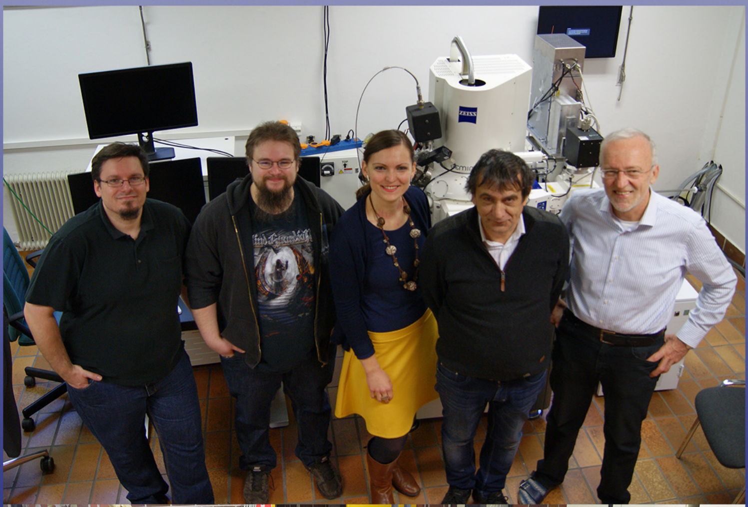
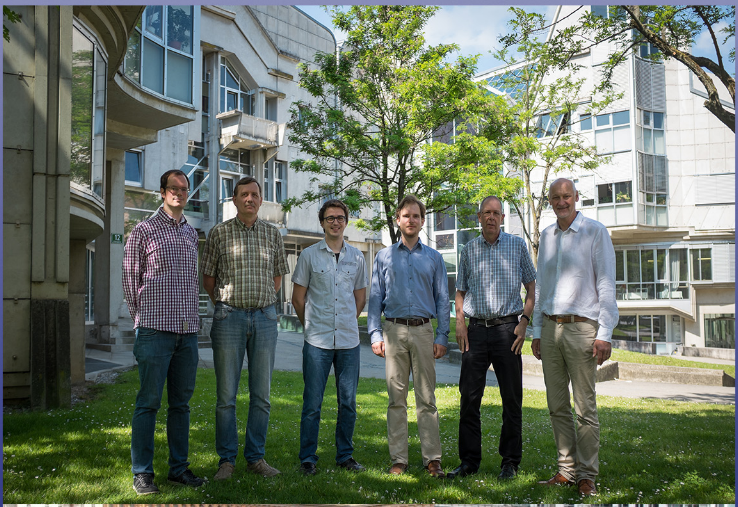
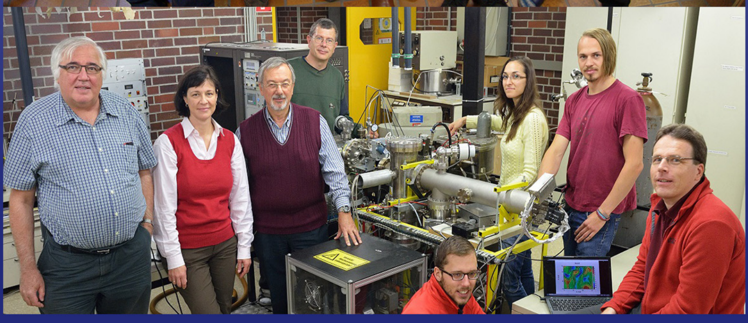
ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

Fusion Research in Austria

Activities in 2014 and 2015







Photos on cover page

Top left:	Material scientists at Erich-Schmid-Institute of Materials Science at ÖAW Group leader: R. Pippan *Courtesy ÖAW-ESI*
Top right:	Modelling experts at Technische Universität Graz Group leader: W. Kernbichler *Courtesy Institute of Theoretical and Computational Physics, TU Graz*
Bottom left:	Modelling, plasma-wall interaction and probe diagnostics at Universität Innsbruck Group leaders: A. Kendl, M. Probst, P. Scheier, K. Schöpf, R. Schrittwieser *Courtesy Institute for Ion Physics and Applied Physics, UIBK*
Bottom right:	Experts in plasma-wall interaction and plasma diagnostics at Technische Universität Wien; group leader: F. Aumayr. *Courtesy Institute of Applied Physics, TU Wien*

Fusion Research in Austria

Activities in 2014 and 2015

Vienna
April 2016

Fusion Research in Austria - Activities in 2014 and 2015

Compiled by Monika Fischer

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CONTENTS

Introduction	**2**
On the Road to Fusion Energy	**4**
Participation in EUROfusion Work Packages	**7**
Participation in F4E Grants	**25**
Table: Overview on Participation in EUROfusion Work Packages	**26**
Management Structure	**27**
Austrian Representatives in Committees Relevant for Fusion Research and Development (2014/2015)	**28**
Abbreviations and Acronyms	**29**
Contact Information	**30**

INTRODUCTION

The start of the EUROfusion consortium at the beginning of 2014 and its strategic orientation along the missions of the *Roadmap for the Realisation of Fusion Energy* marked a new era for fusion research in Europe, with changes that also affected the Austrian Fusion Research Programme. I am very pleased to note that the first two years of Horizon 2020 and EUROfusion have shown that the Austrian Fusion Research Programme is well integrated into the overall European effort in fusion research.

In early 2014, the Austrian Academy of Sciences, who had been the national partner to the bilateral Contracts of Association with EURATOM for many years, was nominated Programme Manager by the Federal Ministry of Science, Research and Economy. It continues to host the coordination office of the Austrian Fusion Research Unit, which is now called Fusion@ÖAW. Fusion research is performed at the Erich Schmid Institute of Materials Science at ÖAW and at four linked parties: Research Studio iSPACE in Salzburg, Technische Universität Graz, Technische Universität Wien and Universität Innsbruck.

This brochure is intended to highlight Austrian competencies in fusion research, which have been developed and strengthened by successful collaborations on the national and international level over many years.

The largest part of Austrian fusion research is performed at university institutes, with approximately twenty PhD students per year. Education and training of young researchers therefore continues to be an important objective of the Austrian Fusion Research Programme. The general consensus that training and education of the "generation ITER" are major priorities of the European effort deserving special support also prevails among the members of the EUROfusion consortium. I am very pleased that the value of teaching and mentoring is well recognized through the work package *Education*.

As Austria does not have its own fusion facilities, opportunities to contribute to experiments and modelling at JET, ASDEX Upgrade and Wendelstein 7-X are vital for the successful participation of Austrian scientists in the fusion programme. I would therefore like to commend the efforts by the EUROfusion Programme Management Unit and task leaders to schedule and manage the experimental campaigns under the work packages *Small and Medium-Sized Tokamaks* (MST1 and MST2) as well as the campaigns at JET.

I would also like to take this opportunity to congratulate my colleague Roman Schrittwieser for being awarded “doctor honoris causa” of the Alexandru-Ioan-Cuza Universität in Iaşi (Romania) and my former PhD student Matthias Willensdorfer (now at IPP Garching) for winning a EUROfusion fellowship.

The involvement of industry in the European Fusion Programme and the accessibility of business opportunities triggered by the construction of ITER are of vital importance for the ITER project. In this respect, valuable support is provided by the Industrial Liaison Officer (ILO) at the Austrian Federal Economic Chamber who circulates information about calls and specialized meetings for industry to qualified companies and organizes the participation of delegations from industry in specialized meetings.

Last, but not least I wish to thank all members of our Research Unit for their unbroken commitment and enthusiasm and the institutions listed below for their continuous support to Fusion@ÖAW in order to ensure the continuity of the Austrian Fusion Programme:

the Austrian Ministry for Science, Research and Economy and its representatives,
the President, Presiding Committee and staff of ÖAW,
the Austrian Commission for the Coordination of Fusion Research at ÖAW, and
the responsible officers of the European Fusion Programme.

Vienna, April 2016 (Friedrich Aumayr, Head of Research Unit)

ON THE ROAD TO FUSION ENERGY

EUROfusion

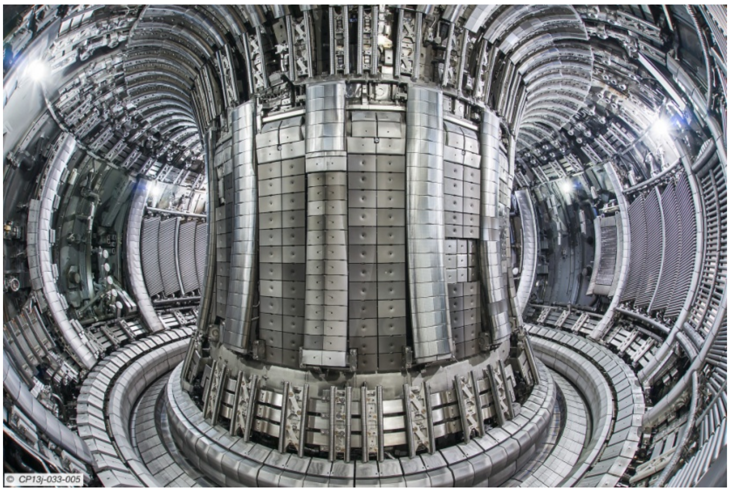
In 2014, 29 research organizations from 27 countries (European Union and Switzerland) signed the EUROfusion consortium agreement. Under Horizon 2020, the European Union's Framework Programme for Research and Innovation, fusion research activities are funded in accordance with the *Roadmap to the realisation of fusion energy", which* outlines the most efficient way to realize fusion electricity in the course of the 21st century. It is the result of an analysis of the European Fusion Programme undertaken in 2012 by the Research Units within EUROfusion's predecessor agreement, the European Fusion Development Agreement (EFDA).

The key facility of the *Roadmap* is ITER, which is presently being built in the South of France and will be the first device to produce net energy from fusion. To prepare for the experimental campaigns at ITER, EUROfusion manages campaigns at European tokamaks such as JET (Culham, UK), ASDEX Upgrade (IPP Garching, Germany) and TCV (Lausanne, Switzerland). and coordinates the advancement of the fusion research base. With a view to future fusion power plants, Wendelstein 7-X represents the largest device of the stellarator concept: https://www.euro-fusion.org/

EUROfusion

JET

JET is presently the largest tokamak in the world and presently the only fusion experiment in operation which is capable of producing fusion energy. EUROfusion provides the work platform to exploit JET in an efficient and focused way. As a consequence, more than 350 scientists and engineers from all over Europe currently contribute to the JET programme. Operation of the JET facilities is provided as an in-kind contribution to the consortium via a contract between the European Commission and the Culham Centre for Fusion Energy. In 2010/2011 JET was upgraded with the "ITER-like wall" and has become a test bed for ITER technologies and plasma operating scenarios. More information: https://www.euro-fusion.org/jet/



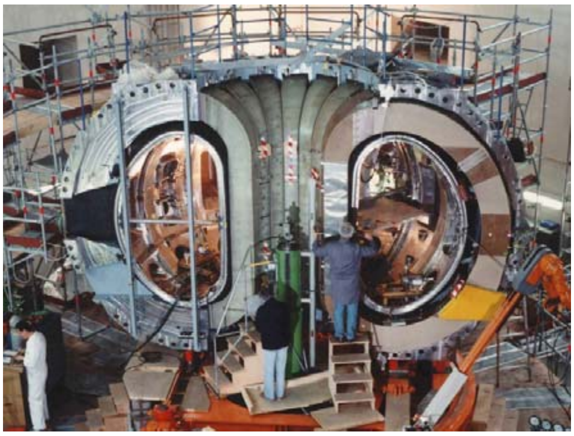
An internal view of the JET vessel with a complete metallic "ITER-Like" wall of beryllium and tungsten.

