Fusion Research in Austria

Activities in 2022 and 2023

Photo on cover page:

9th Fusion Day at TU Wien, Vienna, on 15.11.2022.

Courtesy Technische Universität Wien, Institut für Angewandte Physik

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Activities in 2022 and 2023

Vienna

March 2024

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Compiled and edited by Lätitia Unger and Nadja Lampichler

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It has been three years since EUROfusion entered the new Horizon Europe Framework Programme. During this time, Austrian fusion research has shown itself to be well integrated into the overall European efforts.

A lot has happened in the last three years in the field of nuclear fusion research: records have been announced and important milestones have been reached. The energy output of 59 megajoules during the DTE2 campaign at JET, the generation of 69 megajoules of energy during the DTE3 campaign and thus beating the previous record, and the generation of a plasma with an energy conversion of 1.3 gigajoules over eight minutes at Wendelstein 7-X are just a few examples. Events like these led to a lot of media coverage and to a noticeable increase in public interest in the subject. Further, the number of private companies investing in nuclear fusion has increased significantly recently. The imminent threat of climate change and the future increase in energy demand are making people aware of the necessity and benefits of fusion energy for the future. In addition, the war in Ukraine and, in this context, the dependence on Russian gas have contributed significantly to an even greater awareness of the need for other forms of energy, including nuclear fusion.

ITER, which is currently being built in Cadarache in southern France, will play a key role in making fusion power a reality. It is, however, a first-of-a-kind project, and like all undertakings of this kind, it is not immune to problems and setbacks. In November 2022, it was announced that defects had been found in two important tokamak components. And effects of the Corona pandemic still remain a challenge. These and other reasons lead to a further delay of the first plasma. However, a repair strategy for the damaged components was immediately developed and the construction of ITER has nevertheless made impressive progress over the last two years. We summarised the most important developments in chapter I.

The challenges mentioned in the above paragraph will undoubtedly have an impact on the ITER timeline. For this reason, a baseline review is currently underway and will be presented to the ITER council in 2024. As the EUROfusion Roadmap will also be affected by the current developments, an amendment to it is also being worked on.

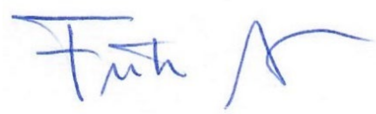
This brochure is intended to highlight the integration of Austrian fusion research into the European Fusion Research Programme and make successes visible. The largest part of Austrian fusion research is performed at university institutes, with approximately fifteen PhD students and their supervisors participating per year. Education and training of young researchers therefore continues to be an important objective of the Austrian Fusion Research Programme, which is well recognized by the number of PhD theses supported within the EUROfusion work package *Training and Education*. Selected theses completed in the period 2022/2023 or near completion are presented in chapter II.3.

As Austria does not have its own fusion facilities, opportunities to contribute to experiments and modelling at ASDEX Upgrade, TCV Tokamak, MAST 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 *Tokamak Exploitation* and *Stellarator – W7X*.

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.

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 cooperation and support:

the Austrian Federal Ministry of Education, Science and Research
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, March 2024 (Friedrich Aumayr
Head of Research Unit, Fusion@ÖAW)

I. ON THE ROAD TO FUSION ELECTRICITY

ITER

On 28. July 2020, the assembly phase of the ITER project officially started. Since then, construction has progressed rapidly and is now 78% complete. ITER is being built in international cooperation, with components delivered by the domestic agencies of all ITER partners (People's Republic of China, European Union, India, Japan, Russian Federation, South Kora and United States of America). The plant is scheduled to start its operation in the 2030s. An exact date cannot be given at present. Currently, a review of the ITER baseline is underway and will be presented to the ITER Council in 2024.

In the last two years many milestones have been achieved. These include e.g. the arrival of poloidal field coil #1 (produced by Russia) in February 2023 and the successful delivery of all toroidal field coils (18 + one replacement coil) to the ITER construction site, but also the lifting and positioning of the first vacuum vessel module into the tokamak pit in May 2022.

Bernard Bigot, who was the Director General of the ITER organization from 2015-2022, passed away in May 2022. In September 2022, the ITER Council appointed Pietro Barabaschi as the new Director General, who has dedicated almost his entire professional career to fusion research and has worked at JET, ITER and most recently at F4E.

On 10 February 2023, poloidal field #1 arrived at the ITER construction site. Its journey began in November 2022 in Saint Petersburg. This marked a significant milestone for the ITER Project, as all seven Members have now delivered at least one of the major components they are responsible for. Also, with PF1 in protective storage, all six poloidal field coils were now safely "home".

Source: ITER Organization

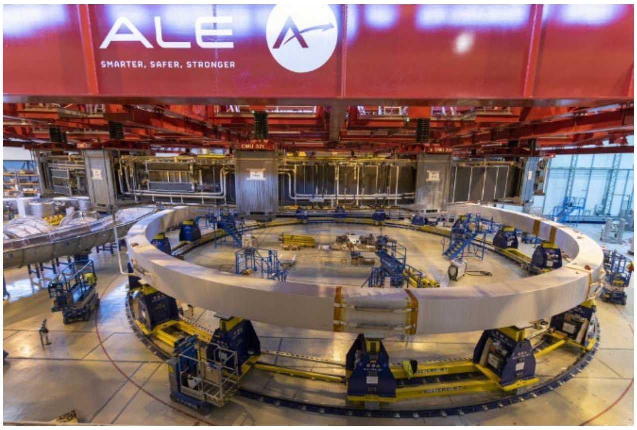
The ITER construction site in February 2023.

Source: ITER Organization

The European Domestic Agency – Fusion for Energy (F4E)

F4E was established for a period of 35 years from 19. April 2007. Calls for tender, vacancies and up-to-date information on the progress of the ITER project are published on the F4E website.

In February 2023, Marc Lachaise was appointed as the new director of F4E. Before that, he worked in various leadership positions in the EDF Group (Électricité de France) for 27 years.



ITER's Poloidal Field coil 4, produced by F4E in Europe, Poloidal Field coils factory, Cadarache. Together with Poloidal Field coil 3, these are the world's biggest superconducting magnets, each measuring 24 m in diameter.

Source: ITER Organization

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.

EUROfusion

The first plasma in ITER is expected to be generated in the 2030s. To prepare for the experimental campaigns at ITER, EUROfusion manages campaigns at European tokamaks such as JET (Culham, UK), ASDEX Upgrade (IPP Garching, Germany), TCV (Lausanne, Switzerland) and MAST-U (Culham, UK) 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. Up-to-date information about recent results, news and vacancies within the European fusion research can be found at www.euro-fusion.org.

In July 2022, the Horizon EUROfusion Event took place in Brussels. It marked the start of a planned annual series of events presenting past and future fusion research highlights.

In July 2023, the **new EUROfusion programme manager** was elected at the 43rd General Assembly Meeting in Cadarache. The voting procedure resulted in the selection of Ambrogio Fasoli (EPFL Lausanne), who took over the daily management of EUROfusion from 1. January 2024. The term of office of the previous programme manager Tony Donné expired at the end of 2023.

Work is currently underway to amend the EUROfusion Roadmap. A working group established for this purpose prepared a first proposal in summer 2023.

Ambrogio Fasoli was elected as the new EUROfusion programme manager on 19. July 2023. He is based at EPFL in Lausanne, Switzerland, but will also often work in the EUROfusion Programme Management Unit in Garching near Munich. Source: EUROfusion

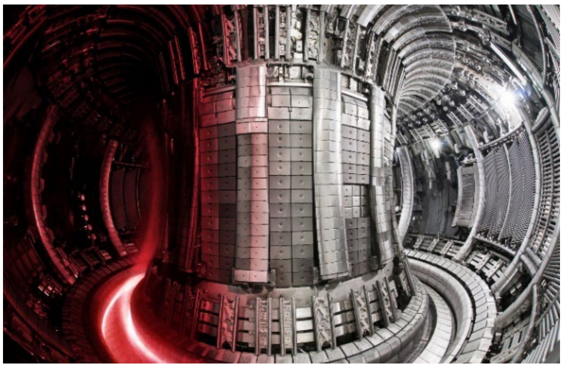
Among other things, the amendment will focus on the parallelization of activities, with the goal of DEMO operation from 2045.

JET (CCFE, Culham, United Kingdom)

JET (Joint European Torus) at the Culham Centre for Fusion Energy (CCFE) was for a long time the largest tokamak in the world. EUROfusion provided the work platform for jointly exploiting JET in an efficient and focused way, managing experiments at JET within the annual work programmes of the ITER Physics Department.

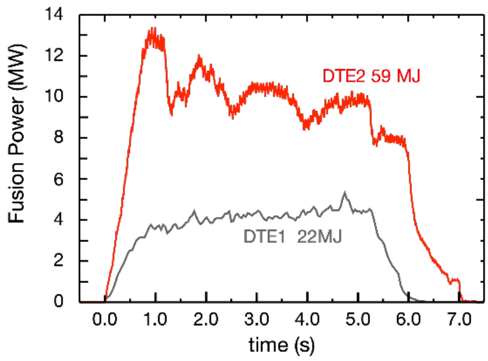
JET was the only facility capable of conducting experiments with the fuel of future fusion power plants, a mixture of deuterium and tritium (DTE). The results of the experiments with JET were therefore of great importance for ITER and other future power plants. In February 2022, the results of the DTE2 campaign conducted with JET in 2021 were presented. The energy output of 59 megajoules achieved in these experiments has more than doubled the previous fusion energy record of 22 megajoules set in 1997.

In September 2022, new experiments with helium were started. ITER will use helium plasmas at the start of its commissioning, therefore the helium experiments are also very important for the future operation of ITER. From August to October 2023 the third and final deuterium-tritium campaign at JET (DTE3) took place. DTE3 involved over 300 scientists from across Europe. The experiments in this campaign generated 69 megajoules of energy, exceeding the record set in 2021.



Interior of JET with a superimposed plasma

Source: [UKAEA]

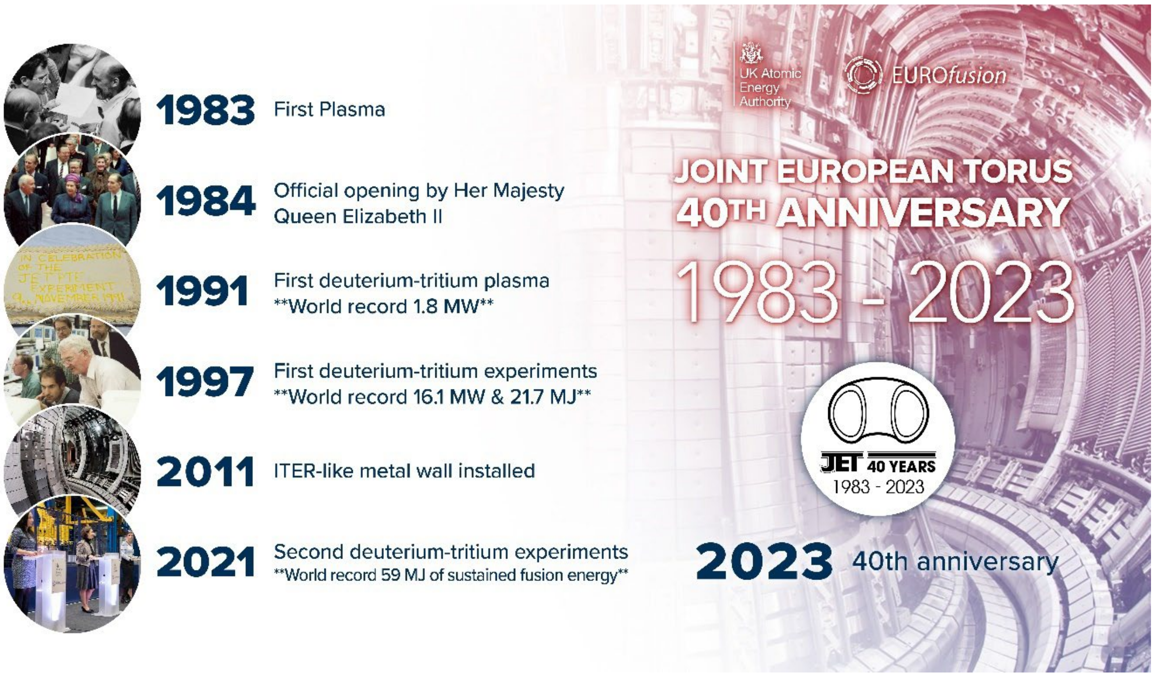


Fusion output comparison between DTE1 in 1997 and DTE2 in 2021.

