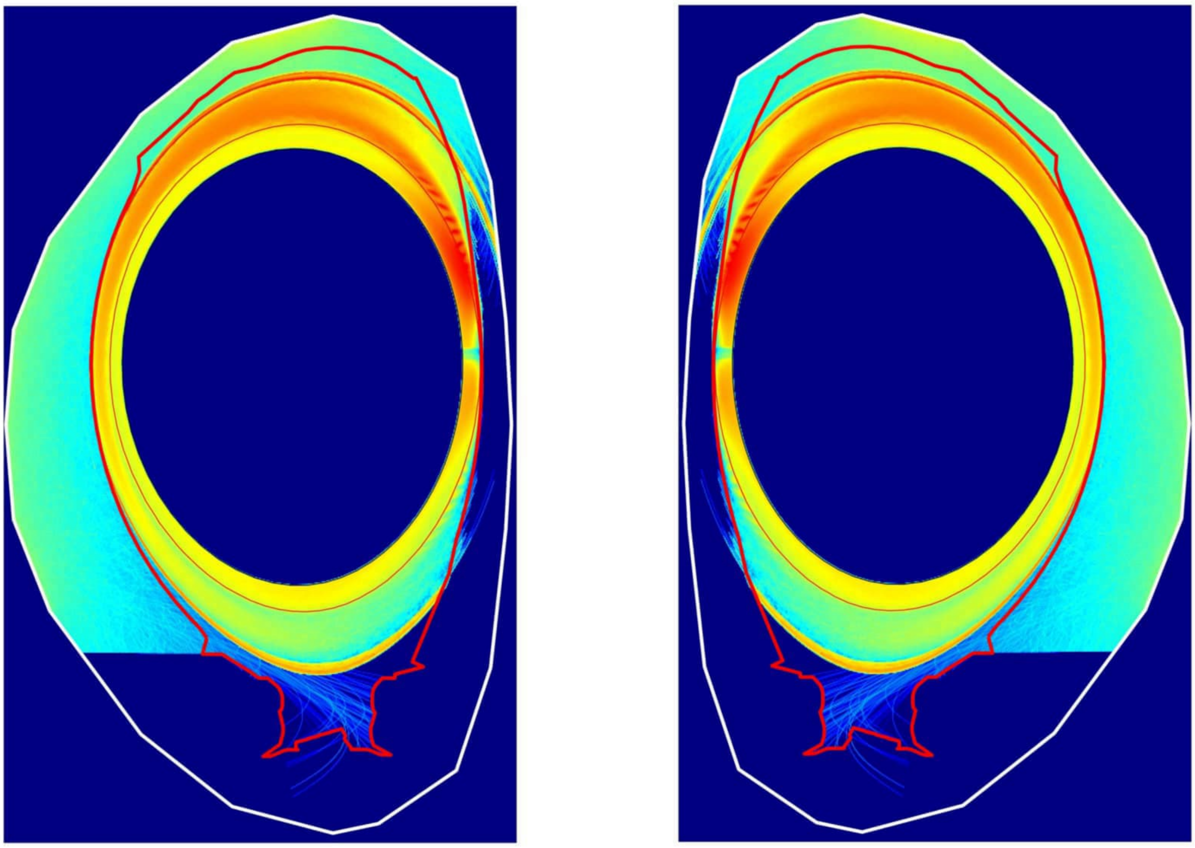

FinnFusion Yearbook 2025

Tommi Lyytinen | Jari Likonen (Eds.)

VTT TECHNOLOGY 448

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Technical Research Centre of Finland Ltd

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Preface

As the IAEA Director General stated: “The fusion energy landscape continues to develop at an extraordinary pace. What was once confined to experimental research and long-term aspirations is now rapidly becoming a cornerstone of national energy strategies and industrial planning. Countries are formulating dedicated fusion policies, companies are selecting sites and designing the first generation of power plants, and regulatory bodies are beginning to issue tailored guidance.” It has been a great pleasure for me to follow in Finland that both the Ministry of Economic Affairs and Employment (MEAE) and the Radiation and Nuclear Safety Authority of Finland (STUK) have taken very important steps towards modernising of fusion energy regulation in Finland. The proposed not yet ratified regulation for fusion at least up to the piloting phase would take place under the Radiation Act rather than under Nuclear Energy Act. This will give a more streamlined process for licensing a fusion pilot plant in Finland, which also puts Finland in forefront among most of the EU countries in which fusion regulation is not yet often separated from the fission regulation. Another important governmental act has been to add fusion energy research explicitly in the newly proposed Finnish energy strategy.

ITER project had its record year in many KPIs, for example the F4E milestone schedule performance index exceeding 90% and over 90% of its commitments and payments implemented. The fourth (out of nine) vacuum vessel sector is now installed in the tokamak pit. The magnetic coil test facility is being constructed on ITER site. Furthermore, the Multilateral International IFMIF-DONES Agreement was signed. ITER also organised the 2nd public-private workshop where ITER is actively distributing the accumulated expertise to private industry and fusion startups including the ITER Engineering Basis Handbook. On the EU side, although the EU fusion strategy is being prepared and not yet published, it has become clear that the focus from the DEMO plant will be shifted to designing a smaller EU fusion pilot plant with a notably shorter timeline. The key scope in the years to come is to design a 14 MeV DT enabling breeding blanket testing & qualification EU fusion pilot plant.

The 5th Nordic bi-annual fusion seminar was held for the first time in Norway in Tromsø in June, under the auspices of UiT the Arctic University of Norway. The keynote speakers included presentations from ITER, EUROfusion, DIFFER and Commonwealth Fusion Systems. Organising Nordic bi-annual fusion seminar in Norway was an opportunity to promote Norway having recently joined EUROfusion via DTU as their international partner. More than 80 scientists and engineers participated in the seminar to discuss the Nordic collaboration in various fusion related themes. St1 and Novatron Fusion Group organised the second edition of Nordic Fusion Forum in Espoo in October in which FinnFusion members were also actively participating. The fusion policymakers, industry leaders, scientists, and investors focused on advancing the development and industrialization of fusion energy across the Nordic region in the event. This forum will spotlight the strategic potential of the Nordics as a hub for next-generation energy.

The quote in the beginning of this preface is from the 30th IAEA Fusion Energy Conference, which took place in Chengdu in People's Republic of China in October. The main highlights of the conference were centred on the transition of fusion from pure scientific research toward industrialisation, commercialisation, and international deployment planning including engineering feasibility, industrial supply chains, pilot plant development and safety regulation. China also used the conference to showcase its expanding fusion ecosystem, technical capabilities with numerous new facilities being under construction.

The key questions to answer right now is whether there are capabilities and willingness to challenge the global pace of fusion energy development in Nordics and Finland. Surely the efforts by MEAE and STUK with respect to fusion regulation are pointing to the right direction, but this is by far not enough to stay in or even win the race of harnessing fusion energy. Much more is needed on the funding front, fusion workforce and supply chain development and political drive – are we ready for that right now?

Tuomas Tala
Head of FinnFusion Consortium

Contents

List of acronyms and names

ACH	Advanced computing hub, hosted by UH
APROS	Software used for modelling, dynamic
ASCOT	Accelerated Simulation of Charged Particle Orbits in Tori (particle tracing code)
AU	Aalto University, Espoo/Helsinki, Finland
AUG	ASDEX Upgrade (tokamak facility)
BMC	Backward Monte Carlo
BB	Breeding blanket
BOP	Balance-of-plant
CCFE	Culham Centre for Fusion Energy
CFD	Computational Fluid Dynamics
CSC	IT Center for Science Ltd, Finland
DIII-D	Tokamak facility at General Atomics, San Diego
DEMO	Future demonstration fusion power plant
DONES	DEMO oriented neutron source
DPA	Displacement-per-atom
DT	Deuterium-tritium
DTP2	Divertor test platform phase 2 (test facility in Tampere)
EDGE2D	Fluid plasma simulation code
EIRENE	Neutral particle simulation code
ELM	Edge localised mode (plasma instability)
ENR	Enabling research
ENS	Early neutron source
ERO	Monte Carlo impurity transport simulation code
EUROfusion	European consortium implementing the Fusion Roadmap
F4E	Fusion for Energy (the European Domestic Agency of ITER)
FDS	Fire Dynamics Simulator

GPU	Graphics Processing Unit
HCPB	Helium Cooled Pebble Bed (Breeding blanket concept)
HEA	High entropy alloy
HELIAS	Helical-axis advanced stellarator
HHFM	High heat flux materials
HLCS	High level control system
HPC	High-performance computing
IAEA	International Atomic Energy Agency
ICRH	Ion cyclotron resonance heating
ILW	ITER-like wall
IMAS	ITER Integrated Modelling and Analysis Suite (collection of codes)
IPP	Institut für Plasmaphysik, Garching/Greifswald
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)
JINTRAC	Set of plasma simulation codes
KSTAR	Korea Superconducting Tokamak Advanced Research (tokamak facility)
LAMMPS	Classical molecular dynamics simulatior code
LUT	Lappeenranta-Lahti University of Technology
MAST	Mega Amp Spherical Tokamak (tokamak facility)
MAST-U	MAST Upgrade
MD	Molecular dynamics (simulation method)
MEAE	Ministry of Employment and Economy
ML	Machine learning
NBI	Neutral beam injection
PFC	Plasma-facing component
PIE	Post irradiation experiment
RBS	Rutherford backscattering spectrometry
RH	Remote handling
RM	Remote maintenance
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)

SRIM	Stopping and Range of Ions in Material (stopping power calculations)
STEP	Spherical Tokamak for Energy Production (planned tokamak facility)
SQUID	Stable Quasi-Isodynamic Design (optimized stellarator concept)
TCV	Tokamak à Configuration Variable (tokamak facility)
TUNI	Tampere University
UH	University of Helsinki
VTT	VTT Technical Research Centre of Finland Ltd
W7-X	Wendelstein 7-x stellarator (stellarator facility)
WCLL	Water-cooled lithium-lead
WEST	Tungsten (W) environment in steady-state tokamak (tokamak facility)

1 FinnFusion organization

1.1 Programme objectives

The Finnish Fusion Programme, under the FinnFusion Consortium, is fully integrated into the European Fusion 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+DEMO and other future fusion devices in collaboration with Finnish industry
- Provide a high-level scientific contribution to the accompanying Euratom Fusion Programme under the EUROfusion Consortium.

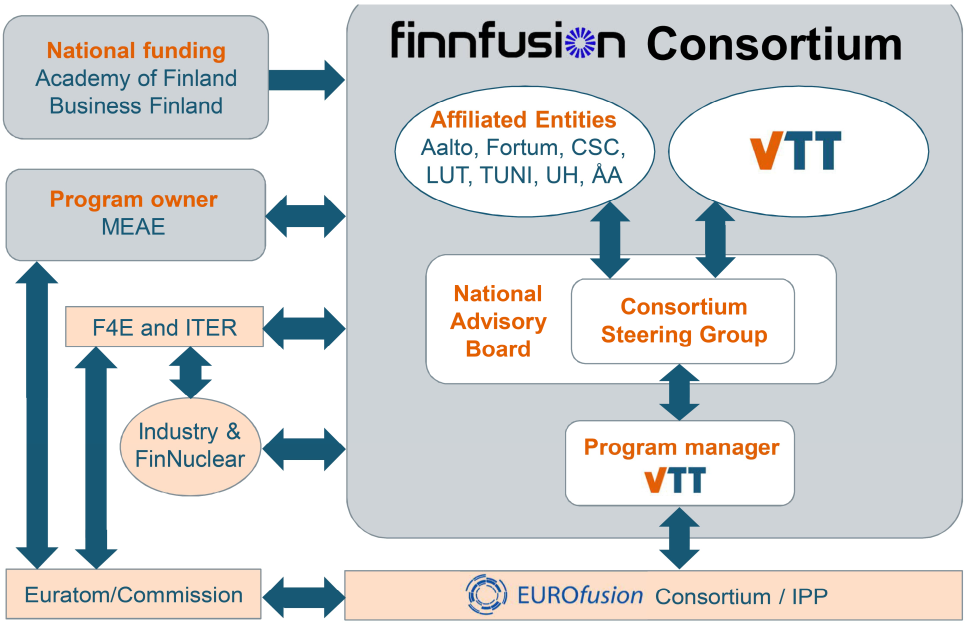
This can be achieved by close collaboration between the Research Units and industry, and by strongly focusing the R&D effort on a few competitive areas. Active participation in the EUROfusion Work Programme and accomplishing ITER technology development Tenders & Grants by F4E and ITER provide challenging opportunities for top-level science and technology R&D work in research institutes and Finnish industry. The goal is to establish an active fusion ecosystem in Finland and supporting companies through business research. Participating in industry activation tasks facilitated by FinNuclear supports wider networking and ecosystem expansion.

1.2 EUROfusion and FinnFusion Consortia

During the Horizon Europe framework program, the Euratom Fusion Research program is organised under the EUROfusion Consortium with 29 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 Europe through a Joint programme of the members of the EUROfusion consortium. A 547 M€ grant for the period 2021–2025 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. Towards the European Commission and the EUROfusion Consortium, Ministry of Employment and Economy acts as the program owner. Now within the EUROfusion Consortium, VTT is the beneficiary and therefore acts as the program manager towards the Commission. The universities carrying out fusion research in Finland and Fortum and CSC are acting as Affiliated Entities to the Consortium. The FinnFusion organigram is presented in Figure 1.1.



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 Prof. Tuomas Tala from VTT. The following institutes and universities participated in 2025:

VTT Technical Research Centre of Finland

Activities: Co-ordination, tokamak physics and engineering

Members: Prof. Tuomas Tala (Head of Research Unit), Dr. Leena Aho-Mantila, Dr. Markus Airila, Amanda Bruncrona, Dr. Antti Hakola (Project Manager), Daniel Jordan, Dr. Aaro Järvinen, Dr. Juuso Karhunen, Adam Kit, Petteri Lehti, Dr. Jari Likonen, MSc. Tommi Lyytinen, Anna Niemelä, MSc. Sixten Norrman, Ulla Peltonen (administration), MSc. Samuli Saari, Dr. Antti Salmi, Kirsi Selin (administration), MSc Joona Sissonen, Dr. Antti Snicker, Dr. Marton Szogradi, Dr. Konsta Särkimäki

Activities: Materials modelling
Members: Timo Avikainen, Dr. Andris Freimanis, Gizem Ersavas Isitman, Dr. Anssi Laukkanen, MSc. Tomi Suhonen

Activities: Mechanical testing of fusion materials
Members: Brahim Dif, Dr. Cholidah Akbar Fitriani

Activities: Probabilistic risk assessment and waste management
Members: Dr. Markus Airila, MSc. Atte Helminen

Activities: Fire safety
Members: Dr. Tuula Hakkarainen, Dr. Timo Korhonen, MSc. Nikhil Verma

Activities: Ecosystem research
Members: MSc.Tapani Ryynänen, Dr. Arho Suominen

Activities: Remote maintenance
Members: MSc. Jarmo Alanen, Dr. William Brace, Laura Goncalves Ribeiro, MSc. Petteri Kokkonen, MSc. Janne Lyytinen, MSc. Hannu Martikainen, Dr. Antti Pulkkinen, MSc. Kari Rainio, MSc. Hannu Saarinen, MSc. Qais Saifi, MSc. Karoliina Salminen, Lic.Tech. Mikko Siuko, MSc. Petri Tikka, Msc. Van Dung Truong, MSc. Arto Ylisaukko-oja

School of Science, Department of Applied Physics

Activities: Physics
Members: Prof. Mathias Groth (Group Leader), MSc. Francis Albert, Dr. Ray Chandra, Dr. Timo Kiviniemi, Dr. Taina Kurki-Suonio, MSc. Roni Mäenpää, MSc. David Rees, Dr. Seppo Sipilä, MSc. Aaron Vesa, Pyry Virtanen, Suvi Niemelä and Gabriella Beni (admin. support)

Students: Henri Kuivasniemi, Vesa-Pekka Rikala, Joona Siljander

Activities: Materials physics
Members: Sara Bouarich (admin support), Dr. Antoine Clement, MSc. Nima Fakhrayi Mofrad, Msc. Evgeniia Ponomareva, MSc. Rafael Nuñez, MSc Ilja Stanovohh, MSc Sreya Viswanathan, Dr Nadezda Korepanova, Prof. Andrea Sand (Group Leader)

CSC IT Center for Science Ltd

Activities: Computation
Members: Dr. Janne Ignatius, Dr. Jan Åström

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

Activities: Robotics in fusion applications
Members: MSc. Qingfei Han, Prof. Heikki Handroos, Linda Riha, Dr. Changyang Li, MSc. Dongyi Li, Dr. Ming Li, MSc. Nikola Petikov, Dr. Peng Shang, MSc. Pradeep Gaude, Docent Huapeng Wu (Project manager), Dr. Qiwei Xue, MSc. Qi Huang, MSc. Ting Wang, Danil Vodolazskii

Tampere University (TUNI)

Activities: Remote handling, DTP2
Members: Prof. Atanas Gotchev, MSc. Tuukka Mattila, Prof. Jouni Mattila (Project Manager), MSc. Laura Gonçalves Ribeiro, MSc. Olli Suominen, MSc. Tomi Äijälä, Dr. Mehdi Heydarishahna, MSc. Kamran Akbar

University of Helsinki (UH)

Activities: Physics, materials (Accelerator Laboratory)
Members: Dr. Tommy Ahlgren, MSc. Pejk Amoroso, MSc. Xudong An, MSc. Alexandre Bergero, M.Sc. Andreas Bruncrona, Dr. Jesper Byggmästar, MSc. Zhehao Chen, Prof. Flyura Djurabekova, MSc. Aslak Fellman, Dr. Fredric Granberg, MSc. Xiaoyu Gui, Dr. Kalle Heinola, MSc. Faith Kporha, Dr. Antti Kuronen, MSc. Victor Lindblad, MSc. Anna Liski, Dr. Eryang Lu, Dr. Ilja Makkonen, Dr. Kenichiro Mizohata, Prof. Kai Nordlund (Project Manager), MSc. Igor Prozheev, Prof. Filip Tuomisto (Project Manager), Dr. Tomi Vuoriheimo, Dr. Guanying Wei, MSc. Jintong Wu, MSc. Iuliia Zhelezova

Activities: Advanced computing hub (ACH)
Members: Mr. Emil Amnell, MSc. Bruno Cattelan, Dr. Laurent Chône, Dr. Fredric Granberg, Prof. Keijo Heljanko, MSc. Oskar Lappi, Prof. Kai Nordlund, Prof. Jukka Nurminen, Mr. Ville-Markus Yli-Suutala

1.4 FinnFusion Advisory Board

FinnFusion Advisory Board steers 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 FinnFusion member parties (Steering Group) and other important Finnish actors in Finnish fusion energy research.

Chair	Janne Ignatius, CSC
Members	Mika Finska, Business Finland
	Marko Kivimäki, Business Finland
	Jussi Åkerberg, Business Finland
	Veikko Puumala, Comatec
	Mikko Helminen, Coresbond
	Klaus-Peter Finke-Härkönen, Finkarkonen
	Megumi Asano-Ulmonen, FinNuclear
	Harri Sairiala, Fluiconnecto
	Max Nyström, Fortum
	Arto Timperi, IM Intelligent Machines
	Sarita Hernesniemi, Luvata
	Olli Naukkarinen, Luvata
	Philip von Segebaden, Novatron
	Olli Suominen, Operview Oy
	Teemu Uotila, QuanScient
	Sami Kiviluoto, Platom
	Juha-Matti Liukkonen, Reaktor
	Linda Werner, St1
	Juho Korteniemi, MEAE
	Jarmo Lehtonen, Tevo Lokomo
	Olli Kalha, ex-ITER
	Karoliina Salminen, VTT
FinnFusion Steering Group	Andrea Sand, Aalto
	Janne Ignatius, CSC
	Eero Vesaoja, Fortum
	Kai Nordlund, UH
	Fredric Granberg, UH
	Huapeng Wu, LUT
	Jouni Mattila, TUNI
	Jani Halinen, VTT
	Ivan Porres, ÅA

Co-ordinator	Tuomas Tala, VTT
Secretary	Antti Snicker, VTT

The FinnFusion advisory board had two meetings in 2025, May 5th at University of Helsinki, Helsinki and December 9th at VTT Centre for Nuclear Safety, Espoo.

1.5 Finnish members in the European Fusion Committees

1.5.1 Euratom Programme Committee, Fusion configuration, Fusion Expert Group

- Marko Kivimäki, Business Finland

1.5.2 EUROfusion General Assembly

- Tuomas Tala, VTT

1.5.3 EUROfusion HPC Allocation Committee

- Andrea Sand, AU

1.5.4 EUROFUSION HPC OPERATIONS COMMITTEE

- Fredric Granberg, UH

1.5.5 EUROfusion Project Boards

- Fusion Technology Department: Leena Aho-Mantila,
- Fusion Science Department: Markus Airila, VTT
- E-TASC Scientific Board: Aaro Järvinen, VTT

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

- Juho Korteniemi, MEAE
- Tuomas Tala, VTT

1.5.7 Other international duties and Finnish representatives in the following fusion committees and expert groups in 2025

- Taina Kurki-Suonio is a member of the organizing committee for the Finnish Nuclear Days, 21 – 22 October 2025.
- Markus Airila and Aaro Järvinen are the VTT representatives in EUROfusion Communications Network (FuseCOM).

- Megumi Asano-Ulmonen is an Industrial Liaison Officer (ILO) for F4E.
- Flyura Djurabekova is the secretary of the REI (Radiation Effects in Solids) international committee and of the ICACS (International Conference on Atomic Collisions in Solids), member of SHIM (Swift Heavy Ions in Matter) conferences, and PISC (Permanent International Scientific Committee) of ISDEIV (International Symposia on Discharges and Electrical Insulation in Vacuum) as well as one of the key members of the international committee of the Mechanisms of Vacuum Arcs (MeVArc) workshop series.
- Kai Nordlund is a member of the international committee of the COSIRES (Computer Simulation of Radiation Effects in Solids) and IBMM (Ion Beam Modification of Materials) conferences.
- Andrea Sand is a member of the High Scientific Council of the European Nuclear Society, and the Finnish delegate (observer) to the DONES Steering Committee
- Antti Hakola is a member of the ITPA expert group on divertor and scrape-off layer physics.
- Tuomas Tala is a member of the ITPA expert group on transport and confinement.
- Fredric Granberg is a member in the Scientific Committee for Models and Data for Plasma-Material Interactions in Fusion Devices (MoD-PMI).
- Arto Timperi is a member of the Fusion Industry Innovation Forum Management Board (FIIF MB) and the DEMO stakeholders' group.

Aaro Järvinen is a member of the Divertor and SOL ITER Science Fellow group.

Antti Snicker is a member of the member of the ITER Scientist Fellows' Network – Energetic Particle Physics group.

2 Plasma Science for ITER, DEMO and stellarators 2025

2.1 WP TSVV: Theory-Simulation-Verification-Validation

2.1.1 TSVV Task 4: Plasma Particle/Heat Exhaust: Gyrokinetic/Kinetic Edge Codes

Research scientists: L. Chôné, UH

Development of the SymPiFE full-orbit kinetic simulation was carried out with the goal of improved scalability and portability. To this end, the particle sub-library is being refactored using the Kokkos ecosystem [Trott, Comput. Sci. Eng. 2021]. Kokkos enables the use of parallel data structures and computing patterns in a backend-agnostic way. As a result, a single codebase can be deployed seamlessly on CPU machines using the OpenMP backend, as well as on GPU devices using the CUDA or HIP backends. Other backends such as SYCL or HPX are supported as well. While MFEM datatypes natively supports host-device memory management, the upgrade to using Kokkos offers significantly more flexibility in terms of control, as well as parallel computing patterns.

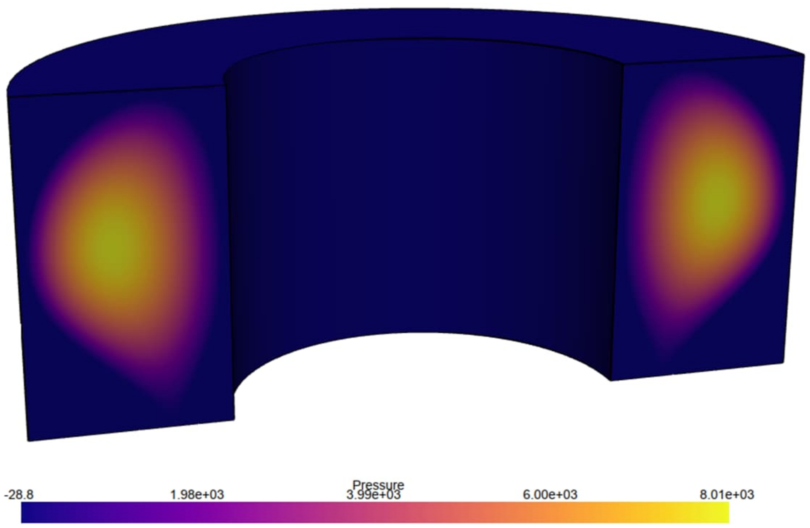


Figure 2.1: Pressure field in a cylindrical domain initialised with AUG-like parametrised equilibrium [Cerfon, Phys. Plasmas 17, 032502 (2010)].

2.1.2 TSVV Task 5 Neutral Gas Dynamics in the Edge

Research scientists: M. Groth, R. Chandra, AU

The inclusion of hydrogenic Lyman line absorption in the drift-enabled SOLPS-ITER modelling of JET-ILW L-mode deuterium discharges resulted in improved predictions of the divertor ion saturation current to the high-field side and low-field side target plates in detached conditions. The kinetic Monte Carlo code EIRENE has been updated with (non-local) photon transport capabilities and has been used to predict the enhancement of ionization rate and modified Balmer-series emission due to hydrogenic Lyman-series absorption for a given steady-state SOLPS-ITER plasma solution, as well as the resulting modifications in radiation energy loss profiles in the electron energy channel. These extensions include selecting arbitrary number of transition lines, inline collisional-radiative models of H and He, and surface reflection of radiation, all of which are now controlled by regular EIRENE input flags. Photon transport feature is available in the newest SOLPS-ITER code package allowing a self-consistent plasma-gas-photon coupling evaluation of the SOL.

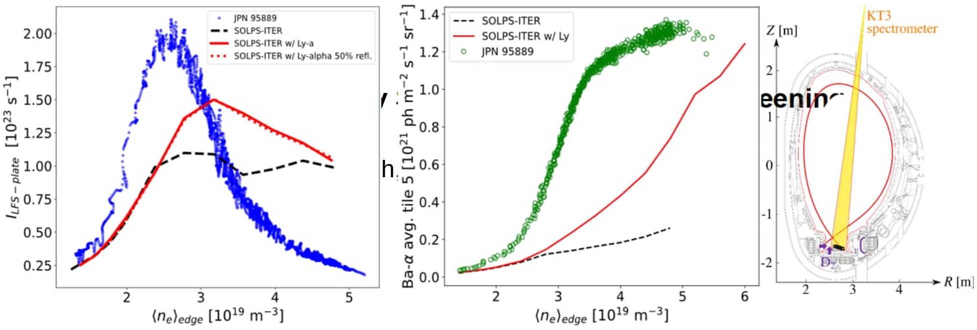


Figure 2.2: Fully-coupled plasma-gas-photon predictions (solid and dashed lines) of the JET-ILW L-mode deuterium plasmas (a) integrated outer target particle flux $I_{LFS,plate}$ and (b) line-integrated D_α emission averaged over the (c) line-of-sights of the KT3 spectrometer, compared with experimental values (scatter). Lyman absorption improves the predictions of peak $I_{LFS,plate}$ values by ~30% and D_α emission by a factor of 3.

2.1.3 TSVV Task 6 Impurity Sources, Transport, and Screening

Research scientists: M. Groth, R. Mäenpää, Pyry Virtanen, AU

ERO2.0 simulations executed on hydrogenic SOLPS-ITER limiter configuration background plasmas predict that the main nickel erosion location in the vacuum vessel wall is the LFS vacuum vessel wall. Of the two limiter plasma scenarios, one is limited on the HFS and the other on the LFS. The nickel erosion rate, as predicted by ERO2.0, in the HFS limited plasma scenario is 8.4×1019 s-1, which is comparable to the lower end of nickel erosion rates predicted for diverted plasmas. For the LFS limited plasma, the predicted nickel erosion rate is approximately 2.3 times higher than in the HFS limited plasma at 1.9×1020 s-1. In limiter plasmas, the highest atomic flux is predicted to be right above and below the contact point between the plasma and limiter surface. There are large gaps between the limiters and antennas on the LFS compared to the HFS where 95% of the atomic flux to the vacuum vessel wall is blocked by the limiters and recessed tiles. The higher nickel erosion rate in the LFS limited scenario, compared to the HFS limited scenario, is caused by the contact point being on the LFS.

