited (see Figure 3.3b).

An interesting feature is strong deposition barriers on both sides of the strike point. These barriers extend throughout all the markers, and could have been caused by strong influx of tungsten from areas surrounding the probes; the probes had been mounted on a special bulk W tile, fitting into the manipulator head of DIM-II (see Figure 3.3c). The deposits also contain significant amounts of N and B, indicating thus co-deposition of W with the main plasma impurities. The erosion profiles are in accordance with the emission profile of WI (400.9 nm), which predicts gross erosion of >5–10 nm at the strike point and sharp decrease towards the peripheral regions.

Presently, SOLPS and OSM simulations are ongoing to create plasma backgrounds for modelling the obtained erosion profiles with the ERO codes. The first results will be reported in the PFMC 2015 conference.

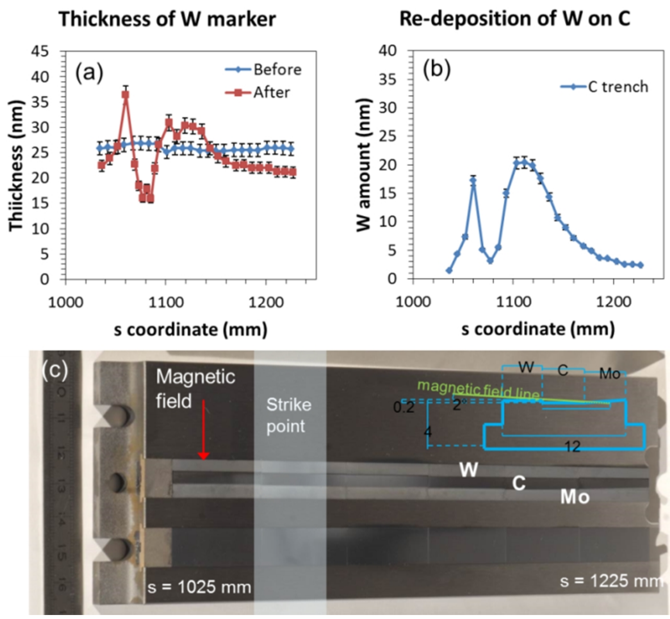

Figure 3.3. (a) Thickness of the W marker before and after the experiment. (b) Re-deposition of W on the uncoated C trench. (c) Photograph of the marker probes after the experiment and schematic drawing of the geometry of the probes.

3.2.2 SOL flow studies in ASDEX Upgrade

In addition to erosion and re-deposition, plasma flows were studied in the scrape-off layer (SOL) at the inner (high-field side, HFS) midplane of AUG. These measurements will provide data to be used in modelling migration of different impurities in tokamaks. To this end, N_2 was injected parasitically into the HFS SOL some 13 cm above the midplane during the discharges. The emission of N was observed both toroidally and poloidally at different radial locations by the spectroscopic system normally used for edge charge-exchange recombination spectroscopy. Nitrogen was selected as the tracer since it is being used as a seeding gas in AUG and it is observed to behave similarly to the widely studied CH_4.

The flow velocities were determined from the Doppler shift of a set of NII lines within 460–465 nm. Altogether six well-separated NII lines were detected in this spectral region, enabling thus good statistical investigation of the data from a single measurement. The preliminary results show toroidal flows in co-current direction, while the poloidal flows are in the electron diamagnetic drift direction. In the SOL, this means migration of impurities towards the inner divertor.

Reasonable agreement was noticed between the flow profiles of N^+ and N^{2+} ions, and almost identical results were found for recycled and injected N^+ measured before and after the injection, respectively (Figure 3.4). The N^+ temperatures, obtained from the widths of the spectral lines, showed yet unexplained discrepancies between the toroidally and poloidally measured values. For both directions, the temperatures were below those measured by CXRS at the LFS midplane, suggesting incomplete equilibration of the N^+ ions with the background plasma.

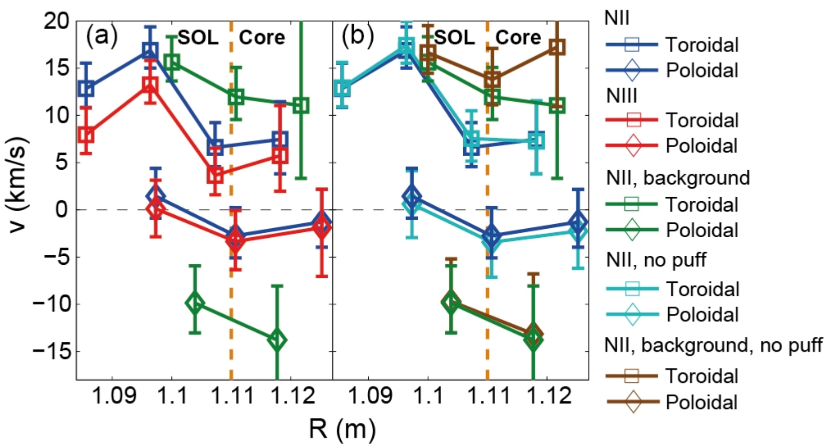

Figure 3.4. (a) Flow velocity injected of N^+ (blue) and N^{2+} (red) ions in toroidal and poloidal directions together with corresponding curves (green) for the background contributions. (b) Comparison between the N^+ flow profiles before (light blue) and after (blue) the gas puff. The background curves before and after the puff are indicated in brown and green, respectively.

New experiments are planned to systematically investigate the behaviour of the impurity flows under varying SOL conditions in L and H mode. In addition, modelling will be done to study the equilibration of the nitrogen ions in different plasmas and to find the connection between the experimentally observed nitrogen flows and the background deuterium flow.

3.3 WP CD: Code development for integrated modelling

Research scientists: O. Asunta, S. Sipilä, S. Äkäslompolo, AU
M. Airila, VTT

Neutral beam injection (NBI) heating is extensively used in present-day tokamaks. NBI will also be one of the main heating schemes and a significant source of non-inductive current drive in ITER. Therefore, modelling NBI is an integral part of integrated simulation of tokamaks. To this end, the Monte Carlo beam ionization code BBNBI and the particle following code ASCOT have been included as actors in the Heating and Current Drive (HCD) workflow of the European Transport Solver (ETS) within the European Integrated Modelling (EU-IM) framework.

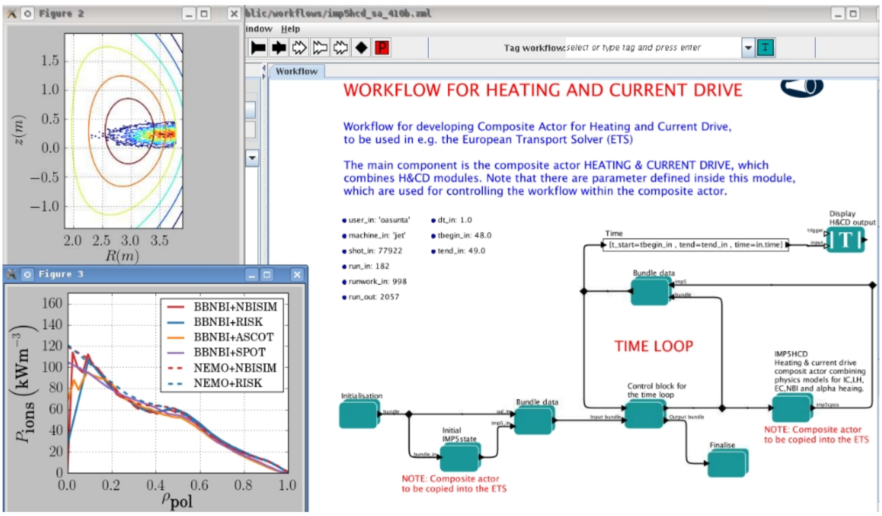

Figure 3.5. WP CD's Heating and Current Drive workflow and outputs of data produced by the ASCOT/BBNBI actors inside the composite actor IMP5HCD.

In 2014, BBNBI and ASCOT have been upgraded to the WP CD's latest data structure version 4.10b (see Figure 3.5). BBNBI and ASCOT have also both been successfully benchmarked against other NBI modelling tools within the HCD workflow. The benchmarks were carried out for JET, ITER, and ASDEX Upgrade plasmas. In addition, BBNBI and ASCOT were used to model neutral beam current drive (NBCD) in the fusion demonstration power plant DEMO. The objectives of this work were to gain valuable insight about the NBCD in DEMO, and to demonstrate that the tools available on EU-IM framework are capable of flexible and sophisticated modelling of NBI as a part of an integrated transport simulation of existing and future fusion devices.

Thomas Jonsson's radiofrequency heating and current drive module RFOF and its inputs have been integrated into the ASCOT actors, and testing and benchmarking of the ASCOT/RFOF ion cyclotron heating and current drive simulation model against other codes has been initiated. Preparations for using ASCOT to model fusion-born alpha particles and ion cyclotron resonance heated (ICRH) particles within the EU-IM framework are also underway.

The AFSI Fusion Source Integrator (AFSI), a tool that provides the fusion-born fast ion source, has been compiled into an actor. Within the EU-IM framework, AFSI currently calculates the reaction rates for fusions between Maxwellian thermal populations. Fusions between any non-Maxwellian populations, e.g. neutral beam ions, have also been implemented in the code and will be enabled soon.

Adaptation of the 3D Monte Carlo impurity transport code ERO into the EU-IM framework continued in 2014. The code can already handle edge and wall CPO's for input and output, but the conversion into a Kepler actor and inclusion into an edge workflow can only be done when all code specific parameters are handled in XML format. This part of the work was completed by generating the XML schema and sample input file for ERO and bypassing the internal specific data parser with an external XML parser that fills the internal data structure of ERO.

3.4 WP ISA: Infrastructure support activities

Research scientist: T. Korpilo, AU

As a part of HLST project, both the wall and limiter plates as the plasma-material boundary were incorporated into the global electrostatic full f gyrokinetic particle-in-cell code ELMFIRE (see Section 10). The main focus was in the numerical realization of the material boundaries. In particular, the boundary conditions for the distribution function and the electric field are important for code stability and plasma behaviour next to the boundaries.

4. Power Plant Physics & Technology Work Programme 2014

4.1 WP BOP: Heat transfer, balance-of-plant and site

Research scientists: M. Airila, S. Norrman, P. Sirén, VTT

The DEMO Power Plant, as defined by the EUROfusion consortium, will be an inductive pulsed machine, generating fusion power for 2–4 hours at a time with intermediary dwell periods required to recharge and regenerate essential systems. Within the work package WPBOP, Primary Heat Transfer System (PHTS) & Balance of Plant (BOP), a dynamic analysis model has been created with the simulation software Apros (see Figure 4.1).

The model is based on a concept where helium is the primary coolant. The purpose of the model was to provide a fully dynamic system-level simulation tool with which to assess the performance, and overall behaviour, of the chosen technology when operated in a pulsed manner. In particular it is necessary to compare this performance with that the water-cooled DEMO concept, which was similarly modelled with Apros by CCFE in an adjoining task within WP BOP.

The model created should be considered as an initial version of an analysis model where process, automation and electrical systems are integrated. The model serves as a basis for future modelling and simulation activities and will therefore be developed with increasing features and complexity over time. Activities within WP BOP are planned to continue until year 2018.

The model encompasses the complete PHTS, including the required number of cooling loops and associated sub-systems. In order to minimize thermal transients on main system components and supply electric power to the grid at a quasi-steady state condition the modelled plant is equipped with an intermediate energy storage circuit consisting of molten salt, between the primary and secondary systems. A simple secondary side includes a high pressure and low pressure turbine with a steam extraction line and a re-heater in between. Heat from the divertor and the vacuum vessel cooling systems is used to preheat the feed water of the secondary circuit.

It is recognised that the dynamics of the primary coolant loops are strongly affected by the time-variant response of the breeding blanket and, therefore, some detail of this component is captured within the model. At present, this involved only a simple hydraulic modelling, with scope remaining for further development using more detailed information from the design of the breeding blanket. This is the case also for the divertor and vacuum vessel heating modelling. Also the dimensions of especially heat exchangers were very roughly estimated in the model and this affected the transient behaviour of the model as fluid and structure volumes will probably store too much/little heat.

As examples of the model performance, two different transient cases were calculated – one where the helium circulators stop to minimum flow at dwell time and one where the circulators remain running. Because the helium circulators require a large portion of onsite power it would be beneficial to have them running at low speed during dwell time. On the other hand repeated starting and stopping of the circulators can lead to increasing risks for material fatigue comparable to those imposed on turbines in a similar situation.

