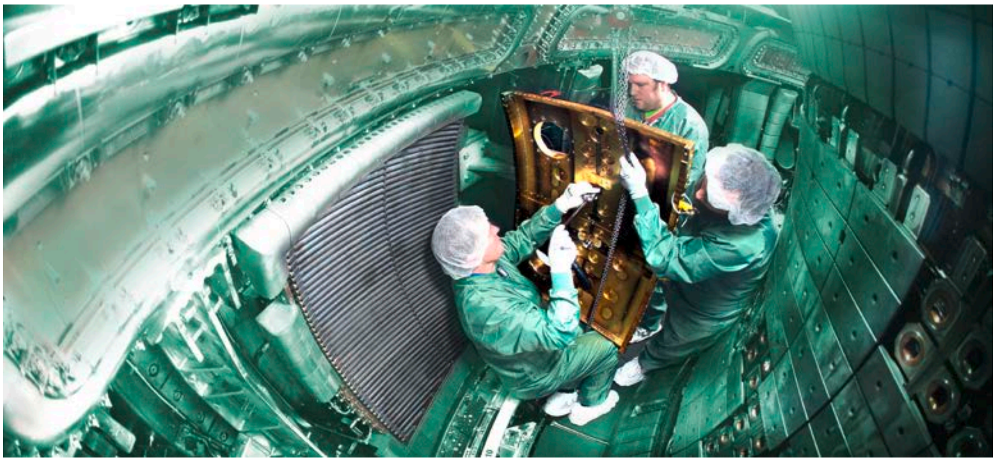
Max-Planck-Institut
für Plasmaphysik

IPP



Max-Planck-Institut für Plasmaphysik

Status Report

Fachbeirat 2015

IPP, Garching

September 2 – 4, 2015

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Part I

1. Introduction and new developments

As a preparation for its 2015 meeting in Greifswald, September 2-4, the Fachbeirat will receive electronic copies the IPP Annual Report 2014 as well as of the talks and posters that will be presented at the meeting. This document provides some additional statistical material about staff, funding, publication output, and the education of junior scientists (Part I) as well as an overview over all research divisions and the CVs of the scientific members and division heads (Part II). A number of annexes[1] complement the information given in this report: Annex I is the Helmholtz "Report on the Review of the Helmholtz Programme Nuclear Fusion". Annex II is the "Report on the 36th Meeting of the W7-X Project Council", which together with Annexes III and IV, the minutes of the first two meetings of the International Programme Committee, provides information about the status of the W 7-X project. Annexes V and VI are the 2013 Report of the Fachbeirat and the response of IPP respectively.

Chapter 2 gives information about the development of IPP staff, while Chapter 3 shows the funding profile for IPP and its distribution over the organisational subunits. Chapter 4 provides some analysis about the publication output of the institute. Finally, Chapter 5 informs about education of PhD students.

Figure 1.1 shows the current organisation of the Board of Directors and the scientific divisions.

The scientific strategy of IPP foresees six scientific divisions both in Garching and in Greifswald plus one scientific director. Currently it is planned to fill five divisions on both sites, reserving the remaining two for future strategic developments, when funding permits. The materials research and plasma wall interaction activities, essential for the machines at both sites, will be carried out under the respective plasma edge and divertor divisions. The procedure for appointing a new director for the "Tokamak Theory" has not been successful so far. A new call for nominations has been sent out recently. In the division "Plasma Edge and Wall" Rudolf Neu has been appointed to a joint professorship (W2) with the Technical University of Munich, faculty for mechanical engineering. Still vacant is the director's position for the division "ITER Technology and Diagnostics", lead by an acting division head.

In addition to the scientific divisions, IPP has been hosting three Independent and Junior Research groups whose scientific activities are reported in the IPP Annual Report: Dr. Rachael McDermott: Helmholtz Young Investigator Group, "Macroscopic Effect of Microturbulence Investigated in Fusion Plasmas" (2012-2017). Dr. Matej Mayer: Helmholtz Russia Joint Research Group, "Hydrogen Isotopes Retention in First-Wall Materials for ITER and Fusion Power Reactors" (04/2011-3/2014). Prof. Frank Jenko: ERC starting/consolidator grant (2011-2015), "Turbulence in Laboratory and Astrophysical Plasmas" (additionally

[1] provided as separate documents

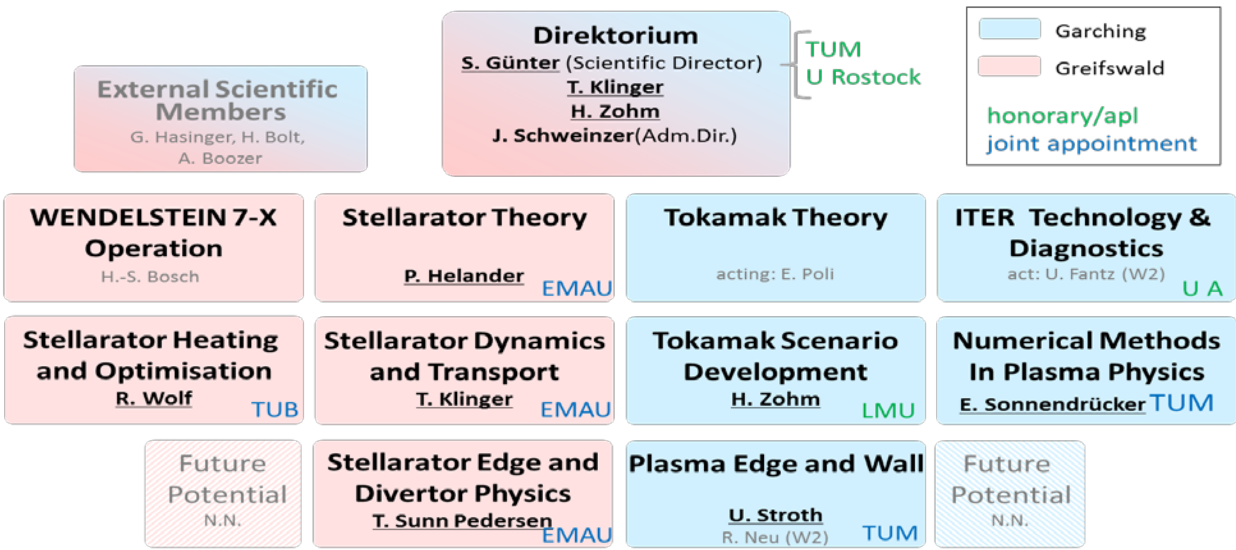
supported by the DFG). However, Prof. Frank Jenko has recently left IPP for a full professorship at the University of California, Los Angeles (UCLA).

With the end of the machine assembly and the start of the Wendelstein 7-X commissioning 2014 the project organisation is being changed to meet the requirements for the first plasma operation phases and the completion of the machine to full performance with long pulse discharges.

The "International Helmholtz Graduate School for Plasma Physics", founded in 2011 in collaboration with the Ernst-Moritz-Arndt University Greifswald and the Technical University Munich (funded by the Helmholtz Society), provides a structured PhD-education and an interdisciplinary research environment[2]. A key aspect of the program is the exchange of lecturers to provide a homogenous portfolio across the institutions, supplemented by external guest lecturers. Currently, (July 2015), 73 students are members of the school, 37 have already graduated. Since the last meeting of the Fachbeirat 14 IPP students have enrolled in HEPP, and 12 have obtained their degrees.

The Max Planck-Princeton Center for Plasma Physics, established in March 2012, in addition to IPP involves the Max Planck institutes for Solar system research and Astrophysics as well as the Princeton Plasma Physics Laboratory and the Astrophysics Faculty of Princeton University. The German contributions to this center are financed by the Max Planck Society. The focus of this center is mainly to exploit synergies between fusion plasma research and the astrophysical plasma community. Originally the funding if the US part had been provided for a period of three years only. After a very successful evaluation, the extension of the funding has been granted for additional three years. On the German side, the Center has recently been prolonged until the end of 2017.

In 2012 the European Commission decided to stop the Contracts of Associations and the corresponding baseline support for the fusion institutes by the end of the year 2013. Since 2014 the European fusion programme is being supported by a newly developed instrument called "programme co-fund action" in the framework of Horizon 2020. Under the lead of IPP, the consortium "EUROfusion" was built, involving all 29 European fusion institutes with several associated third parties. About half of the experimental days on ASDEX Upgrade in 2014 were used in the framework of the Medium Size Tokamaks (MST1) project of the Consortium.



[2] Details can be found in Section 5: PhD Education

Figure 1.1: Organisational Diagram for IPP[3]

2. Staff Statistics

Figure 2.1 shows the evolution of the IPP personnel, divided into the two institute sites, Garching and Greifswald. Until 2003 the numbers are given for individuals, since then for full-time-equivalents (FTEs), therefore a downward jump is visible in 2004. Due to the foundation of the new IPP branch in Greifswald and the start of the construction phase of the Wendelstein 7-X project, an increasing fraction of the staff had to be based in Greifswald. However, since roughly 2004 the staff in Garching has stabilized at the critical mass required to maintain the research there. In Greifswald a further growth was necessary, mainly to meet the requirements regarding engineers and technicians for W7-X construction.
It is important to point out that after several years of flat budget and a small increase over the last 5 years (~2% increase p.a.), starting from 2014, IPP again suffers from a flat national budget. Given the rising costs, in particular for personnel, the institute thus faces substantial financial pressure.

The scientific life at IPP is enriched by a substantial number of young researchers, students and Postdocs. Figure 2.2 shows the development of the numbers of PhD students and Postdocs over the last 10 years. The number of PhD students is increasing since 2014, when the scientific board decided not to limit the number of PhD students any longer.

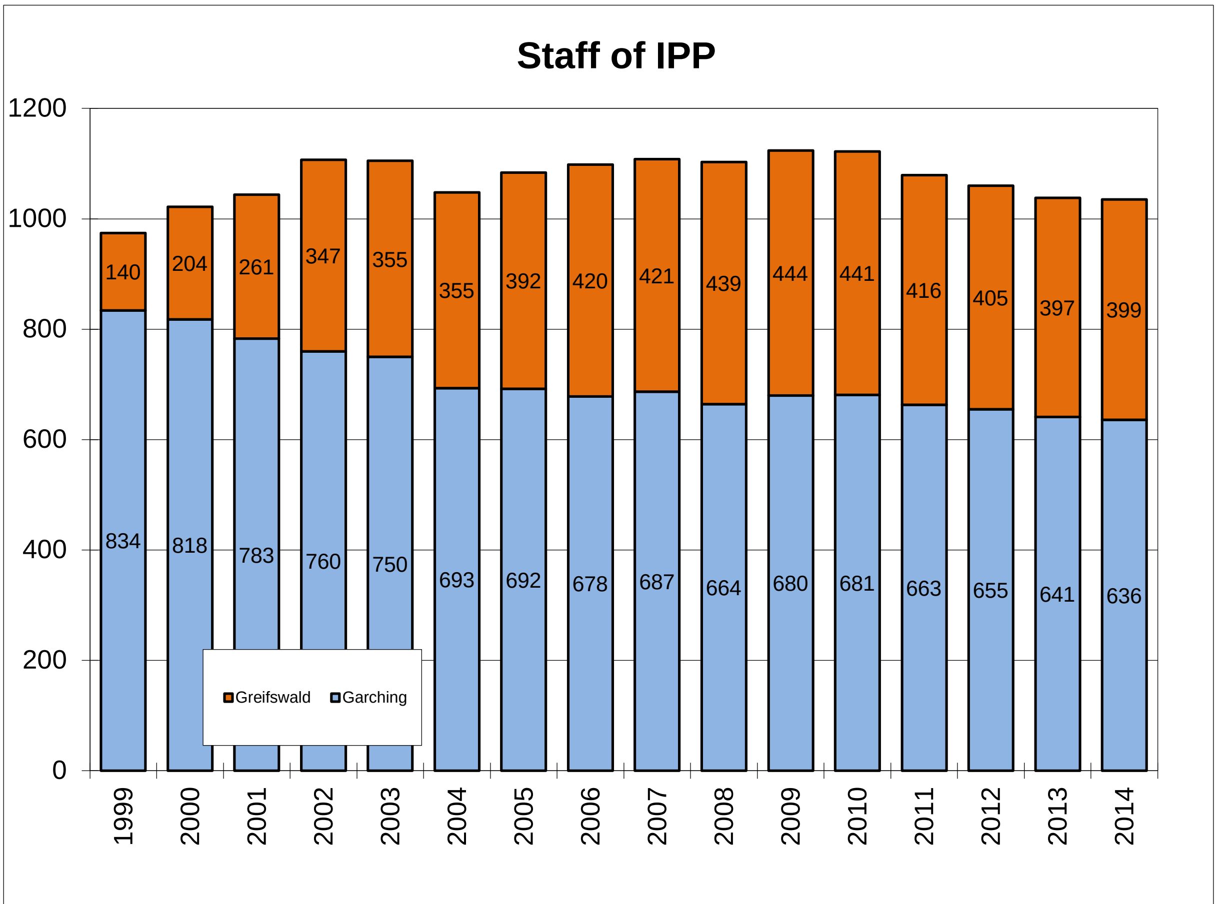


Figure 2.1: Development of IPP staff since 1999

[3] Scientific Members of the Max Planck Society are underlined

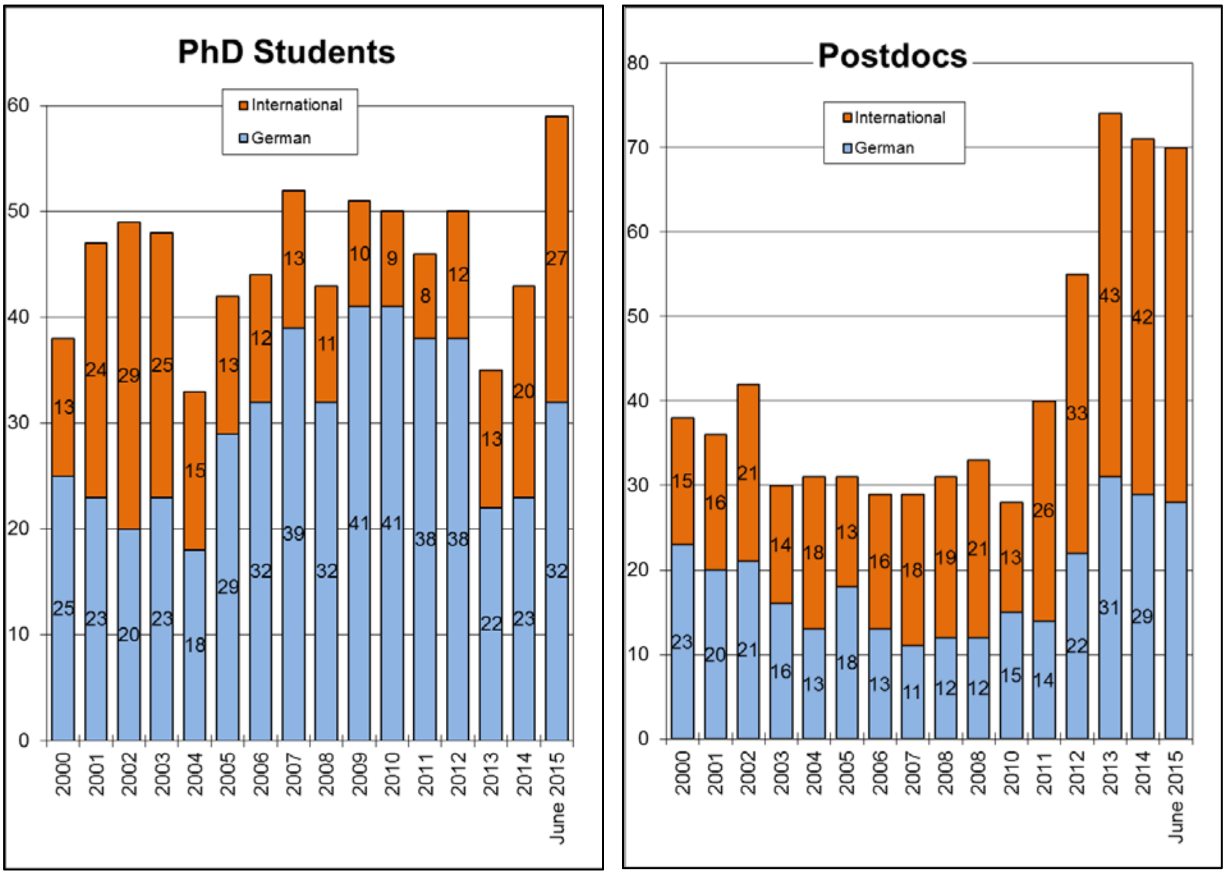


Figure 2.2: Development of IPP PhD Students and Postdocs since 2000

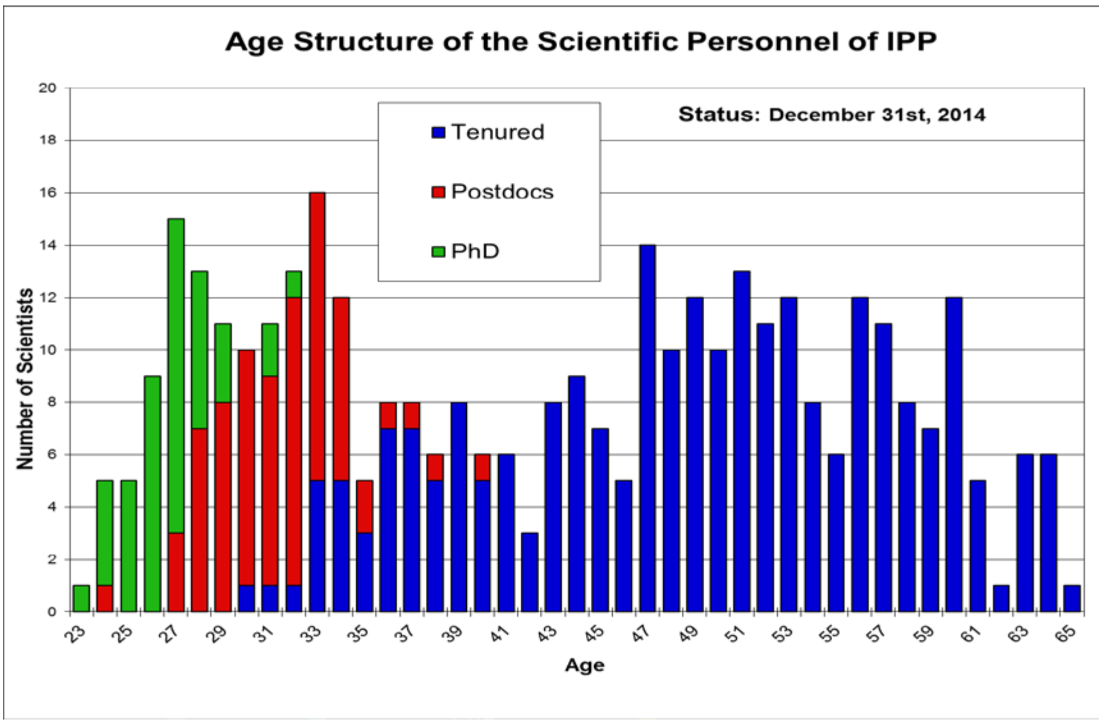


Figure 2.3: Age distribution of IPP Personnel

Figure 2.3 shows the age distribution of IPP scientific personnel in the different status groups. The bulk of the tenured status group has an age around 45-55 years.

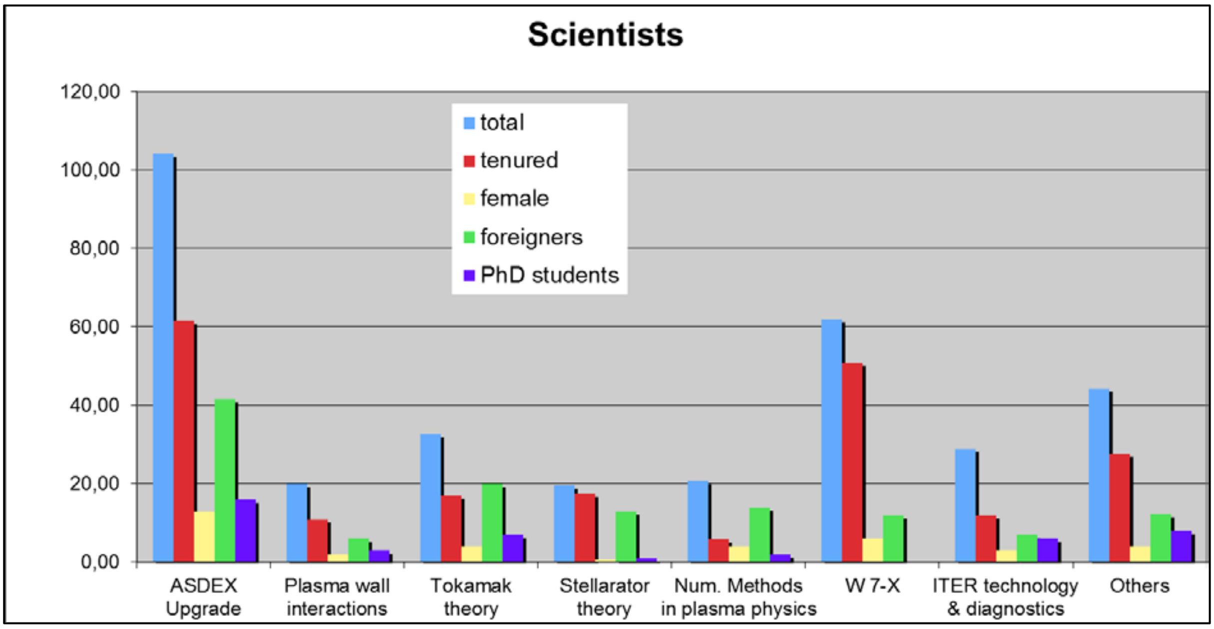


Figure 2.4: Tenure fraction, gender and international balance of IPP scientists (FTEs) on December 31st, 2014

Figures 2.4 and 2.5 show the tenure fraction, as well as the gender and international balance of IPP employees, distributed over the different organisational groups. This figure shows a healthy fraction of international employees, but a relatively low fraction of females, apart from the administrative staff.

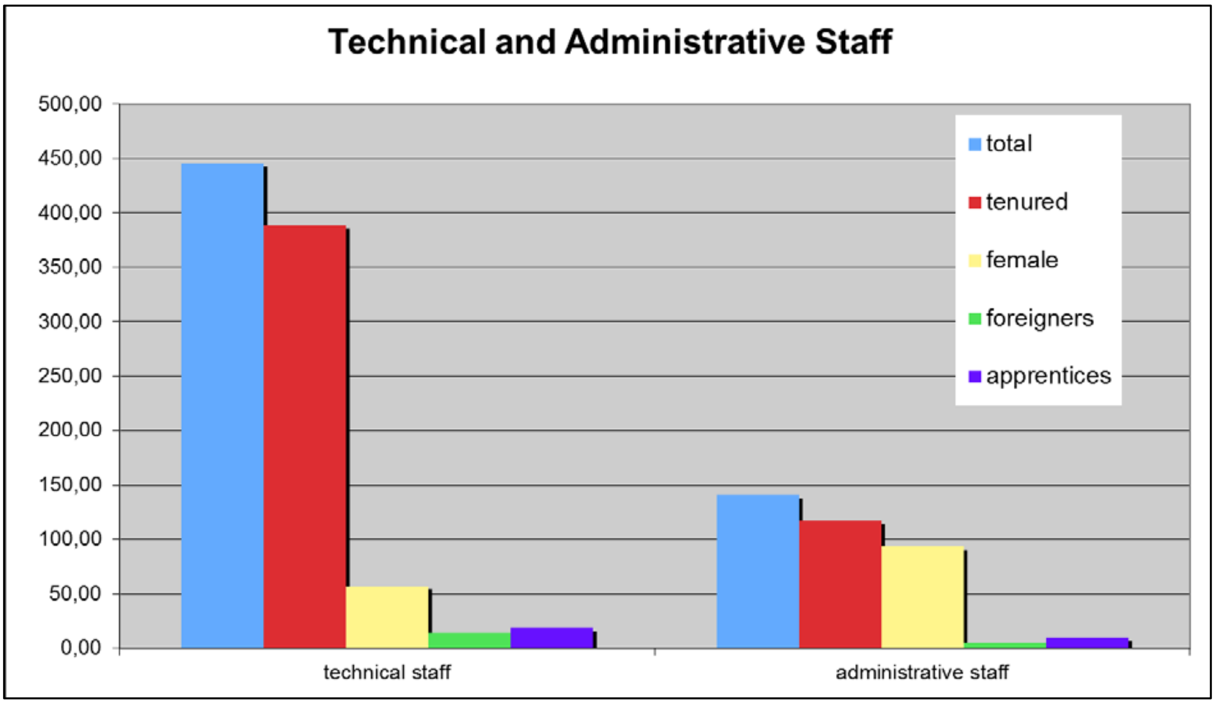


Figure 2.5: Tenure fraction, gender and international balance of IPP technical and administrative staff (FTEs) on December 31st, 2014

Table I shows how far the staffing plan “Greifswald 2014+” has been executed until today. The abbreviations mean: OP: W 7-X operation division (H.-St. Bosch), E3: Stellarator heating and optimization (R. Wolf), E4: Stellarator edge and divertor physics (Th. S. Pedersen), E5: Stellarator dynamics and transport (Th. Klinger), ST: Stellarator theory (P. Helander). “Planned” means that the positions correspond to the approved staffing concept; “existing” means that the person already had a tenured contract; “hired” means that the recruitment process is finished; “blocked” means that the position is provisionally not allowed the be filled for budgetary reasons.

