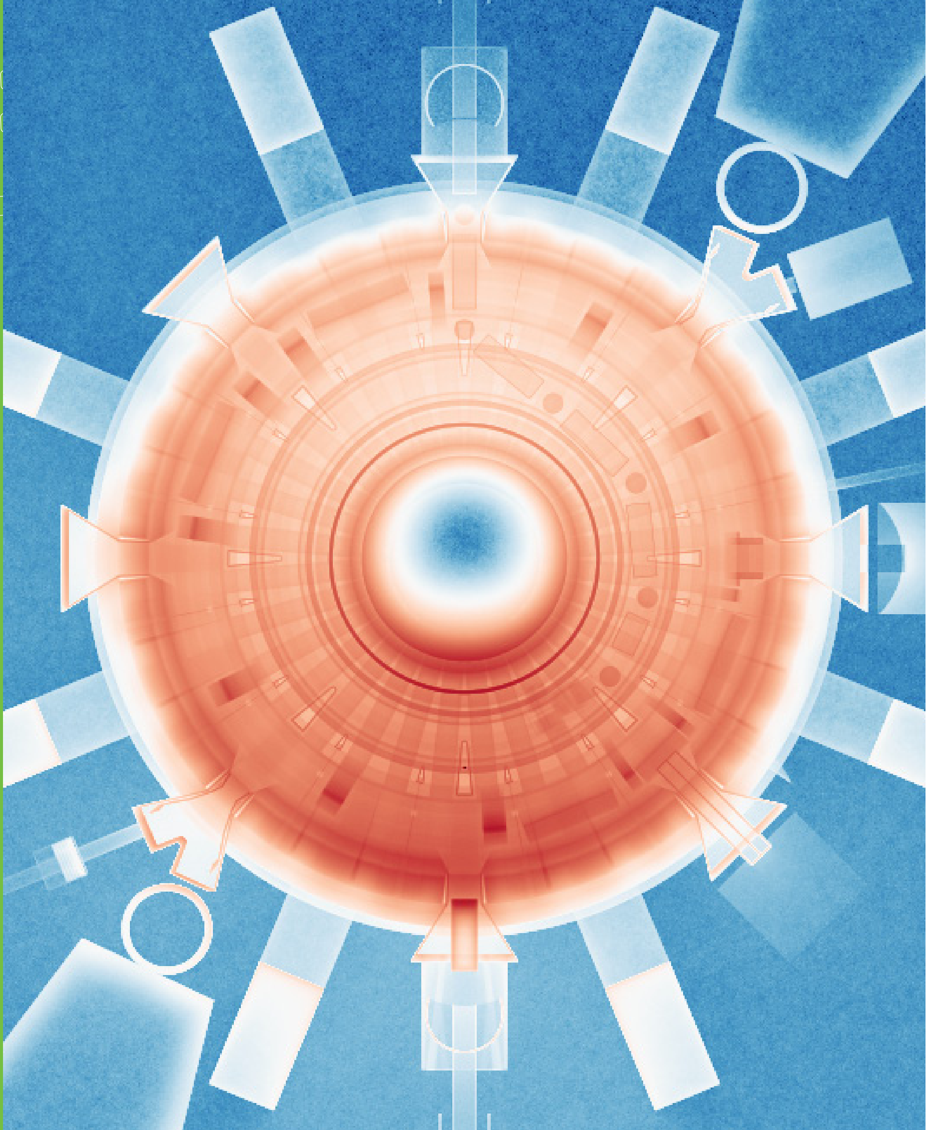

SCIENCE • TECHNOLOGY • RESEARCH HIGHLIGHTS • VISIONS

157

FinnFusion Yearbook 2016

Markus Airila (Ed.)

VTT

VTT SCIENCE 157

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Cover image: Jaakko Leppänen. Simulated neutron flux in JET vessel during detector calibration.

Juvenes Print, Tampere 2017

Preface

The most visible event in fusion research worldwide was without any doubt the inauguration of Wendelstein 7-X (W7-X) stellarator in Greifswald, Germany. The Chancellor of Germany, Angela Merkel, pressed the start button of the first official plasma discharge in February 2016. Hundreds of high-level politicians, scientists and press worldwide were witnessing the great day in Greifswald. This is the first major European plasma device inaugurated for a long time. W7-X is the world's largest stellarator, and will be the key device to investigating a stellarator's suitability as possible design for a future fusion power plant. This fact has put the device firmly in the EUROfusion Roadmap to the realisation of fusion energy. The first results from the experiments on W7-X have exceeded the expectations and therefore, the fusion community is eagerly waiting for the second experimental campaign to start and higher performance discharges at higher heating power with plasma facing components capable of larger heat loads to come in the next few years.

The ITER project has progressed significantly faster in 2016 than in earlier years. The new leadership both in ITER and in F4E has been able to create a positive trend within the project. The tighter collaboration between the ITER Organisation and F4E has promoted this. When visiting the ITER site these days, one can recognise already the shape of the torus on the base of the tokamak building and several buildings have been completed with some 3000 workers on-site day and night. A new approach to constructing the vacuum vessel has been launched, but the vacuum vessel remains as the most critical component in the whole project.

The international fusion research field is now in a very hectic stage. While ITER is now steadily progressing towards the first plasma in short 10 years, JT-60SA, a very large super-conducting large tokamak in Naka, Japan built together by the Japanese and European efforts is expecting its first plasma in 2019–2020 period. The Chinese are now pre-designing their DEMO-type of reactor and Europe is intensively preparing for the major DT campaign and operation in JET as well as discussing the site for the early neutron source device and the divertor test tokamak. The number of both the opportunities and challenges in fusion research are right now enormous, and therefore, tight international collaboration on all levels are needed to reach the goal to the realisation of fusion energy to the grid by 2050.

The FinnFusion Consortium participated in several EUROfusion work packages and F4E related activities. The largest ones in EUROfusion were JET experimental campaigns, JET fusion technology, materials' research, plasma-facing components, remote maintenance and medium-size tokamak work packages. A new research topic pursued in FinnFusion in 2016 is the "Early Neutron Source" work package, aiming at building a device to study hard neutron radiation damage to fusion materials. Selected highlights of these activities are reported briefly in Chapters 2 and 3. Within the F4E Framework Project Agreement (FPA) with a Hungarian consortium, the Remote Handling Connector (RHC) project is part of the development project on Diagnostics System for ITER. VTT as a partner of the Consortium has concentrated on the Divertor RHC development. The purpose of a RHC is to connect divertor cassette diagnostics sensors to ex-vessel diagnostics system. Another F4E activity was the computer assisted teleoperation task coordinated by TUT. The purpose of this task is to develop and demonstrate new means to assist RH operator to perform maintenance operations successfully for the ITER Divertor. These tasks are illustrated in Chapter 9.

The FinnFusion annual seminar in 2016 was organised in Lappeenranta by LUT. The theme was "International (outside EU) collaboration and new fusion devices". Several presentations emphasised the networks of FinnFusion to international collaboration and in total, 14 nationalities were represented among the good 50 participants. In addition, all the FinnFusion students and fellows (13 students funded by EUROfusion) presented their work in one separate session.

The future challenge is to exploit further these international networks and expertise to national benefits. In particular, the greatest challenge right now is to find national funding to complement the EU funded projects. Towards the end of the year, a short letter was prepared and handed over to ministry (MEAE) and Tekes to raise the significant concern of finding the matching national funding. FinnFusion is now in all-time high of its life cycle in terms of the number of research activities, numbers of organizations involved and the magnitude of the EU level funding – the future lies in the hands of national funding bodies and authorities on which level the national funding allows FinnFusion to harvest the fruits of the hard work in future. Finland being a strong nuclear energy country, the fusion community expects a positive result, as enhancing nuclear expertise both in industry and research and educating nuclear experts in top-level international environment must be a top priority among the national authorities to decide on funding.

Tuomas Tala
Head of Research Unit
FinnFusion Consortium

Contents

List of acronyms and names

AFSI	AFSI Fusion Source Integrator (simulation code)
APROS	Advanced Process Simulator (simulation code suite)
ASCOT	Accelerated Simulation of Charged Particle Orbits in Tori (particle tracing code)
AU	Aalto University, Espoo/Helsinki, Finland
AUG	ASDEX Upgrade (tokamak facility)
AWP	Annual Work Programme (of EUROfusion)
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 RU)
CFC	Carbon fibre composite
DIII-D	Tokamak facility at General Atomics, San Diego
DEMO	Future demonstration fusion power plant
DFTL	Deputy task force leader
DIFFER	Dutch Institute for Fundamental Energy Research (Dutch RU)
DIV	Divertor
DOF	Degree of freedom
DONES	DEMO oriented neutron source
DTP2	Divertor test platform phase 2 (test facility in Tampere)
EAMA	Articulated serial manipulator on EAST tokamak
EAST	Experimental Advanced Superconducting Tokamak
EDGE2D	Fluid plasma simulation code
EDP	Erosion-deposition probe
EE	End-effector
EFDA	European Fusion Development Agreement (preceded EUROfusion)
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 RU)
ERO	Monte Carlo impurity transport simulation code
ETS	European transport solver (simulation code)
EUROfusion	European consortium implementing the Fusion Roadmap
F4E	Fusion for Energy (the European Domestic Agency of ITER)
FEM	Finite element method (numerical method)
FENDL	Fusion Evaluated Nuclear Data Library
FI	Ferritic insert
FPA	Framework project agreement
FT-2	Tokamak facility
GAM	Geodesic acoustic mode (plasma instability)
GLF23	Plasma transport model based on Gyro-Landau-Fluid equations
HCD	Heating and current drive
HFGC	High-field side gap closure tile in JET vessel
HKM	Hybrid kinetic manipulator
IAEA	International Atomic Energy Agency
IBA	Ion beam analysis
ICRH	Ion cyclotron resonance heating
IFMIF	International Materials Irradiation Facility (under design)
ILW	ITER-like wall
IPP	Institut für Plasmaphysik, Garching/Greifswald
IPP.CR	Institute of Plasma Physics of the Czech Academy of Sciences (Czech RU)
IST	Instituto Superior Técnico (Portuguese RU)
ITER	Next step international tokamak experiment under construction in Cadarache, France (“the way” in Latin)
ITPA	International Tokamak Physics Activity
JET	Joint European Torus (tokamak facility)
JSI	Jozef Stefan Institute (Slovenian RU)
LIBS	Laser induced breakdown spectroscopy
LUT	Lappeenranta University of Technology
MAST	Mega Amp Spherical Tokamak (tokamak facility)
MAST-U	MAST Upgrade
MCMC	Markov chain Monte Carlo (optimization method)

MCMC-ANN	Markov chain Monte Carlo based artificial neural network
MCNP	Monte Carlo reactor physics simulation code
MD	Molecular dynamics (simulation method)
MEAE	Ministry of Economic Affairs and Employment (in Finland)
MPI	Message passing interface (programming interface for parallel computing)
NBI	Neutral beam injection
NJOC	New JET Operating Contract
NPA	Neutral particle analyser
OpenMP	Open multi-processing (programming interface for parallel computing)
PFC	Plasma-facing component
PHTS	Primary heat transfer system
PIC	Particle-in-cell (plasma simulation method)
PMU	Programme Management Unit (of EUROfusion; Garching, Culham)
RACE	Remote applications in challenging environments (research facility)
RAMI	Reliability, availability, maintainability and inspectability
RH	Remote handling
RHC	Remote handling connector
RU	Research Unit (member of EUROfusion)
SERPENT	Monte Carlo reactor physics simulation code developed at VTT
SIMS	Secondary ion mass spectrometry
SOL	Scrape-off layer
SOLPS	Scrape-off Layer Plasma Simulation (fluid plasma simulation code)
SPC	Swiss Plasma Center (Swiss RU)
TCV	Tokamak à Configuration Variable (tokamak facility)
TDS	Thermal desorption spectrometry
TOF-ERDA	Time-of-flight elastic recoil detection analysis
TOFOR	Time-of-flight spectrometer
Tekes	The Finnish Funding Agency for Innovation
TUMAN-3M	Tokamak facility
UH	University of Helsinki
TUT	Tampere University of Technology
VR	Vetenskapsrådet (Swedish RU)
VTT	VTT Technical Research Centre of Finland Ltd
VV	Vacuum vessel
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 EUROfusion Work Programme 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 30 beneficiaries, practically one per member state. IPP from Germany acts as the co-ordinator of the Consortium. VTT acts as the beneficiary to EUROfusion in Finland. EUROfusion Consortium implements the activities described in the Roadmap to Fusion during Horizon 2020 through a Joint programme of the members of the EUROfusion consortium. A 734 M€ grant (including NJOC) for the period 2014–2018 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.

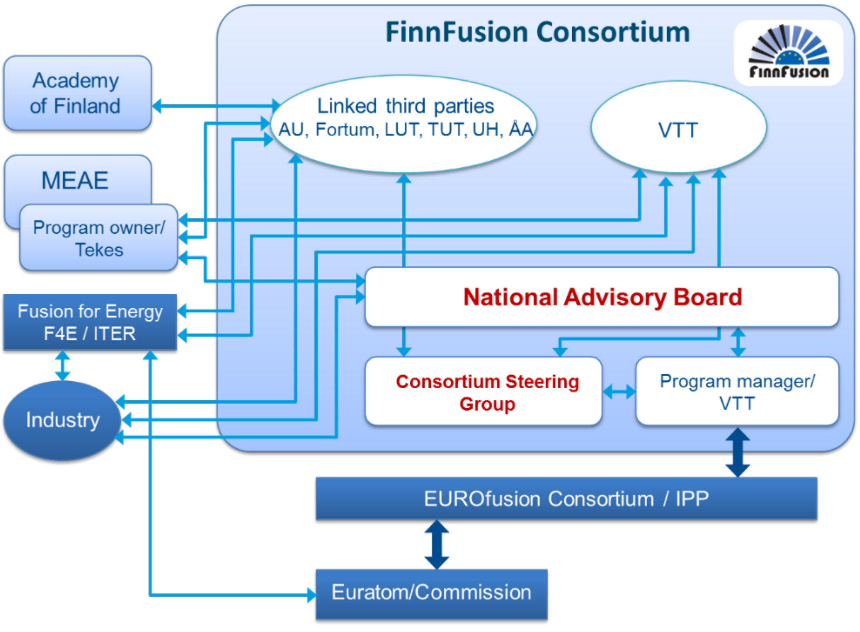

Figure 1.1. Organigram of Finnish Fusion Research Community in 2015–2020.

1.3 Research Unit

The Finnish Research Unit, FinnFusion, consists of several research groups from VTT, universities and industry. The Head of the Research Unit is Dr. Tuomas Tala from VTT. The following institutes and universities participated in 2016:

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, MSc. Eric Dorval, Dr. Antti Hakola, Mrs. Anne Kemppainen (administration), MSc. Seppo Koivuranta, Dr. Jaakko Leppänen, Dr. Jari Likonen (Project Manager), MSc. Sixten Norrman, MSc. Sanna-Paula Pehkonen, Dr. Antti Salmi, MSc. Paula Sirén

Activities: Safety engineering
Members: MSc. Toni Ahonen, MSc. Atte Helminen (Project Manager), Lic.Tech. Ilkka Karanta, Dr. Anna Matala, MSc. Topi Sikanen, MSc. Risto Tuominen, MSc. Tero Tyrväinen, MSc. Pasi Valkokari

Activities: Remote handling, DTP2
Members: MSc. Jarmo Alanen, Tech. Vesa Hämäläinen, Dr. Ali Muhammad (Project Manager), MSc. Harri Mäkinen, MSc. Teemu Mätäsniemi, Dr. Timo Määttä (Project Manager), Dr. Olli Saarela, MSc. Hannu Saarinen, MSc. Karoliina Salminen, Dr. Romain Sibois, Lic.Tech. Mikko Siuko (Project Manager), Dr. Risto Tiusanen, MSc. Outi Venho-Ahonen, MSc. Jarno Videnoja

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

Activities: Physics
Members: Prof. Mathias Groth (Head of Laboratory), Dr. Laurent Chone, MSc. Juuso Karhunen, Dr. Timo Kiviniemi, MSc. Tuomas Korpilo, Dr. Taina Kurki-Suonio, Dr. Susan Leerink, MSc. Paavo Niskala, Dr. Bartosz Lomawoski, Dr. Johnny Lönnroth (PMU secondee), MSc. Ivan Paradela Perez, Dr. Ronan Rochford, Dr. Marko Santala (NJOC secondee), Dr. Seppo Sipilä, MSc. Konsta Särkimäki MSc. Jaroslavs Uljanovs, MSc Jari Varje, Dr. Simppa Äkäslompolo
Students: Petteri Heliste, Andreas Holm, Joona Kontula, Juuso Terävä, Rasmus Viitala, Jaarli Suviranta, Patrik Ollus, Benjamin Grigoriadis, Mike Machielsen (Fusenet, TU/e, the Netherlands)

University of Helsinki (UH), Accelerator Laboratory

Activities: Physics, materials

Members: Dr. Tommy Ahlgren, Dr. Carolina Björkas, MSc. Laura Bukonte, Dr. MSc. Jesper Byggmästar, Flyura Djurabekova, Dr. Fredric Granberg, Dr. Kalle Heinola, Dr. Antti Kuronen MSc. Aki Lahtinen, Dr. Kenichiro Mizohata, Prof. Kai Nordlund (Project Manager), Dr. Jussi Polvi, Prof. Jyrki Räisänen (Project Manager), MSc. Elnaz Safi, Dr. Andrea Sand

Tampere University of Technology (TUT)

Activities: Remote handling, DTP2

Members: MSc. Liisa Aha, MSc. Dario Carfora, Dr. Juha-Pekka Karjalainen, MSc. Janne Koivumäki, MSc. Ville Lyytikäinen, Prof. Jouni Mattila (Project Manager), MSc. Longchuan Niu, MSc. Jarmo Nurmi, MSc. Sergey Smirnov, MSc. Jyrki Tammisto, MSc. Janne Tuominen, MSc. Jukka Väyrynen

Lappeenranta University of Technology (LUT), Lab. of Intelligent Machines

Activities: Robotics

Members: Prof. Heikki Handroos (Project Manager), MSc. Ming Li, Dr. Yongbo Wang, Prof. Huapeng Wu, MSc. Jing Wu

Fortum Power and Heat Ltd.

Activities: Power plant engineering

Members: MSc. Sami Herranen, MSc. Sami Kiviluoto, MSc. Anssi Laakso, MSc. Miko Olkkonen, Dr. Harri Tuomisto

1.4 FinnFusion Advisory Board

FinnFusion Advisory Board gives opinions on the strategy and planning of the national research effort, promotes collaboration and information exchange between research laboratories and industry and sets priorities for the Finnish activities in the EU Fusion Programme. The Board consists of the Parties and other important Finnish actors in Finnish fusion energy research.

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 / Anna Kalliomäki, 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 / Jorma Aurela, MEAE
	Liisa Heikinheimo, TVO
	Timo Vanttola / Satu Helynen, VTT
	Riikka Virkkunen / Johannes Koskinen, 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 2016.

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 EUROfusion HPC Allocation Committee

- Susan Leerink, AU

1.5.6 EUROfusion Project Boards

- WP JET2: Antti Hakola, VTT
- WP JET4: Marko Santala, AU / Markus Airila, VTT
- WP PFC: Jari Likonen, VTT
- WP DTT1: Leena Aho-Mantila, VTT
- WP CD: Timo Kiviniemi, AU
- WP S1 & S2: Taina Kurki-Suonio, AU
- WP BB & BOP: Markus Airila, VTT
- WP RM: Timo Määttä, VTT
- WP MAT: Kai Nordlund, UH
- WP ENS: Mikko Siuko, VTT

1.5.7 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

1.5.8 Procurements and Contracts Committee for the Joint European Undertaking for ITER and the Development of Fusion Energy, "Fusion for Energy" (F4E PCC)

- Herkko Plit, Ministry of Employment and the Economy

1.5.9 Other international duties and Finnish representatives in the following fusion committees and expert groups in 2016

- Markus Airila is the VTT representative in EUROfusion Communications Network (FuseCOM).
- Kalle Heinola is a member of the international committee of the H-Workshop (International Workshop on Hydrogen Isotopes in Fusion Reactor Materials).
- Kalle Heinola is a member of the Local Organizing Committee of the MoD-PMI Workshop (Loughborough, UK).
- 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.
- 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.
- Taina Kurki-Suonio is appointed as an affiliated professor in physics, in particular plasma physics (2014–2016) at Chalmers University of Technology, Gothenburg, Sweden.
- Taina Kurki-Suonio is a member of the *Nuclear Fusion* Editorial Board
- Kai Nordlund is a member of the international committee of the COSIRES Conference (Computer Simulation of Radiation Effects in Solids).
- Harri Tuomisto is a member of the Fusion Industry Innovation Forum Management Board (FIIF MB).
- Harri Tuomisto is a member of the DEMO stakeholders group.

2. ITER Physics Workprogramme 2016

2.1 WP JET1: JET experimental campaigns C35–37

Research scientists: M. Groth, P. Heliste, B. Lomanowski, M. Santala, C. Stavrou, J. Uljanovs, J. Varje, AU
K. Heinola, UH
L. Aho-Mantila, M. Airila, J. Likonen, S.-P. Pehkonen, A. Salmi, P. Sirén, T. Tala, VTT

2.1.1 Overview

JET completed an extensive experimental programme in 2016, consisting of campaigns C36 (Jan–Jul), C37 in hydrogen (Jul–Sep) and C36b (Oct–Nov). Two main milestones in the operation with the ILW were (i) showing the compatibility of operation of high-energy plasmas (~10MJ) with a metallic wall, and (ii) reaching the peak value close to 3×10^{16} neutrons/s in both the hybrid and baseline scenarios. These results indicate the goals that EUROfusion has set for the upcoming JET DT campaign are achievable.

FinnFusion contributed to investigations of plasma edge modelling, experimental plasma-wall interaction studies, core transport studies, and support for JET neutral particle analysers. In this Yearbook we highlight the study of particle transport utilizing the gas puff modulation technique.

2.1.2 About transport studies

Particle transport in tokamaks has received much less attention than electron and ion heat transport channels. It is still often not treated self-consistently in transport modelling and predictions for future tokamaks. Consequently, particle transport and fuelling remain one of the major open questions in understanding the ITER physics. The shape of the density profile has a significant influence on fusion performance and impurity transport.

Particle transport has been extensively studied by performing several dimensionally matched collisionality scans in various plasma scenarios in JET. Gas puff modulation technique has been developed with high quality time-dependent density profile measurements to determine particle transport coefficients. Density peaking has been found to increase with decreasing ion gyro-radius in all H-mode scenarios while in L-mode, no dependency was found as shown in Figure 2.1. The experimentally determined particle transport coefficients confirm that NBI fuelling is one of the main contributors to the observed density peaking in H-mode. This is further supported by predictive transport simulations with GLF23 and gyro-kinetic analysis. These results will extrapolate to future tokamaks in such a way that density peaking may be quite moderate even in low collisionality regimes in the absence of core particle sources.

Additional experiments were conducted to gain information of the plasma fuelling processes through the plasma edge. A new technique utilising strike point sweeping modulation was pioneered to complement the lower-frequency gas puff modulations. A clear effect in electron density was seen at high frequencies potentially providing experimental ionisation source. The analysis of these data is ongoing.

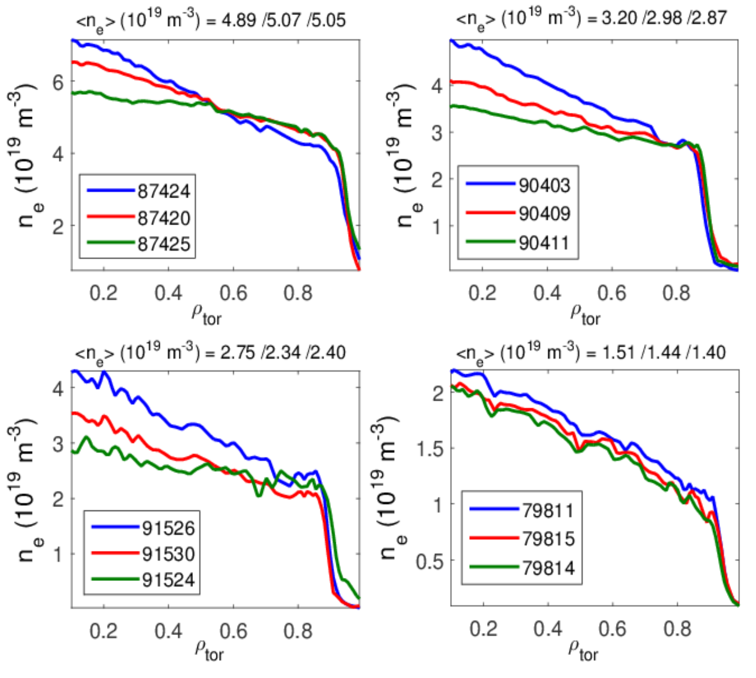

Figure 2.1. Density profiles from the following four different dimensionless collisionality scans: (top left, case (i)) high power ELMy H-mode featuring low β, (top right, case (ii)) hybrid like high β plasma, (bottom left, case (iii)) ELMy H-mode plasma in Hydrogen and (bottom right, case (iv)) L-mode with carbon wall. The blue colour refers to the low collisionality case, the green one to high collisionality (red intermediate).