Source:
https://www.euro-fusion.org/

ASDEX Upgrade

The ASDEX Upgrade tokamak at Max-Planck Institut für Plasmaphysik in Garching near München (Germany) started operation in 1991. In 1996, the first parts of the wall – formerly covered completely with carbon tiles – were coated with tungsten. In 2007, the last carbon tile was replaced. The advantage of the wall completely clad with tungsten was confirmed: ASDEX Upgrade plasmas are stable, clean and thermally well-insulated,

In 2002, ASDEX Upgrade was opened to use by fusion laboratories from all over Europe. The start of EUROfusion in 2014 brought important changes to the organization, execution and evaluation of experiments. The shared exploitation in the framework of the Medium Sized Tokamak Programme (MST1) of EUROfusion started with a successful first year of experimental campaigns. Results obtained from experiments at ASDEX Upgrade provide valuable input for future ITER operation.
More information: http://www.ipp.mpg.de/16195/asdex



View inside the vessel of ASDEX Upgrade during the assembly phase, showing 7 of the 12 magnetic field coils

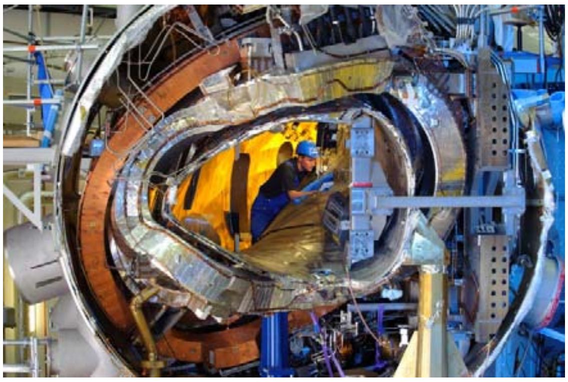
Courtesy Max-Planck-Institut für Plasma-physik, http://www.ipp.mpg.de

Wendelstein 7-X

Wendelstein 7-X, located in Greifswald (Germany), is the worldwide largest stellarator. It is equipped with modular superconducting coils which enable steady state plasma operation. The stellarator is an alternative design concept to the tokamak with a view to a future fusion power plant.

The main assembly of the Wendelstein 7-X stellarator at the Greifswald branch of IPP was completed in 2014. The first plasma was achieved in December 2015 and the facility was officially inaugurated on 3rd February 2016 in the presence of the German chancellor Angela Merkel. The preparation of experimental campaigns, theory and modelling is carried out in close co-operation with the EUROfusion consortium. More information:

http://www.ipp.mpg.de/ippcms/de/pr/forschung/w7x/index



View inside Wendelstein 7-X before it was closed, showing the plasma vessel, one of the stellarator coils, a planar coil, part of the support structure and the cryostat together with a lot of cooling pipes and power supply lines.

Courtesy Max-Planck-Institut für Plasma-physik, http://www.ipp.mpg.de

ITER

The tokamak ITER, which is presently constructed in the south of France in collaboration between the People's Republic of China, the European Union, India, Japan, the Russian Federation, South Korea and the United States of America, will be the first fusion device to produce net energy. It will be the first fusion device to test the integrated technologies, materials, and physics regimes necessary for the commercial production of fusion-based electricity. More information: *http://www.iter.org/*

In March 2015, the ITER Council appointed Bernard Bigot, the former CEO of the French Alternative Energies and Atomic Energy Commission, Director-General of the ITER.

Photo: Osamu Motojima, former Director General of ITER (left) hands over to Bernard Bigot (right).

Photo: http://www.iter.org/
http://fusionforenergy.europa.eu

The European Domestic Agency - Fusion for Energy (F4E)

Fusion for Energy (F4E) is the organization responsible for providing Europe's contribution to ITER. One of the main tasks of the organization is to cooperate with European industry, SMEs and research organizations to develop and provide a wide range of high technology components together with engineering, maintenance and support services for the ITER project.

Together with the ITER International Organization and the Domestic Agencies of the ITER partners, F4E has been strongly involved in the development of an integrated, realistic schedule for the completion of ITER.

By decision of the Governing Board dated 6 October 2015, Johannes Schwemmer has been appointed Director effective as of 1 January 2016.

Photo:
http://fusionforenergy.europa.eu

Information for Austrian industry

Harnessing fusion energy is an industrial effort to be backed up by targeted research. It is the task of the network of Industrial Liaison Officers (ILOs) to raise awareness among qualified companies and advise them on ways to get involved in the ITER project. In cooperation with the ILOs, F4E organizes a series of information days and seminars to report on the roadmap of different procurement packages and facilitate partnerships between companies. In Austria the function of ILO is performed by the Austrian Chamber of Commerce which acts as a contact forum for Austrian companies qualified for participating in high-tech industrial projects.

PARTICIPATION IN EUROFUSION WORK PACKAGES

The Austrian Fusion Research Unit (Fusion@ÖAW) is primarily university-based and comprises research groups at the Austrian Academy of Sciences (ÖAW), Research Studios Salzburg Forschungsgesellschaft (RS Salzburg), Technische Universität Graz (TU Graz), Technische Universität Wien (TU Wien) and Universität Innsbruck (UIBK).

Austrian scientists participate in 12 technical EUROfusion work packages with a clear emphasis on training and education (WPEDU) and involvement in the JET and MST programmes.

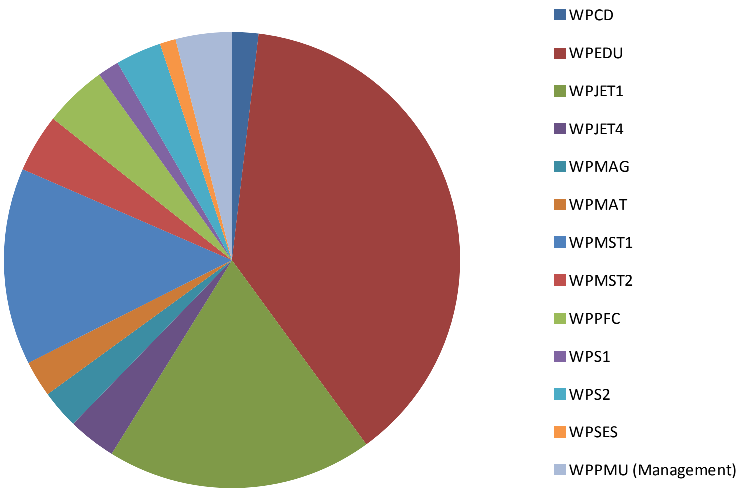


Figure 1. Participation in EUROfusion work packages based on EUROfusion budget data for 2015.

OVERVIEW ON SCIENTIFIC WORK

Fusion Education (WPEDU)

Starting from the 1980ies, fusion education was supported nationally by the Commission for the Coordination of Fusion Research in Austria (KKKÖ). It was further expanded and consolidated under the Contract of Association between EURATOM and ÖAW from 1996 to 2013. Since 1 January 2014, the institutions listed above participate in the EUROfusion Cofund Action (Horizon 2020) and offer mentoring to a yearly average of 20 PhD students working on fusion-relevant PhD-theses. Topics of teaching and theses focus on the competence areas shown above.

Second Fusion Day, Vienna, 20 November 2015 – annual meeting of senior scientists and PhD students contributing to fusion research in Austria (Photo: Fusion@ÖAW)

Enabling Research 2014 (WPENR)

Understanding of turbulent edge/SOL transport and structure formation by joint experiment and modelling approach - WP14-ER-01/ÖAW-01

Principal Investigator: A. Kendl, Institute for Ion Physics and Applied Physics, UIBK

Participating institutions in alphabetical order: CEA (France), DTU (Denmark), ENEA (Italy), IPP Garching (Germany), IPP.CR (Czech Republic), ÖAW / TU Wien (Austria), ÖAW / UIBK (Austria), WIGNER RCP (Hungary)

Scientific output - summary

This project aimed at first-principle-based physical understanding, development and validation of theoretical and numerical models of turbulent edge transport into and across the scrape-off layer (SOL) by measurements using novel diagnostic methods. Such methods include retarding field analyzer (RFA) measurements of ion energy across the scrape-off-layer (SOL) of ASDEX Upgrade (AUG) in L/H density cases, fluctuation measurements in the SOL of AUG with Langmuir probes and ball point probes and fluctuation measurements in COMPASS by means of emissive probes. Fast imaging techniques were applied to investigate filament dynamics. A comparison of the probe data with a simple predictive model based on drift wave instability showed promising agreement.

In addition, lithium beam emission spectroscopy (Li-BES) was applied to measure blob properties (amplitude, radial width, self-correlation time, radial velocity, blob frequency) in L-mode discharges of AUG with different magnetic fields. The existing photo-multiplier system was complemented with a new optical head of the AUG Li-beam diagnostic which enables measuring Li-beam signals offset from the axis of the Li-beam.

Effects of warm ions on blob size/velocity scaling were also investigated by means of gyrofluid simulations for AUG parameters.

Selected publications in journals

G. Birkenmeier, F.M. Laggner, M. Willensdorfer, T. Kobayashi, P. Manz, E. Wolfrum et al., "Magnetic field dependence of the blob dynamics in the edge of ASDEX Upgrade L-mode plasmas", *Plasma Phys. Control. Fusion* ***56*** *(2014)*, http://dx.doi.org/10.1088/0741-3335/56/7/075019

M. Wiesenberger, J. Madsen and A. Kendl, "Radial convection of finite ion temperature, high amplitude plasma blobs", *Physics of Plasmas* ***21*** ***(2014)***, http://dx.doi.org/10.1063/1.4894220

M. Willensdorfer, G. Birkenmeier, R. Fischer, F.M. Laggner, E Wolfrum, G. Veres, F. Aumayr, D. Carralero, L Guimarãis, B Kurzan et al., "Characterization of the Li-BES at ASDEX Upgrade", *Plasma Physics and Controlled Fusion* ***56*** *(2014)*, 025008. http://dx.doi.org/10.1088/0741-3335/56/2/025008

T. Kobayashi, G. Birkenmeier, E. Wolfrum, F.M. Laggner, M. Willensdorfer, U. Stroth, S. Inagaki, S.-I. Itoh and K. Itoh, "Method for estimating the propagation direction of a coherent plasma structure using a onedimensional diagnostic array", *Review of Scientific Instruments* ***85*** *(2014)*, 0835071 – 0835076 http://dx.doi.org/10.1063/1.4893482.

A. Kendl, *"*Inertial blob-hole asymmetry in magnetized plasma filaments", *Plasma Physics and Controlled Fusion* ***57*** *(2015)*, 045012, http://dx.doi.org/10.1088/0741-3335/57/4/045012.

Selected conference presentations

M. Wiesenberger, J. Madsen and A.Kendl, "Full-n gyrofluid blob dynamics in the tokamak scrape-off layer", *41st EPS Conference on Plasma Physics, Berlin, Germany, June 2014.* *http://ocs.ciemat.es/EPS2014PAP/pdf/P1.048.pdf*.

J. Adamek, J., H.W. Müller, J. Horacek, R. Schrittwieser, P. Vondracek, B. Kurzan, P. Bilkova, P. Böhm, R. Panek, COMPASS Team and the ASDEX Upgrade Team, "Radial profiles of the electron temperature on COMPASS and ASDEX Upgrade from ball-pen probe and Thomson scattering diagnostic", *41st EPS Conference on Plasma Physics, Berlin, Germany, June 2014.*

http://ocs.ciemat.es/EPS2014PAP/pdf/P2.011.pdf

S.-Costea, A. Nielsen, V. Naulin, J. J. Rasmussen, H.W. Müller, G. Conway, N. Vianello, N., D. Carralero, R. Schrittwieser, F. Mehlmann, C. Lux, C. Ionita and the ASDEX Upgrade Team, "Investigations of poloidal velocity and shear in the SOL of ASDEX Upgrade", *41st EPS Conference on Plasma Physics, Berlin, Germany, June 2014*. http://ocs.ciemat.es/EPS2014PAP/pdf/P2.001.pdf

F. Laggner, "Lithium beam emission spectroscopy as a tool for tokamak edge electron density fluctuation measurements", *Workshop on Electric Fields, Turbulence and Self-Organisation in Magnetized Plasmas (EFTSOMP), Berlin, Germany, 2014*.