Source: [UKAEA]

40th Anniversary

JET's first plasma was ignited on 25. June 1983. Scientists and staff gathered to celebrate this anniversary. This also marked JET's entry into its final phase: After the third DTE campaign and the new experiments with helium in autumn 2023, the fusion facility will finally be decommissioned in 2024.



JET timeline

Source: UKAEA

Experiments at medium-size tokamaks

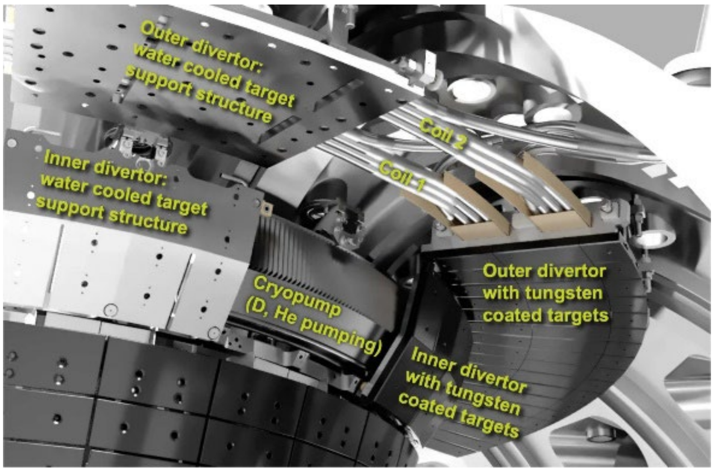
(TE) managed by EUROfusion

With the tokamak exploitation programme, EUROfusion coordinates research on ASDEX Upgrade (AUG), TCV, MAST and WEST. This multi-machine approach is instrumental to progress in the field, as ITER and DEMO core/pedestal and scrape-off layer (SOL) are not achievable simultaneously in present day devices. In the new framework programme *Horizon Europe*, the campaigns are now called tokamak exploitation (TE) instead of MST (medium-size tokamak).

ASDEX Upgrade (IPP Garching, Germany)

The ASDEX Upgrade tokamak produced its first plasma on 21. March 1991. Therefore, the facility celebrated its 30th anniversary in 2021. In 2002, ASDEX Upgrade was opened for use by fusion laboratories from all over Europe. In 2014, joint exploitation started in the framework of the *Medium Size Tokamak Programme* (MST) of EUROfusion.

In July 2022, ASDEX Upgrade was shut down for the next two years. The fusion facility is now being prepared for its next mission: testing a new divertor concept in which the magnetic flux tubes are flared near the power-receiving wall sections, i.e. close to the divertor. For this purpose, new main components will be installed: cryopumps, two concentric in-vessel coils and a new divertor. In July 2024, the tokamak is scheduled to start experimenting again.

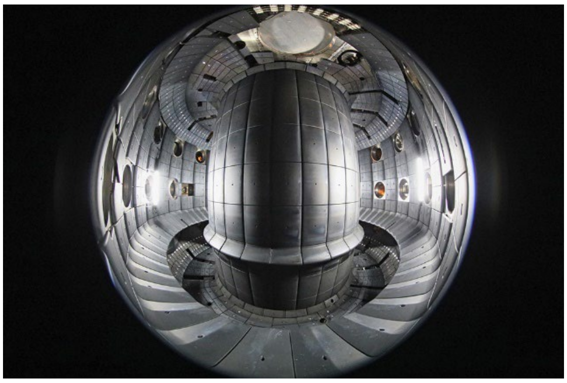


Components of the new upper divertor of ASDEX Upgrade

Source: IPP

TCV (Swiss Plasma Center, Lausanne, Switzerland)

The Tokamak à Configuration Variable (TCV) started operation at École Polytechnique Fédérale de Lausanne (EPFL) in 1992. In 2015/2016 the machine was upgraded to enforce its capabilities such as strong shaping and electron heating with ion heating, additional electron heating compatible with high densities and variable divertor geometry. The TCV programme aims at ITER support, explorations towards DEMO and fundamental research.
In September 2023, the 30th anniversary of TCV was celebrated in Lausanne.

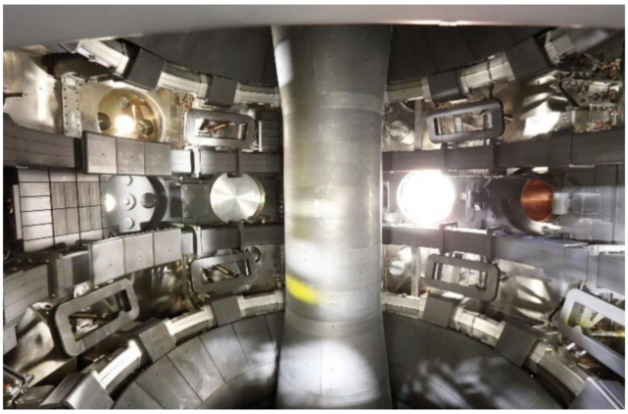


Interior of the TCV tokamak at EPFL

*Source: Alain Herzog/*EPFL

MAST-U (CCFE, Culham, United Kingdom)

The Mega Ampere Spherical Tokamak (MAST) was in operation from 1999-2013. Afterwards it was shut down for a seven-year upgrade program. The upgraded MAST (MAST-U) produced its first plasma in October 2020 and resumed operation. MAST-U is a compact tokamak designed to investigate whether a smaller construction makes cheaper fusion power plants possible. Moreover, it is tackling one of fusion energy's biggest challenges: plasma exhaust. For this, the 'Super-X divertor' is being tested at MAST-U. This is an exhaust system designed to reduce heat and power loads from particles leaving the plasma, which should mean divertor components will last much longer.



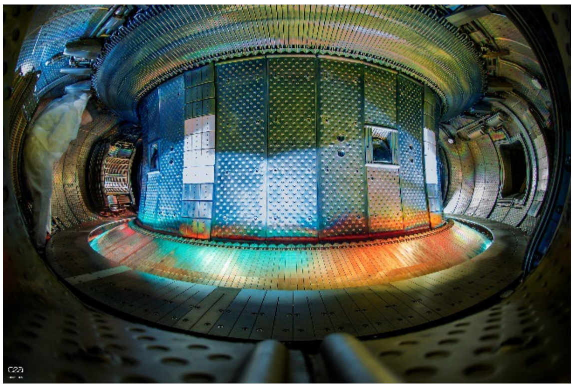
Interior of the MAST Upgrade Spherical Tokamak,

Source: UKAEA

WEST (CEA, Cadarache, France)

The W Environment in Steady-state Tokamak (where W is the chemical symbol for tungsten) is the transformation of the Tore Supra tokamak which was commissioned in 1988. In March 2013, Tore Supra was upgraded to produce plasmas with similar properties to ITER. As part of the upgrade, the reactor, now renamed WEST, received new poloidal coils to achieve diverted operation, a new cooling system, and all-metal cladding.

In February 2023, after an eighteen-month shutdown, WEST was brought back into operation. During this time, it was outfitted with the same exhaust system as ITER. This will allow scientists to study how ITER's wall materials evolve over its lifetime and how this affects its operations.



WEST Vacuum Vessel

Source: CEA

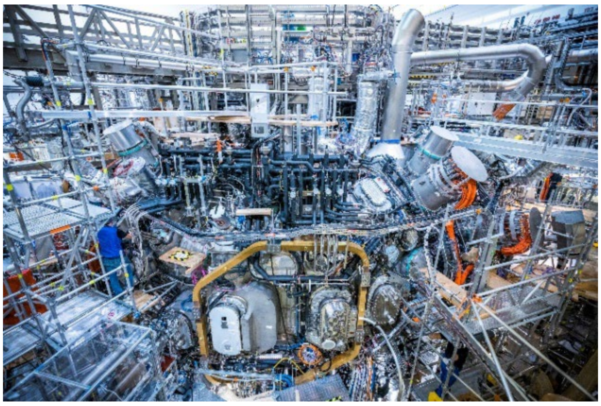
Wendelstein 7-X (IPP Greifswald, Germany)

Wendelstein 7-X is the worldwide largest stellarator type fusion device. After completion of the main assembly phase, the first plasma was achieved in December 2015. The facility was officially inaugurated on 3. February 2016 in the presence of the then German chancellor Angela Merkel.

At the end of 2018, a major reconstruction started. Among other things, a new water-cooled divertor was installed and the cryosystem, plasma heating and measurement systems were expanded. These upgrades enable higher heating power and longer plasma pulses, both important requirements for a key feature of a future fusion power plant: continuous operation.

After more than three years, the experiments finally resumed in autumn 2022. A new milestone was already reached in February 2023: an energy conversion of 1.3 gigajoules was achieved for the first time. The plasma discharge lasted 8 minutes - also a new record for the stellarator.

Within a few years, the plan is to increase the energy turnover at Wendelstein 7-X to 18 gigajoules, with the plasma then being kept stable for up to 30 minutes.



Wendelstein 7-X in November 2021

*Source: J. M. Hosan/*IPP

JT-60SA

On 1. December 2023, the inauguration ceremony for the tokamak JT-60SA took place in Naka, Japan. First plasma was ignited in October 2023. This will be the largest fusion facility working with magnetic confinement before ITER is in operation.