2.2 WP JET2: Plasma-facing components

Research scientists: K. Heinola (Sub-Project Leader), A. Lahtinen, K. Mizohata, J. Räisänen, UH
A. Hakola, S. Koivuranta, J. Likonen, VTT

During the shutdown in 2009–2011, all the carbon-based plasma facing components (PFC) were replaced with the ITER-like wall (JET-ILW). Second set of wall and divertor tiles for post-mortem analyses were removed during the shutdown in 2014. The divertor tiles of JET-ILW are made of tungsten-coated carbon fibre composites (CFC), except the load bearing tiles at the divertor floor, 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 divertor and wall components and in-vessel erosion-deposition probes (EDP) in 2016 and VTT used Secondary Ion Mass Spectrometry (SIMS), Time of Flight Elastic Recoil Detection Analysis (TOF-ERDA), Thermal Desorption Spectrometry (TDS) and tile profiling for the analysis of wall components. The latter two techniques are available at CCFE. Analysis of divertor tiles for erosion, deposition and fuel retention was completed in 2016. SIMS measurements show that the thickest beryllium (Be) dominated deposition layers are located at the upper part of the inner divertor and are up to ~40 µm thick at the lower part of the HFGC tile exposed in 2011–2014. The highest deuterium (D) amounts (> $1 \cdot 10^{18}$ at./cm^2) were found on the upper part of Tile 1, where the Be deposits are ~10 µm thick and on HFGC tile. D was mainly retained in the near-surface layer of the Be deposits but also deeper in tungsten (W) and molybdenum (Mo) layers of the marker coated tiles, especially at W-Mo layer interfaces. SIMS results for deuterium retention on divertor tiles have been compared with TDS and Ion Beam Analysis (IBA) in 2016 and there is a good agreement between the results.

Fuel retention, especially the radioactive tritium (T), in the plasma-facing components plays an important role in the safe operation of future fusion devices such as ITER and DEMO. In ITER, the baseline strategy for the removal of retained T is baking of the main wall at 240°C and at 350°C for the divertor. In order to assess the efficiency of baking for T removal, hydrogen retention/release behaviour has been studied using realistic, ITER-Like tokamak samples exposed in 2010–2012 and in 2012–2014 that were annealed by TDS. The TDS results and computer simulations made at ITER showed that the efficiency of the 350°C appears limited for thick (>50 microns) co-deposits, and significant durations (~1–3 months) might be required to remove significant fractions of retained tritium. Figure 2.2 shows that the thicker the co-deposited layer is the harder the fuel removal is.

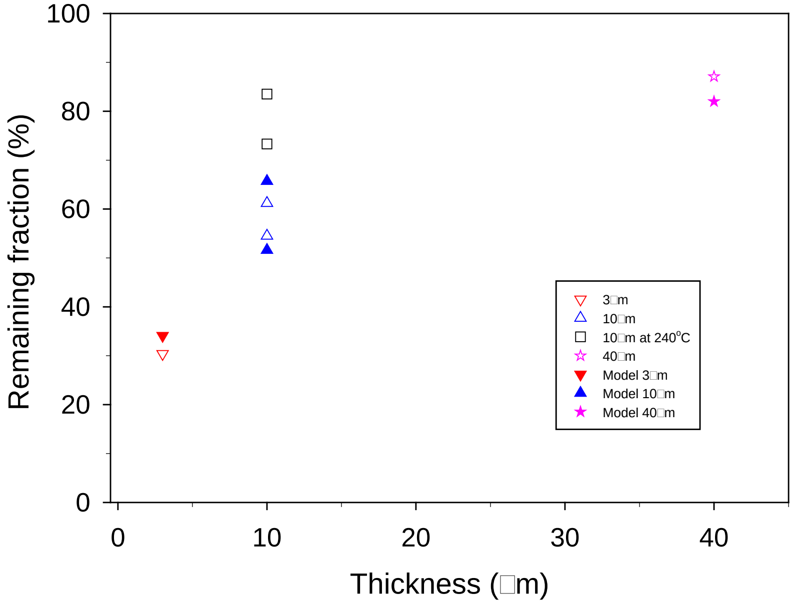

Figure 2.2. The amount of fuel not removed during annealing as a function of layer thickness.

2.3 WP JET3: Technological exploitation of DT operation for ITER

2.3.1 Application of SERPENT to JET neutronics analyses

Research scientists: J. Leppänen, P. Sirén, VTT

Of particular interest for JET is the capability of using neutron sources from plasma scenario simulations. This would allow us to perform sensitivity analyses on the dependence of KN1 and KN2 calibration factors on the plasma regime (ohmic, NBI and/or IC heated). The 2016 objective for VTT was to test and demonstrate SERPENT's capabilities in JET-relevant applications using existing MCNP models converted to SERPENT input format.

Several minor modifications and additions had to be made in the SERPENT source code to accommodate all geometry features in the converted JET models. These modifications included adding new surface types and new options for geometry transformations. A number of consistency checks were run for the SERPENT input models to confirm that the MCNP geometry was reproduced without errors.

First, the volumes of all geometry cells in the MCNP and SERPENT models were calculated by Monte Carlo sampling. The results confirmed that the volumes were preserved to within statistical accuracy. The volume calculation was followed by transport simulations using one of the Remote Handling Models provided by JSI. The ^{252}Cf source spectrum was adopted from the MCNP input. The simulation was run using FENDL-3.0 based cross section libraries. Spatial 2D flux distribution was compared to a reference MCNP6 result obtained using a corresponding mesh tally (Figure 2.3). The differences between MCNP6 and Serpent are shown to be within the range of statistical accuracy.

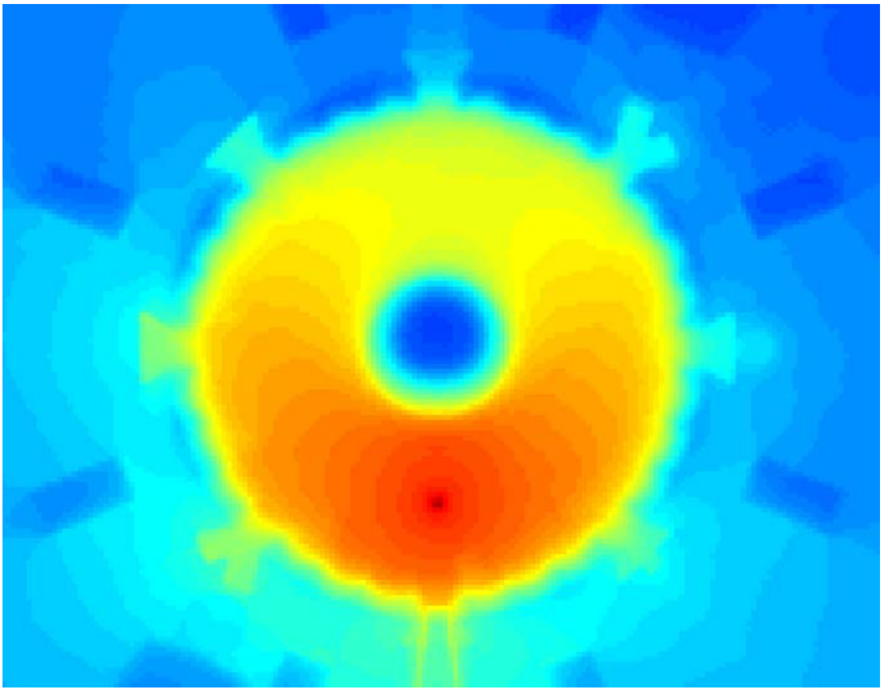

Figure 2.3. Calculated spatial distribution of neutron flux in JET vessel and surroundings from the ^{252}Cf calibration source.

The SERPENT/MCNP comparison also included calculation of ^{115}In activation rates in KN2 irradiation ends. Cross sections for $^{115}In(n,n')$ were obtained from the IRDFF library. The calculations were carried out using input models in which the ^{252}Cf source was moved adjacent to the activated sample. The ^{115}In activation spectra were calculated using track-length estimate based detectors and the results were compared to corresponding F4 tallies calculated by MCNP6 (Figure 2.4). The differences are within the range of statistics.

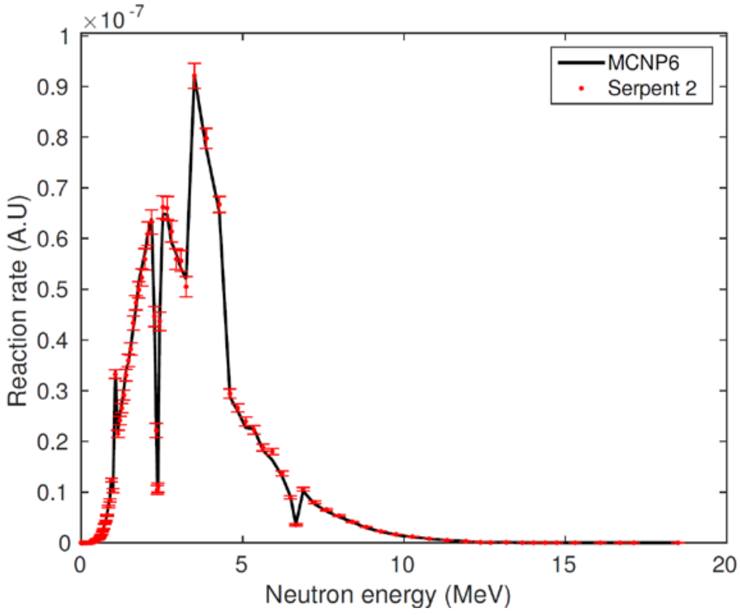

Figure 2.4. Comparison of ^{115}In activation spectra between MCNP and SERPENT.

All calculations were run in the same computer cluster with same number of neutron histories, and the running time for SERPENT was about 50 % (20.8 hours) of that using MCNP6. It was discovered, however, that the input model was not constructed in an optimal way considering the geometry routine used in SERPENT, and further optimization could lead to higher performance.ng MCNP models converted to SERPENT input format.

These preliminary tests and comparison to MCNP6 results provide a good starting point for continuing the studies in 2017. Research topics will include calculations using realistic neutron source models obtained from plasma scenario simulations. The effect of the varied neutron sources (energy spectrum and spatial and directional distribution of emitted neutrons) on KN1 and KN2 calibration factors will be investigated.

2.4 WP JET4: JET 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 was 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 was carried out in collaboration with FinnFusion, VR (Sweden) and JET operator. The participation of FinnFusion in the project was discontinued in 2016.

2.5 WP MST1: Medium-size tokamak campaigns

Research scientists: T. Kurki-Suonio, AU
A. Hakola, S.-P. Pehkonen, A. Salmi, T. Tala, VTT
A. Lahtinen, J. Räisänen, UH

2.5.1 Overview

Of the three MST1 devices, AUG completed its 2015–2016 experimental campaign in May and TCV in December; MAST-U was still being upgraded. A large part of the research on AUG and TCV focused on the following objectives: (i) mitigation and suppression of ELMs by pellets and resonant magnetic perturbations (RMPs), (ii) developing methods for disruption mitigation and avoidance and for controlling runaway electrons, and (iii) developing high-power plasma scenarios with tolerable heat and particle loads on the wall structures. FinnFusion contributed especially to experimental plasma-wall interaction studies, intrinsic torque and momentum transport investigations, as well as analysing the wall loads upon application of different RMPs. In this Yearbook we highlight the response of W plasma-facing components to helium plasmas.

2.5.2 Plasma-wall interaction studies in AUG during helium plasmas

In 2016, much effort was put on investigating plasma-wall interactions on AUG during its dedicated helium campaign. To this end, a number of samples (see Figure 2.5a) – bulk W and Mo samples, graphite samples with W marker coatings, and bulk W samples with pre-formed nanostructures on them – were exposed to ELMy H-mode plasmas in He in the outer strike-point region and the surfaces were analysed for their erosion, deposition, and fuel retention patterns using standard ion-beam methods. No net erosion of W was observed (see Figure 2.5b), but the surfaces had been covered with co-deposited layers, mainly consisting of W, B, C, and D and being the thickest on rough and modified surfaces. This is different from the typical erosion-deposition patterns in D plasmas, where usually sharp net-erosion peaks surrounded by prominent net-deposition maxima for W are observed around the strike point. Moreover, no clear signs of W nanostructure growth or destruction could be seen. The growth of deposited layers may impact the operation of future fusion reactors and is attributed to strong sources in the main chamber that under suitable conditions may switch the balance from net erosion into net deposition. In addition, the absence of chemical erosion in helium plasmas may have affected the thickness of the deposited layers. Retention of He, for its part, remained small and uniform throughout the strike-point region although our results indicate that samples with smooth surfaces can contain an order of magnitude less He than their rough counterparts.

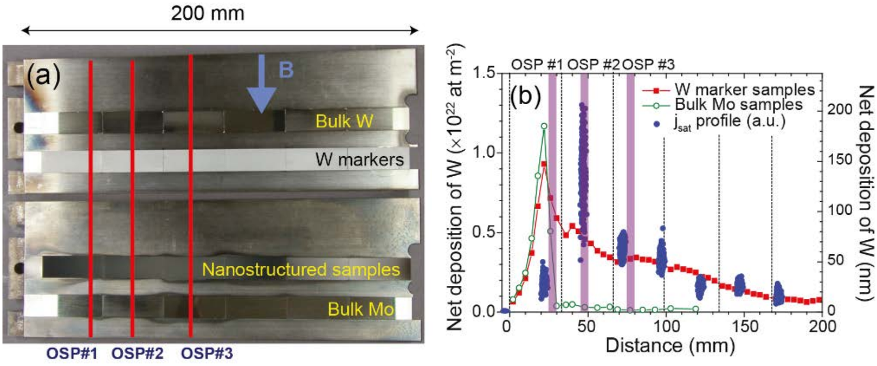

Figure 2.5. (a) Photograph of the four sample types mounted in the target tiles after the plasma experiment in helium. The outer strike point (OSP) positions for three different phases of the experiment have been marked with red lines. (b) Poloidal net deposition profile for the W marker sample and re-deposition profile for W on the bulk Mo samples. For comparison, the profile for the ion saturation flux during the second OSP phase is shown.

2.5.3 Deputy Task Force Leadership activities

In 2016, Antti Hakola continued his activities as a Deputy Task Force Leader (DTFL) of the MST1 Work Package. The DTFL term lasts until the end of 2018 and consists of coordinating specific experiments at the ASDEX Upgrade (AUG), TCV, and MAST-U tokamaks as well as planning, monitoring, and reporting the outcomes of experimental campaigns on the three devices. The responsibility areas of Hakola include the following headlines from the EUROfusion Roadmap: HL1.5 (Control of core contamination and dilution from W PFCs), HL1.6 (Determine optimum particle throughput for reactor scenarios), and HL2.2 (Prepare efficient PFC operation for ITER and DEMO). In 2016, altogether 17 experiments on AUG and TCV were carried out under these headlines. The results were presented in different review meetings and a number of conference contributions and journal articles were submitted. The main highlights were: (i) obtaining significant reduction for W sputtering from the main-chamber structures of AUG by utilizing a novel ion cyclotron resonance heating antenna; (ii) demonstrating flash melting of W by ELMs at the outer strike point region of AUG; (iii) observing that in helium plasmas net erosion can be almost non-existent on AUG; and (iv) both ion-cyclotron and electron-cyclotron heating are powerful tools in conditioning the vessel walls of AUG and TCV and removing fuel and impurities from the wall structures.

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

Research scientists: M. Groth, J. Karhunen, AU
T. Ahlgren, K. Heinola, A. Kuronen, A. Lahtinen, K. Nordlund, K. Mizohata, J. Polvi, J. Räisänen, E. Safi, UH
M. Airila, A. Hakola, VTT

2.6.1 Overview

The PFC Work Package aims at understanding the erosion, fuel retention and surface damage characteristics of different plasma-facing components (PFCs) to be used in ITER or DEMO, both experimentally and with the help of numerical simulations. In 2016, the focus points were: (i) understanding the effect of surface roughness and seeded impurities on erosion and fuel retention of W PFCs; (ii) validating plasma-wall interaction codes; and (iii) preparing for the implementation of experiments on WEST in 2017. Under FinnFusion, the focus areas were surface analyses of tokamak and laboratory samples, modelling of AUG experiments using ERO and SOLPS, and modelling erosion and retention behaviour of Be and W. Here, we highlight the measurements and modelling of SOL flows of injected nitrogen atoms on AUG.

2.6.2 Spectroscopic observation of SOL flows

SOL flows of injected nitrogen impurities have been studied spectroscopically in the HFS midplane region of AUG during L-mode discharges with different degrees of inner divertor detachment. Results from a 2015 experiment indicated reversal of the measured N^+ flow in the near SOL in high-recycling regime and flow always towards the inner target in detached conditions. However, ERO simulations showed poor frictional entrainment of the N^+ ions with the background D^+ flow, while improved entrainment was observed for N^{2+} and N^{3+} ions.

The experiment was repeated in 2016 by recording emission of both N^+ and N^{2+} ions during similar plasma discharges as in 2015 (see Figure 2.6a). Consistent observations regarding the change of the flow direction were made for both ionization states, while the measured N^{2+} velocities were approximately 2–3 times higher than the N^+ velocities, suggesting better entrainment of the N^{2+} ions and improved quantitativity of the measurements at higher ionization states.

To examine the qualitative representativeness of the measured impurity flows in describing the D^+ flow and the phenomena behind the observations, the behaviour of the D^+ flow in the course of detachment has been studied by SOLPS 5.0 by running density and power scans covering the range of the experiment (see Figure 2.6b). Initial results show similar behaviour of the D^+ flow direction as experimentally observed for $N^{+/2+}$ with reversal of the near-SOL flow coinciding with strongly localized ionization of recycled D in the HFS divertor making the divertor pressure exceed the upstream value and reversing the flow direction.

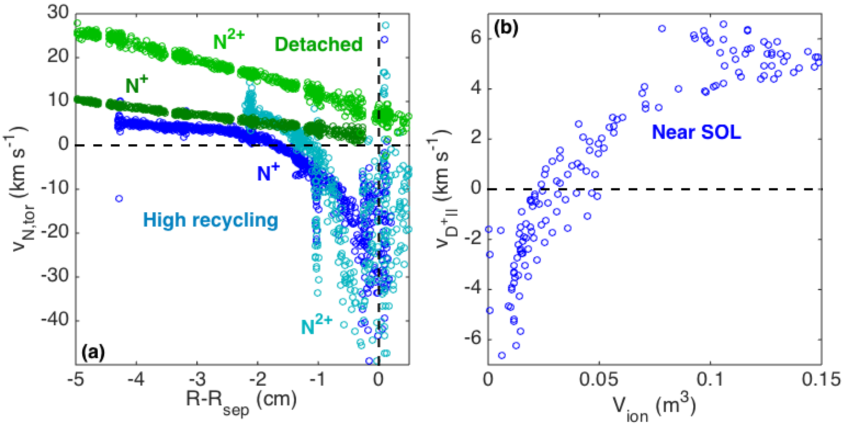

Figure 2.6. (a) Measured radial profiles of toroidal flow velocities of N^+ and N^{2+} ions at the HFS midplane under high-recycling and detached inner divertor conditions. (b) The parallel flow velocity of D+ ions approximately 1.0 cm outside the separatrix at the HFS midplane, given by SOLPS 5.0 density and power scans, as a function of the localization of ionization of recycled D. Here, V_{ion} is given by the volume inside the 50 % contour of the 2D ionization rate map in the HFS divertor volume. In both (a) and (b), positive velocities correspond to co-current flow towards the inner target and negative velocities to flow reversal.

2.7 WP S1: Preparation and exploitation of W-7X campaigns

2.7.1 Fast ions power loads on the first wall of W7-X

Research scientists: J. Kontula, T. Kurki-Suonio, S. Sipilä, S. Äkäslompolo, AU

Due to missing symmetry properties in stellarators, the confinement of fast ions in non-trivial and has to be verified for W7-X. We simulated both the NBI (WP16.S1.C3.T1) and ICRH (WP16.S1.C3.T2) power loads to the W7-X wall with the ASCOT suite of codes using a realistic 3D magnetic field configuration and wall.

The beam ions were generated using the BBNBI code, and their guiding centres (GC) were followed with the ASCOT4 code. Precise wall-hit locations were calculated by switching to full gyro-orbit (GO) following near the walls. The simulations were carried out for nine different operational scenarios, designed for vanishing bootstrap current. These consist of three densities ($n = 0.75 \times 10^{20}$ m^{-3}, $n = 1.5 \times 10^{20}$ m^{-3} and $n = 0.3 \times 10^{20}$ m^{-3}) at three different edge rotational transform values (ι = 5/5, ι = 5/4, and ι = 5/6). The shine-through losses at low-density were prohibitively high, so these scenarios were excluded. The lowest power loads were for the low edge-ι, $n = 1.5 \times 10^{20}$ m^{-3} scenario (0.4 MW, 7 % of the injected power), while the highest loads were for the high edge-ι, $n = 0.75 \times 10^{20}$ m^{-3} scenario (1.1 MW, 20 % of the injected power). Therefore, both plasma density and edge-ι should be considered when planning NBI operation in W7-X

The ICRH test ions were generated by the SCENIC code suite with PICRH = 1.5MW at <β> = 4 %, and simulated with ASCOT4. An ICRH ion ensemble of hydrogen ions was started from the last closed flux surface and followed until they hit the wall. The simulations were made using both the GC and GO formalisms. Since the GO simulations produced a markedly more peaked load distribution (Figure 2.7), the GC approach cannot be relied on to give an accurate picture of the wall load distribution.

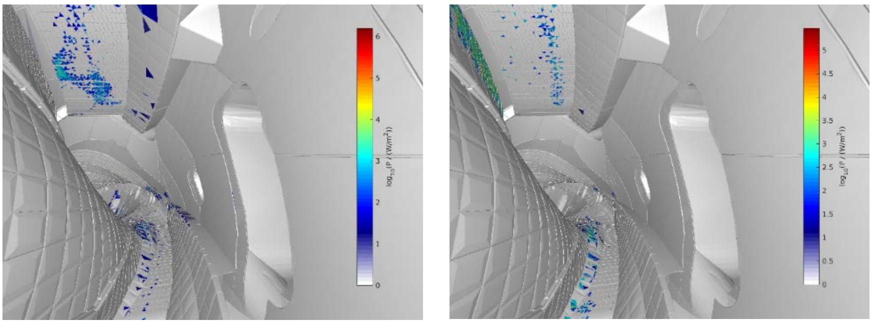

Figure 2.7. ASCOT-simulated W7-X ICRH ion wall load distributions in configuration space for guiding-center formalism (left) and gyro-orbit formalism (right).

2.8 WP CD: Code development for integrated modelling

Research scientists: S. Sipilä, J. Varje, AU
M. Airila, VTT

The ASCOT Fusion Source Integrator (AFSI), recently upgraded with a new Monte Carlo method for calculating fusion products and spectra from arbitrary reactant distributions, was released as a Kepler actor. The actor can be used to calculate reaction rates and fusion products for DD, DT and D^3He reactions between thermal and fast ions as a fusion source in the Heating and Current Drive (HCD) workflow of the European Transport Solver (ETS).

Additionally, the ASCOT4-RFOF model for simulating ICRH accelerated particles was implemented as a Kepler actor. The actor can be coupled to wave codes that calculate the RF field, and it can be used to simulate the ICRH acceleration of fast ions in a time-dependent simulation. Eventually all version of the ASCOT actors will be folded into a single actor capable of a wide range of fast ion simulations in typical plasmas.

Finally, in collaboration with Pietro Vincenzi (Consorzio RFX) the latest European DEMO NBI design was implemented for the Monte Carlo beam ionization actor BBNBI. The model can be used as an NBI source for integrated DEMO modelling as well as detailed studies of different injector geometries. Work was also started for implementing the beam geometries for the JT-60SA NBI injectors.

3. Power Plant Physics & Technology Work Programme 2015

3.1 WP PMI: Plant level system engineering, design integration and physics integration

Research scientists: T. Kurki-Suonio, K. Särkimäki, J. Varje, AU
S. Kiviluoto, Fortum
L. Aho-Mantila, E. Dorval, S. Norrman, A. Salmi, T. Tala, VTT

3.1.1 Introduction

FinnFusion activities within WP PMI cover modelling tasks on fast ions, plasma power exhaust and power plant processes. In this Yearbook, we report the progress of the task *Investigations in fast particles and plasma rotation in DEMO reactor*. The task related to modelling of power plant processes is included in the report under WP BOP (see below).