M. Held, M. Wiesenberger and A. Kendl, "Three-dimensional flux-coordinate independent field-aligned full-f two-field gyrofluid model*" 19th Joint EU-US Transport Task Force Meeting (TTF2014), Culham, UK*.

Estimation of the radial width of the ITER SOL via kinetic model – WP14-ER-01/ÖAW-02

Principal investigator: D. Tskhakaya, Institute of Applied Physics, TU Wien

Participating institutions in alphabetical order: CEA (France) JSI (Slovenia), ÖAW/TU WIEN (Austria) ÖAW/UIBK (Austria)

Scientific output - summary

The aim of the project was the development of a new kinetic code and simulation of the ITER SOL in order to estimate its radial width. The 2D3V (2D in usual and 3D in velocity space) massively parallel kinetic (PIC + MC) code BIT2 was developed. BIT2 allows the simulation of the full-size tokamak SOL with finest resolution in time and space (down to electron Larmor rotation and plasma oscillations). The simulation geometry corresponds to the SOL bounded between inner and outer divertors, outer wall and separatrix. The code can simulate practically any number of plasma, neutral and impurity particle species in 2D approximation. It incorporates all atomic, molecular and plasma-surface interaction processes which are necessary for the simulation of the tokamak SOL in present-day and future fusion devices. The code also allows the simulation of chamber ports, which can be used for synthetic diagnostics as well as for simulating impurity seeding and plasma pumping. Most parts of the code were verified via large set of test runs. Contrary to other 2D kinetic codes, BIT2 is capable of simulating the full-size SOL, thereby following the dynamics of all its components in a self-consistent manner.

During the development of the BIT2 code we had to solve a number of problems which required the introduction of new approaches. Most of these developments as well as manuals for possible up-dates are documented as internal reports (see examples below).

One of the most complex parts of the code – the massively parallel Poisson Solver - was developed and tested in the framework of a separate High-Level Support Team project. The Code has high scaling enabling the use of 16.000 and more processors (see figure 2).

Most of these developments as well as manuals for possible up-dates are documented as internal reports and first modelling results are to be presented at international conferences.

Conference contributions and reports

D. Tskhakaya, "Description of the I/O files of the BIT2 code", BIT2 code manual (October 2014), 23 pages.

S. Costea and J. Kovacic, "New atomic and PSI data for the BIT2 code", internal report (December 2014), 3 pages.

D. Tskhakaya, "BIT2 tests runs", internal report (Dec. 2014) , 14 pages.

D. Tskhakaya and K.S. Kang, “2D kinetic modelling of the scrape-off layer”, to be presented at the *22nd International conference on Plasma Surface interactions, 30 May – 3 June, 2016, Rome, Italy,* to be submitted to *Journal of Nuclear Physics.*

D. Tskhakaya, “Sheath properties in recycling plasma”, *21st ITPA Divertor and Scrape-Off Layer TG Meeting, Princeton, USA, June 2015*.

D. Tskhakaya, “Kinetic modelling of the detached divertor plasma”, *15th International Workshop on Plasma Edge Theory in Fusion Devices, Nara, Japan, September 2015*.

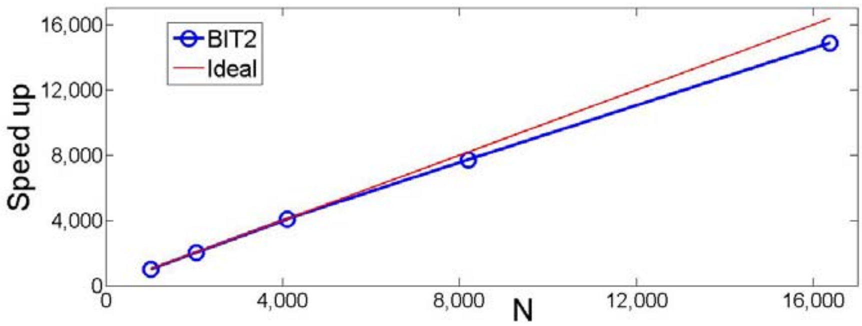


Figure 2. Strong scaling of the BIT2 code. N is the number of processors

ITER PHYSICS

Code Development (WPCD)

Codes developed in the framework of the European Fusion Development Agreement (EFDA) until 2013 and in the EUROfusion Work Package “Code Development” (WPCD) as of 2014

Code	Type	Authors/ co-authors	Institution
BIT 1	Particle-in-cell (PIC)	D. Tskhakaya	TU Wien / UIBK
FIDIT (Fast ion distribution in tokamaks)	Fokker Planck	V. Goloborod’ko K. Schöpf, V. Yavorskij	UIBK
SNBI (source of neutral beam ions) module	Module for NBI generated deuterons and tritons	T. Gassner V. Goloborod’ko K. Schöpf, V. Yavorskij	UIBK
GEMR	Electro-magnetic gyrofluid model	A. Kendl B. Scott	UIBK / IPP Garching
HAGIS	Hamiltonian Guiding Centre System	V. Goloborod’ko K. Schöpf, V. Yavorskij	UIBK
JINTRAC HPI2 pellet module	Pellet ablation and deposition model	F. Koechl B. Pégourié et al.	TU Wien / CEA / CCFE

Publications in scientific journals

D. Tskhakaya, D. Coster and ITM-TF Contributors, “Implementation of PIC/MC code BIT1 in ITM platform”, *Contributions to Plasma Physics* ***54/4-6*** *(2014)*, pp. 393 – 404.
http://dx.doi.org/10.1002/ctpp.201410029

Conference / workshop contributions

G. Falchetto, X. Litaudon, R. Coelho, D. Coster, ...F. Köchl, ... D. Tskhakaya, ..., WPCD and WPISA Teams, “EUROfusion effort in code development for integrated modelling”, presented by I. Voitsekhovitch on behalf of WPCD and WPISA at the *TRANSP Users’ Group meeting, PPPL, USA, March 2015.*

JET Campaigns (WPJET1)

General motivation

ITER will break new ground in fusion science. To ensure the success of future ITER exploitation, the *Roadmap to the realisation of fusion energy* (https://www.euro-fusion.org/2015/01/the-road-to-fusion-electricity/) recommends the preparation of ITER operation on JET and JT-60SA as a main risk mitigation measure.

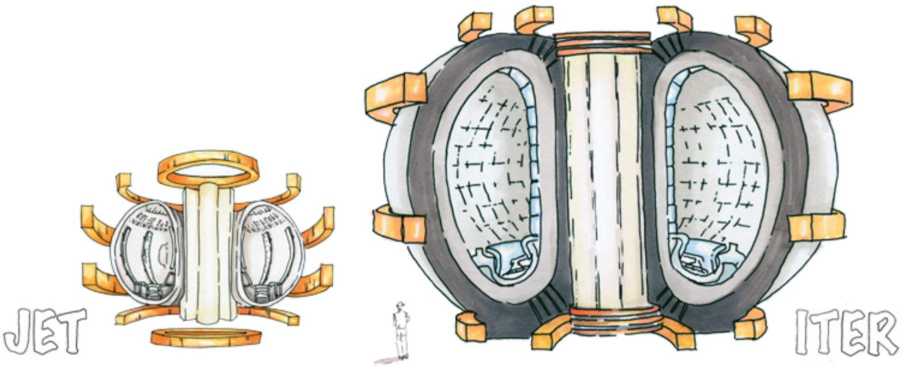


Figure 3. JET's core programme supports ITER in terms of hardware and experiments. Both experiments are tokamaks with similar shape. Source: https://www.euro-fusion.org

Participation in JET campaigns

Predictive modelling of DT fusion yield and fusion product emissivity for baseline and hybrid scenarios for DT operation

K. Schöpf, Goloborod'ko and V. Yavorskij, Institute for Theoretical Physics, UIBK

Publications in scientific journals

V. Yavorskij, V. Goloborod'ko, L.G. Eriksson, V. Kiptily, K. Schoepf, S.E. Sharapov and JET EFDA Contributors, "Predictive Fokker-Planck Modelling of confined and lost fusion alpha particles in ITER", *Journal of Fusion Energy* ***34/4*** *(2015)*, pp 774-784. http://dx.doi.org/10.1007/s10894-015-9862-2

Conference contributions

V. Yavorskij, Yu. Baranov, V. Goloborod'ko, D. Darrow, V.G. Kiptily, K. Schoepf and C. Perez von Thun, "Interpretive and predictive modelling of fluxes of charged fusion products lost from the tokamak plasmas", *14th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems, Vienna, Austria, September 2015.*

Kinetic modelling of the JET SOL and divertor with the code BIT1/BIT2
D. Tskhakaya, Institute of Applied Physics, TU Wien

Publications in scientific journals

D. Tskhakaya, M. Groth and JET EFDA Contributors, "Modelling of tungsten re-deposition coefficient", *Journal of Nuclear Materials* ***463*** *(2015)*, pp. 624-628, http://dx.doi.org/10.1016/j.jnucmat.2014.10.086

JET Enhancements (WPJET4)

Alpha-particle diagnostics

K. Schoepf, V. Goloborod'ko and V. Yavorskij, Institute for Theoretical Physics, UIBK

Key objectives of the simulations for the Gamma Ray Camera Upgrade (GCU) and the Neutron Camera Upgrade (NCU) are: Modelling of distribution functions of neutron beam injection (NBI) ions in selected JET D and DT plasma scenarios, calculation of DD and DT fusion sources and modelling of the distribution functions of DT fusion alphas in JET DT plasmas. This is also relevant for the Gamma Ray Spectrometer Upgrade (GSU) project.

A deliverable on synthetic diagnostics of the Scintillator Probe Upgrade (SPU) has been assigned to V. Yavorskij et al. and consists of the construction of a synthetic diagnostic using particle orbit codes that include full orbit as well as an up-to-date 3D version of the first wall.

K. Schoepf et al. also contribute to the optimization of the Lost Alpha Rays Monitor (LRM) beryllium target position, size and orientation to achieve a maximum gamma emission from nuclear reactions of lost fast alphas with the target beryllium. One of the objectives of this work is the calculation of fast-ion loss fluxes to specific Lost Alpha Monitor (LAM) Be-targets at different positions.

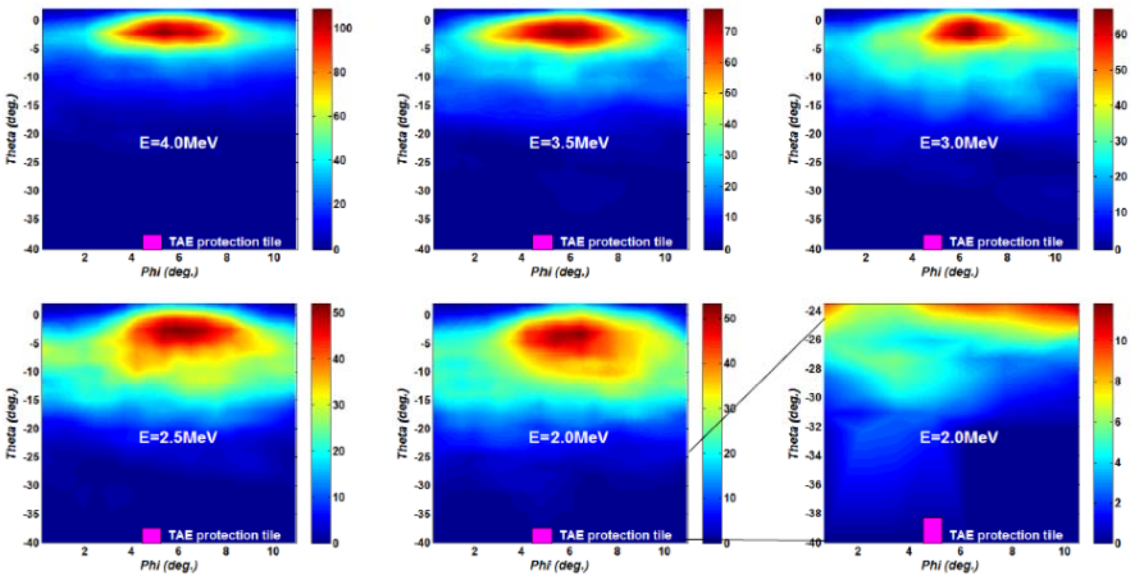


Figure 4. Modelled distributions of the fluxes (in arbitrary units) of diffusively-convectively lost MeV alphas over toroidal and poloidal angles as dependent on the particle energy for JET shot #78075.