	OP					**E3**					**E4**				
	planned	existing	hired	blocked	**open**	planned	exisiting	hired	blocked	**open**	planned	existing	hired	blocked	**open**
Physicists	8	8	0	0	**0**	21	15	1	1	**4**	19	11	1	2	**5**
Engineers (TU)	26	18	5	1	**2**	5	5	0	0	**0**	3	2	1	0	**0**
Engineers (FH)	49	26	21	0	**2**	11	9	2	0	**0**	5	4	1	0	**0**
Technicians	39	12	22	0	**5**	14	7	5	2	**0**	6	3	3	0	**0**
Workers	1	1			**0**					**0**					**0**
Support staff	2	2	0	0	**0**	1	1	0	0	**0**	2	2	0	0	**0**
	125	67	48	1	**9**	52	37	8	3	**4**	35	22	6	2	**5**

	E5					**ST**					**TS**				
	planned	exisiting	hired	blocked	**open**	planned	exisiting	hired	blocked	**open**	planned	exisiting	hired	blocked	**open**
Physicists	15	9	1	1	**4**	21	16	2	2	**1**					
Engineers (TU)	1	1	0	0	**0**	0				**0**	4	2	1	1	**0**
Engineers (FH)	4	4	0	0	**0**	0				**0**	16	8	7	1	**0**
Technicians	4	0	3	1	**0**	4	4	0	0	**0**	9	7	1	1	**0**
Workers					**0**					**0**	31	21	6	2	**2**
Support staff	1	1	0	0	**0**	1	1	0	0	**0**	2	2	0	0	**0**
	25	15	4	2	**4**	26	21	2	2	**1**	62	40	15	5	**2**

Table I: Execution of the staffing plan “Greifswald 2014+”

The number of positions in Garching which have to be refilled due to retirement of tenured staff are:

	2015	2016	2017	2018
Scientists and engineers	1	5	0	1
Technicians	6	1	1	3

3. Budget of the Institute

Figure 3.1 gives a summary of the institute's budget over the last 12 years. The national funding consists of two components: the federal budget providing 90% and the respective state governments contribute 10% to the budget of the institute located in their territory (Bavaria and Mecklenburg-Vorpommern). In addition, IPP is associated with EURATOM and received – until 2013 – the so-called baseline support of up to 20% of the approved Work Programme. Furthermore, there was the possibility to apply for specific preferential support actions through the EFDA program (about 20% in addition to the baseline support) plus some additional funding through various other sources. From 2014 on, the European financial contribution is managed by the Consortium EUROfusion via a so-called "programme co-fund action".

As shown in figure 3.1, the national funding has been on a nearly constant level until 2010. The increase of the national funding from 2007 to 2008 is mainly due to the compensation for the value added tax (VAT), which IPP has to carry since 2008. The ceiling imposed on the national funding line was for political reasons. From 2011 onwards this ceiling was lifted, and IPP has enjoyed a moderate increase in the national funding until 2014 when again a ceiling was defined due to political reasons. Taking into account the loss in buying power due to inflation, this situation leads to considerable constraints for IPP.

The moderate increase between 2011 and 2014 was, however, offset by a significant decrease in the EURATOM funding. Since 2009 the Baseline Support has also been consecutively decreased in anticipation of the significantly increased demands for ITER. With the new funding scheme by EUROfusion the European contribution to the IPP budget seems to stabilize.

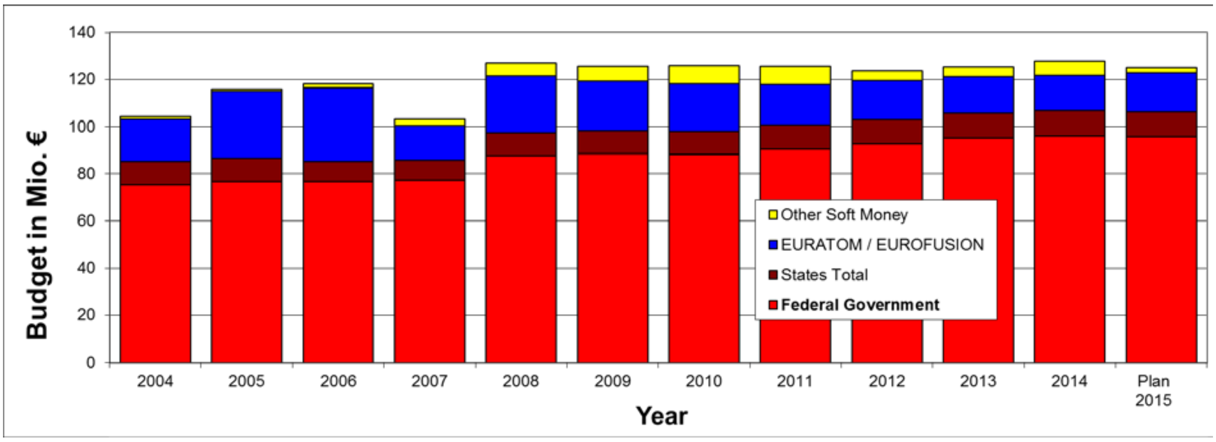


Figure 3.1: Funding profile of IPP 2004 – 2015

4. Quantitative Indicators

Publications:

Scientific publications and their impact are probably the most important criteria of the success of a fundamental research institute. For an experimentally driven Institute as IPP, another criterion is the role it plays as innovator of technology, experimental techniques, instruments and sensors, in particular the operation of large instruments with an international user base. Furthermore, the international standing of its principal scientists (as measured by invited talks, awards etc.), and the career paths of the young scientists it produces, are important criteria. Most of this information is provided in the IPP Annual Reports. Here we give some additional statistical information and analysis.

Table 4.I lists the number of refereed IPP publications over the period 2005-2014 according to data gathered from the "Web of Science", cross-checked against the entries in the MPG eDoc system.[4]

Year	IPP-Publications
2005	345
2006	269
2007	373
2008	270
2009	429
2010	297
2011	449
2012	289
2013	401
2014	378
Total	**3500**

Table 4.I: Refereed IPP publications in the period 2005-2014

Pronounced bi-annual fluctuations introduced by the frequency of large international conferences can be inferred from the table. A more reliable measure of the publication output is therefore given by the 2-year average (Figure 4.1). As will be shown subsequently, the average impact factor of IPP-publications is well above the community average. An expression of this fact is that in 2013 three of the 10 most quoted articles in the journal Nuclear Fusion and three of the 10 most quoted articles in Plasma Physics and Controlled Fusion had IPP first authors (for 2014 the figures are 2 of 10 and 4 of 10 respectively).

[4] Please note that the numbers sometimes are higher than in the former 'Reports to the Fachbeirat'. It appears that articles are continuously being added to the 'Web of Science'

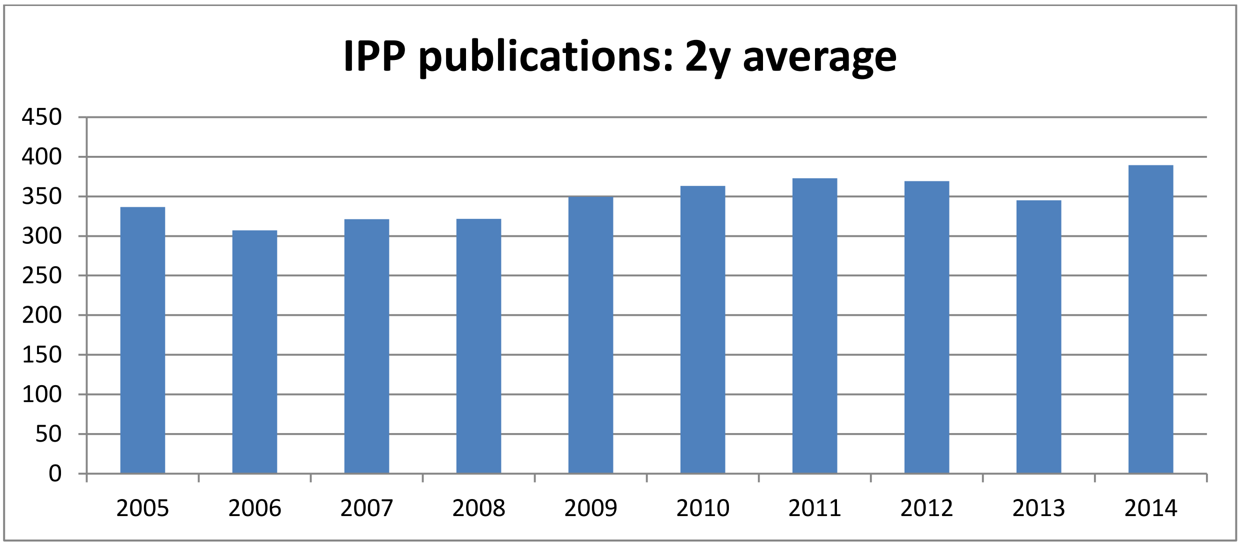


Figure 4.1: Two year-averaged number of refereed IPP publications in the 10-year period 2003-2012

In the following, we compare the scientific output of IPP within and against the relevant physics areas IPP is active in. Figure 4.2 displays the distribution of the IPP publications onto the most often chosen journals, i.e. Physics of Plasmas, Plasma Physics and Controlled Fusion (PPCF), Fusion Engineering and Design (FED), Nuclear Fusion, Journal of Nuclear Materials (JNM), Review of Scientific Instruments (RSI) and Physical Review Letters (PRL) in the last ten years (the absolute figures can be seen in the second column of Table II below). On the one hand, the selection of journals to a certain extent reflects the main research activities of IPP. On the other hand, the five journals with the most published articles provide an adequate reference frame to put the scientific output of the IPP in perspective. For these journals the average number of citations of published articles has been compared to the number of citations of IPP articles, see Figure 4.3

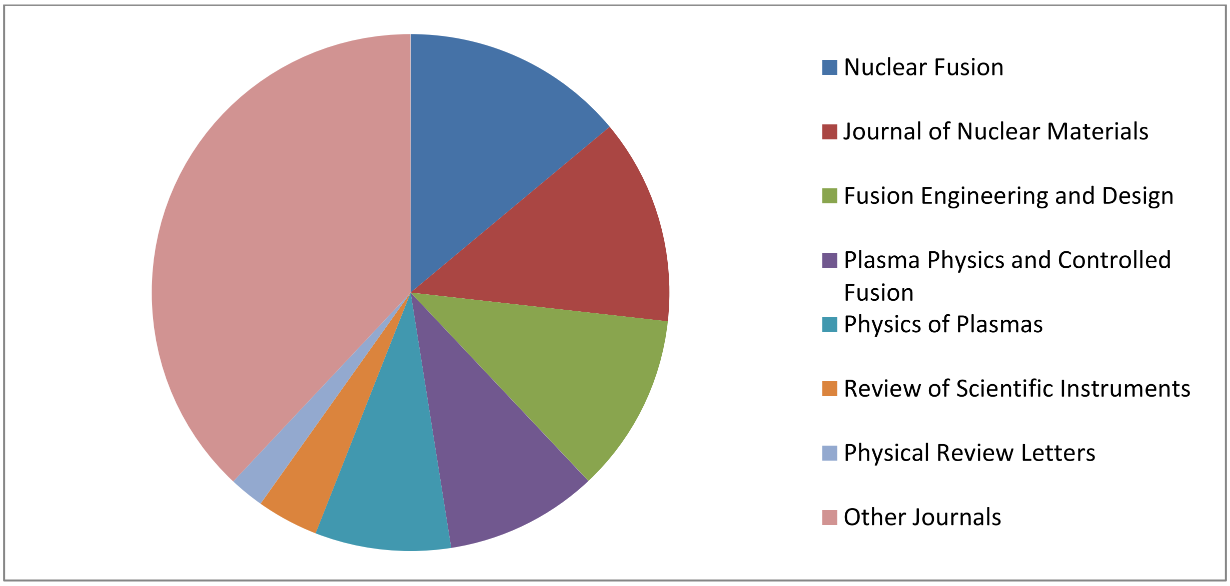


Figure 4.2: Distribution of IPP publications on different journals (2005-2014)

As can be seen from Figure 4.3, the impact of the IPP articles exceeds the respective average of the journals in most cases[5].

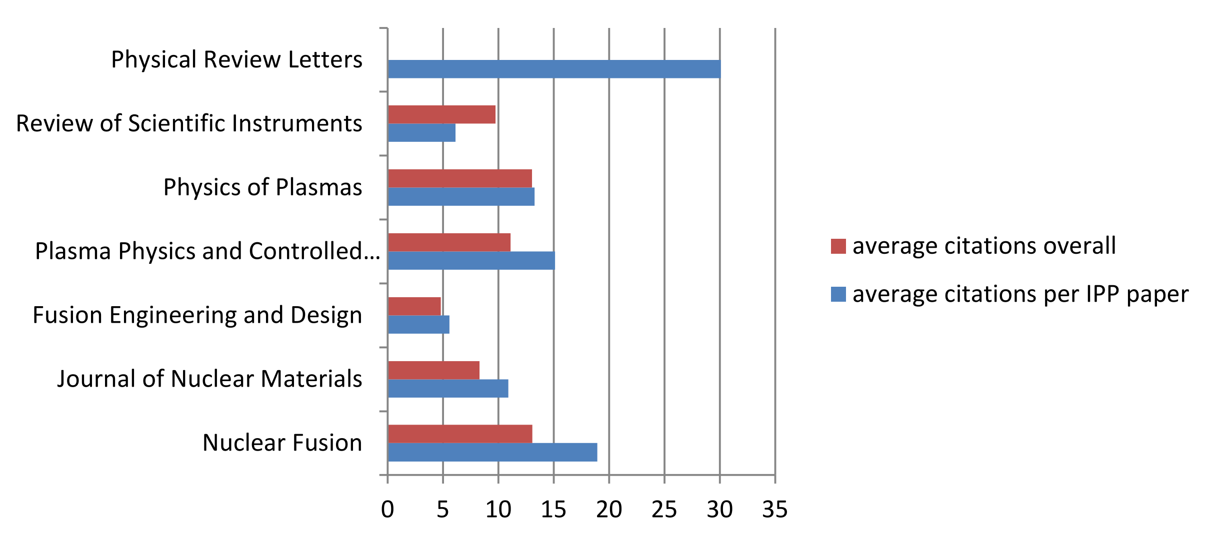


Figure 4.3: Average numbes of citations of an article in a journal (IPP vs. overall).

	Period 2005 - 2014			
	number of IPP papers	average citations per IPP paper	average citations overall	impact factor (2014)
IPP total	3500	11,81		-
NF	488	18,92	13,06	3,062
JNM	449	10,90	8,30	1,865
FED	392	5,58	4,80	1,152
PPCF	333	15,12	11,09	2,186
PoP	297	13,27	13,03	2,142
RSI	135	6,12	9,75	1,614
PRL	76	30,08	n. a.	7,512
Others	1330			

Table 4.II: Article citations in main journals

5 Unfortunately the overall citations figure for the PRL was not available

Prizes

The following prizes were awarded to IPP scientists during the reporting period:

Dr. Benedikt Geiger	Otto Hahn Medal 2013 (MPG)	For fundamental experimental investigations of the dynamics of fast ions in turbulent magnetic plasmas
Dr. Michael Kraus	Otto Hahn Medal 2013 (MPG)	For work on variational integrators in plasma physics
Prof. Hartmut Zohm[6]	John Dawson Award 2014 (American Physical Society)	For the theoretical predic-tion and experimental demonstration of neoclassical tearing mode stabilization by localized electron cyclotron current drive.
Dr. Felix Schauer	Fusion Technology Award 2014 (IEEE)	For the development of super-conducting magnets and stellarator power plant studies
Dr. Benedikt Geiger, Dr. Manuel Garcia Muñoz[7]	Landau-Spitzer Prize for Plasma Physics 2014 (APS and EPS)	For greater understanding of energetic particle transport in tokamaks through collaborative research
Prof. Dr. Ursel Fantz, Bernd Heinemann, Dr. Peter Franzen	Negative Ion Source Prize 2014 (NIBS Award)	For recent innovative and significant achievements in the fields of the physics, theory, technology and/or applications of sources, low energy beam transport, and/or diagnostics of negative ions

6 shared with Prof. James D. Callen and Prof. Chris Hegna from the University of Wisconsin, Dr. Robert J. La Haye from General Atomics, USA, and Dr. Olivier Sauter from Ecole Polytechnique Fédérale de Lausanne, Switzerland.)

7 shared with Dr. David Pace and Dr. Michael Van Zeeland from General Atomics

Cooperation with Universities

IPP has strong connections to many universities at various levels, ranging from joint appointments, joint research projects (the most common case) to financially supported development projects (e.g. for W7-X) and finally student education. For IPP it is very important to attract talented students. Teaching plasma physics at various universities has therefore a long tradition at IPP. In 2014, 25 staff members of IPP taught at universities or universities of applied sciences: Many members of the IPP staff are Honorary Professors, Adjunct Professors or Guest Lecturers at various universities and give lectures on theoretical and experimental plasma physics, fusion research, data analysis and materials science. Table 4.III gives an overview. The teaching programme has been highly successful over the years, and many students who first came into contact with plasma physics through lectures given by IPP staff have later done thesis work or even taken up a career in the fusion research. Lecturing at and cooperation with universities are supplemented by IPP's yearly Summer University in Plasma Physics and advanced courses given in the context of the Joint European Research Doctorate in Fusion Science and Engineering.

University	**Members of IPP staff**
University of Greifswald	Dr. Hans-Stephan Bosch Dr. Andreas Dinklage Prof. Per Helander Prof. Thomas Klinger Dr. Heinrich Laqua Prof. Thomas Sunn Pedersen
Technical University of Berlin	Prof. Robert Wolf
Technical University of Munich	Prof. Sibylle Günter Dr. Klaus Hallatschek Dr. Philipp Lauber Prof. Rudolf Neu Prof. Eric Sonnendrücker Prof. Ulrich Stroth
University of Munich	Dr. Thomas Pütterich Dr. Jörg Stober Prof. Hartmut Zohm
University of Augsburg	Prof. Ursel Fantz Dr. Marco Wischmeier
University of Ulm	Dr. Thomas Eich Prof. Frank Jenko Dr. Emanuele Poli Dr. Jeong-Ha You
Technical University of Graz	Dr. Udo v. Toussaint
University of Bayreuth	Dr. Wolfgang Suttrop
University of Gent	Prof. Jean-Marie Noterdame

Table 4.III IPP staff who taught courses at universities in 2014

EUROfusion

Enabling Research Projects

G. Conway:	Micro-turbulence properties in the core of tokamak plasmas: close comparison between experimental observations and theoretical predictions (2014 – 2017)
B. Geiger:	Velocity space resolved study of the fast-ion transport due to large scale MHD instabilities by combining multiple diagnostics (2014)
M. Hölzl:	Global non-linear MHD modeling in toroidal X-point geometry of disruptions, edge localized modes, and techniques for their mitigation and suppression (2015 – 2017)
F. Jenko:	Nonlinear gyrokinetics and ab initio transport modelling for ITER & beyond: From basic understanding to truly predictive capability and improved control (2014)
E. Sonnendrücker:	Verification of global gyrokinetic codes and development of new algorithms for gyrokinetic and kinetic codes (2014 – 2017)

Fusion Researcher Fellowships (total awarded: 17)

A. Manhard	Influence of Different Defect Types on Hydrogen Isotope Transport and Retention in Tungsten (2014 – 2015)
M. Schneller	Nonlinear Energetic Particle Transport in Fusion Plasmas (2014 – 2015)
D. Vezinet	Soft X-Ray tomography of MHD events in the presence of heavy impurities and tests of a gas detector for neutron-resilient future Soft X-Ray diagnostic (mid 2014 – mid 2016)
E. Viezzer	Impact of poloidal impurity asymmetries on edge current and pedestal stability (2014 – 2015)

EUROfusion Researcher Grants (total awarded: 11)

M. Dunne:	Interpretive and predictive stability calculations in nitrogen seeded and pellet fuelled discharges on ASDEX Upgrade (mid 2015 – mid 2017)
G. Papp	Self-consistent modelling (including experimental validation) of runaway electron dynamics in tokamak disruptions (mid 2015 – mid 2017)
M. Willensdorfer:	Impact of external magnetic perturbations and 3D effects on plasma transport (2015 – 2016)

EUROfusion Engineering Grants (total awarded: 17)

A. Bader:	Integrating a distributed ICRF antenna in DEMO (mid 2015 – mid 2017)

5. PhD Education

PhD education at the Max Planck Institute for Plasma Physics (IPP) in Garching and Greifswald is organised under the umbrella of the International Helmholtz Graduate School for Plasma Physics, HEPP. This graduate school is organising the education for doctoral candidates at IPP together with its neighbouring partner universities, the Technical University of Munich (TUM) and the Ernst Moritz Arndt University of Greifswald. Associated partners are the Leibniz Institute for Plasma Science and Technology (INP) in Greifswald and the Leibniz Computational Center (LRZ) in Garching.

HEPP provides a coherent framework at IPP and the participating universities for qualifying a new generation of internationally competitive doctoral candidates in the field of plasma physics, fusion research, computational physics, surface science and plasma technology. The intention of HEPP is to prepare the doctoral candidates for careers in a range of fusion related fields, i.e. for taking over leading positions in research, management and politics, technology development, or consulting and education. Graduate education in HEPP is structured, systematic, and adapted to the individual needs of the doctoral candidates.

By offering a dedicated training program with a broad spectrum of summer schools, special lectures, colloquia, and workshops as well as access to state-of-the art laboratory equipment and supercomputers, HEPP aims to combine excellent research opportunities and a stimulating environment. The know-how of the two universities, the associated partner institutes, and the two sites of the Max Planck Institute for Plasma Physics is brought together to provide the basis for cutting edge research and education. IPP is a partner of the European Fusion Education Network (FuseNet), and also one of the eight main partners of the Joint Doctoral College in Fusion Science and Engineering (FUSION-DC), which has been approved under the auspices of Erasmus Mundus, the European programme to promote training schemes.

All PhD students sign a work contract that specifies the expected duration (3 years[8]) and rights and duties for graduation[9]. An additional supervision contract in which all parties agree to the "Terms of good practice in doctoral training in the International Helmholtz Graduate School for Plasma Physics" is signed by the academic supervisor, the direct supervisor/mentor, an ombudsperson and the doctoral candidate. The terms of good practice together with detailed additional information on the requirements for graduation can be found on the IPP website. Students and supervisors are strongly encouraged to define a work plan as an important element to structuring the doctoral project. Doctoral candidates also discuss the choice of transferable skill courses with their thesis advisors. Generally, mentors (in many cases these are group leaders qualified as university lecturers) closely work with not more than one or two doctoral candidates, holding weekly or bi-weekly meetings, and are strongly involved in the evaluation of the thesis (in case a candidate is graduating at the university where the mentor gives lectures, the latter even acts as primary reviewer of the thesis). IPP advises quarterly meetings between the candidate, the mentor and the academic supervisor (with optional participation of the ombudsperson).

IPP students are eligible for the Graduate School of the Technical University of Munich and the Graduate Academy at the University of Greifswald, which support doctoral candidates in their research work, promote transferable skills, provide tailor-made qualification

[8] Financing is guaranteed for this period, in exceptional cases a prolongment of up to 12 months is granted
[9] As from June 2015 all PhD candidates are offered work contracts. IPP stipends are no longer issued.

programmes, individual mentoring, subject-related consultation as well as gender and diversity services contributing to optimal conditions for a successful doctorate.

In addition, some of the students take part in the FUSION-DC graduate school or the “European Doctoral Network in Fusion Science and Engineering” programme, which is supported by institutions in Germany (IPP and LMU), Italy (Consorzio RFX and University of Padua), and Portugal (Instituto Superior Técnico). In the framework of the latter, IPP organises a yearly course on “Advanced Fusion Physics’’ that is credited with 6 ECTS and can be included in the curriculum of PhD students at IPP.

Supervisors have access to the numerous special training measures of MPG and HGF.

The bulk of the education for PhD students is provided by the supervisors and research teams in the laboratories. Students have the opportunity to work on first class fusion research installations such as ASDEX Upgrade and W7-X (in the near future), with basic physics experiments like VINETA, devices related to material sciences like the high heat-flux device GLADIS, state-of-the-art technology test stands such as the negative ion neutral beam source ELISE, cutting-edge laboratory equipment, and powerful computing facilities. A large number of excellent senior scientists are available for discussions or to answer questions. Furthermore, the students report frequently on their research in front of an audience with international scientists.

As from their second year, all PhD students are encouraged to engage in international exchange by attending conferences and workshops abroad[10] and are expected to publish at least one refereed article[11] as first author before they hand in their thesis.

[10] For the purpose of internationalization, a dedicated budget is provided for each student in addition to the general funding provided by IPP and the partnering universities

[11] The conditions for the latter are laid out in the work contract

Part II:

The challenges of fusion research require in many cases an interdisciplinary approach. This holds also on the institutional level. For that reason, the research at IPP is organized in a matrix-like structure based on divisions, which are cross-linked by cooperative research projects. The coarse-scale structure is provided in Figure 5.1, where the relative activities of the divisions.