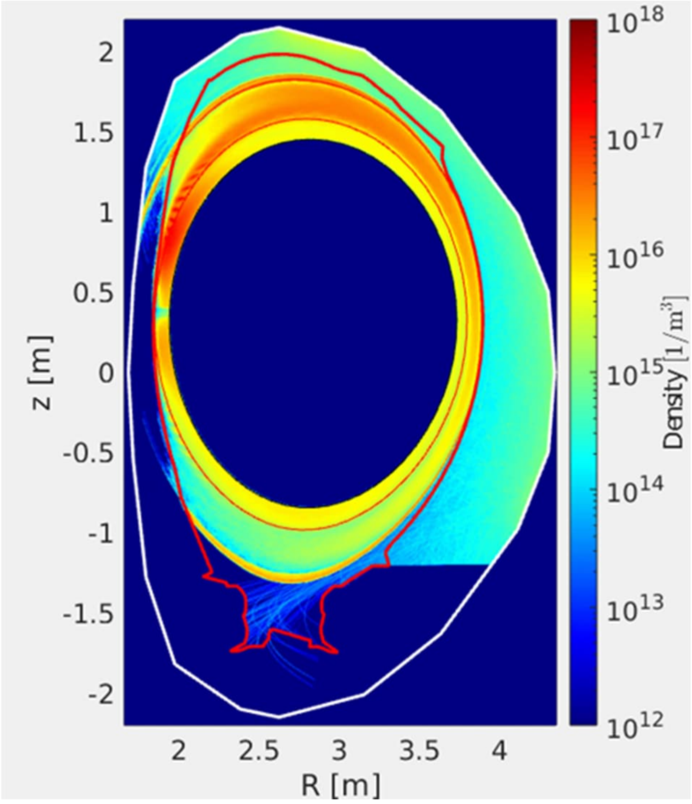


Figure 2.3: ERO2.0 predicted 2D nickel density over all charge states in the HFS limited plasma scenario.

2.1.4 TSVV Task 7 Plasma-Wall Interaction in DEMO

Research scientists: T. Ahlgren, A. Bergero, J. Byggmästar, F. Granberg, F. Kporha, K. Nordlund, UH

During 2025 the focus continued on the development of an ML interatomic potentials for the W-O-H interactions, to enable accurate sputtering simulations of decorated tungsten surfaces. Work on the sputtering of tungsten and decorated tungsten surfaces with classical potentials was done, by various incoming ions. Sputtering and reflection yields, as well and angular and energy distributions were obtained for several ion energies and a wide range of incoming angles. The work on pure tungsten surfaces was finished and the work on effect of deuterium on the sputtering was almost finished in 2025. It has been found that different interatomic potentials yield different results, and the need for an accurate potential is essential. Additional DFT and other validations have been carried out to supplement the other work and finally answer the critical question of the effect of deuterium.

2.1.5 TSVV Task 12 Stellarator optimization

Research scientists: S. Äkäslompolo, AU, K. Särkimäki, VTT

ASCOT5's software development saw progress: GPU porting has resulted in production use of the GPU-code. Further progress includes support of AMD GPUs and additional physics models within the code (See Peybernes et al. Plasma Phys. Control. Fusion (2025), 67 105020). On the IMAS side, a muscle3 actor was generated and the testing on the new gateway is on-going. Key IDS read and write capability was implemented for ASCOT5. Both GPU-porting and extending IMAS implementation are expected to continue outside TSVVs in the future.

2.2 WP PWIE: Preparation of efficient PFC operation for ITER and DEMO

2.2.1 Overview

The main activities under WPPWIE remained the same as in earlier years: determining erosion and deposition patterns on different plasma-facing components (PFCs), performing interpretative and predictive scrape-off layer (SOL) and plasma-wall interaction modelling, and developing laser-induced breakdown spectroscopy (LIBS) for monitoring tritium retention in future fusion reactors. Of these, modelling played the most prominent role in FinnFusion, covering earlier experiments on JET and ASDEX Upgrade (AUG) and understanding how sputtering from various PFCs depends on key material and plasma parameters. A new topic introduced in 2025 was the production and characterization of boron (B)-based reference coatings to be used as proxies for layers originating from boronizations in fusion devices; the formation mechanisms and fuel-retention characteristics of such deposits have gained priority in the newly released research plan of ITER. The LIBS work, for its part, was continued by reporting the results from the 2024 measurement campaign at JET in different conferences and workshops throughout the year. Worth mentioning is also a new time-of-flight secondary ion mass spectrometry (TOF-SIMS) device that was commissioned and taken into routine use at VTT in 2025.

2.2.2 Modelling marker erosion at the divertor region of ASDEX Upgrade

Research scientists: A. Hakola, A. Järvinen, J. Karhunen, S. Saari, VTT

Gross and net erosion of small marker samples during high temperature L-mode plasma discharges in D on AUG were modelled using the ERO2.0 code. The data originated from an experiment performed in 2019, in which molybdenum-coated graphite samples with gold (Au) marker spots (1×1 mm² and 5×5 mm²) were exposed to a series of plasma discharges in the outer strike point region (OSP) of AUG. The present modelling is compared with earlier analyses conducted with the previous ERO code (see A. Hakola et al., Nucl. Mater. Energy 25 (2020) 100863). In 2025, results obtained in 2024 were refined, evaluated, and presented in the PFMC 2025 conference, leading to a publication in Nuclear Materials and Energy (S. Saari et al., Nucl. Mater. Energy 45 (2025) 102032).

The results for Au net erosion rates for the different marker spots in the poloidal direction are shown in Figure 2.4. They indicate good correspondence between the experimental and simulated erosion profiles: a peak around the OSP and a gradual decrease in erosion rates when moving towards the SOL. Newly generated sputtering and reflection data for Au, provided by the SDTrimSP code, were found to have a key role in significantly improving the agreement with experimental data with respect to earlier simulations with simplified approximations. Simulations also predict a predominantly toroidally oriented re-deposition pattern downstream of the marker spots, albeit the modelled surface densities are 2-3 orders of magnitude lower than those on the marker spots. Light impurities appear to play the largest role in marker erosion: nitrogen, carbon, and boron, typical impurities on AUG, account for >85% of the obtained net erosion.

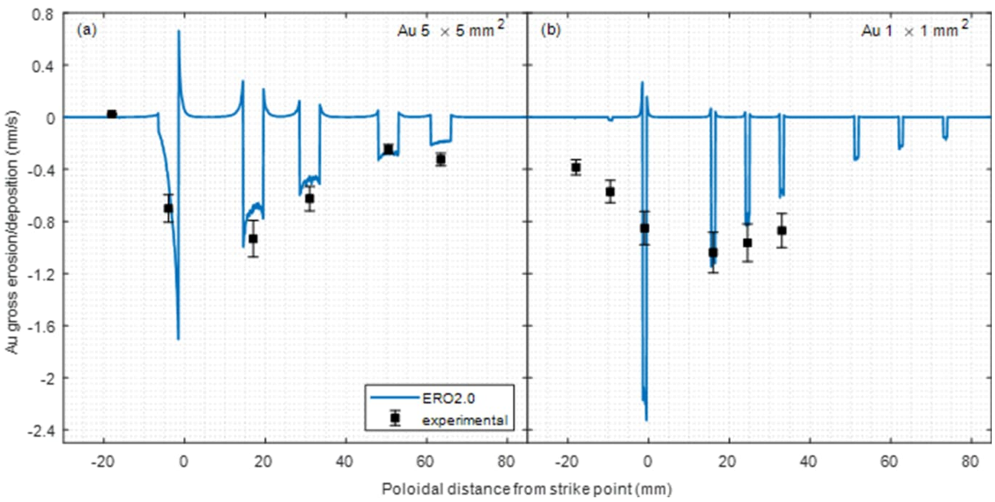


Figure 2.4: Simulated (solid blue line) and experimental (rectangular black spots) net erosion/deposition (negative/positive values) rates for the studied (a) 5×5 mm² and (b) 1×1 mm² Au marker spots.

2.2.1 Production and analysis of boron reference layers for ITER

Research scientists: A. Hakola, J. Likonen, VTT
K. Sarakinos, T. Vuoriheimo, UH

The new baseline of ITER foresees tungsten (W) as the only plasma-facing material in the reactor vessel. To ensure proper conditioning of the all-W device, in particular for controlling oxygen levels in the plasma and enabling reliable start-up of the experimental operations, regular boronizations have been proposed. An unavoidable consequence of boronizations, however, will be the formation of (thick) boron (B)-containing co-deposited layers on the plasma-facing components. To obtain insights on the properties and formation mechanisms of such layers, an extensive programme has been set up under WPPWIE to produce and characterize various B-containing reference layers with pre-defined specifications.

VTT has contributed to the activity by coordinating all the research efforts and carrying out TOF-SIMS analyses for the layers produced by different European laboratories. University of Helsinki, for its part, have produced thin boron layers for round-robin studies and comparing the properties of the as-deposited samples to those by other groups within WPPWIE. The main focus has been put on varying the thickness and oxygen content of the layers as well as investigating the stresses formed on them during the deposition phase at different substrate temperatures. In 2025, the first B layers were produced and characterized while the full analysis of the results was deferred into 2026.

2.2.2 Molecular yields and excitation from W wall erosion

Research scientists: A. Clement, N. Fakhrayi Mofrad and Andrea Sand, AU

Chemical erosion involves the removal of surface atoms by impinging plasma particles through processes involving bond breaking and bond formation, resulting in the release of bound molecules from the plasma-facing surface. These processes, in addition to contributing to the overall erosion of the wall material together with physical sputtering, also introduce molecular species into the plasma, where their behavior differs from that of single atoms. In this project, molecular yields from tungsten surfaces were investigated with molecular dynamics simulations, with particular emphasis placed on analyzing the rotational and vibrational states – or the classical analogs of these – of the released molecules, since these properties significantly impact the dissociation process that the molecule undergoes as it enters the plasma. Good agreement was found with relative vibrational populations measured in experiments. The data obtained in this study provide input for neutral and impurity transport codes such as EIRENE and ERO2.0 offering the potential to improve the precision of these models, and facilitating a more thorough analysis of plasma dynamics.

2.2.3 Molecular dynamics of sputtering of complex surfaces

Research scientists: A. Bergero, F. Granberg, F. Kporha, UH

In 2025 our focus was on developing a ML interatomic potential for W-B and studying preferential sputtering of complex surfaces. The former is necessary to accurately simulate the sputtering of boronized tungsten surfaces with high accuracy. The latter is essential for investigating the sputtering of complex materials, with several elements, and understanding the possible preferential sputtering. We have nearly completed the W-B ML potential intended for surface and sputtering simulations, and finalization is currently in progress. This potential will allow simulations of both the boronization process as well as the sputtering of boronized tungsten surfaces. Sputtering simulations of high-entropy alloys (HEAs) were conducted to observe possible preferential sputtering in complex alloys, and significant preferential sputtering was observed initially. However, after reaching a certain fluence, a steady state was observed, which was quite close to tungsten itself. This suggests that possibly complex alloys with desired properties may be suitable as plasma-facing materials in certain parts of the reactor.

2.2.4 Plasma-edge and plasma-wall interaction modelling

Research scientists: M. Groth, R. Mäenpää, AU

A new deuterated ammonia (ND3) formation, transport and dissociation model implemented in the ERO2.0 Monte Carlo-code predicts a peak line-integrated deuterated nitrogen radical (ND) band emission intensity 50% higher than measured by the vertically viewing divertor spectrometer in low-recycling, Ohmically-heated and nitrogen-seeded JET plasmas. By assuming a greater kinetic energy release (KER) of 10 eV instead of 1 eV upon the dissociation of ND_3 and its radicals, the model predicts a peak line-integrated ND band emission intensity 25% lower than measured. Together these predictions support the assumption of thermal re-release of incident nitrogen atoms and ions from the divertor targets as nitrogen molecules (N_2) and ND_3 in equal fractions.

Band emission from the ND radical has previously been measured in nitrogen-seeded divertor plasmas in the JET and ASDEX Upgrade tokamaks. The proposed model makes use of the AMMONX database for electron-impact dissociation and ionization rates of ND_3 molecules and its dissociation products, and recent computational estimates of the electron-impact excitation rates of the ND radical. The assumption of thermal re-release of incident nitrogen ions and atoms as N_2 and ND_3 in equal fractions is also consistent with the maximum rates of ammonia production observed in measurements of tokamak divertor plasmas as well as with measurements performed in laboratory plasma devices with high surface fluxes of reactive hydrogen and nitrogen species.

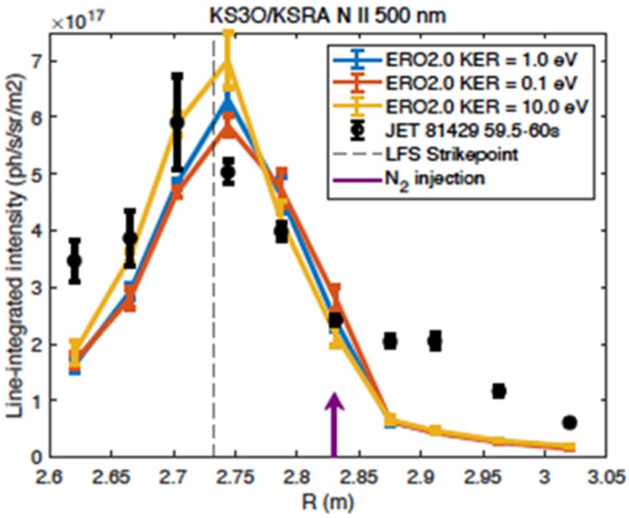


Figure 2.5: Line-integrated intensity of the N II 500 nm transitions measured by the low-field side divertor fibre-optic spectroscopy system (KS3O) survey spectrometer (KSRA) in JET pulse nuber 81429 averaged over the interval t = 19.5 s to 20.0 s and the line-integrated intensities predicted by ERO2.0 assuming that either 0.1 eV, 1.0 eV or 10.0 eV of kinetic energy is imparted onto the dissociation fragments. Error bars represent standard deviations over the time interval (measurement) or standard deviations over iterations/time steps (ERO2.0 predictions). The radial locations of the low-field side strikepoint and the N_2 injection are marked with a dashed grey line and a purple arrow, respectively.

2.2.5 Development of LIBS for studying tritium inventories on JET PFCs

Research scientists: J. Likonen, A. Hakola, J. Karhunen, VTT

The feasibility of laser-induced breakdown spectroscopy (LIBS) for measuring fuel retention was demonstrated for the first time in a tokamak operating with tritium using a remotely controlled in-situ application in JET in October 2024. In JET and future fusion reactors such as ITER and DEMO, thick co-deposited layers will be formed at the inner wall during extended plasma operations. Experiments in present-day fusion devices indicate that these layers consist of eroded plasma facing materials, various impurities and plasma fuel species like deuterium and tritium. Accumulation of radioactive tritium in the reactor vacuum vessel is a particularly critical safety issue requiring active monitoring. LIBS is one of the few techniques available for monitoring the tritium content and the composition of co-deposited layers during maintenance breaks. During the LIBS experiment at JET 840 locations on the main wall and the divertor were analysed successfully. The high spatial accuracy of the MASCOT manipulator was also demonstrated by analysing single castellations on the limiter tiles.

In 2025, the main goal of the work was to analyze spectra recorded primarily from the divertor area using various optical spectrometers. Only the high-resolution

Littrow spectrometer used during the LIBS experiments at JET could resolve the hydrogen-alpha line into isotopic peaks, while the resolution of the Aryelle and Avantes spectrometers was inadequate. The H_α and D_α components were only partially separated from each other due to Stark broadening. A compromise was chosen to reduce the Stark broadening enough while maintaining a high enough signal-to-noise ratio since the emission had not yet faded. The hydrogen isotope peaks were analyzed using a Voigt function and the T/ D ratio was determined. The LIBS measurements were carried out after a thorough tritium clean-up campaign, resulting in a significant reduction in tritium levels. The concentration of tritium was too low to be detected and measured by LIBS in most of the areas analyzed. Figure Figure 2.6 shows the beryllium and hydrogen isotope map for the divertor measured with the Aryelle spectrometer. Beryllium and hydrogen isotopes are mainly located in the inner divertor.

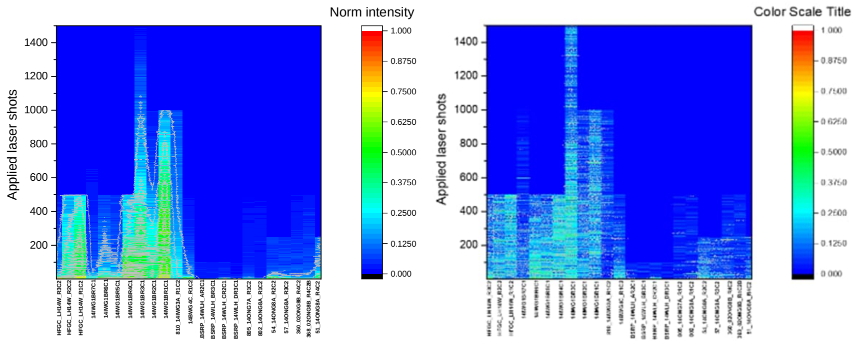


Figure 2.6: Be (left) and hydrogen isotope (right) map for the divertor measured with the Aryelle spectrometer. The horizontal axis represents the analyzed location at the divertor while the vertical axis represents the number of laser shots applied.

2.3 WP TE: Tokamak exploitation campaigns

2.3.1 Overview

In 2025, experiments on WPTE were pursued on four tokamaks: AUG, TCV, MAST-U, and WEST. In addition, analysis and modelling activities for existing JET results from the campaigns completed before 2023 (end of experimental operations on JET) were continued. The first experiments with the new upper divertor of ASDEX Upgrade were performed, and all the desired alternative divertor configurations (ADCs) could be realized and thoroughly characterized. In addition, topics deemed to be important for the new ITER baseline were further pursued, i.e., studying W sources and transport in different parts of the reactor vessel, evaluating the efficiency of boronizations in conditioning the vessel, and developing high-performance scenarios without notable W accumulation. The areas where the

Finnish contribution was the most noticeable were investigating particle and momentum transport (AUG, TCV, MAST-U, WEST, and JET analyses), studying detachment physics (AUG and JET analyses), assessing erosion of plasma-facing materials (AUG, WEST and JET analyses), and modelling the behaviour of fast ions with the help of the ASCOT code (AUG).

2.3.2 Assessment of the impact of the applied molecular charge-exchange reaction rates on detachment access in SOLPS-ITER simulations of MAST Upgrade

Research scientists: J. Karhunen, VTT

The impact of the applied molecular charge-exchange reaction data on the onset of outer divertor detachment in simulations of MAST Upgrade has been studied using SOLPS-ITER coupled with different reaction data sets, providing improved representation of molecular charge-exchange with respect to the standard AMJUEL reaction data of EIRENE. Previously conducted comparison between the standard AMJUEL data and the fully vibrationally resolved so-called Ichihara rates was expanded with modified Ichihara rates, mimicking vibrationally excited D_2 molecules transported from regions of higher electron temperature than in the basic form of the rate data. The impact on the detachment access was studied by scanning the plasma fuelling to lead the outer divertor through attached, high-recycling and detached conditions.

The inclusion of the mimicked D_2 transport in the Ichihara reaction rate data was found to lower the detachment threshold significantly by increasing the roll-over strike-point temperature of the outer target ion current from $T_{e,osp} \approx 0.3$ eV, observed with the standard AMJUEL data, to $T_{e,osp} \approx 1.5$ eV, allowing onset of detachment at up to a factor of 2 lower upstream density than in the standard case with noticeably steeper decay to deepening detachment than with the basic form of the Ichihara rates. The observation was largely attributed to increased D^+ ion losses near the outer target below $T_{e,osp} \approx 2.0$ eV due to increased molecularly assisted recombination associated with the formation of molecular D_2^+ ions.

2.3.3 Erosion of marker coatings on ASDEX Upgrade

Research scientists: A. Hakola, S. Saari, J. Karhunen, VTT

Net erosion of W in the divertor region has been investigated by exposing small platinum (Pt) marker samples on bulk Mo to a series of D-D plasma discharges in the OSP region during L- and H-mode experiments on AUG. Net erosion of the Pt marker samples was quantified using Rutherford Backscattering Spectrometry (RBS), while the material composition and spectral peak identifications were performed using Nuclear Reaction Analysis (NRA) for low-Z elements and Particle-Induced X-ray Emission (PIXE) for high-Z elements (see Figure 2.7). Measurements were carried out both on the Pt marker sample surfaces and on the Mo regions between the Pt markers, allowing characterisation of poloidal variations in erosion/deposition patterns on the markers and deposition of W and other materials between the marker areas around the strike point. PIXE and NRA analyses were performed on samples located around the strike point, providing a detailed picture of the material composition along the poloidal coordinate with additional microbeam measurements and microscopy studies to characterise the shape of the re-deposition patterns with high spatial resolution.

Preliminary analysis shows pronounced net erosion of Pt at the OSP, as well as high deposition of W toroidally downstream on the analysed samples following the H-mode experiment. The erosion of Pt and the deposition of W both gradually decrease toward the far scrape-off layer but remain at measurable levels relatively far away from the OSP. Initial NRA analysis shows only minor traces of deposited light-Z elements on the sample surfaces around the strike point. A more detailed picture of the material composition after the exposure will be obtained with separate TOF-SIMS measurements.

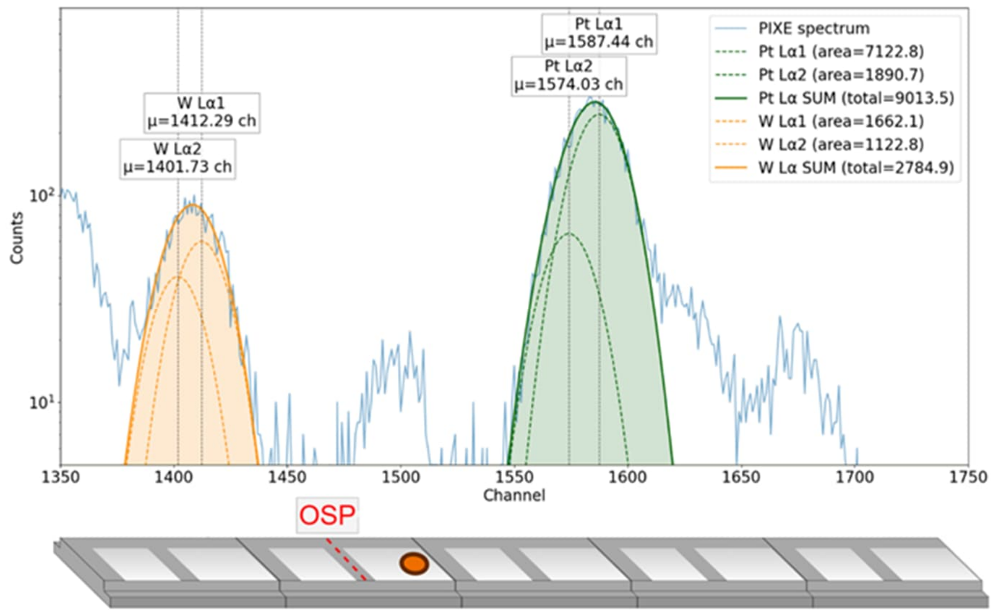


Figure 2.7: Example of PIXE data for the Pt and W concentrations on one of the exposed marker spots close to the OSP region.

2.3.4 Particle transport experiments in WEST

Research scientists: A. Salmi, T. Tala, VTT

Experiments on the WEST tokamak were carried out to investigate particle transport using gas puff modulation under varying lower hybrid current drive (LHCD) power and plasma density conditions. Taking advantage of long steady-state discharges of up to 40 s, a 5-point LHCD power scan (0-4 MW) and a 3-point density scan (1.8-2.7×10^{19} m^{-3} at $\rho_{pol} \approx 0.95$) were successfully completed. Real-time density control, operated with sufficiently low bandwidth, maintained stationary plasma conditions without compensating the imposed 1-5 Hz feed-forward gas modulation.

A key element of the campaign was the newly commissioned mid-plane profile reflectometer, which delivered high-resolution density profiles from $\rho_{pol} \gtrsim 0.35$ to the far scrape-off layer. In burst mode operation, up to 160,000 profiles were obtained per discharge, enabling detailed characterisation of the modulation amplitude and phase response. The diagnostic resolved density perturbations as small as ~1×10^{17} m^{-3} and showed excellent repeatability despite significant broadband background fluctuations in the 0.5-15 Hz range. Line-averaged density data from the interferometer provided complementary measurements and robust cross-validation.

The analysis of the discharges is in progress and will support qualitative comparison with independent synthetic modelling using HFPS-TGLF and SOLEDGE over similar parameter scans. First tentative modelling indicates weak neutral penetration, while the observed density peaking appears to be mainly sustained by a significant inward turbulent particle pinch.

2.3.5 RMP coil induced toroidal torque experiments in MAST Upgrade

Research scientists: T. Tala, A. Kirjasuo, A. Niemelä, A. Salmi, VTT

Plasma toroidal rotation is less well-known transport channel than heat or particle transport, including both momentum transport and in particular rotation sources. In this work, we have studied rotation changes or torque sources induced by Resonant Magnetic Perturbations on MAST-U tokamak. Relatively repeatable pulses in L-mode plasmas in both n=2 and n=4 RMP coil configurations were performed on MAST-U by introducing RMP coil modulation waveforms at various amplitudes and frequencies. In the n=4 RMP coil configuration, quite surprisingly an edge rotation acceleration was measured due to the RMP coil current, resulting in an increase of relative edge rotation by 20% (~5km/s) at $\rho_{tor} \approx 0.97$ at maximum RMP coil current of 1.9kA. This increase in rotation is limited to the region of $\rho_{tor} > 0.9$.

In the n=2 RMP coil configuration, we performed an RMP coil current scan shown in Figure 2.8. Similar edge rotation acceleration was observed as with n=4 configuration, the acceleration being higher with increasing RMP coil current. At the highest RMP coil current, significant rotation braking was also seen at $\rho_{pol} \approx 0.55$-0.85 as shown in the Figure 2.8.

To interpret and quantify the mechanisms responsible for this edge rotation acceleration and core braking, modelling with the MARS-K code is being carried out. Modelling the n=4 case with MARS-K is suggesting the observed co-torque in the edge region while the modelling results in n=2 configuration are in disagreement with experiments. Investigation of other possible sources of RMP-driven torque, such as the stochastic torque, is ongoing.

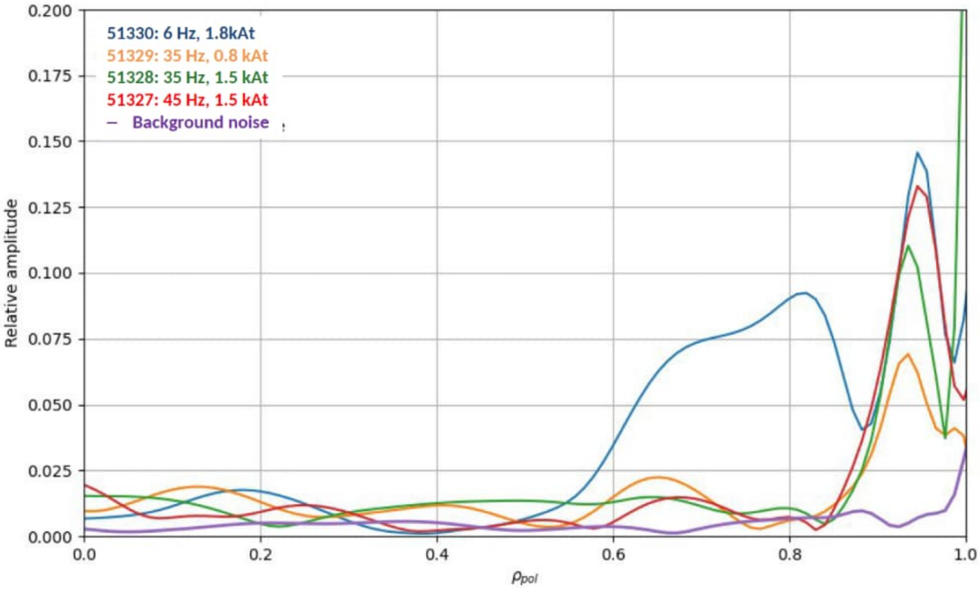


Figure 2.8:Relative rotation amplitude for different RMP coil current magnitudes.