Conference contributions

T. Craciunescu, V. Kiptily, K. Schoepf, V. Yavorskij, V. Goloborod'ko, ... and JET contributors, "JET horizontal gamma-ray spectrometer upgrade for the alpha-particle diagnostic during the DT campaign", *ITPA- Diagnostics Meeting, Cadarache, November 2014*.

V. Kiptily, S. Soare, V. Zoita, T. Craciunescu, M. Curuia, Klaus Schoepf, V. Yavorskij, V. Goloborodko ...and the project team, "Lost alpha-particle gamma-ray monitor for the JET DT campaign", *27th Meeting of the ITPA Topical Group on Diagnostics, ITER Organization, Cadarache, November 2014*.

V. Goloborodko, V. Kiptily, K. Schoepf and V. Yavorskij, "Evaluation of fluxes of lost alphas for gamma-ray diagnostics in ITER", *14th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems, Vienna, Austria, September 2015*.

Experimental Campaigns on Medium-Size Tokamaks (WPMST1)

General motivation

Experimental campaigns in small and medium-sized tokamaks such as ASDEX Upgrade (IPP Garching), TCV (EPFL, Lausanne) and MAST (CCFE, UK) support the future exploitation of ITER as described in the *Roadmap to the realisation of fusion energy*. Proof-of-principle concepts are better investigated in small and flexible experiments and then scaled up to the larger machines. Examples are the investigation of alternative divertor configurations or testing of the material behaviour of tungsten, which will be used as a divertor material in ITER.

Figure 5. The Fusion Roadmap comes alive. Source: https://www.euro-fusion.org

Participation in experimental campaigns on medium-sized tokamaks in cooperation with the EUROfusion MST1 Team and the ASDEX Upgrade and TCV Teams

Pedestal studies and of inter-ELM profile evolution in ASDEX Upgrade
F. Aumayr, F.M. Laggner et al., Institute of Applied Physics, TU Wien

Papers in scientific journals

E. Viezzer, E. Fable, T. Pütterich, A. Bergmann, M. Cavedon, R. Dux, R.M. McDermott, C. Angioni, R.M. Chruchill, M.G. Dunne, F.M. Laggner, B. Lipschultz, U. Stroth, E. Wolfrum and the ASDEX Upgrade Team, "Collisionality dependence of edge rotation and in-out impurity asymmetries in ASDEX Upgrade H-mode plasma", *Nuclear Fusion* ***55/12*** *(2015)*,
http://dx.doi.org/10.1088/0029-5515/55/12/123002

F.M. Laggner, E. Wolfrum, M. Cavedon, F. Mink, E. Viezzer, M.G. Dunne, P. Manz, H. Doerk, G. Birkenmeier, R. Fischer, S. Fietz, M. Maraschek, M. Willensdorfer, F. Aumayr, the EUROfusion MST1 Team and the ASDEX Upgrade Team, "High frequency magnetic fluctuations correlated with the inter-ELM pedestal evolution in ASDEX Upgrade", submitted to *Plasma Physics and Controlled Fusion*.

Conference contributions

F.M. Laggner, E. Wolfrum, M.G. Dunne, M. Cavedon, P. Manz, G. Birkenmeier, R. Fischer, E. Viezzer, M. Willensdorfer, F. Aumayr, the EUROfusion MST1 Team and the ASDEX Upgrade Team, "The effects of triangularity and main ion species on the inter-ELM profile evolution in ASDEX Upgrade", *42nd EPS Conference on Plasma Physics, Lisbon, Portugal, June 2015,*
http://ocs.ciemat.es/EPS2015PAP/pdf/P1.147.pdf

Filamentary transport in the scrape-off-layer (SOL) –radial transport of poloidal momentum

R. Schrittwieser, C. Ionita-Schrittwieser, S. Costea, B.S. Schneider, Institute for Ion Physics and Applied Physics, UIBK

Papers in scientific journals

F. Mehlmann, S. Costea, R. Schrittwieser, V. Naulin, J.J. Rasmussen, H.W. Müller, A.H. Nielsen, N. Vianello, D. Carralero, V. Rohde, C. Lux, C. Ionita and the ASDEX Upgrade Team, "Electric probe measurements of the poloidal velocity in the scrape-off layer of ASDEX Upgrade", *Contrib. Plasma Phys.* ***54*** *(2014)*. http://dx.doi.org/10.1002/ctpp.201410078

J. Adámek, J. Horacek, J. Seidl, H.W. Müller, R. Schrittwieser, F. Mehlmann, P. Vondracek, S. Ptak, COMPASS and ASDEX Upgrade Team, "Direct plasma potential measurements by ball-pen probe and self-emitting Langmuir probe on COMPASS and ASDEX Upgrade", *Contrib. Plasma Phys.* ***54*** *(2014).*

H. Zohm, ….., S. Costea, ….., R. Schrittwieser et al, "Recent ASDEX Upgrade Research in Support of ITER and DEMO", *Nuclear Fusion* ***55*** *(2015),* 104010 (12pp).

Conference contributions

B.S. Schneider, S. Costea, C. Ionita, R. Schrittwieser, V. Naulin, J.J. Rasmussen, R. Stärz, N. Vianello, J. Kovacic and T. Gyergyek, "Robust highly emissive probe for plasma potential measurements in the edge region of toroidal plasma", 1st EPS on Plasma Diagnostics, Frascati, Italy, April 2015, http://pos.sissa.it/archive/conferences/240/072/ECPD2015_072.pdf.

N. Vianello, H.W. Müller, M. Agostini, L. Aho-Mantila, M. Bernert, G. Birkenmeier, D. Carralero, P.Carvalho, S. Costea, T. Eich, L. Guimarais, C. Ionita-Schrittwieser, A. Kendl, B. Lipschultz, J. Madsen, M.L. Magnussen, F. Militello, V. Naulin, A. Nemes-Czopf, V. Nikolaeva, J.J. Rasmussen, F. Reimold, R.Schrittwieser, ..., M. Wiesenberger et al., "SOL filamentary transport at high density", oral contribution, *1st MST1 Science Review Meeting, Garching, Germany, September 2014*.

H.W. Müller, D. Carralero, J. Adamek, G. Conway, S. Costea, J.C. Fuchs, M. Komm, V. Naulin, R.Schrittwieser, M. Spoalore, N. Vianello and the ASDEX Upgrade Team, "Latest SOL measurements using probes", oral contribution *ASDEX Upgrade Ringberg Seminar, November 2014*.

N. Vianello, M. Agostini, L. Carraro, D. Carralero, R. Cavazzana, G. De Masi, I. Furno, C. Hidalgo, P.Innocente, C. Ionita, L. Marrelli, E. Martines, A. Maszi, B. Momo, H.W. Müller, V. Naulin, M.E. Puiatti, J. J. Rasmussen, C. Rea, G. Spizzo, P. Scarin, R. Schrittwieser et al., invited lecture, *1st International and Interdisciplinary Workshop on Fusion and Technological Plasmas (FUSTECH), Collaborative Research Center SFB-TR87, Ruhr-University Bochum*, *December 2014*.

S. Costea, J.J. Rasmussen, N. Vianello, H.W. Müller, V. Naulin, R. Schrittwieser, A.H. Nielsen, J. Madsen, C. Ionita, M. Spolaore, D. Carralero, F. Mehlmann and the ASDEX Upgrade Team, "Investigation on radial transport of poloidal momentum in the SOL of AUG during the L-I-H transition", *42nd EPS Conference on Plasma Physics, Lisbon, Portugal, June 2015,* http://ocs.ciemat.es/EPS2015PAP/pdf/P1.151.pdf

H. Nielsen, L. Aho-Mantila, J. Madsen, H.W. Müller, N. Vianello, H. Radhakrishnan, J. Signoret, M.Wischmeier, B. Sieglin, D. Carralero, G. Birkenmeier, R. Coelho, J. Juul Rasmussen, V. Naulin, M. Løiten, L. Tophøj, R. Schrittwieser, S. Costea and the ASDEX Upgrade Team, "First principle numerical simulations of the SOL in ASDEX Upgrade", *42nd EPS Conference on Plasma Physics, Lisbon, Portugal, June 2015, http://ocs.ciemat.es/EPS2015PAP/pdf/P1.105.pdf*

J. Juul Rasmussen, V. Naulin, A.H. Nielsen, J. Madsen, L. Tophøj, A.S. Christensen, M. Løiten, O.E.Garcia, R. Schrittwieser, C. Ionita, S. Costea, B.S. Schneider, N.Vianello, N. Yan and G.S. Xu, "Plasma transport in the Scrape-off-Layer of magnetically confined plasma and the plasma exhaust", *XXXIIth International Conference on Phenomena in Ionized Gases (Iasi, Romania, July 2015*.

See also publications / presentations listed under MST2 and S1

Modelling of toroidal rotation and effects of non-resonant magnetic perturbations

S. Kernbichler, M.F. Heyn et al., Institute of Theoretical and Computational Physics, TU Graz

Publications in scientific journals

S. Kasilov, W. Kernbichler, A. Martitsch, H. Maaßberg and M.F. Heyn, "Evaluation of the toroidal torque driven by external non-resonant non-axisymmetric magnetic field perturbations in a tokamak", Evaluation of the toroidal torque driven by external non-resonant non-axisymmetric magnetic field perturbations in a tokamak", *Physics of Plasmas* ***21*** *(2014).*
http://dx.doi.org/10.1063/1.4894479

Conference contributions

W. Kernbichler, G. Kapper, S. Kasilov and N.B. Marushchenko, "Computation of the Spitzer function in sellarators and tokamaks with finite collisionality", *18th Joint Workshop on Electron Cyclotron Emission and Electron Cyclotron Resonance Heating", Nara, Japan, April 2014*.

A.F. Martitsch, S.V. Kasilov, W. Kernbichler and H. Maassberg, "Evaluation of non-ambipolar particle fluxes driven by non-resonant magnetic perturbations in a tokamak", *41st EPS Conference on Plasma Physics, Berlin, Germany, June 2014.* *http://ocs.ciemat.es/EPS2014PAP/pdf/P1.049.pdf*

W. Kernbichler, S. Kasilov and A. Martitsch, "Neoclassical toroidal viscosity in quasilinear regimes", *19th Joint EU-US Transport Task-Force Meeting, Culham, UK, September 2014*.

C.G. Albert, M.F. Heyn, S.V. Kasilov, W. Kernbichler and A.F. Martitsch, "Toroidal rotation in resonant regimes of tokamak plasmas due to non-axisymmetric perturbations in the action-angle formalism", *42nd EPS Conference on Plasma Physics, Lisbon, Portugal, June 2015.*
http://ocs.ciemat.es/EPS2015PAP/pdf/P1.183.pdf

A.F. Martitsch, S.V. Kasilov, W. Kernbichler, M.F. Heyn, E. Strumberger, S. Fietz, W. Suttrop and the ASDEX Upgrade Team, "Evaluation of the neoclassical toroidal viscous torque in ASDEX Upgrade",. *42nd EPS Conference on Plasma Physics, Lisbon, Portugal, June 2015.*
http://ocs.ciemat.es/EPS2015PAP/pdf/P1.146.pdf

C.G. Albert, M.F. Heyn, S.V. Kasilov, W. Kernbichler and A.F. Martitsch, "Toroidal torque in resonant transport regimes of tokamak plasmas with perturbed axisymmetry within Hamiltonian theory", *20th International Stellarator-Heliotron Workshop, Greifswald, Germany, October 2015*.