The initial analysis model of DEMO created with Apros demonstrated to allow detailed simulation of plant transients arising as a result of pulsed operation, and a means with which to identify potential issues and mitigation strategies. The functionality of the model is such that different kinds of scenarios related to i.e. operation of equipment during power/dwell periods, can be easily configured. The model also showed that there are still many uncertainties related to component selections and operational strategies of the plant especially related to process control during transfer between power and dwell time operation. This model serves as a basis for further development into a more detailed model which allows investigations of both higher-level trade-off studies and optimization and operational limits of specific areas.

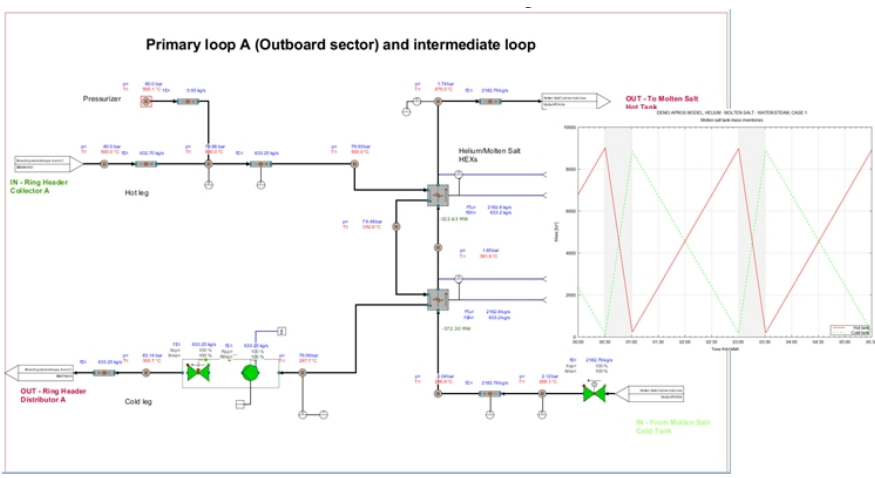

Figure 4.1. Part of Apros DEMO-model and molten salt hot and cold tank behaviour.

4.2 WP RM: Remote maintenance systems

Research scientists: J. Järvenpää, H. Mäkinen, K. Salminen, R. Sibois, M. Siuko, VTT

The development of the remote maintenance system for DEMO is driven by the need to maximise the overall plant availability and minimise the plant down time for maintenance. In addition to the ITER experience, novel concepts will be developed and validated. The design of the in-vessel components and their interfaces needs to be optimised for reliable remote handing operations. Validation of specific design concepts for maintenance aspects such as in-vessel attachments, remote maintenance transporters and servo manipulators is needed.

VTT's contribution in WP RM is in In-vessel Remote Maintenance Systems. The objective is to develop the in-vessel components to ensure remote handling compatibility, addressing mechanical fixation, earth bonding, service connections etc. with prototyping and mock-ups substantiating the design.

VTT is responsible for the Divertor Cassette Handling Work Package. VTT's partner with smaller contribution is ENEA from Italy, and the coordinator of the whole WP RM is RACE from UK. In 2014, the VTT work has been conducted in three main tasks:

- Divertor Cassette handling concept design development
- Divertor Cassette Mover and Test Platform design
- Divertor Cassette fixation and earth bonding design

4.2.1 Divertor Cassette handling concept design development

Divertor Cassette handling concept design development includes investigation of new cassette handling options. The baseline is to have 45 degrees inclined port, but five different options (horizontal, inclined, hybrid, vertical up and vertical down) were identified and compared. FMECA analysis for the original inclined port option was completed. Cassette fixation options were also investigated by comparing ITER solution and alternative conceptual design options. Different cassette handling options will be further studied together with end-effector options and different interface requirements.

4.2.2 Divertor Cassette Mover and Test Platform design

The replacement operations of DEMO divertor will be verified on a test platform with cassette mover prototypes. As learnt in ITER, real hardware mock-up reveals problems, which are not seen in virtual models. Therefore VTT has prepared initial requirement specification for the cassette movers and for the test platform. The requirements include for example general principles and estimations, and basic functions needed. The work continues with conceptual design of the cassette mover development together with the different cassette handling options.

4.2.3 Divertor cassette fixation and earth bonding design

Initial requirement specifications have been prepared for developing Divertor fixation systems and earth bonding concepts, and Divertor fixation and earth bonding functional mock-up. Conceptual designs for tooling and end-effectors that are required to perform the cassette handling operations have been developed. The goal was to use ITER experience but also find novel ideas. As a result two different conceptual design options of end-effectors have been described and compared. Cassette fixation design guidelines have been identified, and the work continues to develop the fixations methods and measure them against the requirements.

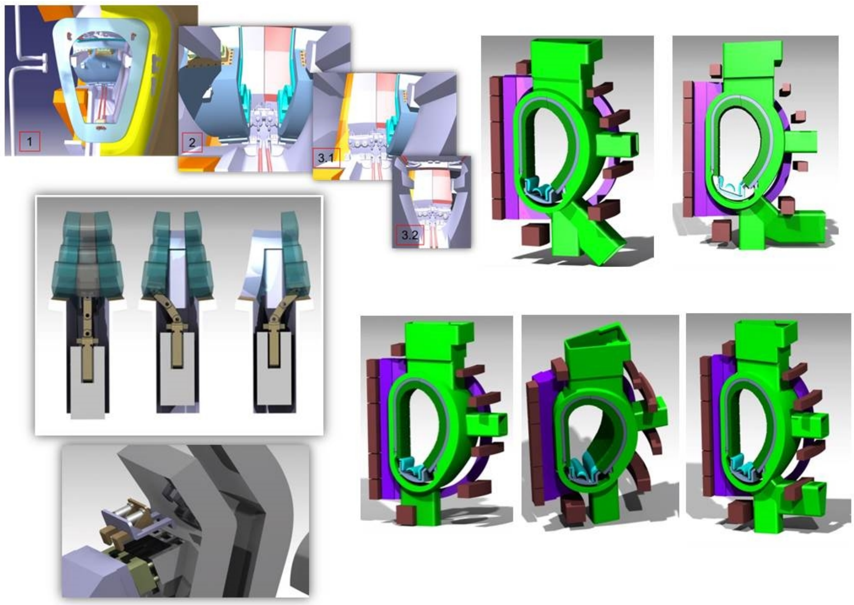

Figure 4.2. Concepts of DEMO RH equipment and RH tunnels.

4.3 WP MAT: Materials

Research scientists: T. Ahlgren, C. Björkas, L. Bukonte, F. Djurabekova, K. Henriksson, P. Kuopanportti, A. Lasa, M. Nagel, K. Nordlund, J. Polvi, E. Safi, A. Sand, V. Tuboltsev, UH

Tungsten will have a crucial role as the primary plasma-facing material in ITER, and is projected to have a similarly important role in DEMO. The development of accurate models to predict the response of W to specific irradiation conditions requires detailed simulations of the formation of primary damage. This can be accomplished by molecular dynamics simulations. The relevant parameters needed as input for larger scale methods such as OKMC or rate theory include, besides the total number of defects, also their spatial distribution. The spatial distribution can in part be characterized by the size-frequency distribution of defect clusters. The objective of this work was to determine that distribution for cascades in W, and investigate the sensitivity of these predictions to the choice of interatomic potential, as well as the dependence on other factors including the ambient temperature and PKA energy.

We performed MD simulations of full collision cascades with PKA energies ranging from 70 eV to 200 keV, comparing the predictions of 5 different interatomic potentials. In addition, we investigated the possible impact of the intermediate range of the potential. This was done by explicitly employing two different versions of a recent potential, which differ only over the interaction range between 0.9 Å and 2.0 Å, and thus defect formation energies, melting point, etc. are the same for both versions. Defect cluster size distributions were determined for 150 keV PKAs. Further, we investigated the effect of PKA energy (comparing to 200 keV cascades), ambient temperature (comparing 0 K and 800 K), and sample geometry (2D with surface vs. 3D bulk) on the defect size distributions.

The intermediate range of the potential was found to have a significant effect on defect numbers, resulting in a difference of roughly a factor of 2, over the whole energy range. However, the effect on clustering could not be determined in this study, since this particular potential predicted only minimal clustering of defects.

Two potentials which predicted strong clustering at higher PKA energies were in agreement concerning the power law distribution of both SIA and vacancy cluster sizes. The distributions were determined for 150 keV PKAs, since lower energy cascades produce only few and/or small clusters. The distribution of both SIA and vacancy clusters was found to be independent of ambient temperature.

The primary damage from foil irradiation with 150 keV W ions was found to be strongly affected by the surface, with many cascades occurring very near to the surface. This resulted in high levels of sputtering, and loss of SIAs to the surface. As a result, the number of vacancies far exceeded that in bulk cascades, while the number of SIAs was much less. However, the size-frequency distribution of vacancy clusters nevertheless followed a power law with the same exponent as in bulk, but with an overall higher frequency of clusters. The distribution of SIA cluster sizes also followed a power law, but with a smaller exponent than in bulk. In addition, the distribution of vacancy clusters from 30 keV ion impacts followed a power law with the same exponent as in the case of 150 keV impacts. For 30 keV impacts, almost no SIA remained in the material, so no cluster size distribution could be determined.

The power law exponent for vacancy clusters was $S = -1.9 \pm 0.1$, which agrees perfectly with an experimental determination of $S = -1.85 \pm 0.09$ of our collaborators at CCFE. The good agreement in vacancy cluster sizes is illustrated in Figure 4.3. These findings, together with associated analysis of the spatial distribution of damage, will enable generating cluster size distributions for higher-level simulations reliably and efficiently, without the need for running time-consuming MD simulations every time.

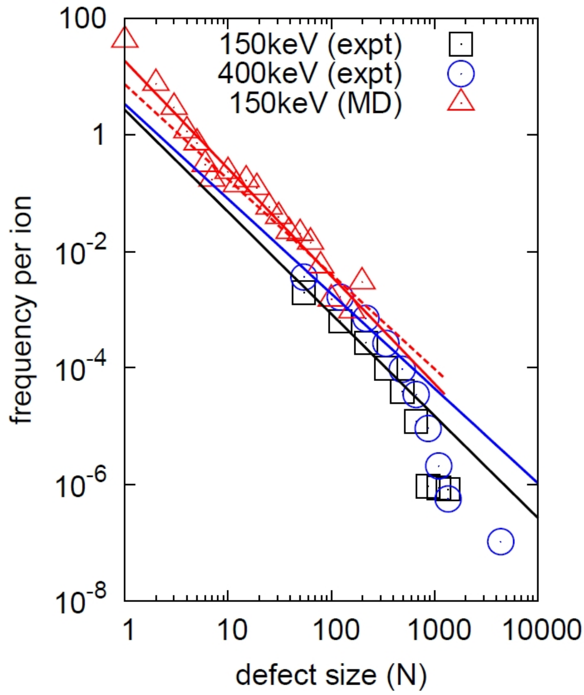

Figure 4.3. Comparison of experimental (squares and circles) and simulated (triangles) vacancy cluster sizes produced by 150 keV and 400 keV atomic recoils, corresponding to typical neutron irradiation conditions in fusion reactors.

5. Public Information

The FinnFusion Annual Seminar was held at the Royal Institute of Technology, Stockholm, Sweden, as a joint Nordic seminar with the Estonian, Danish and Swedish Research Units on 10–12 June 2014. The invited speaker was the EUROfusion Programme Manager Tony Donné presenting the status of the EUROfusion Consortium and particular opportunities for small Parties. The number of participants was about 65, of which 17 were FinnFusion members.

The Annual Report of the Association Euratom-Tekes, *Fusion Yearbook 2013,* VTT Science **54** (2014) 175 p., was published for the Annual Seminar and distributed to Heads of Research Units, key persons of the EUROfusion Consortium and its Parties, and F4E.

During 2014, Finnish and international media published several articles and interviews on the fusion research activities in Finland:

- Markus Airila, *Välähdys tulevaisuudesta (A flash from the future)*, interview on LLNL's ICF results in Karjalainen, 14 February 2014. Also in Keskisuomalainen and Savon Sanomat.
- Eero Hirvijoki, *Fuusioenergiassa riittää laskemista (Computation won't end in fusion energy research)*, interview in Tekniikka & Talous, 14 March 2014.
- Tuomas Tala and Pertti Pale, *Jättiläinen rakentuu (The giant builds up)*, interview in Tekniikka & Talous, 21 March 2014.
- *Suomalaiset saivat merkittävän roolin Iter-fuusioreaktorissa – "Sopimus on käännekohta" (Finnish scientists got an important role in ITER – "The contract is a takeoff")*, Kauppalehti on the remote maintenance contract between F4E and the consortium led by Assystem, including VTT and TUT, 5 June 2014.
- *Tulevaisuudessa robotti voi olla ihmisen paras kaveri (In the future a robot may be man's best friend)*, Helsingin Sanomat on the remote maintenance contract between F4E and the consortium led by Assystem, including VTT and TUT, 8 June 2014.
- VTT, *Uutta tekniikkaa ITER-fuusioreaktorin sisäseinien puhdistukseen* (*New technology for cleaning of plasma-facing components of ITER)*, 16 June 2014.