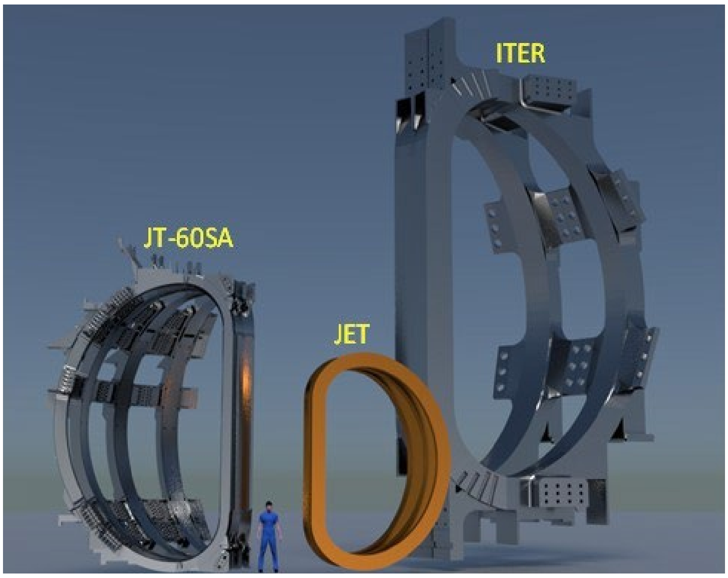


Image comparing JT-60SA, JET and ITER

Source: www.jt60sa.org

II. *FUSION RESEARCH IN AUSTRIA*

Activites in 2022 and 2023

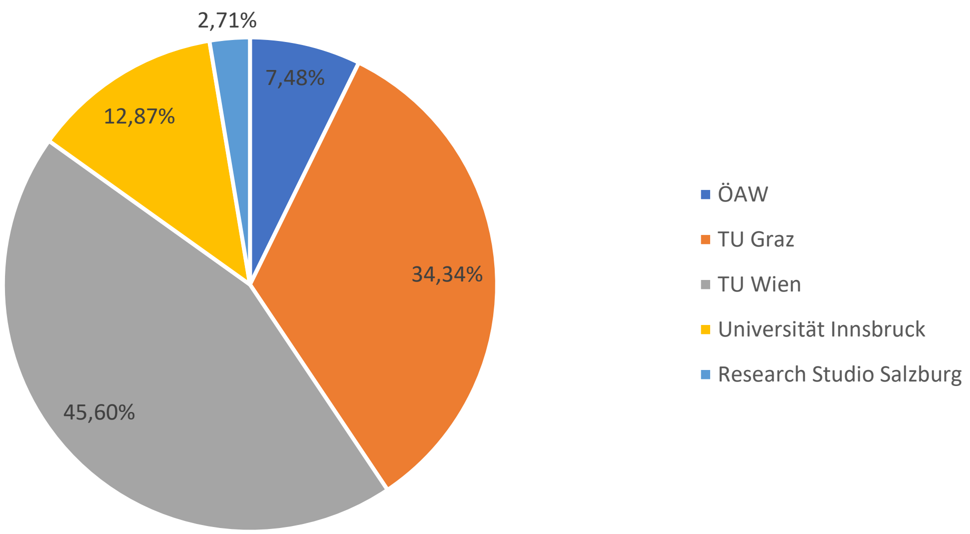
1. *OVERVIEW*

The Austrian Research Unit

The largest part of Austrian fusion research is performed at university institutes, with approximately 18 PhD students per year. Education and training of young researchers therefore continues to be the major focus of the Austrian Fusion Research Programme. Major activities/topics are measurements and experiments in medium-size tokamaks, plasma-wall interaction, modelling and simulation of plasma phenomena in tokamaks and stellarators, materials science, superconductors for fusion application and socio-economic studies on future energy scenarios.

Participation in EUROfusion

The Austrian Academy of Sciences (ÖAW) acts as national entry point and beneficiary of the EUROfusion Grant Agreement. 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. The share of ÖAW and its Affiliated Entities is shown below.



Austrian participation in EUROfusion:

Share of ÖAW and Affiliated Entities (based on expenditure in 2022 and 2023)

Source: Fusion@ÖAW

EUROfusion under Horizon Europe

Horizon Europe is the EU's key funding programme for research and innovation and the successor of the Horizon 2020 programme. The primary objectives of Horizon Europe are to strengthen research in the areas of climate change, the UN's Sustainable Development Goals and EU competitiveness. It was launched in 2021 and is scheduled to last until 2027.

EUROfusion has now been part of the Horizon Europe framework programme for three years. In the last two years, Austrian participation in the individual work packages has remained about the same as in the previous years. A new addition is the *DEMO Design* work package (**WPDES**). The aim of this work package is to support the central DEMO team to advance the technical basis of the experimental fusion reactor DEMO, the successor project to ITER, which is to demonstrate the next generation of electric power from nuclear fusion.

The *Training and Education* work package (**TRED**) still represents the largest EUROfusion participation of Fusion@ÖAW. The following table shows the Austrian participation in the work packages in 2022 and 2023.

Participation in EUROfusion workpackages

Period: 2022/2023

Abbreviations:

PART OF THE PROGRAMME	*INSTITUTION*	*GROUPS INVOLVED*
ITER PHYSICS		
WP01 Tokamak Exploitation (WPTE)	TU Graz TU Wien UIBK	C. Albert F. Aumayr R. Schrittwieser
WP03 Wendelstein 7-X (WPW-7X)	TU Graz	C. Albert
WP04 Theory, Simulation, Verification and Validation (WPAC)	TU Graz	C. Albert
WP05 Plasma Wall Interaction and Exhaust (WPPWIE)	TU Wien UIBK	F. Aumayr M. Probst
WP07 Enabling Research (WPENR)	TU Wien	F. Aumayr
POWER PLANT PHYSICS AND TECHNOLOGY		
WP08 Demo Design (WPDES)	TU Graz	C. Albert
WP10 Breeding Blanket (WPBB)	TU Wien	H. Leeb, E. Jericha
WP18 Materials (WPMAT)	ÖAW-ESI	R. Pippan
WP21 Prospective Research and Development (WPPRD)	TU Wien	M. Eisterer
Socio-Economic Research on Fusion (SERF)		
WP22 Socio-Economic studies (WPSES)	Research Studios Austria FG	M. Biberacher
EDUCATION		
WP24 Training and Education (WPTRED)	TU Graz ÖAW-ESI TU Wien UIBK	14 PhD students 13 mentors

TU Graz = Graz University of Technology
TU Wien = Vienna University of Technology
UIBK = University of Innsbruck
ÖAW-ESI = Erich Schmid Institute of Materials Science at ÖAW

2. RESEARCH HIGHLIGHTS

WP01-TE: Tokamak Exploitation

A quasi-continuous exhaust scenario for a fusion reactor

G. F. Harrer, L. Radovanovic, E. Wolfrum, F. Aumayr et al.

Technische Universität Wien, Institut für Angewandte Physik

To realize fusion reactions, the plasma in the center must be very hot (about 100 million °C), and at the same time the wall of the reactor must not melt. The edge of the plasma must therefore be well insulated from the reactor wall. In this small region, however, plasma instabilities called ELMs occur frequently. During such events, energetic particles from the plasma may hit the wall of the reactor, potentially damaging it. These instabilities are one of the most important obstacles on the way to a commercial reactor. Now the fusion research team of TU Wien in collaboration with the Max Planck Institute for Plasma Physics (IPP) in Garching could demonstrate: there is an operational regime for fusion reactors that avoids this problem. Instead of large potentially destructive instabilities, one intentionally accepts many small instabilities that do not pose a problem for the reactor's walls. The details of the dynamics inside the reactor are complicated: the motion of the particles depends on plasma density, temperature and magnetic field. Depending on how one chooses these parameters, different regimes of operation are possible. In a long-standing collaboration between Friedrich Aumayr's group at TU Wien and the IPP Garching group coordinated by Elisabeth Wolfrum a novel operating regime termed QCE (for Quasi-Continuous Exhaust Regime) has now been developed and shown to prevent the particularly destructive plasma instabilities called "Type-I ELMs" [1].

Experiments already showed a few years ago: If one slightly deforms the plasma through the magnetic coils, so that the plasma cross-section no longer looks elliptical, but rather resembles a rounded triangle, and if one simultaneously increases the density of the plasma especially at the edge, then the dangerous Type-I ELMs can be prevented.

Due to the triangular shape of the plasma cross-section and the controlled injection of additional particles at the plasma edge, many small instabilities occur - several thousand times per second. These small particle bursts hit the wall of the reactor faster than it can heat up and cool down again (i.e. quasi-continuous). Therefore, these mini-instabilities do not play a serious threat for the reactor wall but prevent the large Type-I ELM instabilities that would otherwise cause serious damage.

First thought to be a scenario that only occurs in currently running smaller machines, it has meanwhile become clear that the QCE regime can prevent the dangerous instabilities even in parameter ranges foreseen for reactors like ITER or DEMO. As a last puzzle piece during the last DTE3 experimental campaign at JET in October 2023 the QCE regime could be successfully demonstrated during DT operation at the world's largest Tokamak experiment. The QCE operation regime is therefore probably one of the most promising scenarios for future fusion power plant plasmas.

[1] G. F. Harrer, M. Faitsch, L. Radovanovic, E. Wolfrum, C. Albert, A. Cathey, M. Cavedon, M. Dunne, T. Eich, R. Fischer, M. Griener, M. Hoelzl, B. Labit, H. Meyer, F. Aumayr: Quasicontinuous Exhaust Scenario for a Fusion Reactor: The Renaissance of Small Edge Localized Modes. Physical Review Letters **129,** 165001 (2022), https://doi.org/10.1103/PhysRevLett.129.165001

WP03-W7X: Wendelstein 7X

Visiting Japan to study bootstrap current in large stellarators

C. Albert, R. Babin, S. Kasilov, R. Köberl, L. Drescher and M. Markl

Technische Universität Graz, Institut für Theoretische Physik

Following a successful international experimental proposal, Markus Markl and Christopher Albert from TU Graz had the opportunity to work on-site at NIFS in Japan. The collaboration was initiated together with Andreas Dinklage (IPP Greifswald) and Hiroe Igami (NIFS) on comparative studies of plasma bootstrap current in the two largest stellarators in the world: Wendelstein 7-X and LHD. Our task in this collaboration are analysis and numerical simulations based on the experimental data collected within the last years.

The visits have been very rewarding for both, scientific results, and to strengthen relations between our institutions. The attached photo shows a corridor in the NIFS building with pictures of the LHD experiment together with its mascots. Already from this small impression one can imagine the cultural differences between Japan and central Europe, and how both partners can benefit from a fresh view on their respective approaches. Many of these may not be as self-evident as one might think. One example is the reconstruction of magnetic fields, which is done in the exactly opposite ways in W7-X and LHD, but both lead to excellent results. Daily experiences include the use of a typical Japanese washing machine in the NIFS guest house that is loaded from the top, sings nice melodies when finished and cleans perfectly without heating the water.

The outcomes of our joint research are presented at the IAEA Fusion Energy Conference in London, UK in October 2023. We enjoyed the exchange very much and are looking forward to continue this fruitful collaboration in the coming years!

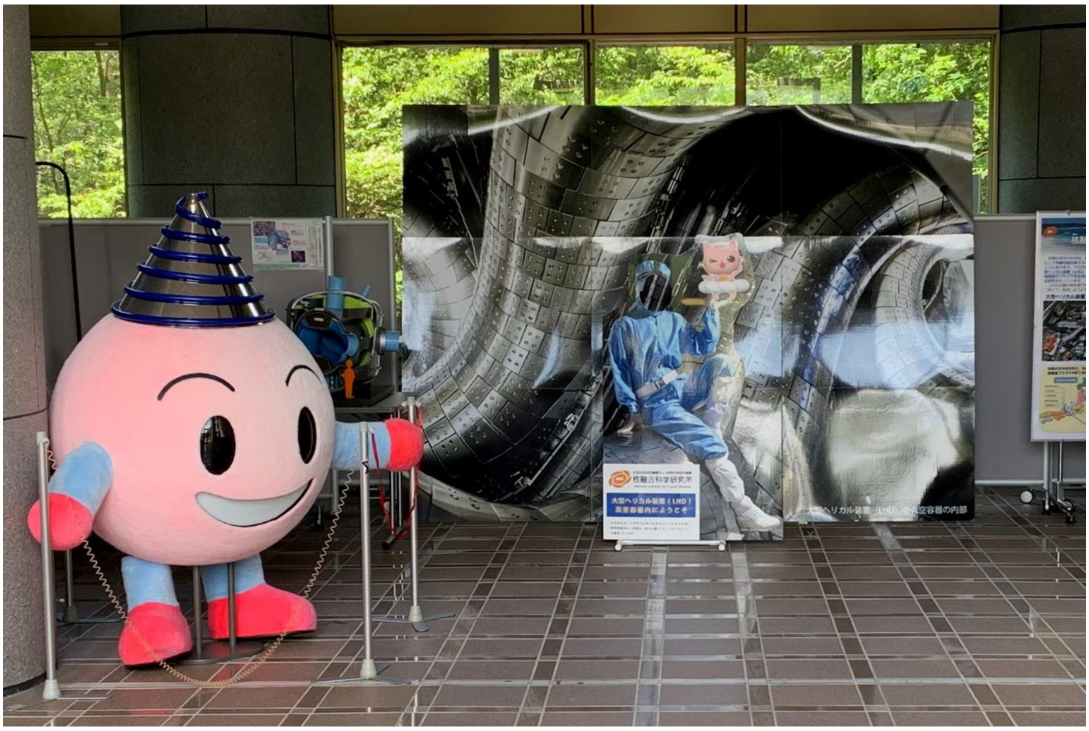


Photo: Corridor in the NIFS building with pictures of the LHD experiment together with its mascots

Source: Christopher Albert, Technische Universität Graz

Sputtering yield of nano-columnar tungsten surfaces under ion irradiation

C. Cupak, M. Fellinger, J. Brötzner, F. Aumayr et al.

Technische Universität Wien, Institut für Angewandte Physik

Erosion of first wall materials in nuclear fusion reactor vessels due to sputtering by plasma ions is of major relevance for lifetime calculations and for estimation of plasma impurity concentrations.