A.F. Martitsch, S.V. Kasilov, W. Kernbichler, G. Kapper, C.G. Albert, M.F. Heyn and the ASDEX Upgrade and EUROfusion MST1 Team, "Effect of 3D magnetic perturbations on the plasma rotation in tokamaks", *20th International Stellarator-Heliotron Workshop, Greifswald, Germany, October 2015.*

W. Kernbichler, S.V. Kasilov, A. Martitsch and G. Kapper, "Solution of drift kinetic equation in stellarators and tokamaks with broken symmetry using the code NEO-2", *20th International Stellarator-Heliotron Workshop, Greifswald, Germany, October 2015.*

Preparation of Exploitation of Medium Size Tokamaks (WPMST2)

Developing a multi-device probe head for MSTs

R. Schrittwieser, C. Ionita-Schrittwieser, S. Costea and B.S. Schneider (Institute for Ion Physic, UIBK)

Background

Originally, R. Schrittwieser et al. proposed the construction of adaptors to make the Innsbruck-Padua probe also usable for the reciprocating probe manipulators of the medium-sized tokamaks TCV and ASDEX-Upgrade. The InnPad Probe has proven its value in numerous ASDEX-Upgrade campaigns for measurements of transport parameters and shear layers in the plasma edge region, even inside the last closed flux surface. It is equipped with six cold Langmuir probes, of which one is protruding by 3 mm from the front plane of the probe, and one triple magnetic pick-up coil.

At the kick-off meeting of the project, however, the collaborators from UIBK, the Technical University of Denmark (DTU, Lyngby) and the Jozef Stefan Institute (Ljubljana) decided to develop a completely new probe head with two cold Langmuir probes, one electron-emissive probe, two retarding field analyzers and two triple magnetic pick-up coils which would be equipped with adaptors for TCV, ASDEX Upgrade and MAST-Upgrade. The design is completed, and further work is in progress.

Presentations at meetings and conferences

B.S. Schneider, R. Schrittwieser, C. Ionita, S. Costea, F. Mehlmann and J. Grünwald, "Emissive probe for hot plasmas", poster, *International Balkan Workshop on Applied Physics*, *Constanta*, *Romania*, *July 2014*, S2 P19.

R. Schrittwieser, C. Ionita, S. Costea, F. Mehlmann, J. Grünwald, B.S. Schneider, V. Naulin, J.J. Rasmussen, H.W. Müller and J. Adàmek, "Probe diagnostics in various plasmas", invited lecture, *Second Interuniversity Attraction Poles (IAP) Workshop on Plasma Diagnostics, Reims, France, June 2014*.

R. Schrittwieser, C. Ionita, S. Costea, F. Mehlmann, J. Grünwald and B.S. Schneider, "Cold and hot probe diagnostics", invited lecture, *14th International Balkan Workshop on Applied Physics, Constanta, Romania, July 2014*.

J. Kovacic, B. Fonda, T. Gyergyek, Tsv. Popov, S. Costea and M. Cercek, "Use of electron emissive probe in plasma with negative ions", *41st EPS Conference on Plasma Physics, Berlin, Germany, June 2014.* *http://ocs.ciemat.es/EPS2014PAP/pdf/P1.125.pdf* .

R. Schrittwieser, C. Ionita, F. Mehlmann, S. Costea, B.S. Schneider, R. Stärz, V. Naulin, J.J. Rasmussen, H.W. Müller, N. Vianello, C. Maszl, M. Zuin, R. Cavazzana and the ASDEX Upgrade Team, "Cold, emissive and armoured probes in magnetized plasmas", invited lecture, *1st International and Interdisciplinary Workshop on Fusion and Technological Plasmas (FUSTECH), Collaborative Research center SFB-TR87, Ruhr University Bochum, Germany, December 2014*

C. Ionita-Schrittwieser, R. Schrittwieser, S. Costea, B.S. Schneider, R. Stärz, V. Naulin, J.J. Rasmussen, N. Vianello, J. Kovacic and T. Gyergyek, "Developing adaptors to facilitate interchangeable probes between MST devices", oral presentation, *Kick-off Meeting, WP15-MST2-14, Centre de Recherches en Physique des Plasmas (CRPP), EPFL, Lausanne, Switzerland, March 2015*.

B.S. Schneider, S. Costea, C. Ionita, V. Naulin, J.J. Rasmussen, N. Vianello, T. Gyergyek, J. Kovacic, H.W. Müller and D. Carralero, oral presentation, "Development of emissive probes for potential measurements in the edge region of toroidal plasmas", *Kick-off Meeting, WP15-MST2-14, Centre de Recherches en Physique des Plasmas (CRPP), EPFL, Lausanne, Switzerland, March 2015.*

B.S. Schneider, S. Costea, C. Ionita, R. Schrittwieser, V. Naulin, J.J. Rasmussen, N. Vianello, J. Kovacic and T. Gyergyek, "Robust highly emissive probe for plasma potential measurements in the edge region of toroidal plasma", *1st EPS on Plasma Diagnostics, Frascati, Italy, April 2015*.

B.S. Schneider, S. Costea, C. Ionita, R. Schrittwieser, V. Naulin, J.J. Rasmussen, R. Stärz, N. Vianello, J. Kovacic and T. Gyergyek, "Indirectly heated strong and robust emissive probe for dense and hot plasmas", *XXXIIth International Conference on Phenomena in Ionized Gases, Iasi, Romania, July 2015*, P1.36.

C. Ionita, B.S. Schneider, P. Jäger, S. Costea and R. Schrittwieser, "Emissive probe of carbon fibres for laboratory and fusion plasmas", *Joint Annual Meeting of the Austrian Physical Society (ÖPG), the Swiss Physical Society (SPG) and the Austrian and Swiss Societies for Astronomy and Astrophysics, Vienna, Austria, September 2015*.

See also publications / presentations listed under MST1 and S1.

Preparation of Efficient PFC Operation for ITER and DEMO (WPPFC)

Qualification of EUROFER as plasma-facing material – Erosion studies of Fe/FeW films under D irradiaton

F. Aumayr, K. Dobes, B. Berger et al., Institute of Applied Physics, TU Wien

Background and summary of work performed

Under the assumption that the plasma in future fusion power plants will be stable and quiescent, the lifetime of the plasma-facing components (PFC) will be dominated by plasma-induced erosion due to ions and energetic neutrals. Since the erosion of high-Z materials will be considerably lower than the erosion of low-Z materials at low ion energies in the near surface region, the use of thin tungsten armours as PFC is envisaged in several DEMO design studies. Steady-state operation, however, will bring new challenges for heat removal from the PFC. An attractive alternative to tungsten armour for recessed areas would be the use of tungsten containing steels such as EUROFER. Experiments at the linear plasma device PISCES-A have shown a strong decrease in the sputtering yield of EUROFER for low energetic D plasma bombardment at high incident fluences. Enrichment of the tungsten surface due to preferential sputtering of the lighter elements is observed and correlates with the reduction of the erosion yield. Our work aims at the understanding of the tungsten surface enrichment process due to the interaction of deuterium ions with tungsten-containing steels.

In the framework of this task, the interaction of mono-energetic deuterium projectiles (250 –eV/D and 1.000 eV/D) with 400 nm thick FeW model films (1.5 at% tungsten) was studied under laboratory conditions and the results compared to pure Fe films (experiments at 465 K with the quartz crystal microbalance technique). After reaching certain D fluences the sputtering yield was measured as a function of ion incident angle (0◦ - 70◦ with respect to the surface normal).

First results

For low D fluences the mass removal rate of FeW is close to the value of pure Fe. With increasing fluences, however, a noticeable decrease of the sputtering yield for FeW was observed which indicates W enrichment of the near surface layer.

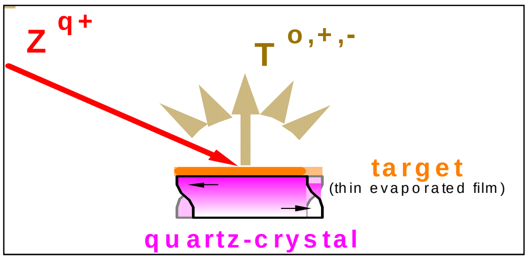


Figure 6. Schematic drawing of the quartz-crystal microbalance set-up at TU Wien

Publications in scientific journals

K. Dobes, V. Smejkal, T. Schäfer and F. Aumayr, "Interaction between seeding gas ions and nitrogen saturated tungsten surfaces", *International Journal of Mass Spectrometry* ***365-366*** *(2014)*, 64-67, http://dx.doi.org/10.1016/j.ijms.2013.11.015

K. Dobes, M. Köppen, M. Oberkofler, C.P. Lungu, C. Porosnicu, T. Höschen, G. Meisl, C. Linsmeier and F. Aumayr, “Interaction of nitrogen ions with beryllium surfaces”, *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* ***340*** *(December 2014)*, 34-38, http://dx.doi.org/10.1016/j.nimb.2014.06.025

M. Oberkofler, D.Alegre, F. Aumayr, S. Brezinsek, T. Dittmar, K. Dobes, D. Douai, A. Drenik, M. Köppen, U. Kruezi, Ch. Linsmeier, C.P. Lungu, G. Meisl, M. Mozetic, C. Porosnicu, V. Rohde, S.G. Romanelli, the ASDEX Upgrade team and JET EFDA Contributors, “Plasma-wall interactions with nitrogen seeding in all-metal fusion devices: Formation of beryllium nitride and ammonia*”, Fusion Engineering and Design* ***98-99*** *(2015)*, 1371-1374, http://dx.doi.org/10.1016/j.fusengdes.2015.01.044

Conference contributions

B. Berger, R. Stadlmayr**,** G. Meisl, M. Cekada, K. Sugiyama, M. Oberkofler, T. Schwarz-Selinger and F.Aumayr, "Transient effects during erosion of WN and FeW films by deuterium ions studied with the quartz crystal microbalance technique", poster, 15th International Conference on Plasma-Facing Materials and Components for Fusion Applications (PFMC-15), Aix-en-Provence/France, May 2015.

B. Berger, R. Stadlmayr, G. Meisl, M. Cekada, K. Sugiyama, M. Oberkofler, T. Schwarz-Selinger and F.Aumayr, "Erosion of fusion-relevant wall materials under ion bmbardment studies with a quartz crystal microbalance technique", *21st International Workshop on Inelastic Ion-Surface Collisions (IISC-21), Donostia-San Sebastián, Spain, October 2015*.

Kinetic modelling of sheath characteristics in front of divertors with BIT1

D. Tskhakaya, Institute of Applied Physics, TU Wien

Background

The detached plasma regime is one of the most promising candidates for reducing divertor heat loads in large tokamaks to an acceptable level. Typically, plasma detachment is reached at sufficiently high upstream SOL densities leading to electron cooling in front of the divertor plates and "roll over" of the divertor ion flux. The physics of plasma detachment is not yet well understood. There are a number of experimental observations, which, however, cannot be reproduced by SOL-simulating large fluid codes. A possible explanation could be the influence of kinetic effects which are not included in these simulations, but possibly have strong effects on the detachment. We therefore aim at performing self-consistent kinetic modelling of plasma detachment and investigation of the characteristics of the detached plasma sheath with the particle-in-cell code BIT1. The model includes plasma recycling and recombination as well as impurity sputtering and transport in the SOL. In order to avoid artificial effects which might result from applying (basically unknown) boundary conditions at the divertor plasma, we simulate the entire SOL, considering detached plasma characteristics for different upstream SOL parameters and impurity sputtering rates.

Conclusion

Our modelling indicated that (i) plasma profiles in the high recycling plasma are not necessarily monotonic, (ii) particle velocity and energy distribution functions are far from the Maxwellian, (iii) sheath classical boundary conditions cannot be applied (see figure 7), (iv) high recombination rates do not affect strongly the plasma sheath characteristics, because the charge-exchange collisions are still the dominating process in detached and near detached divertor plasma.