- Markus Airila, interview on fusion energy, ITER and DEMO in the radio program *Tiedeykkönen*, YLE Radio 1, 26 September 2014.
- VTT, *One of the most demanding ITER operations completed successfully: VTT uses remote control to replace the fusion reactor cassette collecting impurities,* press release, 29 September 2014.
- *Euroopan iso fuusioreaktori harppasi eteenpäin – "Yksi vaativimmista toimenpiteistä" toteutettiin suomalaisvoimin (The big European fusion reactor leaps forward – one of "the most challenging operations" demonstrated by Finnish scientists)*, Talouselämä on VTT's press release, 29 September 2014.
- *Euroopan Iter-fuusioreaktorihanke etenee – VTT toteutti "yhden vaativimmista toimenpiteistä" (The European ITER fusion reactor project progresses – VTT demonstrated one of "the most challenging operations")*, Tekniikka & Talous on VTT's press release, 29 September 2014.
- *VTT: One of the most demanding ITER operations completed successfully: VTT uses remote control to replace the fusion reactor cassette collecting impurities,* Kauppalehti on VTT's press release, 6 October 2014.
- Jorma Järvenpää, *Iter-testit paljastivat tärkeitä puutteita (ITER tests reveal significant shortcomings)*, interview in Tekniikka & Talous, 10 October 2014.
- *Supergraafi* on supercomputing in fusion, Tekniikka & Talous, 10 October 2014.
- Antti Hakola, *Varmasti protolaite syntyy, mutta toimivuus ei ole mitenkään taattua (Surely they will construct a proto, but there's no guarantee that it will work)*, interview on the Lockheed-Martin reactor concept in YLE online news, 16 October 2014.
- Rainer Salomaa and Antti Hakola, *Suomalaistutkijat ihmettelevät, kuinka Lockheed Martinin pieni fuusioreaktori rakennettaisiin (Finnish scientists wonder how Lockheed-Martin would construct its small fusion reactor)*, interview in Helsingin Sanomat, 16 October 2014.
- Antti Hakola, *Mullistava keksintö voisi syrjäyttää ydinvoiman: "Joka talossa oma voimala" (Revolutionary invention could replace nuclear power: "Every house to have own power plant)*, interview in Uusi Suomi, 16 October 2014.
- Filip Tuomisto and Markus Airila, *Suomalaiset Lockheedin fuusioreaktorista: Onpas pojilla kovat puheet (Finnish scientists on Lockheed's fusion reactor: Guys are telling fish stories)*, interview in Digitoday on 21 October 2014.

- Taina Kurki-Suonio, *Miltä kuulostaisi rekan kontissa kulkeva ydinvoimala? (How would it sound to have a nuclear power plant in a truck container?)*, interview on fusion and in particular the Lockheed-Martin reactor concept in Aamulehti, 9 November 2014.
- *VTT:n Iter-robotti onnistui (VTT's ITER robot successful),* Metallitekniikka on VTT's press release, 18 November 2014.
- Tuomas Tala, *Fuusiounelmaa toteutetaan jo (The fusion dream is already being realized),* interview in Tekniikka & Talous, 12 December 2014.
- *Suomalaistutkimus lupaa hyvää fuusioenergiasta – Kuuma plasma ei pääse tuhoamaan reaktoria (Finnish study brings good news for fusion – Hot plasma not to destroy the reactor),* Tekniikka & Talous on Tuomas Koskela's doctoral dissertation, 17 December 2014.

Lecture course at Aalto University, School of Science:

- *Fundamentals of plasma physics for space and fusion applications* (T. Kurki-Suonio, A. Snicker and E. Hirvijoki, spring 2014).

6. Education and Training

6.1 WP EDU – FinnFusion student projects

6.1.1 Overview

After EUROfusion introduced the Education funding instrument, the FinnFusion consortium adopted the practice of nominating *FinnFusion students* to whom the Education funding is specifically directed. The selection is done by the FinnFusion Advisory Board after proposals from the university professors working in the programme. Such a selection is used as an incentive to the students and a strategic means to direct the programme in the long run.

During 2014, four doctoral dissertations and four Master's theses were completed (see section 12.5.4).

6.1.2 Doctoral students

Student: Paula Sirén (VTT)
Supervisor: Mathias Groth (AU)
Mentors: Markus Airila, Tuomas Tala (VTT)
Topic: *Modelling of heat sources and balance-of-plant of DEMO fusion reactor*
Report: The project aims at providing a heat deposition model for process simulation codes such as Apros. The model requires a realistic source distribution of neutrons from the plasma and a transport model in the surrounding structures. In 2014 a first version of a plasma neutron source for the Serpent neutronics code was developed using a JET DT plasma as an example. Supporting JET plasma transport simulations were carried out with NCLASS and the results reported in the EPS Plasma Physics Conference and the IAEA Fusion Energy Conference.

Student: Pekka Alho (TUT)
Supervisor: Jouni Mattila (TUT)
Mentors: Jouni Mattila (TUT)
Topic: *Service-based fault tolerance for cyber-physical systems: a systems engineering approach*
Report: ITER remote handling systems are an example of Cyber-Physical Systems (CPSs), consisting of heterogeneous and interconnected embedded systems that control or interact with physical processes. Failures in CPSs can lead to loss of experiment time, damage to the equipment and environment, or loss of life, meaning that dependability and resilience are key properties for their design. Objective of this research has been to develop dependable control system architecture for remote handling control systems utilizing service-based architectural style, in order to handle uncertainty introduced by the dynamic and open networked computing environments. For 2014, main results include finalization of doctoral dissertation and two journal articles about fault tolerance of service-based CPS architectures.

Student: Laura Bukonte (UH)
Supervisor: Kai Nordlund (UH)
Mentors: Tommy Ahlgren (UH)
Topic: *Defect evolution in materials*
Report: Tungsten (W) is one of the most promising divertor materials in the next step fusion devices due to its extraordinary thermal and mechanical properties. However, continuous high heat and particle loads introduce defects, such as vacancies, that are one of the main reasons for hydrogen (H) retention in plasma-facing components. Therefore, studying vacancy mobility and formation is of crucial importance. The diffusion of monovacancies in W was studied using Molecular Dynamics (MD) and Density Functional Theory (DFT). The diffusion pre-exponential factor for monovacancy diffusion was found to be two to three orders of magnitude higher than commonly used in computational studies, resulting in attempt frequency of the order 10^{15} Hz. Multiple nearest neighbour jumps of monovacancy were found to play an important role in the contribution to the total diffusion coefficient, resulting in an upward curvature of the Arrhenius diagram. Theoretical thermodynamics approach was employed to study the equilibrium vacancy concentration in W as a function of H concentration and temperature. We found that the commonly neglected vibrational entropy term has significant effect on vacancy formation. Our thermodynamics model showed that vacancies are formed in crystalline W due to the presence of H impurities.

Student: Dario Carfora (TUT)
Supervisor: Kalevi Huhtala (TUT)
Mentors: Harri Mäkinen (VTT)
Topic: *Iterative Design Process of DEMO Divertor Remote Handling System using Multicriteria and Participative Approach*
Report: The aim of the research is to develop a novel design methodology to support the design process of the remote handling (RH) system for DEMO reactor. A design process converts stakeholder needs and requirements to required functionalities. The methodology shall be based on a System Engineering approach. The process for collection of the requirements and specification for DEMO RH has been started parallel with the concept design phase. The main result of 2014 activities was the study of the most feasible design of the maintenance port for replacing the divertor cassettes. Different solutions were developed and compared using an Analytic Hierarchy Process (AHP) approach. In the AHP, the important factors are arranged in a hierarchic structure. As a result of the AHP process two best solutions were selected for the further development.

Student: Aaro Järvinen (AU)
Supervisor: Mathias Groth (AU)
Mentors: Mathias Groth (AU)
Topic: *Interpretative simulations of impurity seeded JET ELMy H-mode plasmas*
Report: Radiative power exhaust with nitrogen and neon injection in JET plasmas has been experimentally investigated and simulated using the multi-fluid code EDGE2D-EIRENE. In highly shaped, high confinement mode plasmas with the ITER-like wall, in an ITER-relevant, high-triangularity, vertical-target configuration, the simulations show that the low field side divertor peak heat flux can be reduced in similar fashion with either nitrogen or neon injection, qualitatively consistent with experimental observations. Whereas nitrogen radiation occurs mainly in the divertor chamber in JET, neon radiation is predicted and measured to occur partially in the confined plasma. When adjusting the impurity injection rate to reproduce the measured radiated power, the simulations capture the experimentally observed particle and heat flux reduction at the low-field side divertor plate. However, in these partially detached conditions, the divertor deuterium Balmer alpha intensity is underestimated by a factor of 3–5, indicating a shortfall in the deuterium radiation.

Student: Juuso Karhunen (AU)
Supervisor: Mathias Groth (AU)
Mentors: Mathias Groth (AU), Antti Hakola (VTT)
Topic: *Spectroscopic studies of material migration and deposition in fusion devices*
Report: Samples from the inner divertor of the JET ILW were analysed by LIBS to assess the capability of LIBS for studying ITER-relevant deposited layers. The results showed good agreement between elemental depth profiles and spatial deposition profiles obtained by LIBS and SIMS. In addition, the retained deuterium was detected and successfully distinguished from hydrogen. Secondly, toroidal and poloidal SOL flows were measured at the HFS midplane of ASDEX Upgrade during L-mode discharges using Doppler spectroscopy on injected nitrogen impurities. The results suggest flows mainly towards the inner divertor with a reversal in poloidal direction in the near SOL, most probably due to perpendicular drifts. Moreover, modelling of the experiment with SOLPS was begun to provide background plasmas for further ERO simulations of the impurity flows.

Student: Ane Lasa (UH)
Supervisor: Kai Nordlund (UH)
Mentors: Kai Nordlund (UH)
Topic: *Atomistic Simulations of Divertor-Plasma Interactions in Fusion Reactors*
Report: Plasma-wall interactions taking place in a fusion reactors divertor were studied by computational means. The work was mainly based on atomistic scale calculations, and a Kinetic Monte Carlo algorithm has also been developed to extend the results to macroscopic scales, enabling a direct comparison with experiments. Two particular topics were: (i) Deuterium irradiation of various W-C composites, focusing on deuterium implantation, variations of the substrate composition and C erosion mechanisms. The obtained yields were compared to Binary Collision Approximation results, in order to improve the description of the latter method. (ii) Porous nano-morphology formation in tungsten by helium plasma exposure. A morphology growth model was derived where the time dependence is driven by the evolution of the surface roughness, which is a stochastic process and thus evolves as the square root of time.

Student: Paavo Niskala (AU)
Supervisor: Mathias Groth (AU)
Mentors: Timo Kiviniemi (AU)
Topic: *Study of flow dynamics and its effect on confinement in tokamaks*
Report: Microturbulence is currently understood as the main driver of enhanced transport in tokamak fusion devices, while the geodesic acoustic mode (GAM) presents a possible mechanism for regulating turbulent transport. To learn more about and to control the turbulence, advanced computer models and simulations are required. The student has analysed predictions from the full-f, gyrokinetic turbulence code ELMFIRE to investigate oscillations of radial electric field and their relationship with transport. The studies have concentrated on FT-2 and Textor tokamak plasmas, including collaboration with researches at the Ioffe institute in St. Petersburg. The simulations exhibit clear fluctuations with GAM properties. These oscillations also have distinct temporal correlation with transport, supporting the idea of GAMs as a transport regulating mechanism in fusion plasmas.

