

## Implementing Agreement for Cooperation in Development of the Stellarator Concept

### 2006 Executive Committee Annual Report to the Fusion Power Coordination Committee

January 2007

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## **EXECUTIVE SUMMARY**

The present report overviews the scientific and technical progress achieved in 2006 by the parties to the Stellarator Concept Implementing Agreement, who have greatly benefit from its international collaborative framework. The document reports the collaborations in 2006 and the parties' research plans for 2007, including technical reports on 2006 activities.

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# 1 AUSTRALIA

## 1.1 International collaborations in 2006

1) The contract for the operation of the National Plasma Fusion Research Facility has been extended until 2010 under existing funding. The centrepiece is the flexible heliac H-1NF which is used for fundamental experiments in magnetic configuration topology, instabilities, turbulence, flows and confinement transitions at moderate heating power, and the development of imaging spectroscopy and microwave diagnostics for broader use in the fusion program. The H-1NF heliac is able to access L-H confinement transitions at very low power (<100 kW) and can be used to study configuration effects on confinement with very rapid turnaround.

2) M. Shats and his group in the heliac have demonstrated the role of zonal flows, spectral condensation and self-organisation in regulating the outward transport of particles and achieving enhanced plasma confinement. Collaboration with NIFS in this area is ongoing.

3) MHD and configuration studies have led to two collaborations: A large volume of data on Alfvén range instabilities in H-1 has been gathered following the installation of a second 20 coil poloidal Mirnov array, and extensive computer controlled configuration scans. An innovative data mining technique has been developed to classify the vast data set into a small number of clusters representing distinct phenomena.

- This technique has been successfully applied to the new poloidal array data from Heliotron-J, during a visit by B. Blackwell in 2006, through a collaboration on a comparative study of the phenomena in both machines.
- A collaboration between C. Nührenberg of MPIPP Greifswald, B. McMillan of CRPP Lausanne, R. Dewar and M. Hole of the ANU Department of Theoretical Physics, and B. Blackwell and J. Howard aims to compare the experimental observations of MHD activity with eigenvalue calculations using the CAS3D code performed on a sequence of VMEC equilibria describing H-1NF configurations.

4) There are a number of collaborations in the plasma diagnostics, in particular in the area of optical spectroscopy. One-dimensional modulated coherence imaging systems (J. Howard) have now been operating successfully on H-1 for some years, and have revealed a range of new physical phenomena in low-field discharges. A significant conceptual breakthrough realised a completely passive 4-quadrant optical system for 2-d coherence imaging with high time resolution. This space-multiplex approach allows instantaneous snapshots of plasma transient phenomena to be obtained. The systems and their derivatives have underpinned a number of international collaborations.

- An Australian government-funded collaboration between the ANU, Consorzio RFX and IPP-Greifswald has seen the installation of coherence imaging systems on RFX and WEGA stellarator, with experiments also planned for the ASDEX divertor. The systems have the unique capability to obtain high speed two-dimensional images of plasma flows and temperatures (or other

spectroscopically derived quantities) and so are well suited for the study of asymmetric radiating plasma regions.

- A system intended for the Korean KSTAR tokamak was tested on the Hanbit device in 2006 and will be installed for MSE and CXRS on KSTAR in 2008.
- Birefringent filters are being constructed for Thomson scattering on JT-60U in a collaboration with T Hatae from JAEA. First trials of the filters will be undertaken on TPX-RE reversed field pinch in March 2007.
- A collaboration between B. James (Sydney University), K. Takiyama (Hiroshima), and J. Howard (ANU) has resulted in the production of a very successful highly directional pulsed supersonic beam. In conjunction with dual photomultiplier array, this provides non-perturbing, spatially localised, time resolved measurements of electron temperature and density.

5) The Australian heliac program at the ANU has produced several technological spin-offs that are now attracting support independent of the fusion program. These include technology for long distance, non-line-of-sight VHF digital wireless communications in rural Australia (the BushLAN project), and infrared coherence imaging spectroscopy systems for use in defence remote sensing and process control in steel production. For example, a variant of the 4-quadrant solid state spectrometer described above was successfully trialled at Bluescope Steel mills in 2006. The new system promises to be able to provide accurate surface-temperature estimates without the need for emissivity or emissivity-slope corrections.

#### - Theoretical collaborations

1) A collaboration between ANU (R. Dewar), MPIPP Greifswald (C. Nührenberg) and University of Maryland (T. Tatsuno) on the spacing statistics of eigenvalues produced with the CAS3D code has continued.