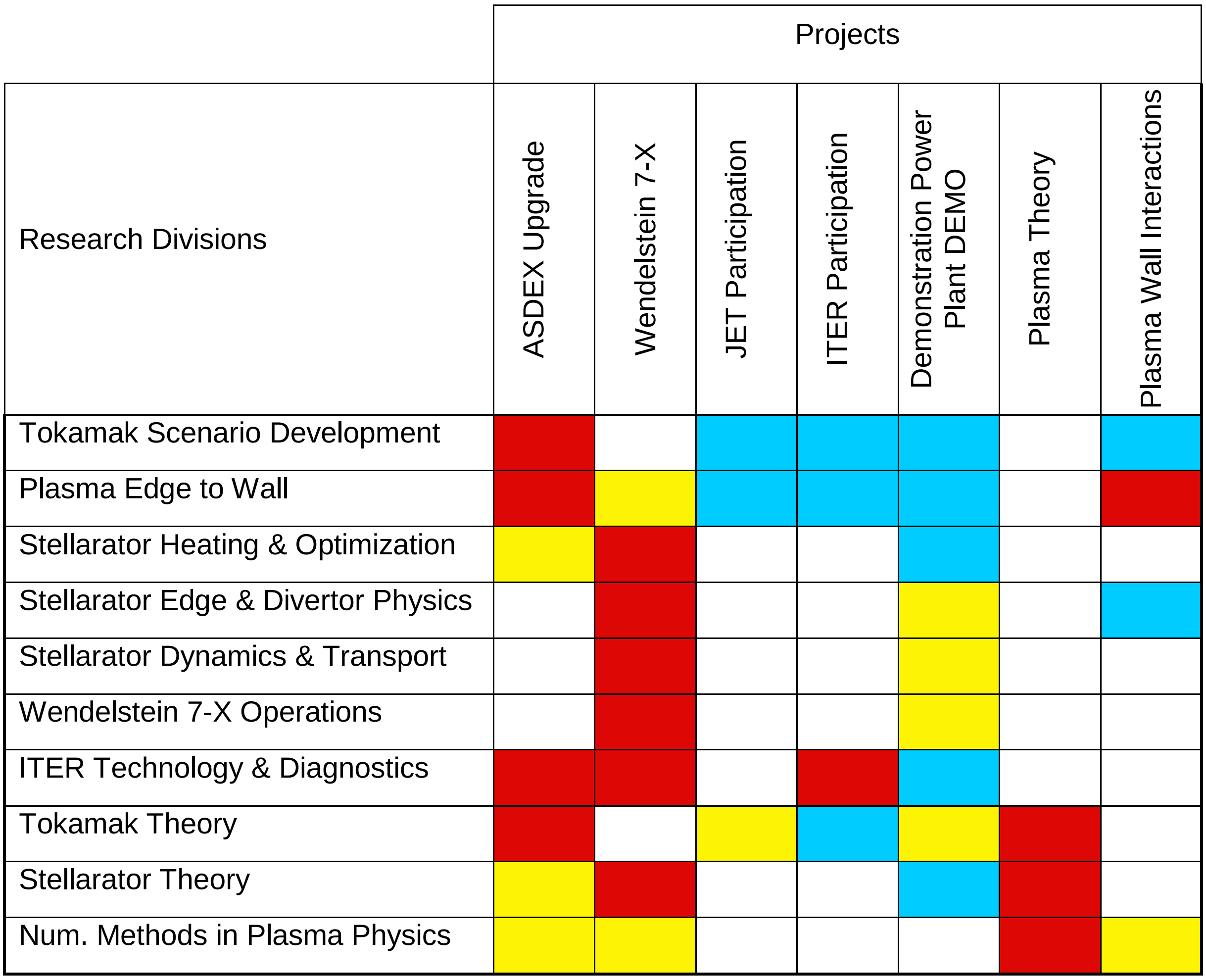


Figure 5.1: Matrix structure of IPP

within the projects is indicated by the following color scheme:

major activities — activities — minor activities

Additional information on the individual divisions and the projects is provided subsequently.

6. Information on the individual divisions and independent research groups

Wendelstein 7-X Completion project (Th. Klinger)

The project coordinates human resources, technical activities, the technical part of industry contracts as well as the contributions from other research centres, and takes care of the interfaces between physics and engineering in this complex and challenging venture. The project is managed by the Project Director Wendelstein 7-X Completion (T. Klinger), who is also member of the IPP board of directors. The project organisation relies on four technical divisions and four interfaces to the institute's scientific divisions (c.f. Figure 5.2). Around 70 professionals work inside the technical project divisions. In addition, up to 100 engineers, technicians and workers will be contracted via staff leasing agreements. EURATOM supports the project with 2 senior experts working in Greifswald and Garching on key project tasks. The quality management office (the project is QM ISO 9001 certified) reports directly to the project director.

The division "Project Coordination" (PC) is now responsible for coordinating the project management efforts of the W7-X completion Project. Its main task is the monitoring and control of the integrated financial and time planning of the project and of the hardware contributions by the scientific divisions. This includes budget control and external contract monitoring. PC is also responsible for the process organisation within the project, the coordination of project design reviews, project specification processes, and international collaborations.

The division "Design and Configuration" (DC) is responsible for all central design tasks and the fast and consistent implementation of component changes. It also takes care of the development and maintenance of IT design tools and interfaces to external collaborators.

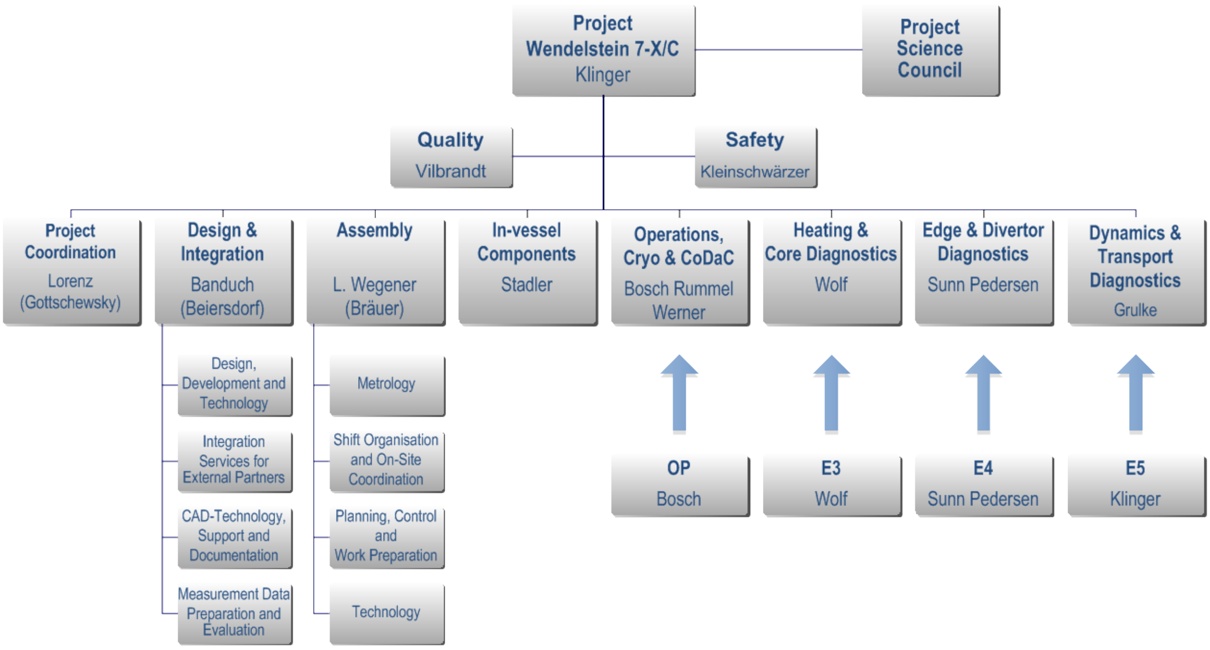


Figure 5.2: Organizational chart of the Wendelstein 7-X Completion project (7/2015)

The division “Assembly” (AS) is responsible for the integration of additional major components of the stellarator, in particular in-vessel components, cooling circuits and cryo-components. In addition, the division is responsible for the development of suitable assembly technologies and tools.

The division “In-Vessel Components” (IVC) is based in Garching, as the manufacturing takes place mainly in the Garching central workshops. In addition, Garching design capacities are used and the test programmes are conducted with Garching facilities (e.g. the GLADIS-device for the test of high heat-flux components). In particular, the division is responsible for the manufacturing of the high-heat flux divertor and related sub-systems. The other four divisions have no own personnel but are established to appropriately manage the interfaces to the scientific divisions E3, E4 and E5 and the scientific/technical division OP. The project board consists of the Project Director (chair), the heads of the technical project divisions PC, DC, AS, IVC, one representative of E3, E4, and E5, and three representatives of OP.

The collaboration with other institutions is a key element of the Wendelstein 7-X project. The cooperation with KIT on the ECRH system is well established. The diagnostics systems are being developed in collaboration (among other) with FZJ/Jülich, PTB/Braunschweig, KFKI-RMKI/Budapest, IPPLM/Warsaw, the University of Opole and CIEMAT/Madrid.

Wendelstein 7-X Operation (OP)

S. Bosch is the head of this scientific/technical Division.

This Division is dedicated on the commissioning and the later operation of Wendelstein 7-X. Therefore, in principle, it consist of four groups, namely

i. device operation, i.e. organisation of the experimental operation, device safety, configuration management and documentation,
ii. Magnets and cryo system, responsible for the cooling and operation of the superconducting magnets, but also for the normal conducting control- and trim coils.
iii. Torus and torus hall, at the moment responsible for Engineering and Vacuum technology (all other mechanical tasks for the torus are still handled in the project “W7-X completion” by the assembly division). After the completion of W-X, this group will be enlarged and will take full responsibility of all aspects of the torus and the torus hall.
iv. CoDaC, responsible for device Control, data acquisition, software and electronics development and general IT-support.

The Division has been established in the year 2014 by relocation of personnel. Envisaged are initially 7 research scientists, 20 engineers (university degree), 33 engineers (applied university degrees) and 92 staff in total.

Tokamak Scenario Development (E1): H. Zohm

The operation of the tokamak ASDEX Upgrade, as well as the integrated development of high performance ITER- and DEMO-relevant plasma scenarios, are the main tasks in the Division E1. Since 2014, operation under EUROfusion also means running the machine partly under the MST1 programme, which, from the host side, is mainly co-ordinated by E1. In terms of fusion physics, the major focus of E1 is on core physics such as core transport, MHD stability and fast particle physics as well as the physics of heating and current drive, the elements that have to be integrated for scenario development. The ASDEX Upgrade related part consists of 49 research scientists, six post-docs, four PhD students, 28 engineers and 64 technicians who are organised in the groups “ASDEX Upgrade Project Co-ordination”, “Operation”, “Maintenance & Extension”, “Power supplies”, “Control & Data Acquisition”, “Scenario Development”, “Transport”, “ECRH” and “ICRF”. Another group (“KiP”) is in charge of delivering the In-Vessel Components for the W7-X stellarator in Greifswald. Finally, 4 researchers have their main emphasis on DEMO-related projects, 3 of them via a secondment at the EUROfusion PMU.

The central task of the Division is the operation and, together with the Division “Plasma Edge and Wall”, the scientific exploitation of the ASDEX Upgrade tokamak. The Division has developed systems for plasma diagnostics, plasma heating and plasma fuelling and continues to improve and extend their capabilities. It has also developed a digital system for real-time control of the confined tokamak plasma, which forms the basis for exploring complex plasma scenarios with optimised current and pressure profiles, preparing ITER and DEMO operational scenarios. The optimisation of the tokamak principle to achieve higher performance, stability and pulse length is the overall scientific goal of the Division. Research thus focuses on the physics of the plasma core. Main fields of interest are particle and energy transport (including fast particles) as well as the physics of MHD instabilities and their active control. Disruption physics, including avoidance and mitigation techniques, are also on the agenda. For the integrated scenario development, also the physics of heating and current drive is an important area studied in E1. Frequently, these studies are conducted as joint experiments with other tokamaks to obtain important scaling information in several areas. In particular, scientists of the Division participate on a regular basis in JET campaigns. Here, one of the main aims is to test promising plasma scenarios/concepts developed on ASDEX Upgrade on a larger device in order to prove their relevance for ITER and DEMO.

Finally, scientists from this department are involved in IPP’s contributions to ITER in the field of RF heating and diagnostics as well as studies on DEMO.

Plasma Edge to Wall (E2M): U. Stroth

The Division is organized in five groups consisting of 29 research scientists, 12 post-docs and 19 PhD students, most of the post-docs and PhD students being externally funded. Besides the operation and evaluation of various diagnostics (visible, VUV, X-ray and charge exchange spectroscopy, mass spectrometry, electron cyclotron emission, conventional and Doppler reflectometry, Thomson scattering, lithium beam emission spectroscopy and Langmuir probes, a new divertor manipulator) at the tokamak ASDEX Upgrade, the scientific work concentrates on physical processes ranging from the plasma edge to the plasma-facing components. In addition to ASDEX Upgrade related work, the Division strongly contributes to the scientific program at JET and to ITER- and DEMO-related research. The Division leads the Virtual Institute on “Plasma Dynamical Processes and Turbulence Studies using Advanced Microwave Diagnostics” with nine international partners. At the plasma edge, research encompasses turbulent transport, L-H transitions and the radial electric field, the pedestal dynamics including ELMs and the effect of magnetic perturbations used for ELM mitigation on transport. One focus is on turbulent transport where together with the partners from the Virtual Institute new reflectometer systems have been brought into operation and close links with theory have been established to foster close comparison between experiment and simulations. Another focus is on divertor physics where divertor detachment, power loads and the density limit are studied by combined simulation and experimental efforts. An important objective of the Division’s different research is the development of integrated solutions for high-power plasma operation combining the choice of the plasma-facing material with safety issues, exhaust capabilities and clean plasma conditions. The exploitation of the tungsten wall in ASDEX Upgrade is continued and new activities regarding materials such as EUROFER have been started. The spectroscopy studies include the low-temperature plasma dynamical processes in the divertor up to transport of highly charged ions in the plasma core. To elucidate the impurity cycle and tritium inventory in divertor tokamaks, experiments on the fusion devices are complemented by laboratory studies of fundamental properties of plasma-wall interaction, the impact on material surfaces, reactive plasma processes, and materials synthesis and characterisation. Different aspects such as erosion and hydrogen inventory, surface modification of exposed materials, and characterisation of new materials are merged into a comprehensive assessment. The Division operates a world-wide unique surface science laboratory including a 3 MV Tandem Accelerator and the high-heat-flux test facility GLADIS which is also testing W7-X divertor modules. Further topics include ITER-related plasma-wall interaction issues such as lifetime studies of and tritium inventory investigations in plasma-facing materials, as well as material developments for doped tungsten with low oxidation rate, hydrogen diffusion barriers for tungsten coatings and on tungsten-fibre reinforced tungsten.

Stellarator Heating and Optimization (E3): R. Wolf

In preparation of the operation and the start of the scientific exploitation of Wendelstein 7-X the Division has been newly arranged. With about 50 scientists, engineers and technicians this Division is responsible for the plasma heating systems, the profile diagnostics of the main plasma parameters and the neutron counters. Its research will focus on the verification of the optimization criteria, the physics of plasma heating and fast particle confinement.
The main tasks in preparation of the first operational campaign of Wendelstein 7-X are the commissioning of the ECRH system and the implementation of diagnostics that are required for first plasma operation. The research and development programme in general focuses on preparing the plasma heating systems ECRH, NBI and ICRH for later operational phases and on upgrading and enhancing diagnostic techniques with focus on the final goal of steady state operation at reactor relevant plasma parameters. All of these activities rely on collaborations with partners from Europe, Japan and the US. In addition, stellarator power plant studies have been resumed together with Stellarator Theory and engineering support from the Operations Division. In the framework of larger collaborations the contributions of the Division include transport studies on LHD, the implementation of a new magnetic field diagnostic on ASDEX Upgrade, and contributions to the International Stellarator/Heliotron Profile Database.

Stellarator Edge and Divertor Physics (E4): Th. S. Pedersen

The Division has 35 members of staff of which about half are scientists. The main focus of the Division is on understanding and controlling the exhaust of plasma, and its interaction with the material surfaces, in particular the divertor, where the main part of the exhaust plasma heat and particle flux will be intercepted and pumped away. At the same time, an intense heat (up to 10 MW/m2) cannot be allowed to cause excessive erosion or sputtering of materials, since this would lead to impurity accumulation and radiative losses for the core plasma, or short life times of the plasma facing components. This will be investigated with a number of edge diagnostics, including infrared and visible light divertor observation, spectroscopic measurements, fast Li-beam, Langmuir probes, laser induced fluorescence, calorimetry, and a thermal He-beam diagnostic.

In OP1.1 the Division will concentrate on the verification and adjustment of the magnetic topology, making use of the flux surface measurement diagnostic and the IR/visible limiter observation systems, to demonstrate good nested flux surfaces up to the limiter (no large islands near LCFS) and on detecting and eliminating (using the trim coils) low-order magnetic errors, i.e. on ensuring equal power distribution across all 5 inboard limiters. A further focal point of OP1.1 will be scrape-off layer (SOL) physics studies, making use of the relatively short magnetic field line connection lengths of the limiter configurations, compared to the later island divertor configurations of OP1.2 and beyond. Of particular importance to this study will be SOL-width measurements and their comparison to various models taking into account the impact of recycling neutrals and impurity transport. The transition from initially helium to later hydrogen plasma operation in OP1.1 will be used to investigate the differences in plasma start-up and SOL physics behaviour.

Stellarator Transport and Stability (E5): Th. Klinger

The "Stellarator Dynamics and Transport" Division addresses (a) the magneto-hydrodynamic equilibrium and magneto-hydrodynamic instabilities, (b) neoclassical (diffusive) transport of particles, energy and impurities, (c) turbulence and anomalous transport in optimised stellarators. During the first operational phase OP 1.1, the Division runs the high-efficiency extreme-ultraviolet spectrometer (HEXOS), horizontal and vertical bolometers, correlation and Doppler reflectometry diagnostics, various magnetic diagnostics, a pulse height analysis (PHA) system, and a multi-purpose manipulator. This suite of initial plasma diagnostics allows one to address first scientific questions related to impurity levels, magnetohydrodynamic equilibrium, turbulence and transport of particles and energy. With the help of numerical models, it is intended to distinguish between neoclassical and turbulent impurity transport in the optimised magnetic configuration. Similarly, turbulence levels and turbulence localisation will be investigated. The Division is also dealing with integrated data analysis, which is understood as a cross-divisional activity.

The scientific team is under development and currently consists of 9 professional scientists, 4 postdocs, 5 PhD students, and 6 technical staff.

Parallel to the scientific activities related to Wendelstein 7-X, fundamental research on magnetic reconnection is conducted in the linear laboratory device VINETA.II. This work is done under the auspices of the Max Planck-Princeton Centre for Plasma Physics

Tokamak Theory (TOK)

E. Poli is the Acting Head of this Division since November 2014.

The "Tokamak Theory" Division in Garching consists (as of June 2015) of 11 research scientists, 1 support staff, 6 post-docs, 8 PhD students[12].

The goal of our department is the development of a quantitative, predictive model of tokamak performance based on a first-principle understanding of the related physics processes, through an effort ranging from the derivation of the appropriate physical models, through their implementation into codes, to the application of the codes for basic physics understanding, interpretation of existing experiments, planning and modelling of future machines like ITER and DEMO. On this road, emphasis is also put on the integration of the numerical tools with the final goal of comprehensive plasma simulations. In most of these activities, the Division is at the cutting edge of the current research worldwide. In the field of turbulent transport, the approaches taken include developing and using gyro-kinetic codes (both particle-in-cell, NEMORB and Eulerian, GENE), the development of gyro-fluid codes, and fluid treatments capable of treating the edge, separatrix and Scrape-Off Layer taking the real geometry into

[12] These numbers include the colleagues working in the ERC independent research group, whose activity will cease by the end of 2015 due to the appointment of its leader, Frank Jenko, at UCLA, but not those belonging to the MHD group under the leadership of Sibylle Günter, whose results are reported in a separate section.

account. Multi-scale and global problems are increasingly being addressed. In addition to the turbulence-based descriptions, effort is also going into the further development and use of transport codes, both for the core and edge/SOL (ASTRA, SOLPS). Modelling of heating scenarios in present and future machines is actively pursued, in particular for waves in the ion-cyclotron and electron-cyclotron frequency range, with codes like TORIC and TORBEAM. They are also used in support of relevant diagnostic systems. Significant effort is spent in supporting codes, which are widely used outside of IPP.

Stellarator Theory (ST): P. Helander

The "Stellarator Theory" Division in Greifswald consists of 19 research scientists, five support staff, four post-docs and three PhD students. In the Division, basic theory of magnetic confinement in three-dimensionally shaped magnetic fields is developed, and direct theoretical support is provided for Wendelstein 7-X. In terms of scientific topics, neoclassical and turbulent transport is investigated, as well as MHD equilibrium and stability, fast-ion physics, heating, edge physics, and stellarator optimisation. Fundamental studies are aimed at investigating in what ways the 3D magnetic geometry affects plasma behaviour and performance. For instance, how different are micro-instabilities and turbulence in different stellarators, and how do stellarators differ from tokamaks in this regard? On the more applied side, many of the world-leading codes for calculating transport, stability and heating in stellarators have been developed within the Division. The preparation for Wendelstein 7-X uses a suite of such codes for self-consistently calculating the evolution of plasma scenarios, which are used to develop experimental plans and to prepare for the interpretation of diagnostic data. The Division is involved in the Max Planck-Princeton Research Center for Plasma Physics, and maintains an extensive net of collaborations with almost every other fusion theory department in the world.

Numerical Methods in Plasma Physics (NMPP): E. Sonnendrücker

The "Numerical Methods in Plasma Physics" (NMPP) Division in Garching consists of 7 research scientists, 8 post-docs and 3 PhD students, structured in four research groups: Kinetic Modelling and Simulation, Fluid Modelling and Simulation, Plasma-Material Modelling and Foundations, Zonal Flows and Structure Formation in Turbulent Plasmas. The Division also hosts the six members of the EUROfusion High Level Support Team (HLST).

Its scientific aim is to develop new numerical methods and algorithms for plasma physics applications. The research emphasis is on the numerical methods not on the physics but the Division works in close collaboration with the Tokamak and Stellarator theory Divisions at IPP. The work consists on the one hand on collaborating with the other theory Divisions on major algorithmic upgrades of existing codes, like the verification of global gyrokinetic codes (also supported by EUROfusion as Enabling Research Project), the efficient inclusion of diffusive collision models in the EUTERPE PIC code and matrix free Jacobian computation in the MHD code JOREK, thus greatly extending the accessible system sizes. On the other hand the Division explores new concepts that might be helpful in future codes, like geometric integrators that transfer many important properties like conservation properties at the discrete level, and information compression concepts, i.e. tensor trains. The latter have already enabled more efficient simulations of the five or six dimensional phase space in kinetic solvers. The Division is also collaborating with Inria, University of Strasbourg and CEA Cadarache in France on the development of a library mostly aimed at kinetic plasma simulation.

The aim of HLST is to ensure optimal exploitation of the High Performance Computing equipment devoted to magnetic fusion research, by helping with sequential and parallel optimisation and implementing more efficient algorithms.

ITER Technology & Diagnostics (ITED)

U. Fantz is the Acting Head of this Division.

The Division focuses the IPP activities with respect to technology and diagnostic developments for ITER. The ITER Diagnostics group is responsible for the R&D activities of the ITER Bolometer diagnostic and the Diagnostic Pressure Gauges for ITER within long-term Framework Partnership Agreements with F4E. To perform the tasks on detector development, engineering analyses, design integration and prototype testing two European consortia are being led by IPP and several laboratory test facilities are in operation. IPP is strongly supported by the Fraunhofer ICT-IMM in the bolometer detector development and by Wigner RCP and MTA EK (Hungary) for engineering activities. For the pressure gauges, Sgenia (Spain) performs engineering simulations. The IPP contributions to ITER within Third Party contracts are coordinated by this group as well. The major task of the Neutral Beam Injection (NBI) group is the development of a powerful RF driven negative hydrogen ion source for the NBI systems of ITER. Basic research is done at the test facility BATMAN, equipped with the ITER prototype source developed at IPP (1/8 size of the ITER NBI source). The ELISE test facility – operational since 2013 – is equipped with a half size ITER NBI source and is an important part of the F4E roadmap for the ITER NBI system. The experimental programme is strongly supported by laboratory experiments at the University of Augsburg and accompanied by modelling activities. Strong collaboration exists with Consorzio RFX in Padua, the Host of the European Neutral Beam Test Facility and IPR India responsible for the ITER diagnostic beam. The NBI group participates also on the European activities regarding the assessment of a possible NBI system for DEMO; the main topics here are the reliability and the stability of the ion source operation and the overall plug-in efficiency of the system. Furthermore, the NBI group is responsible for the construction and support of the NBI-system for W7-X and the operation and further development of the 20 MW NBI-system on ASDEX Upgrade.

Independent and Junior Research groups (JRG)

Independent Research Group on “Turbulence in Laboratory and Astrophysical Plasmas” (Frank Jenko)

Our research efforts center around key issues in the areas of theoretical plasma physics and fusion research. These include the physics of turbulence and turbulent transport in magnetized plasmas, the interpretation and prediction of transport processes in tokamak experiments (in collaboration with colleagues from experimental physics), as well as aspects of basic plasma physics and plasma astrophysics. In this context we combine a wide range of analytical and numerical techniques – including extreme computing on large supercomputers – and bridge fundamental theory, applied theory, and direct experimental comparisons.

Focus areas in 2014 included the interaction of energetic particles with plasma turbulence in tokamaks, the nature of L-mode and H-mode near-edge turbulence, the character and role of electromagnetic effects in high-performance discharges, the first full-flux-surface turbulence computations in stellarator geometry, as well as various applications of gyrokinetic simulation to space and astrophysical problems (like guide-field reconnection and turbulent dissipation in the solar wind). The main tool used in these studies was the gyrokinetic GENE code.

Helmholtz Junior Research Group "Macroscopic effects of micro-turbulence investigated in fusion plasmas" (Rachael McDermott)

The Helmholtz Young Investigators group „Macroscopic effects of micro-turbulence investigated in fusion plasmas" lead by Dr. Rachael McDermott was started on December 1 2012. At that time Dr. Benedikt Geiger was hired as a postdoc and has been instrumental to the construction and exploitation of three new diagnostics systems (2CXRS and 1 BES). These systems are now fully operational. The work of a PhD student focuses on the measurement of the poloidal asymmetry in the measured toroidal rotation profiles. Comparison of initial measurements with calculations from the neoclassical code NEOART indicate that in NBI heated H-modes the total flow structure is indeed neoclassical. A second PhD position is planned for the group starting in the fall of 2015. This PhD thesis will focus on the transport of low-Z impurities in the plasma and aims to separate the convective and diffusive fluxes via modulation experiments.