2.3.6 Analysis of JET-ITER baseline scenarios with neon seeding.

Research scientists: A. Järvinen, A. Bruncrona, D. Jordan, A Niemelä, A. Kit, VTT

WPTE RT01 analysis within JET have focused on understanding the role of neon seeding on the pedestal performance in the JET-ITER Baseline Scenarios. The Ne-seeded JET-ITER baseline is a robust scenario that can achieve simultaneous partial divertor detachment and high confinement with small or no ELMs at JET. In these highly fuelled, high-triangularity scenarios with vertical target divertor configuration, Ne-seeding opens access to reduced pedestal top electron density with low pedestal collisionality and improved overall confinement, primarily driven by pedestal pressure increase relative to the unseeded conditions. Simultaneously, ELMs are reduced in size and eventually disappear with increasing neon content. To provide physics insight for these observations a team of scientists has been simulating the core-edge integration aspects of these scenarios via multiple simulations tools, including EDGE2D-EIRENE, SOLEDGE3X, SOLPS-ITER and JINTRAC-COCONUT in addition to dedicated pedestal analysis. The key contribution from FinnFusion has been the EDGE2D-EIRENE simulation contribution as well as application of the pedestal MHD surrogate model (Section 4.1.1) for physics analysis within WPTE RT01. Overall, there are several potential contributors to pedestal density reduction: (1) increase in pedestal transport, (2) reduction of ionization sources, (3) reduction of separatrix densities, and (4) changes in the dynamical evolution of the scenario dye to the changes in the ELM characteristics. Within selected boundary conditions in EDGE2D-EIRENE, it is possible to obtain a substantial reduction of pedestal ionization source and separatrix density as a function of increased neon content in the simulation domain (Figure 2.9). While the impact on pedestal density reduction is almost as significant as seen in the experiments, it is reasonable to expect that the EDGE2D-EIRENE simulations setup overestimates the effect and that all of the four contributors, mentioned above, do play a significant role.

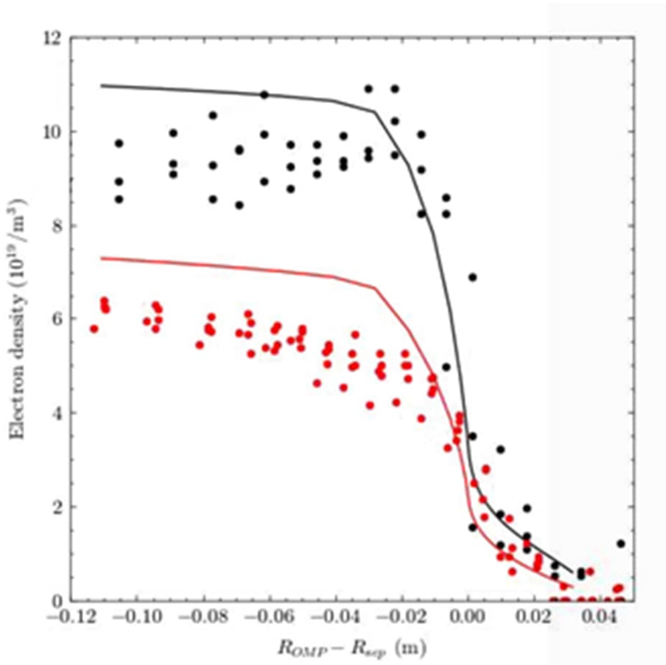


Figure 2.9: Example of pedestal density reduction, as predicted by EDGE2D-EIRENE as a result of reduced pedestal ionization source. The black represents unseeded conditions and the red neon seeded conditions. Lines are EDGE2D-EIRENE simulations.

2.3.7 Fast ion studies in AUG

Research scientists: S. Sipilä, AU, A. Snicker, VTT

ASCOT4-RFOF ICRH simulations of a 5% hydrogen population were made to provide the lost hot ion wall load distributions in ASDEX Upgrade discharge #42762 at three different time values. The aim was to explain the observed failed tile in one of the ICRH antenna limiters. The simulation revealed a persistent hot spot of ion wall load on the antenna limiter in question. The cause of the hot spot at that location is under investigation.

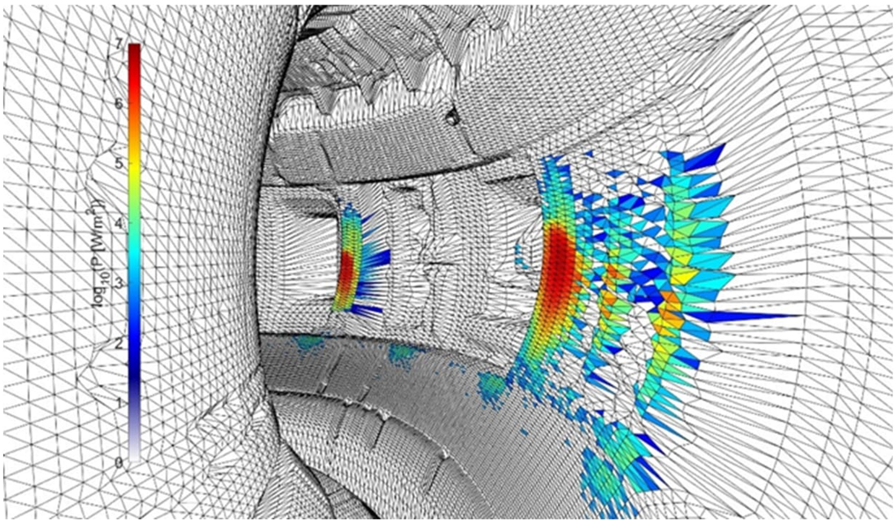


Figure 2.10: Simulated wall load of ICRH hot tail ions in AUG discharge #42762 at t=6.95s. The hot spot on the ICRH antenna limiter shown in the foreground was found to be consistently wider and hotter than any other hot spot on the wall in all simulated time slices (4.05s, 4.45s, 6.95s).

2.3.8 EIRENE gas flow studies in JET

Research scientists: M. Groth, A. Vesa, AU

Calibrating the toroidally symmetric 2D model against the 3D, toroidally non-symmetric JET vessel indicates that, despite the geometrical and other modelling simplifications, the effective pumping speeds of H_2, D_2 and T_2 simulated with the time-dependent neutral Monte-Carlo code EIRENE agree within 50% of the corresponding measurements. The 2D vessel can be further calibrated by introducing conductance-lowering structural elements in the 2D framework, so that an overall agreement between the real 3D and the model 2D vacuum configuration can be achieved. The effective pumping speed of the vessel does not depend on the injection amount for pressures below 0.3 Pa. The injection and pressure gauge locations do not affect the magnitude of the effective pumping speed. Due to the introduction of the louvres to the JET sub-divertor in the change from Mark I to Mark II divertor structure, the measured effective pumping speed of D_2 in the vessel decreased from 200 m^3/s to 112 m^3/s. In both experiments and simulations the total conductance of the vessel is smaller than the nominal pumping speed of the pumping configuration. Thus, the pumping capability of the vessel is maximized when the conductance leading to the pump is significantly larger than the nominal pumping speed of the used pumps.

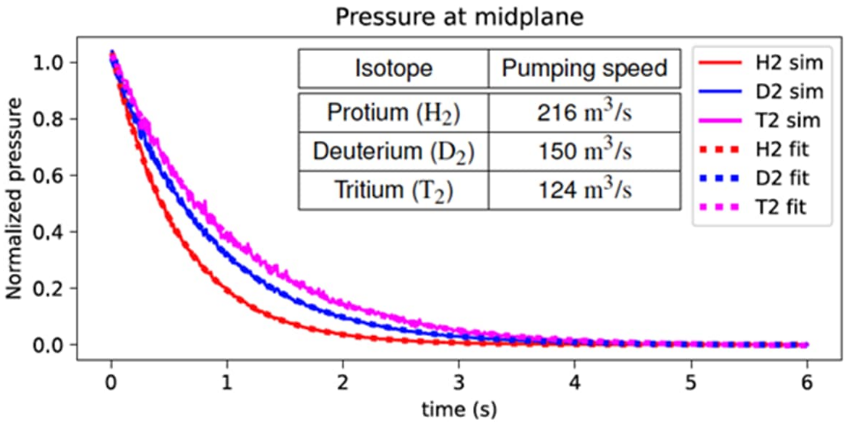


Figure 2.11: Simulated effective pumping speeds of H_2, D_2 and T_2 measured at the low-field side midplane.

2.3.9 Task force Leadership activities

Research scientists: A. Hakola, VTT

In 2025, Antti Hakola continued his duties as one of the Deputy Task Force Leaders (TFL) for WPTE, as part of the team of seven TFLs. Hakola was in charge of topics related to (i) material erosion, migration, and fuel retention; (ii) characterization of runaway electrons (RE), and (iii) plasma operations in alternative divertor configurations. Related experiments or analyses/modelling activities were carried out on all the operating devices (AUG, TCV, MAST-U, and WEST). Besides coordinating research activities, the deputy TFL duties included reporting of the scientific outcomes and preparing new campaigns. A large part of the time in 2025 was consumed in planning the high-level program of WPTE for the extension period of the present EU Framework Programme (2026-2027) and drafting the necessary documents.

On AUG and WEST, much effort was put on operating the machines following full or partial boronizations, in addition to which the ADC investigations on AUG took the largest share of the available machine time in the period April-July 2025. Worth mentioning is the second high-fluence campaign on WEST that was carried out in cold divertor plasma conditions, in the so-called X-point radiator (XPR) regime. Another important achievement on WEST was controlled W damage studies, induced by an energetic RE beam, that will provide urgently needed feedback for the disruption avoidance strategy of ITER. MAST-U and TCV, for their part, had a versatile program in their timelines covering all the relevant aspects from scenario development, including small-ELM regimes, to edge- and SOL-physics studies and from fast-ion investigations to development of plasma control schemes. Analysis of

JET discharges were performed to cast light on plasma operations with low W concentrations in the core. Such a scenario with high performance and high ion temperature could also be achieved on AUG.

2.4 WP W7X: W7-X exploitation

2.4.1 Modelling of the effect of particle species on beam losses in W7-X

Research scientists: J. Kontula, T. Kurki-Suonio, P. Ollus, K. Särkimäki, S. Äkäslompolo, AU

The upcoming campaigns in W7-X will include not only the hydrogen isotopes H and D but also He as both NBI injection and target plasmas. The species effect on the beam-ion confinement and associated power loads was studied with the ASCOT code to estimate the location and intensity of the hot spots. For this analysis, standard, high and low mirror configurations were considered to provide results covering the variation of the mirror term most likely to affect the beam-ion behaviour. Beam-ion losses were highest for D beams and lowest for He beams. Changing the target plasma from hydrogenic species to helium also produced higher losses. Hot-spot analysis showed peak loads up to 3 MW m^{-2} for D beams, with 1 MW m^{-2} and 0.1 MW m^{-2} for H and He beams, respectively. Losses were predominantly to carbon components independent of the mirror term. This is particularly apparent for the low-mirror configuration, showing that 97%–99% of the power loads avoid the more delicate steel components.

2.4.2 Wall power loads from ICRH-generated ions in W-7X stellarator

Research scientists: T. Kiviniemi, T. Kurki-Suonio, AU, Christoph Slaby, IPP

ASCOT simulations of impact ion cyclotron resonance heating (ICRH) generated fast ions on ICRH antenna were completed. Very persistent problem with the starting positions of the particles spreading between rho=0.85-1.025 instead of being at rho~1 was shown to be due to differences in standard configuration magnetic backgrounds. Simulations were done for four different antenna positions including liner position, the working position and two positions in between them. This was done using the same wall data as in [J Kontula et al 2023 Plasma Phys. Control. Fusion 65 075008]. The initial data set was multiplied by a factor of 52 to get 1000000 particles for statistics. Scaling of the results to proper units was discussed and is now given in SI units. Consistently with the results shown in [C. Slaby et al. 2022 J. Phys.: Conf. Ser. 2397 012006] for one single antenna position, loads caused by ICRH-generated fast ions on ICRH antenna are small compared to NBI ion load although a clear increase of load as a function of antenna position is shown in the present work as shown in Figure 2.12 with peak loads being just ~20 kW/m^2.

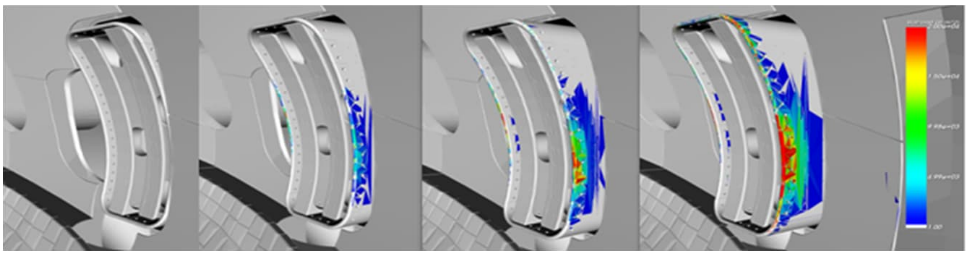


Figure 2.12: Power load on W7-X ICRH antenna components caused by the energetic ions produced by the antenna itself increase as a function of antenna position. Here, the leftmost position is the liner position and rightmost the working position.

3 Digital Solutions for Fusion 2025

3.1 WP AC: Code development for integrated modelling

Research scientists: E. Amnell, B. Cattelan, L. Chôné, F. Granberg, K. Heljanko, O.Lappi, K. Nordlund, J. Nurminen, V-M. Yli-Suutala, UH
J. Åström, CSC, D. Jordan, A. Järvinen, VTT

During the final full production year of the ACH-VTT, the focus was on completing ongoing tasks and finalization of projects. The focus was on our core expertise, GPU, HPC, AI&ML and BO/BI. An almost finished framework for carrying our BO/BI on surrogate models has been developed and can be used for any of the fusion codes within EUROfusion, enabling simple BO/BI. Surrogate model development, for more accurate MD simulations, faster prediction of results to be used in higher scale models and coupled surrogate models with BO to fast obtain uncertain parameters, were done. The use of AI/ML for anomaly detection and automated analysis was developed and deemed to be effective, even without any training on the anomalies needed. Work on GPU enabling and porting for specific important fusion codes was done, and general optimization of codes was carried out, to be ready to use the expanding infrastructure of HPC. Development of new scalable domain-decomposition methods has continued, and a great performance boost will be achieved by implementing these new developments into the existing heavy fusion codes.

3.2 WP ENR: Enabling Research

FinnFusion participated in four Enabling Research projects in 2025.

3.2.1 Comparison of He effects in concentrated equiatomic refractory alloys and pure tungsten

Research scientists: F. Djurabekova, G. Wei, J. Byggmästar, Zh. Chen, F. Tuomisto, K. Mizohata, T. Sutinen UH, T. Suhonen, A. Laukkanen, VTT

Throughout 2025, we utilized multi-scale simulation methods to investigate the interaction and dynamic behavior of helium (He) in tungsten (W) and W-based high-entropy alloys (HEAs). This work began with the development of a new interatomic potential to model He-WTaVMoNb interactions, which was used to calculate binding and migration energies across various compositions. Key findings revealed that in cascade-damaged structures, voids act as stronger He traps than vacancy loops. Furthermore, minor Vanadium (V) additions (5–10%) were shown to effectively suppress He clustering at high temperatures (900–1500 K), while adaptive Kinetic Monte Carlo simulations demonstrated that He and V atoms inhibit vacancy cluster growth by slowing the migration of triple-vacancy complexes. Surface studies also indicated that WTaV coatings lead to shallower "fuzz" formation during plasma exposure.

Experimental validation continued at multiple research facilities. At CNRS-IJCLab, sample preparation and TEM observations were performed on diverse matrices, including W-V and WTaMo alloys, to characterize He bubble formation. At CNRS-CEMHTI, annealing experiments at 1073 K following ^{3}He implantation revealed that W-V binary alloys exhibit significant He release, in sharp contrast to pure W where no release was detected. Meanwhile, at the Helsinki Accelerator Lab, He diffusion pathways were investigated in refractory HEAs (WTaVMoNb) and MEAs. The findings indicate that increasing elemental diversity suppresses long-range He migration by promoting localized trapping at specific elemental sites (V, Nb, Ta) where lattice distortions create effective potential wells. Collectively, these results highlight the critical role of alloying elements in controlling He evolution.

3.2.2 Electronic interactions of slow ions and their influence on defect formation & sputter yields for plasma-facing components

Research scientists: A. Aro, E. Ponomareva, N. Fakhrayi Mofrad, R. Nuñez, A. Sand, AU

Energetic particles traveling through a material experience energy losses to electrons through electronic stopping. These energy losses are shown by time dependent density functional theory (TDDFT) to depend strongly on the local environment, with electron density variations and orbital effects playing a role. In this project, we incorporate this detailed picture of trajectory dependent energy losses of light ions into large scale molecular dynamics simulations of surface sputtering of Fe and W. Coupling models for electronic energy losses of H(D,T) and He in Fe and W were fitted to TDDFT data, and used within a two-temperature molecular dynamics framework. We found that the detailed treatment of trajectory dependent energy losses had a stronger effect on sputtering predictions for W surfaces than for Fe surfaces, which we ascribe to the relatively smaller size of the plasma particles in the W matrix allowing longer penetration paths. This results in proportionately longer trajectories of the light ions within W as compared to Fe, before the collision resulting in a sputtering event takes place. During this traversal of the target material, the plasma particle predominantly travels through low electron density regions, hence the effective stopping power is lower than that predicted by SRIM for random trajectories. This work adds a new level of understanding and improved accuracy to sputtering simulations, providing greater confidence in the support of modelling for extrapolating experimental data to realistic reactor conditions.

3.2.3 The impact of boron intermixing in PFC on atomic, structural and mechanical features: sputter yields, near-surface morphology, and fuel retention

Research scientists: A. Clement, N. Fakhrayi Mofrad, A. Sand, AU

The use of boron (B) for wall conditioning is being considered for future tokamaks, raising interest in the behavior of a boron-coated tungsten (W) surface and co-deposited mixed W-B surface layers, and their performance in a fusion tokamak. This combination of elements has not previously been studied in depth for fusion reactor conditions, and no suitable interatomic potential has existed, even for pure boron in its crystalline form. In this project, a semi-classical interatomic potential for boron and for the mixed boron-tungsten system was developed, to enable investigations into atomistic scale processes of surface erosion in the B-coated W and mixed W-B surface layers. The potential provides a good description of pure boron and pure tungsten, while simultaneously describing several known stoichiometries for the W-B system, including W_2B, WB, WB_2, W_2B_5 and WB_4. The versatility of the potential allows investigation of dynamical surface modification under particle bombardment, in addition to providing predictions of sputtering yields from various stable crystalline structures as well as amorphous configurations. With this new potential, we have modeled sputtering of pure boron by boron ions, finding good agreement with predictions obtained using the BCA code SDTrimSP, indicating that physical sputtering is the predominant process in this case. Preliminary studies of cumulative impacts on a WB surface have also been carried out, where preferential sputtering of B is apparent. Future work will focus on adding hydrogen to the W-B potential, to enable studies of chemical sputtering effects.

3.2.4 Novel methods for fast-ion tomographic reconstructions: Fast-ion tomography in 4D

Research scientists: A. Snicker, VTT, O. Hyvärinen, UH

In 2025, the work culminated in a paper demonstrating a physics-informed method for reconstructing four-dimensional fast-ion phase-space distribution functions by encoding neoclassical collisional physics as prior information. The approach addresses the ill-posed nature of fast-ion tomography, where sparse diagnostic data alone are insufficient to uniquely determine the distribution.

The method used the orbit-following code ASCOT5 to compute neoclassical anisotropic slowing-down distributions for neutral beam injection (NBI) fast ions in realistic tokamak geometry. These slowing-down distributions were employed as basis functions that inherently encode Coulomb collisions, pitch-angle scattering, orbit effects, and spatial transport. For a JET equilibrium, basis functions were constructed for full, half, and third NBI energy components, each subdivided into ten source regions based on poloidal flux, yielding up to 60 physics-informed basis functions.

Fast-ion reconstruction was formulated as a regularized inverse problem, where coefficients of these basis functions were inferred from synthetic diagnostic data. Weight functions for neutron emission spectroscopy and gamma-ray spectroscopy diagnostics were computed using the Orbit Weight Computational Framework, allowing realistic forward modeling of measurements. Tikhonov regularization was applied to stabilize the inversion and enforce smoothness of the reconstructed coefficients along the beam path.

Results demonstrate that for a single NBI source, the reconstructed fast-ion distribution reproduces both spatial and velocity-space features of the true distribution with good quantitative agreement, as shown in Figure 3.1. However, reconstructions involving two simultaneous NBIs were significantly more challenging due to overlapping basis functions and limited diagnostic phase-space coverage, leading to degraded accuracy.

The study showed that neoclassical physics-based priors significantly improve high-dimensional fast-ion reconstructions and provides a scalable framework applicable to other devices and diagnostics, including ITER-relevant scenarios.

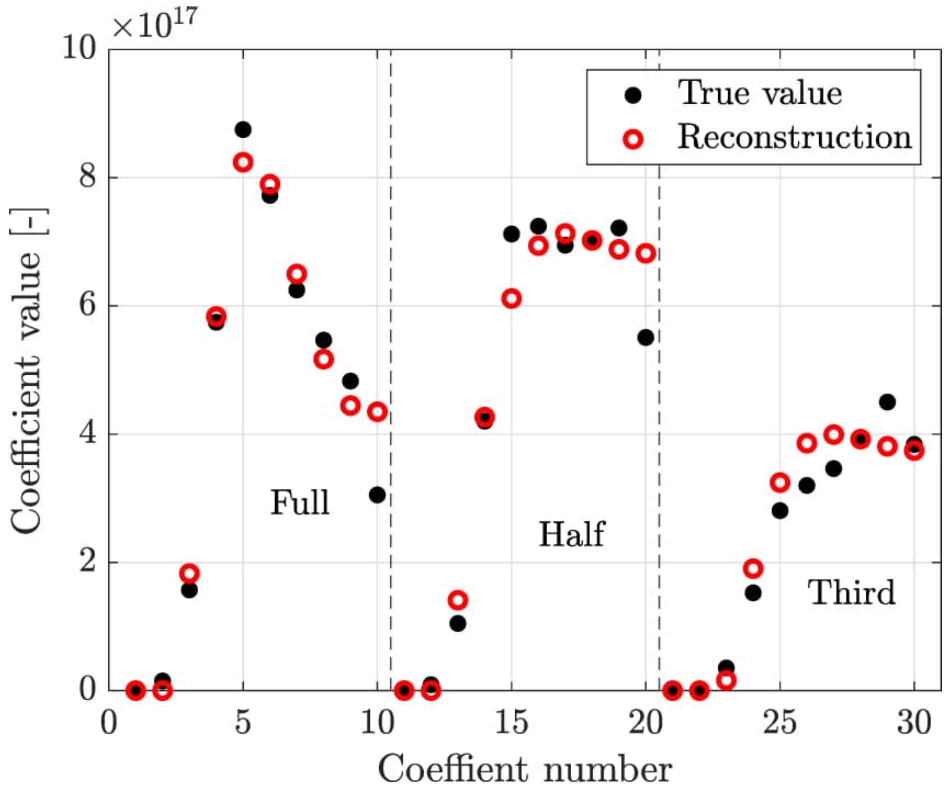


Figure 3.1: True and reconstructed expansion coefficients for a single beam. ‘Full’, ‘Half’, ‘Third’ denote the energy components of the beam. O. Hyvärinen *et al* 2025 *Nucl. Fusion* **65** 092003.

4 ITER Technology and DEMO preparation 2025

4.1 WP PrIO: Preparation of ITER first experimental campaigns

4.1.1 Accelerating pedestal MHD stability evaluations through machine learning

Research Scientists: A. Järvinen, A. Bruncrona, VTT

The focus of this EUROfusion 2024 – 2025 project was to accelerate linear pedestal magnetohydrodynamic (MHD) simulations encompassed by the MISHKA code via machine learning techniques. EPED-like workflows for pedestal predictions combine reduced transport assumptions, such as the standard ballooning critical pedestal (BCP) approach, with the overall MHD stability envelope. The latter is established via repeated magnetic equilibrium and stability calculations and represents a computational bottleneck in these workflows. The aim of this project was to accelerate this component via surrogate modelling methods. A proof-of-principle MHD surrogate model, called KARHU, was generated, covering a fraction of the JET pedestal database [Bruncrona2025]. A data generation workflow was generated within the Enchanted-surrogates software package (available in GitHub: https://github.com/DIGIfusion/enchanted-surrogates). The workflow was based on the logic in which Europed generates profiles, self-consistent magnetic equilibria and MISHKA simulations. Overall, about 20 000 magnetic equilibria were created with about 200 000 MISHKA simulations, covering a range of toroidal mode numbers. Finally, a high-capacity regression model, consisting primarily of convolutional neural network layers was trained with the obtained dataset. The model establishes good regression performance and can be used as a replacement of full MISHKA simulations in Europed workflows. The surrogate model is publicly available in GitHub. In 2025, the coverage of the model was extended for DIII-D, TCV, JT-60SA as well as for multiple isotope for the JET operational space (Figure 4.1).

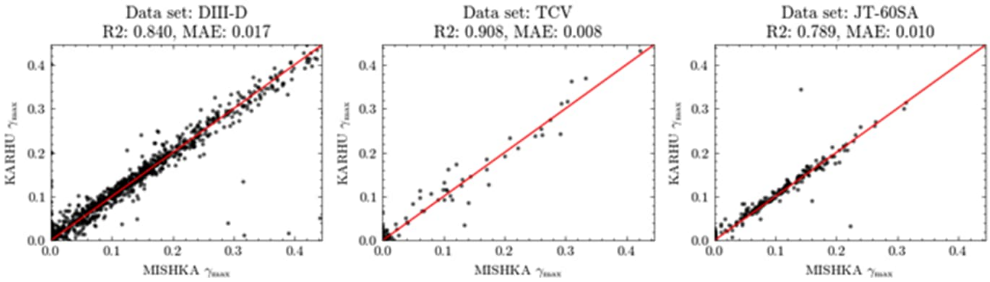


Figure 4.1:. Regression performance of the surrogate model extended for DIII-D, TCV, and JT-60SA.

4.1.2 AI/ML methods for ASCOT NBI physics

Research Scientists: A. Snicker, K. Särkimäki, D. Jordan VTT, P. Vinzenci (CNR), R. Delogu (RFX)

This work reports the development and application of an integrated workflow for generating data-efficient AI/ML surrogate models for neutral beam injection (NBI) shine-through and slowing-down in ITER plasma scenarios. The workflow couples METIS and CHEASE for plasma scenario generation with BBNBI5 and ASCOT5 for NBI ionization, shine-through, and fast-ion slowing-down calculations, and is externally controlled to enable automated dataset generation for machine learning.

During 2025, the workflow was substantially extended and finalized. Key upgrades included support for user-defined plasma and beam species, HDF5 output, configurable marker numbers, and fully autonomous active learning. The workflow was deployed across multiple computing environments, using the ITER SDDC cluster for METIS, CHEASE, and BBNBI5, and the CSC supercomputer for computationally intensive ASCOT5 simulations. This enabled large-scale studies despite limitations in IMAS portability.

Approximately 30,000 plasma configurations were generated for shine-through studies and about 400 for slowing-down studies, focusing on D injection into DT plasma in the ITER 15 MA Q=10 H-mode scenario. Several data sampling strategies were evaluated, including Sobol sequences, static sparse grids, and spatially adaptive sparse grids. Results demonstrate that adaptive sampling methods are significantly more data-efficient than static approaches. Gaussian Process Regression (GPR) emerged as the most effective modelling approach, offering superior accuracy with a few hundred samples and intrinsic uncertainty quantification. For slowing-down studies, repeated ASCOT simulations enabled explicit estimation of Monte Carlo noise, which was incorporated into the learning process, as shown in Figure 4.2.

While extension to JT-60SA was not completed due to limited personnel resources, the workflow is now mature and will be further applied in a follow-on enabling research project. The developed tools provide a practical and scalable foundation for AI-assisted modelling of NBI physics in ITER.