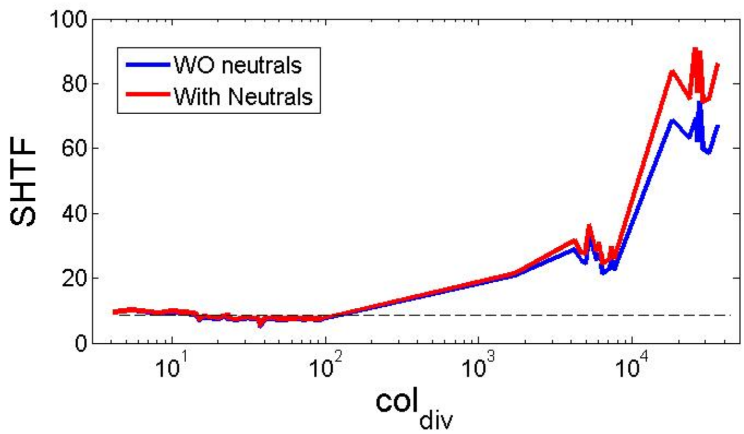


Figure 7. Sheath Heat Transmission Factor (SHTF), $Q_{div} / \Gamma_i T_e$, vs divertor plasma collisionality. The dashed line denotes the classical value. Q_{div}, Γ_i and T_e denote the total power load and the main ion flux to the divertor plate, and the electron temperature, respectively.

Publications in scientific journals

D. Tskhakaya, “Kinetic modelling of the detached dvertor plasma”, *15th International Workshop on Plasma Edge Theory in Fusion Devices, Nara, Japan, September 2015*. *Contrib. Plasma Phys.**2** (2016), http://dx.doi.org/10.1002/ctpp.201610004.*

D.D. Tskhakaya, L. Kos, and D. Tskhakaya, “Stability of the Tonks{Langmuir discharge pre-sheath”, accepted for publication in *Physics of Plasmas (2016).*

Conference contributions

D. Tskhakaya, “PIC modelling of the plasma sheath”, *EUROfusion Joint Working Session of WPJET1/WPJET2/WPMST1/WPPFC, Tervaniemi, Finland, February, 2015*.

D. Tskhakaya, “Pre-sheath modelling”, *EUROfusion Joint Annual Meeting of WPJET2 and WPPFC, November 2015, JET Culham, UK*.

A. Kirschner, G. Kawamura, D. Tskhakaya, D. Borodin, S. Brezinsek, C. Linsmeier and J. Romazanov, “Modelling of impurity transport and plasma-wall interaction in fusion devices with the ERO code: basics of the code and examples of application”, *15th International Workshop on Plasma Edge Theory in Fusion Devices, Nara, Japan, September 2015;* accepted for publication in *Contrib. Plasma Phys. (2016).*

D. Tskhakaya, “Overview of recent PIC modelling of sheath characteristics”, *EUROfusion Joint Working Session of WPJET1/WPJET2/WPMST1/WPPFC/WPCD, Lisbon, Portugal, March 2016.*

A. Kirschner, G. Kawamura, D. Tskhakaya, D. Borodin, S. Brezinsek, C. Linsmeier and J. Romazanov, “Modelling of impurity transport and plasma-wall interaction in fusion devices with the ERO code: basics of the code and examples of application”, *15th International Workshop on Plasma Edge Theory in Fusion Devices, Nara, Japan, September 2015.*

Calculations of electron-impact ionization cross sections (EICSs) of plasma-relevant compounds

M. Probst, S. Huber et al., Institute for Ion Physics and Applied Physics, UIBK

Materials science plays an important role in the development of the context of the ITER project. Tungsten (W) is considered as a divertor material, and beryllium (Be) will be used as first-wall material. The divertor and the plasma-facing first wall plates in a fusion device must withstand extreme conditions and the degradation processes taking place must be well-understood for safe operation.

We apply several methods of computational materials science that complement each other in order to reach this goal:

- The physicochemical properties of metallic beryllium and tungsten surfaces and of their alloys have been studied by high-quality density functional calculations. The results indicate how easily a Be or W atom can be removed from the surface in terms of the required energy [1].
- The same surfaces were studied by molecular dynamics simulations. We investigated the sputtering by deuterium (D) atoms and the subsequent reactions that can lead to BeD_n molecules.

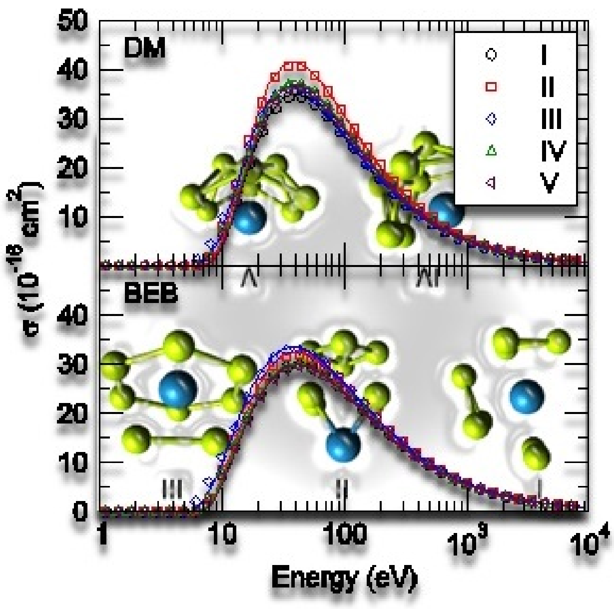


Figure 8. Electron-Impact cross sections of Be_nW molecules calculated with the binary-encounter-Bethe (BEB) and the Deutsch-Märk (DM) formalisms [2].

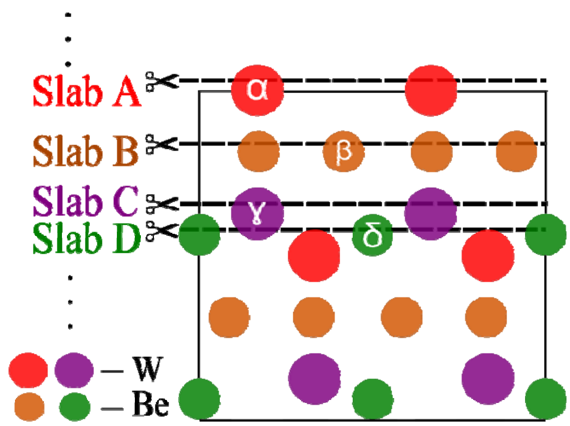


Figure 9. Atoms residing on different $Be_{12}W$ surfaces (α, β, χ and δ) have different binding energies. All of them must be considered [1].

The influence of molecules that become plasma components on the energy balance of the plasma was expressed in terms of electron-impact cross sections (EICS) [2]. EICS are reaction probabilities between electrons and molecules, normally at high electron energy. The total number of reacting particles depends on their concentration. By means of quantum-thermo-chemical calculation we can estimate the equilibrium reaction constants that govern the relative concentrations in a network of particles.

Publications in scientific journals

[1] M. Gyoeroek, A. Kaiser, I. Sukuba, J. Urban, K. Hermansson and M. Probst, "Surface binding energies of beryllium/tungsten alloys", *Journal of Nuclear Materials* ***472*** *(2016), pp. 76-81.* http://dx.doi.org/10.1016/j.jnucmat.2016.02.002

[2] I. Sukuba, A. Kaiser, S. Huber, J. Urban and M. Probst, "Electron impact ionization cross sections of beryllium-tungsten clusters", *European Physical Journal D: Atomic, Molecular, Optical and Plasma Physics* ***70 (1)*** *(2016)*, pp. 1-10.

The Stellarator – an Alternative Concept of a Fusion Plant

Stellarators are a possible long-term alternative to tokamaks. The *Roadmap to the realisation of fusion energy* therefore dedicates a mission of its own to stellarator research. The newest experimental device, Wendelstein 7-X (IPP Greifswald, Germany) can help answer specific questions for ITER and DEMO.

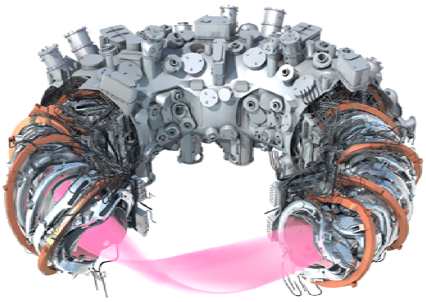


Figure 10. The stellarator Wendelstein 7-X: computer graph showing the plasma vessel, magnetic coil system, parts of the outer shell and plasma current.

Courtesy Max-Planck-Institut für Plasma-physik, http://www.ipp.mpg.de

Preparation and Exploitation of W-7X Campaigns (WPS1)

Probe diagnostics for Wendelstein 7-X

R. Schrittwieser, C. Ionita-Schrittwieser, S. Costea and B.S. Schneider (Institute for Ion Physics and Applied Physics, UIBK)

Originally we proposed the construction of a probe head containing one or more emissive probes for a reciprocating probe manipulator of Wendelstein 7-X for measurements of transport parameters and shear layers in the plasma edge region. A prototype of the probe head of graphite was planned to contain several cold probe pins and initially one, in a later state up to four, electrically heated electron emissive probe (EEP) pins. The probe pins will be arranged in such way that the radial, poloidal and toroidal electric field components can be determined simultaneously; in addition an ion-biased probe pin would be necessary.

Electron-emissive plasma probes have the advantage that they can be used for the direct and reliable determination of the plasma potential because the floating potential of the probe adjusts itself close to the plasma potential. EEPs facilitate and accelerate especially localized measurements of the plasma potential and offer the unique possibility to observe variations of the plasma potential with high temporal resolution.

Since our group s also involved in investigations of filamentary transport in the SOL in medium-sized tokamaks and in the development of a new probe head under the work package MST2, it seems advantageous and sensible to adjust the original objective of the probe design for W7-X. A probe head carrying two cold Langmuir probes, one EEP, two ion retarding field and two triple magnetic pick-up coils is presently designed under MST2. By means of various adaptors this probe head is intended for use in TCV, ASDEX Upgrade and later also in MAST-Upgrade. As a large part of the design has already been completed, it now appears feasible to construct the same type of a new probe head with a suitable adaptor also for Wendelstein 7X. This would have very advantageous synergetic effects and allow for analogous investigations in a stellarator and MSTs.

Presentations at meetings and conferences

<u>R. Schrittwieser</u>, <u>C. Ionita</u>, <u>R. Stärz</u>, <u>S. Costea</u>, <u>B.S. Schneider</u>, V. Naulin, J.J. Rasmussen, A.H. Nielsen, T. Gyergyek, J. Kovacic, Tsv. Popov, M. Dimitrova and P. Ivanova, "Feasibility study for a probe head with emissive probes for Wendelstein 7-X", oral contribution, *Kick-off meeting, EUROfusion WP14-IPH-S1, March 2014*.

See also publications / presentations listed under MST1 and MST2

Stellarator Optimization: Theory Development, Modelling and Engineering (WPS2)

Modelling of electron cyclotron current drive for finite collisionality plasmas

W. Kernbichler, S. Kasilov et al., Institute of Theoretical and Computational Physics, TU Graz

Summary of work performed

The low-shear concept of Wendelstein 7-X avoids low-order rational flux surfaces in the plasma core, since these can form magnetic islands. This feature might be destroyed by an even small bootstrap current, which should be compensated by electron cyclotron current drive (ECCD). Therefore, the impact of finite collisionality effects on the generation of currents by ECCD in a high-mirror configuration of W7-X was investigated. Computations were performed with a combination of the transport code NEO-2, a drift kinetic equation solver for plasmas with finite collisionality using the full linearized Coulomb collision operator without simplifications on device geometry, and TRAVIS, a ray-tracing code for modeling electron cyclotron current drive, heating and emission. Methods and first results were presented at several topical workshops and conferences as listed below.