Recently we have extended our laboratory studies from conventional rough tungsten (W) surfaces to corrugated and oriented structures. For example, vertical W columns with 500 nm height and 50 nm diameter were deposited on our QCM sample surfaces in Madrid (Fig. 1), so that direct investigations with our QCM experiment under Ar+ bombardment were possible in Vienna. In parallel, SPRAY simulations of such complex structures were conducted. As an important result we could show both numerically and experimentally, that such nano-columnar W surfaces show a strong reduction in the sputter yield in comparison to a flat surface. In addition, the sputter yield is nearly independent on the ion's incidence angle [1].

Since the geometry of the W nano-columns was identified as the main reason for the change in sputter yields, in a follow up publication [2] we have now tuned these structures to obtain the best sputtering properties (lowest erosion). By using a large number of SPRAY simulations, we have optimized the separation width and height of the W columns to achieve minimum sputter yields. Fluence dependent studies are planned for the near future which might be of relevance of such structures for application as a wall material in nuclear fusion devices.

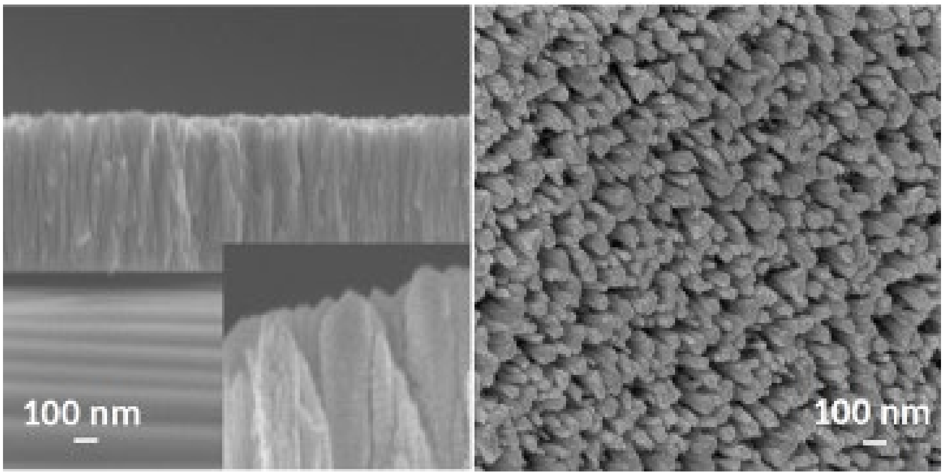


Fig. 1: W nano-pillars as deposited on a QCM sample for ion beam experiments [1]

Source: Technische Universität Wien

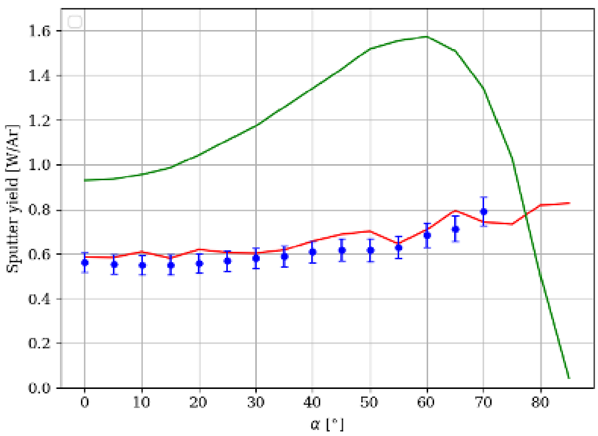


Fig. 2: W nano-columnar samples show a strong reduction in sputtering yield (experimental data point in blue, SPRAY simulation in red) as compared to flat W targets (green curve) when bombarded by 1 keV Ar+ ions under an incidence angle α. Results taken form [1].

Source: Technische Universität Wien

Relevant publications:

[1] A. Lopez-Cazalilla, C. Cupak, M. Fellinger, F. Granberg, P. S. Szabo, A. Mutzke, K. Nordlund, F. Aumayr, and R. González-Arrabal: Comparative study regarding the sputtering yield of nanocolumnar tungsten surfaces under Ar+ irradiation. Physical Review Materials **6,** 075402 (2022), https://doi.org/10.1103/PhysRevMaterials.6.075402

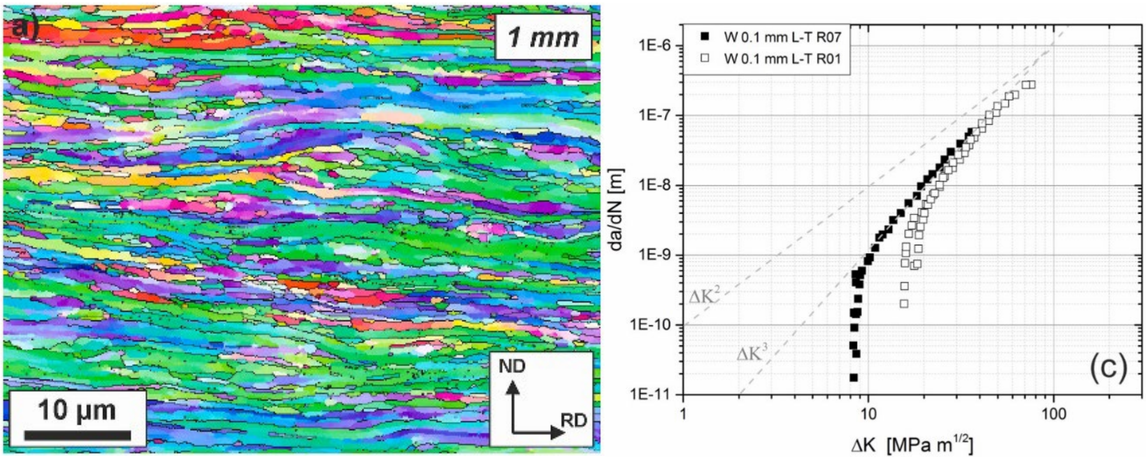
[2] C. Cupak, A. Lopez-Cazalilla, H. Biber, J. Brötzner, M. Fellinger, F. Brandstätter, P. S. Szabo, A. Mutzke, F. Granberg, K. Nordlund, R. González-Arrabal, and F. Aumayr: Sputter yield reduction and fluence stability of numerically optimised nanocolumnar tungsten surfaces. Physical Review Materials **7,** 065406 (2023), https://doi.org/10.1103/PhysRevMaterials.7.065406

WP18-MAT: Materials

Understanding the fracture behaviour of tungsten

R. Wurster, S. Pillmeier, R. Pippan et al.

Erich-Schmid-Institut für Materialwissenschaft



Left: Microstructure of a rolled tungsten plate (taken from D. Firneis et al., Mat Sci Eng A 838 (2022) 142756) Right: Fatigue crack growth curves for sheets of 0.1 mm thickness, experiments were performed at room temperature (taken from S. Pillmeier et al., Mat Sci Eng A 805 (2021) 140791)

Tungsten, as a plasma facing component, will be exposed to severe conditions in an operating fusion reactor. Due to its inherent brittleness, the fracture behaviour of tungsten and tungsten-based materials is of large interest. Recently, the beneficial effect of rolling on the fracture behaviour was demonstrated by comparing the material's response to quasi-static mechanical loading as a function of increasing degree of rolling and testing temperature. An improved fracture resistance with decreasing sheet thickness and increasing temperature was found. For the investigated tungsten sheets, the fracture process cannot be described by a single quantity anymore but the behaviour has to be described by the so-called R-curve, representing the increased fracture resistance during stable crack growth.

In real applications, tungsten materials will also face repeated loading. So, it is of utmost importance to additionally investigate the response of tungsten to cyclic loading. This was first performed at room temperature, resulting in – to the best knowledge of the authors – the first study on the fatigue crack growth behaviour of tungsten. In the most recent step, the scope of investigations has been expanded to elevated temperatures, i.e. determining the fatigue crack growth under fusion relevant conditions. For doing so a furnace-equipped vacuum chamber had to be built into a dynamic mechanical testing machine. This setup allows now the investigation of fatigue crack growth in a fully controllable environment.

Relevant publications:

Pillmeier S., Žák S., Pippan R., Hohenwarter A., Influence of cold rolling on the fatigue crack growth behavior of tungsten. Materials Science and Engineering: A, **805**, 140791 (2021), https://doi.org/10.1016/j.msea.2021.140791

Firneis D., Wurster S., Nikolić V., Pippan R., Hohenwarter A., The beneficial effect of rolling on the fracture toughness and R-curve behavior of pure tungsten. Materials Science and Engineering: A, **838**, 142756 (2022), https://doi.org/10.1016/j.msea.2022.142756

WP24-TRED: Training and Education

Improved models for large amplitude plasma edge turbulence

M. Held, A. Kendl, F.F. Locker, E. Reiter et al

Universität Innsbruck, Institut für Ionenphysik und Angewandte Physik

The full-f gyrofluid model for plasma edge turbulence, which is valid for arbitrary fluctuation amplitudes (i.e. "full-f"), has been extended and implemented in simulation codes.

A generalized polarization model was applied in the FELTOR code, and the necessity for the extended wave number range ("full-k") has been demonstrated by improved computation of blob propagation [1], which is the dominant transport mechanism across the magnetic field in the scrape-off layer region of tokamaks and stellarators. A novel polarization solver was tested in the TIFF code, which enabled cross-verification of the FELTOR results, and showed the influence of the "full-f full-k" gyrofluid model on drift wave edge turbulence [2].

The model and FELTOR code have also been extended to additional fully self-consistent "impurity" ion species with arbitrary concentration, and simulations showed their impact on blob transport [3].

The models and codes are presently being further extended, for example for simulations of magnetic reconnection processes in connection with plasma turbulence.

Relevant publications:

[1] M. Held, M. Wiesenberger: Beyond the Oberbeck-Boussinesq and long wavelength approximation. Nuclear Fusion **63**, 026008 (2023) https://doi.org/10.1088/1741-4326/aca9e0

[2] A. Kendl: TIFF - gyrofluid turbulence in full-f and full-k. Submitted to Computer Physics Communications (2023). Preprint: arXiv:2306.02352.