Helmholtz-Russia Joint Research Group "Hydrogen Behaviour in Advanced and Radiation-damaged Materials" (Matej Mayer)

This joint research group comprised scientists from the IPP, from the Kurchatov Institute, from the Troitsk Institute for Innovation and Fusion Research (TRINITI), and from the National Research Nuclear University (MEPhI) (all three located in Moscow region). It was funded by the Helmholtz Association (4/2011-3/2014). The funding was used for one Post-Doc and one PhD student working at IPP, temporary Russian guest scientists, travel expenses and investments. The group investigated the accumulation and diffusion of hydrogen isotopes in radiation-damaged plasma-facing materials foreseen for future fusion power plants in laboratory experiments and by computer simulations.

MHD group (Sibylle Günter)

In the last years, a set of 2D MHD codes has been extended to 3D geometry in order to study the stability of 3D equilibria (CASTOR_3DW + STARWALL). General flux coordinates (in addition to straight field line coordinates) were implemented, which are more appropriate for the description of instabilities located close to the separatrix, e.g. edge localized modes (ELMs).

The non-linear MHD code JOREK is being used to investigate edge localized mode (ELM) crashes in realistic ASDEX Upgrade geometry and with realistic rotation profiles in order to validate how well experimental properties can be reproduced. Further activities are the - very successful - preparation and the kinetic modeling of runaway experiments in ASDEX Upgrade.

In the field of energetic particle physics, the group is developing, verifying and validating several theoretical and numerical models in order to understand and predict the transport of energetic particles in present-day and future tokamaks. The aim is to describe a burning plasma on several levels of complexity - ranging from simple 1-D bump on tail models via hybrid-MHD (XHMGC) and hybrid-gyrokinetic (LIGKA/HAGIS) to fully non-linear electromagnetic PIC simulations (NEMORB). Ongoing activities comprise both the principal understanding of non-linear wave-particle (Alfvén waves with energetic ions) and wave-wave (several Alfvén waves with turbulent wave spectrum) interaction as well as the application of these concepts to ASDEX Upgrade experiments and planned ITER scenarios.

7. CVs of the Directors and (Acting) Division Heads

Prof. Dr. Sibylle Günter

Personal Details:

Date/Place of Birth:	20.4.1964, Rostock
Present Position:	Scientific Director, Max-Planck-Institut für Plasmaphysik Garching/ Greifswald

Education and Training:

1982 – 1987	Study of Physics at Rostock University
1987 – 1990	PhD in Physics at Rostock University
1996	Habilitation, Rostock University

Career:

1990 – 1996	Employed at University of Rostock as Research Scientist in quantum statistics
1996 – 1998	Employed at IPP Garching as Research Scientist in MHD theory
1998 – 2000	Group leader MHD theory at IPP Garching
2000 – 2011	Scientific Member of the Max Planck Society and Director of Tokamak Physics Division at IPP
since 2001	Adjunct Professor at University of Rostock
since 2006	Honorary professor at Technical University Munich
since 2007	Member of the IPP directorate
since 2011	Chair of the scientific board and Scientific director of IPP

Awards:

2013	Cross of the Order of Merit of the Federal Republic of Germany
2014	Election as member of the National Academy of Science and Engineering

Scientific interest:

The work of Prof. Günter aims at developing an integrated understanding of the complex phenomena determining the performance of toroidal confinement devices. Her recent, personal contributions have concentrated on, the non-linear evolution of MHD instabilities as well as on computational physics (treatment of problems with extreme anisotropic properties).

Prof. Günter has been the chair of the General Assembly of the consortium EUROfusion (till end of 2014), now acting as deputy chair. She is the scientific leader of the Max Planck-Princeton Research Center on Plasma Physics. She is member of the Senate of the Max Planck Society as well as several evaluation boards and boards of trustees.

Selected Publications:

1. S. Günter et al., Interaction of energetic particles with large and small scale instabilities, Nucl. Fus. 75 (2007) 920-928
2. S. Günter and K. Lackner, A mixed implicit-explicite finite difference scheme for heat transport in magnetised plasmas, J. Comput. Phys. 228 (2008) 282
3. Q. Yu, S. Günter, K. Lackner, M. Maraschek Seed island formation by forced magnetic reconnection, Nucl. Fusion 52 063020 (2012).
4. E. Strumberger, S. Günter, C. Tichmann, MHD instabilities in 3D tokamaks, Nucl. Fusion, 54, 064019 (2014)
5. S. Günter et al., Fast sawtooth reconnection at realistic Lundquist numbers, Plasma Phys. Control. Fusion 57, 014017 (2014)

Dr. Hans-Stephan Bosch

Personal Details:

Date/Place of Birth:	29.5.1957, Stuttgart, Germany
Present Position:	Division Head Wendelstein 7-X Operation, Deputy, Scientific Director of the “Project Wendelstein 7-X”, Max-Planck-Institut für Plasmaphysik Greifswald

Education and Training:

1977 – 1979	Study of physics, Westfalian Wilhelms-University, Münster (WWU)
1979 – 1983	Study of physics at Ludwig-Maximilians University, Munich (LMU)
1983 – 1986	Ph.D. work, IPP Garching and Technical University Munich (TUM)
1986	Ph.D. Rerum Naturalium
1987	Otto-Hahn medal of the Max Planck Society
2000	Habilitation in Experimental Physics, Humboldt University Berlin (HUB)
2008	Venia Legendi, Ernst-Moritz-Arndt University Greifswald (EMAU)

Career:

1987 – 1988	Post-doctoral research staff, Princeton Plasma Physics Laboratory, Princeton
1988 – 1990	Research staff at IPP (ASDEX)
1990 – 2000	Research staff at IPP (ASDEX-Upgrade) and group leader
2000 – 2003	Head of the directors staff office (WTB) at IPP
2004 – 2013	Head of Project Coordination W7-X, IPP Greifswald
since 2013	Division Head “Wendelstein 7-X Operations”

Scientific interest:

The research interests of Dr. Bosch are fusion product physics, divertor physics and particle exhaust. He was involved in all these topics as well as in the device operation of the ASDEX Upgrade tokamak until 2000. After some years devoted to science administration and the project coordination of W7-X, since 2012 he has prepared and lead the commissioning of Wendelstein 7-X and now leads the operation of Wendelstein 7-X.

Selected Publications:

1. H.-S. Bosch, G. M. Hale, *Improved Formulas for Fusion Cross Sections and Thermal Reactivities*,Nucl. Fusion **32** (4), 611-631 (1992)
2. H.-S. Bosch, W. Ullrich, D. Coster, O. Gruber, G. Haas, A. Kallenbach, R. Schneider, R. Wolf and ASDEX Upgrade Team, *Helium Transport and Exhaust with an ITER-like Divertor in ASDEX Upgrade*, J. Nucl. Mater. **290-293**, 836-839 (2001)
3. H.-S. Bosch, V. Erckmann, R. W. T. König, F. Schauer, R. J. Stadler, A. Werner, *Construction of Wendelstein 7-X – Engineering a Steady-State Stellarator*, IEEE Transactions on Plasma Science **38** (3), 265-273 (2010)
4. H.-S. Bosch, R. Wolf, T. Andreeva, J. Baldzuhn, et al., Technical challenges in the construction of the steady-state stellarator Wendelstein 7-X, Nucl. Fusion **53** (12) 126001 (2013)
5. H.-S. Bosch, R. Brakel, M. Gasparotto, H. Grote, D. A. Hartmann et al., Transition from Construction to Operation Phase of the Wendelstein 7-X Stellarator, IEEE Transactions on Plasma Science **42** (3) 432-438 (2014)

Prof. Dr.- Ing. Ursel Fantz

Personal Details:

Date/Place of Birth:	29.6.1963, Sindelfingen
Present Position:	Acting Head (W2), ITER Technology & Diagnostics Division Max-Planck-Institut für Plasmaphysik Garching Head of the Experimental Plasma Physics group at Augsburg University

Education and Training:

1984 – 1991	Study of Physics at University of Stuttgart
1991 – 1995	PhD in Electrical Engineering at University of Stuttgart
2002	Habilitation at University of Augsburg
2008	Appointment as Full Professor at University of Augsburg

Career:

1982 – 1984	Physical Technical Assistant at the Institute of Theory in Electrical Engineering, University of Stuttgart
1991 – 1995	Research Scientist at Institute of Plasma Research, University of Stuttgart
1995 – 2004	Scientific Assistant at the Chair of Experimental Plasma Physics, University of Augsburg with focus on low temperature plasma physics
since 2004	At IPP with focus on the development of negative hydrogen ion sources for ITER
since 2008	Head of the Experimental Plasma Physics group, University of Augsburg
since 2010	Division head (acting) of the ITER Technology & Diagnostics Division

Awards:

1996	Anton- and Klara-Röser-Prize for PhD Thesis, University of Stuttgart
2006	Erwin Schrödinger Prize, HGF: Helmholtz Association of National Research Centres
2014	Award of the NIBS Symposium for recent innovative and significant achievements in the field of physics and technology

Scientific interest:

Prof. Ursel Fantz’s main field of interest is low temperature plasmas physics with emphasis on the negative hydrogen ion source development for the neutral beam systems of fusion devices, in particular to ITER. She is focussing on the diagnostics of molecular low temperature plasmas for which the modelling activities are always closely linked to the experiments. Fundamental research is carried out at several laboratory experiments at the university supporting strongly the negative ion source development at IPP. Her interests range from fundamentals to applications towards prototype developments combining physics with engineering issues.

Selected Publications:

1. P. Franzen, U. Fantz, D. Wünderlich, B. Heinemann, R. Riedl, W. Kraus, M. Fröschle, B. Ruf, R. Nocentini and the NNBI Team, Progress of the ELISE test facility: results of caesium operation with low RF power, Nucl. Fusion 55 (2015) 053005.
2. U. Fantz, P. Franzen, B. Heinemann, and D. Wünderlich, First results of the ITER-relevant negative ion beam test facility ELISE, Rev. Sci. Instrum. 85 (2014) 02B305.
3. P. Franzen and U. Fantz, On the NBI system for substantial current drive in a fusion powerplant: Status and R&D needs for ion source and laser neutralizer, Fus. Eng. Des., 89 (2014) 2594.
4. U. Fantz, P. Franzen and D. Wünderlich, Development of negative hydrogen ion sources for fusion: experiments and modelling, Chem. Phys. 398 (2012) 7.
5. U. Fantz, Basics of plasma spectroscopy, Plasma Sources Sci. Technol. 15 (2006) S137-S147.

Prof. Dr. Per Helander

Personal Details:

Date/Place of Birth:	17.03.1967, Umeå, Sweden
Nationality:	Swedish
Present Position:	Director, Stellarator Theory Division, Max-Planck-Institut für Plasmaphysik Greifswald

Education and Training:

1985 – 1989	Study of Physics at Chalmers University of Technology, Göteborg, Sweden
1990 – 1994	PhD in Plasma Physics at Chalmers University of Technology

Career:

1995 – 1996	Post-doc. at Massachusetts Institute of Technology, Cambridge, USA
1996 – 2006	Research Scientist at UKAEA Culham Laboratory
2004 – 2006	Honorary lecturer, Bristol University
2005 – 2008	Adjunct Professor, Chalmers University of Technology, Göteborg,
since 2006	Scientific Member and Director of Stellarator Theory Division at IPP
since 2008	Professor at Greifswald University (Chair for Theoretical Plasma Physics)

Scientific interest:

Most aspects of plasma theory, with an emphasis on the kinetic theory of transport and stability in fusion devices – both for tokamaks and stellarators. Recent contributions include work on neoclassical transport theory, plasma rotation and gyrokinetics in stellarators

Selected Publications:

1. P. Helander and D.J. Sigmar: Collisional Transport in Magnetized Plasmas, Cambridge University Press 2002, paperback edition 2005.
2. P. Helander and A.N. Simakov, Intrinsic ambipolarity and rotation in stellarators, Physical Review Letters 101, 145003 (2008).
3. J.H.E. Proll, P. Helander, J. W. Connor and G. Plunk, Resilience of quasi-isodynamic stellarators against trapped-particle instabilities', Physical Review Letters 108, 245002 (2012).
4. P. Helander, Microstability of magnetically confined electron-positron plasmas, Physical Review Letters 113, 135003 (2014).
5. P. Helander, Theory of plasma confinement in non-axisymmetric magnetic fields, Reports on Progress in Physics 77, 087001 (2014).

Prof. Dr. Thomas Klinger

Personal Details:

Date/Place of Birth:	22.3.1965, Eutin, Germany
Present Position:	Director, Stellarator Scenario Development Division, Scientific Director of the "Project Wendelstein 7-X", Member of the Board of Directors Max-Planck-Institut für Plasmaphysik Greifswald

Education and Training:

1985 – 1991	Study of physics, (CAU) Christian-Albrechts University Kiel
1991 – 1994	Ph.D. work, CAU Kiel and Université Henri Poincaré Nancy
1994	Ph.D. Rerum Naturalium
1995	Research stay Alfvén Laboratory, Royal Institute of Technology, Stockholm
1996	Research stay Centre de Physique Théorique, Marseille
1997	Research stay Max-Planck-Institut für Plasmaphysik, Garching
1998	Habilitation in Experimental Physics, Venia Legendi 1999

Career:

1994 – 1999	Research Associate, Christian-Albrechts University Kiel
1999 – 2001	Associate Professor for Experimental Physics, (EMAU) Ernst-Moritz-Arndt University Greifswald
2000 – 2001	Department Head Institute of Physics, EMAU Greifswald
2001	Scientific Member of the Max Planck Society IPP Garching/Greifswald
2002	Full Professor for Experimental Plasma Physics, EMAU Greifswald
since 2005	Elected Member of the Board of Directors, IPP
since 2005	Scientific Director of the Project Wendelstein 7-X, Director of "Stellarator Scenario Development" Division

Scientific interest:

The research interest of Prof. Klinger is experimental non-linear plasma dynamics. The current focus is on pressure driven instabilities like drift-waves and flute modes, kinetic Alfvén waves, wave-particle interaction and plasma turbulence. Related are subjects as turbulent transport and control of plasma instabilities. Recently, the non-linear dynamics and kinetics of reconnection became a central subject of interest. Until start of operation of Wendelstein 7-X goes in operation, the experiments were mostly conducted in laboratory devices with a strong emphasis on basic plasma research in magnetized plasmas.

Selected Publications:

1. T. Klinger, C. Baylard, C. D. Beidler, J. Boscary, H.-S. Bosch, A. Dinklage, D. Hartmann, P. Helander, H. Massberg, A. Peacock, T. S. Pedersen, T. Rummel, F. Schauer, L. Wegener, R. Wolf, Towards assembly completion and preparation of experimental campaigns of Wendelstein 7-X in the perspective of a path to a stellarator fusion power plant, Fusion Engineering and Design, 88(6-8), 461-465 (2013)
2. T. Windisch, O. Grulke, V. Naulin, T. Klinger, Formation of Turbulent Structures and the Link to Fluctuation Driven Shared Flows, Plasma Physics and Controlled Fusion, 53(12), Article No 124036 (2011)
3. C. Brandt, O. Grulke, T. Klinger, J. Negrete, G. Bousselin, F. Brochard, G. Bonhomme, Spatiotemporal mode structure of nonlinearly coupled drift wave modes, Physical Review E, 84(5), Article No 056405 (2011)
4. T. Windisch, O. Grulke, T. Klinger, Radial propagation of structures in drift wave turbulence, Physics of Plasmas, 13(12), Article No 122303 (2006)
5. C. Schröder, T. Klinger, D. Block, A. Piel, G. Bonhomme, V. Naulin, Mode selective control of drift wave turbulence, Physical Review Letters, 86 (25), 5711-5714 (2001)

Dr. Emanuele Poli

Personal Details:

Date/Place of Birth:	13.12.1971, Cremona, Italy
Present Position:	Acting head of Tokamak Physics Division, Max-Planck-Institut für Plasmaphysik Garching

Education and Training:

1990 – 1995	Physics Studies, University of Pavia, Italy
1996 – 1999	Dr. phil., University of Pavia & IPP Garching Thesis title: Diffraction effects on electromagnetic Gaussian wave beams in anisotropic inhomogeneous plasmas

Career:

1999 – 2001	PostDoc, Max-Planck-Institut für Plasmaphysik, Garching
Since 2001	Res. Scientist, Max-Planck-Institut für Plasmaphysik, Garching
Since 2006	Group Leader for Wave Physics and Kinetic Theory in the Tokamak Physics Division, IPP Garching
2012	Habilitation (venia legendi), University of Ulm
Since Nov. 2014	Acting head of the Tokamak Physics Division, Max-Planck-Institut für Plasmaphysik, Garching

Scientific experience and interest:

Heating and current drive in magnetic-fusion devices, in particular for electron-cyclotron (EC) waves; application to diagnostics and role of wave scattering; kinetic theory and toroidal kinetic effects on plasma instabilities, in particular tearing modes; role of waves in the stabilization of MHD instabilities and related impact on the design of the ITER/DEMO.

Selected Publications:

1. E. Poli et al.: TORBEAM, a beam tracing code for electron cyclotron waves in tokamak plasmas, Comp. Phys. Comm. 136 (2001), 90.
2. E. Poli et al., Reduction of the ion drive and scaling of the neoclassical tearing mode, Phys. Rev. Lett. 88 (2002), 075001.
3. E. Poli et al., The role of kinetic effects on the polarization current around a magnetic island, Phys. Rev. Lett. 94 (2005), 205001.
4. M. A. Henderson et al., Overview of the ITER EC upper launcher, Nucl. Fusion 48 (2008) 054013.
5. E. Poli et al., Electron-cyclotron-current-drive efficiency in DEMO plasmas, Nucl. Fusion 53 (2013), 013001.

Prof. Dr. Ulrich Stroth

Personal Details:

Date/Place of Birth:	07.09.1957, Erbach, Germany
Present Position:	Director, Plasma Edge and Wall Division, Max-Planck-Institut für Plasmaphysik Garching

Education and Training:

1977 – 1982	University education in physics, TU Darmstadt
1982 – 1986	PhD thesis at Institute Laue Langevin, Grenoble, France.
1986 – 1998	Max-Planck-Institut für Plasmaphysik
1995 – 2000	Coordinator of the European Transport Task Force for stellarator-tokamak comparisons
1996	Habilitation, University of Heidelberg

Career:

1996 – 2000	Lecturer (Privatdozent), University of Heidelberg
1999 – 2004	C3 professor for plasma physics and director at the Institut für Experimentelle und Angewandte Physik at Universität Kiel
2002 – 2003	Managing director of Institut für Experimentelle und Angewandte Physik, Universität Kiel
2004 – 2010	Full professor for plasma physics at University of Stuttgart and director of Institut für Plasmaforschung
2008 – 2010	Dean (Prodekan) of physics department, Univ. of Stuttgart
2010 – 2012	Acting head of Institut für Plasmaforschung at University of Stuttgart
2010 –	Max-Planck Director and Head of the Division Plasma Edge and Wall, Max-Planck Institut für Plasmaphysik (IPP), Garching
2012	Professor at Technical University of Munich in the field of Experimental Plasma Physics

Scientific experience and interest:

Experimental low- and high-temperature plasma physics, magnetic confinement and nuclear fusion research, plasma and fluid turbulence, neoclassical and turbulent transport, microwave applications to plasmas, waves in plasma, plasma modeling, plasma-technological applications, plasma-wall interaction and divertor physics, space plasma physics

Selected Publications:

1. U. Stroth and ASDEX Upgrade Team, Overview of ASDEX Upgrade results, Nucl. Fusion 2013
2. U. Stroth, P. Manz, M. Ramisch: On the interaction of turbulence and flows in toroidal plasmas, Plasma Phys. Contr. Fusion, 53, 24006 (2010)
3. P. Manz, M. Ramisch, U. Stroth, Physical Mechanism behind Zonal-Flow Generation in Drift-Wave Turbulence, Phys. Rev. Letter 103, 165004 (2009)
4. U. Stroth et al.: Study of Edge Turbulence in Dimensionally Similar Laboratory Plasmas, Phys. Plasmas, 11, 2558 (2004)
5. U. Stroth et al.: Internal Transport Barrier Triggered by Neoclassical Transport in W7-AS, Phys. Rev. Lett. 86, 5910 (2001)

Prof. Dr. Thomas Sunn Pedersen

Personal Details:

Date/Place of Birth*:*	01.05.1970, Roskilde, Denmark
Nationality:	American and Danish
Present position:	Director, Stellarator Edge and Divertor Division, Max-Planck-Institut für Plasmaphysik Greifswald

Education and Training:

1990 – 1995	M. Sc. in Applied Physics Engineering, Technical University of Denmark
1996 – 2000	PhD in Physics at MIT, Cambridge, MA, USA (Experimental Plasma Physics)

Career:

2000	Postdoctoral Associate, Columbia University (LDX experiment)
2000 – 2005	Assistant Professor of Applied Physics, Columbia University, USA
2005 – 2007	Associate Professor of Applied Physics, Columbia University, USA
2007 – 2011	Associate Professor of Applied Physics with tenure, Columbia University, USA
2010 –	Director of Stellarator Edge and Divertor Divison, Max-Planck-Institut für Plasmaphysik
2012 –	Professor of Physics, Ernst-Moritz-Arndt University, Greifswald

Awards:

2005	CAREER Award, NSF Division of Physics
2002	Junior Faculty Award, DOE Office of Fusion Energy Sciences (see Grants)

Scientific interest:

Prof. Thomas Sunn Pedersen’s interests are related to magnetic confinement of plasmas. The plasmas of interest include fusion plasmas, pure electron plasmas, partially neutralized plasnas, and electron-positron plasmas, and the confinement devices of interest include stellarators and tokamaks. He is interested in equilibrium, stability, and confinement in a broad sense, but has worked specifically on impurity transport in tokamaks, kink stability in tokamaks, and equilbrium and stability of non-neutral plasmas in stellarators.

Selected Publications:

1. T. Sunn Pedersen, T Sunn Pedersen, J R Danielson, C Hugenschmidt, G Marx, X Sarasola, F Schauer, L Schweikhard, C M Surko and E Winkler, "Plans for the creation and study of electron--positron plasmas in a stellarator", New Journal of Physics 14, 035010 (2012)
2. Q. R. Marksteiner, T. Sunn Pedersen, J. W. Berkery, M. S. Hahn, J. M. Mendez, and H.Himura, Observations of an ion-driven instability in nonneutral plasmas confined on magnetic surfaces, Phys. Rev. Letters 100, 065002 (2008)
3. T. Sunn Pedersen, D. A. Maurer, J. Bialek, O. Katsuro-Hopkins, J. Hanson, M. E. Mauel, R. James, A. Klein, Y. Liu, G. A. Navratil, “Experiments and Modeling of External Kink Mode Control Using Modular Internal Feedback Coils”, Nuclear Fusion 47, p. 1293 (2007)
4. J. P. Kremer, T. Sunn Pedersen, R. G. Lefrancois, Q. Marksteiner, “Experimental confirmation of stable, small-Debye-length, pure electron plasma equilibria in a stellarator”, Phys. Rev. Letters 97 095003 (2006)
5. T. Sunn Pedersen and Allen H. Boozer, "Confinement of Nonneutral Plasmas on Magnetic Surfaces ", Phys. Rev. Letters 88, p. 205002 (2002)

Prof. Dr. Eric Sonnendrücker

Personal Details:

Date/Place of Birth:	25.10.1967, Strasbourg, France
Nationality:	French
Present position:	Director, Numerical Methods in Plasma Physics Division, Max-Planck-Institut für Plasmaphysik Garching, Professor, Zentrum Mathematik, TU München

Education and training:

1988 – 1992	Ecole Normale Supérieure de Cachan, France
1991	Agrégation de Mathématiques
1991	DEA d'Analyse Numérique, Université Paris XI, Orsay, France
1992 – 1995	PhD in Mathematics, Ecole Normale Supérieure de Cachan, France

Career:

1996	Post-doc Forschungszentrum Karlsruhe (Humboldt fellow), Germany
1996 – 2000	Research Scientist at CNRS, Nancy, France
2000 – 2012	Professor in applied mathematics, university of Strasbourg, France
2012 –	Director computational plasma physics Division, Max-Planck-Institut für Plasmaphysik, Garching bei München, Germany
2012 –	Professor in Mathematics at TU Munich

Scientific interest:

Mathematical modeling and development of numerical methods for problems in plasma physics and beam physics. This includes the development of asymptotic models when some parameters are small, and mostly the development and analysis of numerical methods for the kinetic equations of plasma physics.