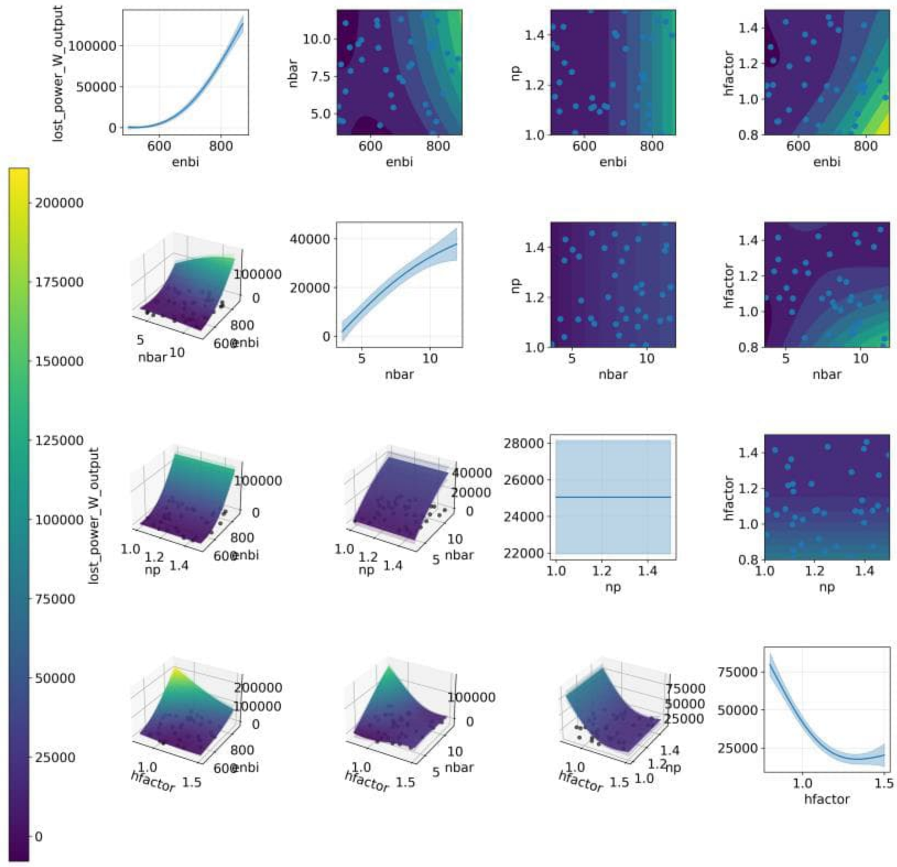


Figure 4.2: Lost power of injected D NBI as a function of the plasma parameters for the ITER 15 MA H-mode scenario, together with the error estimates.

4.2 WP DES: Design activities

4.2.1 ASCOT simulations for the volumetric neutron source

Research Scientists: A. Snicker, K. Särkimäki, VTT

The work reports progress of ASCOT-based fast-particle modeling for the Volumetric Neutron Source (VNS), with emphasis on neutral beam injection (NBI) and alpha-particle physics. The primary objective was to establish a realistic modeling chain for NBI ionization, fast-ion slowing-down, and alpha-particle confinement and losses using BBNBI, ASCOT5, and AFSI.

A detailed VNS NBI geometry was implemented in ASCOT5 based on CAD data, representing four tangential deuterium injectors operating at 120 keV. Because individual beamlet definitions are not yet available, injectors were modeled using macro parameters with randomized beamlet generation (1000 beamlets per injector). Improvements were made to the ASCOT5 injector routines, including support for clockwise/anticlockwise injection and enhanced visualization capabilities.

Ionization and slowing-down simulations indicate modest NBI shine-through (~1.9%), with beam ionization occurring predominantly on the low-field side and a tendency toward edge-peaked fast-ion distributions. No beam ion losses were observed. Alpha-particle source calculations show a total fusion power of approximately 22.5 MW, with significant contributions from beam-thermal reactions. While thermal alpha confinement is good (~1.5% losses), beam-thermal alpha losses are substantial (~14%), indicating poor confinement for this population.

Parameter scans demonstrated that central NBI deposition can be achieved either by reducing plasma density to ~25% of nominal or by increasing NBI energy to 150–180 keV (see Figure 1), with manageable increases in shine-through. The study highlights the need for improved equilibrium resolution, a detailed 3D wall model, and higher marker statistics for reliable wall-load estimates. Planned next steps include improved IMAS data integration, cross-code consistency checks, ripple-induced loss studies, and exploration of higher-energy and tilted NBI configurations.

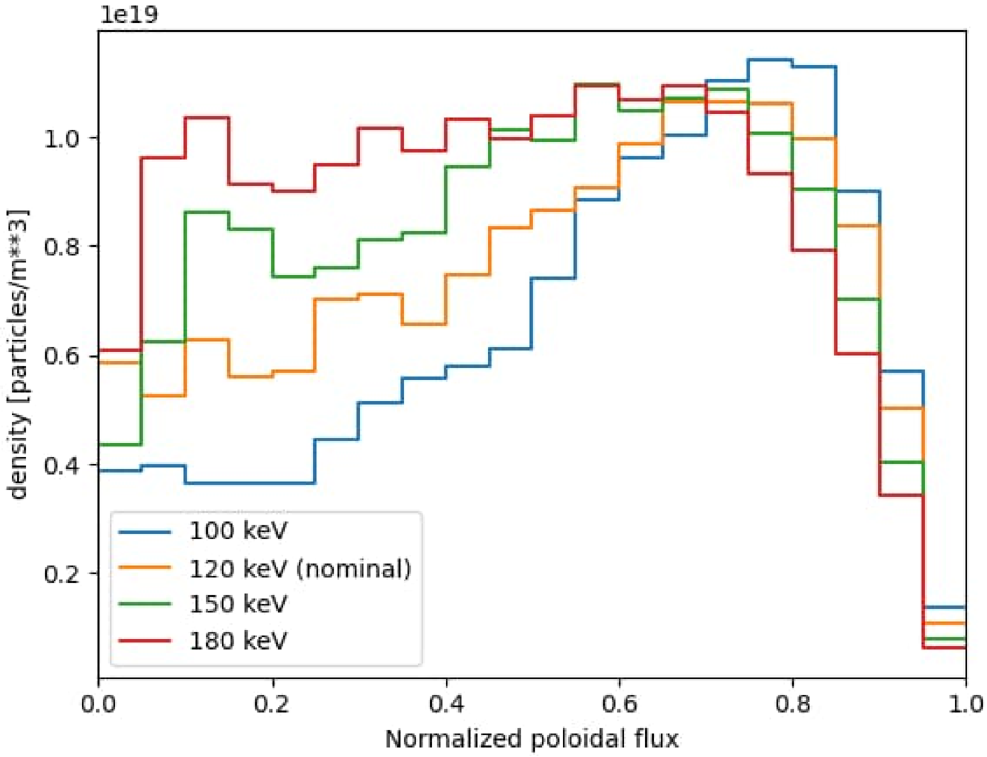


Figure 4.3: NBI distribution as a function of injection energy. Central deposition is crucial for the objectives of the machine and is not obtained using the nominal 120 keV injection energy.

4.3 WP RM: DEMO Remote maintenance

Research scientists: K. Salminen, W. Brace, J. Lyytinen, H. Martikainen, M. Siuko, J. Alanen, L. Ribeiro Goncalves, V. Truong, P. Kokkonen, S. Qais, E. Strömmer, A. Ylisaukko-Oja, T. Sipola, T. Vaarala, T. Tenhunen, M. Alamäki, J. Koskinen, M. Tahkola, T. Välisalo, J. Sarsama, Z. Akhtar, Petri Tikka, U. Peltonen VTT
H. Wu, C. Li, M. Li, Q. Han LUT
Comatec, Fulvisol Oy, Coresbond

4.3.1 Overview

In 2025, WPRM activities centered on advancing remote maintenance technologies and collaborative systems engineering, e.g., in-vessel, ex-vessel, service joining, and test facility activities. VTT continued in the WPRM management roles: project leader (Karoliina Salminen), project support officer (Petri Tikka), and technical clerk (Ulla Peltonen). VTT was also leading the port area maintenance and design tools strands and the remote maintenance test platform activities (William Brace). VTT played a key role in supporting Demo Central Team studies in divertor handling, contributing to feasibility assessments of DEMO LAR architectures and developing strategies for accessing in-vessel hardware. VTT also progressed the design of remote maintenance test rigs. LUT contributed through research on control systems and flexible robotic structures, with a focus on modelling and precise control for blanket handling. VTT and LUT participated in developing catalogue-based approaches, advancing the integration of RM equipment and systems, and supporting the transition to data-centric engineering methods. The work is a participatory collaboration between the Finnish research group, which includes VTT, LUT, and industry partners such as Comatec, Fulvisol, and Coresbond.

4.3.2 RM System Design

The design work of the RM System focuses on the long-term goal of integrating fundamental scientific principles and innovative technologies to enable Remote Handling (RH) capabilities for maintenance within an activated environment (AE). Considerations for the AE include design aspects such as recoverability, rescuability, safety, minimal risk, and maintainability. The design process involves developing prime movers, end effectors, robot manipulators, and tools to support handling activities, including installing and replacing systems within the AE, releasing and securing locking mechanisms, dust cleaning, inspection, and in-situ maintenance.

Previous tasks involved designs for the prime movers and end effectors, focusing on developing specialized equipment and assessing commercial-off-the-shelf (COTS) components for capability and future expansion. The COTS activities also help attract Finnish industrial companies to the development of fusion power plants. The current work centers on developing robotic manipulators and maintenance tools to assist with handling and in-situ maintenance activities. Various tools are required for safe and efficient maintenance within a fusion reactor. They are used to maintain and repair critical systems that are inaccessible to humans due to AE factors, such as radiation, high temperatures, and strong magnetic fields.

The tools are used for specific tasks such as gripping, lifting, bolting, cutting, welding, heating, cleaning, aligning, connecting, disconnecting, and conducting non-destructive testing (NDT). They must be suitable for RH and withstand ionizing radiation, high surface temperatures, residual magnetic fields, and dust. The tools also need to be compact because the work area may be limited. They can be powered by electricity, pneumatics, or water hydraulics, which requires expertise and the involvement of Finnish industrial specialists in the development process. Tools constitute a specific category within the RM system, associated with specialized robot manipulators and operated by the prime mover. Consequently, the design process was further concentrated on dedicated robot manipulators (DRMs). Although various industrial robot manipulators are available commercially, as identified through COTS design, their deployment is constrained by space, reach, and AE considerations.

VTT, in collaboration with the industrial partner Comatic, developed a multi-purpose deployer (MPD) as a DRM concept for deploying RM tools. Previous research indicated that standard industrial robots lack the necessary reach to deploy RM tools for potential maintenance tasks. The MPD is a recognized RM system employed for power plant maintenance; for instance, alternative MPD designs are utilized in EUROfusion DEMO, F4E ITER, and China CFETR. These systems are engineered to support multi-ton payloads and are characterized by sturdy steel frames and extensive supporting structures. Moreover, smaller deployers have been developed in China EAST, USA TFTR, India SST-1, Italy RFX-mod, and France TORE SUPRA. Compared to these prior designs, the DRM MPD concept represents a distinctive innovation by the Finnish research group, constructed upon and integrated with the existing configuration of a prime mover and end effector (EE), thereby providing maximum reach and degrees of freedom for tool manipulation.

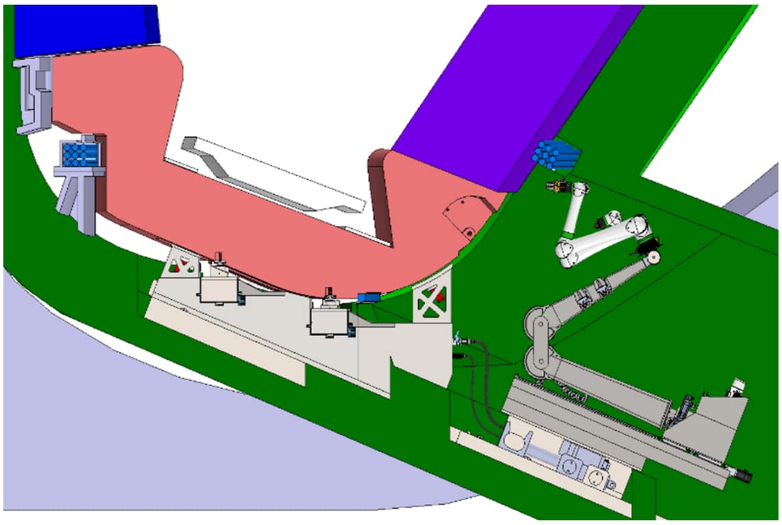


Figure 4.4: Lower port Multipurpose Deployer for divertor tool handling mounted on the Serapid chain mover and End effector concept (Courtesy of VTT & Comatec).

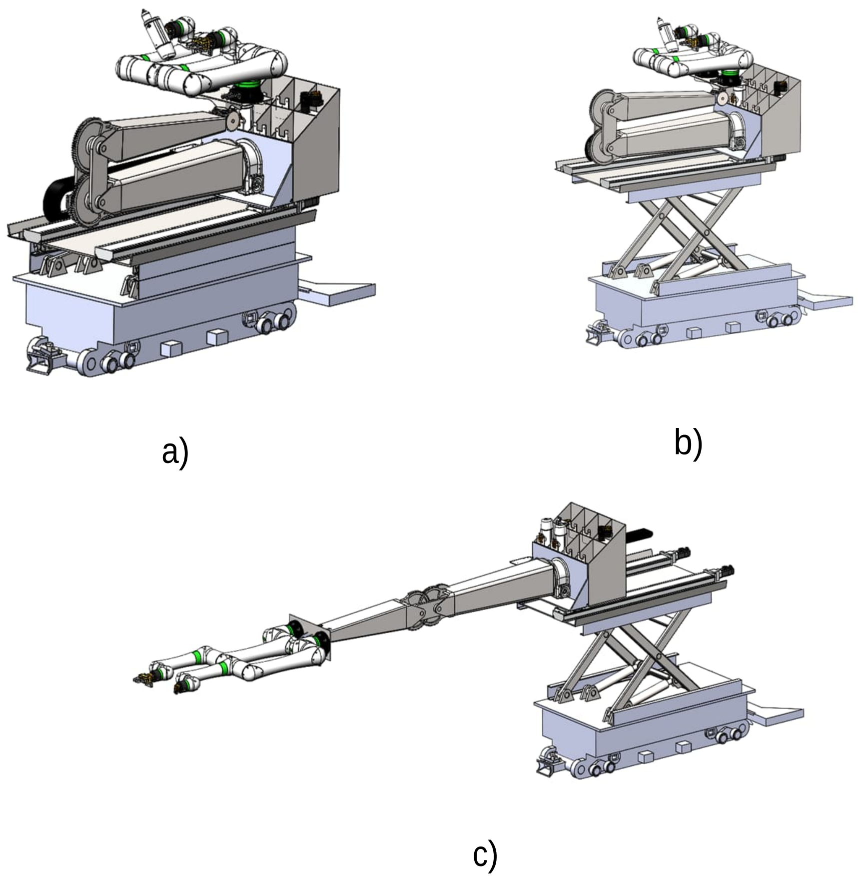


Figure 4.5:The lower port multipurpose deployer in a) compact form, b) vertical deployment, and c) full (horizontal and vertical) deployment stage (Courtesy of VTT & Comatec).

4.3.3 RM Technology R&D

The research initiative by RM Technology R&D in Finland focuses on developing innovative software design tools and methodologies that leverage digital transformation in the design field. In 2025, the focus was on digital transformation through applying machine learning and artificial intelligence (ML/AI) to conceptual design processes. The application of ML/AI aims at the catalogue-based design (CBD) methodology, which uses commercial-off-the-shelf (COTS) products and integrates robots with higher maturity and technology readiness levels (TRL). Using ML/AI is crucial for accelerating progress toward these innovative solutions by increasing the amount and usefulness of data extracted from the CBD. COTS products used as RH systems need redesigning to ensure compatibility with operations within an activated environment (AE). Therefore, the research incorporates these data science techniques to model all design factors simultaneously, reducing design complexity and boosting creativity throughout the entire design process.

The digital transformation process starts with contextualizing data extracted from COTS products to obtain high-level data as input variables for a hybrid AI-optimizer. This contextualization is based on performing a risk assessment of using COTS robots as RH systems, considering uncertainties in design, requirements, and deployment operations within a fusion power plant. These uncertainties are evaluated from three perspectives: plant design assessment using grounded theory data analysis to assess COTS technologies; technology readiness assessment through scatter plot analysis and TRL re-evaluations based on AE factors; and space reservation assessment for potential incompatibility caused by space constraints.

The input variable data are fed into the hybrid AI-optimization system, which comprises a multiphysics modeler, a surrogate modeler, and an inverse-problem algorithm. The model is simulated to generate limited training data for surrogate modelling (SM), serving as a substitute for the forward process of the original multiphysics model. This SM allows inverse algorithms to identify optimal design variables for multi-objective optimization and provides a quick way to verify existing design specifications. The inverse algorithm produces optimal design parameters that meet multi-objective goals and validate concepts from the SM. The designer evaluates the results and refines the design iteratively until an optimal solution is found; its specifications are fed back into the SM, creating a closed-loop process.

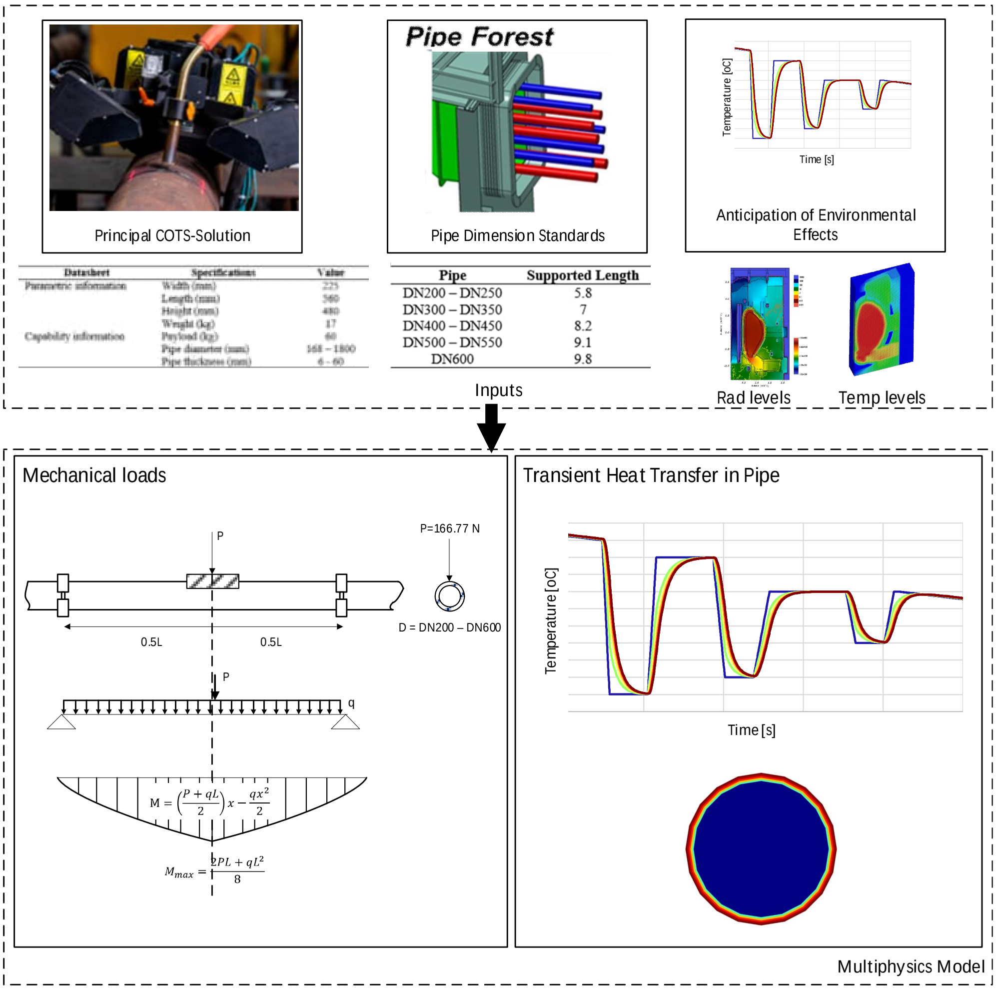


Figure 4.6: AI application in Fusion Remote Maintenance Equipment design, descriptions of inputs, and multiphysics model.

4.3.4 Remote Maintenance at LUT

Research scientists: L. Changyang, Q. Han, W. Huapeng, L. Ming, Qiwei Xue, Qingfei Han, Ting Wang, Pradeep Gaude, Q. Huang, D. Vodolazskii, Z. Wang

LUT participates in the WP RM with four major areas: Plant Architecture Assessments in WP2&3 (Bluemira modelling), condition monitoring, Stochastic modelling, Port Closure Plate, and support to Port Plant Systems. In-Vessel Maintenance R&D WP6 Development (MPD).
1) In the In-vessel maintenance system, the development of MPD for limiter maintenance is being conducted. A new concept of MPD has been studied.
2) In Condition monitoring, AI algorithms (data-driven methods) are being studied, and methods of human condition monitoring in a man-in-loop remote handling system are being developed.

3) In the stochastic modelling, the study investigates the effects of deviations of the robotic dynamic parameters on the performance of the robotic control system, in terms of control system stability, position tracking accuracy and the feasibility of the actuators.
4) Plant Architecture Assessments involve the study of a Multi-objective Optimisation Framework for Breeding Blanket Design with Remote Maintenance Consideration.

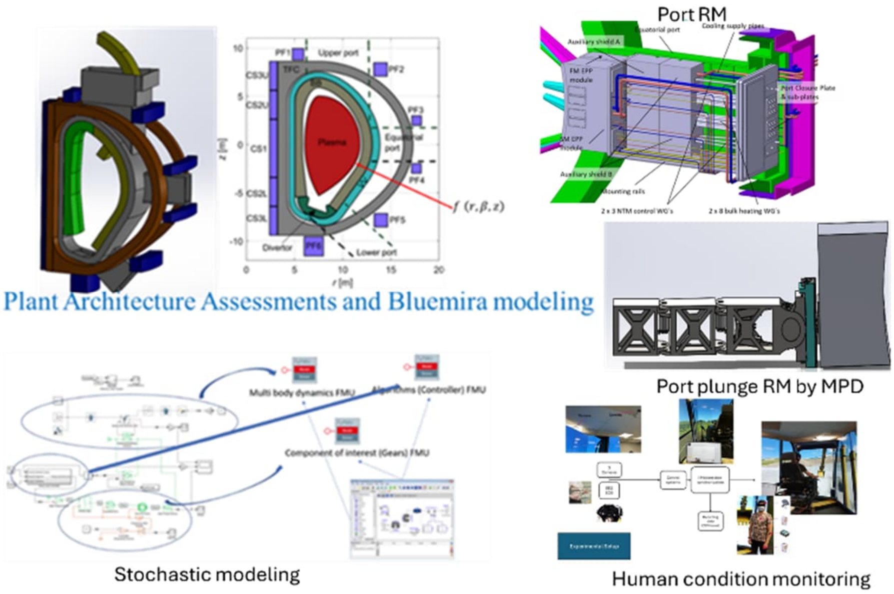


Figure 4.7: LUT activities on remote maintenance

4.3.5 EUROfusion WP RM Project Leader

In 2025, the work package management facilitated the ongoing collaboration, integration, and development of the 10 RUs working on WPRM, involving them in a broader range of remote maintenance work. One of the main activities in 2025 was the Gate 2a (G2a) review in November 2025. From WPRM, the review focused on the assessment of blanket handling. The work package management provided the G2a report and related presentation using input material from several strands working in the WPRM. The G2a report included the status of blanket handling concept, upper port service joining activities, blanket handling control systems, and the status of the new blanket handling test facility in Odense, Denmark.

One of the tasks during 2025 was to support the construction of a new remote handling test facility in Denmark. The tasks included attending design reviews, ensuring resources were appropriately allocated, keeping the schedule on track, and making certain that all required information was communicated to stakeholders.

2025 was the last year of the 2021-2025 funding period, and conclusions and reports were collected to highlight the main achievements and learnings from this period. Work package management prepared the Call for Participation documents for the extension period 2026-2027 and created the draft WPRM Work Plan for

2026-2027. Call responses from Research Units were evaluated, selections made, and draft budget was created for the extension period. Preparation work for the extension period included re-structuring the work package, updating the budget and work plan, and communicating with all RUs interested in working in WPRM.

5 Innovation, DEMO and Fusion Power Plants 2025

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

Research scientists: S. Norrman, VTT

Design modifications of the Indirect Coupled Design (ICD) alternative of the Helium-Cooled Pebble-Bed (HCPB) concept has been implemented in the Apros model. In this concept HITEC molten salt is used in an Intermediate Heat Transfer system (IHTS), containing large energy storage tanks, that ensures a continuous operation of the steam turbines during dwell operation. The design has been improved regarding the intermediate heat exchangers (IHX) as well as regarding the piping layout of the Primary Heat Transfer System (PHTS) and the intermediate heat transfer system (Figure 5.1). From previously having 4 + 4 vertical heat exchangers in opposite sides of the tokamak building, there are now 8 horizontal heat exchangers arranged radially around the tokamak to ensure the same lengths of cooling pipes. This removes a previous more complex piping layout and simplifies installation. One IHX serves two sectors with parallel cooling of the sectors. This provides redundancy in case of failures. Additionally, the horizontal heat exchangers contain internal helium circulators, which further reduces space in the tokamak building. Testing and tuning the functionality of a custom made Apros component of the new horizontal heat exchangers has been the main work during the year. No development- and analysis work has been done for the Water-Cooled Lithium-Lead (WCLL) Apros-model.

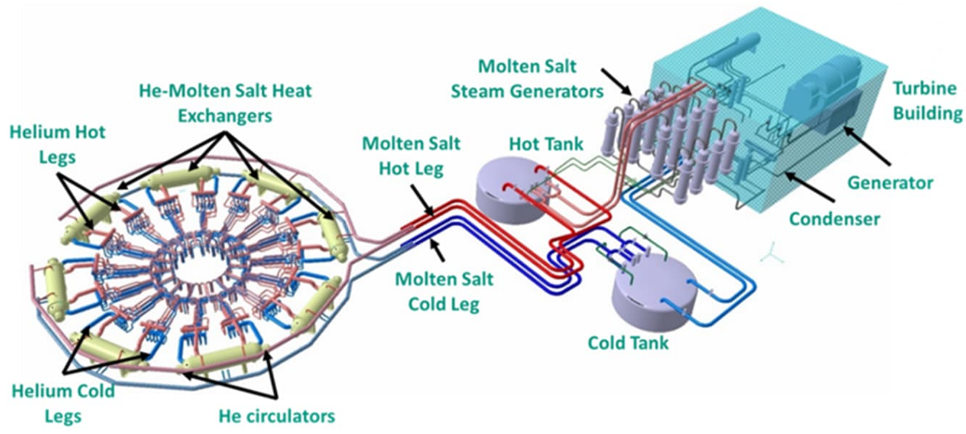


Figure 5.1: HCPB BOP reference configuration; indirect coupling design, 3D CAD Model.

5.2 WP MAT: Materials

5.2.1 WP MAT Hot cells

Research scientists: P. Arffman, P. Lappalainen, VTT

Regarding fusion research, no new experimental studies on the mechanical properties of irradiated materials were carried out in 2025. Instead, the work focused on an advanced analysis of previously acquired tensile test data from irradiated CuCrZr specimens. CuCrZr alloy is a key candidate material for high-heat-flux components in fusion applications, including ITER divertor and first-wall structures, owing to its high thermal conductivity, good mechanical strength, and favourable irradiation resistance. In addition to radiation-induced changes in strength and ductility, neutron irradiation may also affect the stability of plastic deformation. The objective of the present analysis was therefore to examine dynamic strain ageing (DSA) and Portevin–Le Chatelier (PLC) type behaviour using tensile data from 13 miniature specimens irradiated in four capsules at doses of 0.66–1.30 dpa and irradiation temperatures of 139–238 °C.

The evaluation was based on three complementary signal-processing metrics derived from the tensile curves: stress-drop periodicity in strain space, FFT harmonicity in the time domain, and wavelet ridge continuity. These metrics were combined into a PLC index to distinguish between scattered DSA-type fluctuations and more organized PLC-type deformation behaviour. The results showed that irradiation-modified flow instability was present in the dataset, but that it appeared predominantly as irregular and short-lived fluctuations rather than as sustained serrated flow associated with clear PLC band formation. A representative example is shown in Figure 1 for specimen 39, where the stress–strain response and the corresponding strain-hardening-rate signal illustrate intermittent plastic-flow fluctuations in the specimen exhibiting the highest PLC index in the analysed dataset.