Student: Elnaz Safi (UH)
Supervisor: Kai Nordlund (UH)
Mentors: Carolina Björkas (UH), Jussi Polvi (UH)
Topic: *Multiscale modeling of plasma-wall interactions: (i) Multiscale modelling of Be-D interactions under reactor-relevant parameters; (ii) Atomistic simulations of D irradiation on Fe-alloys in ITER vacuum vessel*
Report: (i) D irradiation on Be surfaces was simulated, varying the D impact energy and flux, as well as Be surface temperature and D surface concentration. As a second step, an Object Kinetic Monte Carlo (OKMC) code was used to study the D retention properties and depth profiles as well as its diffusion behaviour in Be. Single atoms, vacancies and traps are the objects of this algorithm. The results show that the Be erosion peaks at impacting energies of 50 eV, due to the swift chemical sputtering mechanism. These erosion yields are suppressed when increasing the D concentration in the surface, due to dilution of the Be surface atoms. The results show little dependence on the D flux − within the range studied here − but strongly on the substrate temperature. The Be erosion ramps up at temperatures above 600 K, as the D desorbs instead of piling up at the surface as at lower temperatures.
(ii) In this work, molecular dynamics (MD) simulations of D ion irradiation on ferrite (pure BCC Fe), Fe-1%C and cementite (Fe_3C) structures were carried out by scanning over various plasma parameters and surface conditions. In the simulations, the incoming D ions had impact energies from 20 to 500 eV, and surface tem-

peratures ranged from 300 to 800 K. Preliminary results show that, with increasing impact energy, the sputtering yield of Fe atoms increases, while C atoms do not participate in materials erosion significantly, mostly staying in the simulation cell, bonding with incoming D ions and forming hydrocarbons. These results show little dependency on the substrate temperature, within the range studied here.

Student: Antti Snicker (AU)
Supervisor: Mathias Groth (AU)
Mentors: Taina Kurki-Suonio (AU)
Topic: *Towards realistic orbit-following simulations of fast ions in ITER*
Report: During 2014 the student finished his PhD work "Towards realistic orbit-following simulations of fast ions in ITER". In his thesis new numerical models for fast ions are presented, tested and validated. Part of the validation work carried out in close collaboration with the ASDEX Upgrade team was not included in the thesis. Most importantly, a detailed validation study for model of the effect of the MHD modes on fast ions was completed. In this study an agreement with ASCOT simulations and FIDA diagnostic was found both with and without the MHD activity, in this case it was (1,1) internal kink mode. During December, the student successfully defended his Ph.D. thesis and obtained the Ph.D. degree.

6.1.3 Pre-doctoral students

Student: Aki Lahtinen (UH)
Supervisor: Jyrki Räisänen (UH)
Mentors: Antti Hakola (VTT), Jari Likonen (VTT)
Topic: *Surface density of ^{15}N on ASDEX Upgrade samples*
Report: Time Of Flight – Elastic Recoil Detection Analysis (TOF-ERDA), Nuclear Reaction Analysis (NRA) and Secondary Ion Mass Spectrometry (SIMS) were used to study the surface density of the tracer isotope ^{15}N on samples removed from ASDEX Upgrade (AUG). For comparison, also samples implanted with ^{15}N were studied with TOF-ERDA and NRA. For the implanted samples, TOF-ERDA and NRA results were similar and very close to the implanted dose. For the AUG samples, NRA gave larger surface densities than TOF-ERDA. The reason for the discrepancies is related to the roughness of the AUG samples. In the NRA measurements the beam spot was larger than in TOF-ERDA and the analysed area contained rougher surface where the retention of ^{15}N is high. Technical problems limited the number of SIMS measurements and more research is therefore needed to find optimal settings to detect ^{15}N with SIMS.

6.2 WP TRA – EUROfusion Fellowship

Particle source and edge transport studies in JET H-mode gas puff modulation experiments

Research scientist: A. Salmi, VTT

Gas modulation experiments in H-mode plasmas featuring a scan in collisionality to study particle transport and sources at the plasma edge have been carried out on JET. The local electron density response to the gas injection was measured with a high resolution reflectometry along the midplane and with Lithium beam in the scrape off layer (SOL). Modulation amplitudes below 1% (in the core) are reliably measured thus allowing minimal plasma disturbance. The linearity of the electron density response was verified in identical plasmas by having different gas modulation amplitudes.

D_α and D_β among other radiation lines were measured with wide angle and divertor cameras yielding quantitative information of the propagation of the radiation front. Roughly 50 ms delay is seen between the top radiation and the divertor radiation when injecting gas from the top (see Figure 6.1). This together with ongoing dynamic EDGE2d-EIRENE modelling will allow further code validation and provide new insight on the dynamics of the particle source, and ultimately, edge transport.

The data also show that the Edge Localised Mode (ELM) frequency, here ~50-100 Hz, and ELM sizes are affected by the gas modulation thus complicating transport and particle source analysis. Typically, the ELM size decreases and frequency increases with the gas but the sensitivity varies between plasmas and also feature opposite trends.

Finally, gas modulation is seen to influence the 2.45 MeV D-D neutron yield. ASCOT calculations show that this is consistent with the beam-target yield variation due to the modulation of neutral beam (NB) penetration with electron density. The magnitude of the NB particle source modulation, however, appears to be too small to influence the interpretation of the bulk electron density modulation.

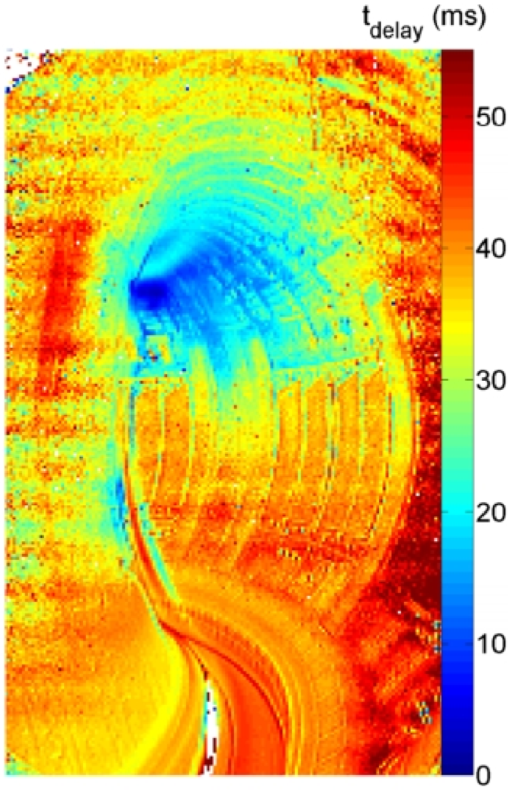

Figure 6.1. Poloidal wide angle camera view illustrating the time delay of the modulated D_β radiation intensity w.r.t gas entry into the plasma (near dark blue spot).

6.3 EFDA Fellowship

Understanding and predicting power exhaust physics in ITER-like devices using sophisticated 2D edge modelling in comparison to present-day experiments

Research scientist: L. Aho-Mantila, VTT

L. Aho-Mantila's EFDA Fellowship finished successfully in early 2015. Within this 2-year project, L. Aho-Mantila carried out experimental analyses and numerical simulations on the effects of impurity-seeding on tokamak plasmas. The experimental characterization was done using the ASDEX Upgrade and JET tokamaks. In the experiments, carefully controlled levels of N impurities were injected into the plasma edge in order to increase the radiation and reduce the divertor power loads. The influence of various edge plasma parameters on the tokamak power exhaust was assessed by analysing the corresponding numerical solutions obtained with the SOLPS5.0 code package.

As the studies were performed for two devices of different size, important information regarding the scaling of tokamak power exhaust was obtained. In present-day devices, plasma drifts could be shown to play an important role in reproducing the parametric dependencies observed in the experiments (Figure 6.2). The power exhaust characteristics were further shown to depend on the main plasma density and the geometry of the divertor targets. The results are important for extrapolating present-day power exhaust scenarios to reactors like ITER and DEMO.

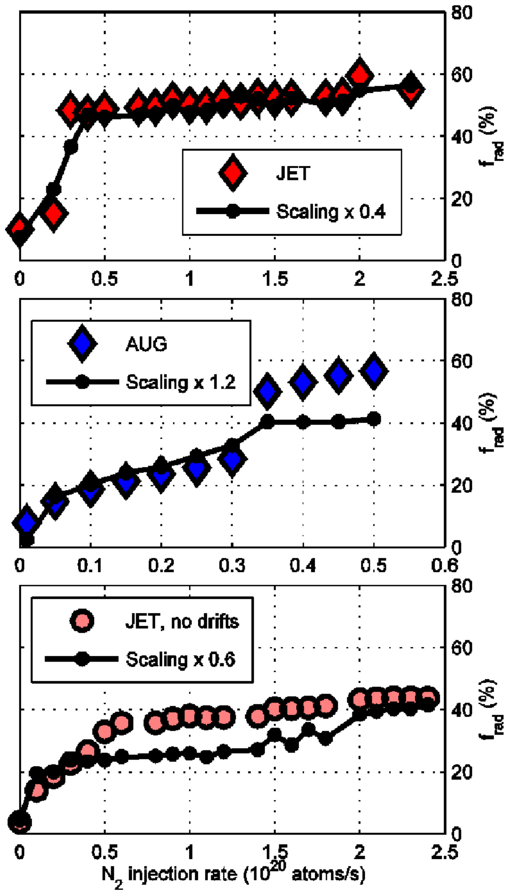

Figure 6.2. Comparisons between the modelled plasma radiation (disconnected markers with colours) and the radiation calculated based on empirical dependencies (connected markers in black). The simulations for JET reveal the importance of including drifts in the calculations (diamond markers) in order to reproduce the empirical radiation characteristics. (Figure presented at the 21st International Conference on Plasma Surface Interactions, reproduced from L. Aho-Mantila et al, J. Nucl. Mat. 2015.)

7. Enabling Research

Research scientists: A. Snicker, S. Äkäslompolo, AU

Enabling research projects WP14-ER-01/CIEMAT-05 and WP14-ER-01/IPP-01 are included in this report. In both of these proposals fast ion orbit-following code ASCOT was planned to model the interaction between the fast ions and magnetohydrodynamical instabilities in ASDEX Upgrade tokamak. While in CIEMAT-05 MHD modes in question were mostly of Alfvénic nature, in IPP-01 they were neoclassical tearing modes and internal kink modes.

In IPP-01, the leading idea was to measure the velocity space distribution function of the confined beam ions using FIDA diagnostic. This experimental result can be directly compared with the numerical ASCOT simulations. It was found out that in the presence of a strong internal (1,1) kink mode in ASDEX Upgrade discharge #30383, the fast ions get transported outside the q=1 flux-surface, leading to redistribution of beam ions. This redistribution was measured to be up to 30% of the beam ion density. In ASCOT simulations, similar redistribution was found. Using FIDASIM code, capable of simulating the synthetic FIDA diagnostic, very good correspondence between ASCOT and TRANSP simulations and experimental FIDA measurements was found in MHD-quiescent discharges while TRANSP could not explain the FIDA measurements with MHD activity. ASCOT signal with the MHD modes included was in much better agreement with the experimental signal.

In CIEMAT-05, the Alfvénic modes were excited in the early ramp-up phase of the discharge #30370. The losses caused by the modes were measured using FILD-diagnostic. It turned out that the equilibrium used in the numerical analysis was not consistent with the experimental measurements: stability codes calculating the Alfvénic spectrum found that the measured modes are not excited and/or are located in different spatial regions than they were measured. For these reasons, the interaction between the fast ions and MHD modes was not possible to simulate with ASCOT. However, MHD-quiescent ASCOT simulations revealed that part of the FILD signal that is not correlated with the MHD modes can be reproduced by numerical simulations of prompt beam ion losses. This is shown in Figure 7.1 showing the experimental FILD pattern and Figure 7.2 showing the simulated FILD pattern. The correspondence is broken for the signals correlated with MHD activity, suggesting that the interaction of beam ions with MHD modes, or some other physical phenomena neglected in ASCOT simulations, does have a role in this discharge. This will be investigated in future.

These projects included three missions to ASDEX Upgrade, during and after the experimental campaign. As a product of the projects, two manuscripts are considered to be published in peer-reviewed journals.

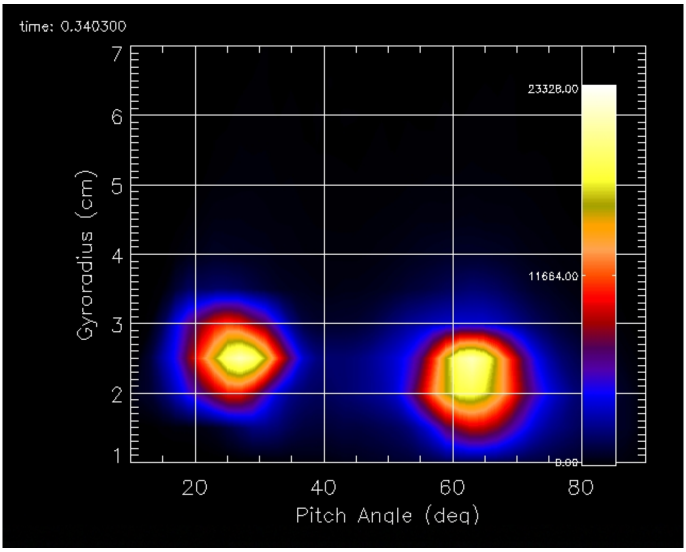

Figure 7.1. Experimental FILD pattern.