3.1.2 Investigations in fast particles and plasma rotation in DEMO reactor

Due to the inadequate numerical accuracy of the magnetic fields used in 2015, we took upon the task of recalculating the fields using the methods developed during an ITER project (F4E-GRT-379). As the result, the EUROfusion community now has available DEMO magnetic field with quality sufficient for fast ion following, as well as the corresponding slowing-down and wall power-load distributions for both fusion alphas and beam ions.

The 2015 fusion alpha simulations were repeated with the new magnetic backgrounds for the unmitigated ripple case and the ferritic insert (FI) cases with 25 %, 50 %, 75 % and 100 % FI mass. With the recalculated field, the losses were reduced by 30–80 %. Additionally, the FIs were found to provide an order of magnitude reduction in the losses already at 50 % of the design mass. The peak load of < 50 kW/m^2 was concentrated on the outer midplane.

The latest DEMO reference design was implemented for the ASCOT NBI ion source BBNBI in collaboration with P. Vincenzi (Consorzio RFX). Beam slowing-down simulations were performed for three cases: 2D equilibrium, unmitigated ripple, and with full FI mitigation. The beam ion confinement was good even for unmitigated ripple, and with FIs the losses were reduced by over 90 % and no alarming hot spots were identified. Also the slowing-down distribution was found quite insensitive to the magnitude of the toroidal ripple.

The beam ion simulations also give the torque profile that includes both the collisional and the j × B contributions. The total NBI driven torque for a single 16.8 MW beam was 25.2 Nm. The torque profile was used in the Astra simulations to determine the actual plasma rotation, but the predictions remain indecisive due to the large uncertainties in the intrinsic rotation.

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

Research scientists: E. Dorval, S. Norrman, VTT
S. Kiviluoto, Fortum

The development of the dynamic system-level analysis model of the helium cooled primary heat transfer system (PHTS) concept of DEMO using Apros has continued within WP BOP. The model has been revised according to the latest configuration information and data received from EUROfusion (see Figure 3.1).

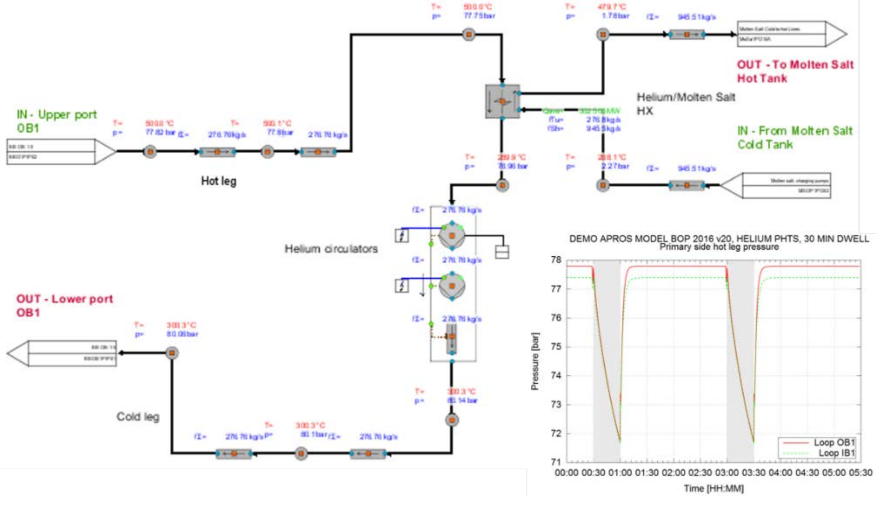

Figure 3.1. Outboard loop 1 and pressure behaviour in the WP BOP Apros-model.

The most profound model changes are related to the PHTS, where dimensions have been fixed according to a loop configuration consisting of six outboard and three inboard circuits. Regarding plant operation, it is now assumed that the helium circulators stop during dwell, but a small flow will be maintained with pony motor compressors for decay heat removal from the breeding blanket units. In the intermediate heat transfer circuit, it is assumed that the hot molten salt tank is bypassed during dwell.

Simulation results show that the drop of primary loop pressure is modest without pressurizers in the loops. Further, there is a high risk of freezing of molten salt especially in some heat exchangers during dwell time. To overcome this problem a different molten salt substance should be used and the power conversion system should be revised for further analyses.

In WP PMI, a configuration with an additional molten salt heat exchanger in the feed water loop was analysed. The function of the heat exchanger was to compensate the loss of heat from divertor and vacuum vessel cooling loops during dwell. The molten salt and feed water flows were adjusted accordingly. In general, the results showed more stable gross electricity output but controlling the plant became more challenging due to bigger variation in the molten salt flow rates. Another part of the task was to analyse component failures and their effect on the cooling chain. A preliminary evaluation was made and mitigating actions were proposed.

3.3 WP RM: Remote maintenance systems

Research scientists: J. Lyytikäinen, R. Sibois, M. Siuko, R. Tiusanen, O. Venho-Ahonen, J. Videnoja, VTT
S. Herranen, S. Kiviluoto, A. Laakso, Fortum

3.3.1 Divertor Cassette Handling

The divertor cassette Handling AWP 2016 includes four subtasks. The subtasks are shortly described below.

3.3.1.1 Assessment of the alternative divertor configurations

The assessment of alternative divertor configuration focused in 2016 on the layout of the Cassette cooling pipes. Divertor Cassette size and shape have not changed in 2015 and remain a one-piece cassette concept. Recommendations from the Remote Maintenance point of view regarding the following topics have been performed in 2016 activities:

- Cooling pipe routing (500mm straight pipe stub)
- Access to cassette fixation
- Cooling pipes during Cassette transportation
- Toroidal and radial transportation
- Pipes handling

Constant communication between WPDIV and WPRM are essential for good integration the reactor component design and their remote handling.

3.3.1.2 Divertor Cassette Transporter & Platform

The scope of this subtask was to develop divertor cassette transporter concepts for the combined 25° and Horizontal 2016 port configuration. Requirement analysis for the divertor cassette transporter was carried out and requirement list updated. Three Divertor Cassette End-Effectors concepts have been developed.

3.3.1.3 Divertor Cassette Fixation Tooling and EE Proof of Principle Design.

The scope of this subtask is the development of the proof of principle tooling/end-effector concept design solutions for the optional cassette fixation mechanisms and the definition of the space allocations and motion trajectories for cassette fixation tooling solutions. First generic studies for pins insertion/extraction, preloading and general end effectors able to operate on the “knuckle” outboard fixation system have been developed. Further progresses on this activity are ongoing basing on the development of the divertor fixation alternative solutions. The work is carried out in co-operation with ENEA/Create.

3.3.1.4 Divertor Cassette Fixation and Earth Bonding Tooling Design Development

This work is focused on the integration activities between DIV and RM in the development of a remote handling compatible fixation designs. First evaluations and optimization of “knuckle” system have been carried out and a solution providing flexible elements in the outboard area has been proposed.

Integration of outboard fixation system with cooling pipes and their interface with end effectors are under development. The work is carried out in co-operation with ENEA/Create.

3.3.2 DEMO requirements review (industry task)

DEMO RM team has taken significant efforts to elicit requirements with other DEMO work packages but elicitation has thus far only involved those within the DEMO project. Now EUROfusion are keen to ensure greater engagement with industrial expertise. VTT as a researcher of DEMO's RM systems got an assignment to assess and suggest improvements to the RM system requirements document and selected Fortum as a current operator of a fission power plant to work as a subcontractor.

Fortum focused on high-level requirements in selected topics to give an industrial perspective to DEMO's maintenance requirements. With the operational experience and expertise from Loviisa nuclear power plant Fortum proposed new requirements and remarks to be implemented into the DEMO's maintenance requirements. These proposals were categorized into the management of maintenance, quality, ageing, organization, radiation protection and safety, waste, storage and chemistry. At this early stage of designing the DEMO fusion power plant it is enough to have high level requirements in mind as the final equipment and systems have not been defined. As soon as design proceeds to more detailed phases these requirements should be periodically revisited and defined in detail.

Fusion and fission nuclear power plants have some similarities as they both need well-designed and prepared maintenance programs for maximum effectiveness of the plant operation. The quality of every process, equipment and components of the nuclear power plant needs to be as high as reasonably possible to keep the power plant safely functional.

3.4 WP MAT: Materials

Research scientists: T. Ahlgren, L. Bukonte, J. Byggmästar, F. Granberg, A. Kuronen, K. Nordlund, A. Sand, A. Zitting, UH

3.4.1 High-entropy alloys for enhanced radiation tolerance

The conventional metals we know from everyday life are based on one element forming a well-ordered crystal structure, with additional elements mixed in at small concentrations. A conceptually new way of making metals was thought out only recently, when it was found that one can mix numerous (three to seven) different types of metal atoms at completely random positions in equal concentrations, while still retaining a single good crystalline phase. In these, so called equiatomic or high-entropy alloys, the atoms are thus completely disordered in position.

For the inherently high-radiation environments of fusion reactors, it is of course desirable to find materials that can withstand the radiation with as little degradation as possible. Hence, it is natural that there has been a long-running drive to find metals that can endure as high radiation levels as possible, and indeed a few kinds of steels and other metals like nickel and tungsten have been found to be quite tolerant to radiation. However, all of them are known to fail eventually, and hence materials with even better radiation tolerance are continuously sought for.

Even though a metal with high degrees of disorder like high-entropy alloys might not at first seem like a good candidate to avoid radiation-induced disorder, one might turn the argument around: maybe the high level of disorder in fact would prevent the disorder level from increasing? In a recent closely-knit collaboration between the Oak Ridge National Laboratory and the University of Helsinki, the first ever studies of radiation tolerance of high-entropy alloys were carried out. The results of a combination of experimental and modeling efforts reveal that atom-level disorder in NiFe and NiCoCr alloys, compared to elemental Ni, indeed lead to a substantial reduction of damage accumulation under prolonged irradiation.

The random arrangement of multiple elemental species lead to unique site–to–site lattice distortions, that slow down the motion of extended defects, known as dislocation formed by the irradiation. This in turn lead to slower growth of large dislocation loops (see Figure 3.2), which are the dominant form of radiation damage in metals at high doses. Understanding of alloying effects on modified energy landscapes in such chemically disordered single-phase alloys will allow prediction of radiation-tolerance alloys for next-generation nuclear reactors and other high-radiation environments.

The analysis also revealed that alloying effects on significant reduction of dislocation mobility is generic, and not specific to the current choice of materials or number of elements in the system. The large improvement from NiFe to NiCoCr demonstrates that a reduction will depend on material choice, and suggests that there may be alloys with even larger damage reduction than the currently observed one – especially in more chemically disordered alloys with increasing number of principal elements at significant concentrations, where the number of possible element combinations and alloy compositions are practically limitless.

The results are published in the most respected journal in physics, Physical Review Letters[1] and highlighted in New Scientist[2].

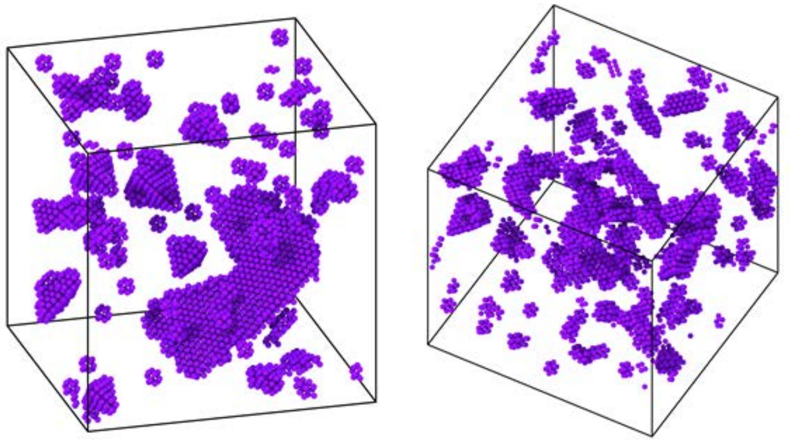

Figure 3.2. Left: radiation damage in a conventional metal, Ni. Right: radiation damage for exactly the same dose in NiFe equiatomic alloys. Due to the random arrangement of atoms in NiFe, the defect structures are smaller in these alloys.

3.5 WP ENS: Early Neutron Source definition and design

Research scientists: A. Helminen, I. Karanta, T. Tyrväinen, T. Sikanen, A. Matala, T. Ahonen, R. Tuominen, P. Valkokari, VTT

The structural materials of fusion device DEMO are validated against fusion characteristic neutron spectrum in International Fusion Materials Irradiation Facility – DEMO Oriented Neutron Source (IFMIF-DONES), illustrated in Figure 3.3. IFMIF-DONES is designed in the Work Package Early Neutron Source (WPENS) project.

In 2016, VTT involvement in WPENS concentrated on the safety, reliability and maintenance analysis related tasks.

In the safety analysis, the safety documentation of the previous design phase of IFMIF-DONES was reviewed and based on the findings system descriptions were generated for the safety relevant systems. The system descriptions were collected to a common database. The database will be used for the creation of more detailed failure modes and effects analysis (FMEA) of the systems in the following years.

[1] F. Granberg, K. Nordlund, M. W. Ullah, Ke Jin, Chenyang Lu, Hongbin Bei, Lumin Wang, F. Djurabekova, W. J. Weber, and Y. Zhang, "Mechanism of radiation damage reduction in equiatomic multicomponent single phase alloys," Phys. Rev. Lett. **116**, 135504 (2016).

[2] https://www.newscientist.com/article/2081605-new-alloys-could-lead-to-next-generation-of-nuke-plant-metals/

FMEA create the ground for more detailed safety analysis, such as postulated initiating event and probabilistic risk analysis, which are essential for the licensing of IFMIF-DONES.

In the reliability and maintenance analysis, the reliability, availability, maintainability and inspectability (RAMI) requirements identified previously were studied and different stakeholder expectations were captured and formulated in the form of RAMI design requirements for IFMIF-DONES systems. The objective of RAMI design requirements of IFMIF-DONES is to ensure the irradiation of suitable number of test samples up to the desired level of damage in the required time schedule so that sufficient data on the characterization of the materials exposed to high-energy neuron radiation will be available in time enough for the design of DEMO.

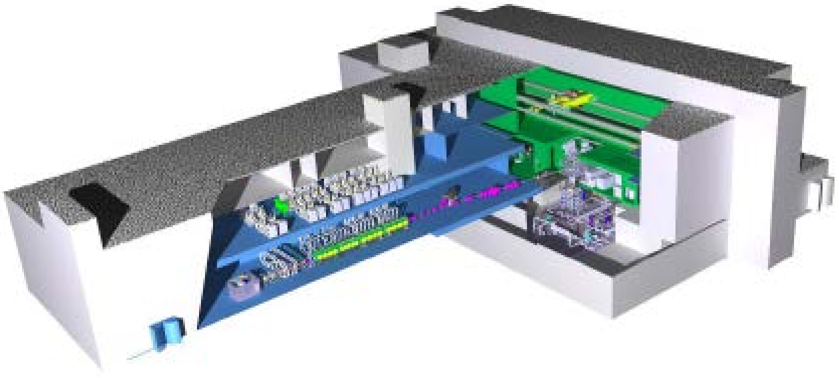

Figure 3.3. Illustration of the IFMIF facility.

4. Public information

The FinnFusion Annual Seminar was held at Lappeenranta University of Technology, Lappeenranta, Finland, on 23–24 May 2016. As invited speakers, Dr. Michele Romanelli, CCFE, UK, presented the JT-60SA project and Shanshuang Shi, ASIPP, China, presented major Chinese fusion energy projects. The number of participants was 52. The Annual Report, *FinnFusion Yearbook 2015,* VTT Science **129** (2016) 79 p., was published for the Annual Seminar.

During 2016, Finnish and international media published several articles and interviews on the fusion research activities in Finland:

- Tuomas Tala, interview on fusion on the main national TV channel YLE1, 9 January 2016.
- Taina Kurki-Suonio, *Saksalaisten toinenkin fuusioreaktorikoe onnistui (Also the second fusion experiment in Germany was successful)*, interview in Tekniikka & Talous on the first hydrogen plasma of W7-X, 12 February 2016.
- Kai Nordlund, *Materiaalia tulevaisuuden ydinreaktoreihin? – Suomessa kehitetään säteilyä kestäviä materiaaleja (Materials for future nuclear reactors? - Radiation resistant materials are developed in Finland)*, interview in Tekniikka & Talous on high-entropy alloys, 11 April 2016.
- Markus Airila, *Fuusiovoimalan pitkä ja kivinen tie (Long and stony road to fusion energy)*, interview in Loimu (online April 2016).
- T. Määttä et al. provided figures to R. Buckingham and A. Loving, *Remote-handling challenges in fusion research and beyond*, Nature Physics Insight 12 (2016) 391.
- Kai Nordlund, *Liian nopeita törmäyksiä (too fast collisions)*, interview and visualizations on plasma-material interactions in Helsingin Sanomat, 27 October 2016.

Lecture courses at Aalto University, School of Science:

- *Fusion Technology* (M. Groth, spring 2016).
- *Fundamentals of Plasma Physics for Space and Fusion Applications* (T. Kurki-Suonio, S. Leerink, spring 2016).

- *Energialukutaito (Energy literacy)* (J. Ala-Heikkilä, T. Kurki-Suoio, fall 2016).

Studia generalia lecture:

- Taina Kurki-Suonio, *Lämpöydinfuusio – ei skandaalinkäryisiä yrityskauppoja vaan kärytöntä energiaa (Thermonuclear fusion – no scandal-smelling corporate acquisitions but smoke-free energy)*, Finnish Nuclear Science and Technology Symposium, Helsinki, 2 November 2016.

5. Education and training

5.1 WP EDU – FinnFusion student projects

5.1.1 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 term.

During 2015, eight doctoral dissertations and three Master's theses were completed (see Section 10.5.4).

5.1.2 Doctoral students

Student:	Juuso Karhunen (AU)
Supervisor:	Mathias Groth (AU)
Instructors:	Mathias Groth (AU), Antti Hakola (VTT)
Topic:	*Spectroscopic studies of material migration and deposition in fusion devices*
Report:	SOL flows of injected N^+ and N^{2+} ions were studied spectroscopically in the HFS midplane region of ASDEX Upgrade during L-mode discharges with different degrees of inner divertor detachment. Similar to an earlier experiment in 2015, the results showed reversed $N^{+/2+}$ flow in the near SOL in high-recycling regime and non-reversed flow in detached conditions with $v_{N2+} \approx 2–3 \times v_{N+}$, suggesting better entrainment of the N^{2+} ions with the D^+ flow. Density and power scans covering the range of the experiment have been run by SOLPS 5.0. Initial results attribute the flow reversal in high-recycling regime to strongly localized ionization of recycled D in the divertor volume.

Student: Paavo Niskala (AU)
Supervisor: Mathias Groth (AU)
Instructor: Timo Kiviniemi (AU)
Topic: *Isotope effect in transport and flows of fusion plasmas*
Report: This thesis presents computational studies of the isotope effect on turbulent transport and flow dynamics in tokamak plasmas. A parameter scan with the simulation code ELMFIRE found that the amplitude of the flows tends to increase and particle flux decrease with isotope mass. Studies of ohmic hydrogen and deuterium discharges produced similar trends, in agreement with experimental measurements. The decrease in the flux explained by a difference in the scale and cross-phase of the turbulent fluctuations in the simulations. To explore the isotope effect further, the comparison will be expanded to new measurements and discharges with different currents.

Student: Konsta Särkimäki (AU)
Supervisor: Mathias Groth (AU)
Instructor: Taina Kurki-Suonio (AU)
Topic: *Stochastic processes and particle transport in tokamaks*
Report: The transport of fast particles in tokamaks, e.g. alpha particles and runaway electrons, at times can become stochastic in itself or driven by a stochastic process. In such cases, the mathematical treatment differs from the familiar deterministic dynamics, and some models might break down while new ones become available. The student has so far studied two instances of stochastic transport: stochastic field line transport and stochastic ripple diffusion, and in addition collisional transport where the driving mechanism is stochastic. The studies so far have resulted in a new transport model for runaway electrons in broken flux surfaces, and a new collision operator whose novel features include adaptivity and applicability in the relativistic regime. The student is also involved in fast particle studies concerning future tokamaks JT-60SA, ITER, and DEMO.

Student: Jaro Uljanovs (AU)
Supervisor: Mathias Groth (AU)
Instructor: Mathias Groth (AU)
Topic: *Study of the effects of Hydrogen isotopes on the divertor and edge physics in JET (Joint European Torus)*
Report: A comparison of the effect of the use of hydrogen as the main fuel (as opposed to deuterium) in a JET experiment has been performed as part of the PSI 2016 (plasma-surface interactions) conference. Here the student has also explored the effect of changing the magnetic configuration on the neutral dynamics in the divertor

region and the fuelling of the plasma. Currently the effects of disregarding the sub-divertor within current edge-modelling codes is being explored, by studying the various dependencies of the pumping albedo for both deuterium and tritium. In addition, an attempt was made to simulate plasmas in the corner divertor configuration, highlighting the lack of such capability in the current edge simulating codes. The future tritium and deuterium-tritium experiments at JET will provide the groundwork for a full exploration of the isotope effect on divertor and plasma-edge physics.

Student: Jing Wu (LUT)
Supervisor: Huapeng Wu (LUT)
Instructor: Huapeng Wu (LUT)
Topic: *Control of remote controlled robot for fusion reactors*
Report: The EAMA (EAST Articulated Maintenance Arm) is an articulated serial robot arm working in experimental advanced superconductor tokamak for the inspection and the maintenance. This work implements algorithms in software calibrating and compensating for the joints movement. For the yaw joint, the error model is built by the curve fitted method, which has unneglectable nonlinearities. Based on curve fitted model, the extended Kalman filter is adapted to correct and compensate the segment position error. For pitch joint, the retrieval algorithms neuro network and expert system are utilized to complete unformulated cluster data in the date estimation. Adaptive Neuro-fuzzy Inference System is applied to forecast the disclosed hysteresis loop compensation data. The final result shows that the root mean squared error is significant improved and satisfies the accuracy requirement up to 0.02 degree.

Student: Janne Koivumäki (TUT)
Supervisor: Jouni Mattila (TUT)
Instructor: Jouni Mattila (TUT)
Topic: *Stability-Guaranteed Force-Sensorless Contact Force/Motion Control of Heavy-Duty Hydraulic Manipulators*
Report: In ITER vacuum vessel divertor, a high-precision force/motion closed-control is needed to operate 10 tonnes divertor cassettes. The operations must be performed precisely and safely (the stability of the closed-loop control system is the primary requirement) in a narrow space with a water hydraulic manipulator. However, the dynamic behaviour of hydraulic robotic manipulators is highly nonlinear, making their closed-loop control design and stability analysis an extremely challenging task. In the studies, the student extended an impedance control and a hybrid position/force control methods (the most famous contact control methods needed for force-reflecting teleoperation) for hydraulic robotic manipulators for the first time

with a rigorously guaranteed stability. The state-of-the-art motion/force control performances were reported. The results can be found in the student's Ph.D. thesis in:
J. Koivumäki, *Stability-Guaranteed Nonlinear Model-Based Control of Hydraulic Robotic Manipulators*, Ph.D. thesis, Tampere University of Technology, 2016, Available: http://urn.fi/URN:ISBN:978-952-15-3894-0

Student: Longchuan Niu (TUT)
Supervisor: Jouni Mattila (TUT)
Instructor: Jouni Mattila (TUT)
Topic: *Computer Aided Teleoperation utilizing 3D scene construction by stereo camera*
Report: Remote handling of Divertor Cassette Locking System in harsh ITER conditions is performed using teleoperated manipulators. Integration of stereoscopic cameras into manipulation enables a new means of Computer Aided Teleoperation of remote handling by precisely tracking of both tools and target objects. This improves usability and safety. Existence of several constraints in high dose of radiation environment such as noises, limited resolution of radiation-tolerant camera sensors are typical design challenges. To maximize the precision of tracking, a novel 3D template matching method, similar to Iterative Closest Point (ICP) algorithm, is being used. A prototyped eye-in-hand 3D vision system is implemented together with the robot's control system. The prototype implementation result verifies efficacy of the proposed method.