Of the 13 specimens analysed, 11 were classified as DSA-dominated without PLC banding, with PLC index values concentrated in a narrow range of about 0.32–0.35. Only two specimens, 39 and 40, showed weak PLC-like behaviour, with PLC index values of 0.67 and 0.51, respectively. These two specimens belonged to the 1.18 dpa / 238 °C irradiation condition but were tested at room temperature, whereas the corresponding elevated-temperature tests at 240 °C remained DSA-dominated. This indicates that room-temperature testing was the most favourable condition for the emergence of more organized serration behaviour in the present irradiated material. However, even in these cases the wavelet ridge continuity remained low, confirming that the instability was still limited and intermittent rather than fully developed PLC banding. No clear evidence of distinct Lüders-type band propagation was identified; instead, the observed behaviour was interpreted primarily as DSA-type serrated flow.

Overall, the results indicate that neutron irradiation in CuCrZr promotes stochastic DSA-type flow fluctuations while suppressing strongly organized PLC behaviour. These findings provide additional insight into irradiation-induced changes in plastic-flow stability and support the structural assessment of CuCrZr components under fusion reactor operating conditions.

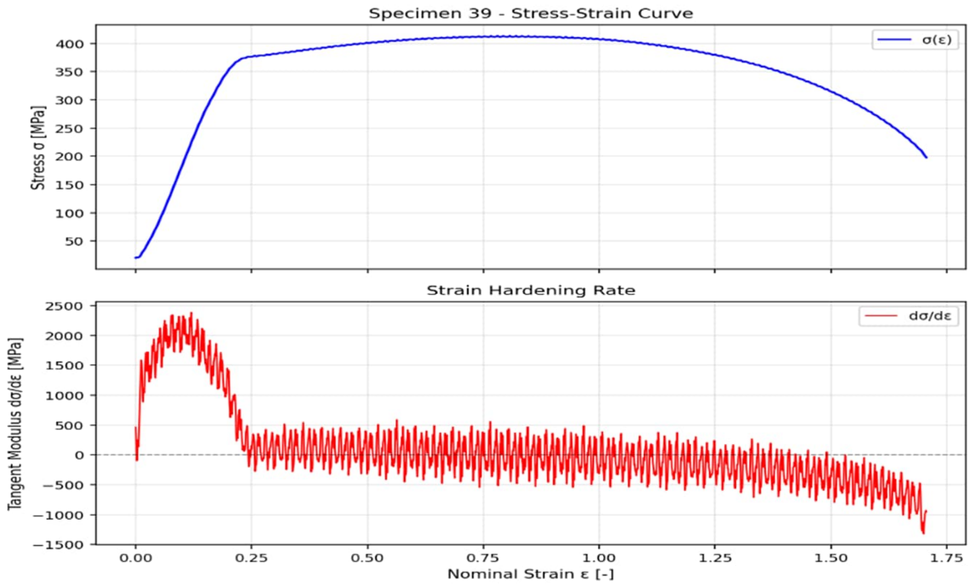


Figure 5.2: Stress–strain response and strain-hardening-rate signal for specimen 39, which showed the highest PLC index in the analysed dataset and was classified as weak PLC. The observed fluctuations remained intermittent, and no clear evidence of sustained band propagation was identified.

5.2.2 MicroStructural characterization, in-situ micromechanical testing and multiscale materials modeling

Research scientists: T. Suhonen, A.Laukkanen, M.Lindroos, Y. Baumann, T.Andersson, VTT

This task focuses on mechanical tests by standardized and miniature testing approaches (tensile, fatigue, creep, toughness, fatigue, cyclic deformation etc.), determination of thermophysical properties and microstructure characterization with different microscopy techniques.

The miniature testing capabilities developed and tested during earlier years, mainly in-situ SEM mechanical testing and small punch creep tests will be conducted for extruded plate from SCK.CEN (5A-2) and pipe (from ENEA) samples. Special emphasis will focus on the effects of different microstructural features e.g. texture.

The work contributes to the experimental characterization program on CuCrZr testing and characterization. The techniques and respective results feed directly into multiscale materials modeling capabilities developed by VTT, and the interactions between characterization, experimental and modeling activities enable the results to be exploited in full and further their interpretation and usefulness. Typically, this means that in situ experiments at small scale are also modeled, which greatly enriches the value of the set experiments, their quantitative analysis and the understanding that can be built based upon them.

From VTT's perspective, such methods also promote the bridging of the associated work on various fundamental mechanisms related to the properties of interest, enabling the results to be utilized in further material and solution design and development tasks directly.

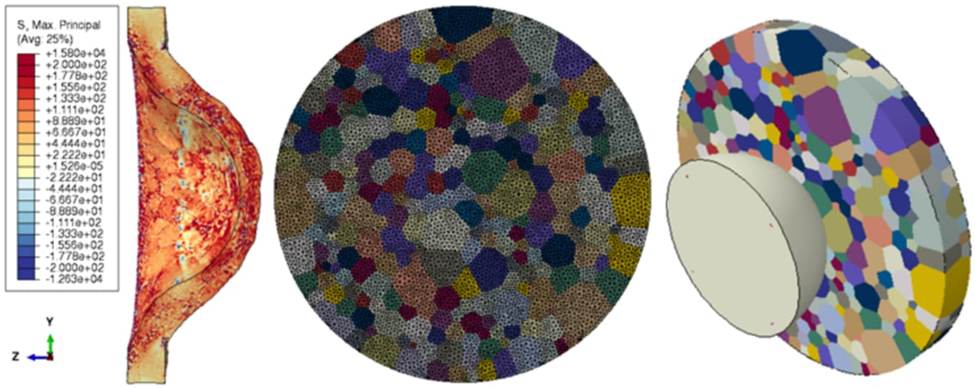


Figure 5.3: Small punch creep results.

5.2.3 Serpent2 stellarator neutronics modelling

Research scientists: T. Lyytinen, P. Lehti, A. Snicker, VTT

During 2025, Serpent neutronics modeling for stellarators was extended from HELIAS 5B to the Stable Quasi-Isodynamic Design (SQuID) and, in principle, to arbitrary configurations. The workflow begins from VMEC-based Fourier coefficients defining the plasma boundary and coil filaments, from which coil geometries are constructed. A ray-tracing method was developed to fit reactor layers—breeding blanket, shield, and vacuum vessel—within the available space by solving a last closed flux surface (LCFS)–coil distance matrix. This is passed to the SBGeom tool to generate mesh geometries, which are exported as STL files for Serpent2 simulations (see Figure 5.4).

Analysis of the SQuID configuration indicates promising tritium breeding ratios of 1.2–1.3 (assuming 10% losses, including divertor effects). However, radiation shielding remains insufficient even with boron carbide layers. The reduced LCFS–coil distance in certain regions, compared to HELIAS 5B, was identified as the primary limitation. Additionally, optimal moderator–shield material fractioning requires further attention, as increasing neutron absorbers alone is insufficient to meet shielding requirements.

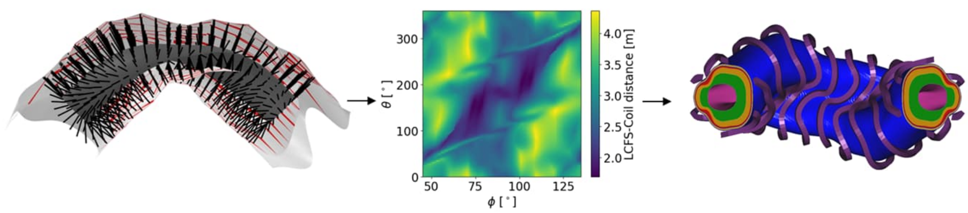


Figure 5.4: Methodology of generating stellarator geometry for Serpent2 simulation. Left: Rays traced from the last-closed flux surface to the surface made of coils. Middle: Distance matrix obtained from ray tracing. Right: Full reactor geometry constructed using the distance matrix.

5.2.4 IREMEV activities

Research scientists: A. Bruncrona, F. Granberg, V. Lindblad, K. Nordlund, J. Wu, UH
G. Karhulahti, I. Stanovohh, S. Viswanathan, E. Ponomareva, N. Korepanova. A. Sand, AU

At UH the work on understanding the effect of deuterium present during irradiation in tungsten was finished. We showed that the saturation level of defects is higher if deuterium is present (see Figure 5.5), and that if vacancies or voids are filled with deuterium, the defect production in single cascades is higher than if deuterium is not present. We systematically analyzed how defects in iron affect the Rutherford Backscattering Spectroscopy in channeling mode signal. Different defects and orientations have their own yields, and by using our combined Molecular Dynamics with long-term evolution of defects, we could explain the lack of a signal yield at room temperature in ultra-pure iron. Our effort on obtaining more insight from Positron Annihilation Spectroscopy results showed that our developed technique can be used to get more information from already existing results. This can be done for various materials just by obtaining the annihilation characteristics from first-principle calculations.

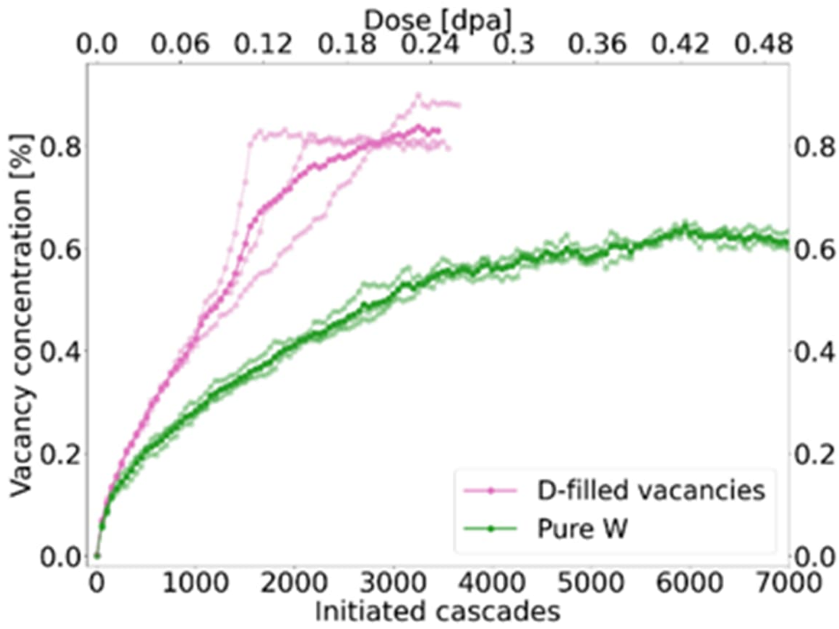


Figure 5.5: Defect evolution in pure tungsten and in tungsten with deuterium present during irradiation.

The objective of the work carried out at Aalto has been to develop and validate energy loss models for self-ion irradiation – needed for collision cascade simulations – focusing on the materials W, Fe and Cu. The use of two-temperature molecular dynamics in cascade simulations allows accounting for the thermal transport properties of the electronic system, and the electron-phonon coupling in addition to electronic stopping energy losses, both of which are found to affect the damage predictions when varying the coupling parameters between the ionic and electronic subsystems. Formulating a computationally efficient coupling between ions and electrons that accurately captures the relevant physical processes during the different stages of a cascade has remained a challenge, with a number of ad hoc solutions involving artificial cut-off parameters having been tested. Our approach builds on the assumption that the instantaneous coupling strength depends on the local electronic density experienced by the ion. Such a model, which we refer to as the unified two-temperature model, provides the flexibility and power needed for capturing cascade dynamics, but requires extensive ab initio data and an involved model fitting procedure to obtain a coupling function for any given ion-target combination. Within the IREMEV project during this year, we have validated a model for W, developed and validated a model for Fe, and carried out the initial ab initio simulations with which to formulate a model for Cu.

5.3 WP SAE: Safety and Environment

5.3.1 Decommissioning plan outline

Research scientists: Vesa Laitinen, Tomi Pakarinen, Platom, Markus Airila, VTT

Considering the decommissioning aspect in DEMO design activities is essential as the choices made in the design phase may have crucial impacts on the execution of decommissioning and dismantling. In 2025, Platom compared the D&D design recommendations given in the preceding deliverable of the last year with the current design of DEMO. The main conclusion is that many of the recommendations are already covered by the design, but the integration of some additional design features could also be studied.

In addition, many features facilitating decommissioning currently exist to serve other lifecycle phases or activities. All in all, the requirement documentation and safety guidelines could be updated to put more emphasis on the D&D aspect and to include also new guidance for the facilitation of decommissioning. This would help to integrate decommissioning as an inherent part of the DEMO design process.

The decommissioning strategy of DEMO is evaluated for two different options: implementing a safe enclosure period of two decades versus a safe enclosure period of 50 years. Most factors of strategic relevance favour the shorter enclosure period, but a major open question concerns the radiological conditions existing in the in-bioshield area at this point of time. Hereby, more accurate data on the radiation levels is needed to justify this approach, or to show that a longer enclosure period is needed. On the other hand, the radiological modelling could also indicate that decommissioning of DEMO after an enclosure period shorter than 20 years is feasible.

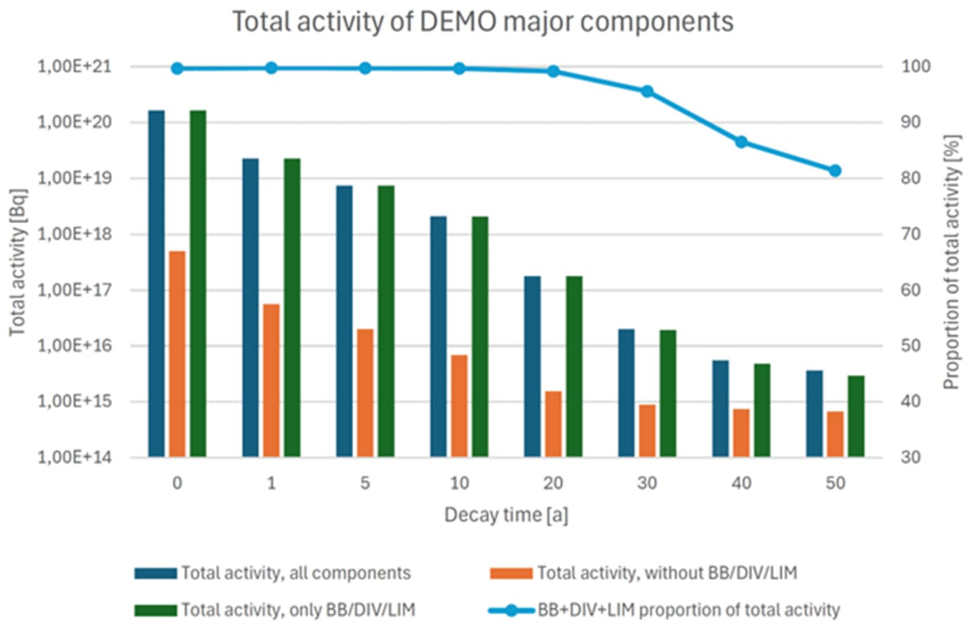


Figure 5.6: *Total activity of DEMO major components for three different cases. [EFDA_D_2SVWX8]. This demonstrates how significant the activity content of the breeding blanket, divertor and limiter actually is in relation to the other components: up to until 20 years of decay time, 99.1–99.8 % of the total DEMO radioactivity inventory is included in these three systems.*

The decommissioning scenario developed in our work describes one possible sequence of dismantling for the main DEMO components located inside the bioshield. An important presumption for the scenario is that the dose rates emitted by the main components are low enough to allow an open connection between the tokamak pit and the maintenance hall. Additionally, the dose rates are assumed to be of the sort that do not require the dismantling to be executed relying solely on remote technologies.

For developing the decommissioning planning of DEMO further, the radiation levels in the dismantling work area at different points of time after the permanent shutdown should first be estimated by calculations and modelling. Based on this, an initial selection of decommissioning strategy and dismantling methodology could be made. Knowing these factors, the decommissioning strategy and scenario could be progressed and made more detailed based on the chosen approach.

5.3.2 Waste recycling process optimization

Research scientists: Kimmo Hilden, Vesa Laitinen, Platom
Markus Airila, VTT

DEMO will produce notable amounts of radioactive waste during its lifetime primarily due to neutron activation of materials. Some amount is produced in the operational period in connection with component replacements, while the majority of waste will be generated during the decommissioning phase. The total lifetime inventory of neutron activated radioactive waste is approximately 87 000 tonnes, whereof 78 000 tonnes is produced as the result of post-operational and decommissioning activities.

Radioactivity of the waste can be notably decreased by radioactive decay (waiting period), which accordingly improves the conditions for carrying out waste management activities. However, only a very limited amount of the inventory can be cleared of regulatory control after a decay period of reasonable duration. This intends that in order to further advance the reutilization of the waste materials, they need to be recycled as radioactive material as they are, or alternatively novel treatment technologies need to be researched and developed to reduce the content of radioactive substances. A fundamental challenge is the separation of radionuclides that share very similar chemical characteristics with the base material of the component.

Defining appropriate duration for the applied decay period of the radioactive waste after the operational phase is a question of optimization, which is largely connected to decommissioning planning and overall waste management strategy. In the 2025 task, Platom examined a waste management scenario that is based on starting the facility decommissioning after 20-25 years of safe enclosure after the final shutdown of DEMO. This would enable part of the waste to be treated and either recycled or disposed directly while proposing decay storing for the components of higher activity concentrations. Alternative solutions would be to delay the decommissioning even further or to develop readiness for waste management activities that are largely based on remote technologies.

5.3.3 Fire accident analyses

Research scientists: T. Hakkarainen, T. Korhonen, N. Verma, VTT

Fire safety of the Cryostat was examined in detail. The primary objective was to ensure the Cryostat’s structural stability under fire conditions. Fires were considered possible only during long maintenance breaks, when air was present instead of the normal vacuum. Because detailed fire loads had not yet been defined, the analysis was based on generic fire scenarios, typically assuming a fire load density of 400 MJ/m², with some cases considering 1200 MJ/m². A solvent fire at the Cryostat base level was also included.

Multiple analysis methods were applied, ranging from analytical calculations to zone models and CFD simulations, in order to evaluate their suitability. OZone model results indicated that fire safety was improved when the number of open top or bottom openings was minimized, and that fire size and height strongly affected structural heating. CFAST simulations showed that increasing the number of open bottom manholes increased air availability, leading to higher heat release rates and temperatures, with temperature development governed by the interaction between fire size and opening configuration. Variations in steel thermal properties were found to have only minor effects. CFD simulations using FDS were used to assess the load-bearing capacity of different Cryostat configurations. Inclusion of the CTS was shown to be essential for realistic modelling. The results demonstrated that some maintenance-phase fires could threaten the Cryostat's global load-bearing capacity, while local damage could be mitigated through robust design.

Layered measures were recommended, focusing on fire prevention, early detection, particularly vapour detection for solvents, and mitigation through heat or oxygen control to minimize risks during maintenance operations.

6 Communications

6.1 Nordic Fusion seminar

The 5th Nordic bi-annual fusion seminar was held for the first time in Norway in Tromsø in June, under the auspices of UiT the Arctic University of Norway. The keynote speakers included presentations from ITER, EUROfusion, DIFFER and Commonwealth Fusion Systems. Organising Nordic bi-annual fusion seminar in Norway was an opportunity to promote Norway having recently joined EUROfusion via DTU as their international partner. More than 80 scientists and engineers participated in the seminar to discuss the Nordic collaboration in various fusion related themes.

6.2 Articles and public relations

Finland:

- STT: St1 vauhdittaa fuusioenergian kehitystä Pohjoismaissa yhdessä Novatron Fusion Groupin kanssa, 19.3.2025.
- STT: St1 joins forces with Novatron Fusion Group to accelerate fusion energy in the Nordics, 19.3.2025.
- Kauppalehti: ”Koko vetyhype on vähän puhkaistu” – Tässä on energiatransition seuraava suosikkihevonen, 20.3.2025.
- Tekniikka ja Talous: Suomeen suunnitellaan nyt ensimmäistä fuusiovoimalaa, kertoo energiayhtiö T&T:lle - "Suomi hyvässä asemassa", 4.6.2025.
- Yle News: “Amerikkalaisyhtiö lupaa fuusiovoimalansa pilotin tuottavan energiaa sähköverkkoon jo 30-luvun alkupuolella”, 31.1.2025.
- Taina Kurki-Suonio, “Energy future, focusing on the potential of fusion energy”, popularized lecture, Aalto university, 8.5.2025 and 25.10.2025
- Jari Likonen, ”Äärimmäisen tarkka TOF-SIMS-laite auttaa kehittämään materiaaleja koviin oloihin – vetymoottoriin, poranteriin tai fuusioreaktoriin”, VTT press release, 25.6.2025.
- Yle: Fuusioenergian kehitysyhtiö aikoo rakentaa ensimmäisen suuren testireaktorin pian – VTT: Suomi on paras vaihtoehto | Talous | Yle

- Kauppalehti/Talousaamu (Henkka's live interview + web): Nappaako Suomi jätti-investoinnin? Yllättävä valttikortti paljastui: "Olemme vähän pidemmällä" | Kauppalehti
- Yle TV News: Interview of Markus Airila and Peter Roos: Yle Uutiset 20.30 | Yle Uutiset | Yle Areena (18:05)
- Helsingin Sanomat (print and web): Fuusioreaktoria rakentava ruotsalaisyhtiö etsii isoa tonttia Helsingin seudulta | HS.fi
- Tekniikka ja Talous: Suomeen suunnitellaan 100 MW:n fuusioreaktoria – Teknologiaa kuvaillaan läpimurroksi, yksi sijaintipaikka ylitse muiden | Tekniikka&Talous
- Same in Kauppalehti: Suomeen suunnitellaan 100 MW:n fuusioreaktoria – Teknologiaa kuvaillaan läpimurroksi | Kauppalehti
- Uusi teknologia: Suomi fuusioreaktorin paikaksi – vai sittenkin Ruotsiin tai Tanskaan? - Uusiteknologia.fi
- ETN: Suomeen halutaan Pohjoismaiden ensimmäinen fuusioreaktori
- STT: Suomella hyvä mahdollisuus Pohjoismaiden ensimmäisen fuusioreaktorin sijoituspaikaksi, 20.10.2025.
- Uusi Juttu: Suomi nousi otollisimmaksi Pohjoismaaksi fuusioreaktorille. Professorin mukaan kilpajuoksuun pitää päästä mukaan nyt, 21.10.2025.

International:

- Finans DK: København udpeges som potentiel placering for revolutionerende atomreaktor - Finans
- Energy News: Finlande en tête pour accueillir le premier réacteur à fusion nordique selon une étude - energynews.pro
- Investor's Hangout: Nordic Fusion Energy Development: Future Prospects and Locations - Investors Hangout
- Third News: https://third-news.com/article/12068246-ad7f-11f0-a8a8-9ca3ba0a67df#gsc.tab=0
- Finanzen: Report shows best locations for fusion reactor in the Nordics | finanzen.net
- Cision: Report shows best locations for fusion reactor in the Nordics, 20.10.2025.
- NuclearNewswire Nuclear News: "DOE signs up first foreign partner for ARPA-E project", 8.1.2025.
- ArcticToday: St1 joins forces with Novatron Fusion Group to accelerate fusion energy in the Nordics.

6.3 Courses on fusion studies

- Introduction to plasma physics for fusion and space applications (T. Kurki-Suonio, autumn 2025).
- Fusion Energy Technology (M. Groth, T. Kiviniemi, spring 2025).
- Radiation Damage in Materials (A. Sand, spring 2025)

7 Education and training

7.1 WP EDU: FinnFusion student projects

7.1.1 Overview

7.1.2 Doctoral students

Aalto University

Student: Francis Albert Devasagayam (AU)
Supervisor: Mathias Groth (AU)
Instructor: Timo Kiviniemi (AU)

Topic: *Plasma flows and turbulence in gyrokinetic simulations*
Report: Using the Gyrokinetic Electromagnetic Numerical Experiment (GENE) code, the Geodesic acoustic mode (GAM) intermittency in the core of FT-2 is studied by performing a global non-linear simulation. The simulation results revealed intermittency in GAMs close to the low-order rational surface (q=3). This finding constitutes the first observation of GAM intermittency in a gyrokinetic simulation. The underlying cause of this GAM intermittency is attributed to the non-linear coupling between GAMs and turbulence at this radial location. Furthermore, the density fluctuations exhibited intermittency at the same radial location, confirming the non-linear coupling between GAMs and turbulence. The impact of the Krook-type source operators on the GAM dynamics in the GENE simulations is investigated. Global non-linear simulations showed that the GAM amplitude increases with increasing Krook-type source operator, driven by an increased GAM drive. The zonal flows amplitude decreases with increasing value of the Krook-type source operators in the center region. Notably, the GAM damping in the center region increases by 15 to

30% with increasing operator values. Despite the GAMs exhibiting intermittency, their quiescent and active periods differ with operator values.

Student: Roni Mäenpää (AU)
Supervisor: Mathias Groth (AU)
Instructor: Mathias Groth (AU)

Topic: *Nitrogen transport and chemistry in divertor plasmas*
Report: A deuterated ammonia (ND_3) formation, transport and dissociation model implemented in ERO2.0 and applied to low- recycling, Ohmically-heated and nitrogen-seeded plasmas in JET predicts that ND_3 is concentrated in the low-field side divertor corner, and to a lesser degree in the high-field side divertor corner and above the high-field side divertor shoulder. Nitrogen atoms and ions incident on divertor targets and main chamber walls that do not undergo fast reflection are recycled as ND_3 or nitrogen molecules (N_2) in equal fractions, an assumption based on experimental findings in laboratory plasma devices and tokamak divertor plasmas with a significant wall inventory of nitrogen but no active N_2 seeding. Only electron-impact reactions (with two or fewer non-electron products) from the AMMONX database are included in the model due to the ionizing character of the low-recycling divertor plasma. The predicted densities of ND_2 and ND in the low-field side divertor are found to be sensitive to the assumed kinetic energy release associated with the dissociation reactions of ND_3, ND_2 and ND due to the higher velocities and shorter lifetimes of the dissociation fragments leading to lower predicted densities.

Student: Evgeniia Ponomareva (AU)
Supervisor: Andrea Sand (AU)
Instructor: Andrea Sand (AU)
Topic: *Capturing electronic stopping effects in ion irradiation simulations of nuclear materials*

Report: Accurate predictions of sputtering under low-energy ion irradiation are crucial for assessing plasma-wall interactions in fusion devices. In this study, we investigated how different treatments of electronic energy dissipation affect sputtering and reflection yields for hydrogen and helium ions impacting tungsten and iron surfaces at energies from a few hundred eV to 2 keV. Using real-time time-dependent density functional theory (rt-TDDFT), we calculated trajectory-resolved electronic energy losses and derived a density-dependent electronic stopping function for use in large-scale molecular dynamics simulations. Our sputtering simulation results show that incorporating a trajectory-dependent description of electronic stopping leads to systematic changes in predicted sputtering yields, particularly for tungsten and at lower impact energies, where ions preferentially travel through regions of lower electron density. At the same time, we reveal that ion reflection counts are negligibly affected by the choice of the stopping model. Clear material-dependent trends are identified; in tungsten, sputtering outcome is defined primarily by projectile electronic stopping, while in iron, recoil contributions become more significant. Overall, this study demonstrates that an accurate treatment of electronic stopping is required for improving predictive simulations of low-energy plasma-material interactions.

Student: David Rees (AU)
Supervisor: Mathias Groth (AU)
Instructor: Mathias Groth (AU)
Topic: *Impact of main ion species on divertor plasma detachment in tokamaks*

Report: The total radiated power is equal between D and He in experiment and simulation in low and high-recycling conditions. However, the SOLPS-ITER radiated power is half that of bolometry for both species. Comparison with synthetic bolometry by line-of-sight shows a larger disagreement on the high-field side than the LFS. For plasma heated with 1 MW of neutral beam heating, simulated power to the LFS target is within 0.5 MW of IR camera measurements (IRTV), for both species. For 5 MW, SOLPS simulates twice as much power to the target than seen by IRTV. In JET-ILW, input (Ohmic and NBI heating) and output (Bolometry and divertor IRTV) power can be balanced for the 1MW heating case, but there is a density independent 2 MW deficit for 5 MW heating case, which is not measured to leave the plasma by the diagnostics. The strongest source of radiated power in the He simulations are the UV lines of the Lyman series of He+1, at over 80% of total radiated power, with the proportion independent of density or heating power. A synthetic diagnostic of the JET-ILW VUV spectrometer, performed by the 3D ray-tracing code Cherab, underpredicts measured Lyman lines by a half. The disagreement between SOLPS and bolometry is specifically due to underprediction of the Lyman line radiation.