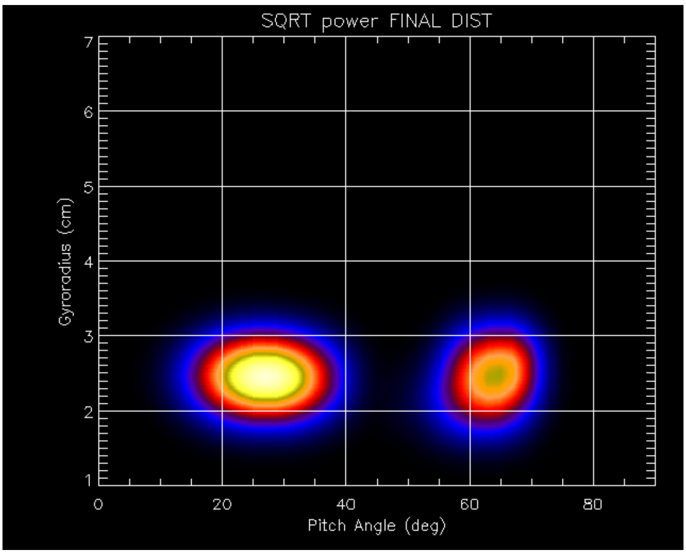

Figure 7.2. Simulated FILD pattern.

8. NJOC and PMU

8.1 Overview

Three FinnFusion scientists were seconded to work the entire year 2014 in the new JET operating contract team (NJOC) and one scientist in the EUROfusion Programme Management Unit (PMU). This section highlights one of the NJOC projects. The other three duties were:

- NJOC Neutron Diagnostic Specialist, Marko Santala, AU
- NJOC ASCOT Code Responsible Officer, Tuomas Koskela, AU
- EUROfusion PMU WP JET1 Responsible Officer, Johnny Lönnroth, AU.

8.2 NJOC – Plasma-Wall Interaction Physicist

Research scientist: K. Heinola, UH

Kalle Heinola (UH) has been seconded since 1st of February 2012 to Erosion/Deposition Group at JET Plasma Operations & Boundary Physics Unit in CCFE. The primary CCFE supervisor is Dr. Guy Matthews. The secondment for the New JET Operating Contract (NJOC) is long-term for four years as Plasma-Wall Interaction Scientist. The Erosion/Deposition Group is responsible for the long-term material migration and fuel retention studies in the JET ITER-Like Wall (ILW) and Following-ILW campaigns (FILW). These studies involve installing and replacing both passive and active diagnostic systems in dedicated interventions in-between experimental campaigns.

Main responsibilities of the Secondee are

- Organising, with the assistance of NJOC technical staff, removal of long-term samples and their sending to EUROfusion Research Units participating in the surface analysis activity
- Design, procure and install of long-term samples required for future JET operation
- Participation in development of new surface diagnostic concepts
- Co-ordination of NJOC activities linked to exploitation of the marker tiles
- Assisting with operation and/or maintenance of JET systems for which the JET Plasma Boundary Unit is responsible of

Summary of Secondee's activities during the reporting period 2014

- Sub-Project Leader in EUROfusion Work Package JET2
- Acting Leader of Erosion/Deposition Group (maternity leave)
- Member of the Project Planning Board for shutdowns 2014 and 2016 (Project: In-Vessel Replacements, IVER)
- Participation to Working Groups for JET operation beyond 2016 (post-DT)
- Global fuel retention analysis of JET-ILW campaign
- Erosion/deposition in JET-ILW by surface analyses of first wall tiles
- Preparation to the JET 2014 intervention taking place in beginning of 2015, e.g.
  - Responsible Officer for the tile/diagnostics exchange programme
  - Diagnostics: wiring survey and power supplies for Quartz Microbalance diagnostic (QMB), improvement of ex-vessel QMB diagnostic system and installation of the upgraded QMB systems.
  - Diagnostics: new Rotating Collector mechanism for extended lifetime
  - Diagnostics: design of new diagnostics the Sticking Monitor
  - Planning of ^{10}Be Sampling Experiment in JET Beryllium Handling Facility 3
- Participation in CCFE's Material Research Facility (MRF):
  - Participation to CCFE Enabling Research Project carried out at MRF
- Participation in JET operation
  - QMB Operator and Visual Systems Operator (VSO) during experimental campaigns
- Participation in JET EDGE Modelling Meetings
  - Plasma parameters from JET experiments and EDGE2D modelling to be used in Multi-scale Modelling of fuel retention in JET divertor. Multi-scale calculations are performed with Rate Theory Equations combining results from first-principles DFT calculations, MD simulations and experimental/EDGE2D data.

9. International collaborations

9.1 DIII-D tokamak

Research scientists: M. Groth, AU
A. Salmi, VTT

9.1.1 Impact of cross-field drifts on the onset of detachment

Mathias Groth visited General Atomics and the DIII-D National Fusion Facility in November and December of 2014 to lead an experiment on determining the impact of cross-field drifts (E×B and B×∇B) on the onset of detachment at the low-field side divertor plate. These experiments were conducted in both low-confinement and high-confinement mode plasmas, and included, for the first time, 2-D flow measurements Coherent Imaging System developed by Lawrence Livermore National Laboratory. Furthermore, the experiments exploited the paramount divertor diagnostics in DIII-D, foremost the divertor Thomson scattering (DTS) system. The experiments were accompanied by edge fluid code simulations using SOLPS and UEDGE, as part of an edge modeling initiative at DIII-D.

The experiments showed that the onset of detachment, i.e., T_e< 2 eV as measured by the DTS channel closest to the outer target plate, is not much affected by the direction of the toroidal magnetic field. Depending on the measurement location of the upstream density, the outer divertor plasma either detaches at 20% higher (line-averaged density in the edge) or 20% lower (pedestal density) in the reversed field configuration. Assuming the line-averaged density being sufficiently representative for the density at the separatrix, the observation on the onset of detachment are consistent with the $E_R \times B_T$ and $E_{pol} \times B_T$ drifts in the common SOL, and not in the private flux region.

9.1.2 Effect of Test Blanket Modules on plasma torque

Non-axisymmetric magnetic perturbations can lead to increased energy, particle losses and generate toroidal torque on the plasma thereby influencing plasma rotation and performance. ITER will be equipped with six Test Blanket Modules (TBMs) to study different Tritium breeding concepts. They contain significant amounts of ferritic material which will magnetise and consequently create localised 3D magnetic perturbations.

To aid ITER and to study the TBM effect on the plasma DIII-D conducted a campaign with a mock-up model for the perturbation field and among many other results showed up to 60% reduction in toroidal rotation. To understand in more detail whether TBM generated torque is dominantly in the core or at the edge of the plasma and how it scales with plasma parameters further dedicated experiments utilising modulation technique have been conducted.

In April 2014 Antti Salmi visited DIII-D where two experimental sessions were successfully planned and executed. The focus was on dimensionless beta and collisionality scan, both of which theoretically play an important role in neoclassical toroidal viscosity, which is believed to be responsible for most of the TBM torque. Simulations, data validation and analysis of experimental measurements are ongoing. Preliminary results show clear differences between high and low beta and high and low collisionalities (see Figure 9.1).

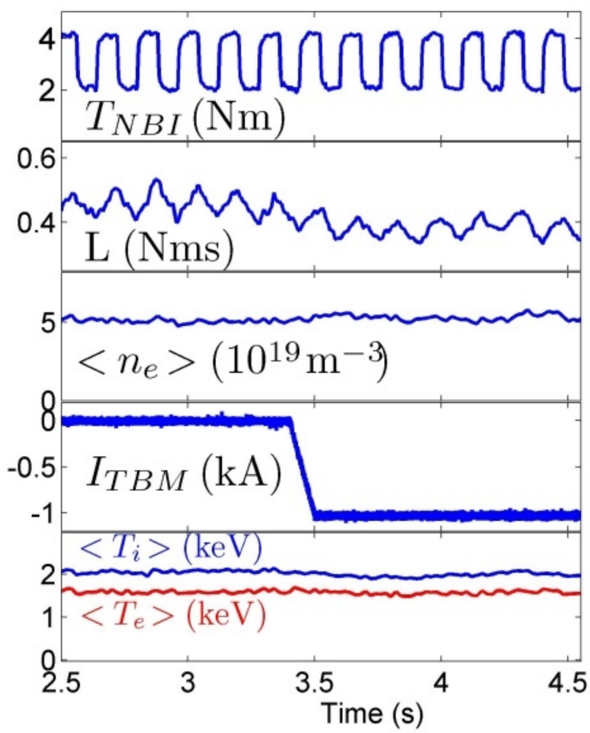

Figure 9.1. Experimental time traces of NBI torque modulation before and after TBM onset. The dynamic response of the rotation at each radius provide the means for extracting the TBM torque profiles.

9.2 Ioffe Institute

Research scientist: S. Leerink, AU

Collaborative work has been performed by Aalto University and the Ioffe institute in St Petersburg regarding code validation of the gyrokinetic full-f global code development project ELMFIRE (see Section 10) and the large aspect ratio tokamak FT-2. The main focus has been on coherence studies between particle and heat transport and fluctuations of the density and potential, with special emphasis on the role of the geodesic acoustic mode in obtaining increased confinement regimes. For this purpose synthetic diagnostics for several reflectometer diagnostics have been incorporated into the ELMFIRE code. Turbulence modulation at the GAM frequency is for the first time supported by experimental observations at the FT-2 tokamak and confirmed by ELMFIRE simulations, predicting strong modulation of the electron thermal diffusivity induced by GAMs, which propagates inward and possesses the GAM temporal and spatial structure. In order to obtain energy power balance in the simulations the transport shortfall observed mainly in the ion channel near the plasma boundary needs to be understood in more detail. For this purpose an in-depth study of the scaling of the energy confinement time is planned for 2015.

10. Full-f gyrokinetic turbulence code ELMFIRE

Research scientists: T. Kiviniemi, T. Korpilo, S. Leerink, P. Niskala, AU

The gyrokinetic full 5D particle distribution code ELMFIRE was used for simulating small and middle-sized tokamaks. As a part of our co-operation with Ioffe Institute, the predictive power of the code was shown by reproducing experimental steady-state plasma profiles in the FT-2 tokamak. A direct comparison of the simulation results with the FT-2 data showed that the experimental density profiles were well maintained in the simulation and that the plasma current profile based on ASTRA predictions was correctly reproduced by the ELMFIRE code. A steady increase of the plasma energy content however was observed in the simulation meaning that ohmic heating, radiation cooling and radial energy transport losses are not alone enough for power balance. For the present work, the code was extended from a radial annulus to full radius version by including the magnetic axis and scrape-off-layer regions (see Figure 10.1) to the simulation domain. Furthermore confinement studies for the linear ohmic confinement regime were started and results consistent with Alcator scaling were found for low density plasmas in agreement with FT-2 experiments.

Investigation of GAM oscillations in gyrokinetic simulations has continued. Phenomenological analysis of oscillation properties in the edge pedestal has been conducted for parameters similar to a TEXTOR L-mode discharge in the presence of a steep density gradient and dominating trapped electron mode turbulence. Parametric dependence of radial electric field oscillations were studied as a function of gradient scale lengths, mass number and temperature as an input and GAM frequency, amplitude and radial wave length as an output. Onset of turbulent transport and radial electric field oscillations with geodesic acoustic mode characteristics was observed when the radial density profile was steepened. Clear correlation of oscillations of transport coefficients and E_r was found in time, and changes in amplitude of GAMs were found to follow changes in level of electron transport.

Analytic equations for the effect of sampling on numerical noise in density in gyrokinetic particle-in-cell method were formulated and compared to numerical results. As an application, ELMFIRE was involved in three CRESTA projects namely visualization co-operation with Deutsche Luft and Raum, linear solver development with HLRS Stuttgart and 3D domain decomposition development with Åbo Akademi.

The ELMFIRE work was supported by WP ISA, WP EDU, Academy of Finland and Tekes as well as computer resources from PRACE, IFERC and CSC.