Conference contributions

W. Kernbichler, G. Kapper, S.V. Kasilov and N.B. Marushchenko, "Computation of the Spitzer function in stellarators and tokamaks with finite collisionality", *18th Joint Workshop on Electron Cyclotron Emission and Electron Cyclotron Resonance Heating, Nara, Japan, April 2014*. http://dx.doi.org/10.1051/epjconf/20158701006

G. Kapper, W. Kernbichler, S.V. Kasilov and N.B. Marushchenko, "Modeling of electron cyclotron current drive for finite collisionality plasmas in Wendelstein 7-X,", *42nd EPS Conference on Plasma Physics, Lisbon, Portugal, June 2015. http://ocs.ciemat.es/EPS2015PAP/pdf/P1.164.pdf*

G. Kapper, S.V. Kasilov, W. Kernbichler, A.F. Martitsch and N.B. Marushchenko, „Impact of finite collisionality effects on electron cyclotron current drive in stellarators", *20th International Stellarator-Heliotron Workshop, Greifswald, Germany, October 2015*.

S. V. Kasilov, W. Kernbichler and V.V. Nemov, "Real space and flux coordinate calculations and fast particle losses in the optimized stellarator", *20th International Stellarator-Heliotron Workshop, Greifswald, Germany, October 2015*.

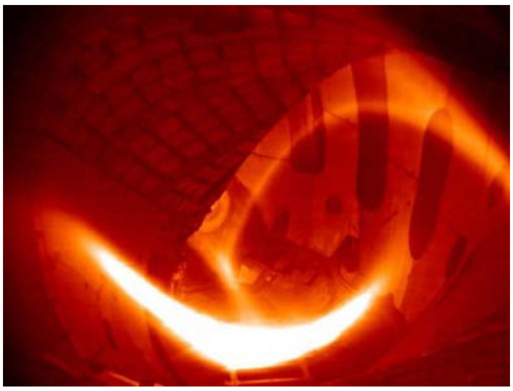


Figure 11. The first hydrogen plasma in Wendelstein 7-X.

Courtesy Max-Planck-Institut für Plasmaphysik, http://www.ipp.mpg.de

POWER PLANT PHYSICS AND TECHNOLOGY

Magnet System (WPMAG)

Characterization of high-temperature superconductors

M. Eisterer, D.X. Fischer, R. Prokopec et al., Atominstitut, TU Wien

Summary of work performed

Commercially available coated conductors were irradiated in a fission research reactor to investigate their robustness against neutron radiation in a fusion magnet. A maximum fast neutron fluence of 3.3×10^{22} m^{-2} (E>0.1 MeV) was achieved. A strong influence of the operation temperature on changes of the critical current was found. At low temperatures, no degradation of the critical currents was observed at low temperatures up to the highest neutron fluence. It was shown that Cd and Gd are suitable materials to shield the low energy neutrons, which significantly contribute to the neutron spectrum of the fission reactor and cause defects in superconductor tapes. Shielding of thermal neutrons is essential for simulating radiation effects in fusion magnets by a fission reactor as a neutron source, if the superconductor contains elements which have a high neutron capture cross section at low energies. Low energy neutrons are negligible in the expected neutron energy distribution within a fusion magnet.

Short coated conductor samples were patterned to reduce the critical currents. It was demonstrated that this technique is suitable to assess high critical current densities at low temperatures.

Conclusion

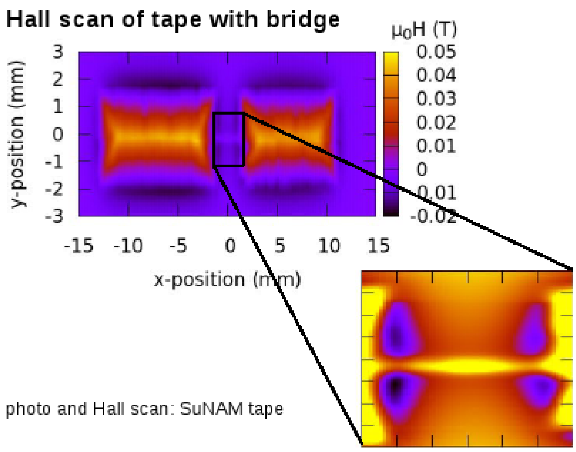


Figure 12. Hall scan of a tape with a bridge

Results have shown that low energy neutrons can be effectively shielded by Gd or Cd foil. The differences in the resulting neutron spectrum do not cause significant differences in the properties of the irradiated Gd-123 tape. This indicates a small sensitivity of the tape to irradiation with neutrons of intermediate energies which are present in a (moderate) fusion spectrum. We conclude that we can use Cd as the shield material to obtain a sufficient approximation of the neutron energy distribution in fusion magnets. However, damage energy calculations for both the (shielded) fission and fusion spectra are desirable in order to enable a proper prediction of the influence of neutron radiation on superconducting properties.

A reduction of the superconducting cross section by etching (if permitted by the tape architecture) enables a characterization of short coated-conductor pieces down to a temperature of 4.2 K with the existing set-up.

Publications in scientific journals

R. Prokopec, D. X. Fischer, H. W. Weber and M. Eisterer "Suitability of coated conductors for fusion magnets in view of their radiation response", *Supercond. Sci. Technol.* ***28*** *(2015),* 014005. http://dx.doi.org/10.1088/0953-2048/28/1/014005

Conference contributions

D.X. Fischer, R. Prokopec, D. Kagerbauer, C. Eckhardt and M. Eisterer, "Assessment of critical currents in coated conductors at low temperatures", *12th European Conference on Applied Superconductivity (EUCAS), Lyon, France, 6th September 2015.*

Materials (WPMAT)

Fracture toughness experiments and microstructural analysis on tungsten foils/laminates

R. Pippan, P. Kutlesa, V. Nikolic et al., Erich Schmid Institute of Materials Science at ÖAW

Summary of work performed

A technique for producing and treating specimens for investigating the fracture behaviour of 100 µm thin tungsten foils was developed in order to obtain suitable specimens for fracture experiments. Depending on the crack plane and crack propagation direction with respect to the foil plane, we distinguish between three principal crack systems:

- ✓ ***Red system*** with a crack propagating across the foil plane
- ✓ ***Yellow system*** with a crack propagating perpendicular to the foil plane
- ✓ ***Green system*** with a crack propagating within the foil plane

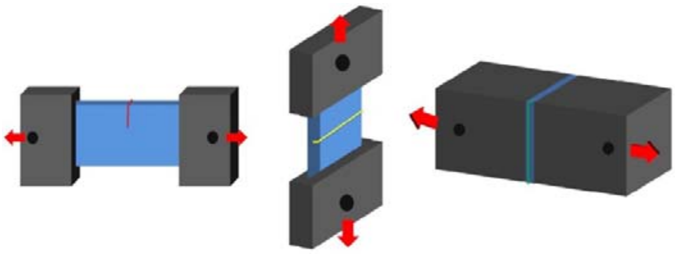


Figure 13. Testing systems depending on crack propagation; loading directions are indicated with red arrows.

Fracture experiments were performed at different testing directions, temperatures and speed using a universal testing machine. The fracture surfaces of every tested specimen were analyzed in detail. A scanning electron microscope (SEM) with an electron back–scattered diffraction (EBSD) detector was used for investigating the fracture surface, evaluating the microstructure of the foil, and analysing texture and grain orientation. Different heat treatments were performed in order to evaluate and compare changes in the microstructure of the investigated materials. .Crack tip opening displacement (CTOD) measurements were performed for evaluating fracture toughness in the ductile regime. We also studied the possibility of using a pico-second laser as a tool for crack introduction.

Conclusion

The fabrication route of thin tungsten foils for fracture behaviour experiments was completed and tested for the red crack system. The fracture behaviour of thin tungsten and potassium-doped tungsten (WVM) foils show an improved behaviour and significantly higher fracture toughness values compared to bulk W materials, which may be due to the grain shape induced by the higher degree of deformation. With a change in testing temperature, the fracture surfaces show brittle behaviour at liquid nitrogen and delamination and ductility at higher temperatures. Experimental results for WVM obtained until now indicate even better behaviour in comparison with W foil, which could be related to the more stable microstructure of these materials.

The fabrication route for the yellow system was completed and initial fracture experiments were performed. The green system does not appear feasible till now.

Conference contributions

V. Nikolic, S. Wurster and R. Pippan, “Improved fracture behavior and microstructural characterization of thin tungsten foils”, poster, *15th International Conf. on Plasma-Facing Materials and Components for Fusion Applications (PFMC15), Aix-en-Provence, France, 18th May 2015.*

V. Nikolic, S. Wurster, D. Firneis and R. Pippan, “Improved fracture behavior and microstructural characterization of thin tungsten foils”, oral presentation, *17th International Conference on Fusion Reactor Materials (ICFRM), Aachen, Germany., 11th October 2015.*

Socio-Economic Studies (WPSES)

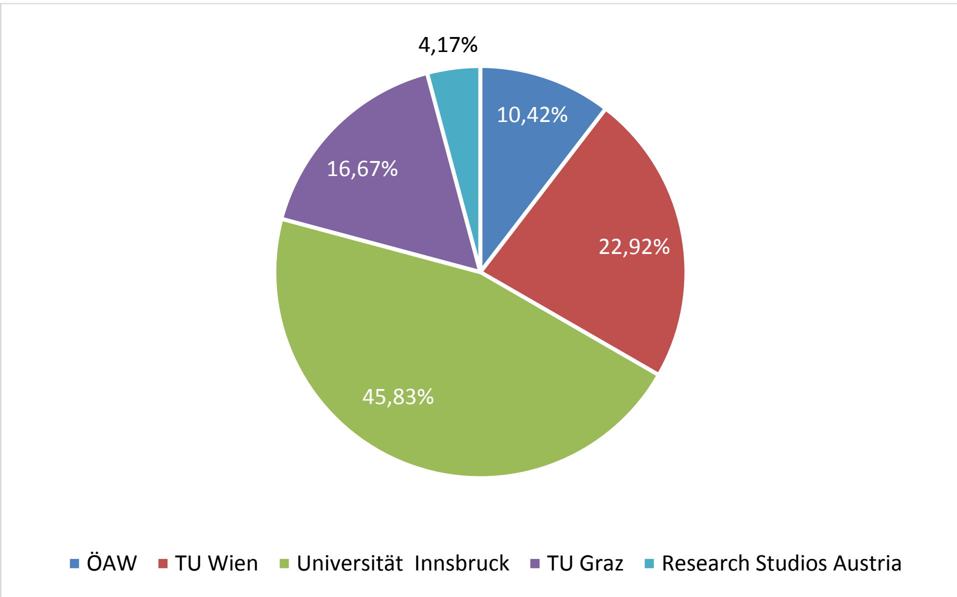
Development of the EFDA TIMES model

M. Biberacher and S. Gadocha, Research Studios Salzburg FG

The EFDA-TIMES Model (ETM) is an economic model of the global energy system based on the TIMES (The Integrated MARKAL-EFOM System) Framework. The development of the EFDA-TIMES model within EFDA-SERF (Socio Economic Research on Fusion) started in 2004.General scope of the model is the identification of trends in the development of the global energy system with a special focus on fusion power shares in the energy system on the long run (time horizon up to 2100).

In the framework of the EUROfusion Work Package "Socio-Economic Studies" the EFDA-TIMES model is further exploited in co-operation of experts from the consortium members CIEMAT (Spain), CCFE (United Kingdom), IPP Garching (Germany), DTU (Denmark), ENEA (Italy) and ÖAW (Austria). The TIMES economic model generator in which ETM is implemented is a technology-rich tool, intended for the investigation of the local, national or multi-regional energy system evolvement over a long time period. The EFDA-TIMES model is specifically designed to explore the role of fusion technology in a future energy market and identify which parameters affect its market competitiveness. The model time horizon covers the time range from 2005 (the base year) to 2100 and assumes that from 2050 on fusion power plants are likely to be ready for the market (further information: https://www.euro-fusion.org/collaborators/socio-economics/economics/model/).