Student: Van-Dung Truong (VTT)
Supervisor: Petri Kuosmanen (AU)
Instructor: William Brace (VTT)

Topic: *A Model-Based Methodology for Quantification of Risks for Probabilistic Reasoning in Complex Systems*

Report: The research focuses on developing a novel approach to identify and quantify technical risks during the early conceptual design phase of high-risk technical systems, such as Remote Maintenance systems in DEMO fusion power plants. The research addresses risks from three key facets: failure modes, situational, and quality risks. The project's first year (2024) published a balancing model based on domain modelling and qualitative physics reasoning aligned with Dimensional Analysis and the Buckingham Pi theorem to capture fundamental system relationships. The second year (2025) studied the quality risk quantification based on the Stochastic Petri Nets, an extension of Petri Nets, combined with statistical methods, focusing on quality risks. The upcoming years will continue to improve the balancing model by the integration of machine learning models with the identified DA and Pi Theorems as a physics-informed surrogate model, utilising the similitude similarity characteristics for solving situational and failure mode risks and assisting the identification of optimal conceptual design solutions under uncertainties.

Student: Brahim Dif
Supervisor: Andrea Sand, Aalto University
Instructor: Janne Heikinheimo, VTT
Topic: *Mechanical characterisation of ITER-specification tungsten using tensile and small punch testing methods*

Report: Two types of mechanical tests were conducted on ITER-specification tungsten (A.L.M.T, Japan): tensile and small punch testing (SPT). Tensile testing provides fundamental mechanical properties whilst SPT on the other hand is biaxial in nature, which offers comparable data using miniature specimens. The study aimed to characterise the mechanical properties of the ITER- W and explore a correlation factor between the two approaches. Re-evaluation of the SPT correlation factors of ITER-specification tungsten in this study revealed noticeable deviation from the commonly adopted value in the European standard, with the yield strength factor showing the largest discrepancy. Furthermore, all correlation factors exhibited a noticeable temperature and directional (anisotropy) dependence, highlighting the importance of using material-specific values for accurate properties estimation.

Student: Tommi Lyytinen (VTT)
Supervisor: Andrea Sand (AU)
Instructor: Antti Snicker (VTT)
Topic: *Using Monte Carlo methods to simulate transport of fusion-born neutrons in complicated reactor geometries*

Report: During 2025, a ray-tracing–based methodology was developed to fit breeding blanket geometries within the constrained space between the plasma boundary and the coils in stellarators. Owing to the inherently three-dimensional geometry, the plasma–coil distance varies significantly, requiring efficient use of all available space for the breeding blanket, shielding, and vacuum vessel to achieve optimal performance. The methodology was applied to the HELIAS 5B and SQuID (Stable Quasi-Isodynamic Design) stellarator configurations to evaluate tritium breeding and coil shielding. For HELIAS 5B, coil shielding was significantly improved compared to a uniform blanket thickness approach, reaching near-acceptable limits. In contrast, the SQuID configuration exceeded shielding limits by a substantial margin, primarily due to the reduced plasma–coil distance in the inboard regions.

Student: Nima Fakhrayi Mofrad (AU)
Supervisor: Andrea Sand (AU)
Instructor: Andrea Sand (AU)
Topic: *Exploring plasma-wall interactions: A computational approach*

Report: In this project, plasma–wall interaction (PWI) phenomena in plasma-facing materials were analyzed using computational approaches. The core of the study consisted of Molecular Dynamics (MD) simulations that model the bombardment of candidate wall materials by energetic ion species. The aims of the work can be summarized as follows:

1. Tungsten–Hydrogen (W–H) Interaction Studies**:** To obtain quantitatively reliable values for reflection coefficients and sputtering yields of tungsten under hydrogen bombardment, with particular emphasis on hydrogen-saturated W surfaces. This included a systematic assessment of how the ion impact energy influences reflection and erosion.
2. Outgassing and PWI in Beryllium**:** To perform a multiscale investigation of beryllium erosion and outgassing driven by plasma particle impacts. The resulting data provided high-fidelity input parameters for edge plasma and impurity transport.
3. Erosion Assessment for Fe and W Surfaces**:** To deliver accurate predictions of erosion for iron and tungsten plasma-facing surfaces, incorporating the influence of surface crystallographic orientation and structure. Computational predictions were compared and validated against experimental measurements carried out by collaborators at TU Wien.

Collectively, these objectives were directed toward building a comprehensive, simulation-based framework for predicting material performance in fusion-relevant plasma environments.

Student: Sreya Viswanathan (AU)
Supervisor: Andrea Sand (AU)
Instructor: Antoine Clement (AU)
Topic: *An Investigation of electronic effects of self-ions in Iron for nuclear material research*

Report: Understanding primary radiation damage is essential for the development of robust structural materials for fusion applications. These materials are subjected to prolonged irradiation by energetic particles, and their performance depends on how damage is generated and evolves at the atomic scale. Iron (Fe), as the main constituent of steels used in structural reactor applications, is therefore an important model system for investigating the early stages of radiation damage. In particular, electronic energy-loss processes are expected to play a key role in the response of Fe under ion irradiation.

In this work, we investigated the electronic stopping of self-ions in Fe using ab initio calculations. These simulations explicitly describe the interaction between energetic ions and the electronic subsystem of Fe, providing insight into electronic energy loss and the early stages of damage formation.

We employed a recent electron-density-dependent model to describe the coupling between atomic and electronic subsystems within a two-temperature molecular dynamics framework. The model was parameterized using electronic stopping data obtained from our ab initio calculations. This allows electronic energy dissipation to be incorporated into large-scale molecular dynamics simulations.

Student: Ilja Stanovohh (AU)
Supervisor: Andrea Sand (AU)
Instructor: Andrea Sand (AU)
Topic: *Effects of temperature on vacancy saturation in nickel-based equiatomic multi-component alloys*

Report: Materials in fusion reactors are exposed to intense neutron irradiation, leading to the accumulation of structural damage that can gradually compromise performance. We investigate how radiation damage accumulates in nickel and related alloys in the athermal regime using a novel semi-analytical model that accounts for how successive collision cascades overlap and interact with pre-existing damage in the material. Using this model, one can predict the saturated vacancy concentration using parameters derived from only individual cascade data. To explore the predictive power of the model, we benchmark its predictions of the saturated vacancy concentration against corresponding results from direct MD cumulative cascade simulations at various ambient temperatures. We show that, at higher temperatures, the saturated vacancy concentration is reduced in both the semi-analytical model predictions and the cumulative cascade simulation results. However, material-specific differences can only be captured when defect clustering with increasing dose is taken into account. Hence, we demonstrate that the evolving damage microstructure must be considered by future theoretical models predicting damage accumulation.

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University of Helsinki

Student: Alexandre Bergero (UH)
Supervisor: Fredric Granberg
Instructor: Fredric Granberg
Topic: *Development of W-B interatomic potential and sputtering simulations*

Report: Sputtering simulations using molecular dynamics was performed on the high entropy alloys MoTaNbVW and NbVW, and a direct comparison to W was done, using a TabGAP potential. These simulations included Ar irradiation with energies between 200 and 1000 eV going from 0-75 degrees incoming angle for single impact and 0-45 degrees for cumulative impacts. A W-B TabGAP machine learning interatomic potential has been trained to do similar sputtering studies for pure boron, boron deposited on W and BW. This potential is not fully ready, additional validations and studies are still needed. The potential will hopefully be able to accurately deposit boron over different tungsten surfaces and estimate the sputtering yield of different tungsten-boron mixing under irradiation.

Student: Andreas Bruncrona (UH)
Supervisor: Fredric Granberg
Instructor: Flyura Djurabekova
Topic: *Radiation damage evolution in fusion reactor materials*

Report: I became a doctoral researcher in September 2025, and I have been working on writing an article based on the work of my M.Sc. thesis with additional research and analysis. The initial work involved Molecular Dynamics (MD) simulations of cumulative displacement cascades, with the aim of comparing the effect of fixed versus randomly sampled PKA energies on the defect build-up in tungsten and iron. The additional work also utilized similar MD simulations but investigated the effect of energy loss due to electronic stopping power on the damage evolution in the same metals. This was done by running cumulative cascade simulations with various the kinetic cut-off energies, below which electronic stopping is no longer applied, and comparing with results from simulations without electronic stopping applied at all.

Student: Amanda Bruncrona (VTT)
Supervisor: Minna Palmroth (UH)
Instructor: Aaro Järvinen (VTT)
Topic: *Acceleration of MHD stability simulations with machine learning techniques*

Report: Published a proof-of-principle machine learning surrogate model for the ideal MHD stability code MISHKA-1 focusing on JET-ILW parameter space. Completed integration of the model into the pedestal prediction workflow Europed, resulting in a 72% acceleration of the workflow. The model is currently being extended to all other EUROfusion devices and efforts are going towards additionally predicting resistive MHD stability.

Student: Daniel Jordan
Supervisor: Mina Palmroth
Instructor: Aaro Järvinen
Topic: *Data efficient surrogate models for plasma micro instability simulations in conventional tokamak geometries*

Report: Local linear micro instability simulations provide a wealth of information in reduced quasilinear models for heat, particle and momentum flux. Although they are too slow for many applications such as device design, predictive maintenance, inter shot analysis. Modern machine learning techniques allow many high dimensional and heavy simulations to be interpolated so that fast inferences can be made in production workflows without running the full fidelity simulation every time. My PhD focus is to generate a machine learning model of local linear GENE that covers the parameter space applicable to JET pedestals and its conventional tokamak geometry. Initial applications are in uncertainty quantification, eventually it will be applied to transport modelling.

Student: Bruno Oliveira Cattelan (UH)
Supervisor: Fredric Granberg (UH)

Instructors: Fredric Granberg (UH)
Topic: *A Machine Learning Approach for Binding Energy Estimation in Dislocations*

Report: In this project, we work on extending the existing results from (Hesslow L et al. Journal of Plasma Physics. 2019; 85(6) :475850601) where a neural network was created to estimate the Dreicer runaway generation rate with impurities present. This work used the CODE tool to create their dataset. The impurities taken into consideration were Argon and Neon.
We create a new neural network that not only handles much heavier impurities (up to Tungsten) but also uses the newer DREAM modelling tool. This allows for a higher quality estimation. It is our hope that once our model is completed we can integrate it to the DREAM tool, similarly to how it was done with the original one. This will directly impact users of the tool that make use of the neural network component of Dreicer generation rate.

Student: Otso Hyvärinen (UH)
Supervisor: Samuli Siltanen (UH)
Instructor: Antti Snicker (VTT)
Topic: *Using ASCOT and inversion methods to solve 4-D distribution function of burning plasmas*

Report: Solving high-dimensional (≥ 3) fast-ion distribution function from measurements is an ill-posed problem that requires imposing prior information into the solution space. In 2025, we tackled the reconstruction of the 4D distribution function, by using ASCOT to calculate slowing down functions from particle distributions generated by neutral beam injector (NBI). These slowing down functions constituted a basis in which the reconstruction problem could be solved. We showed that for JET we could reconstruct the 4D fast-ion distribution function from one of beams well, which was published in a peer-reviewed journal article in 2025. To develop our method of using basis functions, we studied a creation of basis functions from a constant of motion source grid. This research is currently under way, but the construction of such basis was already demonstrated at the end of 2025.

Student: Faith Kporha (UH)
Supervisor: Fredric Granberg
Instructor: Fredric Granberg
Topic: *Sputtering simulations of W and D-decorated W surfaces*

Report: To better understand how the surface morphology of plasma-facing components affects tungsten sputtering and reflection, molecular dynamics simulations were performed to obtain sputtering yields of pristine tungsten under impurity ion bombardment. Two interatomic potentials were compared to assess their predictive performance. The study was then extended to deuterium-decorated tungsten surfaces. Simulations were conducted following the same methodology as for pristine tungsten, examining different surface orientations, ion incidence angles, deuterium decoration levels and deuterium penetration depths. Results from both potentials were validated against DFT- MD calculations. In addition, development of a machine-learned interatomic potential for the W–O–H system has been ongoing. This development will enable more accurate description of the interactions and sputtering simulations of even more complex surfaces.

Student: Anna Niemelä (VTT)
Supervisor: Minna Palmroth
Instructor: Aaro Järvinen
Topic: *Machine learning facilitated transport models for spherical tokamak plasma confinement devices*

Report: This PhD project aims to improve the accuracy and computational efficiency of turbulence predictions in spherical tokamak plasmas. Turbulence driven by electrostatic and electromagnetic fluctuations governs plasma transport and strongly affects confinement performance. In the low-collisionality regimes typical of these plasmas, fluid models are insufficient, requiring nonlinear gyrokinetic simulations that solve the Vlasov–Maxwell equations. These simulations can require millions of CPU hours, limiting their use for real-time analysis and extensive parameter exploration.
To address this challenge, the project develops machine learning models designed to accelerate gyrokinetic simulations while maintaining high physical fidelity. The focus is on residual turbulence at the plasma edge, where shear-flow stabilization suppresses fluctuations and transport barriers form. The aim will be fast, predictive tools suitable for real-time applications, experimental validation, and predictive applications

Student: Joona Sissonen (VTT)
Supervisor: Minna Palmroth (UH)
Instructor: Antti Snicker (VTT) and Konsta Särkimäki (VTT)
Topic: *Theory and models for Monte Carlo simulations of minority particle populations in fusion plasmas*

Report: ASCOT5 is a state-of-the-art neoclassical test-particle code that sparks jealousy in all its competitors through its superior parallelism and genuinely pleasant user experience. While ASCOT5 handles 3D simulations without breaking a sweat, it was originally developed with tokamak devices in mind. Due to the rising interest in stellarator devices, the need has been identified to make ASCOT5 even better suited for stellarator simulations. Significant mental effort was put into this during the year 2025 since the start of the project on 29 December.

Student: Jintong Wu
Supervisor: Fredric Granberg
Instructor: Fredric Granberg
Topic: *From collision cascades to long-term defect dynamics: a computational study of irradiation effects in fusion relevant materials*

Report: In 2025, I developed a coupled OKMC and MD modeling approach to simulate long-term microstructural evolution at experimentally comparable dose rates. Building on this, we introduced a new quantification method based on a quadratic programming formulation to infer the most probable void-size distribution in irradiated tungsten, also iron later, both fusion related materials. This approach enables direct, quantitative comparisons between our coupled OKMC–MD simulations and experimental measurements.

Student: Victor Lindblad (UH)
Supervisor: Kai Nordlund (UH)
Instructor: Fredric Granberg (UH)
Topic: *Studying kink formations on screw dislocation lines using MD*

Report: A growing body of experiments, along with several computational studies, has consistently shown that deuterium present during irradiation increases the fraction of saturated defects. Yet despite these observations, we still do not fully understand the mechanisms behind this behavior, especially processes occurring at the atomistic scale. To investigate the observed increase in defect accumulation and deuterium retention under certain conditions, we performed a series of MD irradiation simulations. These included single-impact simulations on both cells containing pre-existing vacancies and up to nanometer-sized voids, with and without the presence of deuterium. We also performed high-dose irradiation simulations across different configurations to replicate the experimental conditions reported in earlier studies. Our results show that, in both single-impact and cumulative-impact simulations, the presence of deuterium-filled vacancies and voids leads to greater defect production and higher deuterium retention. We link these effects mainly to a greater defect generation during the heat-spike phase, together with a decreased efficiency of defect recombination.

Student: Iuliia Zhelezova (UH)
Supervisor: Filip Tuomisto (UH)
Instructor: Filip Tuomisto (UH)
Topic: *Formation and stabilization of Ga vacancies in β-Ga_2O_3: effects of Al-alloying, Si-doping, and proton irradiation*

Report: We investigated irradiation-induced vacancy defects in *β*-$(Al,Ga)_2O_3$ single crystals using temperature-dependent positron annihilation spectroscopy, including positron lifetime and Doppler broadening measurements. The crystals were grown by the Czochralski method with Al contents of 0–25 % in both undoped and Si-doped forms. While undoped samples exhibit the characteristic anisotropy of *β*-Ga_2O_3 and signatures of split Ga vacancies, Si-doped crystals show reduced anisotropy and enhanced positron trapping, indicating the presence of unrelaxed Ga vacancies.

To further probe defect formation, selected samples were subjected to 6 MeV proton irradiation. In undoped alloys, irradiation leads to a clear increase in positron lifetime, accompanied by reduced Doppler anisotropy and decreased W2 parameters, consistent with the formation of unrelaxed Ga vacancies. In contrast, Si-doped samples show only minor changes upon irradiation, suggesting that such vacancy defects are already dominant prior to irradiation.

These results demonstrate that proton irradiation effectively introduces unrelaxed Ga vacancies in undoped β-(Al,Ga)2O3, while Si-doping and Al-alloying stabilize similar defect configurations. The combined effects of alloying, doping, and irradiation promote compensating defects that limit doping efficiency and contribute to insulating behavior in highly alloyed materials.

Student: Oskar Lappi (UH, ACH)
Supervisor: Keijo Heljanko (UH, ACH)
Instructor: Keijo Heljanko (UH, ACH)
Topic: *Developing Scalable Algorithms for Monte Carlo Neutral Transport in Eiron*

Report: My work is centered around Eiron, a simplified Monte Carlo neutral transport model that I've developed in order to investigate different parallel algorithms in EIRENE. This year, we finished a study comparing three parallel algorithms: a traditional domain replication algorithm (used by EIRENE), a shared memory OpenMP algorithm (also used by EIRENE), and a novel domain decomposition algorithm, which would be a candidate for improving the scalability of EIRENE. The domain decomposition algorithm outperformed the other two algorithms in both strong scaling and weak scaling experiments. This work was submitted to the Journal of Computational Physics, but it was unfortunately rejected. A preprint is available on arXiv (arXiv:2511.04489).

In collaboration with Emil Løvbak from KIT, and KU Leuven colleagues, we also implemented a 2D Kinetic-diffusion Monte Carlo (KDMC) algorithm using Eiron. This work has been accepted for publication in Contributions to Plasma Physics. KDMC is a hybrid method, which saves on performance in the diffusive regime (when the mean-free path of particles is short). This is the first time the method has been applied in two dimensions. In the test cases we ran, the errors are on the order of 1% when compared to a benchmark kinetic Monte Carlo simulation. I attended the 3rd Annual meeting of EUROfusion HPC ACHs at EPFL in Lausanne, where I presented results from the domain decomposition work.

LUT University

Student: Pradeep Gaudel (LUT)
Supervisor: Huapeng Wu (LUT)
Instructor: Changyang Li (LUT)
Topic: *Design and analysis of heavy-duty manipulator for nuclear applications*

Report: Advanced robotic systems are necessary for handling large and heavy components in harsh conditions of a fusion reactor. The Multipurpose Deployer (MPD), a robotic manipulator designed to lift and position reactor limiters weighing 6 to 20 tons inside the vacuum vessel, is presented in this paper along with its actuation system. High torque servo motors were selected over hydraulic systems because of their accuracy, robustness, and ability to withstand radiation-induced deterioration. The MPD uses high-force linear actuators for accurate extension and retraction movements and harmonic drive gearboxes for a smooth and regulated torque transfer. The MPD offers a precise, safe, and effective way to do remote maintenance on nuclear fusion reactors by integrating high-torque motors, precision gearboxes, and sophisticated control systems in its unique and robust design. The project delivers the preliminary design and framework for detail design in the future.

Student: Qingfei Han (LUT)
Supervisor: Heikki Handroos (LUT), Huapeng Wu
Instructor: Huapeng Wu (LUT)
Topic: *Bionic research on multilevel mechanisms in the locomotion behavior of Gekko*

Report: This study investigates the gecko (Gekko gecko), focusing on its multi-level locomotor control strategies. The research includes the following aspects: observing the detachment behaviour of geckos on vertical surfaces with different roughness; developing a finite element model of digit detachment and validating its detachment characteristics using bionic digits; analysing the foot modulation strategies of the gecko at various inclinations and verifying digit arrangement characteristics using a bioinspired gecko foot; and investigating the limb movement characteristics and joint variables of the gecko during turning on vertical surfaces, with experimental validation of the advantages of its flexible spine in turning through a bioinspired gecko robot.

Student: Qi Huang (LUT)
Supervisor: Huapeng Wu (LUT)
Instructor: Huapeng Wu (LUT)
Topic: *Globally Optimal Symbolic Estimation of Offsets and Gravity Parameters for Wrist-mounted Force/torque Sensor*

Report: Most robotic contact tasks rely on wrist-mounted force/torque (F/T) sensors for precise force perception. However, sensor readings are coupled with non-contact forces that must be compensated. In most contact scenarios, the robot operates in a quasi-static state, allowing dynamic effects to be neglected. Therefore, only the gravity and offset parameters need to be estimated. Existing methods, however, have limited generality and often require additional installation information or an initial parameters value. This work presents a new perspective of simultaneous optimization for force and torque residuals. A globally optimal estimation solution is derived via a symbolic method, which is easily applicable to various robot installation setups and independent of initial values. Simulation and real world experiments demonstrate that the proposed method outperforms existing approaches in multiple aspects.

Student: Nikola Petkov (UKAEA)
Supervisor: Huapeng Wu (LUT)
Instructor: Huapeng Wu
Topic: *A Kinematics Optimization Framework with Improved Computational Efficiency for Task-Based Optimum Design of Serial Manipulators in Cluttered Environments*

Report: To accelerate design optimization at improved efficiency, we design a novel robust design framework built on a new kinematic design synthesis, which allows for simultaneously optimizing dimension and topology of a serial manipulator's kinematics for arbitrary tasks in constrained environments, using a generalised parametric kinematic model. Significantly, in contrast to standard solutions, we develop a novel computationally effective reachability verification method, which rapidly aborts infeasible motions by exploiting efficient collision checks, based on the Rapidly-exploring Random Tree (RRT) algorithm. The effectiveness of the proposed design framework is verified and evaluated by comparing to baseline benchmarks. Results demonstrate the novel design framework can accelerate kinematic design optimization by an order of magnitude compared to the current state-of-the-art, and optimise link dimension and joint type simultaneously of serial robots for cluttered environments.

Student: Saifi Qais (VTT)
Supervisor: Huapeng Wu (LUT)
Instructor: Huapeng Wu (LUT), Brace William (VTT)
Topic: *A Probability-Conserving Finite Cell Weight Variation Method for Uncertainty Quantification in Nonlinear Structural Dynamics*

Report: Efficient, high-fidelity uncertainty quantification (UQ) for strongly nonlinear dynamical systems remains challenging: Monte Carlo simulation (MCS) is accurate but costly, while many surrogate methods struggle to capture multimodality and strong local structure. This paper extends the Finite Cell Weight Variation (FCWV) method — previously developed for static problems — to time-dependent nonlinear dynamics and evaluates its performance on seven test cases. Cases 1–6 use a demanding one-dimensional nonlinear benchmark; Case 1 applies the analytical conservation/transformation formulas from our prior static work, now extended here to the dynamic setting, while Cases 2–6 implement the FCWV numerical update rules. Case 7 applies FCWV to a fully multidimensional 3D double-pendulum model with four independent uncertain inputs. We introduce a practical "fit-to-normals" representation that makes FCWV broadly applicable to non-Gaussian inputs and typically reduces the number of cells required for a target accuracy. Across our examples, FCWV reproduces complex, arbitrarily shaped output PDFs (including multimodality and sharp local features) and closely matches corresponding MCS references — in the 1D benchmark cases FCWV reduced elapsed computation by roughly 90%, while in the multidimensional double-pendulum test FCWV reduced elapsed computation by over 98%. We discuss practical limits (dimensional scaling and sensitivity to repeatedly stretched, low-probability regions) and outline remedies (adaptive cell refinement, dimension-mitigation/surrogates, and a novel sampling algorithm under development). FCWV complements existing UQ tools by providing a probability-conserving route to high-resolution output distributions for complex nonlinear systems.

Student: Yongping Shi (LUT)
Supervisor: Huapeng Wu (LUT)
Instructor: Huapeng Wu (LUT)
Topic: *Adaptive dynamic compensation motion control for Fusion reactor*

Report: This study intends to build a laboratory moving base manipulator platform. According to the design of the cladding structure, the equivalent moving base manipulator is designed. The Stewart moving platform is used to control the base of the manipulator. The ground verification system is built to simulate the fusion robot system, and the ground test of reaction optimization is completed. The correctness of the simulation experiment is verified by comparing the simulation results with the simulation results, and the effectiveness of the optimization method is verified by comparing the optimization parameters with the ground test results.

Student: Ting Wang (LUT)
Supervisor: Huapeng Wu (LUT)
Instructor: Huapeng Wu, Li Changyang (LUT)
Topic: *Multi-objective Optimisation Framework for Breeding Blanket Design with Remote Maintenance Consideration*

Report: To ensure continued and stable operation of the nuclear fusion device, the blanket must be periodically replaced due to material consumption. The presence of highly radioactive and extreme temperature environment makes remote operation the only feasible method for blanket maintenance. However, the heavy self-weight of current blanket designs poses significant challenges for remote maintenance. Therefore, a structural redesign of the blanket is essential to improve the feasibility and efficiency of remote operations. Meanwhile, the tritium breeding capability and heat transfer performance of the blanket are critical physical indicators that directly affect the energy output of the fusion device and must be considered during the redesign phase. In this work, we propose a multi-objective optimisation framework that balances both the physics availability of the blanket and the engineering feasibility of the blanket maintenance. A parametric modelling approach for blanket geometry is proposed to enable flexible adaptation of the blanket shape under different design requirements. To demonstrate the framework, a case study on the remote maintenance optimisation is conducted, achieving up to 35% reduction in lifting torque through blanket geometric optimisation, thereby providing robust support for remote maintenance and offering useful insights for an overall systematic analysis of the blanket design.

Student: Zhiyong Wang (LUT)
Supervisor: Huapeng Wu (LUT)
Instructor: Huapeng Wu (LUT)
Topic: *Microstructural evolution and mechanical behaviour of oxide dispersion strengthened steel formed by laser selective melting*

Report: In this study, RAFM steel is investigated and a new fabrication method is proposed. RAFM steel powder doped with 0.5wt. % Y_2O_3 particles (ODS-RAFM steel) were manufactured by selective laser melting (SLM). The samples were normalized and tempered. An analysis was conducted to examine the impact of Y_2O_3 particles on the microstructure and properties of the RAFM steel. X-ray diffraction analysis of the phase composition of ODS-RAFM steel (primarily Fe-Cr) showed that grains in the (110) orientation increased significantly after heat treatment. Examination of the microstructure of the ODS-RAFM steel showed a small number of microcracks along the grain boundaries, which was mainly related to the high melting point oxides. The interface between Y_2O_3 and the matrix was prone to stress concentration during the forming process, and the direction of crack expansion was perpendicular to the lath boundaries. TEM micromorphology revealed that MX carbonitride and Y-Ta-O oxides were dispersed throughout the matrix. Few M23C6 particles demonstrated the carbon atoms bonded more strongly with Ta and V atoms. Precipitations could pin the dislocation effectively and play a key role in improving the strength of ODS-RAFM steel. The improvement in mechanical properties reflects the change in microstructure, where the grain boundary strengthening and Orowan strengthening plays a key role. This paper finds that the performance of RAFM steel can be improved by the addition of Y_2O_3 nanoparticles using additive manufacturing, which provides a theoretical basis for further development of structural materials for future nuclear fusion devices.

Student: Qiwei Xue (LUT)
Supervisor: Huapeng Wu (LUT)
Instructor: Huapeng Wu (LUT)
Topic: *Transformer-Based Contrastive Learning for Remote Photoplethysmography Signal Recovery Amid Landmark Loss*

Report: Remote photoplethysmography (rPPG) is emerging as a cost-effective solution for real-time, non-contact monitoring of human physiological states in industry, playing a crucial role in reducing risks associated with accidents and health complications. However, rPPG performance is often impacted by complex backgrounds and head movements, which cause facial landmarks to be partially or completely occluded, leading to failures in signal extraction and reduced monitoring accuracy. To address these challenges, we propose a landmark detection hybrid network (LD-HNet), a transformer-based multi-scale fusion network to mitigate the impact of challenges. The key innovation lies in the integration of multi-scale feature fusion with attention-based spatial correlation analysis. By leveraging multiple layers of feature extraction through ResNet, the network captures both global and fine-grained facial details. Depthwise separable convolutions further enhance efficiency by compressing features, ensuring that the model remains lightweight and suitable for real-time applications. The transformer based architecture employs attention mechanisms to analyze spatial correlations between landmarks, dynamically prioritizing informative features. The attention mechanism dynamically redistributes focus across the face, compensating for missing regions by enhancing the contribution of visible, stable landmarks, thereby preserving the integrity of the extracted rPPG signals while continuously adjusting the regions of interest to adapt to varying head poses. Additionally, we introduce the Heavy Machinery Simulation Dataset, which includes video and rPPG data from heavy machinery operators. This dataset emphasizes the difficulty of detecting facial landmarks affected by head movements, presenting a real-world challenge. Comprehensive experiments indicate that LD-HNet surpasses the current method, exhibiting strong performance across various datasets and proving adaptability in diverse conditions.