2) A collaboration between ANU (R. Dewar and M. Hole) and Princeton PPL (S. Hudson) has continued investigation of a new formulation of the 3-D MHD stability problem with the aim of developing better equilibrium codes for stellarators, with possible applications to electron transport barrier studies. R. Dewar briefly visited PPPL in 2006.

3) E. Solano of CIEMAT visited ANU for 11 weeks to work on singularity theory applied to toroidal equilibria.

4) Other collaborations on fusion theory between ANU theorists and Culham, MPIPP Garching, the University of Texas, and Polytechnico Turin have possible stellarator applications.

Finally, a group of about 100 Australian Scientists and Engineers, the Australian ITER Forum, have been promoting the ITER project locally, culminating in a successful workshop in Sydney in October, to exploring ways in which Australia might participate in this exciting project.



## **1.2 Research plans for 2007**

1) Experiments on the H-1NF heliac in the next years will extend studies of turbulence, flows and self organization, and extend magnetic configuration studies of instabilities driven by fast particles from ICRF and ECR heating.

2) Configuration studies will focus on the effects of Alfvén-driven instabilities and turbulence which can be moderated through fine control of the H-1 magnetic configuration. Plasma density and polarimetry interferometers will provide profile information for configuration studies and mode structure of Alfvénic instabilities. Mapping of magnetic Islands and observation of their effect on plasma will be made by a combination of electron beam mapping and optical and probe plasma diagnostics.

3) Combined with fast, gated CCD cameras, the newly developed passive 4-quadrant optical coherence imaging systems will be used to study rf-phase resolved evolution of the particle velocity distribution functions in low field H-1 plasma discharges. A new absolutely calibrated supersonic gas injector designed for fuelling studies will be used in conjunction with the recently upgraded tomographic plasma interferometer and imaging spectroscopy systems to characterise particle transport.

### **- Theoretical research plans**

1) Further development of the new MHD equilibrium formulation will be carried out.

2) A comparison between the modulational stability theory of zonal flow generation and observations on H-1NF in H-mode will be continued.

3) Comparisons between numerical simulations and low-dimensional models of confinement transitions will be continued.

## **2 EU**

### **2.1 GERMANY**

#### **2.1.1 International collaborations in 2006**

##### **- Collaborations with EU**

1) P. McNeely, T. Richert (IPP Greifswald) to FZ Jülich, February 2006, Development and construction of a diagnostic high energy neutral particle injector, coordination meeting with collaboration partners FZJ and Budker Institute of Nuclear Physics Novosibirsk

2) Leszek Ryc (IPPLMF Warsaw) to IPP Greifswald, 13.03.–15.03.2006, Cooperation X-ray pulse height analysis diagnostics for W7-X

3) M. Hirsch, H. Hartfuss, N. Marushchenko to Szczecin, 19.–20.04.2006, Development of analysis methods for polarimetry in W7-X, establish cooperation

- 4) H. P. Laqua (IPP Greifswald) to EPFL-Lausanne, 26.–28.04.2006, Experimental investigation on electron Bernstein wave heating
- 5) N. Marushchenko visited Maritime University, Szczecin, Poland, 19.04.–20.04.2006, Microwave plasma diagnostics
- 6) Jürgen Nührenberg (IPP Greifswald) to EPFL Lausanne, 26.06.–30.06.2006, Integrated optimization of stellarators
- 7) Sergey Kasilov (TU Graz) to IPP, 15.07.–16.08.2006, Studies of kinetic plasma model for the 3D edge plasma balance code
- 8) M. Rome' (University of Milan) to IPP-Greifswald, 17.07.–14.08.2006, Particle balance analysis for W7-AS
- 9) B. Seiwald (TU Graz) to IPP Greifswald, 07.08.–01.09.2006, Implementation of the codes NEO (neoclassical transport coefficients) and SORSSA (optimisation of stellarator configurations with respect to neoclassical properties)
- 10) M. Sanchez (CIEMAT) to IPP Greifswald, 09.–13.10.2006, Development of a multichannel CO<sub>2</sub>-Interferometer for W7-X
- 11) Marek Scholz, Lesław Karpinski, Krzysztof Pytel, Krzysztof Drozdowicz (IPPLMF Warsaw) to IPP Greifswald, 9.10.–11.10.2006, Cooperation neutron diagnostics for W7-X
- 12) Roman Zagorski (IPPLMF Warsaw) to IPP Greifswald, 12.11.–22.12.2006, Plasma edge modelling for ergodic configurations
- 13) Włodzimierz Stiepniewski (IPPLMF Warsaw) to IPP Greifswald, 12.11.–26.11.2006, Plasma edge modelling for ergodic configurations
- 14) J. Preinhaelter, J. Urban (Academy of Sciences of the Czech Republic) to IPP Greifswald, 20.11.–1.12.2006, Ray-tracing calculation for electron Bernstein wave heating at the Wega Stellarator
- 15) B. Bieg (Szczecin University of Technology) to IPP Greifswald, 28.–29.11.2006, Quasi isotropic approximation for polarimetry analysis
- 16) David Tskhakaya (Uni Innsbruck) to IPP Greifswald, 17.09.–30.09.2006 and 10.12.–23.12.2006, Plasma edge modelling with PIC
- 17) B. Schweer, H.-T. Lambertz (FZ Jülich) to IPP Greifswald, November 2006, Kick Off Meeting for Development of control system for diagnostic injector W7-X
- 18) Ireneusz Książek (Opole University) to IPP-Garching (1 week), Development of a C-, O-Monitor system for W7-X
- 19) R. Preuss to U-Stuttgart (1 week), Scaling studies
- 20) Wolfgang Biel (FZ-Juelich) to IPP Greifswald for 1 week, Design review of VUV