Student: Laura Bukonte (UH)
Supervisor: Kai Nordlund (UH)
Instructor: Tommy Ahlgren (UH)
Topic: *Defect evolution in materials*
Report: The diffusion of hydrogen impurities in tungsten is studied as a function of temperature, hydrogen concentration and pressure by employing the molecular dynamics method. The H atom is an endothermic impurity in W with high solution energy leading to low equilibrium concentrations of H in W.
However, large H flux from a fusion device can result in concentrations that considerably exceed the equilibrium value in W. Our molecular dynamics studies indicate that the hydrogen diffusion coefficient decreases with the increasing H concentration due to the neighbouring interstitial site blocking and repulsion between H atoms.
The commonly accepted and so far used H diffusion migration barrier of 0.39 eV is revised and proposed to be 0.25 eV, which is in agreement with DFT studies and experiments.

A new analysis method to determine diffusion coefficients that accounts for the random oscillation of atoms around the equilibrium position is presented. This correction improves the accuracy of determining the diffusion coefficient at all temperatures, but the main advantage is that it makes it possible to simulate atomic diffusion, and determine the corresponding diffusion coefficients at lower temperatures than previously.

Student: Jesper Byggmästar (UH)
Supervisor: Kai Nordlund (UH)
Instructor: Kai Nordlund (UH)
Topic: *Multiscale modelling of radiation effects in fusion reactor materials*
Report: We have studied thermally activated unpinning of edge dislocations from voids in BCC iron using molecular dynamics simulations. We found that the elastic shear softening of iron at increased temperatures results in a temperature dependence on the activation energy. Accounting for the shear softening, we obtain a relation between the activation energy, critical shear stress, and temperature. The obtained relation can be used in larger scale simulation methods, such as dislocation dynamics. Additionally, we have carried out irradiation simulations in iron to study the defect production in overlapping collision cascades. The formation of dislocation loops and other defect clusters were studied.

Student: Aki Lahtinen (UH)
Supervisor: Jyrki Räisänen (UH)
Instructors: Antti Hakola (VTT), Jari Likonen (VTT)
Topic: *Plasma-wall interactions in fusion devices*
Report: In 2016, the work concentrated on analysis of the deuterium (D) retention using secondary ion mass spectrometry (SIMS) on the divertor tiles removed from the JET tokamak after the second ITER-Like Wall campaign in 2013–2014 (ILW-2). Compared to the first ILW campaign (ILW-1) in 2011–2012, D retention was observed to be higher after the ILW-2. Higher D retention on the ILW-2 divertor tiles is related to the changes in the plasma conditions and strike point distribution. In addition, the SIMS measurements for the ILW-2 samples were done deeper than after the ILW-1, and some of the studied tiles were exposed during both ILW-1 and ILW-2 campaigns and therefore had a longer exposure time.

Student: Elnaz Safi (UH)
Supervisor: Kai Nordlund (UH)
Instructors: Carolina Björkas (UH), Jussi Polvi (UH)
Topic: *Multiscale modeling of plasma-wall interactions: (i) A top-to-bottom multi-scale approach of Be erosion by D; (ii) MD simulations of the effect of Ar, Ne and D co-bombardment on W and Be*
Report: In the first part of the work, Kinetic Monte Carlo (KMC) simulations were carried out to estimate equilibrium D concentrations in Be at different surface temperatures and defect concentrations. It is seen that the D concentration at Be surface decreases with increasing surface temperature due to the diffusion of D in Be. Furthermore, Molecular Dynamics (MD) simulations were run on mixed Be–D surface samples at different temperatures according to KMC profiles. 4000 non-cumulative D impacts yield the Be-D erosion yield with higher confidence.

In the second part of the work, W and Be surface were irradiated with a mixture of x % of Ar or Ne with (100–x) % of D (where x = 0, 5, 10 & 20) under different impact energies and substrate temperature. Higher W and Be erosion yields are obtained with increasing the percentage of x.

Student: Paula Sirén (VTT)
Supervisor: Filip Tuomisto (AU)
Instructor: Jaakko Leppänen (VTT)
Topic: *Generating fusion plasma neutron source for Serpent MC neutronics computing*
Report: Neutrons generated by AFSI-ASCOT simulations have already been applied as a neutron source of the Serpent neutron transport code in ITER studies. Additionally, AFSI has been selected to be a main tool as the fusion product generator in the complete analysis calculation chain: ASCOT–AFSI–SERPENT (neutron and gamma transport Monte Carlo code)–APROS (system and power plant modelling code), which encompasses the plasma as an energy source, heat deposition in plant structures as well as cooling and balance-of-plant in DEMO applications and other reactor relevant analyses.

Synthetic neutron and fast ion diagnostics in JET were new applications of AFSI Ascot Fusion Source Integrator in 2016. AFSI has been used to calculate neutron production rates and spectra corresponding to the 19-channel neutron camera (KN3) and the time-of-flight spectrometer (TOFOR) as ideal diagnostics, without detector-related effects (see Figure 5.1). AFSI calculates fusion product distributions in 4D, based on Monte Carlo integration from arbitrary reactant distribution functions. The distribution functions were calculated by the ASCOT Monte Carlo particle orbit following code for thermal, NBI and ICRH particle reactions.

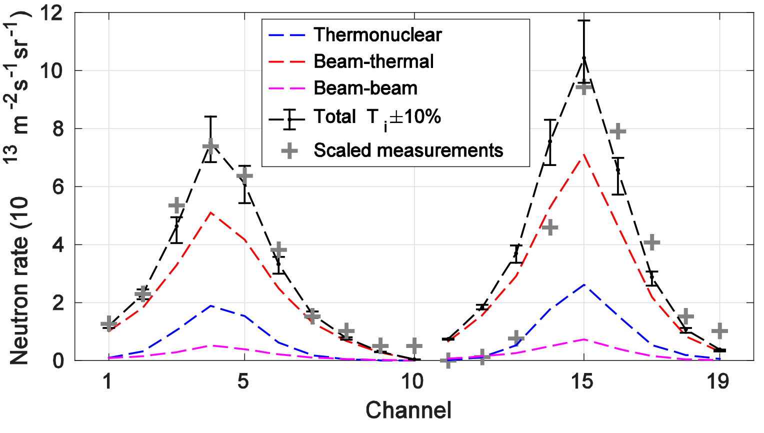

Figure 5.1. Normalised neutron production rates calculated by AFSI in KN3 neutron camera in JET with the comparison of experimental measurements.

5.2 WP TRA – EUROfusion Researcher Grant

Modelling primary radiation damage with extended molecular dynamics – defect morphology in the presence of electronic effects

Research scientist: A. Sand, UH

Predicting the long-term effects of the irradiation on mechanical and physical properties of reactor wall materials requires multi-scale modelling schemes, where the initial state subject to subsequent microstructural evolution consist of the primary damage created from the collision cascades induced by neutron impacts. Atomistic simulations of cascades have been useful in predicting many aspects of the primary damage. However, a long-standing issue in these simulations has been the neglect of electronic effects, including electron-phonon coupling and electronic thermal conduction, both of which are expected to impact the evolution of the cascade. The focus of this project, which commenced in early 2016, is to obtain reliable data on primary damage formation in tungsten (W) and iron (Fe), accounting for electronic energy-loss effects, and to express this data in a form suitable for input into microstructural evolution codes.

As a first part of this project, the sensitivity of cascade simulations to energy losses has been investigated. The phase of cascade development that is most sensitive to energy losses is found to be the heat spike phase. Individual cascades vary strongly; hence direct comparison of cascades simulated with different methods is in effect impossible. Instead, a method of simulating the heat spike, removing the randomness of full cascades, has been developed, allowing efficient investigation of the sensitivity of results to simulation parameters.

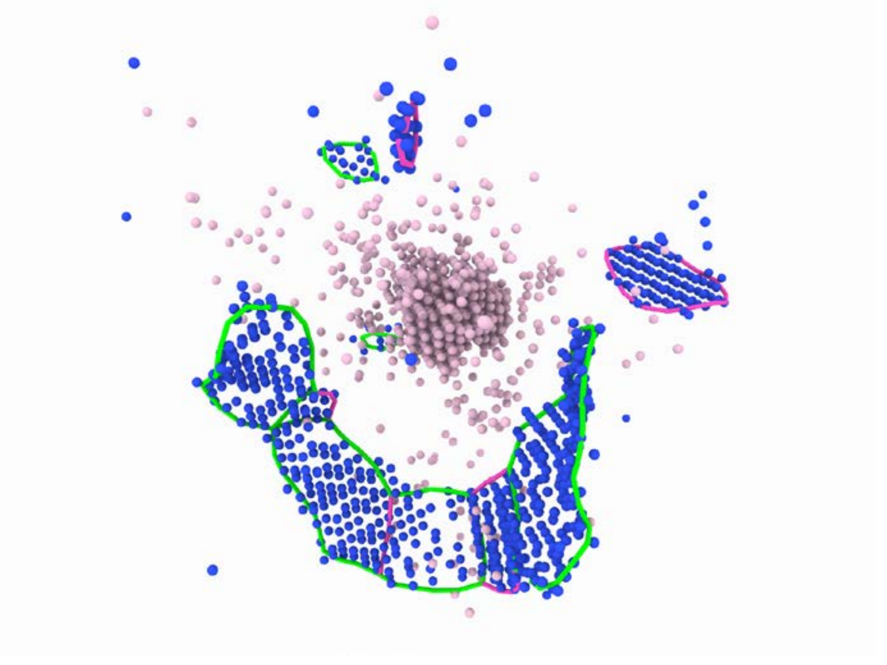

Figure 5.2. The complex defect clusters making up the primary damage after a 200 keV cascade in W. Pink spheres represent vacancies and blue indicates interstitials. Lines are dislocation loops.

Predictions of defect statistics from full cascades in Fe and W have also been compared, both in bulk, and in thin foils where surface effects play a large role. Results from this work indicate that cascades in Fe may be less sensitive to electronic energy losses than what has been found to be the case in W. Figure 5.2 illustrates simulated defect clusters in tungsten.

5.3 WP TRA – EUROfusion Researcher Grant

Static and dynamic parameter calibration of multipurpose deployer for DEMO in-vessel remote maintenance

Research scientist: Yongbo Wang, LUT

For ITER or the future DEMO remote maintenance system (WPRM), several types of special tailored automatic manipulators are needed for vacuum vessel (VV) component transportation, inspection, and removal from and replacement to the VV wall. Due to the extreme work conditions, such as big size, big payload and high environment temperature, both the static and dynamic error sources should be considered when design a controller.

Static calibration involves the identification of parameter errors originated from machining and assembling processes. For this purpose, a 6-DOF industrial manipulator and a 10-DOF redundant serial-parallel manipulator have been used for our case studies. We have proposed a MCMC-based calibration method for identifying geometric parameters as well as removing the influence of redundant parameters. Furthermore, we have also developed a vision-based self-calibration method for on-site calibration of customized fusion reactor manipulators.

Dynamic calibration involves experimental identification of dynamic parameters such as link masses, joint friction, and the moment inertial. A symbolic linear dynamic identification model of a 6-DOF industrial robot has been built up for dynamic parameter identification purpose. Fourier series excitation trajectories are generated by minimizing condition number of the observation matrix. Due to the lack of torque sensors mounted on the 6-DOF industrial robot, the SimMechanics was used to simulate the real robot to get joint torques for dynamic parameter identification purpose (see Figure 5.3). A global optimization method, i.e. Differential Evolution (DE) algorithm, has been successfully utilized in three different objective functions for identifying geometrical errors, dynamic errors, and generate Fourier series excitation trajectories respectively.

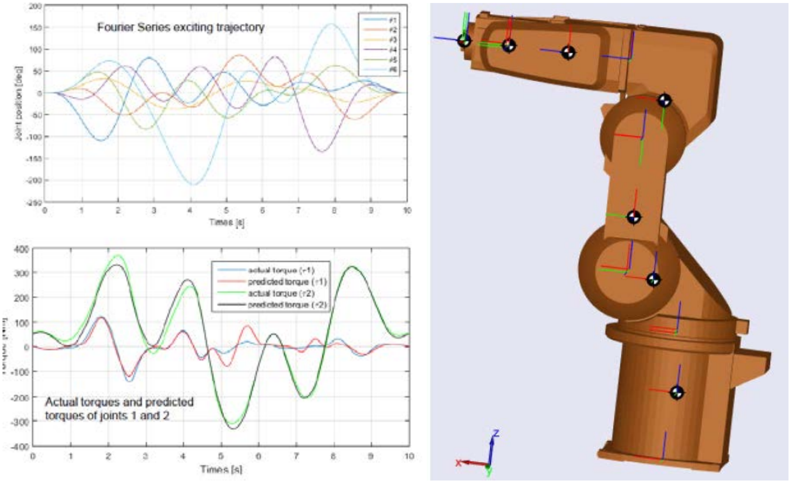

Figure 5.3. SimMechanics simulation for dynamic parameter identification.

5.4 WP TRA – EUROfusion Engineering Grant

Design of control systems for remote handling of large components

Research scientist: Ming Li, LUT

Inside the DEMO machine, heavy-duty manipulators are foreseen to be widely employed. A hybrid kinematic manipulator (HKM) is being designed at RACE (Remote Applications in Challenging Environments, UKAEA) to handle the breeder blanket segments for DEMO; the multi-purpose deployer and divertor cassette deployer are also at the conceptual design stage.

From the simulation analysis, it is acknowledged that the computation-effective deformation prediction of the manipulators is important for the control system development, in order to compensate the deformation displacements in real-time, as well as optimize the trajectories of handling process in the iterative algorithms.

It is noted that the finite element method (FEM) may not be feasible under the current computer technology, to satisfy the real time performance required by the control system and optimization algorithms, due to its intensive computation. Additionally the parameters deviation of the manipulators under repeatedly heavy duties in harsh environments makes the FEM prediction no longer promising.

An artificial neural network (ANN) based method is being developed currently, for the deformation modelling of the manipulators. The Bayesian inference is being investigated for the ANN training and model selection, based on the Markov Chain Monte Carlo method. The joints deformation modelling is taken as elementary component of the deformation due to its significant overall contribution, the deviation-prone characters and some extent uncertainties.

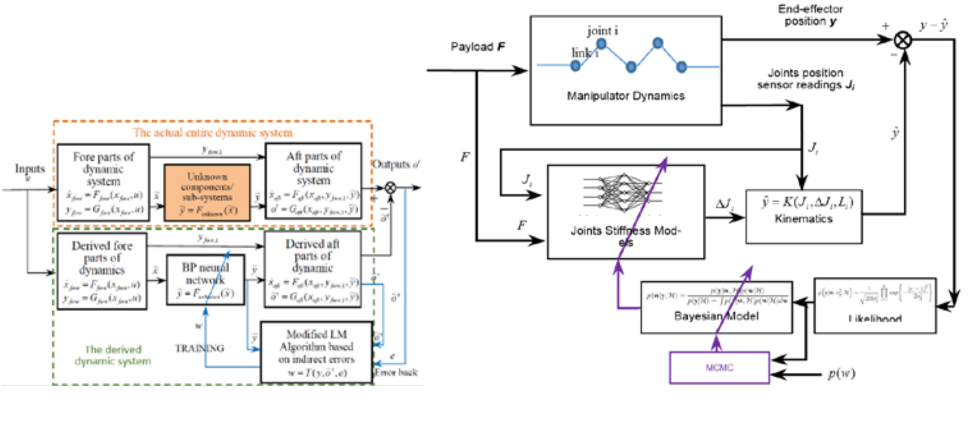

Figure 5.4. Left: Neural network as approximator; Right: Deformation identification by MCMC-ANN.

A method of identifying the uncertainties or unknowns from entire dynamics system has been developed, a modified Marquardt-Levenberg algorithm has been developed for the training of ANN, presented in Figure 5.4 (left), and the friction model of a parallel kinematics robot has been identified successfully.

The similar concept can be extrapolated to the components deformation modelling of the manipulators, using the joints sensor readings and end-effector measurements, and the concept is presented in Figure 5.4 (right).

6. Enabling Research

Research scientists: M. Groth, T. Kiviniemi, T. Kurki-Suonio, S. Leerink, K. Särkimäki, AU
K. Heinola, UH
J. Likonen, VTT

FinnFusion participated in four Enabling Research projects in 2016:

- AWP15-ENR-01/CCFE-03: Predictive model for pedestals
- AWP15-ENR-01/CCFE-08: Tritium and deuterium retention in metals with variable radiation-induced microstructure (TriCEM)
- AWP15-ENR-01/CEA-09: Kinetic modelling of runaway electron dynamics
- AWP15-ENR-01/IPP-01: Verification and development of new algorithms for gyrokinetic codes (NumKin)

In this report we highlight the TriCEM project coordinated by CCFE.

6.1 Tritium and deuterium retention in metals with variable radiation-induced microstructure

Tritium interaction with fusion materials and its retention and release from materials under realistic operating conditions is one of the major unknowns in fusion science and technology. This project aims at combining expertise in experimental and modelling areas related to Plasma Facing Components and Structural Materials.

The role of University of Helsinki (UH) and VTT is to use Thermal Desorption Spectroscopy (TDS) for the characterization of defects and traps, and release of hydrogen isotopes from EUROFER and tungsten materials, and to use Secondary Ion Mass Spectrometry (SIMS) for depth profiling of deuterium and tritium as well as to characterise the impurities in these materials.

TriCEM activities at UH comprises of self-irradiation of tungsten, EUROFER and Iron-Chromium (Fe8%Cr) samples in order to provide damage network to the materials studied further within TriCEM for hydrogen isotope retention.

The self-irradiations were carried out using a 2.5 MeV Tandem accelerator, and a 500 keV implanter. For each material three self-irradiation doses were used: 10^{12}, 10^{13}, and 10^{14} at/cm^2 corresponding to 0.01, 0.1 and 1.0 dpa. For the W samples a 2.0 MeV $^{184}W^{++}$ beam was used, and for the EUROFER and Fe8%Cr samples a 500 keV $^{56}Fe^{+}$ beam was used.

The amounts of carbon and oxygen impurities in EUROFER and tungsten were determined by SIMS by using ion implanted calibration samples prepared at UH. Figure 6.1 shows depth profiles for FeC, O and FeO ions. The amounts of carbon and oxygen correspond well with the literature values of these impurities in EUROFER. In addition to impurity characterization, first analyses of samples exposed to deuterium plasma were made.

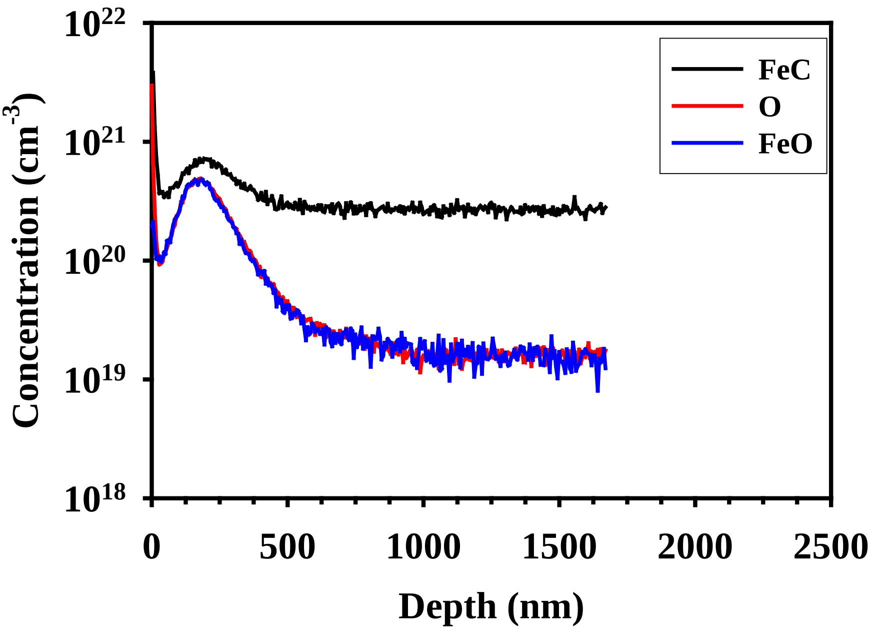

Figure 6.1. SIMS depth profiles of carbon and oxygen implanted Eurofer sample.

7. International collaborations

7.1 DIII-D tokamak

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

7.1.1 Plasma detachment studies

Investigations of the physics of detachment in the DIII-D tokamak continued in 2016 for helium plasmas. Several visits of the DIII-D National Fusion Facility in San Diego, California, USA were made to participate in experiments toward improved understanding of divertor detachment and the previously observed radiation shortfall when comparing edge fluid predictions to measurements. These experiments, executed in similar as possible divertor configuration to previous studies in deuterium, critically included configurations in reversed toroidal field configurations and utilised the advanced suite of diagnostics in the lower divertor. The studies showed that if the measured divertor (in 2D, measured by divertor Thomson scattering) densities are provided, the radiation shortfall vanishes in SOLPS5.0 simulations (J.D. Canik, APS 2016 invited talk). The plasma profiles of electron temperature and their parallel-B gradients, and the parallel-B gradients of electron density below the X-point are sufficiently reproduced in the simulations. The connection between the main SOL and the divertor entrance, and the ion contribution toward the parallel-B pressure balance was identified as an outstanding issue. While these findings apply to helium plasmas only, the radiation shortfall/divertor condition mismatch issue in deuterium plasma remained. Deuterium plasmas with carbon as a minority impurity species were simulated using the EDGE2D-EIRENE code, including cross-field drifts and the EIRENE 2008 model.

7.1.2 Particle transport/density peaking (ITPA TC-15)

T. Tala and A. Salmi visited General Atomics (San Diego, USA) for the DIII-D part of the ITPA TC-15 experiment to study particle sources and transport in a set of dimensionless scaling experiments in which collisionality is varied. The experiment was performed as planned on DIII-D, and a half a day contingency was added in addition to the plan. The 3-point dimensionless collisionality scan shows that the increase in peaking at lower collisionality can be predicted by the changes in core fuelling. There is no indication that the increase in peaking is linked to an increase in v/D. Along with the decrease in collisionality, there is an increase in turbulence intensity because of the increase in injected power and temperature gradients. Therefore, while collisionality does not seem to affect the density gradient, changes in turbulence regime can affect the local density gradient.

7.2 Ioffe Institute

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

A long-standing collaborative effort is in place between Aalto University and the Ioffe institute in St Petersburg regarding code validation of the gyrokinetic full-f global code development project ELMFIRE to turbulence measurements at the FT-2 tokamak and most recently also the TUMAN tokamak. The 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 (GAM) in obtaining increased confinement regimes. For the FT-2 tokamak, the emphasis in 2016 has been on identifying the Isotope effect where the ELMFIRE simulations reproduced the isotope effect in particle confinement and identified the significance of the turbulent cross-phase. For the Tuman-3M tokamak, a set of simulations of L-mode, early H-mode and late H-mode discharges were performed to study transport properties as well as GAMs. The turbulence growth rates were analysed and incorporated into an analytical model to predict the L-H transition in the TUMAN tokamak (L. Askinazi, invited talk at EPS2016).

8. Full-f gyrokinetic turbulence code ELMFIRE

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

Main core of the work on a full-f gyrokinetic particle-in-cell code ELMFIRE has been in the co-operation with FT-2 and TUMAN-3M groups both located in Ioffe Institute, St. Petersburg, Russia (see section “International collaboration” for details). Here, a special emphasis has been on isotope effect on particle confinement and geodesic acoustic modes (GAMs). In addition, the work has consisted of active code development including Tuomas Korpilo’s doctoral thesis work on whole cross section version of the code for which main results have now been published. To continue this work, the development of the code for the implementation of the new logical boundary condition and more realistic FT-2 limiter has been started.

The radial propagation of GAMs has been investigated in context of EUROfusion Enabling research project “Numerical Methods for the Kinetic Equations of Plasma Physics”. Analytic work on the effect of sampling on random noise in gyrokinetic PIC simulation was published. Development and optimization of the MPI/OpenMP hybrid version of ELMFIRE has required extensive testing and has greatly reduced the memory imprint, which allows for much higher resolution and accuracy.

During 2016, ELMFIRE group had invited talks in Joint Varenna-Lausanne International workshop (Varenna, Italy), in 21st Joint EU-US Transport Task Force (Leysin, Switzerland) and in NUMKIN meeting (Strasbourg, France).

9. Fusion for Energy activities

9.1 System level design for the Remote Handling Connector and ancillary components

F4E grant: F4E-FPA-328-SG05

Research scientists: T. Määttä, J. Lyytinen, P. Tikka, P. Kilpeläinen, H. Martikainen, S. Rantala, H. Saarinen, H. Mäkinen, R. Tuominen, J. Alanen, K. Salminen, O. Venho-Ahonen, VTT

Within the F4E Framework Project Agreement (FPA) with a Hungarian consortium the Remote Handling Connector (RHC) project is part of the development project on Diagnostics System for ITER. VTT as a partner of the Consortium has concentrated on the Divertor RHC development within a special grant (SG05).