Tampere University

Student: Tuukka Mattila (TUNI)
Supervisor: Jouni Mattila (TUNI)
Instructor: Jouni Mattila (TUNI)
Topic: *Immersive multimodal teleoperation for ITER RH manipulators*

Report: This project aims to create an immersive teleoperation system for heavy-duty ITER manipulators that improves operator comfort, precision, and awareness in remote work environments. The approach combines realistic dynamic simulation with a VR interface integrating a Varjo XR-3 headset, stereo cameras, and haptic (force feedback) feedback for intuitive control. Additional eye-tracking and AR overlays will enhance perception and responsiveness. The system will be used to study how immersive multimodal feedback increases the operator's sense of embodiment and control efficiency when interacting with heavy-duty manipulators. The outcomes are expected to inform future human–machine interface design and training solutions for ITER teleoperation.

Student: Mehdi Heydari Shahna (TUNI)
Supervisor: Jouni Mattila (TUNI)
Instructor: Jouni Mattila (TUNI)
Topic: *Safety-guaranteed fault-tolerant control for ITER Remote Handling (RH) manipulators*

Report: ITER Remote Handling (RH) manipulator operations in vacuum vessel are susceptible to modeling uncertainties, and external disturbances because of high-nonlinearity dynamics and arduous tasks under heavy loads. To enhance the control performance during these challenges in both model-based and model-free system framework, this study focuses on designing a robust fault tolerant control strategy, ensuring user-defined safety by constraining the system signals within a safely predefined values. In addition, the control design ensures the stability, and robustness of the system under heavy loads, while optimal control gains can be auto-tuned to minimize control performance errors.

Student: Tomi Äijälä (TUNI)
Supervisor: Jouni Mattila (TUNI)
Instructor: Jouni Mattila (TUNI)
Topic: *Generic data driven methods for high precision reversable modeling for ITER RH manipulators*

Report: In ITER Remote Handling (RH) manipulator operations in vacuum vessel are subject to heavy loads and due to the limited space, they require high-precision absolute accuracy in their motion control. For operations safety, all individual RH manipulators need to be calibrated for absolute accuracy which comprises compensation of mechanical properties as well as deflections due to the load. This process is so-called kinematic calibration of forward kinematic (FK) model that describes robot's 6 DOF tool center point as a function of joint angles. However, for the robot's closed loop control purposes, inverse kinematic (IK) model is also needed, thus FK model developed has to be invertible, continuous function. This process is non-trivial with data-driven methods requiring reversable models. The objective of this study is to develop generic data driven methods for obtaining both FK and IK models for heavy-duty RH manipulators subject to structural deflections.

7.2 WP TRA: EUROfusion Researcher and Engineering Grants

7.2.1 Evaluating the Mechanical Properties of Neutron-Irradiated CuCrZr Using Small Punch Testing

Research scientist: Cholidah Akbar Fitriani, VTT

Small Punch Tensile Testing (SPT) has gained considerable interest in nuclear materials research, offering the capability to characterize materials with limited sample volumes. Utilizing specimens that are less than 1% the volume of those specified in standard tensile testing (ASTM E8M), SPT provides an efficient and valuable method for preliminary screening and evaluating the properties of irradiated materials. These aspects are important when material availability is restricted, as frequently encountered in fusion materials research. The use of small specimens further allows for the reutilization of samples previously subjected to other mechanical assessments, such as fracture toughness tests. Within the EUROfusion framework, VTT has conducted fracture toughness testing on CuCrZr alloys under both unirradiated and irradiated conditions. Building on previous work and acknowledging the benefits of SPT, a project was established under the EUROfusion Researcher Grant. The research is structured around three main areas. Firstly, it investigates the deformation behavior of unirradiated CuCrZr under small punch loading conditions, utilizing the coupled digital image correlation (DIC)-SPT facility at the University of Bristol. Secondly, the project aims to develop an SPT testing rig for the characterization of irradiated materials. Finally, with substantial experimental data anticipated, inverse finite element analysis will be employed to determine the true stress–true strain relationship of CuCrZr in both unirradiated and irradiated states. This study is expected to enhance understanding of the method's reliability and provide crucial engineering data for the design of DEMO and future commercial reactors.

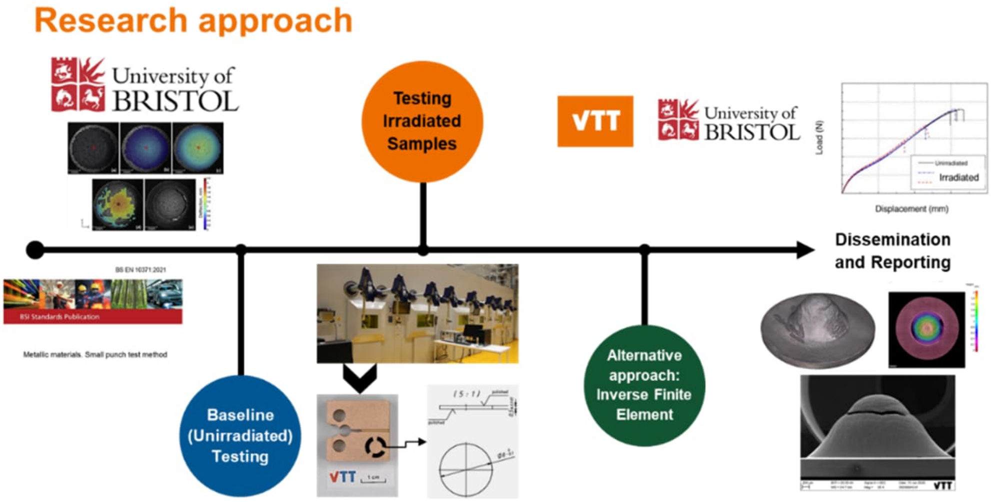

Figure 7.1: Schematic representation of the research approach of the ERG project which will use small punch tensile tests and inverse finite element analysis to evaluate the effects of irradiation on the mechanical properties of CuCrZr. The project will involve international collaboration with the University of Bristol.

8 International collaborations

8.1 DIII-D tokamak

8.1.1 Comparisons of electron temperature, density, and pressure profiles in DIII-D Discharges with EDGE2D-EIRENE predictions

Research scientists: M. Groth, AU

Standalone EIRENE simulations constrained with 2D Divertor Thomson Scattering electron temperature and density, and target Langmuir probe ion saturation current measurements are consistent with the measured low principal quantum number Lyman and Balmer hydrogenic neutral, and Fulcher hydrogenic molecular band emissions in detached plasma conditions in DIII-D ohmically heated plasmas. Such agreement implies that the EIRENE physics models and tabulated reaction rates are sufficiently accurate to predict the neutral densities and hydrogenic emissions in steady state, low power conditions.

8.2 CFETR + EAST

Research scientists: H. Wu, LUT
K. Salminen, W. Brace, VTT

The Finnish research group (FRG), which includes VTT, LUT, and industry partners, is internationally recognized as a leading researcher in developing RH systems for divertors in fusion power plants, with a divertor test facility at VTT's laboratory. The Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP), has developed numerous RH systems for ITER and CFETR. In 2025, they invited VTT and LUT to discuss collaboration and include them in the RH system design for their new test facility, the Burning Plasma Experimental Superconducting Tokamak (BEST). The visit focused on exploring opportunities, establishing contacts, and understanding potential areas for collaboration, especially divertor RM. It provided a valuable opportunity to observe all key maintenance systems within a single institute and to understand how these tools work as an integrated system. A workshop was organized to facilitate a collaborative brainstorming session on ideas, from theory to practical application. Topics covered included kinematics, dynamics, conceptual design, machine vision, and AI algorithms developed by the ASIPP team. The visit was crucial for securing commercial contracts and beneficial for FRG to generate new ideas for developing innovative concepts for fusion power plant maintenance, as well as for expanding VTT's RM fusion portfolio.

LUT has participated in the development of welding/cutting machine CFETR VV assembly and the developments of mobile robot and control algorithm for blanket RM maintenance. The works were done by two doctoral degree researchers.

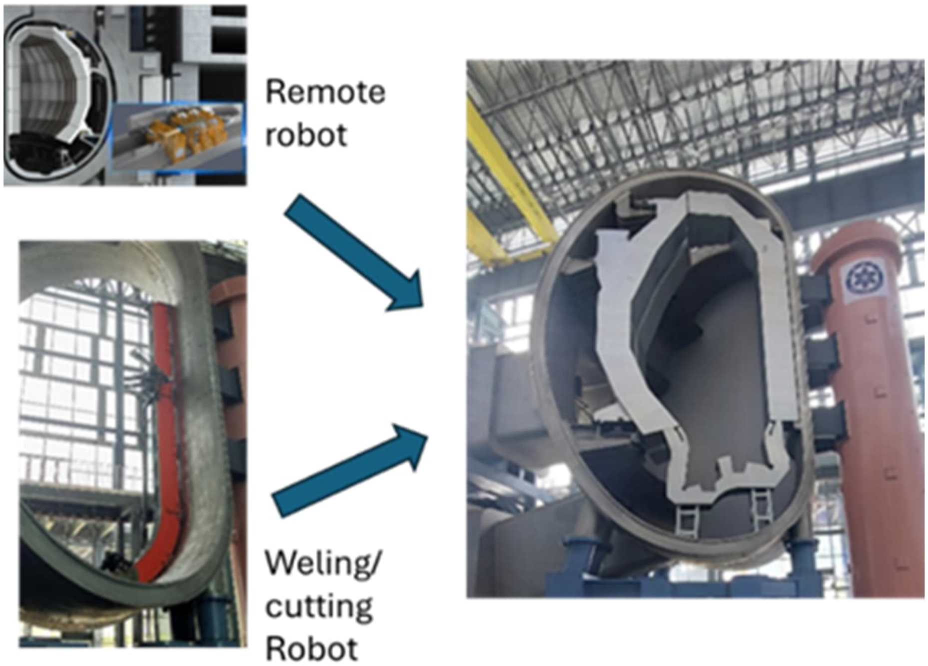

Figure 8.1: Welding/cutting machine and mobile robot and control algorithm for CFETR maintenance.

8.3 KSTAR

Research scientists: T. Tala, A. Kirjasuo, VTT

The purpose of the KSTAR experiment was to have additional and repeat pulses for the original experiment in 2022 to investigate the scaling of the intrinsic torque with the normalized gyro-radius in KSTAR to extrapolate to ITER baseline scenario at ρ*~0.001 as a part of the ITPA TC-9 joint activities between JET, AUG, DIII-D and KSTAR. After having performed the experiment, we have a 4-point ρ* scan by keeping other dimensionless plasma parameters (q, $\nu*$ and β) as constant as possible.

We achieved a factor of around 1.7 variation in ρ*, resulting a good 4-point ρ* scan of a factor 1.7. The variation in (q, $\nu*$ and β) are small as it should in the dimensionless scaling experiment. Therefore, any observed changes in momentum transport in intrinsic torque can be assigned dominantly be due to the changes in ρ*. Work is on progress to quantify whether the quality of the toroidal rotation data from the various CER systems will be good enough to extract momentum transport coefficients and intrinsic torque profiles at small enough error bars.

9 Fusion for Energy activities

9.1 Development and Validation of Water Hydraulics and Control System for the Divertor Assembly Transporter

F4E grant: F4E-GRT-1781

Research scientists: L. Gonçalves Ribeiro, J. Alanen, J. Lyytinen, H. Saarinen, P. Tikka, VTT

Subcontractors: O. Suominen (Operview), J. Syrjämäki (Coresbond), P. Ojala (Coresbond), M. Paloniitty (Coresbond)

The new F4E GRT 1781 grant was prepared in early 2025 and entered full execution in May 2025. It builds on earlier developments at the Divertor Test Platform 2 (DTP2) in Tampere, which continues to serve as the main integration and testing environment for ITER's Divertor Remote Handling strategies.

As F4E now prioritizes validating a simplified Divertor Assembly Transporter (DAT) to support the first assembly of the ITER divertor, this grant focuses on maturing, integrating, and testing the key subsystems required for DAT operation. The scope includes:

- Updating the Cassette Multifunctional Mover (CMM) prototype at DTP2 and performing functional tests.
- Finalizing the design, manufacturing and testing of a Cassette Toroidal Mover (CTM) hydraulic power unit prototype.
- Updating and validating the low level water hydraulic control functions and DigiValve software.
- Integrating and testing at DTP2 the new versions of the High Level Control System (HLCS) subsystems delivered by GTD - the Operations Management System (OMS), the Command-and-Control system (C&C), and the General Robotics Framework (GENROBOT).
- Updating the HLCS integration specification, HLC (including EDD), to ensure consistent interfaces across C&C, GR, RDA, and VR.

- Advancing the Remote Diagnostics Application (RDA) for compatibility with the revised HLCS interfaces and implementing new diagnostic and visualization workbenches.
- Improving robustness and maturity of machine vision systems and integrating at DTP2 the Remote Handling Viewing System (RHVS) delivered by Operview.
- Developing kinematic and non kinematic calibration tools for hydraulic, low DOF, heavy load remote handling movers and validating them under representative DTP2 operating conditions.
- Improving the fidelity of the DTP2 Virtual Reality (VR) environment model and integrating the updated model into the F4E selected VR platform VR4Robots.

VTT carries out this work with the support of its subcontractors Coresbond and Operview:

Coresbond supplies the Hydraulic Power Units (HPUs) for CMM and CTM and contributes to the continued evolution of the DigiValve technology.

Operview deploys and integrates at DTP2 its Remote Handling Viewing System (RHVS), already selected for ITER, which provides video streams of the remote environment.

In the first year (2025), efforts have primarily focused on finalizing the design of the CTM HPU and on the development of calibration tools for hydraulic remote handling movers.

Figure 9.1: Divertor test platform 2 (DTP2)

10 Complementary research in FinnFusion

10.1 STEP collaboration

10.1.1 Activation of cross-field drifts in SOLPS-ITER simulations of STEP with fully tracked Ar impurities

Research Scientists: J. Karhunen, A. Järvinen VTT

The impact of activating cross-field drift terms in SOLPS-ITER simulations of STEP with fully tracked Ar impurities in connected double-null configuration has been studied by comparing simulations with identically set input power, D_2 fuelling and Ar seeding rates with the drift terms on and off. This strongly improves the representation of the Ar impurities in the simulations with respect to the previously documented first drift simulations of STEP in which the presence of a fixed concentration of Ar was mimicked via modified reaction rates of the D^+ ions.

The activation of drifts was found to result in strong accumulation of Ar in the inner lower divertor which became pronouncedly detached with the ionization front of Ar shifting upstream close to the X-point. This allowed increased leakage of neutral Ar into the outer lower divertor and, subsequently, Ar ions into the LFS SOL. Due to diffusion inwards, up to 50% increase in the Ar content inside the separatrix was observed, leading to increased radiative losses in the core.

The shift of the peak heat flux crossing the separatrix towards the upper X-point due to the $\nabla B \times B$ drift and drift-induced changes in the poloidal heat transport in the SOL gave rise to an up-down asymmetry in the power entering the divertor volumes with the upper divertors receiving 52% of the power. Particularly the outer upper divertor experienced doubling of the peak target heat flux with the drifts active, but detachment and tolerable heat loads were retained due to simultaneously increased Ar radiation.

10.1.2 Fast ion studies for STEP

Research Scientists: A. Snicker, K. Särkimäki, S. Saari, VTT

ASCOT has been used to model the new configuration STEP SPR-068, which has a more conservative aspect ratio than the initial configurations (see Figure 10.1). In this configuration, ASCOT has been applied to four tasks related to fusion-born alpha particles: (1) calculating losses due to TF ripple while assuming different TF outer leg radii, (2) calculating losses caused by RMP coils, (3) evaluating the torque induced by alpha particles in the plasma under different 3D magnetic field scenarios, and (4) estimating tungsten sputtering in the first wall resulting from alpha particle losses.

The TF ripple losses were found to decrease to favorable levels at an outer radius of approximately R_{outer} = 10.5m, with the exact value depending on the assumed number of TF coils. ASCOT simulations reproduced the trends observed in LOCUST simulations regarding the dependence of alpha particle losses on the RMP coil row phase differences. However, the absolute loss levels predicted by ASCOT were significantly higher than those obtained with LOCUST, an issue that requires further investigation.

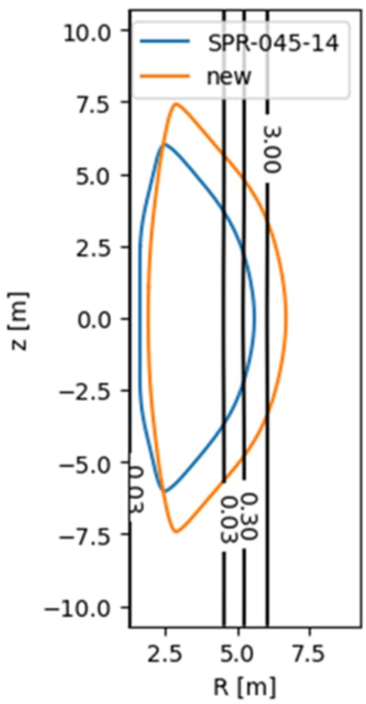

Figure 10.1:Comparison of earlier STEP configuration (SPR-045) and the newest (SPR-068) plasma equilibrium. As is easily seen, the new configuration has more conservative aspect ratio.

In the presence of alpha particle losses, a $j \times B$ torque was found to be induced in the plasma. Future work will investigate the feasibility of utilizing this torque to drive plasma rotation. The tungsten sputtering caused by alpha particles has already been used in a follow-up study to investigate tungsten transport and its impact on core plasma performance.

10.2 Alpha-particle confinement in Infinity Two Fusion Pilot Plant baseline plasma design

Research Scientists: A. Snicker, K. Särkimäki, J. Sissonen, VTT

ASCOT5 played a central role in the comprehensive assessment of fusion-born alpha-particle confinement, wall loads, and Alfvén eigenmode (AE) stability for the Infinity Two Fusion Pilot Plant baseline plasma design. Infinity Two is a four-field-period, quasi-isodynamic stellarator optimised for reactor-scale deuterium–tritium operation, where robust energetic-particle confinement is a critical design requirement.

Within this study, ASCOT5 was used for detailed Monte Carlo simulations of both guiding-centre and full-orbit alpha-particle dynamics, including realistic Coulomb collisions with background electrons and ions. Fusion-born alpha particles were initialised using the AFSI module in ASCOT5, which generates self-consistent spatial and velocity distributions based on DT fusion reactivity and plasma profiles. The simulations incorporated three-dimensional magnetic fields including finite-β effects and regions beyond the last closed flux surface, enabling predictive modelling of both core confinement and wall interactions.

ASCOT5 simulations demonstrated excellent core confinement, with less than 8% alpha-particle losses and below 4% energy losses from the core plasma. Losses were shown to be dominated by deeply trapped particles, consistent with quasi-isodynamic confinement theory. Full-orbit ASCOT5 simulations confirmed that finite Larmor radius effects do not significantly degrade confinement in the baseline configuration.

Crucially, ASCOT5 was also used to compute spatially resolved power wall loads using detailed 3D wall geometries (see Figure 1). These simulations showed peak alpha-particle power loads of approximately 2–2.5 MW m^{-2}, localised near magnetic island x-points, values that are compatible with existing high-heat-flux plasma-facing component technologies. Furthermore, slowing-down distributions from ASCOT5 provided key input for Alfvén eigenmode stability analyses, supporting the conclusion that Infinity Two is stable against alpha-driven AEs at its nominal operating point.

Overall, ASCOT5 provided the quantitative foundation for evaluating energetic-particle confinement, wall loading, and stability in a reactor-scale stellarator design, demonstrating the key impact of Finnish fast-particle modelling expertise in fusion pilot plant development.

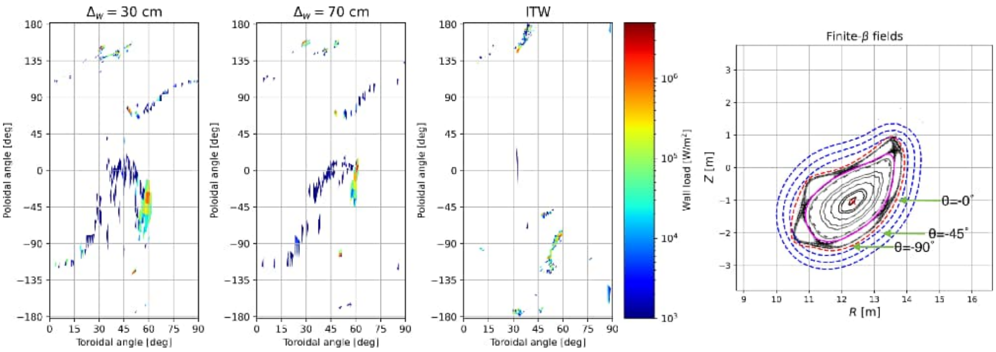

Figure 10.2: Power wall loads on the θ ϕ -plane for flat SOL profiles for wall with (*a*) Δw =30 , (*b*) Δw =70 and (*c*) for the ITW. Only the first field period ($0\circ \leq \phi \leq 90\circ$) is shown given the four-field-period periodicity of wall loads in ASCOT5 simulations. (*d*) Poincaré sections of Infinity Two at ϕ =60∘ show the approximate poloidal locations, θ , where peak wall loads occur. Carbajal L, Varela J, Bader A, et al. Alpha-particle confinement in Infinity Two Fusion Pilot Plant baseline plasma design. *Journal of Plasma Physics*. 2025;91(4):E94.

10.3 Novatron

Research Scientists: P. Keto, T. Schatz, M. Airila, M. Airola, N. Gotcheva, M. Ilvonen, J. Järvenpää, L. Warsta, K. Van Zweel, T. Tala, P. Kotiluoto, VTT

Over the past five years, international competition in fusion energy has intensified, with numerous fusion technologies emerging worldwide. Besides the mainstream magnetic confinement concepts (tokamaks and stellarators), and alternative mirror concept is being developed by the Novatron Fusion Group (NFG), recognized as a pioneer in Nordic fusion energy. NFG aims to demonstrate its distinctive fusion technology through the construction of an industrial-scale pilot plant, N3, in one of the Nordic countries – Sweden, Finland, Denmark, or Norway.

The selection of a site for N3 depends not only on technical criteria but also heavily on the status of national approach on fusion strategy, regulatory environment, and societal factors. Drawing from international experiences, it is evident that robust government support and a skilled workforce are critical for the successful establishment of a fusion pilot plant.

In 2025, commissioned by NFG, VTT formulated initial screening criteria based on regulatory frameworks, international best practices, technical needs, external hazards, environmental impact, societal considerations, and stakeholder feedback. These criteria, which included both exclusionary and discretionary elements, were applied across the Nordic region using geospatial analysis as the first step. This process led to the identification of primary focus areas, which were then examined in greater detail to pinpoint potential sites.

Based on the results, the siting process can be further advanced within these primary areas through site-specific studies to ensure alignment with the preliminary criteria. The results also highlight the need for ongoing dialogue with local

stakeholders and regulators to clarify how current regulations should be applied to fusion projects in each country. Ultimately, maintaining a transparent siting process is essential for sustaining public trust, as it openly addresses both the benefits and risks associated with deploying fusion technology.
The next steps are to further develop the Nordic ecosystem for fusion and to conduct additional studies to identify the most suitable site options for N3.

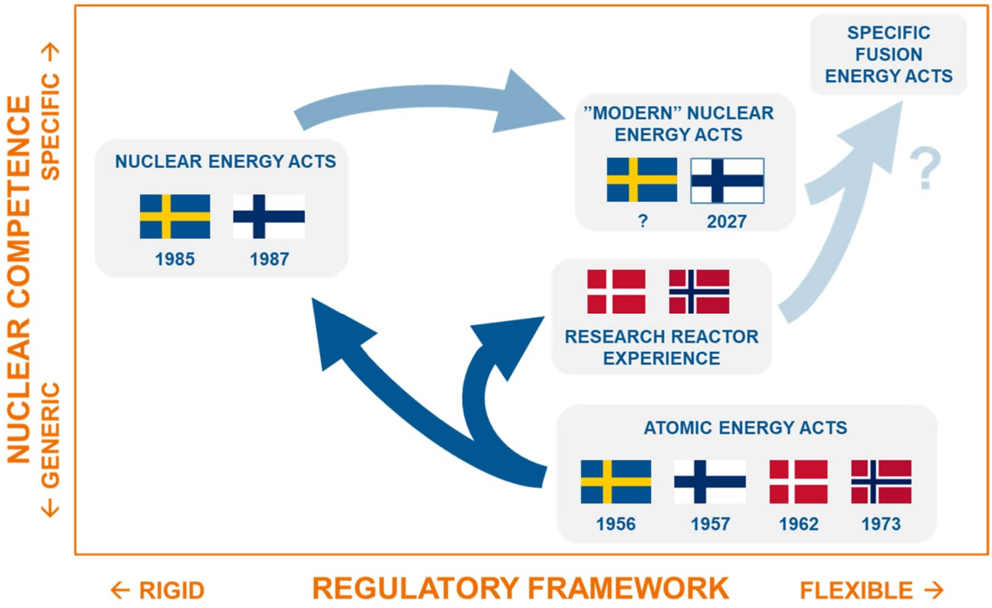

Figure 10.3: Simplified illustration of the history, present status, and potential future development of regulatory frameworks to be applied to fusion in the Nordic countries. All countries initiated their nuclear energy programs in the 1950's, starting with research reactors and national Atomic Energy Acts. Obviously, the legislation and other regulation at that time was less specific ("flexible" on the horizontal scale). In the 1970's, commercial nuclear power production started in Finland and Sweden. While this meant significant development of specific nuclear competences, simultaneously the regulation has been constantly tightening (the countries moved to "rigid" on the horizontal scale and to "specific" on the vertical scale). Meanwhile, Denmark and Norway continued accumulating experience on research reactors, with less need to detailed regulation. Most recently, Finland has initiated the renewal of the Nuclear Energy Act, enabling the more flexible Radiation Act to be applied to experimental use of fusion reactors. The same idea has been discussed in Sweden, with no timeline for the renewal yet. Ultimately, the target state could be a national Fusion Energy Act, proportionally adjusted to the regulation needs of fusion. If Denmark or Norway would set the same goal, they would be approaching the target state from another angle, without similar burden of rigid nuclear regulation but also with less accumulated nuclear competency that can also be applied in the field of fusion.

10.4 Code development in FinnFusion

10.4.1 ASCOT5 – a state-of-the-art simulation environment for fast ions and beyond

Research Scientists: K. Särkimäki, A. Snicker, J. Sissonen, VTT, S. Äkäslompolo, T. Kurki-Suonio, P. Ollus, S. Sipilä, G. Fourestey, AU

New features that entered the production were the generation of IC heated ions, energy losses due to radiation reaction force, and accounting for the plasma rotation in collisions. The stellarator capabilities were expanded, and post-processing tools were improved e.g. to provide fast-ion torques as an output. Additional physics were ported to GPUs while the porting of the guiding-center mode is still ongoing. The IMAS actor is still in development, but the interface to the IDS was expanded further and now includes the simulation output.

The user-base continues expanding and the code has seen new users, especially in the stellarator community. The code remains open source.

In addition to ASCOT5, ASCOT4-RFOF code development, management, and support continued in 2025 under IMAS.

10.4.2 Molecular Dynamics

Research Scientists: J. Byggmästar, F. Granberg, A. Kuronen, K. Nordlund, V-M. Yli-Suutala, UH, J. Åström, CSC, J. Westerholm, ÅA

General effort on the speeding up of especially the tabGAP implementation in LAMMPS has been ongoing. The GPU enabling of the algorithm and other essential parts, like electronic stopping, have enabled massive simulations of billions of atoms in a reasonable human time. In addition to the general speed-up, there has been a massive development of different ML interatomic potentials for complex materials in 2025. The knowledge obtained will help further development of new interatomic potentials.

11 Other activities

11.1 Missions and secondments

Antti Hakola to WEST facilities, CEA, Cadarache, France, 24 February – 1 March 2025 (WPTE).

Antti Hakola to W7-X facilities, Greifswald, Germany, 3 – 7 March 2025 (WPW7X).

Tuomas Tala and Antti Salmi to MAST-U facilities, Culham, UK, 10 – 21 March 2025 (WPTE).

Karoliina Salminen to SDU, Blanket handling test facility design review, Odense, Denmark, 16 – 18 March 2025 (WPRM).

Karoliina Salminen to IPP Garching, Divertor handling workshop, Garching, Germany, 25 – 27 March 2025 (WPRM).