[3] E. Reiter, M. Wiesenberger, M. Held, G.W. Zarate-Segura, A. Kendl: Non-trace full-F gyro-fluid interchange impurity advection. Journal of Plasma Physics **89**, 905890110 (2023) https://doi.org/10.1017/S0022377822001283

Edge plasma turbulence and transport phenomena and advanced probe diagnostic

R. Schrittwieser, C. Ionita-Schrittwieser, et al.

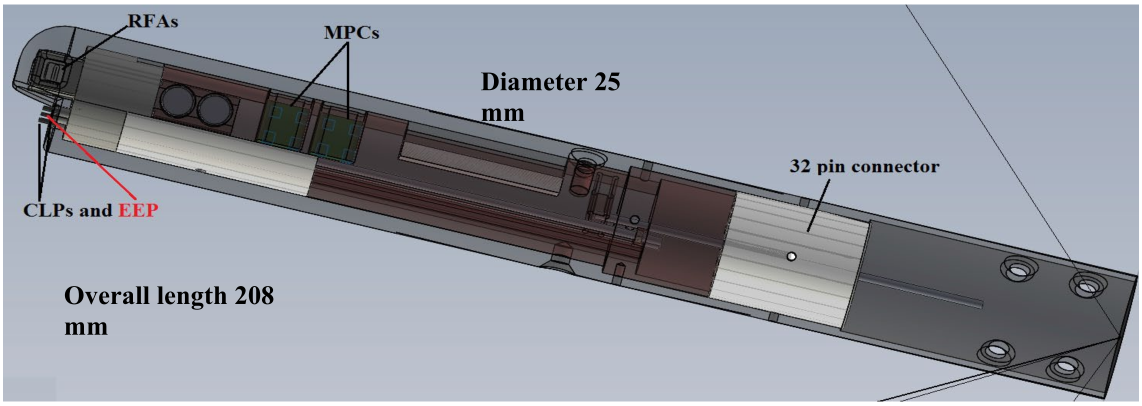
Innsbruck Experimental Plasma Physics Group (IEPPG) 2022 – 2023

Currently, the research efforts of the IEPPG were concentrated on the development of a New Probe Head (NPH) for MSTs, containing one specially developed emissive probe, strong and resilient enough to be employed also on the reciprocating probe manipulators of AUG and TCV, also envisaging future applications in the Wendelstein 7-X stellarator (W 7-X), Max-Planck-Institute for Plasma Physics, Greifswald, Germany (Fig. 1). These efforts, which would make it possible to measure the plasma potential and its fluctuations directly also in these much larger fusion plasma experiments, are still under way.

In addition, in collaboration with the Tyrolean company CarbonCompetence (https://www.carboncompetence.com/en/) in Wattens, new efforts are planned to test Plasma Facing Components (PFC, including probe casings) coated with Ultra-Nano Crystalline Diamond (UNCD) on their resilience and possible suitability for fusion plasma experiments in MSTs and other toroidal fusion devices. During applications in the EAST (Experimental Advanced Superconducting Tokamak, Hefei Institute of Physical Science, Chinese Academy of Sciences) UNCD coatings were seen to considerably increase the stability of graphite probe casings against sputtering effects by the strong plasma in the SOL and even further inside.

[1] B.S. Schneider, C. Ionita-Schrittwieser, S. Costea, O. Vasilovici, J. Kovacic, T. Gyergyek, B. Koncar, M. Draksler, R.D.Nem, V. Naulin, J.J. Rasmussen, M. Spolaore, N. Vianello, R. Stärz, A. Hermann, R. Schrittwieser, „New diagnostic tools for transport measurements in the Scrape-Off Layer (SOL) of Medium-Size Tokamaks“, Plasma Phs. Contr. Fusion **61,** 054004 (2019), https://doi.org/10.1088/1361-6587/ab0596,

[2] C. Ionita, R. Schrittwieser, G.S. Xu, N. Yan, H. Wang, V. Naulin, J.J. Rasmussen, D. Steinmüller-Nethl, „Diamond-coated plasma probes for hot and hazardous plasmas”, Materials **13,** 4524 (2020), https://doi:10.3390/ma13204524.



On top:

- Two CLPs (Cold Langmuir Probes) pins.
- EEP (Electron Emissive Probe) in between the two CLPs.
- Two RFAs (Retarding Field Analysers) facing upstream and downstream, respectively.

Inside:

- Two triple Magnetic Pick-up Coils (MPC – from RFX) about 40 mm behind the front side.

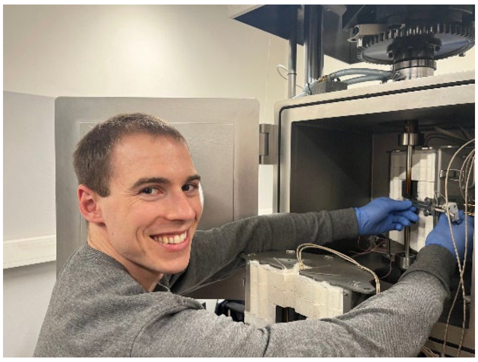
New Probe Head (NPH) for use on reciprocating probe manipulators of AUG and TCV and in modified form possibly also in W7X.

Source: Roman Schrittwieser, Universität Innsbruck

3. SELECTED PHD THESES COMPLETED/NEAR COMPLETION IN 2022/2023

Michael Pegritz, Austrian Academy of Sciences (Erich Schmid Institute of Materials Science)

Fatigue crack analysis of tungsten for nuclear fusion applications
Supervisor: R. Pippan



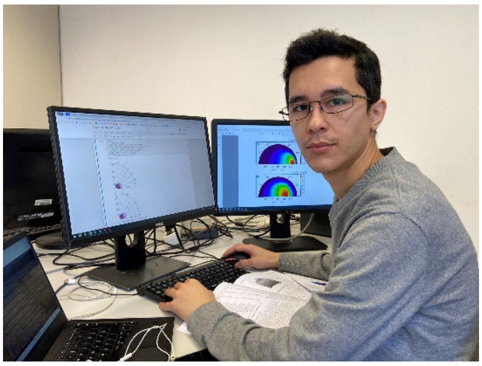
In his dissertation, Michael is studying how tungsten breaks at high temperatures under repeated loading or fatigue conditions. Tungsten is an important material for fusion reactors because of its ability to remain strong at elevated temperatures. The body centered cubic lattice structure is responsible for the pronounced temperature dependence of tungsten's fracture toughness, the point where it breaks. Respectively, the operating temperature affects the damage tolerance as well as the fatigue crack growth (FCG) behavior of tungsten samples or components.

As a promising plasma facing material in nuclear fusion reactors, tungsten is subject to completely new demands in terms of failure safety and damage tolerance. Plasma events as well as the production process of plasma facing materials inevitably initiate cracks.

As part of his dissertation, Michael set up a high temperature vacuum testing system that can carry out FCG experiments in the fusion relevant temperature window. After the setup was complete, he studied the temperature and microstructure dependency of fracture and other material properties. With these fatigue crack propagation experiments, the reliability and remaining service life of pre-cracked structural components can be evaluated. The resulting comparative results of different tungsten qualities can contribute to the EUROfusion material selection process.

Shokirbek Shermukhamedov, University of Innsbruck (Institute for Ion Physics and Applied Physics)

Molecular Dynamics of Surface-Plasma interactions with Machine Learned Potential Energy Functions
Supervisor: M. Probst



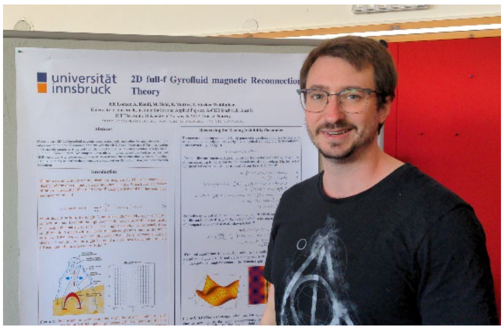
Shokirbek and his project group are investigating the behavior of plasma-surface interfaces with respect to the processes taking place in a fusion device. The plasma is composed of hydrogen isotopes and trace particles as well as of atoms and molecules sputtered from near and far surfaces. In their investigations the surfaces consist of beryllium and tungsten and their alloys. Molecular dynamics simulations can model the surface degradation caused by a stream of impinging plasma atoms. This determines the lifetime of the wall materials. In turn, the composition of the plasma is also altered, changing its energy balance and ultimately its burning time.

Shokirbek's research includes method development regarding quantum chemical scattering algorithms, improved integrators, optimization of the neural-network approach and other features of these computationally demanding non-standard simulations. The goal is to calculate rates and kinetic parameters on a microscopic scale using steady-state atomistic molecular dynamics simulations. For example, the dependence of the sputtering yield on the angle and energy of the incoming particle and on the surface temperature can be established.

These data are very much in demand in the material science and fusion research community because they constitute a part of the necessary input for non-atomistic macroscopic simulations to predict the behavior of walls and plasma of a fusion device.

Franz Ferdinand Locker, University of Innsbruck (Institute for Ion Physics and Applied Physics)

Gyrofluid full-f full-k turbulent magnetic reconnection
Supervisor: A. Kendl



In his Ph.D. thesis Franz works on the problem of magnetic reconnection, i.e. the reorganization of magnetic fields in a magnetized plasma. The magnetic reconnection plays an important role on the sun. The corona of our home star is much hotter than it should be, and up to now it is still not clear why that is. However, a strongly held opinion is that the magnetic reconnection redistributes energy to the particles and heats them up.

Magnetic reconnection also plays a role in fusion, as the tokamak also contains a magnetized plasma. In this case it can lead to disturbances of the plasma's confinement. The confinement time – that is the time that the plasma can be kept confined – is important for the power output. By carrying out computer simulations and including magnetic reconnection into all the equations, Franz and his working group try to find general conditions that improve the confinement times. For this, they simulate certain areas of a tokamak. They try to understand the physics behind what makes the plasma more stable and what makes it more well behaved.

Simulations of this kind are important because direct diagnostics with probes are limited in a superhot plasma, and on top of that very expensive.

Lidija Radovanovic, TU Wien (Institute of Applied Physics)

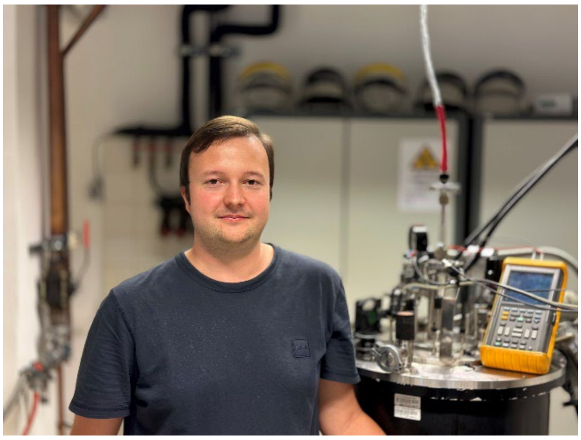
Edge core coupling: physical parameters determining the pedestal width
Supervisor: F. Aumayr

As part of her PhD thesis, Lidija is researching the physical parameters which determine the width of the outermost region of the plasma in a tokamak, the pedestal. The pedestal is a very thin layer at the edge of the plasma, where huge pressure, density and temperature gradients are located and very fascinating physical processes take place. In order to find out what parameters determine the width of this layer, Lidija uses experimental methods and evaluates data from the discharges on ASDEX Upgrade, but also runs simulations in order to better understand the physics behind it.

The benefit of this research is to understand how to tailor the pedestal so that more energy stays confined in the plasma, allowing more fusion to take place, and at the same time, how to avoid instabilities. This is very important, especially because of the particle and energy losses that occur due to the instabilities and that could damage the plasma facing components. Additionally, it can help improve the efficiency of a future reactor.

<u>Alexander Bodenseher, TU Wien (Atomic Institute)</u>

Scattering and superfluid density in superconductors
Supervisor: M. Eisterer



Over the course of his PhD, Alexander is trying to improve our understanding of damage caused by neutron radiation to high temperature superconductors. Magnetic confinement fusion requires high magnetic fields and the only economically feasible way to achieve these fields is to use superconducting materials for the magnet coils. The fusion reaction creates neutrons that reach the magnet system and alter different properties of the superconductor, for instance the transition temperature or the maximum current carrying capacity. Alexander and his research group are recreating this using the TRIGA Mark II research reactor of the Atomic Institute, irradiating samples and observing any changes to the physical properties using different direct and indirect measurement techniques.

The magnet system of a fusion reactor is one of the major cost factors for the whole reactor. It is very important to know how the superconducting coils behave over the course of the lifetime of the whole system. A deeper understanding of the basic physics also allows the material of the magnet coils to be adapted to the specific environmental conditions in a fusion reactor.

What became of …?

<u>Lei Chen, ITER Organization</u>

Lei completed her PhD in Professor Michael Probst's group at the University of Innsbruck in March 2020. During her dissertation project entitled "Atomistic Investigations on Plasma Facing Components of Beryllium and Tungsten" she was working on developing potential functions for atomistic modeling of beryllium, tungsten sputtering and hydrogen retention of the ITER plasma-facing surfaces via machine learning techniques.