spectrometer system HEXOS for W7-X

21)A. Dinklage to FZ Juelich/FOM (1 week), Workshop organization

22)S. Zoletnik, G. Kocsis, A. Molnar, S. Recsei,(KFKI-RMKI Budapest) to IPP Greifswald, several visits of 1-2 weeks duration, Design of the W7-X video diagnostic

23)R. König, (IPP Greifswald), to FZ-Jülich, regular exchange and visits: Design of a thermal He-beam diagnostic

24)R. König, U. Neuner, (IPP Greifswald) to KFKI Budapest, Hungary, regular exchange: Design of the W7-X video diagnostic

25)WEGA: "Electron Cyclotron Waves Heating Experiments" with CIEMAT, Regular exchange, via Video

26)Daihong Zhang and WEGA team (IPP Greifswald), with Paris-sud university, information exchange per e-mail, application of collisional-radiative models to diagnostics at the WEGA Stellarator

27)Rainer Burhenn (IPP Greifswald) with Wolfgang Biel (FZ-Juelich), Development and test of a VUV spectrometer system for W7-X, regular communication

28)WUT (Uni Warschau) to IPP Greifswald (Victor Bykov), 20.12.2006– ..., Additional structural analyses for W7-X according to Task Agreement N°1 dated 20.04.2005

29)WUT to IPP Greifswald (Victor Bykov, Wolfgang Dänner), 02.11.2006– ..., Parametric FE model ( creation of module A-C and testing and verification)

30)Visits to IPP Greifswald: A. Capriccioli (ENEA) from 03.12.–15.12.2006, from 01.08.2006-03.08.2006

31)WUT to IPP Greifswald (Andrzej Dudek), 18.12.2006– ..., Modifications to the "Triple Connection FE Submodel" (NPC2Z2+NPC3Z2+NPC4Z2)

32)WUT to IPP Greifswald (Victor Bykov, Wolfgang Dänner), 27.12.2005–31.12.2006, Detailed finite element analysis of critical central support elements of the W7-X Coil support system

33)ENEA to IPP Greifswald (Victor Bykov, Andrey Tereshchenko) Oct.2005–31.12.2006, Global model of OV+PV+MB

34)BAM (Bundesanstalt für Materialforschung, Adlershof, Berlin) to IPP Greifswald (Michael Laux), 12.12.–31.12.2006, 10 h Laser-Profilometrie

35)BAM to IPP Greifswald (Johann Lingertat), 24.11.–12.12.2006, 10 h Laser-Profilometrie

36)BAM to IPP Greifswald (Michael Laux), 19.10.–24.11.2006, 10 h Laser-Profilometrie

37)BAM to IPP Greifswald (Johann Lingertat), 17.10.2007–2007, Tribological tests on

## NSE for W7-X

- 38) ENEA to IPP Greifswald (Johann Lingertat), 19.08.2005–31.12.2006, Design of lateral support connections between adjacent non-planar coils of W7-X according to the technical specification
- 39) KRP to IPP Greifswald (Johann Lingertat), 11.10.2006– ..., Execution of friction tests 2U, 2V and 2W
- 40) KRP to IPP Greifswald (Johann Lingertat), 07.06.2006– ..., Mechanical test of bolted connection between W7-X coils and central ring strain gauges on 3 segments
- 41) Collaboration with CIEMAT on quality control of the manufacture of the support structure for W7-X by Spanish industry. D. Pilopp (IPP), A. Cardella (IPP/EC)
- 42) Collaboration of CIEMAT with IPP on the design of components for the W7-X cryostat (P. S. Sanchez/CIEMAT at IPP from 19.04.2006 till 18.04.2008)
- 43) Collaboration with CEA-Saclay on the testing of superconducting coils for W7-X. Mobility is granted for the IPP members J. Baldzuhn, H. Ehmler, A. Hölting, K. Hertel
- 44) Collaboration with CEA-Cadarache on the testing of divertor target elements in the SATIR facility (J. Boscary/IPP)
- 45) Collaboration of CEA with IPP on the support of the design of cryocomponents (Guerrini, since 01.06.2005), the back office (Baylard) and metrology (Poncet)
- 46) Collaboration of CEA with IPP on the design of the cryostat (Chauvin)
- 47) Training programmes Members of the European training scheme (Tomarchio magnet fabrication, Croari magnet testing)
- 48) Support by EC experts to the construction of the superconducting coils for W7-X (C. Sborchia), the design of the cryostat (A. Cardella) and the design of the in vessel components (R. Tivey, A. Peacock)