Selected publications:

1. Nicolas Crouseilles, Michel Mehrenberger, Eric Sonnendrücker (2010): Conservative semi-Lagrangian schemes for the Vlasov equation, J. Comput. Phys. 229, 1927-1953.
2. Eric Sonnendrücker, Abigail Wacher, Roman Hatzky, Ralf Kleiber (2015): A split control variate scheme for PIC simulations with collisions, J. Comput. Phys., 295, pp. 402–419.
3. F. Filbet and E. Sonnendrücker (2006): Modeling and Numerical Simulation of Space Charge Dominated Beams in the Paraxial Approximation. Math. Models Methods Appl. Sci. 16, no. 5, 763–791.
4. E. Sonnendrücker, J. Roche, P. Bertrand, A. Ghizzo (1999): The semi-Lagrangian Method for the Numerical Resolution of Vlasov Equations, J. Comput. Phys. 149, 201-220
5. E. Frénod, E. Sonnendrücker (2001): The Finite Larmor Radius Approximation, SIAM J. Math. Anal. 32, no. 6, 1227–1247

Prof. Dr. Robert Wolf

Personal Details:

Date/Place of Birth:	23.02.1964, Munich, Germany
Present Position:	Director, Stellarator Optimization Division, Max-Planck-Institut für Plasmaphysik Greifswald

Education and Training:

1983 – 1989	Study of Physics at Rheinisch-Westfälische Technische Hochschule Aachen
1989 – 1993	PhD study in Plasma Physics at Joint European Torus (JET) and Heinrich-Heine-Universität Düsseldorf
2002	Habilitation, University of Mons-Hainaut, Belgium

Career:

1993 – 1995	Employed at JET, Culham, UK, as Post Doc
1995 – 1996	Employed at Max-Planck-Institut für Plasmaphysik Berlin as Post Doc
1996 – 2002	Employed at Max-Planck-Institut für Plasmaphysik Garching as Research Scientist
2000 – 2002	Deputy Task Force Leader/Task Force Leader of Task Force S2 (advanced tokamak scenarios) at JET, Culham, UK
2002 – 2007	Director at Institut für Plasmaphysik, Forschungszentrum Jülich
2003 – 2007	Full Professor for High Temperature Plasma Physics at Ruhr-Universität Bochum
since 2006	Director at Max-Planck-Institut für Plasmaphysik, Head of Department Stellarator Heating and Optimization
since 2010	Full Professor at the Astrophysics Department of the Technical University of Berlin

Scientific interest:

Prof. Wolf’s main fields of interest are the transport and stability properties of fusion plasmas aiming at the development of steady state plasma operation. Starting with the characterization of the magnetic field and internal transport barriers in tokamak plasmas with large non-inductive current fractions, he extended his work towards the effect of helical magnetic field perturbations in tokamaks to control transport, plasma rotation and stability. Moving on to investigate the optimization criteria of stellarators, at present he is responsible for the development of diagnostics, heating systems, and control and data acquisition of Wendelstein 7-X, again with the objective of facilitating steady state operation.

Selected Publications:

1. R. C. Wolf et al., Motional Stark Effect Measurements of the Local Magnetic Field in High Temperature Fusion Plasmas, accepted for publication in J. Inst. (2015)
2. H.-S. Bosch, R. C. Wolf et al., Technical challenges in the construction of the steady-state stellarator Wendelstein 7-X, Nucl. Fusion 53 (2013) 126001
3. R. C. Wolf et al., A stellarator based on the optimization criteria of Wendelstein 7-X, Fusion Eng. And Design 83 (2008) 990
4. R. C. Wolf et al., Effect of the dynamic ergodic divertor in the TEXTOR tokamak on MHD stability, plasma rotation and transport, Nucl. Fusion 45 (2005) 1700
5. R. C. Wolf, Internal Transport Barriers in Tokamak Plasmas (Review Article), Plasma Phys. Contr. Fus. 45 (2003) R1

Prof. Dr. Hartmut Zohm

Personal Details:

Date/Place of Birth*:*	02.11.1962, Freiburg i. Breisgau, Germany
Present Position:	Director, Tokamak Scenario Development Division, Member of the Board of Directors Max-Planck-Institut für Plasmaphysik Garching

Education and Training:

1983 – 1988	Study of Physics at Karlsruhe University, 1988 Diploma in Physics (Theoretical Solid State Physics)
1988 – 1990	PhD in Physics at Heidelberg University (Experimental Plasma Physics)
1996	Habilitation (Experimental Physics) at Augsburg University

Career:

1990 – 1996	Employed at Max-Planck-Institut für Plasmaphysik as Research Scientist
1991 – 1992	Assigned to General Atomics (DIII-D tokamak) in San Diego, CA, USA
1996 – 1999	Professor for Plasma Research, Faculty for Electrotechnical Engineering, Stuttgart University
1996 – 1999	Head of Plasma Heating Group, Institut für Plasmaforschung, Stuttgart University
since 1999	Director at Max-Planck-Institut für Plasmaphysik, Head of Department Tokamak Scenario Development (ASDEX Upgrade tokamak experiment)
since 2002	Honorary Professor at Ludwig Maximilian University Munich (Physics)
since 2011	Member of Directorate of Max-Planck-Institut für Plasmaphysik
2013	Visiting Professor, University of Wisconsin, Madison, USA (Physics), 5 months

Awards:

Otto-Hahn-Medal (1991)
John Dawson Award for Excellence in Plasma Physics Research (2014, in team of researchers for the development of suppression of neoclassical tearing modes by ECCD)

Scientific interest:

Prof. Hartmut Zohm’s main fields of interest are the magnetohydrodynamic (MHD) stability of fusion plasmas and their heating by Electron Cyclotron Resonance Heating (ECRH). By combining these two fields, he pioneered the active stabilisation of neoclassical magnetic islands, which set a major performance limit to the tokamak, by ECRH. His present field is the study of tokamak physics on the ASDEX Upgrade tokamak which is operated by his department. Most recently, he became involved in the European studies for a demonstration fusion power plant (DEMO).

Prof. Zohm is member of several committees such as the ITPA coordinating committee, the IEA Implementing Agreement on Collaboration of Tokamak Programmes, the Programme Advisory Committees of KSTAR (Deajon, Korea), EAST (ASIPP Hefei, China), the EUROFusion STAC as well as chair of the scientific advisory board of IPP.CR (Prague, Czech Republic) and the External Advisory Board of the EPSRC Centre for Doctoral Training in the Science and Technology of Fusion Energy in the UK. He is also a member of the board of editors of the ‘Nuclear Fusion’ journal and a member of the advisory board of the ‘Annalen der Physik’ journal.

Selected Publications:

1. Zohm, H., ASDEX Upgrade Team, EUROfusion MST1 Team: ‘Recent ASDEX Upgrade Research in Support of ITER and DEMO’, Nucl. Fusion 55 (2015) 104010.
2. Zohm, H.; Assessment of DEMO Challenges in Technology and Physics, to appear in Fusion Engineering and Design (2013).
3. Zohm, H. ; On the minimum size of DEMO, Fus. Sci. and Technology 57 (2010) 613
4. Zohm, H. et al.: Overview of ASDEX Upgrade Results, Nucl. Fusion 49 (2009) 104009.
5. Zohm, H. et al.; Control of MHD Instabilities by ECCD: ASDEX Upgrade Results and Implications for ITER, Nucl. Fusion 47 (2007) 228-232

Report on the Review of the Helmholtz Programme ”*Nuclear Fusion*”

Forschungszentrum Jülich (FZJ)
Max Planck Institute for Plasma Physics (IPP)
Karlsruhe Institute of Technology (KIT)

Greifswald, 05 - 07 March 2014

Foreword

On the basis of the “Strategic guidelines of the ministries for the research field Energy” and in accordance with policy and procedures of programme-oriented funding in the Helmholtz Association, the Helmholtz Senate Commission elected the following review panel for the programme “Nuclear Fusion”.

Chair of the Review Panel

Albrecht	**Wagner**		Savièse, SWITZERLAND

Members of the Review Panel

David T.	**Anderson**	University of Wisconsin-Madison	Madison, USA
Martine	**Baelmans**	Katholieke Universiteit Leuven	Leuven, BELGIUM
Kurt	**Ebbinghaus**	Deutsches ITER Industrie Forum (DIIF) e.V.	Ventabren, FRANCE
Laila A.	**El-Guebaly**	University of Wisconsin-Madison	Madison, USA
Sehila	**Gonzalez de Vicente**	EFDA - European Fusion Development Agreement	Garching, GERMANY
Gregory W.	**Hammett**	Princeton Plasma Physics Laboratory	Princeton, USA
Ahmed*	**Hassanein***	Purdue University	West Lafayette, USA
Manfred	**Hennecke**	Federal Institute for Materials Research and Testing	Berlin, GERMANY
Amanda	**Hubbard**	MIT Plasma Science & Fusion Center	Cambridge, USA
Aart	**Kleijn**	Center of Interface Dynamics for Sustainability	Chengdu, People´s Republic of CHINA
Olaf	**Kübler**		Küsnacht, SWITZERLAND
Stewart	**Prager**	Princeton Plasma Physics Laboratory	Princeton, USA
Akio	**Sagara**	National Institut for Fusion Science – NIFS	Toki, JAPAN
Joaquin	**Sanchez**	Laboratorio Nacional de Fusion	Madrid, SPAIN
Uwe	**Schumacher**	University of Stuttgart	Stuttgart, GERMANY
Tony	**Taylor**	General Atomics	San Diego, USA

*Ahmed Hassanein was actively involved in the review process, but could not participate in the evaluation in Greifswald.

A list of the delegates of the Senate Commission, the delegates of the ministries, the delegates of the head office of the Helmholtz Association and the programme collaborators participating in the evaluation can be found in the annex.

Task of the evaluation

During the on-site review, the panel is asked

- ► to consider if and how the programme addresses the strategic long-term goals established by the stakeholders and the Helmholtz Association and if the programme is planning appropriate steps to address developments in the field for the next period;
- ► to assess whether the importance, quality, and productivity (past and future) of the research and training activities warrant a successful implementation of the future proposal;
- ► to assess the potential of the programme for successfully translating its research into benefits, or in disseminating its work and in public engagement;
- ► to determine whether the resources requested for the future plans are adequate to attain the strategic goals;
- ► to advise on the realistic expectations for the development of the programme's work over the next five years and on key performance indicators against which the production may be monitored;
- ► to report to the Helmholtz Association.

Information provided to the Review Panel

The review panel has taken into account the following information:

- ❖ the submitted written programme proposal for the years 2015-2019
- ❖ including information on
  - – resources for the years 2015-2019
  - – major scientific aims and content
  - – main performance indicators
  - – core competencies of the participating centres
  - – publications and CVs of leading programme participants
- ❖ the presentations of the programme participants

–	Prof. Dr.-Ing. Holger Hanselka	President, Helmholtz Centre KIT and coordinator of the Research Field Energy: General overview about the Research Field Energy
–	Prof. Dr. Robert Wolf	Helmholtz Centre IPP and spokesperson of the Research programme “Nuclear Fusion”: Introduction to the programme
–	Prof. Dr. Thomas Klinger	Helmholtz Centre IPP and spokesperson of the topic “Stellarator Research”
–	Prof. Dr. Arne Kallenbach	Helmholtz Centre IPP and spokesperson of the topic “Tokamak Physics”
–	Dr. Klaus Hesch	Helmholtz Centre KIT and spokesperson of the topic “Fusion Technologies and Materials”
–	Prof. Dr. Ulrich Samm	Helmholtz Centre FZJ and spokesperson of the topic “Plasma-Wall Interactions”

- ❖ the discussions with the programme participants in
  - – the plenary session and
  - – small groups
- ❖ the additional information on

- cross-programme activities and
- results of the mid-term evaluations of the involved Helmholtz centres

Executive Summary

After three days of discussion from 05 - 07 March 2014 the review panel came to the following major conclusions and made the following recommendations for the programme and its topics.

General remarks on the programme

Nuclear Fusion is one of the seven research programmes in the research field *Energy* within the Helmholtz Association. Three Helmholtz Centres participate in the fusion programme: Forschungszentrum Jülich (FZJ), Karlsruhe Institute of Technology (KIT), and the Max-Planck Institut für Plasmaphysik in Munich/Greifswald (IPP), which is an institute of the Max-Planck Society and an associate member of the Helmholtz Association.

The evaluation presented here is based on the written material and on the presentations and discussions (on 6 and 7 March 2014) at the IPP in Greifswald. The Review Panel formulated in closed session its assessment of the strategic significance of the programme and its topics, of the proposed strategy of programme in context of progress in fusion, of the matching with Helmholtz mission, and of the competence and complementarity of participating centres.

This assessment, together with some specific recommendations, is presented in this Report.

The Strategy of the Programme “Nuclear Fusion”

Fusion research is one element of the European Strategy Plan for Energy Technology (SET-Plan). The SET-Plan defines the long-term European goal of a carbon-neutral and sustainable energy supply. To reach this goal totally new technologies need to be developed, among them nuclear fusion. The same goal is reflected in the strategic guidelines defined by the two ministries, BMBF and BMWi, which foresee the research in nuclear fusion as a long-term option, focussing on the key aspects tokamak physics, stellarator physics, research on fusion-related technology and materials, and plasma-wall interactions.

For several decades, Europe has been playing a leading role in fusion research and is hosting ITER, the leading international project in fusion. The construction and operation of ITER is to provide a solid scientific and technological basis for a decision about the future steps and projects towards fusion as a technically realistic and economic energy source. The European fusion community has recently defined its roadmap towards this goal, strategically focussed its programmes, defined milestones, and has adapted its management and coordination structures accordingly.

The strategy of the proposed 5-year research programme for *Nuclear Fusion* is perfectly aligned with this European road map. Furthermore, the programme matches perfectly the core elements of the Helmholtz mission: strategic research for grand challenges with cutting edge research, development and operation of large-scale facilities and complex infrastructure for the national and international scientific community, and creating wealth for society and industry through transfer of knowledge and technology.

In view of the importance of fusion research, the very high quality of the participating scientists and engineers, and the quite unique infrastructure, the panel noted with astonishment, that the budget foreseen for this programme has been capped at 120 M€ per year as a result of changes of the political framework conditions. As a consequence the programme cannot participate in the annual overall increases in the Helmholtz budget.

The Programme *Nuclear Fusion* is divided into four Programme Topics:

- i) Stellarator Research;
- ii) Tokamak Physics;
- iii) Fusion Related Technologies and Materials Research;
- iv) Plasma-Wall Interactions;

Compared to the previous evaluation, the number of topics has been reduced by two, resulting in four topics. These four topics are focused very well on the key elements in the area of magnetic confinement fusion for energy production. In addition, two cross-topic activities complement the research in the four main topics, ‘Theory Challenges’ and ‘The Route to a Fusion Power Plant’. These cross-topic activities were not part of this review, but their elements played an important role in all four topic areas.

The Panel noted that the proposed programme addresses in addition to key *scientific* challenges also the associated *technological* challenges very well, fully in line with the European road map.

The Panel evaluated the scientific quality of the overall programme as truly excellent and rated the topics highly on the given scale. The researchers are internationally of a very high standing. Furthermore, some of them play a central role in the new European fusion coordination and funding structure, thus acting as architects in their field.

<u>Programme topic 1 “Stellarator Research”</u>

(This programme topic is 34% of the programme: 30.6% at IPP, 3.4% of allied programme partners)

The scientific quality and originality of the stellarator programme are outstanding. The W7-X facility offers unique solutions to essential scientific challenges, making the presented research unquestionably world-leading in a critical area of energy research.

Scientific Quality and *Originality*: The W7-X facility has a unique, confinement-optimized design, and is crucial in the world programme in determining the feasibility of the stellarator concept. The associated theory builds on past accomplishments at IPP and continues its originality.

Competence: The competence of team is outstanding. Concerning the construction and management, the project has been on schedule for the last 7 years, which is remarkable. The team managed to unite diverse sets of skills and knowledge into a single facility, builds on historic theoretical competence and established an excellent stellarator theory group, which has good balance between W-7X-specific physics and more general physics.

Strategic significance: This research is strategically crucial for fusion to solve the steady state and disruption challenges, and achieve high gain. The stellarator is a potential solution and W7-X is the right machine as it optimizes confinement and possibly scales to a reactor.

Alignment: W7-X complements international stellarator efforts in Japan, Spain, Australia, and the US.

Coherence: The staff has the critical mass as well as the correct distribution of skills. It is wise that the Greifswald team is not seeking ITER construction work, but is focusing on make W7-X work.

Management and cooperation: The management of the programme is impressive, with unusual coherence and collegiality among the leaders. The fact that the project has been on schedule and technically successful since 2007 highlights the high competence of the management of the construction team. The Panel commends the team for the successful construction of W7-X and the physics productivity to date. The cooperation between the 3 institutes seems excellent, with KIT and FZJ groups participating in the W7-X programme. There is good participation of EU and international labs in other activities in the W7-X programme.

Specific Recommendations:

- The Panel recommends being careful not to switch too soon to a new management structure for the research phase, given the significant hardware activities that will persist for some time.
- It recommends involving experimentalists from Garching and other stellarator laboratories around the world participate already in the initial operation of W7-X. It supports the activities and plans of the team to execute such collaborations.

Programme topic 2 "*Tokamak Physics*"

(This programme topic is 30% of the programme: 28.5% at IPP and 1.5% of allied programme partners)

By focusing on plasma exhaust and the materials required for plasma exhaust, the tokamak programme topic contributes significantly to achieving the goal of tapping fusion energy. The programme is very well aligned with the European roadmap.

Scientific Quality and *Originality*: A strength of the ASDEX Upgrade (AUG) programme is the depth of analysis, comparison to theory and simulation, leading to increased physics insight. The scientific competence is extremely high. The team includes many very well respected researchers, and has attracted some renowned scientists and high potentials, including from outside the EU. IPP developed a world-leading code with the key physics important in tokamak turbulence, which is being extended to the stellarator. The plans for validation tests over the next 5 years are excellent.

Competence: The AUG facility is a world leader in divertor and scrape-off layer physics, both experimentally and in model development, as well as testing power plant relevant materials in a tokamak environment. The planned programme in this area will maintain this strength.

IPP and FZJ have developed some of the best boundary/divertor codes available world-wide. The additional work required for continued improvement and validation at high density will be addressed in Topic 4. The panel supports the ongoing effort and emphasis in the plan on validating the code in Topic 2. This work will also support the stellarator programme.

Strategic significance: Handling of high heat fluxes with scenarios planned for ITER and for DEMO, in which AUG plays a leading role worldwide, is needed for ITER. It will determine what is feasible for DEMO and whether different divertor approaches are required. AUG already made important impacts through use of tungsten as plasma facing components. This is a unique and important role in the world programme. The proposed upgrades directly support this mission. Testings of P92 steel is a bold step, which provides critical information on the feasibility of EUROFER for DEMO, but might pose challenges for operation of AUG.

The programme has a strong leading role in development and application of electron cyclotron heating and current drive, spanning Topics 1, 2 and 3. It will continue to play a critical role in exploitation of AUG and W7-X, of major importance for ITER and DEMO.

The synergy between the tokamak and stellarator programme is a unique strength of the Helmholtz programme.

Real time control, in both the core and boundary areas, is a particular strength. The programme has the goal to prototype the control techniques which will be needed for ITER.

Alignment: The programme is extremely well aligned with the EU roadmap towards a DEMO, contributing in nearly all areas. The AUG programme strongly supports future ITER operation and the DEMO programme. IPP will lead many of the new EUROFUSION tasks. The programme strongly supports JET and ITER and is well aligned with the European and international tokamak programmes.

Management and Leadership: Strong scientific leadership is evidenced by the continued success of the programme, the integration of programme elements, and generation of new ideas and initiatives. Scientists from AUG are key participants and leaders in the ITPA (International Tokamak Physics Activity). AUG scientists have productive collaborations with other scientific teams around the world. The Helmholtz scientists are leaders in the new EUROFUSION organization, leading 6 of 17 groups.

Specific Recommendations:

- Continue the productive interaction between the tokamak and stellarator groups, increasing the interactions between the AUG and W7-X experimental teams as W7-X moves into operation.
- Continue considering multiple options for an attractive DEMO.
- The ongoing AUG research programme should support the broader range of operational scenarios/options, such as the improved H-mode, the hybrid regime and advanced non-inductive scenarios.
- Improve measurement of the density and temperature in the divertor in order to significantly improve understanding of important divertor behaviour and the validation of divertor models.

<u>Programme topic 3 “Fusion Technologies and Materials”</u>

(This programme topic is 26% of the programme: 21% at KIT and 5% at IPP)

The work on fusion related technologies and materials is an absolutely essential element in the transition from research facilities to future fusion power plants. The development of radiation resistant materials is highly likely to determine the success or failure of fusion as an energy source.

Scientific Quality and *Originality*: The Helmholtz research on fusion technologies and materials is internationally recognized for its high quality, outstanding productivity, and completeness of the programme. The topic shows originality and novelty in many areas, e.g. innovative He-cooled divertor designs, novel fuel cycle concept, new generation of materials, and high quality tests.

Competence: The analytical and experimental work is internationally recognized as being the best of its kind. In general, German institutions are holding the number one position in the EU competition for grants in this area of research.

Strategic significance: The proposed work was chosen considering the overall needs for the fusion programme.

Alignment: It is a comprehensive, well-integrated programme, covering the main challenges and technical issues for ITER and DEMO. Activities are perfectly aligned with the development of fusion, along the lines of the European Roadmap. Activities contribute to key areas/challenges in the fusion roadmap. In many cases, these activities make use of large-scale unique facilities, such as the tritium laboratory and HELOKA helium system. Activities have the potential for generating intellectual properties and industrial applications.

Coherence: The technologies and materials programme provides multiple opportunities for significant scientific impact in numerous areas of development. The R&D steps and milestones are clearly outlined and highly likely to meet their goals for ITER and DEMO. There is considerable expertise at the three centres (KIT, IPP, and FZJ) where scientists collaborate efficiently to solve the technology and material-related challenges facing ITER and DEMO.

Management and Leadership: The programme is well planned with credible milestones compatible with the overall EU goals for the construction and operation of ITER followed by a DEMO. Good management is implemented through the formation of the EU fusion consortium and the agreed-upon contributions from German participants. The EU fusion community has an extensive experience with collaborations in multinational projects. This forms the basis for good and efficient communications in future programmes.

Specific Recommendations

- Expand the world-wide collaboration programme in the technology and material areas.
- Continue to play an active role in seeking means to test materials through exposure to 14 MeV neutrons to predict materials performance beyond a neutron dose of ~20 dpa with a sufficient level of reliability.
- Develop design rules and codes for brittle materials (W and Cu).
- Address “Safety and Environmental” issues, not only safety.
- Update milestones to include testing in relevant neutron environment.

Programme topic 4 “Plasma-Wall Interactions”

(This programme topic is 10% of the programme: 7.7% at FZJ, 2.3% at IPP)

Understanding and controlling plasma wall interactions (PWI) are of utmost importance for the design of a fusion reactor. Its research should be vigorously pursued at all levels: linear devices, large plasma devices and theory. Due to its importance it is correct to treat PWI as an independent research topic. FZJ and IPP are key players within the international fusion research community in this field and the research programme is considered to be well-focused.

Scientific Quality and *Originality*: The theme has all relevant research instruments and simulation codes in operation at a very high level. The scientific output in terms of publications, leadership, conferences and training is excellent.

Competence: The team is open to new developments, sincerely assesses them and can flexibly adapt the programme to new research outcomes achieved worldwide.

Strategic significance: The importance of the tackled problem is clear; heat and particle exhaust is a main challenge for fusion. The combination of hot cells including loading and plasma interaction, and experimental characterization facilities give the research team a unique position in the international community. By considering various options, assessing them and subsequently determining priorities, the team has established a well thought-through research strategy which is judged to be well focused.

Alignment: The team is very much committed to the overall research goals in fusion research (well aligned with the EUROfusion programme and numerous contributions for F4E). It has recently given up the TEXTOR facility in order to optimize its contribution to PWI research, within the given financial constraints. The complementarity of FZJ and IPP Garching efforts on PWI is very good. The topic plays an important role in the investigations at AUG and W7-X, both through experiments and numerical calculations.

Coherence: The topic brings complementary experimental facilities together. For areas involving irradiation the researchers rely on the network they have set up.

Management and Leadership: The number of coordination meetings (once every 6 months) seems to be sufficient. For specific developments key persons are appointed to coordinate the collaboration: one for W7-X and one for JET. The research project benefits from the good collaboration with other groups in material sciences at FZJ. The transition from TEXTOR to focusing more on PWI were accomplished very well by implementing the proposed strategy from dedicated experiments to the larger devices (from a managerial and personnel point of view, making use of available expertise, competences and facilities).

Specific Recommendations:

- The panel recommends to keep good connections with large scale experiments
- Keep the integration between theory and experiments
- Further strengthen the connections with other material science groups at FZJ.
- Preferably engage in a network to get access to neutron facilities.
- Coherence of the programme improved over the past period, this activity should be further strengthened.

<u>Overall conclusion</u>

The four programme topics are strongly interrelated and interdependent, addressing issues of critical importance for nuclear fusion as energy source. Among them, the stellarator programme is probably the most remarkable, as the W7-X facility has a unique design and is extraordinary in its originality. Hence, the highest rated topic within the research programme is topic 1. The stellarator concept complements in a promising way the tokamak concept which is the baseline approach of today and implemented in ITER.

<u>Future outlook</u>

The strategy of the research programme for *Nuclear Fusion* has a time frame which exceeds the 5-year period of the present evaluation by decades. It will also in the time beyond this evaluation continue to be closely aligned with the European road map for Nuclear Fusion and the European Strategy Plan for Energy Technology (SET-Plan) which defines the long-term European goal of a carbon-neutral and sustainable energy supply. All critical elements which need to be solved in order to meet the goal of demonstrating the feasibility of fusion as energy source are addressed by the programme in a strategically and technically very convincing way.

Statements and Recommendations of the Review Panel

Programme topic 1 "Stellarator Research"

General remarks

The stellarator programme is remarkable in many ways. Scientifically, the W7-X facility is a unique design, extraordinary in its originality. Strategically, the stellarator is crucial to the world fusion programme, offering unique solutions to essential scientific challenges. It is highly aligned with the high standards of the Helmholtz Foundation for cutting edge research with big ambitions. The competence of the team is outstanding, manifest in the successful construction of W7-X and the physics productivity to date. The management of the programme is impressive, with unusual coherence and collegiality among the leaders. In summary, the stellarator programme is unquestionably world-leading in a critical area of energy research.

Scientific quality

Originality

The stellarator research facility is unique in the world. The originality of the stellarator programme is extraordinary, featuring a unique confinement- optimized design with an exceptional test of island divertor. This outstanding setup enables crucial research for determining the feasibility of stellarators for energy production. Based on past accomplishments at IPP in experimental and theoretical research the programme continues with highly original projects, e.g., gyrokinetic codes, stellarator optimization (turbulence minimization).