After defending her dissertation, she continued for six months of post-doctoral research in Professor Michael Probst's group. Then she worked as Monaco/ITER postdoctoral fellow at the ITER organization where she analyzed the ITER plasma-facing components (PFC) damages induced by the high heat loads typical of unmitigated plasma instabilities such as plasma disruptions. The work is an important part of the continuing effort to refine the ITER "disruption budget", and provides a key input for both the assessment of PFC operational lifetime and the ongoing update of the ITER Safety Files. Since July 2022 she has been working as a technical responsible officer in the blanket team at ITER.

Awards

Christiana Hörbiger Prize for Martina Fellinger and Lidija Radovanovic (02/2022)

Fusenet master thesis prize for Lidija Radovanovic (06/2022)

FuseNet PhD Event Awards for Lidija Radovanovic (Best Overall Presentation) and Martina Fellinger (Best Poster Design) (07/2022)

Franz Viehböck Appreciation Award 2022 for Johannes Brötzner (12/2022)

Fusenet master thesis prize for Tobias Peherstorfer (06/2023)

FuseNet PhD Event Award for Fabian Grander (Best overall presentation) (08/2023)

10 Fusion Days

On Nov. 15, 2022, the ninth **Fusion Day** took place at the Vienna University of Technology (TU Wien, photo on the front cover of the brochure). In the following year, we visited the Erich Schmid Institute of Materials Science (ESI, ÖAW) in Leoben. The aim of this annual event is primarily the exchange and networking of scientists of the Austrian fusion research program.

After an online-only event in 2020 as well as a hybrid event in 2021, the Fusion Days in 2022 and 2023 were again held on-site only. About 40 participants came from all over Austria to attend the events, present their latest results and exchange ideas with their colleagues.

The scientific meetings were opened at 9 am by Professor Friedrich Aumayr, Director of the Austrian Fusion Research Unit and Professor at TU Wien, who warmly welcomed all participants and introduced the guest speaker. In 2022, Daniel Primetzhofer, who is a professor at the Department of Physics and Astronomy at Uppsala University in the field of applied nuclear physics, joined. He is also the director of the Tandem Laboratory, whose goal is to provide and develop tools for ion beam-based research. Fitting to the topic, the title of his talk was "Studies of first wall materials using ion beams". In 2023, Johann Riesch, a materials scientist at the Max Planck Institute for Plasma Physics, held the following key note speech: "Development of plasma facing materials and components at the Max Planck Institute for Plasma Physics".

The guest lectures were followed by several interesting 20-minute talks by students as well as project group leaders who presented recent research results of their groups.

10th Fusion Day in Leoben.

Source: Fritz Aumayr, Technische Universität Wien

4. *PUBLIC INFORMATION AND OUTREACH*

In the last two years, nuclear fusion has been strongly represented in the media. This was mainly due to reports about achieved records and milestones. However, the climate crisis and rising energy prices have also brought this topic more and more into focus. All of this led to an increasing public interest, which can be seen in the high number of newspaper articles and interviews, but also in the increasing demand for lectures on this topic.

How topical the subject is can also be seen from the fact that nuclear fusion is being featured in a new exhibition on the subject of the energy transition.

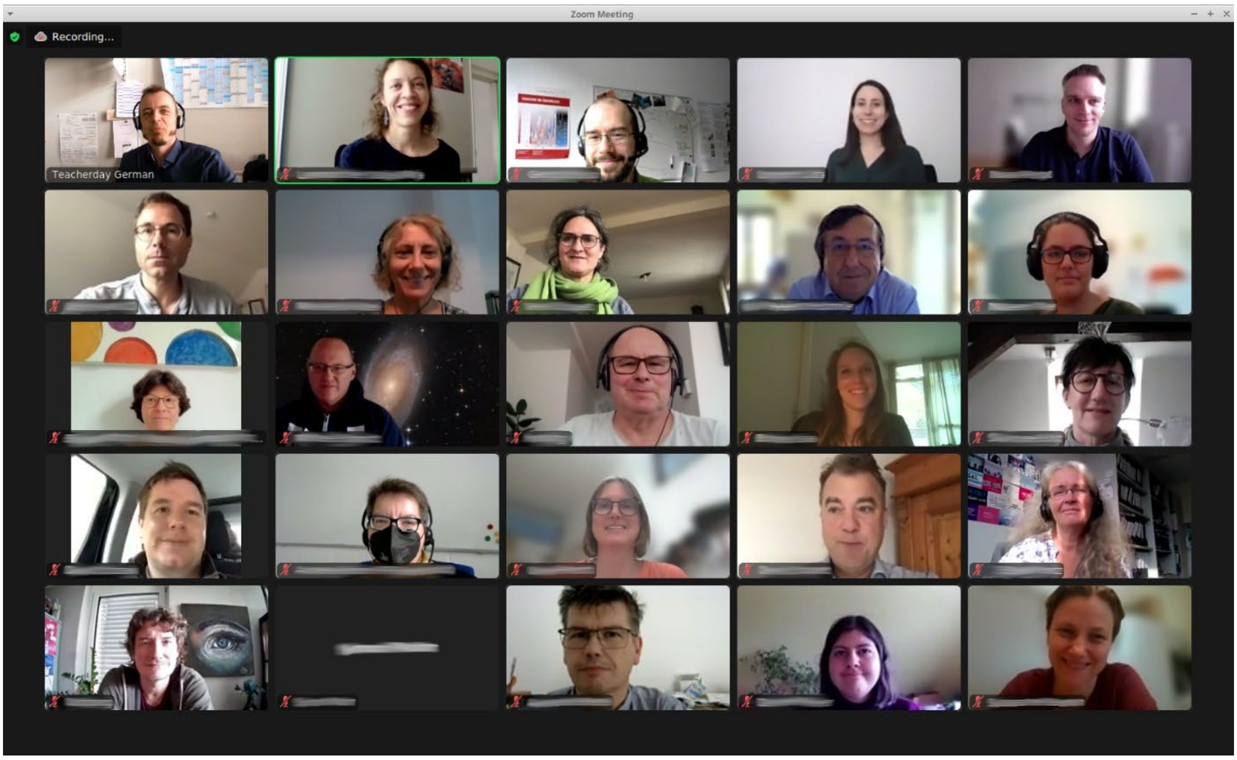
FuseNet Teacher Days

On 2. October 2020, the European Fusion Teacher Day took place for the very first time as a Zoom online event. This meeting was organized by the FuseNet Association – The European Fusion Education Network (www.fusenet.eu). It is a platform for the coordination of European fusion education activities.

The FuseNet Teacher Day is aimed at secondary school teachers and consists of two parts: a local and a European session. First, experts from national labs and universities introduce the topic of nuclear fusion and talk about local fusion research. In the second part, new teaching materials are presented, along with a live stream from the largest fusion research facilities. After the event, participants receive a textbook together with other teaching materials.

With over 500 participants, the first edition was a great success, but the 2nd European Fusion Teacher Day, held on 1. October 2021, attracted even more people. In 2020, we had 10 registrations from Austria and 20 in 2021. Therefore, we have strengthened our efforts to acquire even more teachers in the years to come. In 2022 and 2023, 37 teachers from Austria have subscribed to the event. The development of the number of participants shows that our work has paid off.

In the local session 2023, Winfried Kernbichler from Graz University of Technology also gave an introductory lecture for the participating teachers on nuclear fusion.



3rd Teacher Day in 2022

Source: FuseNet

Exhibition “Energy transition – a race against time”

In June 2023, a new exhibition entitled “Energy transition – a race against time” opened at the Vienna Museum of Science and Technology. The exhibition is part of the *Thinking forward* exhibition series and was developed in collaboration with the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK). It will be on display until the end of 2024.

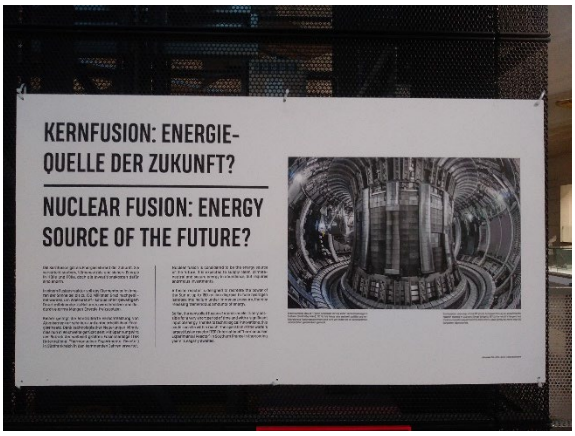
Energy is a central element of our modern society. In many areas of our life we are heavily dependent on energy. It is difficult to imagine life without electricity or mobility, for example. However, factors such as the rising energy demand, global warming and the energy crisis make a transition to sustainable energy more urgent than ever before.

The exhibition addresses questions like: Why do we need more and more energy? Why is energy transition necessary? How can we accomplish the energy transition? What innovations help us do so and what can we all contribute in our daily lives? On five levels, it demonstrates the complex dynamics of the energy transition and the climate crisis, gives an overview of possible strategies and novel technologies and seeks to open up new perspectives for visitors that empower them to actively participate in the climate discourse.

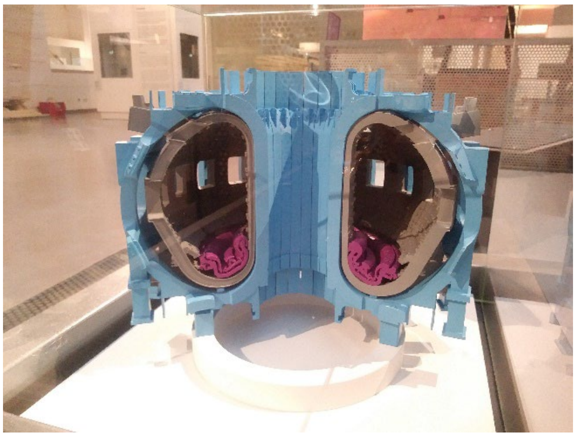
Within the framework of the exhibition, nuclear fusion is also discussed as a possible energy alternative for the future. It is presented as a safe and environmentally friendly energy source. The future nuclear fusion research experiment ITER is presented and even a small 3D model of the reactor is exhibited.