AUSTRIAN PARTICIPATION IN EUROFUSION: SHARE OF ÖAW AND LINKED THIRD PARTIES



PARTICIPATION IN F4E GRANTS

PROGRAMME HEADING	*INSTITUTION*	*SCIENTISTS INVOLVED*
Nuclear Data	TU Wien	H. Leeb

Overview on participation in EUROfusion workpackages

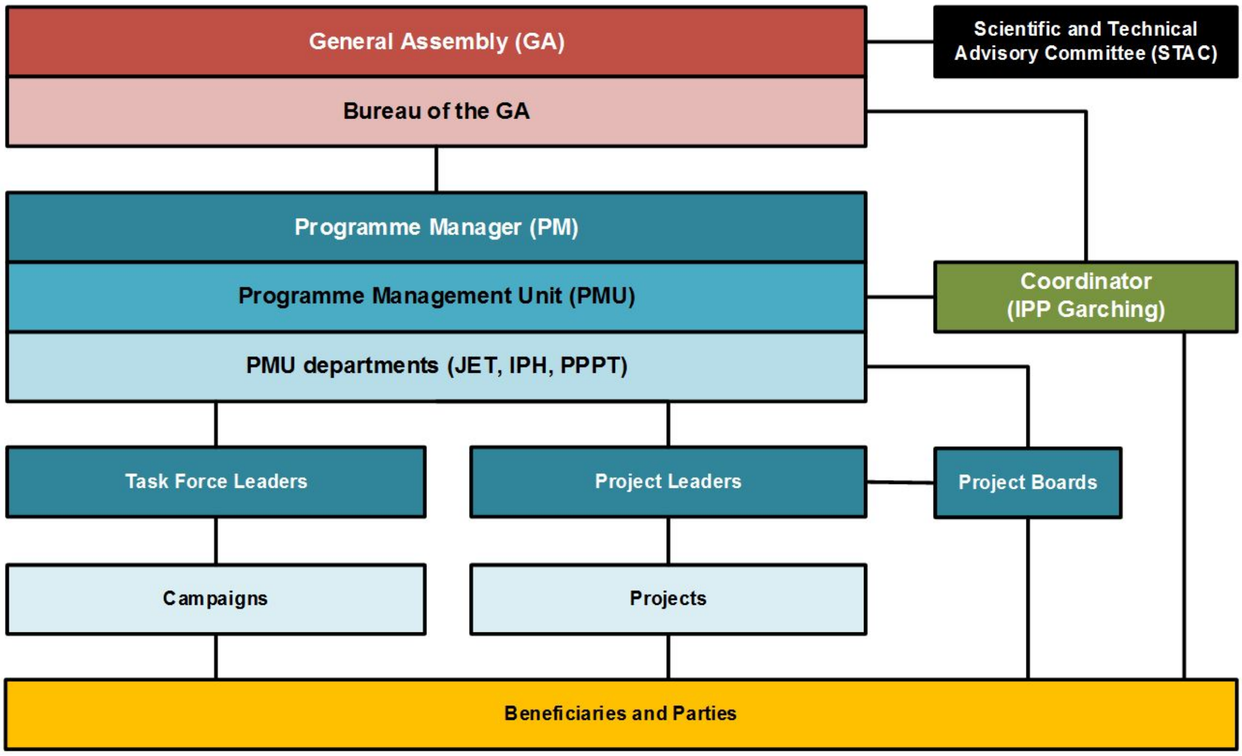
Period: 2014/2015

PART OF THE PROGRAMME	*INSTITUTION*	*SCIENTISTS INVOLVED*
ITER PHYSICS		
WP01 JET Campaigns (WPJET1)	UIBK	K. Schöpf
WP04 JET Enhancements (WPJET4)	UIBK	K. Schöpf
WP05 Medium-Sized-Tokamak Campaigns (WPMST1)	TU Graz TU Wien UIBK	W. Kernbichler F. Aumayr A Kendl R. Schrittwieser
WP06 Preparation of the Exploitation of Medium-Sized Tokamaks (WPMST2)	UIBK	R. Schrittwieser C. Ionita
WP07 Preparation of efficient PFC operation for ITER and DEMO (WPPFC)	TU Wien TU Wien UIBK	F. Aumayr D. Tskhakaya M. Probst
WP11 Preparation and Exploitation of W7-X Campaigns (WPS1)	TU Graz TU Wien UIBK	W. Kernbichler F. Köchl R. Schrittwieser
WP12 Stellarator optimization theory development, modelling and engineering (WPS2)	TU Graz	W. Kernbichler
WP13 Code Development for integrated modelling (WPCD)	TU Wien UIBK	D. Tskhakaya K. Schöpf
POWER PLANT PHYSICS AND TECHNOLOGY		
WP16 Magnet system (WPMAG)	TU Wien	M. Eisterer
WP25 Materials (WPMAT)	ÖAW-ESI	R. Pippan
Socio-Economic Research on Fusion (SERF)		
WP28 Socio Economic studies (WPSES)	Research Studios Austria FG	M. Biberacher
EDUCATION		
WP30 Education (WPEDU)	TU Graz ÖAW-ESI TU Wien UIBK	20 PhD students 12 mentors
ENABLING RESEARCH (2014)		
WP32 Enabling Research (WPENR)	TU Wien TU Wien UIBK UIBK UIBK	D. Tskhakaya F. Aumayr A. Kendl. Schrittwieser K. Schöpf

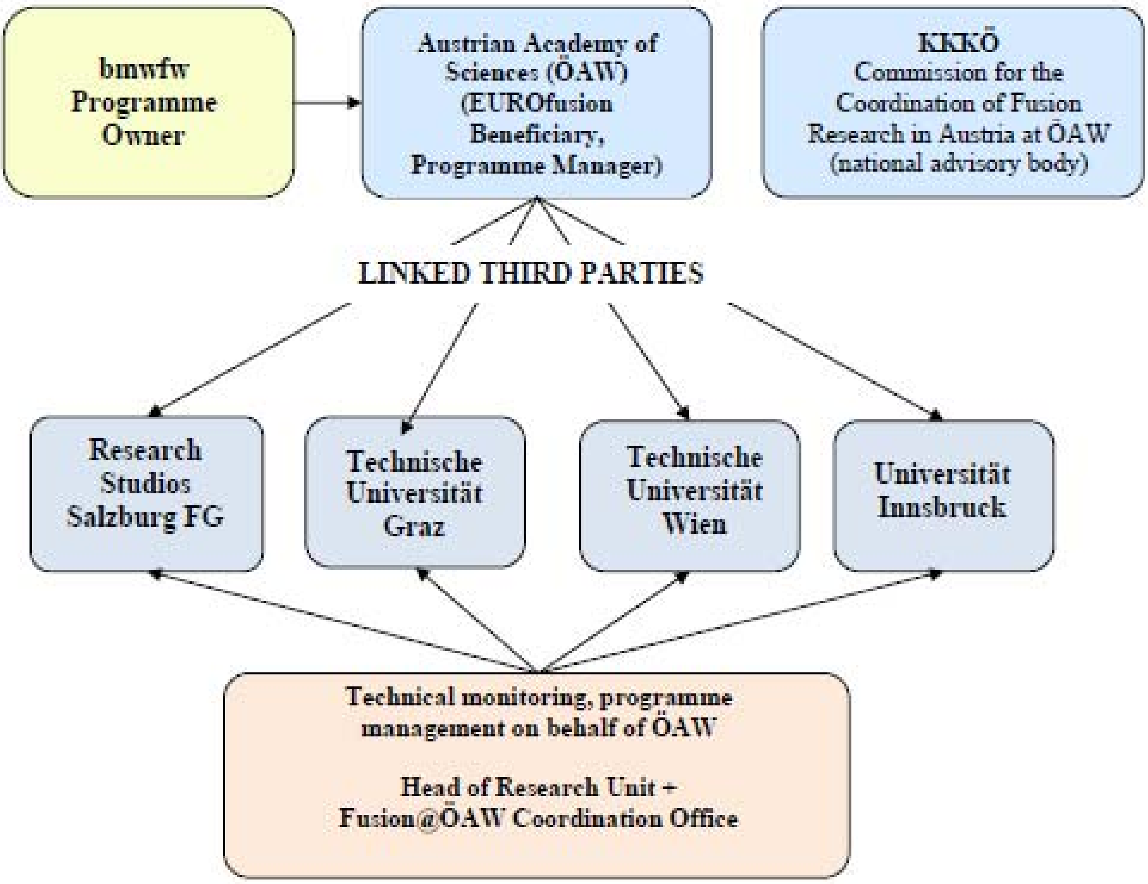
Abbreviations: TU Graz = Technische Universität Graz
TU Wien = Technische Universität Wien
UIBK = Universität Innsbruck
ÖAW-ESI = Erich Schmid Institute of Materials Science at ÖAW

MANAGEMENT STRUCTURE

EUROFUSION ORGANIGRAM



AUSTRIAN PARTICIPATION (Fusion@ÖAW)



AUSTRIAN REPRESENTATIVES IN COMMITTEES RELEVANT FOR FUSION RESEARCH AND DEVELOPMENT (2014/2015)

Fusion Programme Committee

Dr. Daniel Weselka	Federal Ministry of Science, Research and Economy
Univ.Prof.Dr. Friedrich Aumayr	Institute of Applied Physics / Technische Universität Wien

EUROFusion General Assembly

Univ.Prof.Dr. Friedrich Aumayr	Institute of Applied Physics /Technische Universität Wien

Governing Board of *Fusion for Energy*

Dr. Daniel Weselka	Federal Ministry of Science, Research and Economy
Univ.Prof.Dr. Harald W. Weber	Atominstitut / Technische Universität Wien

F4E Administration and Finance Committee/
F4E Administration and Management Committee (as of 2015)

Mag. Monika Fischer	Austrian Academy of Sciences

Industrial Liaison Officer	Mag. Gregor Postl		Austrian Federal Economic Chamber
	Mag. Birgit Murr		Austrian Federal Economic Chamber
Public Information Group	Mag. Monika Fischer		Austrian Academy of Sciences
	Mag. Elisabeth Wieninger	(2014)	Austrian Academy of Sciences
	Lätitia Unger BSc	(2015)	Austrian Academy of Sciences

Kommission für die Koordination der Kernfusionsforschung in Österreich (KKKÖ)

Chair:	Univ.Prof.Dr. Peter Steinhauser (ÖAW)

ABBREVIATIONS AND ACRONYMS

Fusion experiments

AUG	ASDEX Upgrade, facility at IPP Garching
COMPASS	Tokamak at the Institute of Plasma Physics of the Czech Academy of Sciences, Prague
ITER	“The way” (under construction at Cadarache, France)
JET	Joint European Torus, UKAEA, Culham, UK
PISCES-A	Linear plasma device at Forschungszentrum Jülich
TCV	Tokamak à Configuration Variable, EPFL, Lausanne, Switzerland
W7-X	Wendelstein 7-X, IPP Greifswald, Germany

Scientific and technical abbreviations

H-mode regime	A high confinement regime develops when a tokamak plasma is heated above a characteristic power threshold, which increases with density, magnetic field and machine size. It is characterised by a sharp temperature gradient near the plasma edge (resulting in an edge “temperature pedestal”). The H-mode typically doubles the energy
L-mode regime	The low confinement regime of additionally heated tokamak operation
Li-BES	Lithium beam-emission spectroscopy
BEB	Binary encounter Bethe formalism
DM	Deutsch-Märk formalism
EBSD	Electron backscatter diffraction
ECCD	Electron cyclotron current drive
EEP	Electron emissive probe
ETM	EFDA-TIMES model
LAM	Lost alpha monitor
LRM	Lost alpha rays monitor
PFC	Plasma-facing components
PIC simulation	Particle-in-cell simulation
SEM	Scanning electron microscope
SOL	Scrape-off layer
SPU	Scintillator Probe Upgrade at JET

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Back cover: ITER side-cut. Source: http://www.iter.org/

Photo of sunset: Fusion@ÖAW

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Fusion Research...

...bringing the sun to Earth