Competence

The very high competence of the team is reflected by the fact that the construction of W7-X has been on schedule for the last 7 years. By pulling together a diverse set of capabilities into a single facility and building on historic theoretical competence (such as inventors of quasi-symmetry), an excellent stellarator theory group could be established. In addition, the developed diagnostics are at the state of the art.

Strategic significance

Alignment

The review panel agreed on the project's unprecedented strategic relevance for fusion. Crucial challenges in the field of stellarator research, such as the steady state and disruption challenges and achieving high gain, can only be tackled and overcome with this stellarator programme.

The proposed research plan for stellarator research is rated outstanding. The team managed to set up a stellarator concept, which not only addresses the most pressing questions in stellarator physics, but also fits perfectly into the EU fusion roadmap and complements international stellarator efforts in Japan, Spain, Australia and the US. In addition, the entire strategy is very well aligned with the Helmholtz energy goals, tackling a grand challenge with cutting-edge research and enormous ambition and dedication.

Coherence
The current staff has critical mass for achieving very ambitious goals with a very well balanced distribution of skills. The panel appreciates the decision of the Greifswald team very much not to engage in construction work in the ITER project, but focus all efforts on bringing W7-X to the operational phase.

Management and cooperation
The excellence of the construction management team gave rise to a successful completion of the stellarator. The project has been on schedule since 2007. The cooperation between the 3 institutes appears to be excellent, with KIT and FZJ groups participating in the W7-X programme.
In addition, the review panel has the impression that the theory group has a good balance between W-7X-specific physics and more general physics. The panel would like to emphasize that the W7-X programme is well connected with EU and international labs, which participate in W7-X related research.

Appropriateness of expenditure and recommendation for financing

The committee did not examine the expenditure for the stellarator program in detail. However, the financing of the program appears to be appropriate. The appropriateness of the funding for construction of W7-X seems clear from the progress that is being made consistent with the planned schedule. It is important that the experimental and engineering team be strongly funded for the critical commissioning of the facility and initiation of plasma operations. We believe that an adequate team is indeed planned within the allocated funding, although this should be confirmed in detail.

Specific recommendations

- The management of the research programme is a shared responsibility among three experimental physicists. While perhaps not a common arrangement, it has been very successful for ASDEX-Upgrade and will likely be similarly successful for W7-X. However, the team should be careful not to switch too soon to the new management structure for the research phase, given the significant hardware activities that will persist for some time.
- Second, it could be an advantage for the initial operation of W7-X to have experimentalists from Garching and other stellarator labs around the world participate in the run programme. The panel supports the plans to execute such collaborations.

Rating

X = whole number 1 (lowest) – 7 (highest) – see rating scales in the annex

Scientific quality**: **7 originality 7, competence 7
Strategic significance**: **7 alignment 7, coherence 7, management 6, cooperation 6

This topic is rated best within the research programme.

Programme Topic 2 “Tokamak Physics”

General remarks

The topics 1, 2, and 4 of the planned Helmholtz Programme have established a strong focus on plasma exhaust and the materials required for plasma exhaust, a major challenge for the realization of fusion energy. The Tokamak Programme is very well aligned with and a leading contributor in this effort.

Scientific quality

The scientific competence of the tokamak group, based at IPP, is extremely high. The team includes many very well respected researchers, and has attracted some new high-potentials, including from outside the EU. They have an excellent publication record, strong participation in international conferences and working groups (such as the International Tokamak Physics Activity).

IPP has developed a world-leading gyrokinetic code with the key physics thought to be important in tokamak turbulence and is extending the code to the stellarator. The plans for validation tests over the next 5 years are excellent.

ASDEX Upgrade is a world leader in divertor and scrape-off layer physics, both experimentally and in model development, as well as in testing reactor-relevant materials in a tokamak environment. The planned programme in this area will maintain this strength.

A particular strength of the ASDEX Upgrade programme is the depth of analysis, comparison to theory and simulation, leading to increased physics insight.

The panel supports the ongoing effort and emphasis in the plan for validating the boundary/divertor codes, whose development and improvement will be addressed in topic 4. We note that this work will also support the stellarator programme.

Strategic significance

Alignment

Since Germany has set a goal for steep reduction in carbon emissions, and also decided to stop its fission programme, it is challenging to find large-scale power production which could meet this ambitious goal in a cost effective manner. Fusion is one of the few options available. The research is necessarily long-term. This also aligns well with goal oriented scientific research mission. Tokamak research in particular requires large-scale complex infrastructure.

The programme is exceedingly well aligned with the EU roadmap towards a DEMO, contributing in nearly all areas. Accordingly, the priorities in the ASDEX Upgrade programme strongly support ITER operation and the DEMO programme, evidenced by strong focus on the ITER baseline scenario. We note that IPP will lead many of the new EUROFUSION tasks.

The Helmholtz tokamak programme strongly supports JET and ITER and so is well aligned with the European and international tokamak programmes. An example of strong recent impact is that the successful ASDEX Upgrade tungsten plasma-facing components (PFCs) led to the installation of a metal ITER-like wall in JET, and recent adoption of an all-tungsten divertor in ITER.

Coherence

The synergy between the tokamak and stellarator programme is a unique strength of the Helmholtz programme. Examples on the theory side include stability, gyrokinetic and boundary simulations. On the experimental side there is synergy in developing diagnostics and between 3D perturbation on ASDEX-U for ELM control and the Island divertor and trim coils on W7-X. Helmholtz should be commended on facilitating the strong interaction between the two centres.

The Helmholtz programme has a strong leading role in development and application of electron cyclotron heating and current drive, spanning topics 1, 2 and 3. The electron cyclotron will continue to play a critical role in the scientific exploitation of ASDEX Upgrade and W7-X and will be a major heating and current drive tool for ITER and DEMO.

A central aim of the ASDEX Upgrade POF-III programme is to integrate handling of high heat fluxes with scenarios planned for ITER and for DEMO, using impurity seeding with real time control. This development, in which ASDEX Upgrade plays the leading role worldwide, is needed for ITER. It will determine what is feasible for DEMO and whether different divertor approaches are required.

The team has already made important impacts through use of plasma facing components (PFCs) made from tungsten, which have impacted plans for ITER, and also revealed the impact such changes can have on operating space (e.g. impurity accumulation at low density). This is a unique and important role in the world programme.

Nearly all of the proposed upgrades directly support this mission, by increasing the heating power and pulse length and upgrading the capability of the device to handle it. We think this is appropriate. The proposed flexible ion cyclotron range of frequencies (ICRF) frequency is particularly important since it could allow central heating at the full field of AUG. The proposed testing of P92 steel as part of the PFCs is a bold step which provides critical information on the feasibility of EUROFER for DEMO, but might pose challenges for operation of AUG.

Development and routine use of real time control, in both the core and boundary areas, is a particular strength. A key example is the stabilization of Neoclassical Tearing Modes using ECH. The programme has the ambitious but realistic goal to prototype the control techniques which will be needed for ITER. Continued collaboration on developing ITER control and data acquisition is encouraged.

Management and Cooperation

The IPP programme has strong scientific leadership, evidenced by the continued success of the programme, the integration of programme elements, and generation of new ideas and initiatives.

Scientists from ASDEX Upgrade are key participants and leaders in the ITPA (International Tokamak Physics Activity).

The ASDEX Upgrade scientists have productive collaborations with other scientific teams around the world in important experimental and theoretical topics.

The Helmholtz scientists are leaders in the new EUROFUSION organization, leading 6 of 17 groups.

Appropriateness of expenditure and recommendation for financing

The facilities enhancements proposed for the ASDEX Upgrade are highly valuable and recommended to enable ASDEX Upgrade to remain a world leading programme in developing fusion energy. A central aim of the ASDEX Upgrade programme is to optimize integrated plasma exhaust for fusion systems and integrated tests of plasma facing materials, consistent with the main theme of the Helmholtz programme. Nearly all of the proposed facility upgrade directly support this mission, especially the heating and current drive upgrades, the infrastructure for high power and long pulse, and the optimal divertor. With these enhancements, ASDEX Upgrade will continue as the world leader in this important area. In addition, the heating and current drive, the power upgrades, and the plasma control upgrades enables outstanding scenario development in support of ITER and DEMO, and supports continued excellent scientific research to establish physics basis and validate theory for fusion. The proposed flexible ICRF is particularly important as it provides central heating at full field. The diagnostic enhancements are critically important to continue the scientific excellence of the research programme.

Specific recommendations

- The panel commends the productive interaction between the tokamak and stellarator groups, and encourages increased interactions between the ASDEX Upgrade and W7-X experimental teams as W7-X moves into operation.
- The Tokamak programme should continue to consider multiple options for an attractive DEMO, and the ongoing ASDEX Upgrade research programme should support the broader range of operational scenarios/options, such as the improved H-mode, the hybrid regime and advanced non-inductive current drive scenarios.
- Improved measurement of the density and temperature in the divertor would contribute significantly to the physics understanding of important divertor behaviour (such as detachment) and the validation of divertor models

Rating

X = whole number 1 (lowest) – 7 (highest) – see rating scales in the annex

Scientific quality 6.5: originality 6.5, competence 7

Strategic significance 6.5: alignment 7, coherence 7, management 6, cooperation 6.5

Programme topic 3 “Fusion Technologies and Materials”

General remarks

Helmholtz research on fusion technologies and materials is internationally recognized for its high quality and outstanding productivity besides the uniformity and integrity of the programme.

It is a comprehensive, well-integrated programme, covering the main challenges and technical issues for ITER and DEMO, with the participating German institutions holding the number one position in the EU competition for grants in this area of research.

The Panel was impressed by the competence of the technologies and materials team of ~40 scientists providing detailed answers to our 23 questions during the afternoon session on Thursday March 6, 2014.

Scientific quality

The proposed work on technologies and materials was chosen thoughtfully and in consideration of the overall needs for the fusion programme. There is originality and novelty in many areas of the proposed research: innovative He-cooled divertor designs, a novel fuel cycle concept, major breakthrough for next generation of Electron Cyclotron Resonance Heating, promising high-temperature superconducting cables, enhanced helium cooling system, pioneer diagnostic work at IPP, innovative coupling of computer-aided design (CAD) with 3-D neutronics codes and rigorous activation method, new generation of materials, and high quality tests. The analytical and experimental work is recognized internationally as being the best of its kind.

Fuel Cycle: KIT will develop advanced engineering models for the DEMO fuel cycle along with a novel concept based on a "short-cut from the primary vacuum pumps to the fuelling systems."

Plasma Heating: The current and planned activity for plasma heating places the German institutes at a leading position worldwide, with Japanese institutes being close followers.

Plasma Diagnostics: The diagnostics work developed so far at IPP has been excellent. ASDEX is equipped with a very comprehensive system of first class diagnostics and the developments done for W7-X are also in the front line of each technology, including unique systems.

Magnets and Magnet Components: KIT is the world leader in developing and testing innovative High Temperature Superconductor cable design for future fusion conductors. The scientific impact and resulting benefits would be extremely valuable to the design of future fusion magnet systems.

Plant Engineering: Plant engineering is a key element in the design of fusion reactors, including the development of systems code, helium cooling system, safety concepts, remote handling equipment, port plugs, and others. KIT is strongly engaged in those topics.

Breeding Blanket Development: KIT blanket activity provides the opportunity for notable scientific impact at the national and international levels, having strong theoretical and experimental programmes and several ties established with industries. KIT has the highest level of expertise in this field and is leading the European consortium for the development of test blankets.

Divertor Technology: KIT is ahead of the rest of the world in the unique area of divertor research and has been developing innovative He-cooled divertor designs that are either adopted or modified by power plant designers in other countries. There is originality to the proposed fabrication approaches and previous tests done with the JUDITH facility have been of very high quality.

Neutronics: This area of research represents an essential element of the 3-D nuclear analysis for ITER and DEMO. The open source work developed at KIT was inspirational to other groups in Europe and around the world. The method originally developed by KIT is becoming the standard for 3-D activation at many worldwide institutions.

Structural Materials for Blanket and Divertor: The materials programme provides multiple opportunities for significant scientific impact in the area of materials science in the fusion environment that could lead to enhanced mechanistic understanding, leading to significant advances in materials science and alloy performance. This internationally recognized group is currently leading worldwide efforts to address the difficult scientific and technical issues with the application of tungsten as a plasma facing and high heat flux material along with the development of advanced steel-based structural materials for fusion systems. IFMIF is undoubtedly the most effective fusion neutron irradiation facility that would establish the viability of materials for DEMO.

Strategic significance

Alignment

The technologies and materials activities of the Helmholtz Association are perfectly aligned with the development of fusion as an environmentally attractive energy, along the lines of the European Roadmap.

These activities contribute to key areas/challenges in the fusion roadmap: For the ITER success these challenges are: heating systems, diagnostics, cryopumps, current leads, neutronics analysis, tritium technologies, etc., and for DEMO: tritium self-sufficiency, breeding blanket technologies, tritium recovery and processing, radiation resistant materials, high temperature superconductors, remote maintenance, safety and economics.

In many cases, these activities make use of large-scale unique facilities, such as tritium laboratory, helium loop (HELOKA), Electron cyclotron resonance heating test bench, new facility (KALOS) for ceramic breeder production, and hot materials laboratory.

These activities have the potential for generating intellectual properties and industrial applications.

Coherence

The technologies and materials programme provides multiple opportunities for significant scientific impact in numerous areas of development.

The R&D steps and milestones are clearly outlined and highly likely to meet their goals for ITER and DEMO.

There is considerable expertise at the three centres (KIT, IPP, and FZJ) where scientists collaborate efficiently to solve the technology and material-related challenges facing ITER and DEMO.

Management and cooperation

The programme is well planned with credible milestones compatible with the overall EU goals for the construction and operation of ITER followed by a DEMO. Good management is in place due to the formation of the EU fusion consortium and the agreed upon contributions from German participants. The EU fusion community has an extensive experience working together. This forms the basis for good and efficient communications in future programmes.

However, this group cooperates mainly with Europeans. It would be beneficial to enhance the collaboration with international scientists outside Europe.

Appropriateness of expenditure and recommendation for financing

The technologies and materials programme comprises a comprehensive approach to the challenges presented by the need for more advanced technologies and higher performance structural materials for all components comprising the power core system of both tokamak and stellarator. The assigned budget of ~31 M€ per year seems adequate to achieve the identified technology and material milestones. Nevertheless, if the 120 M€ cap (imposed on the Helmholtz nuclear fusion budget) could be lifted or a few percent increase to the overall budget could become available, the panel supports an increase to reinforce the materials programme and to continue supporting existing and new facilities at KIT. For instance, the panel recommends the construction of the new KALOS facility for the fabrication of ceramic breeder – one of the largest proposed infrastructures.

Recommendations

- Expand the worldwide collaboration programme in the technology and material areas.
- Continue playing an active role in seeking a means to validate materials for DEMO using 14 MeV neutron source and permit the prediction of materials performance beyond a neutron dose of ~20 dpa with a sufficient level of reliability. Also, address the relevance of data obtained using coupon testing to material validation for DEMO.
- Develop design rules and codes for brittle materials (W and Cu).
- Address “Safety and Environmental” Issues, not only safety.
- Collaborate with the researchers in Topic 1 to simplify the stellarator geometry.
- Accelerate the development of the systems code to select between design options. Include the economic package in the code to assess the impact on machine cost. Benchmark against systems codes developed in the US, UK and Japan.
- Assess the reweldability limit for ferritic/martensitic steel and the lifetime limiting factor for W alloys. Develop low-activation material for the vacuum vessel that does not require post weld heat treatment (PWHT).
- Update milestones to include testing in relevant neutron environment whenever needed.

Rating

X = whole number 1 (lowest) – 7 (highest) – see rating scales in the annex

Scientific quality 6.75: originality 6.5, competence 7

Strategic significance 6.5: alignment 7, coherence 6.5, management 6, cooperation 6.5

Programme topic 4 "Plasma-Wall Interactions"

General remarks

Plasma Wall Interaction (PWI) plays a key role in the development of a fusion reactor. As the pulse duration in the experimental devices increases from a few seconds, via several minutes, to continuous operation in an energy producing reactor, the load on the first walls and in particular on the divertor surfaces increases dramatically and could be a show stopper of a future reactor. PWI deals with materials under such very special extreme conditions: bombardment of the surfaces by energetic particles (with energies beyond a few eV), especially energetic neutrons. The proposed move towards the impact of neutron irradiation on PWI is a very timely and relevant one.

PWI has a strong connection to other parts of the fusion programme. Though, given its crucial role in between plasma physics and materials for fusion technology, it is entirely correct to treat PWI as an independent topic.

As a key player within the international fusion research community, the Helmholtz research laboratories within topic 4 realised and will execute a well-focused research plan. There are fruitful collaborations with other subfields in the fusion community. The research topic provides very important input to AUG, W7-X, JET, ITER, and DEMO.

Both with respect to experiments and numerical simulations, the research efforts logically span from fundamental research over interpretation of present day experiments (AUG, JET) to contributions for the design of next step fusion devices (W7-X, ITER and DEMO). This led e.g. to the introduction of W as divertor material for ITER. The implementation of the ITER-like wall in JET has been performed by this team.

Scientific quality

The team has a worldwide leading position on PWI. It is the only consortium that has a strong presence at all relevant experimental levels: surface science studies and analysis, linear plasma devices, high heat load devices, insertion devices on the AUG tokamak, implementation of PWI in tokamak operation and tokamak diagnostics. The results will be transferable to the stellarator research as well.

The PWI team is leading in maintaining and developing codes to simulate PWI on a multi-scale level. Especially the plasma edge codes (B2-EIRENE, EMC3-EIRENE) complemented with numerical codes for sheath properties, local edge impurity transport, and surface processes such as ERO and SDTrim, Monte Carlo codes for erosion-deposition studies and ion-solid interactions in general, are strongly improved by the developments at FZJ and IPP and provide key numerical tools for the advancement in plasma wall interaction research. The recent development of codes from 2D to 3D is in addition a major achievement towards supporting W7-X. The team takes advantage of the FZJ supercomputer centre in code development.

The figures on scientific output in publications, conference and other presence, numbers of PhD students, participation in young investigation groups measured per FTE are outstanding

within this topic. It should be noted that the performed research puts them in a preferential position as no large facilities needs to be run or constructed.
The PWI team has taken excellent decisions in the choice of future research. Here, the choice for neutron irradiated materials and the presence of beryllium on the surfaces, the potential role of EUROFER as plasma facing component deserve to be mentioned.

Strategic significance

The understanding and control of Plasma-wall interactions (PWI) are crucial for nuclear fusion research. As heat and particle exhaust is a main challenge for realizing ITER and DEMO, the presented research plan highly contributes to building the physics base, developing technological innovations as well as to enabling the interpretation of ITER scenarios and a successful design for DEMO.

The unique combination of available experimental devices consisting of hot cells including loading and plasma interaction, experimental characterization facilities and large scale fusion devices is well-aligned with the Helmholtz mission. It provides a sound basis for excellent and innovative research. As beryllium is present in the fusion reactor the fact that it can be incorporated in the experiments is a major asset. However, it should be noted that there is no on-site access to neutron irradiation installations. The present approach to irradiate samples in external facilities is the most cost effective one. Within the integrated approach followed to incorporate as many critical factors for the material as possible, there is at present no possibility to include the effect of tritium in the linear plasma devices at FZJ. Necessary characterization studies to assess tritium inventory in next step devices when using new PFC materials can, however, be partially covered at KIT or SCK/CEN (Belgian Nuclear Research Centre, Mol, Belgium, TEC-partner). In addition the availability of the supercomputing facility at FZJ will be crucial for the development and validation of numerical approaches to this multiscale topic.

The proposed research plan is based on a sound assessment of needs within the fusion programme. Alternative options such as liquid metals (including liquid lithium, tin or lead) and moving targets were evaluated and prioritized based on scientific arguments. This led to a well-focused plan.
Simultaneously it can be concluded that the team is open to new developments, sincerely assesses them and can flexibly adapt the programme to new research outcomes achieved worldwide. This is amongst others witnessed by the incorporation of EUROFER in AUG.

The team is very much committed to the overall research goals in fusion research. As such it is in a natural way well aligned with the European EUROFUSION programme. The research group also contributed to numerous projects for F4E. After successful operating TEXTOR for many years, the research group at FZJ recently stopped the in-house tokamak experiments and reoriented towards dedicated installations for detailed studies of PWI. This research topic has in the last years been reorganized, leading to clearly complementary and collaborative efforts between FZJ and IPP Garching. Overall the proposed research subtopics, both experimentally and numerically, serve well the constructional needs of W7-X as well as the interpretation of experiments and diagnostics at AUG and W7-X. By bringing complementary experimental facilities together and building up a network for irradiating test samples, the PWI team is ready to tackle the challenges of PWI by bridging material science and plasma physics.

The research on plasma wall interaction is mainly situated at FZJ. Research activities at IPP and FZJ are well coordinated during biannual meetings. For specific subtopics (such as support to W7-X or participation in JET-campaigns) key persons are explicitly appointed. At the FZJ site there is a growing collaboration with material scientists working in other application areas and other Institutes.

Finally, it should be stressed that the management at FZJ successfully accomplished the change from a research programme oriented towards the in-house tokamak to an integrated focus on plasma wall interactions by dedicated experiments on location in combination with contributions to the larger fusion devices. Within this process care was taken to integrate the personnel and to set up attractive research projects, making maximal use of available expertise, competences and facilities. It is clear that the new management and its structure at FZJ are successful and well established. FZJ now works on a number of devices, notably the high heat flux devices Judith 1 and 2, and the linear plasma devices PSI-2 and Jule-PSI. Two of those four devices are located in the ‘hot materials’ laboratory.

Appropriateness of expenditure and recommendation for financing

The expenditures foreseen for the research on Plasma-Wall interaction are appropriate and should allow to keep the research at their present high standards and to continue the leading role of the Helmholtz institutes in the field of plasma-wall interactions. It is however important to keep the financial support on the same level in order to keep the concerted infrastructure up-to-date and running.

Specific recommendations

- In order to sustain a high level competence centre on plasma wall interactions,
    - the research needs to stay well-connected with the fusion device experiments in AUG, JET and in the future in W7-X
    - the integration between theory and experiments needs to be continued.
- To fully explore the uniqueness of the FZJ site, a further strengthening of the collaboration with other FZJ material science groups is recommended.
- Although the coherence of the programme strongly improved over the past period, efforts in this direction should be continued further.

Rating

X = whole number 1 (lowest) – 7 (highest) – see rating scales in the annex

Scientific quality: 6.5*;* originality: 6.5, competence: 7

Strategic significance: 6.5; alignment 7, coherence 6, management 6, cooperation 7

Evaluation and Recommendations on the Large Investments Planned

The fusion programme is strongly intertwined with its infrastructure. Due to this strong interrelation the individual infrastructures have been discussed as part of the review of the four topics individually, while this section highlights general conclusions.

The programme should be complemented on the realization of a worldwide unique infrastructure of the highest quality. The infrastructure in terms of size is only surpassed by the purely international facilities ITER and JET. The German programme members contribute significantly to both facilities. The available infrastructures are well chosen, while certain limitations are attempted to be overcome by the realisation of planned infrastructures.

Scientific quality:

Wendelstein 7-X will be the world leading machine of its kind. This outstanding setup enables crucial research for determining the feasibility of stellarators for energy production.
The size of ASDEX-Upgrade is relatively small and proposed efforts to increase the scaled power levels of the machine are highly desirable.
The programme topic “Fusion Technologies and Materials” has requested extensions to its portfolio of infrastructures, which are fully justified.
The programme topic “Plasma-wall interactions” is currently renewing its infrastructure and has terminated the work with TEXTOR. The infrastructures in this topic present and planned are well chosen.
The panel has noted that good neutron irradiation facilities would complement the programme. However, the construction of such a facility cannot be achieved on a national level.

Benefit for the programme:

Overall, the scientific significance of the infrastructures used by the programme is very high.
The review panel agreed that the W-7X project has unprecedented strategic relevance for fusion.
The infrastructure is essential to the programme, in spite of the external availability of ITER and JET. In fact, the infrastructures are very relevant in the international context.

Appropriateness of expenditure:

In all cases the expenditures are reasonable for a programme of this scope and size.

Evaluation and Recommendations on the Programme

General remarks

The Helmholtz programme "Nuclear Fusion" is divided into the four research topics Stellarator Research, Tokamak Physics, Fusion Related Technologies and Materials Research and Plasma-Wall Interactions, which are focusing on the key elements in the area of magnetic confinement fusion for energy production and complement each other very well. In addition, two cross-topic activities draw on work performed in the research in the four main topics, 'Theory Challenges' and 'The Route to a Fusion Power Plant'. Although these cross-topic activities were not part of this review, their elements played an important role in all four topic areas. The proposed 5-year research programme for *Nuclear Fusion* is perfectly aligned with the European road map and with the Helmholtz mission. The scientists in the four programmes are world-leading in their field, committed to this excellent complementary approach, and have set up an unique infrastructure, which will be the cornerstone for fusion research in the upcoming years.

Scientific quality

The Panel evaluated the scientific quality of the overall programme as truly excellent and rated the topics very highly on the given scale. The scientific and developmental work of the Helmholtz centres FZJ, IPP and KIT on nuclear fusion is performed in a strong and excellent international cooperation, which on this high level and this completeness does not exist in other parts of the world. The scientific quality of the four topics is with no doubt among the top 5-10% in the world, with parts of the research certainly being ranked world leading. The researchers are internationally of a very high standing and play a central role in the new European fusion coordination and funding structure, thus acting as architects in their field. The four topics are strongly interrelated and interdependent, addressing issues of critical importance for nuclear fusion as energy source. Among them, Stellarator Research is probably the most remarkable, as the W7-X facility has a unique design and is extraordinary in its originality. The Panel notes, however, that all of the topics received the highest rating for their scientific competence and therefore does not recommend any budget shifts.