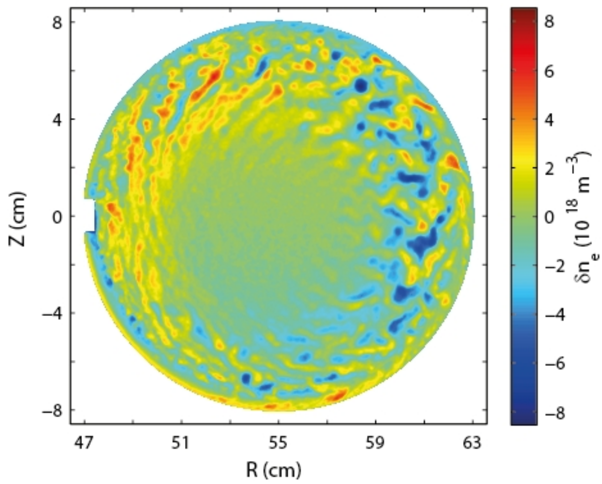

Figure 10.1. Turbulent density fluctuations in poloidal cross section extending from magnetic axis to the scrape-off-layer.

11. Fusion for Energy activities

11.1 Simulating fast particle heat loads on ITER walls

F4E grant: GRT-379, "RIPLOS-2"
Research scientists: O. Asunta, T. Bergmans, E. Hirvijoki, T. Kurki-Suonio, A. Snicker, S. Sipilä, K. Särkimäki, S. Äkäslompolo, AU

A 3-step method for accurately calculating the ITER magnetic field with detailed models for both the field coils and ferritic components was developed: In the first step, the magnetization of ferritic inserts (FI) and test blanket modules (TBM) is evaluated using the FEM multiphysics tool COMSOL. In the second step, COMSOL models FIs and TBMs as permanent magnets and calculates the field produced by these components. Finally, this perturbation field is added to the vacuum field, accurately calculated by integrating the Biot-Savart law. This process produces fields that include the effect of ferritic components at unprecedented accuracy, see Figure 11.1.

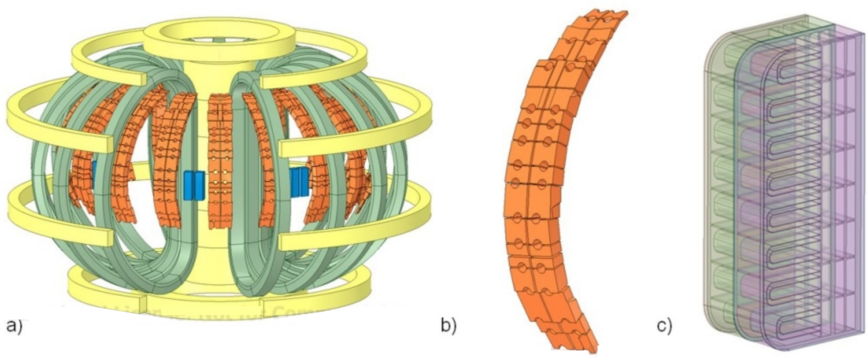

Figure 11.1. Detail level of the ITER magnetic components modelling. a) Cutaway view of ITER magnetic components with two toroidal field coils (shown in green) removed. Poloidal field coils are shown in yellow, FIs in red and TBMs in blue. b) Close-up of a FI. c) Semi-transparent close-up of a TBM module showing its internal structure.

Using these magnetic fields, the confinement of fusion alphas and NBI ions was investigated using the ASCOT code for the flat top phase (470 s) of the ITER baseline scenario at 15 MA. The alphas were calculated from the thermonuclear fusion reactivity, while the beam ions were generated by the beamlet-based numerical injector BBNBI. The FIs were found very effective in reducing losses, and the introduction of the TBMs did not jeopardize the integrity of the first wall, the peak heat loads being limited to less than 100 kW/m^2.

11.2 Divertor remote handling

F4E grant: F4E-GRT-401

Research scientists: J. Järvenpää, H. Mäkinen, T. Määttä, H. Saarinen, K. Salminen, M. Siuko, VTT
L. Aha, V. Lyytikäinen, J. Mattila, J. Tuominen, M. Viinikainen, TUT

Third Fusion for Energy remote handling grant (2012–2015) has concluded the ten-year development and testing phase of the ITER divertor Remote Handling (RH) operations at Divertor Test Platform 2 (DTP2). The development work has been done in collaboration of VTT and TUT. To demonstrate the results of the grant, final RH trials were organized at DTP2. The aim of the trials was to validate the full exchange sequence of the second and central divertor cassettes. The members of team have been photographed in Figure 11.2.

11.2.1 Exchange of the second and central divertor cassettes

The objective of the grant was to demonstrate the full exchange sequence of second and central divertor cassettes. The work included mechanical design of several new components, manufacturing and testing of them, as well as developing the control systems to be able to operate in ITER-like conditions. The objective was to demonstrate that the full exchange sequence, featuring the new cassette locking system design, can be performed successfully and within safe operational limits.

The development of the second cassette exchange process included redesign and manufacturing of the cassette locking systems tools. The full exchange sequence of the second cassette under ITER-like operational conditions was demonstrated to F4E 09/2014.

The goal of the central cassette RH trials was to demonstrate the feasibility of the central cassette end-effector conceptual design and associated remote handling tasks. The development work was done to improve initial plans and design into more practical and operationally robust solutions. During the grant remarkable improvements were done both in the hardware design and remote handling processes. One of the main objectives of the grant was fulfilled when performing successful RH trials on the exchange of the central cassette to F4E representatives 02/2015.

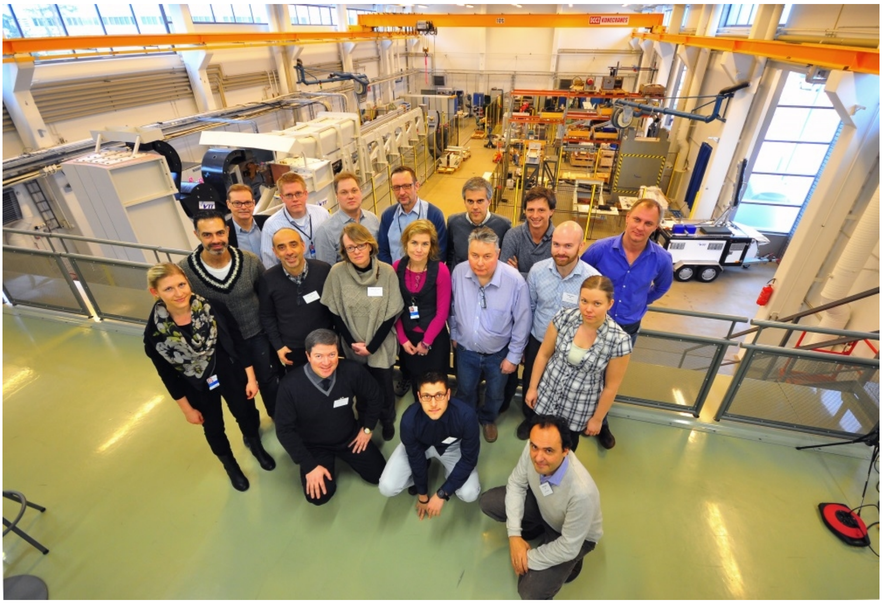

Figure 11.2. Group photo of the RH team.

11.2.2 ITER divertor remote handling future

Since the DTP2 work was started more than ten years ago, extensive knowledge has been gained in working with ITER vessel requirements, and considering the environment in mechanics, control, and operating virtual reality systems.

In the future DTP2 work will continue in different industrial procurement consortiums. Europe's contribution to ITER's Remote Handling systems is in the range of 250 Million EUR. F4E and its suppliers will have to deliver the Divertor and Neutral Beam Remote Handling systems, the Cask Transfer system and the In-Vessel Viewing and Metrology system. Currently the DTP2 team has been agreed to continue the work in the Divertor and Neutral Beam Remote Handling systems.

12. Other activities

12.1 Missions and secondments

Kalle Heinola to JET Plasma Boundary Group, Culham, UK, 1 Jan–31 Dec 2014 (NJOC)

Tuomas Koskela to JET Analysis and Modelling Group, Culham, UK, 1 Jan–31 Dec 2014 (NJOC)

Johnny Lönnroth to EUROfusion Programme Management Unit, Culham, UK, 1 Jan–31 Dec 2014 (WP PMU)

Marko Santala to JET Spectroscopy and Neutron Group, Culham, UK, 1 Jan–31 Dec 2014 (NJOC)

Antti Salmi to JET facility (United Kingdom), 6–17 Jan 2014 (EFDA JET Order)

Leena Aho-Mantila to IPP (Germany), 6 Jan–16 Mar 2014 (EFDA Fellowship)

Tuomas Tala to JET facility (United Kingdom), 13–17 Jan 2014 (EFDA JET Order)

Jari Likonen to JET facility (United Kingdom), 27–31 Jan 2014 (EFDA JET Order)

Antti Hakola to FZJ (Germany), 17–19 Feb 2014 (WP PFC)

Jari Likonen to JET facility (United Kingdom), 20–26 Feb 2014 (WP JET2)

Antti Snicker to IPP (Germany), 9–19 Mar 2014 (Enabling Research)

Leena Aho-Mantila to JET facility (United Kingdom), 17–21 Mar 2014 (EFDA Fellowship)

Jari Likonen to JET facility (United Kingdom), 17–21 Mar 2014 (WP JET2)

Tuomas Tala to IPP (Germany), 17–21 Mar 2014 (WP MST1)

Markus Airila to JET facility (United Kingdom), 17–28 Mar 2014 (EFDA JET Order)

Mathias Groth to JET facility (United Kingdom), 17–28 Mar 2014 (EFDA JET Order)

Aaro Järvinen to JET facility (United Kingdom), 17–28 Mar 2014 (EFDA JET Order)

Ane Lasa to JET facility (United Kingdom), 17–28 Mar 2014 (EFDA JET Order)

Elnaz Safi to JET facility (United Kingdom), 17–28 Mar 2014 (WP JET1)

Leena Aho-Mantila to IPP (Germany), 22 Mar–31 Aug 2014 (EFDA Fellowship)

Tuomas Korpilo to Others/inside Europe (to be specified below), 31 Mar–1 Apr 2014 (WP ISA)

Antti Hakola to CRU (Croatia) and JSI (Slovenia), 31 Mar–3 Apr 2014 (WP PFC)

Tuomas Korpilo to HLST meeting, 31 Mar–1 Apr 2014 (WP ISA)

Jari Likonen to JET facility (United Kingdom), 7–11 Apr 2014 (WP JET2)

Tuomas Tala to MIT, Boston, US, 8–12 Apr 2014 (International Collaborations)

Antti Salmi to DIII-D, General Atomics, San Diego, USA, 8–19 Apr 2014 (International Collaborations)

Tuomas Tala to General Atomics/DIII-D, 12–20 Apr 2014 (International Collaborations)

Tuomas Tala to IPP (Germany), 12–15 May 2014 (WP MST1)

Otto Asunta to CEA (France), 18–22 May 2014 (WP CD)

Simppa Äkäslompolo to IPP (Germany), 26–28 May 2014 (WP S1)

Taina Kurki-Suonio to IPP (Germany), 26–28 May 2014 (WP S1)

Antti Hakola to IPP (Germany), 2–13 Jun 2014 (WP MST1)

Juuso Karhunen to IPP (Germany), 2–13 Jun 2014 (WP MST1)

Tuomas Tala to JET facility (United Kingdom), 16–27 Jun 2014 (EFDA JET Order)

Jari Likonen to JET facility (United Kingdom), 16 Jun–4 Jul 2014 (EFDA JET Order & WP JET2)

Paula Sirén to JET facility (United Kingdom), 23 Jun–4 Jul 2014 (EFDA JET Order)

Antti Snicker to IPP (Germany), 29 Jun–11 Jul 2014 (Enabling Research)

Antti Hakola to IPP (Germany), 29 Jun–18 Jul 2014 (WP MST1)

Juuso Karhunen to IPP (Germany), 29 Jun–18 Jul 2014 (WP MST1)

Benoît Marchand to IPP (Germany), 6–11 Jul 2014 (WP MST1)

Taina Kurki-Suonio to IPP (Germany), 6–18 Jul 2014 (WP MST1)

Tuomas Tala to IPP (Germany), 7–11 Jul 2014 (WP MST1)

Aaro Järvinen to JET facility (United Kingdom), 22 Jul–22 Aug 2014 (EFDA JET Order)

Tuomas Tala to JET facility (United Kingdom), 18–22 Aug 2014 (EFDA JET Order)