The purpose of a RHC is to connect divertor cassette diagnostics sensors to ex-vessel diagnostics system. When exchanging the divertor cassettes the connection to the diagnostic system must be un-plugged. Because of the hazard environment in the vessel the un-plugging will be performed by Remote Handling System. The amount of diagnostics signals varies between different cassettes and in the most challenging case the amount of pins to be connected in a RHC is over 200. Out of the 54 divertor cassettes 18 contain diagnostics sensors.

The goal of the grant is to design RHC at a system level and support the design through mock-up testing. The design has represented the conceptual design phase of the connector taking into account space limitations, harsh environment requirements (thermal load, irradiation, vacuum) and needs for reliability and remote handling ability. A principle structure of a divertor Remote Handling Connector and one model of the RHC concept are illustrated in Figure 9.1. After the analysis of the over 400 requirements the corresponding requirements were described and classified. In this process, a new tool for requirement management was implemented. The work has continued in 2016 with creation of seven concepts and analysing and selection of the options for further development. For the analysis of the design, several mock-ups were created and tested in a mock-up testing platform. After the selection out-board concept was chosen to be the major concept for the RHC. In addition, in-board concept was kept as a bac-up solution for the RHC. The major critical part of the RHC was the flexible cable solution, which is due to the needs for compliance during the assembly and operation. This solution needs further development in the structure of the RHC and in the cables. These issues will be focused in the preliminary design phase of the RHC.

The DTP2 platform at VTT has a very important role in the development of the mock-ups and the final connectors. The special connector types and the development of demanding remote operated connectors can contribute new special products for the Finnish industry.

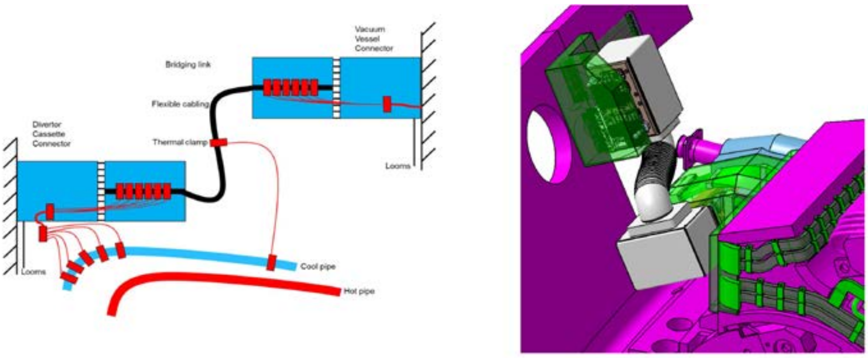

Figure 9.1. A principle structure of a divertor Remote Handling Connector and one model of the RHC concept.

9.2 Remote handling control system development

F4E grant: F4E-GRT-0689

Research scientists: L. Aha, J. Mattila, TUT
J. Alanen, A. Muhammad, T. Mätäsniemi, O. Saarela, H. Saarinen, VTT

The Computer Assisted Teleoperation task is coordinated by TUT. Purpose of this task is to develop and demonstrate new means to assist RH operator to perform maintenance operations successfully for the ITER Divertor. The new features are based on the detection of a target, e.g. the RH Equipment, and recognizing its position and orientation in a relation to its environment using stereo-camera images. In accordance with the project plan for year 2016, the System setup and pre-processing sub-task has been completed as well as the 3D reconstruction through stereo matching. System development and testing has been started.

10. Other activities

10.1 Missions and secondments

Kalle Heinola to JET facility as Visiting Scientist, 1 Jan–31 Dec 2016

Marko Santala to JET facility as NJOC Neutron Diagnostic Specialist, 1–31 Jan 2016

Johnny Lönnroth to EUROfusion PMU as WP JET1 Responsible Officer, 1 Jan–6 May 2016

Tuomas Tala to IPP (Germany), 11–15 Jan 2016 (WP MST1)

Antti Hakola to IPP (Germany), 12–22 Jan 2016 (WP MST1)

Jari Likonen to CCFE (United Kingdom), 14–22 Jan 2016 (WP JET2)

Antti Salmi to IPP (Germany), 17–20 Jan 2016 (WP MST1)

Jaro Uljanovs to to CCFE (United Kingdom), 22 Jan–15 Feb 2016

Antti Salmi to DIII-D, General Atomics, San Diego, USA, 24–31 Jan 2016 (International Collaborations)

Tuomas Tala to DIII-D, General Atomics, San Diego, USA, 24–31 Jan 2016 (International Collaborations)

Antti Hakola to IPP (Germany), 2–5 Feb 2016 (WP MST1)

Mathias Groth to General Atomics, San Diego, California, USA, 4–22 Feb 2016 (International Collaborations)

Antti Hakola to IPP (Germany), 9–12 Feb 2016 (WP MST1)

Antti Hakola to IPP (Germany), 15–18 Feb 2016 (WP MST1)

Tuomas Tala to IPP (Germany), 15–18 Feb 2016 (WP MST1)

Jari Likonen to CCFE (United Kingdom), 15–24 Feb 2016 (WP JET2)

Marko Santala to CCFE (United Kingdom), 15 Feb–3 Mar 2016 (WP JET4)

Aki Lahtinen to IPP (Germany), 22–26 Feb 2016 (WP MST1)

Antti Hakola to IPP (Germany), 22 Feb–4 Mar 2016 (WP MST1)

Romain Sibois to CCFE (United Kingdom), 24–27 Feb 2016 (WP RM)

Mikko Siuko to CCFE (United Kingdom), 24–27 Feb 2016 (WP RM)

Antti Hakola to IST (Portugal), 7–10 Mar 2016 (WP PFC)

Kalle Heinola to IST (Portugal), 7–10 Mar 2016 (WP PFC)

Jari Likonen to CCFE (United Kingdom), 7–11 Mar 2016 (WP JET2)

Jari Varje to JET facility (United Kingdom), 7–11 Mar 2016 (WP JET1)

Paula Sirén to JET facility (United Kingdom), 7–18 Mar 2016 (WP JET1)

Marko Santala to JET facility (United Kingdom), 8 Mar–17 May 2016 (WP JET4)

Tuomas Tala to Institute for plasma research society, Bhat, Gandhigar, India, 13–19 Mar 2016 (ITPA)

Juuso Karhunen to IPP Garching (Germany), 14–18 Mar 2016

Antti Hakola to IPP (Germany), 21–24 Mar 2016 (WP MST1)

Atte Helminen to PMU-Garching (Germany), 3–6 Apr 2016 (WP ENS)

Topi Sikanen to PMU-Garching (Germany), 3–6 Apr 2016 (WP ENS)

Jaro Uljanovs to to CCFE (United Kingdom), 3–15 Apr 2016

Jari Likonen to CCFE (United Kingdom), 4–6 Apr 2016 (WP JET2)

Jari Likonen to Univ. of Toyama (Japan), 11–15 Apr 2016 (International Collaborations)

Antti Hakola to IPP (Germany), 4–8 Apr 2016 (WP MST1)

Taina Kurki-Suonio to IPP (Germany), 11–15 Apr 2016 (WP MST1)

Mathias Groth to DIII-D/General Atomics, 11 Apr–6 May 2016 (WP JET1)

Antti Hakola to CEA (France), 18–21 Apr 2016 (WP PFC)

Juuso Karhunen to IPP Garching (Germany), 18–29 Apr 2016

Antti Hakola to IPP (Germany), 25–29 Apr 2016 (WP MST1)

Jari Varje to JET facility (United Kingdom), 2–13 May 2016 (WP JET1)

Antti Hakola to SPC (Swiss Confederation), 9–13 May 2016 (WP MST1)

Paula Sirén to JET facility (United Kingdom), 9–20 May 2016 (WP JET1)

Kalle Heinola to VTT/UH (Finland), 10–13 May 2016 (Enabling Research)

Antti Hakola to IPP (Germany), 17–20 May 2016 (WP MST1)

Taina Kurki-Suonio to IPP (Germany), 17–20 May 2016 (WP MST1)

Sanna-Paula Pehkonen to IPP (Germany), 17–20 May 2016 (WP MST1)

Tuomas Tala to IPP (Germany), 17–20 May 2016 (WP MST1)

Antti Hakola to IPP (Germany), 23–25 May 2016 (WP MST1)

Andrea Sand to CCFE (United Kingdom), 25–28 May 2016 (Researcher Grants)

Taina Kurki-Suonio to CEA (France), 5–8 Jun 2016 (Enabling Research)

Andrea Sand to CIEMAT (Spain), 5–10 Jun 2016 (WP MAT)

Fredric Granberg to CIEMAT (Spain), 6–10 Jun 2016 (WP MAT)

Antti Hakola to IPP (Germany), 7–10 Jun 2016 (WP MST1)

Andrea Sand to CCFE (United Kingdom), 8 Jun–30 Sep 2016 (Researcher Grants)

Otto Asunta to IPP.CR (Czech Republic), 12–15 Jun 2016 (WP CD)

Mathias Groth to CCFE (United Kingdom), 13–16 Jun 2016 (WP JET1)

Petteri Heliste to JET facility (United Kingdom), 13–17 Jun 2016 (WP JET1)

Jari Varje to IPP.CR (Czech Republic), 13–24 Jun 2016 (WP CD)

Antti Hakola to SPC (Swiss Confederation), 14–17 Jun 2016 (WP MST1)

Paavo Niskala to IPP Garching (Germany), 15–17 Jun 2016

Antti Hakola to IAP (Romania), 20–22 Jun 2016 (WP PFC)

Jari Likonen to CCFE (United Kingdom), 20 Jun–8 Jul 2016 (Enabling Research, WP JET2)

Paula Sirén to JET facility (United Kingdom), 20 Jun–2 Sep 2016 (WP JET1)

Kalle Heinola to VTT/UH (Finland), 26–30 Jun 2016 (WP JET2)

Taina Kurki-Suonio to ITER IO (France), 26–30 Jun 2016 (ITPA)

Antti Hakola to SPC (Swiss Confederation), 27–30 Jun 2016 (WP MST1)

Markus Airila to Wigner RCP (Hungary), 28–30 Jun 2016 (WP PI)

Antti Hakola to IPP (Germany), 11–15 Jul 2016 (WP MST1)

Jari Varje to JET facility (United Kingdom), 11 July–2 Sep 2016 (WP JET1)

Antti Hakola to CCFE (United Kingdom), 18–22 Jul 2016 (WP PMU)

Mathias Groth to DIII-D/General Atomics, San Diego, California, USA, 4–22 Aug 2016 (WP JET1)

Jari Likonen to CCFE (United Kingdom), 15–19 Aug 2016 (WP JET1)

Tuomas Tala to MIT, Boston, US, 5–14 Sep 2016 (WP JET1)

Antti Hakola to IPP (Germany), 13–21 Sep 2016 (WP MST1)

Jari Varje to JSI (Slovenia), 19–30 Sep 2016 (WP CD)

Kalle Heinola to IST (Portugal), 25–30 Sep 2016 (WP JET2)

Jari Likonen to CCFE (United Kingdom), 25 Sep–1 Oct 2016 (WP JET2)

Markus Airila to JSI (Slovenia), 26–30 Sep 2016 (WP CD)

Bartosz Lomanowski to NFRI (Korea), 29–30 Sep 2016 (WP JET1)

Yongbo Wang to CCFE (United Kingdom), 1 Oct–31 Jan 2016 (Researcher Grants)

Paula Sirén to JET facility (United Kingdom), 3 Oct–11 Nov 2016 (WP JET1)

Antti Hakola to IPP (Germany), 4–7 Oct 2016 (WP MST1)

Atte Helminen to CIEMAT (Spain), 4–7 Oct 2016 (WP ENS)

Jari Varje to JET facility (United Kingdom), 10–28 Oct 2016 (WP JET1)

Jari Likonen to CCFE (United Kingdom), 16–22 Oct 2016 (WP JET2)

Timo Kiviniemi to University of Strasbourg, 17–18 Oct 2016 (Enabling Research)

Sami Herranen to CCFE (United Kingdom), 20–21 Oct 2016 (WP RM)

Sami Kiviluoto to CCFE (United Kingdom), 20–21 Oct 2016 (WP RM)

Anssi Laakso to CCFE (United Kingdom), 20–21 Oct 2016 (WP RM)

Mikko Siuko to CCFE (United Kingdom), 20–21 Oct 2016 (WP RM)

Tuomas Tala to JAEA, Naka, Japan, 24 Oct–28 Jan 2016 (ITPA)

Antti Hakola to National Institutes for Quantum and Radiological Science and Technology, Naka, Japan, 24–28 Oct 2016 (WP MST1)

Tuomas Tala to JAEA, Naka, Japan, 24–28 Oct 2016 (ITPA)

Aki Lahtinen to CCFE (United Kingdom), 31 Oct–9 Nov 2016 (WP JET2)

Kalle Heinola to Rokkasho, Japan, 10–18 Nov 2016 (WP JET2)

Antti Hakola to IPP (Germany), 13–18 Nov 2016 (WP MST1)

Juuso Karhunen to IPP Garching (Germany), 14–25 Nov 2016

Tuomas Tala to IPP (Germany), 15–17 Nov 2016 (WP MST1)

Jari Likonen to IPP (Germany), 15–18 Nov 2016 (WP MST1)

Antti Hakola to CIEMAT (Spain), 20–25 Nov 2016 (WP PFC)

Kalle Heinola to CIEMAT (Spain), 22–24 Nov 2016 (WP JET2)

Jari Likonen to CCFE (United Kingdom), 23–27 Nov 2016 (WP JET2)

Jaakko Leppänen to JET facility (United Kingdom), 28 Nov–1 Dec 2016 (WP JET3)

Paula Sirén to JET facility (United Kingdom), 28 Nov–1 Dec 2016 (WP JET3)

Konsta Särkimäki to CCFE (United Kingdom), 30 Nov–2 Dec 2016 (WP SA)

Jari Varje to CCFE (United Kingdom), 30 Nov–2 Dec 2016 (WP SA)

Mikko Siuko to ENEA (Italy), 5–7 Dec 2016 (WP RM)

Jarno Videnoja to ENEA (Italy), 5–7 Dec 2016 (WP RM)

Antti Hakola to SPC (Swiss Confederation), 5–9 Dec 2016 (WP MST1)

Juuso Karhunen to IPP Garching (Germany), 12–16 Dec 2016

Jari Likonen to CCFE (United Kingdom), 12–16 Dec 2016 (WP JET2)

Ming Li to CCFE (United Kingdom), 16–24 Dec 2016 (Engineering Grants)

Sami Herranen to CCFE (United Kingdom), 19–20 Dec 2016 (WP RM)

Anssi Laakso to CCFE (United Kingdom), 19–20 Dec 2016 (WP RM)

Miko Olkkonen to CCFE (United Kingdom), 19–20 Dec 2016 (WP RM)

Mikko Siuko to CCFE (United Kingdom), 19–20 Dec 2016 (WP RM)

Tuomas Tala to CCFE (United Kingdom), 19–20 Dec 2016 (WP RM)

Outi Venho-Ahonen to CCFE (United Kingdom), 19–20 Dec 2016 (WP RM)

10.2 Conferences, seminars, workshops and meetings

Antti Hakola, Kalle Heinola and Jari Likonen participated in the ITPA Meeting, Frascati, Italy, 25–29 Jan 2016.

Kalle Heinola participated in the WP JET2 Project Board Meeting, CCFE, UK, 23 Feb 2016.

Jing Wu participated in experiment on EAMA robot, ASIPP (China), 1 Mar–31 Dec 2016.

Antti Hakola, Kalle Heinola, Mathias Groth, Iván Paradela Pérez, Elnaz Safi and Jaro Uljanovs participated in the Modelling Meeting (WP PFC & JET2), Lisbon, Portugal, 8–11 Mar 2016.

Antti Hakola and Jari Likonen participated in a Finnish-Estonian-Slovakian project meeting on joint LIBS activities, Tallinn, Estonia, 18 Mar 2016.

Antti Hakola, Paavo Niskala, Jaro Uljanovs and Jari Varje participated in the 50th Annual Meeting of the Finnish Physical Society (Physics Days 2016), Oulu (Finland), 29–31 Mar 2016.

Kalle Heinola participated in the WP JET2 Ion Beam Analysis Meeting, CCFE, UK, 4–6 Apr 2016.

Tuomas Tala participated in the 13th EUROfusion General Assembly Meeting, Lisbon, Portugal, 11–12 April 2016

Jaakko Leppänen and Paula Sirén participated in the PHYSOR 2016 conference, Sun Valley, ID, 1–6 May 2016.

52 participants in the FinnFusion Annual Seminar, Lappeenranta, Finland, 23–24 May 2015.

Jaakko Leppänen and Paula Sirén participated in the XI ITER Neutronics Meeting, Karlsruhe, Germany, 23–27 May 2016.

Antti Hakola, Kalle Heinola, Juuso Karhunen, Aki Lahtinen, Jari Likonen and Jaro Uljanovs participated in the 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices (PSI 2016), Rome, Italy, 29 May–4 Jun 2016.

Kalle Heinola participated in the International Hydrogen Workshop, Milan, Italy, 6–8 Jun 2016.

Konsta Särkimäki participated in the 4th Runaway Electron Meeting, Pertuis, France, 6–8 Jun 2016.

Kalle Heinola participated in the MoD-PMI Workshop, Loughborough, UK, 22–24 Jun 2016.

Tuomas Tala participated in the 35th F4E Governing Board meeting, Cadarache, France, 29–30 Jun 2016.

Taina Kurki-Suonio and Jari Varje participated in the 16th ITPA-EP meeting, ITER IO (France), 26–30 Jun 2016.

Taina Kurki-Suonio (invited presentation), Timo Kiviniemi, Antti Salmi, Konsta Särkimäki, Tuomas Tala and Jari Varje participated in the 43rd EPS Conference on Plasma Physics, Leuven, Belgium, 4–8 Jul 2016.

Markus Airila participated in the 14th EUROfusion General Assembly Meeting, Eindhoven, the Netherlands,11–12 Jul 2016.

Konsta Särkimäki participated in the Theory and Simulation of Disruptions Workshop, Princeton, NJ, 20–22 Jul 2016.

Paavo Niskala participated in the workshop “Theory of Fusion Plasmas”, Varenna, Italy, 29 Aug–2 Sep 2016.

Susan Leerink and Paavo Niskala participated in the 21st Joint EU-US Transport Task Force Meeting, Leysin, Switzerland 5–8 Sep 2016.

Ming Li, Shanshuang Shi, Yongbo Wang, Bingyan Wao, Huapeng Wu, Jing Wu, 29th Symposium on Fusion Technology (SOFT 2016), Prague, Czech Republic 5–9 Sep 2016.

Jaakko Leppänen and Paula Sirén participated in the Serpent User Group Meeting, Milan, Italy, 26–30 September 2016.

Andrea Sand participated in the 8th Multiscale Materials Modeling (MMM) international conference, Dijon, France 9–14 Oct 2016.

Tuomas Tala participated in the 15th EUROfusion General Assembly Meeting, Naples, Italy 10–11 October 2016.

Timo Kiviniemi participated in NUMKIN 2016: International Workshop on Numerical Methods for Kinetic Equations, Strasbourg, France, 17–18 Oct 2016.

Antti Hakola, Kalle Heinola, Taina Kurki-Suonio, Susan Leerink and Tuomas Tala participated in the 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 Oct 2016.

Kalle Heinola participated in the ITPA Meeting, Naka, Japan, 24–27 Oct 2016.

Markus Airila, Antti Hakola, Sami Kiviluoto, Mikko Siuko, Taina Kurki-Suonio, Tuomas Tala and Jari Varje participated in the Nuclear Science and Technology Symposium 2016, Helsinki, 2–3 Nov 2016.

Kalle Heinola participated in the Annual Meeting (WP PFC & WP JET2), Madrid, Spain, 21–24 Nov 2016.

Olli Saarela participated in ITER Remote Handling Progress Review and Standardisation Workshop, Cadarache, France, 22–24 Nov 2016.

Tuomas Tala participated in the 24th European Fusion Programme Workshop, Zakopane, Poland, 28–30 Nov 2016.

Tuomas Tala participated in the 36th F4E Governing Board meeting, Barcelona, Spain, 1–2 Dec 2016.

Antti Hakola participated in the Programme Committee meeting of the 44th European Physical Society Conference on Plasma Physics, Culham, United Kingdom, 15 Dec 2016.

Tuomas Tala participated in the 16th EUROfusion General Assembly Meeting, Madrid, Spain, 15–16 Dec 2016.

10.3 Other visits

Kalle Heinola acted as a Member of PhD Defense Jury and PhD Thesis rapporteur, CEA, Cadarache, 3 Nov 2016.

10.4 Visitors

2 visitors from Tecnalia, Spain, at ROViR, VTT, Tampere, on 19 Jan 2016.

3 visitors from Assystem, UK, at ROViR, VTT, Tampere, on 2 Feb 2016.

9 visitors from Tampere AKK, at ROViR, VTT, Tampere, on 16 Mar 2016.

Prof. Pavel Veis, Comenius University, Bratislava, Slovakia, visited VTT on 17 Mar 2016.

2 visitors from F4E, Bacelona, Spain, at ROViR, VTT, Tampere, on 17–18 Mar 2016.

Mike Machielsen, TU/e, Eindhoven, the Netherlands, visited Aalto University as FuseNet student on 18 April–17 June 2016.

Dr. Laurent Chônĕ from the CEA/Aix-Marseille University, France, visited Aalto University on 16–17 Mar 2016.

1 visitor from Okazaki, Japan, at ROViR, VTT, Tampere, on 17 May 2016.

Dr. Leonid Askinazy, Dr. Alexey Gurchenko, Prof. Evgeniy Gusakov and Dr. Mikhail Irzak, Ioffe Institute, Saint Petersburg, Russia, visited Aalto University on 24 May–1 Jun 2016.

3 visitors from IFE, Halden, Norway, at ROViR, VTT, Tampere, on 2 Jun 2016.

5 visitors from DENZO, Japan, at ROViR, VTT, Tampere, on 20 Jun 2016.

Dr. Aleksandra Baron-Wiechec, CCFE, UK, visited VTT on 22–26 Aug 2016.

4 visitors from TFT, Finland, at ROViR, VTT, Tampere, on 1 Sep 2016.

17 visitors from Japo Ltd and Meluta Ltd steering groups at ROViR, VTT, Tampere, on 9 Sep 2016.

25 visitors from Logistics and Intelligent traffic group between Finland and Russia at ROViR, VTT, Tampere, on 19 Oct 2016.

Prof. Song Yuntao, the director of ASIPP, China, visited Helsinki University and Lappeenranta University of Technology on 5–9 Nov 2016.

Emmi Tholerus, CCFE, UK, and Pietro Vincenzi and Matteo Vallar, Consorzio RFX, Italy, visited Aalto University on 14–25 Nov 2016.

Dr. Leonid Askinazy, Dr. Alexey Gurchenko, Prof. Evgeniy Gusakov and Dr. Mikhail Irzak and Mr. Oleg Krutkin, Ioffe Institute, Saint Petersburg, Russia, visited Aalto University on 11–18 Dec 2016.

Publications 2016

Hyperlinks to electronic publications in the pdf version of this Yearbook.