Strategic significance

The Panel came to the conclusion that the work done at the three German fusion centres is in very good agreement with the strategy developed on the European and international level, especially concerning the support to the ITER construction, the Tokamak Physics Activity, the Broader Approach, the "allied programme participants" of Wendelstein 7-X and of ASDEX Upgrade and the technological aspects of nuclear fusion. The Panel got the impression that while the plasma physics community in Europe has a very strong collaboration with the US in many fusion-related areas, there is no transatlantic cooperation with Europe in place in the area of material research. The panel proposes to extend the collaboration of Europe with the US also in material research for fusion.

Talent management

The German fusion centres, FZJ, IPP and KIT, make a substantial effort to sustain the high level of scientific and technological competence in nuclear fusion over the generations. In order to inform the general public, the scientists engage strongly in public lectures, open days, summer universities and lectures at German universities, the number of which increased substantially during the last years. Examples are the Carolus Magnus Summer School arranged by FZJ, the Summer-University for plasma physics presented by IPP and the Summer School on Fusion Technologies organized by KIT, all for at least 60 participants every year. As a result there are numerous talents in the highly qualified postdoctoral programmes of the centres.

All three nuclear fusion centres follow a family-friendly staff policy, certified as part of the “audit berufundfamilie” initiative several times within the last decade.

The review panel is impressed by this successful talent support which resulted in a large number of very good PhD students. A number of them will preserve the fusion science competence for the future. The panel noted that the ratio of students to staff scientist is lower in the centres in comparison to universities, with 0.1 in comparison to 0.5. It is to a large extent due to the fact that the centres build, operate and maintain very large facilities which require a substantial scientific and technical staff. The large infrastructures are operated both as user facilities and as part of the own scientific programs. While the training is quantitatively at such a level that the foreseen need of future fusion scientists can be recruited from the young scientists trained, the number of students should not be limited by the expected future needs. Students can pursue a career in industry, contribute to the total knowledge base of the country and in particular concerning fusion. Training for use within the field should set a lower limit, but no upper limit to training.

It is interesting to split the numbers into ones for the four topics. The ratios of students to staff scientists are: Stellarator Research 0.02, Tokamak Physics 0.07, Fusion Technologies 0.07, Plasma-wall interactions 0.2. As the first topic is leaving the construction phase, to which students could only contribute in a limited way, an increase in the number of students is to be expected.

Management and infrastructure

The strong scientific leadership of the programme is complemented by an impressive management of the programme with very well planned coherence and collegiality among the leaders. In addition, scientists are key participants in international projects around the world, having established a remarkable knowledge base and network.

The infrastructure established within the scope of the Helmholtz programme is unique and of the highest quality world-wide. The additionally planned investments are well chosen and will be crucial for achieving the aspired goals.

Technology transfer

A close partnership of the German fusion centres with industry has existed for a number of years. It not only resulted in the identification of regions of common interest, but now also led to substantial innovations that were transferred and implemented in standard process chains in European industrial companies. The review panel on the Helmholtz programme Nuclear

Fusion welcomes very much, that the German industrial involvement in nuclear fusion for ITER grew substantially in the last year after the decision was made that the risk of the project should not be put to industry alone. Hence the Helmholtz programme contributes substantially to the high level of industrial engagement, which presently grew up to about 400 M€.

Contribution to cross-programme activities and initiatives

Cross-programme initiative "Large-Scale Data Management and Analysis (LSDMA)"

The panel supports the cross-programme initiative, in which Topic 1 and 2 cooperate with other programmes to cope with the management and analysis of "big data". By strategically combining the competences of various programmes in a complementary approach, the Helmholtz centres initiated a strategically relevant cooperation. With Wendelstein going into steady-state operation, very large data volumes will be generated, requiring a constant development of novel techniques for storing and analysing data. Hence the fusion programme is a vital partner in this initiative.

Cross-programme activity "Materials Research - Energy Supply"

FZJ is involved in the cross-programme activity "Materials Research – Energy Supply" in which materials scientists collaborate to meet the challenges in materials science for energy generation and mutually benefit from each other's research. The experience of non-fusion groups with materials at ultra-high temperatures complements the research of topic 3 and 4, while the investigation of surface phenomena and hydrogen in materials provide useful insight for materials scientists of different disciplines.

Appropriateness of expenditure and recommendation for financing

In view of the importance of fusion research and the very high quality of the participating scientists, engineers, and the quite unique infrastructure, the panel noted with astonishment, that the budget foreseen for this programme has been capped at 120 M€ per year as a result of changes of the political framework conditions.

The Panel recommend the funding of the proposed Large Infrastructures as they will be extremely important for the proposed programmes.

Future outlook

The strategy of the research programme for *Nuclear Fusion* is closely aligned with this European road map for Nuclear Fusion and the European Strategy Plan for Energy Technology (SET-Plan) which defines the long-term European goal of a carbon-neutral and sustainable energy supply. Hence the programme is not limited to the 5-year period of the present evaluation, but tackles the crucial challenges, which need to be overcome for the demonstration of the feasibility of fusion as an energy source. The strategy for reaching this goal was presented in a strategically and technically very convincing way.

Savièse, 30 April 2014

Albrecht Wagner, chair of the review panel

Annex

To ensure a fair and comparable process for all programmes the Helmholtz Senate Commission nominated the following delegates to participate in the review.

Delegates of the Helmholtz Senate Commission

Siegfried	**Dais**	Robert Bosch GmbH	Gerlingen-Schillerhöhe, GERMANY
Wolfram	**Münch**	EnBW AG	Karlsruhe, GERMANY
Beatrix	**Vierkorn-Rudolph**	Federal Ministry of Education and Research	Bonn, GERMANY

Delegates of the head office of the Helmholtz Association

Aurelia	**Herrmann-Köck**	Representative Research Field Energy	Berlin, GERMANY
Tobias	**Sontheimer**	Representative Research Field Energy	Berlin, GERMANY
Jürgen	**Mlynek**	President	Berlin, GERMANY
Sören	**Wiesenfeldt**	Head of Research Section	Berlin, GERMANY

The following scientists represented the programme and its topics during the review.

Harald	**Bolt**	Forschungszentrum Jülich (Board of Directors)	Jülich, GERMANY
Wolfgang	**Breh**	Karlsruhe Institute of Technology	Karlsruhe, GERMANY
Michael	**Czyperek**	Forschungszentrum Jülich	Jülich, GERMANY
Sibylle	**Günter**	Max Planck Institute for Plasma Physics (Board of Directors)	Greifswald, GERMANY
Holger	**Hanselka**	Karlsruhe Institute of Technology (Research Field Coordinator / Board of Directors)	Karlsruhe, GERMANY
Per	**Helander**	Max Planck Institute for Plasma Physics	
Klaus	**Hesch**	Karlsruhe Institute of Technology (Topicspeaker for Topic 3)	Karlsruhe, GERMANY

Arne	**Kallenbach**	Max Planck Institute for Plasma Physics (Topicspeaker for Topic 2)	Greifswald, GERMANY
Thomas	**Klinger**	Max Planck Institute for Plasma Physics (Topicspeaker for Topic 1)	Greifswald, GERMANY
Ulrich	**Samm**	Forschungszentrum Jülich (Topicspeaker for Topic 4)	Jülich, GERMANY
Christina	**Wenninger-Mrozek**	Max Planck Institute for Plasma Physics (Board of Directors)	Greifswald, GERMANY
Robert	**Wolf**	Max Planck Institute for Plasma Physics (Programme Spokesperson)	Greifswald, GERMANY
Hartmut	**Zohm**	Max Planck Institute for Plasma Physics (Board of Directors)	Greifswald, GERMANY

Representatives of the Scientific Advisory Boards

Richard	**Hawryluk**	Representative of Scientific Advisory Board (IPP)	Princeton, USA
Günther	**Janeschitz**	Representative of Scientific Advisory Board (KIT)	Karlsruhe, GERMANY
Emanuelle	**Tsitrone**	Representative of Scientific Advisory Board (FZJ)	aint-Paul-Lez-Durance, FRANCE

Representatives of Strategic Partners

Definition of grades

Grade		
7	outstanding	Topic of an exceptionally high international standard (among best 5% internationally), performing pioneering and innovative work, which will most likely have a significant impact on the field and society.
6	excellent	Topic of a very high international standard (among best 10% internationally), performing innovative work, which promises a significant impact on the field and society.
5	very good	Topic of a high international standard (among best 20% internationally), developing innovative approaches, with the potential of significant impact on the field and society.
4	good	Topic of international standard developing competitive approaches.
3	fair	Topic of average international standard developing pre-competitive approaches.
2	Weak	Topic with few competitive aspects and little potential of yielding an impact in the field.
1	not sufficient	Topic which is not competitive and has no potential of yielding an impact in the field.

Report on the 36th Meeting of the W7-X Project Council 10th April 2015 in Greifswald

The “new assembly strategy” agreed at the 32nd meeting of the Project Council on 29th April 2013 has been consistently implemented with considerable success. This is true both for the adherence to cost and time schedules and for the achievement of quality objectives.

At the 85th meeting of the Supervisory Board (Kuratorium), the increased effort required for the cryo-tests was given as the main cause of the two-month delay (up to the beginning of July 2015) in the start of the first operations phase (milestone 30). Since then, the problem has become more serious, leading to 17th August 2015 as the new expected date for the first test plasma. Apart from this, only non-critical delays have been incurred, which will not affect the planned commissioning.

The conclusion of the cryo-tests and the preparations for the baking of the plasma vessel remain on the critical path and are therefore time-determining for the commissioning.

Status of the Work

It should be emphasized that the successful cooling of the coils, the bus conductors and the support structures to 4°K on 11th March is an outstanding achievement. The Project Council regards the excellent vacuum in the cryo-vessel and the absence of cold leaks as proof of the excellent work of Professor Klinger and his team.

The focus of the assembly work still lies in the remaining peripheral tasks such as the installation of cooling circuits, cubicles, cable trays and cables. The increased deployment of personnel minimises the risk of delays for the whole project and will make possible the installation of perhaps15 of the 20 B-priority diagnostics for operation phase 1 (OP1).

The collaboration with FZJ and KIT as well as with the international partners from the USA, Poland, France, Spain, Hungary and Japan remains very good. In its first meeting on the 23rd March 2015, the International Programme Committee adopted the work programme. Plasma operation is to be organised at a further meeting (June/July).

Project risks

Besides the above-mentioned cryo-tests and the preparation for the baking of the plasma vessel, the installation of the control system (CoDaC) also lies on the critical path. The risks associated with late completion will be met by creating local control solutions for the diagnostics. A further risk lies in the possible delay in the granting of the operating permit for W7-X by the authorities.

Meeting Minutes of the 1st Meeting of the W7-X Program Committee			
Location:	IPP Greifswald Günter-Grieger-Hörsaal and video conference VIDEO-MCU: 0049 100 979 19325	**Date**:	March 23rd, 2015 12:02 hrs. - 13:38 hrs.

Participants:	Dr. H.-S. Bosch+ Dr. A. Dinklage Prof. T. Klinger+ Dr. H. Maaßberg+ Prof. R. Neu*+ Prof. T. Sunn Pedersen+ Prof. U. Stroth*+ (USG) Prof. R. Wolf+ Prof. T. Donné*+ (TD) Prof. A. Grosman*+ (AG) Dr. C. Hildalgo*+ (CH) Prof. U. Samm*+ (USJ) Prof. Y. Takeiri *+ (YT) Prof. R. Zagorski*+ (RZ) Dr. M. Zarnstorff*+ (MZ)	**Distribution**: Participants, Prof. P. Helander+, distribution list of WL	

*video +member of the 1st W7-X PC

TOP		**Action**
1	***Welcome – adoption of the agenda (Klinger)*** Klinger introduces and welcomes the PC members. On behalf of the W7-X project, he expresses his gratitude to the PC members for their work on the scientific program for the first operation phase (OP1.1) of W7-X. The members of the PC agreed with the agenda.	
2	***Election of the chair person (Klinger)*** Klinger proposes Wolf (IPP) as the Chairperson of the W7-X PC for two years. *<u>Decision</u>:* The proposal to elect Wolf as the Chairman of the W7-X PC has been unanimously agreed.	
3	***Status of the commissioning schedule (Bosch)*** Bosch reports the status of the commissioning process of W7-X and explains the six phases of the W7-X commissioning process. The latest achievement is the closing of the plasma vessel and vacuum tests are started. The main on-going work packages belong to the periphery and Codac. Bosch reports results of the commissioning of the cryostat. The structural integrity of the cryostat is confirmed by measurements and their agreement with the FE models. The trim coils are commissioned and tested. Cooling down of the cryo-plant and the cold structure has been successfully conducted and	

	cooling down to 4K has been achieved. A cryostat pressure of 10^{-7} mbar has been achieved. Further commissioning of components are underway (diagnostics, ECRH towers, quench detection, control coils). SC coil commissioning will start in early May. First test plasmas are planned to begin from mid of August. *Comments and questions*: CH congratulates the W7-X team for their achievements in the commission of the device. Q: What is the maximum neutron budget? A: 3 x 10^{19} n/year MZ: Q: What is the nature of this limit? A: The limit is specified in the application for the operation permit and is derived from W7-X plasma scenarios assuming deuterium as the main plasma species.	
4	***Physics research plan for OP1.1 (Pedersen)*** Sunn-Pedersen explains the OP1.1 physics plan which has been developed with international involvement: OP1.1 is characterized by the installation of 5 inboard limiters and a maximum heating energy for a single pulse of less than 2 MJ. Highest priority in OP1.1 has the integral commissioning of the main systems. The main physics topics are defined to be realistically achievable within the limits of OP1.1. The proposed sequence of scientific actions is: 1) Flux surface measurements: effects of imposed n=1, m=1 and n=2, m=2 field errors (in view of divertor operation) and effect of compensating trim coils 2) ECRH conditioning and start-up optimization with He: helium is chosen since break-down is easier achieved in helium (in WEGA and Heliotron-J, LHD) and serves to condition the machine 3) ECRH heated helium plasmas: heating schemes are to be assessed to bring forward steady-state like plasma profiles and symmetrization of heat loads on the inboard limiters 4) First experience with hydrogen plasmas: unique possibility to provide experimental data for comparison to EMC3-EIRENE results for limiter configurations. Piggy-back: Even heat loads, density control in feed-forward, limiter physics, and SOL with short connection length. The anticipated heat load-patterns reflect the width of the heat deposition region; the limiter configuration will give important input on the scaling of λ_q versus connection length. The readiness of systems needed to address the mentioned OP1.1 physics goals is summarized, and a survey of ongoing OP1 diagnostics being installed on the device is reported. The minimum goals for OP1.1 are summarized to be:	

	1. Integral commissioning of all systems needed for successful plasma operation 2. Existence of closed flux surfaces all the way to the limiter (at B=2.5 T) 3. Measurement and adequate reduction of B_{11} field errors 4. Reliable ECRH plasma startup scenario in He 5. Basic ECRH interlocks and safe operation scenarios 6. Basic impurity content monitoring 7. Central T_e>1 keV at n_e>5*10^{18} m^{-3} in at least 10 discharges in He Additional physics topics will be: • Electron root transport studies • Scrape-off layer studies • First experiments with ECRH and ECCD • First comparison He vs H (startup, pumping, confinement) The proof of optimization criteria is left for later phases.	
5	***Discussion of the OP1.1 physics research plan (Wolf, Pedersen, Bosch)*** CH: Confirms scientific plan to be sensible. Q: What is the expected value of λ_q and are variations possible? A: A comparison of two connection lengths is possible; more limiter configurations are not planned for OP1.1. The set of Langmuir probes and a dedicated high-resolution IR camera are expected to have adequate resolution so that they can experimentally determine λ_q. MZ: Clear presentation, no further questions. AG: Congratulations on the achievements. Q: What are the measures for device conditioning? A: The plasma vessel will be baked to 150°C and the walls conditioned with glow discharge cleaning, before the start of OP1.1. Helium discharges also serve for conditioning. Overnight glow discharge cleaning between shot days will be available since the magnetic field is ramped down after each shot day in OP1.1 YT: Congratulations on the successful cool-down. Q: How is off-axis heating provided? A: The individual steering of the ECRH beams by mirrors allows one to use toroidal variation of the magnetic field strength to get resonance heating on different magnetic surfaces with the same microwave frequency. Q: Are there ECRH protection measures? A: Yes, highly loaded vessel regions are armored. USJ: Convincing presentation balancing starting up the machine and physics. Q: Do overview cameras exist?	

	A: Yes, there will be 10 overview video cameras installed. Q: What are the diagnostics for impurity monitoring? A: HEXOS, PHA (VUV, XUV spectrometer). Q: How is the data access from outside Greifswald managed? A: Data access from outside is guaranteed All data should go to the central data archive, access with web-interface will be provided. RZ: Congratulations on the achievements; device commissioning and physics questions well balanced. Q: How are Langmuir probes measurements in the SOL planned to be conducted? A: Probes are in different depths of the SOL, resolution limited by number of probes. Langmuir probes are configured so that triple-probe operation should be possible and are spaced such that a good spatial resolution in the SOL is possible. Q: Is a damage of the probes possible? A: Yes, there is the possibility that the probes are burned away in case the heat loads are larger than expected. The probes are constructed with graphite probe tips such that they can be sacrificed without affecting the further physics operation. MZ: Congratulations and plans are promising. TD: Congratulations on the achievements, EUROfusion is ready to launch the call for participation and PB meeting. USG, RN: Congratulations: prioritization appreciated, density scaling of confinement may become an early interesting result.	
6	***Conclusions (Wolf)*** The minutes will be sent out, and any additional written questions will be added to the minutes. Answers will be included in the minutes. The agreed minutes will reflect the consensus on the plan. Next meeting: Late June/early July; a poll will be distributed in due course to find a suitable date. Main topic: Organization of daily operation of the campaign OP1.1.	
7	***Closing (Klinger)*** Klinger expresses his gratitude to the participants for assessing the OP1.1 plan.	

Draft-Meeting Minutes of the 2nd Meeting of the W7-X Program Committee			
Location:	IPP Greifswald Telepräsenzraum and video conference VIDEO-MCU: 0049 100 979 19325	**Date**:	Jul. 16th, 2015 13:00 -14:22

Participants:		**Distribution**:	
	Dr. H.-S. Bosch+ Dr. R. Brakel Dr. A. Dinklage Prof. P. Helander+, Prof. T. Klinger+ Prof. T. Morisaki* Prof. R. Neu*+ Prof. T. Sunn Pedersen+ Prof. U. Stroth*+ (USG) Prof. R. Wolf+ Prof. T. Donné*+ (TD) Prof. A. Grosman*+ (AG) Dr. C. Hildalgo*+ (CH) Prof. U. Samm*+ (USJ) Prof. Y. Takeiri *+ Prof. R. Zagorski*+ (RZ) Dr. M. Zarnstorff*+ (MZ)	Participants, Prof. U. Fantz, Prof. Dr. S. Günter, Prof. Dr. H. Zohm, Dr. J. Schweinzer, Dr. J. Geiger, I. Milch, Dr. U. von Toussaint, Dr. W. Dyckhoff, Prof. Dr. E. Sonnen-drücker, Prof. Dr. A. Kallen-bach, Dr. E. Poli, Dr. G. – M. Lucha	

*video + member of the W7-X PC

TOP		**Action**
1	***Welcome – adoption of the agenda (Wolf)*** The members of the PC agreed with the distributed agenda.	
2	***Minutes of the 1st W7-X PC Meeting (Wolf)*** The minutes of the 1st W7-X PC have been approved.	
3	***Status of operation (Klinger)*** The operations permit will not be granted in time for the planned date of the first plasma (Aug. 24th). There will be a delay at least until mid/end of September. Klinger reports that the application for the operations permit has been submitted to the local authorities 14 months ago. The application needed to comply with the radiation protection of the later deuterium operation. Since the review of the application by external experts is not available yet, the authorities anticipate a delay. However, no show-stoppers have been identified for the approval of the application and the project is confident that the operations permit will be granted to conduct first plasma operation once the review is available. As a consequence, Klinger estimates that first plasma operation is expected	

	between mid of September and beginning of October this year. *Questions and Answers* MZ: How large is the confidence to get the permit in September? TK: There are no concrete statements from the authorities. Following more vague statements, there is a good chance that the first plasma operation will be conducted in September, possibly later and for sure this year.	
4	***Status of the commissioning and update on the OP1.1 schedule (Bosch)*** Bosch summarizes the status of the commissioning process of W7-X. The operation modes of the cryo-plant have been qualified. The coils have been charged individually and the corresponding machine instrumentation has been taken into operation. Charging the entire magnet system demonstrating 2.5 T has been achieved one week ago. First flux surface measurements show closed flux surfaces. The plasma vessel vacuum is $7x10^{-7}$ mbar with four pumps (10^{-8} mbar is expected with all pumps). The background pressure is sufficient to start baking in early August. *Questions and Answers* TMorisaki: Where was the small leak? HSB: The leak is in the plasma vessel not in the cryostat. AG: Is the plasma vessel conditioning affected by the operations permit? HSB: Neither baking nor glow discharges cleaning do require the permit.	
5	***Flux-Surface Measurements on W7-X (Pedersen)*** Pedersen reports about the first flux surface measurements. These measurements clearly demonstrate the existence of nested closed flux surfaces. The findings are in line with expectations, e.g. the position of island chains. *Questions and Answers* CH: Deep congratulations. The reported result demonstrates the success of the construction and assembly procedure. What is the plan for the flux-surface measurements also in view of the delays of the operation? MZ: Congratulations, exciting results TSPE: The available time will be used to explore the configuration space. With the steel scaffolding being installed at present, robust configurations with regard to perturbations will be investigated first. The flux surface measurements will be interrupted once the permit is granted. US: Are iota modifications planned? TSPE: A more detailed measurement of the iota profile and the island chain is planned for the coming week, and fine tuning of iota can be done if this proves advantageous. It is important to note that the equipment for the measurements stays inside the plasma vessel and can be used any time a flux surface verification is required.	
4	***Organization of OP 1.1 (Brakel)*** Brakel presented the plan for the organization of OP1.1. The operation will be organized in long-term planning meetings, weekly meetings and daily meetings. For OP1.1 a task force group will assess the experiment proposals and	

	assign experiment time according to the technical possibilities and priorities for first operation during OP 1.1. *Questions and Answers* US: FZJ colleagues report issues with the data access. RB: The access requires an IPP account, online access of the experiment plan will be provided. TD: The shift of the program may affect colleagues also participating in the programs of JET, AUG and TCV. AD: Issues will be dealt with case-by-case, all involved colleagues are in contact with Scientific Coordinators CH: Suggestion to communicate the SOL investigations with varying connection length to the tokamak community TSPE: The suggestion is gratefully acknowledged and it will be taken care that the results are communicated to the tokamak community	
5	***Date and place for the 3rd PC Meeting (Wolf)*** The forthcoming meeting is planned to be conducted at the occasion of the International Stellarator-Heliotron Workshop (Greifswald, Oct. 5-9, 2015). *Action: Wolf will organize a poll for the meeting date.*	Action-tion-Wolf
6	***Miscellaneous*** MZ: What is the impact of the delay on the overall project plan TK: While a revision of the OP1.2 plan is ongoing, the effective time of OP1.1 will not be shortened to ensure that the technical objectives and the integral commissioning goals are met. MZ: Concerns about the remote data access have been raised by US colleagues HSB: Remote access to the control systems will not be possible due to IT security reasons. Data access will be provided.	
7	***Closing (Wolf)*** Wolf expresses his gratitude to the participants for their work in the program committee.	

Report of the Fachbeirat

September 23-25, 2013

I. Executive Summary

The Institut für Plasmaphysik (IPP) is a world-class research center with two major scientific facilities, ASDEX-Upgrade and W7-X. The research in plasma physics and fusion is very broad and central to the development of fusion. The quality of the research is uniformly excellent and in many areas outstanding and has a major impact in the scientific community. The Institut benefits from outstanding leadership. These conclusions were drawn from the Fachbeirat meeting held in Garching on September 23-25, 2013.

The Fachbeirat reviewed the progress on the W7-X facility and was very impressed. The engineering team has done an excellent job in keeping the project on schedule during the past years and has overcome schedule delays in installing the in-vessel components by advancing the first plasma date using a limiter and then completing the divertor installation. The Fachbeirat strongly supports this decision. Since the last meeting, several major engineering issues such as assembly of the facility within the specified tight tolerances and contact resistance of the current leads have been successfully resolved. Though engineering challenges remain, as would be expected for such a complex project, the Fachbeirat believes that the Project has a credible plan to achieve first plasma close to their schedule.

Over the past year a string of excellent to outstanding results have been reported by the ASDEX Upgrade experiment. These include: development and qualification of ITER scenarios; divertor detachment physics and heat flux mitigation via feedback control of the radiated power; dynamics and mitigation of ELMs and NTMs; fast ion transport and advanced turbulence studies supporting detailed comparison with gyrokinetic simulations.

A broad range of ITER R&D and fabrication activities are underway. Since the last meeting, the ELISE facility has come on-line and is providing an important test of the RF ion source concept for ITER. This was a major accomplishment. A contract has been awarded for the development of diagnostic pressure measurements. Additional projects include development of the bolometer diagnostic with the anticipation that a contract will be awarded by F4E shortly.

The two theoretical departments, tokamak theory centered in Garching and stellarator theory in Greifswald, are uniformly excellent with many outstanding results. High quality theoretical work spans many topics central to fusion physics. The new Division, Numerical Methods in Plasma Physics, is off to a good start and has identified important topics that have the potential to make a major contribution to the theory work. The strong coupling on 3-D physics topics between the Tokamak and Stellarator Theory Divisions is highly commended.