Andrea Sand to Université Lille 1, Unité Matériaux et Transformations, Lille, France, 24–29 Aug 2014 (WP MAT)

Tuomas Tala to JET facility (United Kingdom), 26–29 Aug 2014 (WP JET1)

Markus Airila to JET facility (United Kingdom), 1–5 Sep 2014 (EFDA JET Order)

Leena Aho-Mantila to IPP (Germany), 1 Sep–31 Dec 2014 (EFDA Fellowship)

Timo Kiviniemi to JET facility (United Kingdom), 7–11 Sep 2014 (International Collaborations)

Antti Salmi to JET facility (United Kingdom), 7–11 Sep 2014 (International Collaborations)

Jari Likonen to JET facility (United Kingdom), 8–12 Sep 2014 (WP JET2)

Aaro Järvinen to JET facility (United Kingdom), 8–13 Sep 2014 (EFDA JET Order)

Mathias Groth to JET facility (United Kingdom), 9–26 Sep 2014 (EFDA JET Order)

Antti Hakola to IPP (Germany), 15–18 Sep 2014 (WP MST1)

Paula Sirén to JET facility (United Kingdom), 22 Sep–3 Oct 2014 (EFDA JET Order)

Juuso Karhunen to FOM (Netherlands), 28 Sep–3 Oct 2014 (WP PFC)

Tuomas Tala to JET facility (United Kingdom), 29 Sep–3 Oct 2014 (EFDA JET Order)

Markus Airila to JET facility (United Kingdom), 29 Sep–10 Oct 2014 (EFDA JET Order)

Tuomas Korpilo to HLST meeting, 7–8 Oct 2014 (WP ISA)

Jari Likonen to JET facility (United Kingdom), 9–17 Oct 2014 (WP JET2)

Tuomas Tala to CEA (France), 19–23 Oct 2014 (International Collaborations)

Mathias Groth to General Atomics/DIII-D, San Diego, USA, 1 Nov–6 Dec 2014 (International Collaborations)

Antti Hakola to IPP (Germany), 2–7 Nov 2014 (WP MST1)

Yongbo Wang to PMU-Garching (Germany), 6–8 Nov 2014 (PMU)

Seppo Sipilä to CRU (Croatia), 9–14 Nov 2014 (WP CD)

Otto Asunta to CRU (Croatia), 9–21 Nov 2014 (WP CD)

Jari Likonen to JET facility (United Kingdom), 10–14 Nov 2014 (WP JET2)

Markus Airila to CRU (Croatia), 10–15 Nov 2014 (WP CD)

Juuso Karhunen to JET facility (United Kingdom), 16–21 Nov 2014 (WP MST1)

Simppa Äkäslompolo to CRU (Croatia), 16–21 Nov 2014 (WP CD)

Aaro Järvinen to JET facility (United Kingdom), 16–28 Nov 2014 (WP JET1)

Elnaz Safi to JET facility (United Kingdom), 16–28 Nov 2014 (WP JET1)

Leena Aho-Mantila to JET facility (United Kingdom), 17–21 Nov 2014 (EFDA Fellowship)

Tuomas Tala to JET facility (United Kingdom), 17–21 Nov 2014 (WP JET1)

Kalle Heinola to FZJ (Germany), 23–27 Nov 2014 (WP JET2)

Jari Likonen to FZJ (Germany), 24–27 Nov 2014 (WP JET2)

Antti Hakola to FZJ (Germany), 24–27 Nov 2014 (WP PFC)

Antti Salmi to JET facility (United Kingdom), 24–28 Nov 2014 (WP JET1)

Markus Airila to JET facility (United Kingdom), 24–28 Nov 2014 (WP JET1)

Antti Snicker to IPP (Germany), 10–12 Dec 2014 (WP MST1)

Jari Likonen to JET facility (United Kingdom), 15–19 Dec 2014 (WP JET2)

Antti Snicker to IPP (Germany), 15–19 Dec 2014 (Enabling Research)

12.2 Conferences, seminars, workshops and meetings

M. Groth participated in the 19th ITPA Divertor-SOL Topical Group Meeting, Kanazawa, Japan, 20–23 January 2014.

A. Hakola, J. Karhunen, and J. Likonen participated in a Finnish-Estonian project meeting on joint LIBS activities, Tallinn, Estonia, 06 February and 02 September 2014.

F. Granberg participated in the workshop “Towards Reality in Nanoscale Materials VII”, Levi, Finland, 10–12 February 2014.

T. Tala participated in the 1st EUROfusion General Assembly Meeting, Alphen aan den Rijn, the Netherlands, 18–19 February 2014.

T. Tala participated in the 2nd EUROfusion General Assembly Meeting, Lausanne, Switzerland, 11–12 March 2014.

F. Granberg, T. Makkonen, P. Niskala and K. Särkimäki participated in Physics Days 2014, Tampere, Finland, 11–13 March 2014.

T. Tala participated in the 3rd EUROfusion General Assembly Meeting, Paris, France, 23–24 April 2014.

M. Siuko participated in the WP14-RMS Kick-off meeting, Culham, UK, 28 April 2014.

F. Granberg participated in the 6th Workshop on Nuclear Fe Alloys: Modelling and Experiments (n-FAME), Stockholm, Sweden, 6–7 May 2014.

L. Aho-Mantila, M. Airila, M. Groth, A. Hakola, K. Heinola, A. Järvinen, J. Karhunen, A. Lasa, J. Likonen J. Miettunen, D. Moulton and E. Safi participated in the 21st PSI conference (PSI 2014), Kanazawa, Japan, 26–30 May 2014.

M. Airila participated in the 4th EUROfusion General Assembly Meeting, Brussels, Belgium, 2–3 June 2014.

F. Granberg, M. Nagel and K. Nordlund participated in COSIRES 2014 conference, Alicante, Spain, 8–13 June 2014.

17 FinnFusion participants in the Euratom-Tekes Annual Fusion seminar, Stockholm, Sweden, 10–12 June 2014.

T. Määttä participated in the EFLO Meeting, Barcelona, Spain, 12 June 2014.

M. Airila participated in the 1st FuseCOM Meeting, Lausanne, Switzerland, 18-19 June 2014.

L. Aho-Mantila, T. Kurki-Suonio, P. Niskala and A. Salmi participated in the 41st EPS Conference on Plasma Physics, Berlin, Germany, 23–27 June 2014.

M. Siuko and J. Järvenpää participated in the Divertor PA Meeting, St. Petersburg, Russia, 25–26 June 2014.

M. Airila participated in the 5th EUROfusion General Assembly Meeting, Karlsruhe, Germany, 8–9 July 2014.

K. Nordlund participated in the 2nd IAEA Research Coordination Meeting on Data for Erosion and Tritium Retention in Beryllium Plasma-Facing Materials, Vienna, Austria, 18–19 August 2014.

P. Niskala participated in the 7th International ITER Summer School, Aix-en-Provence, France, 25–29 August 2014.

T. Kiviniemi and A. Salmi participated in the 19th Joint EU-US Transport Task Force Meeting, Culham, UK, 8–11 September 2014.

K. Nordlund participated in the 19th International Conference on Ion Beam Modification of Materials, Leuven, Belgium, 14–19 September 2014.

T. Tala participated in the 6th EUROfusion General Assembly Meeting, Vienna, Austria, 23–24 September 2014.

D. Carfora, A. Hakola, T. Määttä, and S. Äkäslompolo participated in the SOFT 2014 conference, San Sebastian, Spain, 29 September – 03 October 2014.

F. Granberg participated in the 7th International Conference on Multiscale Materials Modeling, Berkeley, California, USA, 6–10 October 2014.

L. Aho-Mantila, M. Groth, A. Järvinen, T. Kiviniemi, T. Kurki-Suonio and T. Tala participated in the 25th IAEA Fusion Energy Conference, St Petersburg, Russia, 13–18 October 2014.

M. Groth and A. Järvinen participated in the 20th ITPA Divertor-SOL Topical Group Meeting, Prague, Czech Republic, 20–23 October 2014.

T. Tala participated in the 13th ITPA Transport & Confinement Topical Group Meeting, Cadarache, France, 20–23 October 2014.

K. Nordlund participated in the NuMat 2014 Conference, Hilton Clearwater, Florida, USA, 27–30 October 2014.

M. Groth participated in the 56th APS DPP Annual Meeting, New Orleans, Louisiana, USA, 27–31 October 2014.

M. Santala participated in the 27th ITPA Diagnostics Topical Group Meeting, Cadarache, France, 3–7 November 2014.

K. Nordlund participated in the 2014 Joint ICTP-IAEA Conference on Models and Data for Plasma-Material Interaction in Fusion Devices, Trieste, Italy, 3–7 November 2014.

A. Hakola participated in the ASDEX Upgrade programme seminar, Ringberg, Germany, 10–14 November 2014.

T. Tala participated in the 7th EUROfusion General Assembly Meeting, Padua, Italy, 13–14 November 2014.

A. Hakola participated in the 22nd European Fusion Programme Workshop (EFPW), Split, Croatia, 30 November–3 December 2014.

T. Tala participated in the 8th EUROfusion General Assembly Meeting, Prague, Czech Republic, 18–19 December 2014.

12.3 Other visits

J. Miettunen visited IPP, Garching, Germany, 24–27 March, 2014.

A. Järvinen visited IPP, Garching, Germany, 7–11 April 2014.

J. Karhunen visited IPP, Garching, Germany, 3–7 November 2014.

A. Järvinen visited DIII-D and General Atomics, San Diego, California, USA, 5–15 November 2014.

12.4 Visitors

France ambassador É. Lebédel and consulate H. Immonen visited VTT (DTP2), 7 February 2014.

F. Escourbiac, L. Ferrand and T. Jokinen from ITER, Cadarache, France visited VTT (DTP2), 2–3 March 2014.

C. Damiani, C. van Hille, E. Ruiz, P. Bates, R. Vitelli, S. Esqué, L. Guerrini and M. Felip from F4E, Barcelona, Spain visited VTT (DTP2), 3–4 March 2014.

T. Stålhane from Norwegian University of Science and Technology from Norway, J. Hedeberg from SP Technical Research Institute of Sweden, Sweden, T. Myklebust from SINTEF, Norway, M. Sundquist from Sundcon Oy visited VTT (DTP2), 16–17 June 2014.

Prof. Song from ASIPP, Mr. Song from Houston University and H. Wu from LUT visited VTT (DTP2), 7 July 2014.

J. Bibby, M. Heath and R. Sharratt from Assystems, UK visited VTT (DTP2), 2 September 2014.

A. Masson and A. Nemeth from European Commission visited VTT (DTP2), 18 September 2014.

S. Esque, and E. Ranz from F4E, Barcelona, Spain, and J. Palmer and A. Fedosov from ITER, Cadarache, France visited VTT (DTP2), 18–19 September 2014.