Entrance area of the exhibition
Source: Technisches Museum Wien

Nuclear fusion is part of the exhibition
Source: Fusion@ÖAW



Energy source of the future?
Source: Fusion@ÖAW



3D model of the ITER tokamak
Source: Fusion@ÖAW

Fusion@ÖAW Media coverage 2022/2023 (Selection)

Articles

JET DTE2 Record:

- Fusionsreaktor ITER wird funktionieren (02/2022), OÖNachrichten
- Energierekord bei Kernfusion (02/2022), science.orf.at
- Wissenschaftler melden neuen Rekord bei Experimenten bei Fusionsenergie (02/2022), science.apa.at
- Bedeutender Durchbruch auf dem Weg zur Fusionsenergie (02/2022), Der Standard
- Rekord bei Experimenten mit Fusionsenergie (02/2022), Wiener Zeitung
- Durchbruch bei Kernfusion: „Mini-Stern“ erzeugt 5 Sekunden Energie (02/2022), futurezone.at

Kann es gelingen, Energie aus Wasserstoff zu gewinnen, Herr Aumayr? (03/2022), Falter

Künstliche Intelligenz beherrscht das nukleare Fusionsfeuer (03/2022), Der Standard

Mit Kernfusion gegen die Klimakrise (09/2022), oeaw.ac.at

Plasma Instabilities:

- Wie Mini-Instabilitäten große Schäden in Fusionsreaktoren verhindern (10/2022), science.apa.at
- Kernfusion: Neue Lösung für Instabilitätsproblem (10/2022), science.orf.at
- Neue Methode löst großes Problem bei der Fusionsforschung (10/2022), Der Standard
- Großes Problem von Fusionsreaktoren gelöst – von Wiener Forschern (10/2022), futurezone.at
- Wann haben wir endlich Strom aus Kernfusion? (11/2022), futurezone.at
- A new solution to one of the major problems of fusion research (10/2022), euro-fusion.org
- Taking Control of Fusion Reactor Instabilities (10/2022), physics.aps.org

Kernfusion: Der Wettlauf um die Sonne auf Erden (11/2022), klimareporter.in

Fusion ignition breakthrough at Lawrence Livermore National Laboratory:

- Erstes Fusionskraftwerk könnte Ender der 2030er-Jahre starten (12/2022), Salzburger Nachrichten
- Auch Österreich mischt bei Forschung zu Kernfusion mit (12/2022), Salzburger Nachrichten
- Österreichs Know-how hilft bei Kernfusion (12/2022), Salzburger Nachrichten
- Wann kommt das Fusionskraftwerk? (12/2022), Der Standard
- Kernfusion hilft spät im Kampf gegen die Klimakrise (12/2022), futurezone.at
- Durchbruch bei Kernfusion (12/2022), science.orf.at
- Der Traum von der Sonne auf Erden: Kernfusion als Energieform der Zukunft? (01/2023), Tiroler Tageszeitung
- Wieder Energiegewinn durch Kernfusion, diesmal mit besserer Ausbeute (08/2023), Der Standard)
- Meilenstein für Kernfusion: Mehr Energie erzeugt als verbraucht, (08/2023), futurezone.at

Commissioning of JT-60SA:

Kernfusion: Weltweit größter Reaktor nimmt Betrieb auf (12/2023), futurezone.at

Japan startet Rekord-Testreaktor zur Kernfusions-Erforschung (12/2023), Salzburger Nachrichten

Japan startet bisher größten Testreaktor zur Kernfusionserforschung (12/2023), Der Standard

Video/Radio interviews

Interview with Roman Schrittwieser (11.01.2022), Radio Tirol

Interview with Friedrich Aumayr (23.02.2022), Café Puls Magazin, Puls4

Was Kernfusion für die Klimakrise bedeuten könnte - Interview with Prof. Friedrich Aumayr (27.11.2022), MeinBezirk.at

Interview with Georg Harrer about nuclear fusion in the podcast "Erklär mir die Welt" (1.8.2023)

Public Talks and presentations

Talk by Friedrich Aumayr at „Pint of Science Festival" (10.5.2022)

Talk by Friedrich Aumayr as part of the „Digitales Klima Event" at TU Wien (19.5.2022)

Participation at the "Long Night of Research" in Innsbruck with the station "Chaos, Klima, Umkipppunkte: Was verbindet ein Fusionsplasma mit nichtlinearer Wetterdynamik? (20.5.2022)

Info Day Technical Physics at TU Wien with a station about nuclear fusion (10.10.2022)

Talk by Georg Harrer at „Young Scientist Symposium 2022" at Institute of Science and Technology: "State of the art in nuclear fusion" (20.10.2022)

Talk about nuclear fusion by Friedrich Aumayr in front of students of the BORG St. Pölten at TU Wien (25.10.2022)

Participation of Franz Ferdinand Locker at the "Science Slam" in Obergurgl with a contribution on turbulence in nuclear fusion plasma (25.11.2022)

Talk by Friedrich Aumayr at the Federation of Austrian Industries Lower Austria (IV-NÖ): „Energie aus Kernfusion" (18.1.2023)

Talk by Christopher Albert as part of a lecture series on nuclear fusion at TU Graz: „Numerische Simulation und maschinelles Lernen in der Fusionsphysik" (7.2.2023)

VHS-Talk by Georg Harrer and Lidija Radovanovic on nuclear fusion at the Planetarium Vienna (7.3.2023)

Prof. Friedrich Aumayr as guest at the VHS Science Talk in the Planetarium Vienna (25.4.2023)

Talk by Martina Fellinger, Lidija Radovanovic and Georg Harrer at ÖAW Children's University Day (21.7.2023)

Talk by Friedrich Aumayr at Rotary Club Melk: "Energie aus Kernfusion" (3.10.2023)

Talk by Winfried Kernbichler at the European Fusion Teacher Day "Einführung in die Kernfusion" (6.10.2023)

Talk by Friedrich Aumayr at Rotaract Club Blue-Danube-NÖ: "Energie aus Kernfusion" (14.11.2023)

Georg Harrer at the Info Day Technical Physics at TU Wien

Source: TU Wien

VHS Science Talk with Prof. Friedrich Aumayr at the Planetarium Vienna

Source: TU Wien

Franz Ferdinand Locker at the Science Slam in Obergurgl

Source: UIBK

ÖAW Children's University Day

Source: TU Wien

5. PUBLICATIONS

Erich-Schmid-Institut für Materialwissenschaft at ÖAW

Articles in scientific journals

2022

D. Firneis, S. Wurster, V. Nikolic, R. Pippan & A. Hohenwarter (2022). The beneficial effect of rolling on the fracture toughness and R-curve behavior of pure tungsten. *Materials Science and Engineering: A, 838*. https://doi.org/10.1016/j.msea.2022.142756

Conference contributions

2022

M. Pegritz, S. Wurster, R. Pippan & A. Hohenwarter (24th October 2022). Fatigue crack growth behaviour of rolled tungsten. *The Nuclear Materials Conference (NuMat2022), Ghent, Belgium*.

2023

M. Pegritz, S. Wurster, R. Pippan & A. Hohenwarter (19th March 2023). Insights on the fatigue crack growth behaviour of rolled tungsten for its application in nuclear fusion. *TMS 2023 Annual Meeting & Exhibition, San Diego, USA*.

M. Pegritz, S. Wurster, A. Hohenwarter & R. Pippan (22nd October 2023). Fracture mechanisms of ITER grade tungsten under static and cyclic loading. *21st International Conference on Fusion Reactor Materials (ICFRM-21), Granada, Spain*.

Technische Universität Graz / Institut für Theoretische Physik – Computational Physics

Articles in scientific journals

2022

C. G. Albert, P. Lainer & O. Bíró (2022). 2D Fourier Finite Element Formulation for Magnetostatics in Curvilinear Coordinates with a Symmetry Direction. *Computer Physics Communications, 277*. https://doi.org/10.1016/j.cpc.2022.108401

C. G. Albert, K. Rath, D. Rügamer, B. Bischl, U. v. Toussaint, C. Rea, A. Maris & R. Granetz (2022). Data augmentation for disruption prediction via robust surrogate models. *Journal of Plasma Physics, 88(5)*. https://doi.org/10.1017/S0022377822000769

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R. Buchholz, M. Willensdorfer, U. Plank, D. Brida, M. Cavedon, S. Kasilov et al. (2022). Dependence of the L-H power threshold on the alignment of external non-axisymmetric magnetic perturbations in ASDEX Upgrade. *Physics of Plasmas, 29*. https://doi.org/10.1063/5.0073841

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C. G. Albert, R. Koeberl, U. v. Toussaint et al. (2023). Uncertainty quantification in three-dimensional magnetohydrodynamic equilibrium reconstruction via surrogate-assisted Bayesian inference. *Contributions to Plasma Physics, 63(5-6)*. https://doi.org/10.1002/ctpp.202200173

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C. G. Albert, F. Maviglia, L. Pigatto, F. Villone, H. Zohm, P. Bruzzone, R. Buchholz, et al. (2023). Studies on EU-DEMO 3D coils requirements and conceptual design for error field correction and plasma control. *Fusion Engineering and Design, 196*. https://doi.org/10.1016/j.fusengdes.2023.114010

M. Eder, L. Bauer, D. Forstenlechner, G. Graßler, S. Kasilov, W. Kernbichler, M. Meisterhofer, M. Scheidt & C. Albert (2023). GORILLA: Guiding-center ORbit Integration with Local Linearization Approach. *Journal of Open Source Software, 8(86)*. https://doi.org/10.21105/joss.04890

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C.G. Albert, R. Buchholz, S. V. Kasilov & W. Kernbichler (20th June 2022). Alpha particle confinement metrics based on orbit classification. *23rd International Stellarator-Heliotron Workshop (ISHW), Warsaw, Poland*.

C. G. Albert, K. Rath, R. Buchholz, S. Kasilov & W. Kernbichler (12th September 2022). Resonant transport of fusion alpha particles in quasisymmetric stellarators. *Theory of Fusion Plasmas Joint Varenna – Lausanne International Workshop, Varenna, Italy*. 10.1088/1742-6596/2397/1/012009

R. Buchholz, C. G. Albert, W. Kernbichler & A. A. Savchenko (27th June 2022). Computation of neoclassical toroidal viscosity with the account of non-standard orbits in a tokamak. *48th EPS Conference on Plasma Physics (EPS), Maastricht, Netherlands*.

R. Buchholz, S. V. Kasilov, W. Kernbichler, A. A. Savchenko & C. G. Albert (12th September 2022). Account of non-standard orbits in computations of neoclassical toroidal viscous torque in the resonant plateau regime of a tokamak. *Theory of Fusion Plasmas Joint Varenna – Lausanne International Workshop, Varenna, Italy*. https://doi.org/10.1088/1742-6596/2397/1/012012

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P. Lainer, S. Kasilov, W. Kernbichler, M. Reichelt & C. Albert (12th September 2022). Iterative approach to linear ideal MHD modeling of plasma response to 3D magnetic perturbations in tokamaks. *Theory of Fusion Plasmas Joint Varenna – Lausanne International Workshop, Varenna, Italy*. https://doi.org/10.1088/1742-6596/2397/1/012014

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Technische Universität Wien / Institut für Angewandte Physik

Articles in scientific journals

2022

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C. Cupak, M. Mayer, M. Balden, S. Brezinsek, V. V. Burwitz et al. (2022). Carbon erosion/deposition on the divertor of W7-X during the operational period OP1.2b. *Nuclear Fusion*, *62(12)*. https://doi.org/10.1088/1741-4326/ac94e2

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G. Harrer, A. Cathey, M. Hoelzl, L. Gil, M. Dunne, G. Huijsmans, J. Kalis, et al. (2023). Probing non-linear MHD stability of the EDA H-mode in ASDEX Upgrade. *Nuclear Fusion, 63(6).* https://doi.org/10.1088/1741-4326/acc818

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2022

F. Aumayr (29th August 2022). Erosion of realistic surfaces during ion bombardment - Case studies for space weathering & nuclear fusion research. *35th European Conference on Surface Science (ECOSS-35), Luxembourg*.

C. Cupak, M. Fellinger, H. Biber, A. Redl, E. Pitthan, M. V. Moro, A. Lopez-Cazalilla et al. (12th June 2022). A precise lab experiment using a quartz crystal microbalance for investigating sputtering of first wall materials. *25th International Conference on Plasma Surface Interaction in Controlled Fusion Devices (PSI-25), Jeju, South Korea*. https://doi.org/10.1016/j.nme.2022.101249

C. Cupak (20th June 2022). Effect of surface roughness on ion induced sputtering*. 29th International Conference on Atomic Collisions in Solids & 11th International Symposium on Swift Heavy Ions in Matter ICACS-SHIM 2022, Helsinki, Finland*.

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G. Harrer, M. Faitsch, L. Radovanovic, E. Wolfrum, A. Cathey, M. Cavedon, M. Dunne et al. (20th September 2022). Progressing the understanding of the quasi continuous exhaust scenario. *18th International Workshop on H-mode Physics and Transport Barriers, Princeton, USA*.