The Max-Planck-Princeton Center for Plasma Physics has recently been established and is making good progress in developing synergies between fusion research and the astrophysics community in the areas of reconnection, turbulence, energetic particle physics, and the magneto-rotational instability. The first workshop was held in Garching and the next one will be held in Princeton in October 2013 with strong participation.

The Fachbeirat supports the excellent work on the DEMO study. IPP has a unique expertise to contribute to both tokamaks and stellarator power plants. This work is tightly coupled with the EU roadmap activities.

The outreach led by the Scientific Director has been excellent, making the case for fusion through numerous presentations, development of a website, and articles in the popular press. This is important, not just for IPP but for fusion in general.

During the past year, there has been a major effort to reorganize how EURATOM supports the fusion program. The Scientific Director has played a major role in these community discussions and her leadership has been very important.

The Fachbeirat very much appreciates the excellent quality of the presentations and organization of the meeting. For future meetings, the presentations should not only include current results but also give greater emphasis on the strategic vision and plan for each department. The Fachbeirat also requests copies of the reports if possible from other programmatic reviews since our previous meeting to provide supplementary information on the current context.

The committee recommends that, in general, meetings should be held every 18 months due to the importance of this program. The timing of the next meeting should be set by near-term needs. In particular, the schedule for the W7-X experiments suggests that the next meeting should be after initial results are obtained and would correspond to a meeting in two years. However, if the reorganization of the EURATOM program were to have a significant impact on the IPP programs, then a meeting in about a year from now may be advisable.

The Fachbeirat also provides detailed comments and recommendations on the W7-X project, the ASDEX Upgrade experiment, theory, ITER fabrication, DEMO, and staff issues below.

II. Division Wendelstein 7-X

II.1 W7-X: Project, Status and Planning (Division Wendelstein 7-X)

The Fachbeirat commends the Project W7-X team for their efforts to complete assembly and notes the outstanding overall progress in the construction progress of W7-X since the last meeting due to the complexity of the project. The project organization has been stable and focused on machine construction.

The Fachbeirat notes the completion of assembly of major components, such as the magnet system, closure of all module connections, the welding of all ports and the thermal insulation. In particular, completion of the welding tasks was extremely important since this task contained considerable risk for the schedule as well as for the quality of the machine assembly. Detailed metrology analysis has shown that all precision requirements have been met.

Three major work packages remain: the current leads, the in-vessel components and the device periphery have to be completed prior to commissioning.

With regard to the current leads, a crash program after the last meeting has been successfully executed. A design change from "Indium foils" to "Indium wires" for the contact of the joint has been designed and tests confirm that it will fulfill the critical requirements of resistance of <5 nOhm.

The installation of in-vessel components and articles on the device periphery is time consuming but does not provide major obstacles. The schedule is under control within buffer times with positive float. The budget is also managed within the 10 % contingency.

The Fachbeirat strongly supports the strategic change to begin operation with a limiter instead of the divertor. The experimental phase after commissioning has now been split into two phases. The first phase, OP 1.1, starting in April 2015 will last three months and be operated with only limiter tiles (without a divertor.) After OP 1.1 the machine will be equipped with an inertially-cooled carbon tile divertor during a shutdown period of 11 months. Then OP 1.2 starts in April 2016. This new sequence of steps accelerates the start-up of the machine, which is now scheduled for April 2015, three months earlier than in the last planning cycle. The experimental run time during the new plan is similar to the old plan but enables the team to identify issues associated with commissioning earlier. Operation with the high heat flux divertor, scheduled for 2019, has not changed.

The team has appropriately remained focused on the construction of the machine. While this has impacted staffing in some of the other W7-X divisions, these priorities are fully supported by the Fachbeirat.

In support of the upcoming experimental program, the research plan needs to be developed. The Fachbeirat urges IPP to complete a first draft research plan with international partners as soon as possible so as to identify operational as well as physics milestones and to make it consistent with the availability and capability of hardware. The Fachbeirat received a presentation on the scope of the OP 1.1 and OP 1.2 and the corresponding installation activities. While this appears to be appropriate, the Fachbeirat requests a more detailed presentation at its next meeting after the research plan is developed.

In addition, it is now time to establish policies and expectations for how the growing multi-institutional scientific collaboration will work together. This should include establishing policies on analysis and reduction of diagnostic data, sharing and access to data and analysis, and publication processes. The group should consider policies and approaches in use on other large international fusion facilities.

The Fachbeirat is glad to see that the re-alignment of the W7-X technical staff, in preparation for operation and research, is underway and appears to be approximately as planned. There will be substantial change by the end of 2014. Continued coordination of the manpower planning with the evolving Research Plan will be needed, and should be discussed at the next meeting.

While the Fachbeirat congratulates the team for their progress in the last 18 months, it is now especially important to remain fully focused on safety and quality. In particular, installation of the in-vessel components must adhere to the highest safety standards, in parallel with the cryogenic cooling operation while ensuring that all installation work is done with the highest quality.

II.2 W7-X core physics and heating (Division Stellarator Optimisation)

Despite the limited resources available to the Stellarator Optimisation Division, excellent progress in preparation for machine operation has occurred.

The collaboration with Poland is progressing very well in preparing for initial NBI during

OP1.2. Modeling tools are being developed to analyze beam ion orbit losses in various experimental configurations. At the next meeting, the plans for additional wall armor and any anticipated limitations in experimental operation should be presented.

There has been very encouraging progress in forming a collaboration with the Belgian group on a high power ICRF system. The Fachbeirat requests an updated plan to be presented at the next meeting defining when the system will begin to support experimental operation. The results of heating and start-up simulations, including possible minority ion losses, and possible access to ion-heating regimes should be also presented.

There is concern about CODAC systems being on the critical path for first plasma and OP 1.1 experiments. W7-X should consider using existing software systems as an expedient to ensure that the OP1.1 schedule is not impacted.

II.3 W7-X edge and divertor physics (Division Stellarator Edge and Divertor Physics)

The Fachbeirat is impressed with the evolution of this newly created division since the last meeting. Though the division is still developing, it is clearly already playing a major role in the project and dealing with challenging issues. The excellent progress in the Division is noted. The Fachbeirat expects that this division will play a leading role in the initial operation and experiment. Currently, the division is strongly focused on construction issues, in particular related to the strategy for PFC installation and the associated phasing of diagnostics.

Concerning the plasma facing components, the manufacturing of the Test Divertor Unit (TDU) as well as the final actively cooled divertor is still on track. However, due to delay in installation, an additional start up limiter is being designed in accordance with the new schedule strategy described above. The design requirements for this component (to extract 2 MJ) seems consistent with the research goals of phase OP 1.1, but more details on the global research plan are needed, and are requested for the next Fachbeirat meeting. The Fachbeirat notes that the team has reacted efficiently and appropriately to the difficulties encountered during the complex installation process and defined a new timeline optimizing the scientific output of the early phases of exploitation of W7-X.

The coordination of the ongoing work on diagnostics is of particular importance to optimize the scientific output of the first experimental campaigns, now that plasma startup is approaching. Diagnostic coordination is being well addressed by the division, and making steady progress, but it should be further developed in tandem with the research plan mentioned above.

III. The ASDEX-Upgrade Program

III.1 ASDEX-Upgrade: overview and core physics (Division Tokamak Scenario Development)

The ASDEX-Upgrade program is well motivated by and well aligned with ITER needs as well as the EU fusion roadmap. This highly regarded program is making important contributions to both ITER and fusion development. The focus on scenario development is backed by excellent to outstanding research on a wide range of science issues. We urge the ASDEX-Upgrade team to better articulate the complementary nature of these two aspects of their work and to advocate for that approach in the broader fusion community.

The role of ASDEX-Upgrade in the EU roadmap was described and provides a context for future upgrades to the device. As the plan for future upgrades further matures, the Fachbeirat requests a presentation.

A few points on specific topical areas:

The results on ELM suppression and mitigation, especially in combination with those from other machines, point up important gaps in our knowledge. The ASDEX-Upgrade team has correctly identified nonlinear aspects of the ELM cycle as a particularly critical gap. Work in this area on both experiments and modeling should be pursued aggressively.

The connections between transport channels, particularly extending work to particles, impurities and momentum, is vital to improve confidence in extrapolating the core and pedestal scenarios to ITER and this effort should continue.

The team has identified a number of serious shortcomings in the empirical scalings developed for ITER. Research to better characterize the discrepancies and identify potential solutions should be targeted to provide the needed basis to refine the ITER research plans.

The Fachbeirat was impressed by the presentations of two young scientists. Oliver Ford discussed promising work on the development of a two dimensional Imaging Motional Stark Effect (IMSE) system to determine the two dimensional current profile on ASDEX-Upgrade. Particularly striking was the ability to model the diagnostic response and sensitivity ab initio, without the need for an explicit calibration. The next step will be to integrate these results with equilibrium analysis and compare them with a full diagnostic suite. Also impressive was the work described by Tim Happel on advanced fluctuations measurements and gyrokinetic simulations, which is discussed in more detail below.

III.2 ASDEX-Upgrade: plasma edge and material physics (Division Edge and Materials)

This research area covers a huge range of studies from basic plasma turbulence to molecular dynamics of hydrogen within the material lattice. In addition, the research of this division provides a foundation for scenario development of core plasmas. It is clear from reactor studies and the results from various tokamaks (e.g. JET, ASDEX) that the choice of wall material has tremendous effects on the physics of the core plasma and the range of operational space and performance. At the same time all the work in this area is based on the bedrock of basic physics.

The development of power dissipation scenarios, which are applicable to ITER and DEMO, is outstanding. ASDEX-Upgrade is at the forefront of work in the development of seeding regimes applicable to ITER and DEMO. This includes work in development of measurements usable for feedback, modeling for scaling of the physics to higher power and larger machines, and balance of radiated power inside vs. outside the separatrix.

The work on divertor physics is excellent. Several initiatives aimed at advancing our knowledge in this area are progressing well. These include enhancement of resolution in radiation measurements and better analysis of power balance, very strong contributions in modeling (which support the other parts of the program), new measurements of in-out asymmetries in radiation and density.

Studies of the scrape-off heat flux length at the divertor have been excellent in terms of contributions to the worldwide database. The recent efforts at ASDEX-Upgrade to expand the range of data associated with the S parameter, which corresponds to heat loss into the private flux region, is very important. We encourage continued coupling of the work at ASDEX to that being done internationally. Given the strength of the theory division, there is an opportunity, which is encouraged, for increased coupling of the experimental work on radial transport of power to theoretical models (including the pedestal) and to other measurements of basic turbulence. In addition, the divertor measurements of heat flux footprints can be better connected to upstream plasma profiles and characteristics to further advance our understanding of radial energy transport there.

Studies of particle and energy transport in the scrape-off layer have been excellent. The lithium beam diagnostic has been used to investigate scaling of blob size and velocity with a comparison to several existing and new, in-house models. Probes have shown the first systematic broadening of SOL profiles in ASDEX as has been observed elsewhere, which should allow cross-machine comparisons. We suggest further expansion of density limit studies and the relationship of turbulence to steady state profile broadening. The connection to previous results and to similar studies on other machines is strongly encouraged as that is the strongest test of our understanding of the underlying physics.

The work on materials research continues to be excellent. New results were presented on hydrogenic retention in self-damaged tungsten (high-energy atoms of the same species, e.g. tungsten, are used to irradiate the same material, to approximate neutron damage) showing an increase in retention with dpa. Comparison of these results with modeling is necessary and, if possible, the studies should be extended to higher temperatures to contribute to the physics of the annealing of nuclear damage. Experiments on tungsten melting and modeling are excellent and well coupled to results at JET, C-Mod and TEXTOR.

The basic modeling of materials physics (e.g. molecular dynamics modeling) is excellent. That effort has been incorporated into the new numerical methods group, which makes very good sense. The outlined work and support (scientists, programmers, students) is excellent and bodes well for future results in this important area, which is required for further progress in predicting material performance (e.g. tritium retention and material characteristics as a function of nuclear and plasma damage).

The Fachbeirat is pleased with the announcement that a new W2 candidate will join IPP in the materials area. This should supply leadership in this crucial area that has long been an outstanding research and support arm of the IPP. Given the number of changes in personnel allocation to divisions over the last 4-5 years and the concerns expressed by materials research staff on previous Fachbeirat visits we would like, in the next meeting, to receive a presentation on materials research activities and strategy for future work. Such a presentation should make it clear what the goals of IPP materials research will be, what the growth of work in this area will be, the relationship to materials research in the EU, and how the resources within the IPP will be allocated.

There has been excellent work aimed at understanding the L-H transition, with power threshold studies, dependence on density and magnetic perturbations, back transition; they have demonstrated that the radial electric field at the transition is prescribed by the ion pressure and have made comprehensive comparisons of the radial electric field profile to predictions.

The ASDEX-Upgrade group does excellent work in the area of understanding ELMs. The ELM stability results that were presented showed a case where the ELMs occurred below the peeling-ballooning stability boundary. This is in contradiction to published results from several other tokamaks and as such could be very important in giving us insight into the limits of current models. These significant data is a result from a systematic survey over many ELMs combined with outstanding diagnostic resolution (to provide input to the stability analysis). Other presented results suggested a short scale-length resistive instability may be causing these ELMs (that are far from the peeling-ballooning stability boundary). Continued development of the underlying models is encouraged and necessary for future progress.

The Fachbeirat congratulates the group on successful application to the "Helmholtz Virtual Institute" program (with German and foreign partners), on advanced microwave diagnostics and turbulence studies enabling a comprehensive set of core and edge fluctuations measurements (especially reflectometry) that should permit further understanding of turbulence/transport and (gyro-kinetic) code validation.

Tim Happel, a young researcher, gave an excellent talk on "Turbulence Investigations using Microwave Reflectometry on ASDEX Upgrade." dealing with experiment / theory-simulation comparison. A set of experiments were conducted in which the temperature gradients were changed, while monitoring fluctuations levels in different wave number ranges. Local GENE simulations reproduced the radial dependence correctly but not the increase with power. Future plans, which we strongly support, include improved density fluctuation measurements over the whole wavenumber spectrum and simultaneous measurements of temperature fluctuations (and their cross-phase with density fluctuations).

This division continues to provide outstanding support of similar work on JET in a number of areas including divertor physics, tungsten sources, and impurity seeding scenarios (for power dissipation). This is an important role both for advancing the tokamak concept and also for providing some feedback on the applicability of techniques and depth of understanding of physics at ASDEX. It also is important in advancing the ITER-like-Wall (ILW) program at JET and thus support the ITER Project.

IV. ITER Activities (Division ITER Technology and Diagnostics)

The ITER Technology and Diagnostics Division comprises the Neutral Beam Injection (NBI) group and the ITER Diagnostics group. The work in this area is excellent to outstanding and very impressive. The activities comprise the following contributions, which mostly are supported by in the framework with F4E:

- Neutral Beam Injection
- Bolometer diagnostics
- Pressure gauges.

A key element of IPP's work for ITER is the development of the neutral beam source for the negative neutral beam injection (NNBI) project. This is a great technological challenge and the IPP work profits tremendously from the high technology infrastructure at Garching and experience with negative ion neutral beams. The project is proceeding very well and has seen at IPP the development of a large size grid with a Cs-coating facility to efficiently produce H^- beams and a very cost-effective high voltage insulation unit as part of the accelerator stage. The ELISE project, which is a half sized prototype of an ITER source, has demonstrated excellent progress with the first beam plasma source achieved in February and the first beam in March of this year It achieves high currents using high power RF dissociation alone with a potential increase of a factor 10 coming from using the use of cesium.

The project offers much more than technology development as interesting issues in plasma physics connected to e.g. mixed plasma stages as H^+ - H^- or the interaction of the plasma with Cs-vapor can be studied in detail, along with issues related to the high currents and large size of the system.

A very promising technological development is a joint venture with industry concerning semiconductor RF amplifiers, which offer much easier handling and promise longer lifetimes and lower power consumption than the traditional use of amplifying tubes.

In a side project oriented towards DEMO a laser-neutralization system as an alternative to a hydrogen filled gas cell is envisaged in order to boost efficiencies at the last stage of the neutral beam system.

The work on ELISE is done in cooperation with Univ. of Augsburg, and RFX Padova and links to activities from many Asian countries.

The Fachbeirat congratulates the group for the recent achievements. It is ideally placed at this institute, which provides the considerable infrastructures needed to operate ELISE. It is difficult to imagine this work being done elsewhere with such an efficient use of resources and know-how. With its close link to the Univ. of Augsburg it also is an excellent educational opportunity for students and has attracted an A.v. Humboldt fellow.

Other contributions listed below are of much smaller size, both on technological requirements and scientific impact but are progressing very well.

The Bolometer development, for which IPP is awaiting to hear from F4E on its bid, has seen further progress. Detailed tests have been performed inside ASDEX using a robot arm to investigate line-of-sight determination and possible background light sources.

A robust pressure sensor has been developed based on previously used technology. It has been tested over the full pressure range (10^{-4}-20 pascal) and up to magnetic fields of 6T. Further investigations to reach operation at full field of 8T are being undertaken.

V. Theory Program (Divisions: Tokamak Theory, Stellarator Theory and Numerical Methods)

The work on theory is done in three organizational elements, Tokamak and Stellarator Divisions and the newly established Division on Numerical Methods in Plasma Physics. The work is uniformly excellent with many outstanding results. The Fachbeirat notes a special strength in that these three groups are working together on 3-D physics, developing and using common codes, which contributes to the excellent quality of their scientific output.

V.1 Tokamak Theory

The Fachbeirat notes the importance of appointing the new theory tokamak director, which may require a proactive search for external candidates and broadening of the job specification. Karl Lackner (Acting Director) is an outstanding scientist, who is highly respected, but this transition needs to be pursued actively.

The activities of the Tokamak Theory Division cover a wide range of topics.

The Fachbeirat offers their congratulations for their robust gyrokinetic turbulence simulation program, in particular for the advances made on the GENE and ORB5/NEMORB codes. The strong effort made at comparisons and benchmarks with several other gyrokinetic codes, including on cases where previous works indicated strong discrepancies with respect to experimental results is very much appreciated. Several leading edge problems have been addressed, such as impurity transport in the presence of rotation and others involving multiscale simulations. We note that they are progressing towards turbulence-based transport simulations. There is, generally speaking, a good coupling to experiments.

For edge physics, we note that activities are based on the SOLPS code, which appears to be in need of numerical optimization.

Nonlinear MHD activities address important fundamental physical problems (sawtooth crash simulations with a reduced model, ELMs).

We were impressed by the outstanding work on the interaction of fast particles with MHD modes, addressed with appropriate numerical tools.

V.2 Stellarator Theory

Highlights in this Division include the development of two of only four global gyrokinetic turbulence simulation codes in the world applicable to 3D configurations (EUTERPE and GENE). They were the first to perform a detailed comparison of these codes. There is also a strong analytic support to these simulations, as well as a good mix of basic theory (e.g. on electron scale turbulence and tokamak/stellarator cross comparison) and applied research (e.g. exploring operational space for W7-X). They are in the unique position to address crucial questions regarding how stellarators and tokamaks compare with regards to their turbulent transport properties and have already obtained significant results.

There is a good opportunity for this division to apply their tools to 3D tokamak problems. As noted above this is occurring and we urge continued strong interaction between the three theory divisions, including the new Numerical Methods Division.

V.3 Numerical Methods in Plasma Physics

The Fachbeirat was very impressed with the qualifications of the new division leader and in the selection of topics for his group. We applaud this group for coupling strongly with the major theory groups, and for having as their goals either to improve existing codes, or develop new codes in very close collaboration with the end users.

Some encouraging new results were presented on a model problem in handling the collision term in gyrokinetic particle codes such as EUTERPE and ORB5 and the division has taken steps to get this implemented and evaluated in the full production code ORB5.

The group is also involved in work to make the GENE code fully global 3D, to extend GYSELA to arbitrary equilibria, and to improve the reliability of the time implicit method used in JOREK.

Their work on contributing to the physics code library "Selalib" is encouraged, provided that this library is found to be useful to plasma physics researchers at IPP and elsewhere.

This group has only one PhD student at present. They might consider trying to recruit more PhD students in order to pursue the more exploratory "high risk" numerical methods that could potentially have a large impact in our field.

The Fachbeirat encourages the presentation of a strategic plan that has been developed in concert with the Theory Divisions at the next meeting.

VI. DEMO Studies

The Fachbeirat endorses IPP's involvement in the EU DEMO studies and believes that it is very important to continue as well as having their own topical investigations. This limited activity is a valuable input to the IPP research strategy.

The German DEMO activity is focused on the seven elements inside the EU roadmap. IPP contributes by chairing the German Working Group and provides technical contributions in the areas of tokamak and stellarator operation, exhaust of power and particles as well as stellarator specific technologies. They are conducting specific studies in the development of an efficient ECCD scenario, blanket maintenance schemes and the effects of ferritic steel on the magnetic field structure for a stellarator power plant. In addition, there has been good progress in adapting PROCESS systems code to treat both stellarators and tokamaks. The overall assessment of this activity is excellent.

Further work in these areas may include: assessment of TAE activity in the high electron temperature ECCD scenario; identification of an experiment to test the novel ECCD scenario and assessment of the effect of magnetic field leakage from port opening from the ferritic blanket. Identification of opportunities for further innovation to improve the attractiveness of DEMO designs should be encouraged.

The Fachbeirat requests an update on activities in this area at the next meeting including more information on the scope of the effort and applied resources.

VII. Staff

The Fachbeirat was impressed by the quality of the posters presented by the staff and especially by the junior staff members. This indicates that the senior staff is effectively mentoring the junior staff members.

In general, the feedback from the staff at the Institut is very positive, which is recognized to be important for the success of the Institut. The working atmosphere, financial support and intellectual challenge were appraised. Concerns that were expressed are connected with the career advancement scheme, possibilities for permanent positions at the Institut and the hiring of PhD students.

Obviously, owing to their different location and the different age structures such items are perceived very differently at Garching and at Greifswald, where the younger organization has greater opportunities.

- In general the number of PhD positions available at IPP is satisfactory. There is a general tendency with plasma physics being less present at German universities than in the past that recruitment has to be done internationally. Due to the different sizes of the physics departments in Munich and Greifswald, this is a more severe issue at Greifswald. One possible measure to attract strong students is to develop a comprehensive hiring plan for both sites through a joint application procedure similar to IMPRS.
- Some staff members indicated concern about advancement opportunities. IPP has the usual tools to address these concerns; however, a relatively static organization does have limited opportunities.
- Senior staff members are worried about the increase of bureaucratic effort often connected to third party funding, which distracts from the research effort.
- The Fachbeirat heard about improved cooperation of staff at both sites, which in part is motivated by joint technical developments and growing scientific involvement of Garching staff at Greifswald.

The young staff members generally expressed that working conditions are excellent and include opportunities to lead experiments, have good access to computing resources, fair publication strategy, which protects their work, possibility to present their work at a large conference once during the thesis, with good preparation, and possibilities to present their work internally (general meetings or group meetings).

The students identified some concerns about the desirability of closer thesis supervision and have provided the Institut their input. This is being reviewed by the graduate department, which plans on responding to the students.

The hard thesis funding limit of three years now has a possible six month extension, which is actually not encouraged by the Institut but is only granted in appropriately justified cases. The Fachbeirat considers this possibility as a suitable way to resolve an issue, which was raised at the previous Fachbeirat meeting.

Students request that both Ph.D. and postdoctoral positions be better advertised in order to increase their opportunities and ensure competition.

The Max-Planck Institut für Plasmaphysik would like to thank the Fachbeirat very much for all its effort during the recent evaluation. We were very pleased to read the positive report, and would also like to thank the Fachbeirat for its valuable recommendations and advice.

The report contains a number of requests for presentations during the next meeting of the Fachbeirat, which we will of course address. In the following I would like to comment on some questions and problems the Fachbeirat raised.

The Fachbeirat was again very positive on the progress of the **W7-X** assembly, but urges the institute to complete the research plan for first operation phase. We entirely agree with the urgency to develop a more detailed research plan very soon. We will develop such a research plan together with our international partner institutions within the year 2014, in parallel to the commissioning. This plan will be presented during the next meeting of the Fachbeirat.

The Fachbeirat stresses the importance of international collaboration. It asks the institute to establish policies and expectations for such collaborations. The corresponding policies, rules and procedures are under development right now and will be presented during the next meeting of the Fachbeirat. Experiences on ASDEX Upgrade as well as on other large fusion devices (e.g. JET) will be carefully taken into consideration. We will also give the requested report on manpower planning at the next meeting.

IPP is very pleased about the excellent report on the **ASDEX Upgrade** results. In particular, we strongly resonate with the advice to advocate the complementary nature of our research in the broader fusion community. In fact, we often present our results in the light of broader science issues and have already advocated that approach in the community. We will take this point into account for the presentations at the next Fachbeirat meeting.

We are also pleased that we were able to fill the W2 position in **materials research**. We will give the requested presentation on materials research activities and the strategy for future work at the next meeting.

The work of the new **computational physics** division has just started. The division has already identified, together with the plasma theory divisions, key codes that would benefit from major improvements in the numerics, and has started working on these. A strategic plan for the future on this issue will be presented at the next Fachbeirat meeting. It is of course planned to hire more PhD students in this field.

We take the advice to heart to improve the hiring procedure for our PhD students. In fact, within the IPP graduate school HEPP, a common hiring platform has already been created and with the re-launch of the IPP internet presence in 2014 the entry to this platform will be located at a more prominent position.

On the question of how close the supervision of PhD theses should be, we are in discussion with our PhD students. All our PhD students are members of the HEPP graduate school, many are also members of the graduate schools of their degree awarding university, and some are also member of international graduate schools. In each graduate school there exist supervision guidelines, which the supervisors adhere to. We consider these guidelines as appropriate, with the right balance between close supervision and scientific freedom of our PhD students.