M. Irzak from Ioffe Institute, St. Petersburg, Russia visited Aalto University, 1–12 December 2014.

E. Gusakov, A. Perevalov and A. Gurchenko from visited Aalto University 8–12 December 2014.

R. Akers from CCFE visited Aalto University for Antti Snicker's PhD defence, 9 December 2014.

R. Rochford from Ireland visited Aalto University, 10–12 December 2014.

Publications 2014

12.5 Publications

12.5.1 Refereed journal articles

1. B. Afra, K. Nordlund, T. Bierschenk, C. Trautmann, M. D. Rodriguez, S. Mudie and P. Kluth, Thermal response of nanoscale cylindrical inclusions of amorphous silica embedded in alpha-quartz, Physical Review B **90** (2014) 224108.
2. E. Joffrin, M. Baruzzo, M. Beurskens, Bourdelle, S. Brezinsek, J. Bucalossi, P. Buratti, G. Calabro, C. Challis, M. Clever, J. Coenen, E. Delabie, R. Dux) P. Lomas,, E. de la Luna, P. de Vries, J. Flanagan, L. Frassinetti, D. Frigione, C. Giroud, M. Groth, N. Hawkes, J. Hobirk, M. Lehnen, G. Maddison, J. Mailloux, C. Maggi, G. Matthews, M. Mayoral, A. Meigs, R. Neu, I. Nunes, T. Puetterich, F. Rimini, M. Sertoli, B. Sieglin, A.C.C. Sips, G. van Roij, I. Voitsekhovitch and JET-EFDA Contributors, First scenario development at JET with the new ITER-like wall, Nuclear Fusion **54** (2014) 013011.
3. C.F. Maggi, E. Delabie, T.M. Biewer, M. Groth, N.C. Hawkes, M. Lehnen, E. de la Luna, K. McCormick, C. Reux, F. Rimini, E.R. Solano, Y. Andrew, C. Bourdelle, V. Bobkov, M. Brix, G. Calabro, A. Czarnecka, J. Flanagan, E. Lerche, S. Marsen, I. Nunes, D. Van Eester, M.F. Stamp and JET EFDA Contributors, L–H power threshold studies in JET with Be/W and C wall, Nuclear Fusion **54** (2014) 023007.
4. M.N.A. Beurskens, L. Frassinetti, C. Challis, C. Giroud, S. Saarelma, B. Alper, C. Angioni, P. Bilkova, C. Bourdelle, S. Brezinsek, P. Buratti, G. Calabro, T. Eich, J. Flanagan, E. Giovannozzi, M. Groth, J. Hobirk, E. Joffrin, M.J. Leyland, P. Lomas, E. de la Luna, M. Kempenaars, G. Maddison, C. Maggi, P. Mantica, M. Maslov, G. Matthews, M.-L. Mayoral, R. Neu, I. Nunes, T. Osborne, F. Rimini, R. Scannell, E.R. Solano, P.B. Snyder, I. Voitsekhovitch, Peter de Vries and JET-EFDA Contributors, Global and pedestal confinement in JET with a Be/W metallic wall, Nuclear Fusion **54** (2014) 043001.
5. E. Lerche, D. Van Eester, P. Jacquet, V. Bobkov, L. Colas, A. Czarnecka, K. Crombe, M.-L. Mayoral, I. Monakhov, F. Rimini, M. Santala, Impact of minority concentration on fundamental (H)D ICRF heating performance in JET-ILW, Nuclear Fusion **54** (2014) 073006.
6. G.P. Maddison, C. Giroud, G. Arnoux, I. Balboa, M. Beurskens, A. Boboc, S. Brezinsek, M. Brix, M. Clever, R. Coelho, J. Coenen, I. Coffey, P. da Silva Aresta Belo, S. Devaux, P. Devynck, T. Eich, R. Felton, J. Flanagan, L. Frassinetti, M. Groth, S. Jachmich, A. Järvinen, E. Joffrin, M. Kempenaars, U. Kruezi, K. Lawson, M. Lehnen, M. Leyland, Y. Liu, P. Lomas, C. Lowry, S. Marsen, G. Matthews, G. McCormick, A. Meigs, R. Neu, I. Nunes, M. Oberkofler, F. Rimini, S. Saarelma, B. Sieglin, A. Sips, A. Sirinelli, M. Stamp, G. van Rooij, D. Ward, Contrasting H-mode behaviour with deuterium fuelling and nitrogen seeding in the all-carbon and metallic versions of JET, Nuclear Fusion **54** (2014) 073016.
7. H. Bergsåker, G. Possnert, I. Bykov, P. Petersson, A. Widdowson, V,. Riccardo, I. Nunes, M. Stamp, S. Brezinsek, K. Heinola, J. Miettunen, M. Groth, T. Kurki-Suonio, J. Likonen, D. Borodin, A. Kirschner, K. Schmid, K. Krieger, First results from the 10Be marker experiment in JET with ITER-like wall, Nuclear Fusion **54** (2014) 082004.

8. A. Lasa, K. Heinola and K. Nordlund, Atomistic Simulations of Be irradiation on W: mixed layer formation and erosion, Nuclear Fusion **54** (2014) 083001.

9. CG. Silva, G. Arnoux, S. Devaux, D. Frigione, M. Groth, J. Horacek, P.J. Lomas, S. Marsen, G. Matthews, L. Meneses, R. A. Pitts, Characterization of scrape-off layer transport in JET limiter plasmas, Nuclear Fusion **54** (2014) 083022.

10. C. Angioni, P. Mantica, T. Puetterich, M. Valisa, M. Baruzzo, E. Belli, P, Belo, F.J. Casson, C. Challis, P. Drewelow, C. Giroud, N. Hawkes, T.C. Hender, J. Hobirk, T. Koskela, L. Lauro Taroni, C.F. Maggi, J. Mlynar, M. L. Reinke, M. Romanelli and JET EFDA Contributors,, Tungsten transport in JET H-mode plasmas in hybrid scenario, experimental observations and modelling, Nuclear Fusion **54** (2014) 083028.

11. C. Guillemaut, R.A. Pitts, A.S. Kukushkin, J.P. Gunn, J. Bucalossi, G. Arnoux, P. Belo, S. Brezinsek, M. Brix, G. Corrigan, S. Devaux, J. Flanagan, M. Groth, D. Harting, A. Huber, S. Jachmich, U. Kruezi, M. Lehnen, C. Marchetto, S. Marsen, A.G. Meigs, O. Meyer, M. Stamp, J.D. Strachan, S. Wiesen, M. Wischmeier and JET EFDA Contributors, Influence of atomic physics on EDGE2D-EIRENE simulations of JET divertor detachment with carbon and beryllium/tungsten plasma-facing components, Nuclear Fusion **54** (2014) 093012.

12. A.. Lasa, K. Heinola and K. Nordlund, The effect of beryllium on deuterium implantation in tungsten by atomistic simulations, Nuclear Fusion **54** (2014) 123021.

13. D. Terentyev, K. Heinola, A. Bakaev, E.E. Zhurkin, Carbon-vacancy interaction controls lattice damage recovery in Iron, Scripta Materialia **86** (2014) 9-12.

14. F. Ghezzi, R. Caniello, D. Giubertoni, M. Bersani, A. Hakola, M. Mayer, V. Rohde, M. Anderle, and ASDEX Upgrade team, Deuterium depth profile quantification in a ASDEX Upgrade divertor tile using secondary ion mass spectrometry, Applied Surface Science **315** (2014) 459-466.

15. K. Nordlund, C. Björkas and T. Ahlgren and and A. Lasa and A. E. Sand, Multiscale modelling of plasma-wall interactions in fusion reactor conditions, Journal of Physics D: Applied Physics **47** (2014) 224018.

16. E. Hirvijoki, O. Asunta, T. Koskela, T. Kurki-Suonio, J. Miettunen, S. Sipilä, A. Snicker, S. Äkäslompolo, ASCOT: Solving the kinetic equation of minority particle species in tokamak plasmas, Computer Physics Communications **185** (2014) 1310-1321.

17. P. Cottier, C. Bourdelle, Y. Camenen, O. D. Gurcan, F. J. Casson, X. Garbet, P. Hennequin and T. Tala, Angular momentum transport modelling: achievements of a gyrokinetic quasi-linear approach, Plasma Physics and Controlled Fusion **56** (2014) 015011.

18. J. Miettunen, M. Airila, T. Makkonen, M. Groth, V. Lindholm, C. Björkas, A. Hakola, H.W. Müller and the ASDEX Upgrade Team, Dissociation of methane and nitrogen molecules and global transport of tracer impurities in an ASDEX Upgrade L-mode plasma, Plasma Physics and Controlled Fusion **56** (2014) 095029.

19. A. Lasa, S.K. Tähtinen and K. Nordlund, Loop punching and bubble rupture causing surface roughening — A model for W fuzz growth, Europhysics Letters **105** (2014) 25002.

20. E. Zarkadoula, S.L. Daraszewicz, D.M. Duffy, M. Seaton, I.T. Todorov, K. Nordlund, M.T. Dove, and K. Trachenko, Electronic effects in high-energy radiation damage in iron, Journal of Physics: Condensed Matter **26** (2014) 085401.

21. L. Bukonte, T. Ahlgren, K. Heinola, Modelling of monovacancy diffusion in W over wide temperature range, Journal of Applied Physics **115** (2014) 123504.

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12.5.3 Research reports

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12.5.4 Academic theses

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187. V. Lindholm, SOLPS simulations of a carbon injection experiment in the ASDEX Upgrade tokamak, MSc thesis, Aalto University, Espoo 2014.

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189. E. Safi, Molecular dynamics simulations of deuterium-beryllium interactions under fusion reactor conditions, MSc thesis, University of Helsinki, 2014.

190. M. Viinikainen, Computer-aided bilateral teleoperation of manipulators, MSc thesis, Tampere University of Technology, 2014.

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Title	**FinnFusion Yearbook 2014**
Author(s)	Markus Airila & Antti Hakola (eds.)
Abstract	This Yearbook summarises the research activities of the FinnFusion Consortium that was established in 2014. The present emphasis of the FinnFusion programme is the following: (i) Technology R&D for ITER construction and systems including industry contracts; (ii) Implementation of the "Fusion Roadmap to the Realization of Fusion Energy" as a member of the EUROfusion Consortium with projects focusing on tokamak experiments and modelling; (iii) Creating concepts for the next generation fusion power plant DEMO in Europe. The members of FinnFusion are VTT Technical Research Centre of Finland Ltd, Aalto University, Lappeenranta University of Technology, Tampere University of Technology, University of Helsinki and Åbo Akademi University. During its first year the FinnFusion Consortium participated in several EUROfusion work packages. The largest ones were experimental campaigns at JET and ASDEX Upgrade and related analyses, materials research, plasma-facing components and remote maintenance. DEMO work on the balance of the plant was a completely new research topic in Finnish fusion activities. EUROfusion also introduced an education work package that allowed FinnFusion to partly fund 10 PhD students within FinnFusion members. In addition, two post-doctoral fellowships funded by the Consortium were running throughout 2014. FinnFusion also provided three NJOC secondees at JET and one EUROfusion Program Management Unit secondee. The F4E activities of FinnFusion continued seamlessly from previous years. Aalto University showed with accurate 3D modelling of magnetic fields and related fast particle losses that escaping energetic particles will not pose a threat to the first wall of ITER. As far as remote handling is concerned, year 2014 was characterized by successful demonstrations of divertor handling operations. For the first time, the annual seminar was organised together with the Swedish and Danish research units in Stockholm in June.
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Nimeke	**FinnFusion-vuosikirja 2014**
Tekijä(t)	Markus Airila & Antti Hakola (toim.)
Tiivistelmä	Tähän vuosikirjaan on koottu vuonna 2014 perustetun FinnFusion-konsortion ensimmäisen vuoden tulokset. Konsortion ohjelman painopistealueet ovat (i) ITER-reaktorin rakentamiseen ja järjestelmiin liittyvän teknologian kehitys yhdessä teollisuuden kanssa; (ii) osallistuminen Fuusion tiekartan toteuttamiseen EUROfusion-konsortion jäsenenä tarjoamalla erityisesti tokamak-kokeisiin ja mallinnukseen liittyvää osaamista; (iii) seuraavan sukupolven eurooppalaisen DEMO-fuusiovoimalan konseptikehitys. FinnFusion-konsortion muodostavat Teknologian tutkimuskeskus VTT Oy, Aalto-yliopisto, Lappeenrannan teknillinen yliopisto, Tampereen teknillinen yliopisto, Helsingin yliopisto ja Åbo Akademi. Ensimmäisenä toimintavuotenaan FinnFusion-konsortio osallistui useisiin EUROfusion-projekteihin. Suurin työpanos kohdistui JET- ja ASDEX Upgrade -koelaitteissa tehtäviin kokeisiin ja analyyseihin, materiaalitutkimukseen, ensiseinämäkomponentteihin ja etäkäsittelyyn. Suomelle täysin uutena aiheena aloitettiin DEMO-laitoksen prosessimallinnus. EUROfusion käynnisti koulutusta tukevan rahoitusinstrumentin, jonka turvin FinnFusion rahoitti osittain kymmenen jatko-opiskelijan työtä jäsenorganisaatioissaan. Lisäksi koko vuoden 2014 ajan oli käynnissä kaksi EUROfusionin rahoittamaa tutkijatohtorin projektia. Kolme FinnFusionin tutkijaa toimi lähetettyinä työntekijöinä JET:n käyttöorganisaatiossa (NJOC) ja yksi EUROfusionin hallinnossa (Program Management Unit). FinnFusionin F4E-työt jatkuivat saumattomasti edellisiltä vuosilta. Aalto-yliopiston tutkijat osoittivat magneettikentän ja nopeiden hiukkasten yksityiskohtaisella 3D-mallillaan, että karkaavat suurienergiaiset hiukkaset eivät uhkaa ITERin ensiseinämän eheyttä. Tampereella sijaitsevan DTP2-koelaitteiston vuotta 2014 värittivät menestyksekkäät diverttorin käsittelyn demonstraatiot. Fuusioalan vuosiseminaari järjestettiin ensimmäistä kertaa yhdessä Ruotsin ja Tanskan fuusiotutkimusyksiköiden kanssa Tukholmassa kesäkuussa 2014.
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