10.5 Publications

10.5.1 Refereed journal articles

1. F. Granberg, K. Nordlund, M.W. Ullah, Ke Jin, Chenyang Lu, Hongbin Bei, Lumin Wang, F. Djurabekova, W.J. Weber, and Y. Zhang, Mechanism of radiation damage reduction in equiatomic multicomponent single phase alloys, Physical Review Letters **116** (2016) 135504.
2. A.E. Järvinen, C. Giroud, M. Groth, P. Belo, S. Brezinsek, M. Beurskens, G. Corrigan, S. Devaux, P. Drewelow, D. Harting, A. Huber, S. Jachmich, K. Lawson, B. Lipschultz, G. Maddison, C. Maggi, C. Marchetto, S. Marsen, G.F. Matthews, A.G. Meigs, D. Moulton, B. Sieglin, M.F. Stamp, S. Wiesen and JET Contributors, Comparison of H-mode plasmas in JET-ILW and JET-C with and without nitrogen seeding, Nuclear Fusion **56** (2016) 046012.
3. J. Varje, O. Asunta, M. Cavinato, M. Gagliardi, E. Hirvijoki, T. Koskela, T. Kurki-Suonio, Y. Liu, V. Parail, G. Saibene, S. Sipilä, A. Snicker, K. Särkimäki and Simppa Äkäslompolo, Effect of plasma response on the fast ion losses due to ELM control coils in ITER, Nuclear Fusion **56** (2016) 046014.
4. Y. Liu, S. Äkäslompolo, M. Cavinato, F. Koechl, T. Kurki-Suonio, L. Li, V. Parail, S. Saibene, K. Särkimäki, S. Sipilä and J. Varje, Modelling of 3D fields due to ferritic inserts and test blanket modules in toroidal geometry at ITER, Nuclear Fusion **56** (2016) 066001.
5. T. Kurki-Suonio, S. Äkäslompolo, K. Särkimäki, J. Varje, O. Asunta, M. Cavinato, M. Gagliardi, E. Hirvijoki, V. Parail, G. Saibene, S. Sipilä and A. Snicker, Effect of the European design of TBMs on ITER wall loads due to fast ions in the baseline (15 MA), hybrid (12.5 MA), steady-state (9 MA) and half-field (7.5 MA) scenarios, Nuclear Fusion **56** (2016) 112024.
6. H.Y. Guo, D.N. Hill, A.W. Leonard, S.L. Allen, P.C. Stangeby, D. Thomas, E.A. Unterberg, T. Abrams, J. Boedo, A.R. Briesemeister, D. Buchenauer, I. Bykov, J.M. Canik, C. Chrobak, B. Covele, R. Ding, R. Doerner, D. Donovan, H. Du, D. Elder, D. Eldon, A. Lasa, M. Groth, J. Guterl, A.E. Järvinen, E. Hinson, E. Kolemen, C.J. Lasnier, J. Lore, M.A. Makowski, A. McLean, B. Meyer, A.L. Moser, R. Nygren, L. Owen, T.W. Petrie, G.D. Porter, T.D. Rognlien, D. Rudakov, C.F. Sang, C. Samuell, H. Si, O. Schmitz, A. Sontag, V. Soukhanovskii, W. Wampler, H. Wang and J.G. Watkins, Developing and validating advanced divertor solutions on DIII-D for next-step fusion devices, Nuclear Fusion **56** (2016) 126010.
7. R. Wenninger, R. Albanese, R. Ambrosino, F. Arbeiter, J. Aubert, C. Bachmann, L. Barbato, T. Barrett, M. Beckers, W. Biel, L. Boccaccini, D. Carralero, D. Coster, T. Eich, A. Fasoli, G. Federici, M. Firdaouss, J. Graves, J. Horacek, M. Kovari, S. Lanthaler, V. Loschiavo, C. Lowry, H. Lux, G. Maddaluno, F. Maviglia, R. Mitteau, R. Neu, D. Pfefferle, K. Schmid, M. Siccinio, B. Sieglin, C. Silva, A. Snicker, F. Subba, J. Varje and H. Zohm, The DEMO wall load challenge, Nuclear Fusion **57** (2017) 046002.

8. P. Sonato, P. Agostinetti, T. Bolzonella, F. Cismondi, U. Fantz, A. Fassina, T. Franke, I. Furno, C. Hopf, I. Jenkins, E. Sartori, M.Q. Tran, J. Varje, P. Vincenzi and L. Zanotto, Conceptual design of the DEMO neutral beam injectors: main developments and R&D achievements, Nuclear Fusion **57** (2017) 056026.

9. P.T. Lang, R. Maingi, D.K. Mansfield, R.M. McDermott, R. Neu, E. Wolfrum, R. Arredondo Parra, M. Bernert, G. Birkenmeier, A. Diallo, M. Dunne, E. Fable, R. Fischer, B. Geiger, A. Hakola, V. Nikolaeva, A. Kappatou, F. Laggner, M. Oberkofler, B. Ploeckl, S. Potzel, T. Pütterich, B. Sieglin, T. Szepesi and the ASDEX Upgrade Team, Impact of lithium pellets on the plasma performance in the ASDEX Upgrade all-metal-wall tokamak, Nuclear Fusion **57** (2017) 016030.

10. A. Hakola, S. Brezinsek, D. Douai, M. Balden, V. Bobkov, D. Carralero, H. Greuner, S. Elgeti, A. Kallenbach, K. Krieger, G. Meisl, M. Oberkofler, V. Rohde, P. Schneider, T. Schwarz-Selinger, A. Lahtinen, G. De Temmerman, R. Caniello, F. Ghezzi, T. Wauters, A. Garcia-Carrasco, P. Petersson, I. Bogdanovic Radovic, Z. Siketic, ASDEX Upgrade Team, and EUROfusion MST1 Team, Plasma-wall interaction studies in the full-W ASDEX upgrade during helium plasma discharges, Nuclear Fusion **57** (2017) 066015.

11. T. Korpilo, A.D. Gurchenko, E.Z. Gusakov, J.A. Heikkinen, S.J. Janhunen, T.P. Kiviniemi, S. Leerink, P. Niskala and A.A. Perevalov, Gyrokinetic full-torus simulations of ohmic tokamak plasmas in circular limiter configuration, Computer Physics Communications **203** (2016) 128.

12. T.P. Kiviniemi and U. Sauerwein, Effect of sampling on random noise in gyrokinetic PIC simulation in real space, Computer Physics Communications **203** (2016) 161–167.

13. A. Gurchenko, E. Gusakov, P. Niskala, A. Altukhov, L. Esipov, T. Kiviniemi, T. Korpilo, D. Kouprienko, S. Lashkul, S. Leerink, A. Perevalov and M. Irzak, The isotope effect in turbulent transport control by GAMs, Plasma Physics and Controlled Fusion **58** (2016) 44002.

14. A.E. Järvinen, S. Brezinsek, C. Giroud, M. Groth, C. Guillemaut, P. Belo, M. Brix, G. Corrigan, P. Drewelow, D. Harting, A. Huber, K.D. Lawson, B. Lipschultz, C.F. Maggi, G.F. Matthews, A.G. Meigs, D. Moulton, M.F. Stamp, S. Wiesen and JET Contributors, Impact of divertor geometry on radiative divertor performance in JET H-mode plasmas, Plasma Physics and Controlled Fusion **58** (2016) 045011.

15. A.B. Altukhov, A.D. Gurchenko, E.Z. Gusakov, L.A. Esipov, M.A. Irzak, M.Yu. Kantor, D.V. Kouprienko, S.I. Lashkul, S. Leerink, P. Niskala, A.Yu. Stepanov and N.V. Teplova, Poloidal inhomogeneity of turbulence in the FT-2 tokamak by radial correlation Doppler reflectometry and gyrokinetic modelling, Plasma Physics and Controlled Fusion **58** (2016) 105004.

16. K. Särkimäki, E. Hirvijoki, J. Varje, J. Decker and T. Kurki-Suonio, An advection–diffusion model for cross-field runaway electron transport in perturbed magnetic fields, Plasma Physics and Controlled Fusion **58** (2016) 125017.

17. L.G. Askinazi, A.A. Belokurov, V.V. Bulanin, A.D. Gurchenko, E.Z. Gusakov, T.P. Kiviniemi, S.V. Lebedev, V.A. Kornev, T. Korpilo, S.V. Krikunov, S. Leerink, M. Machielsen, P. Niskala, A.V. Petrov, A.S. Tukachinsky, A.Yu. Yashin and N.A. Zhubr, Physics of GAM-initiated L–H transition in a tokamak, Plasma Physics and Controlled Fusion **59** (2017) 014037.

18. P. Niskala, A.D. Gurchenko, E.Z. Gusakov, A.B. Altukhov, L.A. Esipov, M.Yu. Kantor, T.P. Kiviniemi, D. Kouprienko, T. Korpilo, S.I. Lashkul, S. Leerink, A.A. Perevalov and R. Rochford, Gyrokinetic characterization of the isotope effect in turbulent transport at the FT-2 tokamak, Plasma Physics and Controlled Fusion **59** (2017) 044010.

19. A.E. Sand, J. Dequeker , C.S. Becquart, C. Domain and K. Nordlund, Non-equilibrium properties of interatomic potentials in cascade simulations in tungsten, Journal of Nuclear Materials **470** (2016) 119–127.

20. K. Piip, H. J. van der Meiden, L. Hämarik, J. Karhunen, A. Hakola, M. Laan, P. Paris, M. Aints, J. Likonen, K. Bystrov, J. Kozlova, A. Založnik, M. Kelemen and S. Markelj, LIBS detection of erosion/deposition and deuterium retention resulting from exposure to Pilot-PSI plasmas, Journal of Nuclear Materials **489** (2017) 129–136.

21. E. Feldbach, E. Tõldsepp, M. Kirm, A. Lushchik, K. Mizohata, J. Räisänen, Radiation resistance diagnostics of wide-gap optical materials, Optical Materials **55** (2016) 164.

22. A. De Backer, A.E. Sand, K. Nordlund, L. Luneville, D. Simeone and S.L. Dudarev, Subcascade formation and defect cluster size scaling in high-energy collision events in metals, Europhysics Letters **115** (2016) 26001.

23. A.E. Sand, M J. Aliaga, M.J. Caturla and K. Nordlund, Surface effects and statistical laws of defects in primary radiation damage: Tungsten vs. iron, Europhysics Letters **115** (2016) 36001.

24. J. Polvi, K. Heinola and K. Nordlund, An interatomic potential for W–N interactions, Modelling and Simulation in Materials Science and Engineering **24** (2016) 065007.

25. M. Rubel, P. Petersson, E. Alves, S. Brezinsek, J.P. Coad, K. Heinola, M. Mayer, P. Petersson, A. Widdowson and JET Contributors, The Role and Application of Ion Beam Analysis for Studies of Plasma-Facing Components in Controlled Fusion Devices, Nuclear Instruments and Methods in Physics Research B **371** (2016) 4–11.

26. Y. Yang, Y. Song, H. Pan, Y. Cheng, H. Feng and H. Wu, Visual servo simulation of EAST articulated maintenance arm robot, Fusion Engineering and Design **104** (2016) 28–33.

27. S. Shi, Y. Song, Y. Cheng, E. Villedieu, V. Bruno, H. Feng, H. Wu, P. Wang, Z. Hao, Y. Li, K. Wang and H. Pan, Conceptual design main progress of EAST Articulated Maintenance Arm (EAMA) system, Fusion Engineering and Design **104** (2016) 40–45.

28. D. Carfora, G. Di Gironimo, G. Esposito, K. Huhtala, T. Määttä, H. Mäkinen, G. Micciche and R. Mozzilo, Multicriteria selection in concept design of a divertor remote maintenance port in the EU DEMO reactor using an AHP participative approach, Fusion Engineering and Design **112** (2016) 324–331.

29. J. Wu, H. Wu, Y. Song, M. Li, Y. Yang and D.A.M. Alcina, Open software architecture for east articulated maintenance arm, Fusion Engineering and Design **109–111** (2016) 474–479.

30. J. Wu, H. Wu, Y. Song, Y. Cheng, W. Zhao and Y. Wang, Genetic algorithm trajectory plan optimization for EAMA: EAST Articulated Maintenance Arm, Fusion Engineering and Design **109–111** (2016) 700–706.

31. A. De Backer, A.E. Sand, C.J. Ortiz, C. Domain, P. Olsson and C.S. Becquart, Comparison of primary damage predictions in tungsten using the Binary Collision Approximation, Molecular Dynamic simulations and the Density Functional theory, Physica Scripta **T167** (2016) 014018.

32. A. Hakola, M.I. Airila, J. Karhunen, M. Groth, A. Herrmann, K. Krieger, T. Kurki-Suonio, G. Meisl, M. Oberkofler, R. Neu, S. Potzel, V. Rohde and the ASDEX Upgrade Team, Gross and net erosion of tungsten in the outer strike-point region of ASDEX Upgrade, Physica Scripta **T167** (2016) 014026.

33. E. Grigore, C. Ruset, M. Gherendi, D. Chioibasu, A. Hakola, and JET contributors, Thermo-mechanical properties of W/Mo markers coatings deposited on bulk W, Physica Scripta **T167** (2016) 014028.

34. C.C. Klepper, D. Borodin, M. Groth, A. Lasa, M. Airila, V. Bobkov, L. Colas, P. Jacquet, A. Kirschner, A. Terra, T.M. Biewer, E. Delabie, C. Giroud and JET Contributors, Estimates of RF-induced erosion at antenna-connected beryllium plasma-facing components in JET, Physica Scripta **T167** (2016) 014035.

35. M. Pribula, J. Krištof, M. Suchoňová, M. Horňáčková, J. Plavčan, A. Hakola, and P. Veis, Use of the near vacuum UV spectral range for the analysis of W-based materials for fusion applications using LIBS, Physica Scripta **T167** (2016) 014045.

36. M. Mayer. S. Krat, W. Van Renterghem, A. Baron-Wiechec, S. Brezinsek, I. Bykov, P. Coad, Yu.M. Gasparyan, K. Heinola, J. Likonen, A. Pisarev, C. Ruset, G. de Saint-Aubin and A. Widdowson, Erosion and deposition in the JET divertor during the first ILW campaign, Physica Scripta **T167** (2016) 014051.

37. J. Beal, A. Widdowson, K. Heinola, A. Baron-Wiechec, K.J. Gibson, J.P. Coad, E. Alves, B. Lipschultz, A. Kirschner, H.G. Esser, G.F. Matthews, S. Brezinsek and JET Contributors, Deposition in the inner and outer corners of the JET divertor with carbon wall and metallic ITER-like wall, Physica Scripta **T167** (2016) 014052.

38. A. Widdowson, A. Baron-Wiechec, P. Batistoni, E. Belonohy, J.P. Coad, D. Paul, D. Flammini, F. Fox, K. Heinola, I. Jepu, J. Likonen, S. Lilley, C. Lungu, G.F. Matthews, J. Naish and O. Pompilian, Experience of handling beryllium, tritium and activated components from JET ITER like wall, Physica Scripta **T167** (2016) 014057.

39. G.F. Matthews, B. Bazylev, A. Baron-Wiechec, J.W. Coenen, K. Heinola, V.G. Kiptily, H. Maier, C. Reux, V. Riccardo, F. Rimini, G. Sergienko, V. Thompson and A. Widdowson, Melt damage to the JET ITER-like Wall and divertor, Physica Scripta **T167** (2016) 014070.

40. J. Likonen, K. Heinola, A. De Backer, S. Koivuranta, A. Hakola, C.F. Ayres, A. Baron-Wiechec, P. Coad, G.F Matthews and M. Mayer, Deuterium trapping and release in JET ITER- like wall divertor tiles, Physica Scripta **T167** (2016) 014074.

41. K. Heinola, A. Widdowson, J. Likonen, E. Alves, A. Baron-Wiechec, N. P. Barradas, S. Brezinsek, N. Catarino, P. Coad, S. Koivuranta, S. Krat, G. F. Matthews, M. Mayer and P. Petersson, Long-term fuel retention in JET ITER-like wall, Physica Scripta **T167** (2016) 014075.

42. S. Brezinsek, S. Wiesen, D. Harting, C. Guillemaut, A.J. Webster, K. Heinola, A.G. Meigs, M. Rack, Y. Gao, G. Sergienko, V. Philipps, M.F. Stamp, S. Jachmich and JET Contributors, Characterisation of the deuterium recycling at the W divertor target plates in JET during steady-state plasma conditions and ELMs, Physica Scripta **T167** (2016) 014076.

43. M. Oberkofler, G. Meisl, A. Hakola, A. Drenik, D. Alegre, S. Brezinsek, R. Craven, T. Dittmar, T. Keenan, S. G. Romanelli, R. Smith, D. Douai, A. Herrmann, K. Krieger, U. Kruezi, G. Liang, Ch. Linsmeier, M. Mozetic, V. Rohde, the ASDEX Upgrade team, the EUROfusion MST1 Team, and JET Contributors, Nitrogen retention mechanisms in tokamaks with beryllium and tungsten plasma-facing surfaces, Physica Scripta **T167** (2016) 014077.

44. S. Wiesen, M. Groth, S. Brezinsek, M. Wischmeier and JET Contributors, Modelling of plasma-edge and plasma-wall interaction physics at JET with the metallic first-wall, Physica Scripta **T167** (2016) 014078.

45. T. Korpilo, T.P. Kiviniemi, S. Leerink, P. Niskala and R. Rochford, Gyrokinetic Simulations of the Tokamak Plasma Edge in Circular Limiter Configuration, Contributions to Plasma Physics **56** (2016) 549.

46. M. Han, H. Wu, Y. Song, Y. Cheng and H. Handroos, Intelligent Method for Tuning H2 PID Controller of Water Hydraulic Manipulator in CFETR blanket maintenances, Industrial Robot **43** (2016) 164–171.

47. S. Äkäslompolo, T. Kurki-Suonio and S. Sipilä, Synthetic Fast Ion Diagnostics in Tokamaks: Comparing the Monte Carlo Test Particle Code ASCOT Against Experiments, Fusion Science and Technology **69** (2016) 620–627.

48. D. Borodin, S. Brezinsek, I. Borodkina, J. Romazanov, D. Matveev, A. Kirschner, A. Lasa, K. Nordlund, C. Björkas, M. Airila, J. Miettunen, M. Groth, M. Firdaouss and the JET Contributors, Improved ERO modelling for spectroscopy of physically and chemically assisted eroded beryllium from the JET-ILW, Nuclear Materials and Energy **9** (2016) 604–609.

49. J. Marian, C.S. Becquart, C. Domain, S.L. Dudarev, M.R. Gilbert, R.J. Kurtz, D.R. Mason, K. Nordlund, A.E. Sand, L.L. Snead, T. Suzudo and B.D. Wirth, Recent advances in computational materials modeling of tungsten as plasma-facing material for fusion energy applications, Nuclear Fusion, accepted.

50. H. Meyer et al. (incl. A. Hakola, L. Aho-Mantila, J. Karhunen, T. Kurki-Suonio, A. Lahtinen, B. Lomanowski, S.-P. Pehkonen, A. Salmi, A. Snicker and T. Tala), the ASDEX Upgrade, MAST and TCV Teams, Overview of progress in European Medium Sized Tokamaks towards an integrated plasma-edge/wall solution, Nuclear Fusion, accepted.

51. A.E. Sand, D.R. Mason, A. De Backer, X. Yi, S.L. Dudarev and K. Nordlund, Cascade fragmentation: impact on primary radiation damage, Materials Research Letters, accepted.

52. L. Bukonte, T. Ahlgren and K. Heinola, Thermodynamics of impurity-enhanced vacancy formation in metals, Journal of Applied Physics, accepted.

53. M. Kelemen, A. Zaloznik, P. Vavpetic, M. Pecovnik, P. Pelicon, A. Hakola, A. Lahtinen, J. Karhunen, K. Piip, P. Paris, M. Laan, K. Krieger, M. Oberkofler, H.J. van der Meiden, S. Markelj and the ASDEX Upgrade Team, Micro-NRA and micro-3HIXE with 3He microbeam on samples exposed in ASDEX Upgrade and Pilot-PSI machines, Nuclear Instruments and Methods in Physics Research B, accepted.

54. M. Li, H. Wu, Y. Wang, H. Handroos and G. Carbone, Modified Levenberg-Marquardt Algorithm for BP Neural Network Training in Dynamic Model Identification of Mechanical Systems, Journal of Dynamic Systems Measurement and Control, accepted.

55. R. Mateus, A. Hakola, C. Porosnicu, C. Lungu, and E. Alves, Study of deuterium retention in Be-W coatings with distinct morphologies, Fusion Engineering and Design, accepted.

56. S. Brezinsek, A. Hakola, H. Greuner, A. Kallenbach, M. Oberkofler, G. de Temmerman, D. Douai, B. Böswirth, M. Balden, D. Brida, R. Caniello, D. Carralero, S. Egleti, K. Krieger, H. Mayer, G. Meisl, S. Poetzel, B. Sieglin, A. Terra, C. Linsmeier, The EUROfusion MST team, ASDEX Upgrade team, Erosion of He pre-exposed tungsten samples by He plasmas in the divertor manipulator of ASDEX Upgrade, Nuclear Materials and Energy, accepted

57. N. Catarino, N.P. Barradas, V. Corregidor, A. Widdowson, A. Baron-Wiechec, J.P. Coad, K. Heinola, M. Rubel and E. Alves, Assessment of erosion, deposition and fuel

retention in the JET-ILW divertor from ion beam analysis data, Nuclear Materials and Energy, accepted.

58. G. De Temmerman, M.J. Baldwin, D. Anthoine, K. Heinola, A. Jan, I. Jepu, J. Likonen, C. Lungu, C. Porosnicu and R.A. Pitts, Efficiency of thermal outgassing for tritium retention measurement and removal in ITER, Nuclear Materials and Energy, accepted.

59. A. Hakola, M.I. Airila, N. Mellet, M. Groth, J. Karhunen, T. Kurki-Suonio, T. Makkonen, H. Sillanpää, G. Meisl, M. Oberkofler and the ASDEX Upgrade Team, ERO and PIC simulations of gross and net erosion of tungsten in the outer strike-point region of ASDEX Upgrade, Nuclear Materials and Energy, accepted.

60. J. Karhunen, M. Groth, P. Heliste, T. Pütterich, E. Viezzer, D. Carralero, D. Coster, L. Guimarais, A. Hakola, V. Nikolaeva, S. Potzel and the ASDEX Upgrade Team, Measurement of N+ flows in the high-field side scrape-off layer of ASDEX Upgrade with different degrees of inner divertor detachment, Nuclear Materials and Energy, accepted.

61. R. Mateus, M. C. Sequeira, C. Porosnicu, C. P. Lungu, A. Hakola, E. Alves, Thermal and chemical stability of the β-W_2N nitride phase, Nuclear Materials and Energy, accepted.

62. G. Meisl, U. Plank, M. Oberkofler, A. Hakola, K. Krieger, K. Schmid, S. W. Lisgo, M. Mayer, A. Lahtinen, A. Drenik, S. Potzel, L. Aho-Mantila, the ASDEX Upgrade Team, JET Contributors, Nitrogen transport in ASDEX Upgrade: Role of surface roughness and transport to the main wall, Nuclear Materials and Energy, accepted.

63. N. Mellet, J. P. Gunn, B. Pégourié, A. Hakola, M. Airila, Y. Marandet, and P. Roubin, Influence of the magnetised sheath on the redeposition location of sputtered tungsten and its effect on the net erosion, Nuclear Materials and Energy, accepted.

64. I. Paradela Pérez, A. Scarabosio, M. Groth, M. Wischmeier, F. Reimold and the ASDEX Upgrade Team, SOL parallel momentum loss in ASDEX Upgrade and comparison with SOLPS, Nuclear Materials and Energy, accepted.

65. K. Piip, H.J. van der Meiden, K. Bystrov, L. Hämarik, J. Karhunen, M. Aints, M. Laan, P. Paris, H. Seemen, A. Hakola and S. Brezinsek, Loading of deuterium and helium by PilotfPSI plasma and their detection by in-situ LIBS, Nuclear Materials and Energy, accepted.

66. G. Sergienko, H.G. Esser, A. Kirschner, A. Huber, M. Freisinger, S. Brezinsek, A. Widdowson, C. Ayres, A. Weckmann, K. Heinola and JET Contributors, Quartz microbalance results of pulse-resolved erosion/deposition in the JET-ILW divertor, Nuclear Materials and Energy, accepted.

67. J. Uljanovs, M. Groth, A.E. Järvinen, D. Moulton, M. Brix, G. Corrigan, P. Drewelow, C. Guillemaut, D. Harting, J. Simpson, A. Huber, S. Jachmich, U. Kruezi, K.D. Lawson, A.G. Meigs, A.C.C. Sips, M.F. Stamp, S. Wiesen and the JET Contributors, The isotope effect on divertor conditions and neutral pumping in horizontal divertor configurations in JET-ILW Ohmic plasmas, Nuclear Materials and Energy, accepted.

68. A. Widdowson, E. Alves, A. Baron-Wiechec, N.P. Barradas, N. Catarino, J.P. Coad, V. Corregidor, A. Garcia-Carrasco, K. Heinola, S. Koivuranta, S. Krat, A. Lahtinen, J. Likonen, M. Mayer, P. Petersson, M.J. Rubel and S. Van Boxel, Overview of the JET ITER-like wall divertor, Nuclear Materials and Energy, accepted.

69. S. Brezinsek, et al. (incl. A. Hakola, M. Airila, C. Björkas, J. Karhunen, A. Lahtinen, J. Likonen, T. Makkonen, J. Miettunen, K. Nordlund, J. Räisänen, E. Safi and WP PFC contributors), Preparation of PFCs for the efficient use in ITER and DEMO – plasma–wall interaction studies within the EUROfusion consortium, Nuclear Fusion, submitted.

70. R.J. Buttery, S. Gerhardt, A. Isayama, R.J. La Haye, E.J. Strait, D. Chandra, S. Coda, J. De Grassie, P. Gohil, M. Gryaznevich, C. Holcomb, D.F. Howell, G. Jackson, M. Maraschek, A. Polevoi, H. Reimerdes, D. Raju, A. Sen, T. Tala, the JET-EFDA contributors , the DIII-D, JT-60 and NSTX teams, Cross-Machine Scaling of Neoclassical Tearing Modes Thresholds with Rotation, Nuclear Fusion, submitted.