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J. Brötzner, C. Cupak, M. Fellinger, H. Biber, A. Lopez-Cazalilla, F. Granberg et al. (22nd May 2023). Sputtering yield reduction for nano-columnar W surfaces under D ion irradiation. *19th International Conference on Plasma-Facing Materials and Components for Fusion Applications (PFMC-19), Bonn, Germany*. https://doi.org/10.1016/j.nme.2023.101507

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Technische Universität Wien / Atominstitut

Articles in scientific journals

2022

R. Unterrainer, D. X. Fischer, A. Lorenz & M. Eisterer (2022). Recovering the performance of irradiated high temperature superconductors for use in fusion magnets. *Superconductor Science and Technology, 35(4)*. https://doi.org/10.1088/1361-6668/ac4636

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Conference contributions

2022

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M. Eisterer (30th August 2022). Influence of fast neutron irradiation on the properties of conventional and high temperature superconductors. *7th International Workshop of Materials Physics, Bucharest, Romania*.

R. Unterrainer, A. Bodenseher, D. X. Fischer, D. Whyte, I. A. Shipulin, R. Hühne & M. Eisterer (23rd October 2022). Recovery of n and p+ irradiation damaged high temperature superconductors for fusion magnet applications. *Applied Superconductivity Conference (ASC'22), Honolulu*.

R. Unterrainer, A. Bodenseher, D. X. Fischer, A. Devitre, D. Whyte & M. Eisterer (29th November 2022). The role of small and large defects in enhancing and degrading the critical currents of coated conductors for fusion magnets. *The 35th International Symposium on Superconductivity, Nagoya, Japan, hybrid*.

H. Leeb, T. Srdinko (24th July 2022). A new R-matrix module for multi-channel calculations with GECCCOS. *15th International Conference on Nuclear Data for Science and Technology (ND2022), Sacramento, California, USA*. https://doi.org/10.1051/epjconf/202328403019

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M. Eisterer, R. Unterrainer, A. Bodenseher, F. Semper, M. Lehner & G. Munier-Gondiant (3rd April 2023). The role of small defects for the degradation of coated conductors in radiation environments. *International Workshop on Coated Conductors for Applications (CCA2023), Houston, USA*.

Universität Innsbruck / Institut für Ionenphysik und Angewandte Physik

Articles in scientific journals

2022

F. Duensing, F. Hechenberger, L. Ballauf, A. Reider, A. Menzel, F. Zappa, D. K. Böhme & P. Scheier (2022). Energetic D+ and He+ Impinging on Solid Beryllium: Observation of Physical and Chemically Assisted Atomic and Molecular Ion Sputtering. *Nuclear Materials and Energy, 30*. https://doi.org/10.1016/j.nme.2021.101110

S. Shermukhamedov, M. Probst, L. Chen & R. Nazmutdinov (2022). Sputtering and Reflection from a Beryllium Surface: Influence of Hydrogen Isotope Mass and Surface Details. *Nuclear Fusion, 62(6)*. https://doi.org/10.1088/1741-4326/ac592a

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A. Kendl, E. Reiter, M. Wiesenberger, M. Held & G. W. Zarate-Segura (2023). Non-trace full-F gyro-fluid interchange impurity advection. *Journal of Plasma Physics, 89(1)*. https://doi.org/10.1017/S0022377822001283

S. Shermukhamedov, M. Probst (2023). Sputtering from rough tungsten surfaces: Data-driven molecular dynamics simulations. *Physics of Plasmas 30(12)*. https://doi.org/10.1063/5.0167840

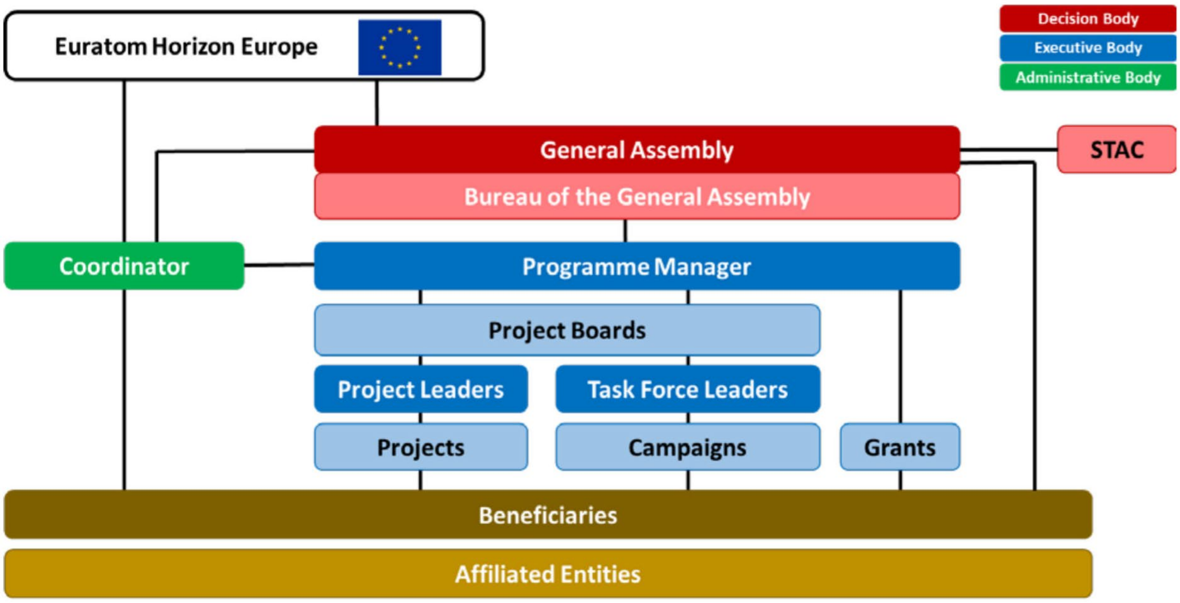
Conference contributions

2023

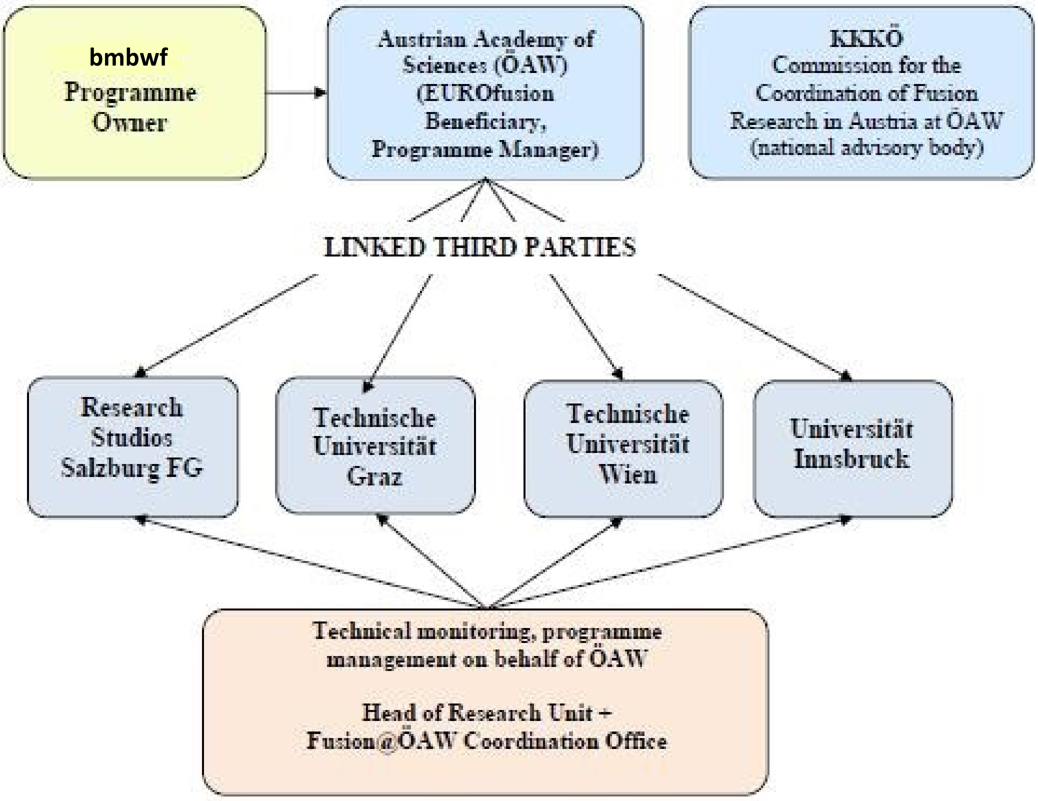
F.F. Locker, A. Kendl, M. Held, A. Stürz & T. Stocker-Waldhuber (12th September 2023). Development of full-f gyrofluid simulations for edge turbulence and magnetic reconnection. *27th Joint EU-US Transport Task Force Meeting (TTF 2023), Nancy, France*.

MANAGEMENT STRUCTURE

EUROFUSION ORGANIGRAM



AUSTRIAN PARTICIPATION (Fusion@ÖAW)



AUSTRIAN REPRESENTATIVES IN FUSION COMMITTEES (2022-2023)

Fusion Programme Committee

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

EUROfusion General Assembly

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Nadja Lampichler, Bakk., BA, MSc.	Austrian Academy of Sciences

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Kommission für die Koordination der Kernfusionsforschung in Österreich (KKKÖ)

Chair:	Univ.Prof.Dr. Anton Rebhan (ÖAW)

GLOSSARY OF SCIENTIFIC AND TECHNICAL TERMS

Bootstrap current

Theory predicted in 1970 that a toroidal electric current will flow in a tokamak which is fueled by energy and particle sources that replace diffusive losses. This diffusion driven bootstrap current, which is proportional to ß and flows even in the absence of an applied voltage, could be used to provide the confining magnetic field: hence the concept of a bootstrap tokamak, which has no toroidal voltage. A bootstrap current consistent with theory was observed many years later on JET and TFTR; it now plays a role in design of experiments and power plants (especially advanced tokamaks).

Collisionality

A measure of how frequently collisions occur in a tokamak plasma. A collisionality of unity corresponds to a trapped particle performing a single banana orbit before being scattered.

Confinement regime

In a magnetic field charged particles (ions and electrons) are forced to follow circular and helical orbits around the field lines. The low-confinement regime of tokamak plasmas with purely Ohmic or weak auxiliary heating is not viable for future fusion power plants. The latter will have to operate in so-called H-mode, i.e. in high-confinement regime with energy confinement in the presence of strong heating.

ELMs

Edge localized modes - instabilities which occur in short periodic bursts during the H-mode in divertor tokamaks. They cause sudden outbursts of the plasma thus expelling particles and depositing large heat flux onto the vessel wall. The plasma loses severe amounts of energy. In high-power fusion devices such as ITER or DEMO, powerful ELMs will cause erosion at the vessel wall. Finding methods to mitigate or suppress ELMs is therefore an important topic in present-day fusion research.

Guiding center orbit

The motion of an electrically charged particle such as an electron or ion in a plasma in a magnetic field can be treated as the superposition of a relatively fast circular motion around a point called the guiding center and a relatively slow drift of this point. The drift speeds may differ for various species depending on their charge states, masses or temperatures, possibly resulting in electric currents or chemical separation.

Pedestal

H-mode's high confinement stems from a sharp increase in the pressure at the edge of the plasma, known as the **edge transport barrier** or **pedestal**.

Zonal flows

Turbulence arising from the enormous difference in temperature between the core and edge of the plasma in e torus shaped tokamaks or stellarators may lead to substantial particle loss and reduced fusion power generation. Like in the giant gas planets Saturn and Jupiter, this temperature gradient also gives rise to global flows around the small torus circumference. The flows can be detected by sampling the electric potential, which shows pronounced bands, each extending on a complete flux surface. The flows exert a damping effect on the turbulence, which is favourable for the plasma confinement and reduces the technical effort necessary to keep the plasma burning.

Sources: https://www.euro-fusion.org/
https://www.ipp.mpg.de/1765980/glossar

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Photo on back cover:

Current „earth-shaped“ picture of the ITER construction site in Saint-Paul-lez-Durance, France.

ITER construction site

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