Aaro Järvinen to UKAEA, WPPrIO mission for the pedestal MHD surrogate model project, Abingdon, UK, 17 – 20 March 2025 (WPTE).

Antti Hakola to AUG facilities, Garching, Germany, 19 – 20 March 2025 (WPTE).

Aaro Järvinen to Kungliga Tekniska Högskolan, mission for the pedestal MHD surrogate model project, Stockholm, Sweden, 24 – 28 March 2025 (WPPrIO).

Antti Hakola to JET facilities, Culham, United Kingdom, 27 – 30 April 2025 (WPTE).

Aaro Järvinen to UKAEA, RT01 JET analysis meeting, Abingon, UK, 12 – 16 May 2025 (WPTE).

Karoliina Salminen to SDU, Blanket handling test facility design review, Odense, Denmark, 2 – 3 June 2025 (WPRM).

Antti Hakola to AUG facilities, Garching, Germany, 30 June – 3 July 2025 (WPTE).

Antti Hakola and Juuso Karhunen to ASDEX Upgrade facilities, IPP Garching, Germany, 14 – 18 July 2025 (WPTE).

Tuomas Tala and Antti Salmi to WEST facilities, Cadarache, France, 6 – 11 April 2025 (WPTE).

Tuomas Tala to JET facilities, Culham, UK, 8 – 16 May 2025 (WPTE).

Antti Salmi to JET facilities, Culham, UK, 12 – 16 May 2025 (WPTE).

Tuomas Tala to ASDEX Upgrade facilities, IPP Garching, Germany, 21 – 25 July 2025 (WPTE).

Jari Likonen to JET facilities, Culham, UK, 22 – 26 September 2025 (WPPWIE).

Mathias Groth to DIII-D, General Atomics, San Diego, USA, 22 September – 15 October 2025 (WPTE, International Missions).

Van-Dung Truong and William Brace to UKAEA, EK and VTT Meeting, Abingdon, Oxfordshire, United Kingdom, 29 September – 2 October 2025 (WPRM).

Karoliina Salminen to SDU, Blanket handling test facility design review, Odense, Denmark, 7 – 9 October 2025 (WPRM).

Aaro Järvinen to IPP Garching, E-TASC Scientific Board Meeting 23-24 October 2025.

Mathias Groth to DIII-D, General Atomics, San Diego, USA, 16 November – 10 December 2025 (WPTE, International Missions).

Aaro Järvinen to QST Naka, JT60-SA Experiment team meeting, Naka, Japan, 8-15 November 2025.

Antti Hakola and Jari Likonen to Forschungszentrum Jülich, Germany, 17 – 21 November 2025 (WPPWIE).

Vesa-Pekka Rikala to Forschungszentrum Jülich, Germany, 3 – 6 November 2025.

W. Brace, C. Li and H. Wu to Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP) CFETR, Hefei, China, 23 November – 1 December 2025 (WPRM).

Tuomas Tala to JET and MAST-U facilities, Culham, UK, 19 November – 5 December 2025 (WPTE).

Anna Niemelä to MAST-U facilities, Culham, UK, 1 – 5 December 2025 (WPTE).

Antti Salmi to JET facilities, Culham, UK, 1 – 5 December 2025 (WPTE).

11.2 Conferences, seminars, workshops, and meetings

Fredric Granberg participated in the Topical Workshop on radiation effects in superconducting magnets (RADSUM), CERN, Switzerland, 15 – 17 January 2025.

Markus Airila, Antti Hakola and Karoliina Salminen participated in the 32nd European Fusion Programme Workshop, Granada, Spain, 28 – 30 January 2025 (WPSAE).

Jari Likonen participated in the 1st JET LIBS data analysis meeting, FZJ, Julich, Germany, 6 February 2025 (WPPWIE).

Markus Airila participated in the binding.energy Conference, online, 19 – 20 February 2025.

Faith Kporha participated in the JT60_SA School, Culham, UK, 13 – 15 March 2025.

Otso Hyvärinen and Joona Sissonen participated in the 18th Technical Meeting on Energetic Particles in Magnetic Confinement Systems, Seville, Spain, 17 – 21 March 2025.

Mathias Groth and Jari Likonen participated in the EUROfusion PWIE reporting meeting, Prague, Czech Republic, 24 – 27 March 2025.

Amanda Bruncrona participated in a workshop at KTH, Stockholm, Sweden, 24 – 28 March 2025.

Alexandre Bergero, Fredric Granberg and Jintong Wu participated in the Physics Days, Oulu, Finland, 26 - 28 March 2025.

Joona Sissonen participated in 33rd ITPA EP Meeting, Sevilla, Spain, 24 – 26 March 2025.

Iuliia Zhelezova participated in the MRS Spring Meeting & Exhibit, April 7-11, 2025, Seattle, Washington, USA..

Markus Airila, Matti Paljakka and Tapani Ryynänen participated in the ITER Business Forum, Marseille, France, 23 – 25 April 2025.

Evgeniia Ponomareva and Sreya Viswanathan participated in Ion-electron effects in large scale atomistic modelling (ELLAM), Aalto University, Espoo, Finland, 23 – 25 April 2025.

Nima Fakhrayi Mofrad participated in the JET A&M Meeting (Culham, UK), April 2025.

Tuomas Tala participated in the 50th EUROfusion General Assembly Meeting, Brussels, Belgium, 23-24 April 2025

Tuomas Tala participated in the ITPA meeting of TG transport and confinement, Cambridge, USA, 28 April – 1 May 2025.

Amanda Bruncrona and Anna Niemelä participated in WPTE RT01 JET Analysis and Modelling meeting, Abingdon, United Kingdom, 12 – 16 May 2025.

Fredric Granberg, Antti Hakola, Faith Kporha, Jari Likonen, Samuli Saari and Jintong Wu participated in the 20th International Conference on Plasma-Facing Materials and Components for Fusion Applications (PFMC), Ljubljana, Slovenia, 19 – 23 May 2025.

Nikola Petkov participated in 2025 IEEE International Conference on Robotics & Automation (ICRA), Atlanta, USA, 19 – 23 May 2025.

Fredric Granberg participated in the Models and Data for Plasma-Material Interactions in Fusion Devices (MOD-PMI), Vienna, Austria, 26 – 28 May 2025.

Aaro Järvinen participated in F4E AI Technology Mapping Workshop, Barcelona, Spain, 26 – 28 May 2025.

Evgeniia Ponomareva participated in E-MRS Spring Meeting, Strasbourg, France, 26 – 30 May 2025.

Karoliina Salminen participated EFPW workshop, Granada, Spain, 27 – 31 May 2025.

Aaro Järvinen participated in the Joint Runaway Electron Modelling and WPTE RT03 Analysis Meeting, Lausanne, Switzerland, 2 – 6 June 2025.

Antti Hakola participated in the 36th ITPA meeting of TG SOL and divertor physics, Hefei, China, 3 – 6 June 2025.

Markus Airila, William Brace, Antti Hakola, Aaro Järvinen, Taina Kurki-Suonio, Jari Likonen, Tommi Lyytinen, Anna Niemelä, Tuula Ruokonen, Qais Saifi, Antti Salmi, Karoliina Salminen, Joona Sissonen, Antti Snicker, Tuomas Tala, Nima Fakhrayi Mofrad, Ting Wang, and Van Dung Truong participated in 5th Joint Nordic Fusion Energy Seminar, UiT, Tromsø, Norway, 17 – 18 June 2025.

William Brace, Van-Dung Truong, Ting Wang, Zhiyong Wang, and Huapeng Wu participated in the 2025 IEEE Symposium on Fusion Engineering, Massachusetts, United States, 23 – 26 June 2025.

Fredric Granberg participated in IREMEV monitoring meeting, CIEMAT, Granada, Spain, 25 – 26 June 2025.

Daniel Jordan participated in the 14th ITER summer school on integrated modelling Aix-Marseille University in Aix en Provence, France, June 30th – July 4th 2025.

Mathias Groth, Aaro Järvinen, Anna Niemelä, Daniel Jordan, Antti Salmi and Aaron Vesa participated in the 51st European Physical Society Plasma Physics conference, Vilnius, Lithuania, 7 – 11 July 2025.

Markus Airila participated in the F4E Strategic Governing Board Meeting and the 64th Governing Board Meeting, Barcelona, Spain, 9 – 11 July 2025.

Evgeniia Ponomareva participated in 3rd DENSE Annual Seminar, Tampere, Finland, 26 – 27 August 2025.

Tommi Lyytinen participated in the IAEA Technical Meeting on Tritium Breeding Blankets and Associated Neutronics, IAEA Headquarters, Vienna, Austria, 2-5 September, 2025.

Antti Hakola participated in the 21st International Symposium on Laser-Aided Plasma Diagnostics (LAPD-21), Les Bains de Saillon, Saillon, Switzerland, 1 – 5 September 2025

Tuomas Tala participated in the 29th EU-US Transport Task Force Workshop, Budapest, Hungary, 9-12 September 2025

Iuliia Zhelezova participated in the 33rd International Conference on Defects in Semiconductors, September 14-19, 2025, Shanghai, China.

Andrea Sand and Antti Hakola participated in the 25th International Workshop on Inelastic Ion-Surface Collisions (IISC-25), Austria, 14 – 19 September 2025.

Fredric Granberg organized the symposia “Synergies and challenges for materials in extreme environments” at the European Materials Research Society Fall meeting, Warsaw, Poland, 15 – 18 September 2025.

Aaro Järvinen participated in the 9th Asia-Pacific Conference on Plasma Physics, Fukuoka, Japan, 21 – 26 September 2025.

Iuliia Zhelezova participated in a seminar at the Institute of High Energy Physics, Beijing, China, September 23, 2025.

Ray Chandra participated in the 20th International Workshop on Plasma Edge Theory in Fusion Devices, Leuven, Belgium, 23 – 26 September 2025.

Alexandre Bergero, Nima Fakhrayi Mofrad, Fredric Granberg, Victor Lidblad, and Evgeniia Ponomareva participated in the 22nd International Conference on Fusion Reactor Materials (ICFRM25), Shizuoka, Japan, 28 September – 3 October 2025.

Ray Chandra participated in the SOLPS-ITER Code Camp 2025, Cadarache, France, 29 September – 3 October 2025 (WPTE).

Tuomas Tala and Adam Kit participated in the 36th ITPA meeting of TG transport and confinement, Sevilla, Spain, 30 September – 3 October 2025.

William Brace, Antti Hakola, Aaro Järvinen, Antti Snicker and Tuomas Tala participated in the 30th IAEA Fusion Energy Conference (FEC2025), Chengdu, China, 13 – 18 October 2025.

Fredric Granberg participated in the 3rd World Materials Conference/9th World Materials Summit, Guilin, China, 14 – 17 October 2025.

Markus Airila participated in the 2nd Nordic Fusion Forum, Espoo, Finland, 20 October 2025.

Fredric Granberg gave a seminar at Beihang University, Beijing, China, 20 October 2025.

Markus Airila, Antti Hakola, Aaro Järvinen, Taina Kurki-Suonio, Karoliina Salminen, Samuli Saari and Seppo Sipilä participated in the Finnish Nuclear Science and Technology Symposium 2025, 21 – 22 October 2025, Helsinki.

Aaro Järvinen participated in E-TASC Scientific Board Meeting, IPP Garching, Germany, 23 – 24 October 2025.

Sreya Viswanathan participated in the FuseNet PhD event 2025, ITER, France, 4-6 November 2025.

Aaro Järvinen participated in JT60-SA Experiment team meeting, Naka, Japan, 8 – 15 November 2025.

Fredric Granberg gave a seminar at FD Mikael Björnbergs minnesfonds jubileumssymposium, Helsinki, Finland, 12 November 2025.

Amanda Bruncrona participated in FCAI AI Day, Espoo, Finland, 13 November 2025.

Fredric Granberg, Antti Hakola and Jari Likonen participated in WP-PWIE monitoring meeting, Jülich, Germany, 17 – 21 November 2025.

Timo Kiviniemi participated in the TSVV-5 Code Camp 2025, Jülich, Germany, 24 – 27 November 2025 (TSVV-5).

Fredric Granberg and Andrea Sand participated in the IREMEV monitoring meeting, Garching, Germany, 1–3 December 2025.

Aaro Järvinen participated in the ITER Science Fellow Network meeting, Cadarache, France, 8 – 12 December 2025.

Jari Likonen participated in the 1st Joint LID/QMS – LIBS meeting, ENEA, Frascati, Italy, 8 – 12 December 2025.

Markus Airila and Nikhil Verma participated in the WPSAE Progress Meeting, online, 9 – 10 December 2025 (WPSAE).

Tuomas Tala participated in the 65th F4E Governing Board Meeting, Cadarache, France, 11-12 December 2025

Otso Hyvärinen participated in the Inverse Days 2025, Helsinki, Finland, 15 – 17 December 2025.

Antti Hakola and Tuomas Tala participated in the 53rd EUROfusion General Assembly meeting, Saariselkä, Ivalo, 16 – 17 December 2025.

11.3 Visitors

Clarisse Bourdelle of CEA, Cadarache, France, visited Aalto University 7 – 8 April 2025.

Design tools workshop in Tampere, 3 – 5 June 2025, including visitors from KIT-Germany, CEA-France, and ENEA-Italy.

Alessandro Biancalani of Ecole Supérieure d'Ingénieurs Léonard de Vinci in Paris, France, visited Aalto University 26 – 27 June 2025.

2nd in-person workshop on Interface TFV/RH – Divertor, 20 – 21 August 2025, including visitors from Italy, Germany, and Eurofusion PMU.

12 Publications 2025

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

12.1 Refereed journal articles

1. Q. Saifi, W. Huapeng, W. Brace, Advancing stochastic modeling for nonlinear problems: Leveraging the transformation law of probability density, Reliability Engineering and System Safety, **258**, 2025, 110895.
2. Z. Hu, J. Wu, Q. Yang, F. Jomard, F. Granberg and M.-F. Barthe, New insight into quantifying vacancy distribution in self-ion irradiated tungsten: a combined experimental and computational study, Nano Letters, **25**, 2025, 10787.
3. Q. Xue, X. Zhang, Y. Zhang, A. Hekmatmanesh, H. Wu, Y. Song and Y. Cheng, Non-contact rPPG-based human status assessment via a spatial–temporal attention feature fusion network with anti-aliasing, Computers in Industry, **165**, 2025, 104227.
4. R. Yin, H. Wu, M. Li, Y. Cheng, Y. Song, H. Pan and H. Handroos, Mastering autonomous assembly in fusion application with learning-by-doing: A peg-in-hole study, Engineering Applications of Artificial Intelligence, **160**, 2025, 111897.
5. M. Zohrevand, J. Likonen, J. W. Coenen and A. Amanov, Effect of ultrasonic nanocrystal surface modification on microstructural evolution and tribological properties of pure tungsten, Tribology International, **210**, 2025, 110792.
6. K. Verhaegh, J. Harrison, D. Moulton, B. Lipschultz, N. Lonigro, N. Osborne, P. Ryan, C. Theiler, T. Wijkamp, D. Brida, C. Cowley, G. Derks, R. Doyle, F. Federici, B. Kool, O. Février, A. Hakola, S. Henderson, H. Reimerdes, A. Thornton, N. Vianello, M. Wischmeier, L. Xiang, the EUROfusion Tokamak Exploitation Team, and the MAST Upgrade Team, Divertor shaping with neutral baffling as a solution to the tokamak power exhaust challenge, Communications Physics, **8**, 2025, 215.
7. B.O. Cattelan, V. Lindblad, F. Granberg and J.K. Nurminen, Neural network estimation of vacancy binding energy to screw dislocations: a case study for iron and tungsten, Neural Computing and Applications, **37**, 2025, 19817.
8. E. Ponomareva, E. Pitthan, V. Moro Marcos, B. Bruckner, P. Bauer, F. Munnik, R. Heller, R. Nunez Palacio, D. Primetzhofer and A.E. Sand, Role of alloying and defects in light ion energy dissipation in iron, Physical Review B, **112**, 2025, 14313.

9. L. Sanchis, T. Kurki-Suonio, K. Särkimäki, P. Ollusa, J. Kontula, S. Äkäslompolo, S. Lazerson, S. Bozhenkov, H.M. Smith and the W7-X Team, Modelling of the effect of particle species on beam losses in W7-X, Nuclear Fusion, **66**, 2026, 026046.

10. A. Chomiczewska, T. Tala, W. Gromelski, I. Ivanova-Stanik, E. Kowalska-Strzeciwilk, N. Wendler, I. S. Carvalho, P. Carvalho, I. Coffey, A. Kirjasuo, M. Lennholm, S. Menmuir, G. Pucella, A. Salmi, B. Thomas, A. Järvinen, J. Karhunen, J. Likonen, A. Hakola and A. Snicker, Impurity study in the dimensionless and dimensional isotope identity experiment between JET Deuterium and Tritium L-mode plasmas, Nuclear Fusion, **65**, 2025, 16045.

11. S.S. Henderson, R.T. Osawa, S.L. Newton, D. Moulton, L. Xiang, R. Futtersack, M. Kryjak, C. Ridgers, J. Karhunen, A. Järvinen, A. Hudoba, S. Bakes, F. Eriksson, H. Meyer, M. Lord, A. Tarazona, A. Cureton, A. Barth, B. Chuilon, T. Hebrard, S. Wang, Z. Vizvary, D. Vaccaro, F. Perez Smith, J. Farrington, J. Harrison, B. Dudson and B. Lipschultz, “An overview of the STEP divertor design and the simple models driving the plasma exhaust scenario, Nuclear Fusion, **65**, 2025, 16033.

12. C. Silva, M. Groth, S. Aleiferis, P. Carvalho, L. Gil, C. Giroud, R.B. Morales, D. Nina, E.R. Solano, B. Thomas, M. Vaz and N. Vianello, E_r measurements in JET L-mode plasmas for a wide range of densities - from the low-recycling regime up to the density limit, Nuclear Fusion, **65**, 2025, 36042.

13. O. Hyvärinen, M. Rud, H. Järleblad, A. Snicker, J. Eriksson, M. Nocente, B.C.G. Reman, A. Valentini, D. Moseev, S. Siltanen, M. Salewski and JET Contributors, Using ASCOT to encode neoclassical collisional physics as prior in fast-ion distribution reconstructions, Nuclear Fusion, **65**, 2025, 092003.

14. A. Valentini, H. Järleblad, M. Nocente, J. Eriksson, S. Fugazza, O. Hyvärinen, V. Kiptily, D. Moseev, B.C.G. Reman, M. Rud, A. Snicker, L. Stagner, M. Salewski and JET Contributors, Orbit-space sensitivity of two-step reaction gamma-ray spectroscopy, Nuclear Fusion, **65**, 2025, 112001.

15. M. Rud, Y. Dong, L.-G. Eriksson, J. Eriksson, P.C. Hansen, O. Hyvärinen, H. Järleblad, Ye.O. Kazakov, D. Moseev, M. Nocente, B.C.G. Reman, A. Snicker, A. Valentini, M. Salewski and JET Contributors, Velocity-space tomography of MeV-range fast-ion distributions in JET using wave–particle interaction priors, Nuclear Fusion, **65**, 2025, 112006.

16. A. Uccello, G. Alberti, M. Pedroni, A. Cremona, F. Ghezzi, M. Saleh, E. Vassallo, L. Bana, D. Dellasega, M. Passoni, C. Tuccari, D. Vavassori, A. Hakola, M. Rasinski, and J. Romazanov, and the GyM Team, Exploring the role of topography in the sputtering process of tungsten by GyM helium plasma, Nuclear Fusion, **65**, 2025, 056006.

17. A. Widdowson, S. Brezinsek, T. Dittmar, D. Douai, R. Felton, G. Gervasini, M. Hook, I. Jepu, R. Knipe, D. Kos, L. Laguardia, D. Matveev, M.-L. Mayoral, G. Papadopoulos, A. Peacock, R. Rayaprolu, G. Sergienko, S. Silburn, P.A. Stanieca, H. Sun, A. Tookey, R. Walker, T. Wauters, H. Weisen, A. Wilcox, R. Yi, Y. Zayachuk, M. Zlobinski, Y. Corre, A. Hakola, E. Joffrin, K. Krieger, E. Tsitrone, JET Contributors, and EUROfusion Tokamak Exploitation Team, Overview of fuel retention and recovery in JET deuterium–tritium operation, Nuclear Fusion, **65**, 2025, 116036.

18. K. Krieger, S. Brezinsek, J. W. Coenen, H. Frerichs, A. Kallenbach, A. W. Leonard, T. Loarer, S. Ratynskaia, N. Vianello, N. Asakura, M. Bernert, D. Carralero, R. Ding, D. Douai, T. Eich, Y. Gasparyan, A. Hakola, Y. Hatano, M. Jakubowski, M. Kobayashi, S. Krasheninnikov, S. Masuzaki, T. Nakano, R. Neu, R. A. Pitts, J. Rapp, K. Schmid, O.

Schmitz, D. Tskhakaya, L. Wang, T. Wauters, and S. Wiesen, Scrape-off layer and divertor physics, Chapter 5 of the special issue: on the path to tokamak burning plasma operation, Nuclear Fusion, **65**, 2025, 043001.

19. Z. Wang, Z. Liu, J. Ma, H. Wu, Y. Wu, N. Zhou, C. Li, W. Shi, T. Zhu and J. Wu, Development of mechanical properties of plasma-facing components of blanket utilizing selective laser melting techniques, Nuclear Fusion, **65**, 2025, 086034.
20. A. Fellman, J. Byggmästar, F. Granberg, K. Nordlund and F. Djurabekova, Fast and accurate machine-learned interatomic potentials for large-scale simulations of Cu, Al and Ni, Physical Review Materials, **9**, 2025, 0533807.
21. J. Wu, D.R. Mason and F. Granberg, Atomistic study of irradiation-induced plastic and lattice strain in tungsten, Computational Materials Science, **251**, 2025, 113738.
22. Y. Shi, T. Ma, H. Wang, T. Zhang, X. Zhang, H. Wu and M. Li, Model-Based Design of the 5-DoF Light Industrial Robot, Robotics, **14**, 2025, 103.
23. F. Kporha, K. Nordlund and F. Granberg, Sputtering of tungsten surfaces by different ion types: a molecular dynamics study, Journal of Nuclear Materials, **613**, 2025, 155856.
24. S.E. Donnelly, G. Greaves, F. Granberg, J. Sharp, A.H. Milston, J.A. Hinks and K. Nordlund, Self-ion-irradiation-induced grain formation in nickel, Journal of Nuclear Materials, 605, 2025, 155588.
25. N. F. Mofrad, J. Romazanov, R. Schumacher, and A. Sand, Computational analysis of plasma-wall interactions in beryllium: A detailed study of physical and chemically assisted physical sputtering, Journal of Nuclear Materials, **609**, 2025, 155758.
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12.2 Conference presentations

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2. Iuliia Zhelezova, Vacancy defects in as-grown / proton irradiated and UID / Si-doped β-Ga2O3 single crystals, GOOD Seminar Series, University of Strathclyde, Glasgow, Scotland, February 12, 2025 (online; invited speaker).

3. O. Hyvärinen, M. Rud, H. Järleblad, A. Snicker, J. Eriksson, M. Nocente, B.C.G. Reman, A. Valentini, D. Moseev, S. Siltanen, M Salewski and JET contributors, Using ASCOT to encode collisional physics into fast-ion distribution reconstructions, 18th

Technical Meeting on Energetic Particles in Magnetic Confinement Systems, Seville, Spain, 17 – 21 March 2025 (poster).

4. F. Granberg, High-dose large-scale simulations of defect evolution in fusion relevant materials, Physics Days, 26 – 28 March 2025 (oral).

5. A. Bergero, High-dose large-scale simulations of defect evolution in fusion relevant materials, Physics Days, 26 – 28 March 2025 (poster).

6. J. Wu Atomistic analysis of irradiation of tungsten with realistic dose rate: a combined OKMC-MD study, Physics Days, 26 – 28 March 2025 (poster).
7. Iuliia Zhelezova, Vacancy defects in Si-doped β-$(Al,Ga)_2O_3$, MRS Spring Meeting & Exhibit, April 7-11, 2025, Seattle, Washington, USA (oral).

8. J. Likonen, S. Almaviva, R. Rayaprolu, R. Yi, I. Jepu, G. Sergienko, A. Widdowson, N. Jones, S. Atikukke, T. Dittmar, J. Karhunen, P. Gasior, Ch. Kawan, M. Sackers, S. Soni, E. Wüst, S. Brezinsek, J. Butikova, W. Gromelski, A. Hakola, I. Jõgi, P. Paris, J. Ristkok, P. Veis, and the UKAEA RACE Team, First Demonstration of Laser Induced Breakdown Spectroscopy using Remote Handling for In-vessel Analysis of Tritiated and Activated JET Components, 20th International Conference on Plasma-Facing Materials and Components for Fusion Applications, 19 – 23 May 2025 (invited).

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10. Toni Sutinen, Helium interaction in tungsten-based alloys: the weaking effect of vanadium, May 14, 2025, Broad-based Physics, University of Helsinki, Bachelor Thesis.

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Title	**FinnFusion Yearbook 2025**
Author(s)	Tommi Lyytinen and Jari Likonen (Eds.)
Abstract	This Yearbook summarises the 2025 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; (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, Comatec Ltd., Coresbond Ltd., CSC - IT Center for Science Ltd., Fortum Power and Heat Ltd., Fulvisol Ltd., Lappeenranta-Lahti University of Technology, Luvata Ltd., Operview Ltd., Platom Ltd., Tampere University, University of Helsinki and Åbo Akademi. FinnFusion participates in several EUROfusion work packages, the largest being remote maintenance, advanced computing, materials research, plasma-facing components and experimental campaigns at ASDEX Upgrade and related analyses also at JET. F4E projects in 2025 focused on the development and validation of water hydraulics and control system for the Divertor Assembly Transporter. EUROfusion supports post-graduate training through the Education work package that allowed FinnFusion to partly fund 35 PhD students in FinnFusion member organizations. In addition, one EUROfusion Researcher and Engineering Grant was running in 2025. The 5th Nordic Biannual Fusion Seminar was held in Tromsø, Norway for the first time in June, hosted by UiT the Arctic University of Norway. Keynote speakers represented ITER, EUROfusion, DIFFER, and Commonwealth Fusion Systems. Bringing the seminar to Norway provided a timely opportunity to highlight the country's recent membership in EUROfusion through DTU as its international partner. More than 80 scientists and engineers attended to discuss Nordic collaboration across a range of fusion-related topics.
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Nimeke	**FinnFusion vuosikirja 2025**
Tekijä(t)	Tommi Lyytinen ja Jari Likonen (toim.)
Tiivistelmä	Tähän vuosikirjaan on koottu FinnFusion-konsortion vuoden 2025 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; (iii) seuraavan sukupolven eurooppalaisen DEMO-fuusiovoimalan konseptikehitys. FinnFusion-konsortion muodostavat Teknologian tutkimuskeskus VTT Oy, Aalto yliopisto, Comatec Oy, Coresbond Oy, CSC - Tieteen tietotekniikan keskus Oy, Fortum Power and Heat Oy, Fulvisol Oy, Helsingin yliopisto, Lappeenrannan-Lahden teknillinen yliopisto, Luvata Oy, Operview Oy, Platom Oy, Tampereen yliopisto ja Åbo Akademi. FinnFusion-konsortio osallistuu useisiin EUROfusion-projekteihin. Suurin työpanos kohdistuu etäkäsittelyyn, kehittyneeseen tietojenkäsittelyyn, materiaalitutkimukseen, ensiseinämäkomponentteihin ja ASDEX Upgrade -koelaitteissa tehtäviin kokeisiin ja analyyseihin myös JET- koelaitteessa. FinnFusionin F4E-työt liittyivät vesihydrauliikan kehittämiseen ja validointiin ITER:n etäkäsittelyä varten. EUROfusion tukee jatko-opiskelua omalla rahoitusinstrumentillaan, jonka turvin FinnFusion rahoitti osittain 35 jatko-opiskelijan työtä jäsenorganisaatioissaan. Lisäksi vuoden 2025 aikana oli käynnissä yksi EUROfusionin rahoittama tutkijatohtorin projekti. Tromssan yliopisto järjesti viidennen yhteispohjoismaisen fuusioalan vuosiseminaarin Tromssassa kesäkuussa 2025. Kutsuttaja esitelmöitsijöitä oli ITER:stä, EUROfusion:sta, DIFFER:stä ja Commonwealth Fusion Systems:stä. Vuosiseminaariin osallistui yli 80 tutkijaa ja insinööriä.
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FinnFusion Yearbook 2025

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