71. K. Heinola, J. Likonen, T. Ahlgren, S. Brezinsek, G. De Temmerman, I. Jepu, G. F. Matthews, R. A. Pitts, A. Widdowson and JET Contributors, Long-term fuel retention and release in JET ITER-Like Wall at ITER-relevant baking temperatures, Nuclear Fusion, submitted.

72. K. Särkimäki, E. Hirvijoki and J. Terävä, Adaptive time-stepping Monte Carlo integration of Coulomb collisions, Computer Physics Communications, submitted.

73. F. Reimold, M. Wischmeier, M. Bernert, S. Potzel, D. Coster, X. Bonnin, D. Reiter, G. Meisl, A. Kallenbach, L. Aho-Mantila, U. Stroth and the ASDEX Upgrade Team, Experimental Studies and Modeling of Complete H-Mode Divertor Detachment in ASDEX Upgrade, Journal of Nuclear Materials, submitted.

74. A. Drenik, D. Alegre, M. Beldishevski, S. Brezinsek, A. de Castro, T. Dittmar, A. Hakola, P. Heesterman, K. Krieger, U. Kruezi, G. Meisl, M. Mozetic, M. Oberkofler, M. Panjan, G. Primc, V. Rohde, G. De Temmerman, R. Zaplotnik, Formation of ammonia in N_2 seeded discharges at AUG and JET, Fusion Engineering and Design, submitted.

75. M. Laan, A. Hakola, P. Paris, K. Piip, M. Aints, I. Jõgi, J. Kozlova, C. Lungu, C. Porosnicu, E. Grigore, C. Ruset, J. Kolehmainen, and S. Tervakangas, Dependence of LIBS spectra on the surface composition and morphology of W/Al coatings, Fusion Engineering and Design, submitted.

76. A. Lahtinen, J. Likonen, S. Koivuranta, A. Hakola, K. Heinola, C. F. Ayres, J. P. Coad, A. Widdowson, J. Räisänen, and JET Contributors, Deuterium retention in the divertor tiles of JET ITER-Like Wall, Nuclear Materials and Energy, submitted.

77. M. Suchonova, P. Veis, J. Karhunen, P. Paris, M. Pribula, K. Piip, C. Porosnicu, C. Lungu and A. Hakola, Determination of deuterium depth profiles in fusion-relevant wall materials by nanosecond LIBS, Nuclear Materials and Energy, submitted.

10.5.2 Conference presentations

78. J. Varje, O. Asunta, M. Cavinato, M. Gagliardi, E. Hirvijoki, T. Koskela, T. Kurki-Suonio, Y. Liu, V. Parail, G. Saibene, S. Sipilä, A. Snicker, K. Särkimäki and S. Äkäslompolo, Effect of plasma response on the fast ion losses due to ELM control coils in ITER, 16th ITPA Topical Group Meeting on Energetic Particle Physics, Cadarache, France, 26–30 June 2016.

79. P.T. Lang, R. Maingi, D.K. Mansfield, R. McDermott, R. Neu, E. Wolfrum, R. Arredondo Parra, M. Bernert, G. Birkenmeier, A. Diallo, M. Dunne, E. Fable, R. Fischer, B. Geiger, A. Hakola, G. Kocsis, F. Laggner, M. Oberkofler, B. Ploeckl, B. Sieglin and the ASDEX Upgrade Team, Impact of Lithium on the plasma performance in the all-metal-wall tokamak ASDEX Upgrade, DPG Frühjahrstagung, Hannover, Germany, 29 February–4 March 2016.

80. I. Paradela Pérez, A. Scarabosio, M. Groth, M. Wischmeier, F. Reimold and the ASDEX Upgrade Team, SOL parallel momentum loss at ASDEX Upgrade and comparison with SOLPS, EUROfusion Joint Working Session on Integrated Plasma-Wall Modelling, Lisbon, Portugal, 8–11 March 2016.

81. J. Uljanovs, M. Groth, A.E. Järvinen, D. Moulton, M. Brix, G. Corrigan, P. Drewelow, C. Guillemaut, D. Harting, J. Simpson, A. Huber, S. Jachmich, U. Kruezi, K.D. Lawson, A.G. Meigs, A.C.C. Sips, M.F. Stamp, S. Wiesen and the JET Contributors, Neutral pumping in horizontal and corner divertor configurations in JET-ILW Ohmic plasmas, EUROfusion Joint Working Session on Integrated Plasma-Wall Modelling, Lisbon, Portugal, 8–11 March 2016.

82. J. Varje, M. Santala, T. Kurki-Suonio, T. Koskela, S. Äkäslompolo, A. Järvinen and the JET contributors, Modelling neutral particle fluxes from fast ions in the JET tokamak, 50th Annual Meeting of the Finnish Physical Society, Oulu, Finland, 29–31 March 2016, paper 7.5.

83. P. Niskala, T.P. Kiviniemi, T. Korpilo, S. Leerink and R. Rochford, Computational approach to the self-organisation of fusion plasmas, 50th Annual Meeting of the Finnish Physical Society, Oulu, Finland, 29–31 March 2016, paper 7.6.

84. A. Hakola, J. Karhunen, M. Laan, P. Paris, K. Piip, M. Pribula, and P. Veis, Laser induced breakdown spectroscopy studies of fuel retention on ITER-relevant wall materials, 50th Annual Meeting of the Finnish Physical Society, Oulu, Finland, 29–31 March 2016, paper 10.6.

85. J. Uljanovs, M. Groth, A.E. Järvinen, D. Moulton, M. Brix, G. Corrigan, P. Drewelow, C. Guillemaut, D. Harting, J. Simpson, A. Huber, S. Jachmich, U. Kruezi, K.D. Lawson, A.G. Meigs, A.C.C. Sips, M.F. Stamp, S. Wiesen and the JET Contributors, The effect of magnetic field configuration on pumping in the Joint European Torus (JET), 50th Annual Meeting of the Finnish Physical Society, Oulu, Finland, 29–31 March 2016, paper 19.10.

86. A. Widdowson, E. Alves, A. Baron-Wiechec, N. Barradas, N. Catarino, J.P. Coad, K. Heinola, J. Likonen, S. Koivuranta, S. Krat, G.F. Matthews, M. Mayer, P. Petersson, M. Rubel and JET Contributors, Overview of fuel retention in the JET ITER-like Wall, 11th International Conference on Tritium Science & Technology, Charleston, SC, 17–22 April 2016, paper 6A-6.

87. P. Sirén and J. Leppänen, Expanding the use of Serpent 2 to Fusion Applications: Development of a Plasma Neutron Source, PHYSOR 2016 Conference, Sun Valley, ID, 1–5 May 2016.

88. 28 presentations in FinnFusion Annual Seminar 2016, Lappeenranta, Finland, 23–24 May 2016.

89. P. Sirén, J. Leppänen and J. Varje, Development steps towards realistic plasma neutron source for Serpent, XI ITER Neutronics meeting, Karlsruhe, Germany, 23–27 May 2016.

90. S.Wiesen, M. Groth, M. Wischmeier, S. Brezinsek, JET contributors, The EUROfusion MST1 team, The ASDEX Upgrade team, The Alcator C-mod team and The EAST team, Plasma-edge and plasma-wall interaction modelling: lessons learned from metallic devices, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper R-02.

91. M. Rubel, P. Petersson, Y. Zhou, J.P. Coad, K. Heinola, C. Lungu, S. Brezinsek, C. Porosnicu, A. Widdowson and JET Contributors, An Overview of Fuel Inventory and Deposition in Castellated Beryllium Structures in JET, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper I-01.

92. T.D. Rognlien, A.G. McLean, M.E. Fenstermacher, A.E. Järvinen, I. Joseph, C.J. Lasnier, A. Moser, W. Meyer, G.D. Porter, M.V. Umansky, and M. Groth, Comparison

of 2D simulations of detached divertor plasmas with divertor Thomson measurements in the DIII-D tokamak, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper I-03.

93. G. Meisl, U. Plank, M. Oberkofler, A. Hakola, K. Krieger, K. Schmid, S. W. Lisgo, M. Mayer, A. Lahtinen, A. Drenik, S. Potzel, L. Aho-Mantila, the ASDEX Upgrade Team and JET Contributors, Nitrogen migration in ASDEX Upgrade and JET: Understanding the dependence on surface temperature, roughness and N transport in the SOL, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper I-04.

94. R. Zagórski, V.Pericoli, H. Reimerdes, L. Aho-Mantila, R. Ambrosino, H. Bufferand, G. Calabro, G. Ciraolo, D. Coster, H. Fernandes, J. Harrison, K. Lackner, J. Loureiro, T. Lunt, G. Mazzitelli, S. McIntosh, F. Militello,T. Morgan, G. Pelka, V. Philipps, F. Subba and B. Viola, Evaluation of the power and particle exhaust performance of various alternative divertor concepts for DEMO, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper I-05.

95. A. Huber, M. Bernert, S. Brezinsek, G. Sergienko, M. Groth, M.N.A Beurskens, C. Guillemaut, V. Huber, S. Jachmich, A. Järvinen, E. Joffrin, Ch. Linsmeier, G.F. Matthews, A.G. Meigs, Ph. Mertens, M.F. Stamp, S. Wiesen, M. Wischmeier, JET contributors and the ASDEX Upgrade Team, Comparative H-mode density limit studies in JET and AUG, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper I-13.

96. M. Mayer, S. Krat, A. Baron-Wiechec, I. Bykov, P. Coad, Y. Gasparyan, K. Heinola, P. Petterson, C. Ruset, G. de Saint-Aubin, A. Widdowson and the JET Contributors, Erosion, deposition and deuterium inventory of the bulk tungsten divertor tile during the first JET ITER-like wall campaign, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper O.04.

97. J. Likonen, K. Heinola, G. De Temmerman, S. Koivuranta, C.F.Ayres, G. F. Matthews, R.A. Pitts, A. Widdowson and JET Contributors, Deuterium release and trapping in ITER-Like co-deposited layers, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper O.05.

98. I. Paradela Pérez, A. Scarabosio, M. Groth, M. Wischmeier, F. Reimold and ASDEX-Upgrade Team, SOL parallel momentum loss in ASDEX-Upgrade and comparison with SOLPS, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper O.12.

99. G. De Temmerman, M.J. Baldwin, D. Anthoine, K. Heinola, A. Jan, I. Jepu, J. Likonen, C.P. Lungu, C. Porosnicu, and R.A. Pitts, Efficiency of thermal outgassing for tritium retention measurement and removal in ITER, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper O.32.

100. A. Lasa, C.C. Klepper, D. Borodin, M. Groth, M. Airila, E. Safi, K. Nordlund, A. Kirschner, I. Borodkina and JET Contributors, ERO Modeling of Enhanced Beryllium Erosion at Antenna-Connected Limiters in JET, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.17.

101. A.G. McLean, S.L. Allen, J. Boedo, B.D. Bray, A. Briesemeister, T.N. Carlstrom, D. Elder, D. Eldon, M. Fenstermacher, M. Groth, D.N. Hill, E. Hollmann, A.E. Järvinen, I.

Joseph, C.J. Lasnier, A.W. Leonard, C. Liu, M.A. Makowski, B. Meyer, A.L. Moser, T.H. Osborne, T.W. Petrie, G. Porter, T. Rognlien, C. Samuell, V.A. Soukhanovskii, P.C. Stangeby, D. Thomas, E. Unterberg, H. Wang and J.G. Watkins, The influence of E×B drifts on detachment characteristics with forward and reverse toroidal field, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.26.

102. J. Karhunen, M. Groth, P. Heliste, A. Hakola, E. Viezzer, T. Pütterich, D. Coster, S. Potzel, D. Carralero, T. Lunt, L. Guimarais, V. Nikolaeva and the ASDEX Upgrade Team, Measurement of N+ flows in the HFS SOL of ASDEX Upgrade with different degrees of inner divertor detachment, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.33.

103. K.D. Lawson, M. Groth, D. Harting, S. Menmuir, D. Reiter, S. Brezinsek, G. Corrigan, P. Drewelow, C.F. Maggi, A.G. Meigs, M.F. Stamp, S. Wiesen and JET Contributors, Inclusion of molecular power loss terms in EDGE2D-EIRENE simulations of JET ITER-like wall L-mode discharges with comparisons of emission profiles, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.47.

104. G. Sergienko, H. G. Esser, A. Kirschner, A. Huber, M. Freisinger, S. Brezinsek, A. Widdowson, Ch. Ayres, A. Weckmann, K. Heinola and JET contributors, Quartz micro-balance results of pulse-resolved erosion/deposition in the JET-ILW divertor, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.54.

105. A. Hakola, M. Airila, J. Karhunen, T. Kurki-Suonio, T. Makkonen, H. Sillanpaa, G. Meisl, M. Oberkofler, N. Mellet and the ASDEX Upgrade Team, ERO and PIC simulations of gross and net erosion of tungsten in the outer strike-point region of ASDEX Upgrade, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.59.

106. N. Catarino, N. P. Barradas, V. Corregidor, A. Widdowson, A. Baron-Wiechec, J. P. Coad, K. Heinola, M Rubel, E. Alves and JET Contributors, Assessment of Erosion, deposition and fuel retention in the JET-ILW divertor from Ion Beam Analysis data, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.60.

107. S. Brezinsek, A. Hakola, H. Greuner, A. Kallenbach, M. Oberkofler, G. de Temmerman, D. Douai, B. Böswirth, M. Balden, D. Brida, R. Caniello, D. Carralero, S. Egleti, K. Krieger, H. Mayer, G. Meisl, S. Poetzel, B. Sieglin, A. Terra, C. Linsmeier, The EUROfusion MST team and the ASDEX Upgrade team, Surface modification of He pre-exposed tungsten samples by He plasma impact in the divertor manipulator of ASDEX Upgrade, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.68.

108. H. Bergsåker, G. Possnert, Y. Zhou, I. Bykov, K. Heinola, J. Pettersson, S. Conroy, J. Likonen, P. Petersson, A. Widdowson and JET contributors, Be migration in JET with ITER-like wall studied with 10Be isotopic marker, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.75.

109. K. Krieger, J.W. Coenen, H. Greuner, J.P. Gunn, A. Hakola, A. Herrmann, Th. Loewenhoff, T. Lunt, R.A. Pitts, S. Potzel, B. Sieglin, G. De Temmerman and the ASDEX-Upgrade Team, Influence of inhomogeneous power flux distribution at tungsten divertor target plates on power handling capabilities, 22nd International

Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.84.

110. A. Lahtinen, J. Likonen, S. Koivuranta, A. Hakola, K. Heinola, C.F. Ayres, J.P. Coad, A. Widdowson, J. Räisänen and JET Contributors, Deuterium retention in the divertor tiles of JET ITER-Like Wall, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.95.

111. M. Wischmeier, C.G. Lowry, G. Calabro, M. Bernert, A. Huber, M.L. Reinke, C. Guillemaut, L. Aho-Mantila, S. Brezinsek, P. Drewelow, S. Glöggler, C.F. Maggi, A. Meigs, G. Sergienko, M.F.F.Nave, G. Sips, M. Stamp, S. Wiesen and the JET contributors, Experimental characterization of the completely detached H-mode operation in JET with metal plasma facing components, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.105.

112. J.M. Canik, A.R. Briesemeister, A.G. McLean, S.L. Allen, M.E. Fenstermacher, M. Groth, C.J. Lasnier, A.W. Leonard, J.D. Lore, M. Makowski, A. Moser, A.C. Sontag, E.A. Unterberg and J.G. Watkins, Comparisons of measured and modeled divertor spectral emission in deuterium and helium plasmas, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P1.117.

113. K. Heinola, T. Ahlgren, J. Likonen, S. Brezinsek, N. Catarino, A. Widdowson and JET Contributors, Long-term fuel release in JET ITER-Like Wall divertor deposits: Computational multi-scale analysis method, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P2.8.

114. S. Mordijck, E.T. Meier, A. Salmi, T. Tala, A. Järvinen, L. Meneses, J. Svensson, R. Gomes, M. Maslov and JET contributors, Comparison of time-dependent ionization and density profile evolution of SOLPS5.0 simulations with JET experiments, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P2.31.

115. J. Uljanovs, M. Groth, A.E. Järvinen, D. Moulton, M. Brix, G. Corrigan, P. Drewelow, C. Guillemaut, D. Harting, J. Simpson, A. Huber, S. Jachmich, U. Kruezi, K.D. Lawson, A.G. Meigs, A.C.C. Sips, M.F. Stamp, S. Wiesen and the JET Contributors, The isotope effect on divertor conditions and neutral pumping in horizontal divertor configurations in JET-ILW Ohmic plasmas, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P2.42.

116. A. Wynn, B. Lipschultz, G. Matthews, M. Brix, M. Groth, C. Guillemaut, J. Harrison A. Huber, U.Kruzei, M. Smithies, S.Wiesen and JET contributors, Radial fluxes and density shoulder formation in the scrape off layer of JET, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P2.46.

117. F. Subba, L. Aho-Mantila, D. Coster, G. Maddaluno, G.F. Nallo, B. Sieglin , R. Wenninger and R. Zanino, Impact of the SOL radiation distribution onto the first wall heat load of DEMO, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P2.53.

118. E. Safi, K. Nordlund, G. Valles and A. Lasa, Multi-scale modeling to relate Be surface temperature, D concentration and molecular sputtering yields, 22nd International

Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P2.62.

119. N. Mellet, J. P. Gunn, B. Pégourié, A. Hakola, M. Airila, Y. Marandet and P. Roubin, Influence of the magnetised sheath on the redeposition location of sputtered tungsten and its effect on the net erosion, International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P2.80.

120. K. Yumizuru, S. Koivuranta, Y. Hatano, J. Likonen, M. Matsuyama, A. Widdowson and JET contributors, Non-destructive tritium analysis of divertor tiles used in JET ITER-like wall campaigns by means of β-ray induced X-ray spectrometry, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P2.103.

121. K. Piip, H.J. van der Meiden, K. Bystrov, L. Hämarik, J. Karhunen, M. Aints, M. Laan, P. Paris, H. Seemen, A. Hakola and S. Brezinsek, Loading of deuterium and helium by Pilot-PSI plasma and their detection by in-situ LIBS, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P2.105.

122. M. Groth, A.G. McLean, D. Harting, E.M. Hollmann, S.L. Allen, A.R. Briesemeister, G. Corrigan, M.E. Fenstermacher, A.W Leonard, M.A. Makowski, E.A. Unterberg and J.G. Watkins, Impact of atomic and molecular deuterium on the 2-D plasma distribution in DIII-D L-mode and H-mode plasmas, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P2.110.

123. A.E. Järvinen, S.L. Allen, M. Groth, A.G McLean, T.D. Rognlien, C. Samuell, A. Briesemeister, M. Fenstermacher, D.N. Hill, A.W. Leonard and G.D. Porter, Interpretations of the impact of cross-field drifts on divertor flows in DIII-D with UEDGE, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P2.111.

124. C.M. Samuell, S.L Allen, W.H. Meyer, A. Jarvinen, A. McLean, T. Rognlien, M. Groth and J. Howard, Carbon Impurity Transport in the DIII-D Divertor and Scrape-Off-Layer, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P3.35.

125. F. Subba, L. Aho-Mantila, R. Ambrosino, D. Coster, V. Pericoli-Ridolfini, A. Uccello and R. Zanino, Efficiency of non-standard divertor configurations in DEMO, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P3.44.

126. Y. Zhou, H. Bergsåker, I. Bykov, P. Petersson, G. Possnert, J. Likonen , J. Pettersson, S. Koivuranta, A.M. Widdowson and JET contributors, Microanalysis of deposited layers in the divertor of JET with ITER-like wall, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P3.56.

127. R. Mateus, M. C. Sequeira, C. Porosnicu, C. P. Lungu, A. Hakola and E. Alves, Thermal and chemical stability of the β-W_2N nitride phase, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P3.70.

128. A. Widdowson, E. Alves, A. Baron-Wiechec, N. Barradas, N. Catarino, J.P. Coad, K. Heinola, J. Likonen, S. Koivuranta, S. Krat, G.F. Matthews, M. Mayer, P. Petersson, M. Rubel and JET Contributors, Overview of fuel retention in the JET ITER-like Wall, 22nd

International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P3.74A.

129. R.P. Wenninger, R. Albanese, R. Ambrosino, F. Arbeiter, J. Aubert, C. Bachmann, L. Barbato, T. Barrett, W. Biel, L. Boccaccini, D. Carralero, D. Coster, T. Eich, A. Fasoli, G. Federici, M. Firdaouss, J. Graves, J. Horacek, M. Kovari, S. Lanthaler, V. Loschiavo, C. Lowry, H. Lux, G. Maddaluno, F. Maviglia, R. Mitteau, R. Neu, D. Pfefferle, K. Schmid, M. Siccinio, B. Sieglin, C. Silva, A. Snicker, F. Subba, J. Varje and H. Zohm, The DEMO Wall Load Challenge, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P3.76.

130. M. Suchoňová, M. Pribula, V. Martišovitš, J. Krištof, C. Porosnicu, C. P. Lungu, A. Hakola and P. Veis, Detection of fuel and trace elements in plasma-facing components using RF-discharge enhanced LIBS, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P3.89.

131. M. Pribula, J. Karhunen, P. Paris, P. Veis, K. Piip, C. Porosnicu, C. Lungu and A. Hakola, Determination of deuterium depth profiles in fusion-relevant wall materials by nanosecond LIBS, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P3.90.

132. D.P. Stotler, R. Hager, K. Kima, T. Koskela, and G. Park, M.L. Reinke, Kinetic neoclassical calculations of impurity radiation profiles, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P3.103.

133. D. Douai, T. Wauters, V. Rohde, A. Garcia-Carrasco, S Brezinsek5, D. Carallelo, R. Cavazzana, A. Hakola, A. Lyssoivan, S. Möller, R. Ouchoukov, P. Peterson, P. Schneider, M. Spolaore and the ASDEX Upgrade Team, Changeover from Deuterium to Helium with Ion Cyclotron Wall Conditioning and diverted plasmas in ASDEX Upgrade, 22nd International Conference on Plasma Surface Interactions in Controlled Fusion Devices, Rome, Italy, 30 May–3 June 2016, paper P3.116.

134. K. Särkimäki, E. Hirvijoki, J. Varje, J. Decker and T. Kurki-Suonio, An advection-diffusion model for runaway electron transport in perturbed magnetic fields, 4th Runaway Electron Meeting, Pertuis, France, 6–8 June 2016.

135. A. Drenik, D. Alegre, S. Brezinsek, A. de Castro, T. Dittmar, A. Hakola, K. Krieger, U. Kruezi, G. Meisl, M. Mozetic, M. Oberkofler, M. Panjan, G. Primc, V. Rohde and R. Zaplotnik, Study of plasma-wall interaction in fusion devices by residual gas analysis, 16th Joint Vacuum Conference / 14th European Vacuum Conference, Portorož, Slovenia, 6–10 June 2016, invited talk.

136. I. Paradela Pérez, A. Scarabosio, M. Wischmeier, F. Hoppe and U. Stroth, Power spreading in tokamak divertor using SOLPS code, 13th Kudowa Summer School, Kudowa-Zdrój, Poland, 13–17 June 2016.

137. A. Widdowson, E. Alves, A. Baron-Wiechec, N.P. Barradas, J. Beal, V. Corregidor, N. Catarino, J.P. Coad, K. Heinola, J. Likonen, S. Koivuranta, S. Krat, M. Mayer, P. Petersson, M. Rubel and JET Contributors, Material migration and fuel inventory in JET ITER-like wall from surface analysis techniques, 2nd International Workshop on Models and Data for Plasma-Material Interaction in Fusion Devices, Loughborough, UK, 22–24 June 2016.

138. T. Tala, R.M. McDermott, J.E. Rice, A. Salmi, W. Solomon, C. Angioni, C. Giroud, J.Ferreira, S. Kaye, P. Mantica, F. Ryter, G. Tardini, M. Yoshida, JET-EFDA contributors, the ASDEX-upgrade team, the DIII-D team, the C-Mod team, the NSTX

team and the ITPA Transport & Confinement Topical Group, Multi-Machine Experiments to Study the Parametric Dependences of Momentum Transport and Intrinsic Torque, 43rd EPS Conference on Plasma Physics, Leuven, Belgium, 4–8 July 2016, paper O2.104.

139. A.E. Järvinen, S.L. Allen, M. Groth, A.G. McLean, T.D. Rognlien, C.M. Samuell, A. Briesemeister, M. Fenstermacher, D.N. Hill, A.W. Leonard and G.D. Porter, Investigations of the impact of cross-field drifts on divertor detachment in DIII-D with UEDGE, 43rd EPS Conference on Plasma Physics, Leuven, Belgium, 4–8 July 2016, paper O4.115.

140. J. Varje, A. Järvinen, T. Koskela, T. Kurki-Suonio, M. Santala and S. Äkäslompolo, Simulation of neutral particle fluxes from fast ions in the JET tokamak, 43rd EPS Conference on Plasma Physics, Leuven, Belgium, 4–8 July 2016, paper O5.131.

141. P.T. Lang, R Maingi, D K. Mansfield, R McDermott, R Neu, E Wolfrum, R Arredondo Parra, M Bernert, G Birkenmeier, A Diallo, M Dunne, E Fable, R Fischer, B Geiger, A Hakola, G Kocsis, F Laggner, M Oberkofler, B Ploeckl, B Sieglin, ASDEX Upgrade Team, Impact of Lithium pellets on the plasma performance in the all-metal-wall tokamak ASDEX Upgrade, 43rd EPS Conference on Plasma Physics, Leuven, Belgium, 4–8 July 2016, paper P1.021.

142. T.P. Kiviniemi, L.G. Askinazi, A.A. Belokurov, A.D. Gurchenko, E.Z. Gusakov, T. Korpilo, S. Leerink, M. Machielsen, P. Niskala and R. Rochford, Gyrokinetic simulation of interplay between GAM and transport in TUMAN-3M tokamak, 43rd EPS Conference on Plasma Physics, Leuven, Belgium, 4–8 July 2016, paper P2.059.

143. E.Z. Gusakov, A.D. Gurchenko, P. Niskala, A.B. Altukhov, L.A. Esipov, M.Yu. Kantor, T.P. Kiviniemi, D.V. Kouprienko, S.I. Lashkul, S. Leerink and A.A. Perevalov, Experimental and global gyrokinetic studies of the isotope effect in turbulent plasma dynamics and particle transport at the FT-2 tokamak, 43rd EPS Conference on Plasma Physics, Leuven, Belgium, 4–8 July 2016, paper P2.074.

144. A. Salmi, M. Lancot, N. Logan, T. Tala, J.S. deGrassie, B.A. Grierson, C. Paz-Soldan and W.M. Solomon, TBM torque scaling with β in DIII-D, 43rd EPS Conference on Plasma Physics, Leuven, Belgium, 4–8 July 2016, paper P5.029.

145. S. Mordijck, C. Chrystal, B. Grierson, W-H. Ko, T.L. Rhodes, L. Schmitz, L. Zeng, P.H. Diamond, E.J. Doyle, C.C. Petty, A. Salmi, W.M. Solomon, G.M. Staebler, T. Tala and X. Wang, Density driven rotation changes in DIII-D H-mode plasmas, 43rd EPS Conference on Plasma Physics, Leuven, Belgium, 4–8 July 2016, paper P5.033.

146. K. Särkimäki, T. Kurki-Suonio, V. Parail, Y. Liu and G. Saibene, Role of increased magnetic field stochasticity due to test blanket modules on radial transport of thermal particles, 43rd EPS Conference on Plasma Physics, Leuven, Belgium, 4–8 July 2016, paper P5.059.

147. K. Särkimäki, E. Hirvijoki, J. Varje, J. Decker and T. Kurki-Suonio, An advection-diffusion model for runaway electron transport in perturbed magnetic fields, Theory and Simulation of Disruptions Workshop, Princeton, NJ, 20–22 July 2016.

148. P. Martin, M. Beurskens, S. Coda, T. Eich, A. Hakola, H. Meyer, the ASDEX Upgrade, MAST and TCV teams, Disruption and Runaway Electron Studies in the EUROfusion Medium Size Tokamaks, Theory and Simulation of Disruptions Workshop, Princeton, NJ, 20–22 July 2016.

149. M. Kelemen, A. Založnik, P. Vavpetič, M. Pečovnik, P. Pelicon, A. Hakola, A. Lahtinen, J. Karhunen, K. Piip, P. Paris, M. Laan, S. Markelj, Micro-NRA and micro-3HIXE with 3He microbeam on samples exposed in AUG Upgrade and pilot-PSI machines, 15th

International Conference on Nuclear Microprobe Technology and Applications, Lanzhou, China, 31 July–5 August 2016, paper PB21.

150. S. Leerink, P. Niskala, A.D. Gurchenko, E.Z. Gusakov, M.A. Irzak, T. Kiviniemi, T. Korpilo, A. A. Perevalov and R. Rochford, Full-f gyrokinetic simulations of the FT-2 tokamak using ELMFIRE, 21st Joint EU-US Transport Task Force Meeting, Leysin, Switzerland, 5–8 September 2016, invited talk.

151. A. Salmi, T. Tala, C. Bourdelle, C. Giroud, R. Gomes, J. Hillesheim, A. Järvinen, C. Maggi, P. Mantica, M. Maslov, L. Meneses, S. Menmuir, S. Moradi, S. Mordijck, V. Naulin, H. Nordman, J. Juul Rasmussen, M. Romanelli, G. Sips, J.L. Svensson, M. Tsalas, H. Weisen, A.Wynn and JET contributors, Particle transport, sources and density peaking in JET H-mode plasmas, 21st Joint EU-US Transport Task Force Meeting, Leysin, Switzerland, 5–8 September 2016, paper P1.11.

152. P. Niskala, L.G. Askinazi, A.A. Belokurov, A.D. Gurchenko, E.Z. Gusakov, T.P. Kiviniemi and T. Korpilo, Interplay of flows and transport in the gyrokinetic simulations of TUMAN-3M plasmas, 21st Joint EU-US Transport Task Force Meeting, Leysin, Switzerland, 5–8 September 2016, paper P1.5.

153. S.-P. Pehkonen, T. Tala, A. Salmi, R.M. McDermott, C. Angioni, T. Pütterich, B. Duval, C. Giroud, J. Ferreira, J. Hillesheim, S. Menmuir, M. Tsalas, M. Maslov, H. Weisen, E. Delabie and JET contributors, Experimental determination and normalised ion gyroradius scaling of intrinsic torque in ASDEX Upgrade, 21st Joint EU-US Transport Task Force Meeting, Leysin, Switzerland, 5–8 September 2016, paper P1.6.

154. S. Brezinsek, M. Rubel, G.F. Matthews, R. Neu, A. Garcia-Carrasco, C. Giroud, C. Guillemaut, N. den Harder, A. Huber, S. Jachmich, J. Likonen, M. Mayer, I. Nunes. G. Sergienko and JET Contributors, Plasma operation with full W divertor – experiences from JET equipped with the ITER-Like Wall, 29th Symposium on Fusion Technology, Prague, Czech Republic, 5–9 September 2016, paper I2.1.

155. M. Halitovs, G. Kizane, J. Likonen and N. Bekris, Influence of divertor material modifications on the inventory of tritium in the divertor region, 29th Symposium on Fusion Technology, Prague, Czech Republic, 5–9 September 2016, paper P1.108.

156. J. Wu, H. Wu, Y. Song, M. Li and T. Zhang, Vibration suppression control of EAMA/EAST Articulated Maintenance Arm, 29th Symposium on Fusion Technology, Prague, Czech Republic, 5–9 September 2016, paper P1.143.

157. S. Shi, H. Wu, Y. Song, H. Handroos, M. Li, B. Mao, Y. Cheng, H. Pan, E. Villedieu and V. Bruno, Error compensation strategy of EAST articulated maintenance arm robot based on static stiffness modeling, 29th Symposium on Fusion Technology, Prague, Czech Republic, 5–9 September 2016, paper P1.144.

158. T. Määttä, H. Saarinen, H. Mäkinen, J. Lyytinen, P. Kilpeläinen, H. Martikainen, P. Tikka, S. Rantala, J.-P. Uusitalo and M. Pérez-Lasala, Remote Handling Connector development for the ITER Divertor Diagnostics, 29th Symposium on Fusion Technology, Prague, Czech Republic, 5–9 September 2016, paper P3.052.

159. R. Mateus, A. Hakola, C. Poroniscu, C. Lungu and E. Alves, Study of deuterium retention in Be-W coatings with distinct morphologies, 29th Symposium on Fusion Technology, Prague, Czech Republic, 5–9 September 2016, paper P3.110.

160. M. Li, H. Wu, H. Handroos, Y. Wang, R. Skilton, A. Loving and M. Coleman, Dynamic Model Identification Method of Manipulator for inside DEMO Engineering, 29th Symposium on Fusion Technology, Prague, Czech Republic, 5–9 September 2016, paper P3.138.

161. M. Laan, A. Hakola, P. Paris, K. Piip, M. Aints, I. Jõgi, J. Kozlova, C. Lungu, C. Poroniscu, E. Grigore, C. Ruset, J, Kolehmainen and S. Tervakangas, Dependence of LIBS spectra on the surface composition and morphology of W/Al coatings, 29th Symposium on Fusion Technology, Prague, Czech Republic, 5–9 September 2016, paper P4.066.

162. A. Drenik, D. Alegre, M. Beldishevski, S. Brezinsek, A. de Castro, T. Dittmar, A. Hakola, P. Heesterman, K. Krieger, U. Kruezi, G. Meisl, M. Mozetic, M. Oberkofler, M. Panjan, G. Primc, V. Rohde, G. De Temmerman and R. Zaplotnik, Formation of ammonia in N2 seeded discharges at AUG and JET, 29th Symposium on Fusion Technology, Prague, Czech Republic, 5–9 September 2016, paper P4.121.

163. Y. Wang, H. Wu, H. Handroos, M. Li, B. Mao and J. Wu, Accuracy improvement studies for remote maintenance manipulators, 29th Symposium on Fusion Technology, Prague, Czech Republic, 5–9 September 2016, paper P4.127.

164. B. Mao, Z. Xie, Y. Wang. H. Handroos and H. Wu, A hybrid DE and PSO algorithm for numerical solution of remote maintenance manipulators, 29th Symposium on Fusion Technology, Prague, Czech Republic, 5–9 September 2016, paper P4.134.

165. J. Wu, H. Wu, Y. Song, H. Pan and Y. Zhang, Robust grasping motion control with force feedback for EAMA robot in fusion tokamak application, 29th Symposium on Fusion Technology, Prague, Czech Republic, 5–9 September 2016, paper P4.136.

166. B.A. Grierson, C. Chrystal, J.A. Boedo, W.X. Wang, J.S. deGrassie, W.M. Solomon, G.M. Staebler, D.J. Battaglia, T. Tala, A. Salmi, S.-P. Pehkonen, J. Ferreira, C.Giroud and and JET Contributors, Validation of Theoretical Models of Intrinsic Torque in DIII-D and Projection to ITER by Dimensionless Scaling, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper EX/11-1.

167. D. Carralero, H.W. Möller, M. Groth, J. Adamek, L. Aho-Mantila, S.A. Artene, G. Birkenmeier, M. Brix, G. Fuchert, P. Manz, J. Madsen, S. Marsen, U. Stroth, H.J. Sun, N. Vianello, M. Wischmeier, E. Wolfrum, ASDEX Upgrade Team, COMPASS Team, JET Contributors and the EUROfusion MST tem, Recent progress towards a functional model for filamentary SOL transport, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper EX/2-2.

168. T. Tala, A. Salmi, C. Bourdelle, L. Giacomelli, C. Giroud, R. Gomes, J. Hillesheim, A. Järvinen, C. Maggi, P. Mantica, M. Maslov, L. Meneses, S. Menmuir, S. Moradi, S. Mordijck, V. Naulin, H. Nordman, J. Juul Rasmussen, G. Sips, J.L. Svensson, M. Tsalas, H. Weisen and JET contributors, Density Peaking in JET − Driven by Fuelling or Transport?, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper EX/P6-12.

169. K. Heinola, J. Likonen, T. Ahlgren, S. Brezinsek, G. De Temmerman, I. Jepu, G. F. Matthews, R. A. Pitts, A. Widdowson and JET Contributors, Long-term fuel retention and release in JET ITER-Like Wall at ITER-relevant baking temperatures, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper EX/P6-2.

170. A. Hakola, S. Brezinsek, D. Douai, M. Balden, V. Bobkov, D. Carralero, H. Greuner, A. Kallenbach, K. Krieger, G. Meisl, M. Oberkofler, V. Rohde, A. Lahtinen, G. deTemmerman, R. Caniello, F. Ghezzi, T. Wauters, P. Petersson, A. Garcia-Carrasco and P. Schneider, Plasma-wall interaction studies in the full-W ASDEX Upgrade during helium plasma discharges, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper EX/P6-21.

171. S. Brezinsek, J. W. Coenen, T. Schwarz-Selinger, K. Schmid, A. Kirschner, A. Hakola, F. L. Tabares, H. van der Meiden, M.-L. Mayoral, M. Reinhart, E. Tsitrone, and WP PFC contributors, Preparation of PFCs for the efficient use in ITER and DEMO –

plasma-wall interaction studies within the EUROfusion consortium, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper EX/P8-41.

172. J. Bucalossi et al. (incl. A. Hakola), Progresses on WEST Platform Construction towards first plasmas, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper FIP/2-1Rb.

173. A. Widdowson, E. Alves, A. Baron-Wiechec, N.P. Barradas, J. Beal, N. Catarino, J.P. Coad, V. Corregidor, K. Heinola, J. Likonen, S. Koivuranta, S. Krat, A. Lahtinen, G.F. Matthews, M. Mayer, P. Petersson, M. Rubel and JET Contributors, Overview of Fuel Inventory in JET with the ITER-Like Wall, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper MPT/1-3.

174. H.F. Meyer, S. Coda, A. Hakola, T. Eich, P. Martin, the ASDEX Upgrade, MAST and TCV teams, Overview of progress in European Medium Sized Tokamaks towards an integrated plasma-edge/wall solution, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper OV/P-12.

175. M. Wischmeier, M. Bernert, G. Calabro, C.G. Lowry, S. Wiesen, F. Reimold, A. Huber, M.L. Reinke, D. Brida, R. Dux, C. Guillemaut, L. Aho-Mantila, S. Brezinsek, P. Drewelow, S. Gloeggler, M. Groth, D. Harting, A. Kallenbach, B. Lipschultz, C.F. Maggi, A. Meigs, M.F.F. Nave, S. Potzel, G. Sergienko, G. Sips, M. Stamp, T. Lunt, B. Viola, the JET contributors, the ASDEX Upgrade and the MST team, Facing the challenge of power exhaust on the way to a future power plant with experiments in the JET and ASDEX Upgrade tokamaks, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper PDP-14.

176. I. Nunes, S. Brezinsek, J. Buchanan, C.D. Challis, I. Carvalho, E.G. Delabie, D. van Eester, M. Faitsch, J. M. Fontecaba, L. Garzotti, M. Groth, J. Hillesheim, J. Hobirk, A. Hubbard, A. Huber, E. Joffrin, Y. Kazakov, D.B. King, A. Krasilnikov, K. Krieger, A.B. Kukushkin, E. Lerche, E. De La Luna, C. Maggi, P. Mantica, M. Maslov, V. Neverov, M. Romanelli, P. Siren, E.R. Solano, M. Stamp, T. Tala, M. Valisa, Valovic, D. Valcarcel, J. Varje, M. E. Viezzer, H. Weisen, S. Wiesen and JET contributors, First results from recent JET experiments in Hydrogen and Hydrogen-Deuterium plasmas, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper PDP-2.

177. R. Akers, S. Äkäslompolo, J. Hess, Y. Liu, S. Pinches, M. Singh, A. Turner, J. Varje, K. Särkimäki and B. Colling, High fidelity simulations of fast ion power flux driven by 3D field perturbations on ITER, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper TH/4-1.

178. W. Guttenfelder, A.R. Field, I. Lupelli, J.-K. Park, T. Tala, J. Candy, S.M. Kaye, M. Peters, Y. Ren and W.M. Solomon, Analysis and prediction of momentum transport in spherical tokamaks, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper TH/P3-14.

179. S. Leerink, P. Niskala, A. Gurchenko, E. Gusakov, A. Altukhov, T. Kiviniemi, S. Lashkul, R. Rochford and T. Korpilo, Coupling full-f gyrokinetic studies to experimental measurements of the isotope effect for FT-2 tokamak plasmas, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper TH/P3-6.

180. T. Kurki-Suonio, J. Varje, K. Särkimäki, S. Äkäslompolo, Y. Liu, S. Sipilä, J. Terävä, V. Parail and G. Saibene, The effect of plasma response on losses of energetic ions in the presence of 3d perturbations in different iter scenarios, 26th IAEA Fusion Energy Conference, Kyoto, Japan, 17–22 October 2016, paper TH/P4-3.

181. P. Martin, M.S. Coda, T. Eich, A. Hakola, H. Meyer, the ASDEX Upgrade, MAST and TCV teams, Overview of the EUROfusion Medium Size Tokamak scientific program,

58th Annual Meeting of the APS Division of Plasma Physics, San Jose, CA, 31 October–4 November 2016, paper BP10.00057.

182. R. Sibois, T. Määttä and M. Siuko, Verification method for the design of remote handling devices using a reliability-based stochastic petri net approach, ASME 2016 International Mechanical Engineering Congress and Exposition, Phoenix, AZ, 11–17 November 11–17, 2016.

183. Jing Wu, Huapeng Wu, Yuntao Song et al., Extended Kalman filter estimator with curve fitting calibration of EAST Articulated Maintenance Arm position disturbance compensation, IEEE International Conference on Electronic Information and Communication Technology (ICEICT 2016), Harbin, China, 20–22 August 2016.

184. T.P. Kiviniemi, T. Korpilo, S. Leerink, P. Niskala, R. Rochford and L. Chone, Implicit solvers in full-f gyrokinetic particle-in-cell simulation code Elmfire and extension to SOL, International Workshop on Numerical Methods for Kinetic Equations, Strasbourg, France, 17–21 October 2016.

185. P. Niskala A.D. Gurchenko, E.Z. Gusakov, T.P. Kiviniemi, S.I. Lashkul and S. Leerink, Coupling experimental and computational studies of the isotope effect in turbulent particle transport, Joint Varenna-Lausanne International Workshop on Theory of Fusion Plasmas, Varenna, Italy, 29 August–2 September 2016.

186. K. Särkimäki, J. Varje, M. Vallar and T. Kurki-Suonio, Preparation of JT-60SA exploitation, JT-60SA Modelling Meeting.

187. A. Hakola, Fusion in the Footsteps of Fission – from Basic Research to Building Reactors, plenary presentation in Nuclear Science and Technology Symposium, Helsinki, Finland, 2–3 November 2016.

188. J. Varje, Neutrons in Fusion Experiments and Reactors, Nuclear Science and Technology Symposium, Helsinki, Finland, 2–3 November 2016.

189. M. Siuko, Remote Handling in Fusion and Fission Research and Industry, Nuclear Science and Technology Symposium, Helsinki, Finland, 2–3 November 2016.

190. S. Kiviluoto, Integrated System Level Simulation and Analysis of DEMO with Apros, Nuclear Science and Technology Symposium, Helsinki, Finland, 2–3 November 2016.

191. T. Kurki-Suonio, Lämpöydinfuusio – ei skandaalinkäryisiä yrityskauppoja vaan kärytöntä energiaa, Studia Generalia lecture in Nuclear Science and Technology Symposium, Helsinki, Finland, 2–3 November 2016.

192. T. Lindén, Compact fusion reactors, Nuclear Science and Technology Symposium, Helsinki, Finland, 2–3 November 2016.

10.5.3 Research reports

193. M. Airila (ed.), FinnFusion Yearbook 2015, VTT Science **129** (2016).

10.5.4 Academic theses

194. Faraz Amjad, Systematic approach for the development of remote handling system concepts for high energy physics research facilities, Doctoral dissertation, Tampere University of Technology, Tampere 2016.

195. Chao Fang, Study on system design and key technologies of case closure welding for ITER Correction Coil, Doctoral dissertation, Lappeenranta University of Technology, Lappeenranta 2016.

196. Fredric Granberg, Interaction mechanisms of edge dislocations with obstacles in Fe and metal alloys, Doctoral dissertation, University of Helsinki, Helsinki 2016.

197. Janne Koivumäki, Stability-guaranteed force-sensorless contact force/motion control of heavy-duty hydraulic manipulators, Doctoral dissertation, Tampere University of Technology, Tampere 2016.

198. Reza Oftadeh, Universal path following of wheeled mobile robots, Doctoral dissertation, Tampere University of Technology, Tampere 2016.

199. Romain Sibois, Quantitative evaluation method for the verification of complex mechatronic systems – Development of a reliability-based design process using stochastic Petri Nets, Doctoral dissertation, Tampere University of Technology, Tampere 2016.

200. Zahra Ziael, Vision-based global path planning and trajectory generation for robotic applications in hazardous environments, Doctoral dissertation, Tampere University of Technology, Tampere 2016.

201. Simppa Äkäslompolo, Fast ion simulations in toroidally asymmetric tokamaks - Model validation with fast ion probes at ASDEX Upgrade and predictive modelling of ITER, Doctoral dissertation, Aalto University, Espoo 2016.

202. Sanna-Paula Pehkonen, Experimental determination on intrinsic torque in JET and ASDEX Upgrade tokamaks, MSc thesis, Aalto University, Espoo 2016.

203. Juuso Terävä, Simulating helium ash in ITER, MSc thesis, Aalto University, Espoo 2016.

204. Jari Varje, Simulation of neutral particle fluxes from fast ions in the JET tokamak, MSc thesis, Aalto University, Espoo 2016.

205. Benjamin Grigoriadis, Study of the triggering mechanism of internal transport barriers in a gyrokinetic simulation for FT-2 tokamak, BSc thesis, Aalto University, Espoo 2016.

206. Patrik Ollus, Validity of guiding center approximation in non-axisymmetric ITER magnetic backgrounds, BSc thesis, Aalto University, Espoo 2016.

207. Rasmus Viitala, Comparing SOLPS simulations with two-point model calculations for predicting power and momentum losses in the scrape-off layer of ASDEX Upgrade, BSc thesis, Aalto University, Espoo 2016.

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Title	**FinnFusion Yearbook 2016**
Author(s)	Markus Airila (Ed.)
Abstract	This Yearbook summarises the 2016 research and industry activities of the FinnFusion Consortium. 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, Fortum Power and Heat Ltd., Lappeenranta University of Technology, Tampere University of Technology, University of Helsinki and Åbo Akademi University. FinnFusion participates in several EUROfusion work packages, the largest being experimental campaigns at JET and ASDEX Upgrade and related analyses, materials research, plasma-facing components and remote maintenance. A new research topic pursued in FinnFusion in 2016 is the *Early Neutron Source* work package, aiming at building a device to study hard neutron radiation damage to fusion materials. On the industry side, one of the very first EUROfusion industry tasks on DEMO remote maintenance was completed by Fortum in 2016. EUROfusion supports post-graduate training through the Education work package that allowed FinnFusion to partly fund 12 PhD students in FinnFusion member organizations. In addition, four EUROfusion post-doctoral research and engineering fellowships were running in 2016. F4E projects in 2016 were related to the development of the diagnostics system for ITER (*Remote Handling Connector*) and computer assisted teleoperation. The FinnFusion annual seminar in 2016 was organised by LUT in Lappeenranta in May.
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Nimeke	**FinnFusion-vuosikirja 2016**
Tekijä(t)	Markus Airila (toim.)
Tiivistelmä	Tähän vuosikirjaan on koottu FinnFusion-konsortion vuoden 2016 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, Fortum Power and Heat Oy, Lappeenrannan teknillinen yliopisto, Tampereen teknillinen yliopisto, Helsingin yliopisto ja Åbo Akademi. FinnFusion-konsortio osallistuu useisiin EUROfusion-projekteihin. Suurin työpanos kohdistuu JET- ja ASDEX Upgrade -koelaitteissa tehtäviin kokeisiin ja analyyseihin, materiaalitutkimukseen, ensiseinämäkomponentteihin ja etäkäsittelyyn. Vuonna 2016 käynnistettiin uutena tutkimusalueena hanke kovien neutronien aiheuttamien materiaalivaurioiden tutkimukseen liittyvän *Early Neutron Source* -työpaketin puitteissa. Fortum toteutti yhden EUROfusionin ensimmäisistä teollisuustoimeksiannoista, joka liittyi DEMO-reaktorin etähuoltojärjestelmiin. EUROfusion tukee jatko-opiskelua omalla rahoitusinstrumentillaan, jonka turvin FinnFusion rahoitti osittain 12 jatko-opiskelijan työtä jäsenorganisaatioissaan. Lisäksi vuoden 2016 aikana oli käynnissä neljä EUROfusionin rahoittamaa tutkijatohtorin projektia. FinnFusionin F4E-työt iittyivät ITERin diagnostiikkajärjestelmän kehitykseen (*Remote Handling Connector*) ja tietokoneavusteiseen etäkäyttöön. Fuusioalan vuosiseminaari 2016 järjestettiin Lappeenrannan teknillisellä yliopistolla toukokuussa.
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