### - Collaborations with Japan

- 1) Y. Suzuki (NIFS) to IPP Greifswald, 10.10.2005–30.03.2006, i.e. 3 months in 2006, Implementation of HINT2 and benchmark of 3D-MHD equilibrium codes
- 2) Masaki Osakabe from NIFS, 19.03.–21.03.2006, W7-AS NB-blib analysis and code development for W7-X and LHD
- 3) Könies visited Takayama at NIFS, Japan from 07.11.–20.11.2005, IAEA TM on energetic particles in magnetic confinement systems and co-operation with NIFS on MHD stability of stellarator and helical plasmas with energetic ions
- 4) Masaki Osakabe (NIFS LHD Toki), to IPP Greifswald, 20.03.–21.03.2006, Cooperation on energetic ion and neutron physics

- 5) Y. Igitkhanov visits NIFS at Toki, Japan from 17.04.2006–17.04.2007
- 6) Masayuki Yokoyama from NIFS Japan, 26.6.–14.7.2006, Collaboration on international stellarator profile DataBase (CERC physics)
- 7) H.-J. Hartfuß visited Sendai, Japan, 02.09.–09.09.2006 for the ITPA Diagnostics Meeting
- 8) C. Beidler, H. Maaßberg and Y. Turkin visited NIFS/University of Kyoto, Japan from 15.09.–30.09.2006, IEA Implementing Agreement on Stellarator Cooperation
- 9) Y. Feng visits NIFS at Toki, Japan from 19.09.–23.12.2006, Numerical studies of plasma, impurity and neutral transport properties in the stochastic layer of LHD
- 10) R. Schneider visited Yokohama/Kyushu, 04.10.–17.10.2006, Collaboration with Keio University Yokohama, A. Hatayama/Lecture at Kyushu University
- 11) Yasuhiro Suzuki (NIFS), to IPP Greifswald, 10.10.2005–31.03.2006, 3D MHD equilibrium code benchmarking
- 12) D. Zhang visited NIFS at Toki, Japan from 20.10.–31.10.2006, Cooperation on bolometry diagnostic development
- 13) F. Wagner visited NIFS/Kyushu University, Japan, 03.11.–18.11.2006, Lectures
- 14) N. Marushchenko visited NIFS, 11.12.–15.12.2006, ECRH modelling at LHD
- 15) N. Marushchenko visited Kyoto University, Japan, 18.12.–22.12.2006, ECCD calculations at Heliotron-J
- 16) R. Preuss to U-Kyoto(1 week), Scaling studies, preparation of profile database
- 17) R. Preuss to NIFS (1 week), Scaling studies, preparation of profile database

**- Collaborations with Russia**

- 1) Efremov to IPP Greifswald (Victor Bykov), 04.07.2005–31.12.2006, Attachment No.1, Finite element analysis support for the W7-X magnet and coil support system
- 2) Alexey Subbotin (Kurchatov Moscow) to IPP Greifswald, 29.01.–26.02.2006, Investigations on ballooning modes in stellarators
- 3) Michael Petelin and Dimitri Shchegolov from IAP Nishny Novgorod, 08.02.–11.02.2006, FADIS design review
- 4) A. Subbotin from Kurchatov Institute Moscow, 29.01.–26.02.2006, Magnetic field coils for optimized stellarators with high  $\beta$
- 5) Efremov to IPP Greifswald (Victor Bykov), 16.02.2006–June.2007, Attachment No.3, Finite element analysis support for the W7-X magnet and coil support system
- 6) N. Marushchenko visited IAP RAS, Nizhny Novgorod, Russia, 10.07.–15.07.2006,

## Benchmark of the ray tracing in the hot plasmas

7) Michael Tinov (Budker-Institute of Plasma Physics Novosibirsk), to IPP Greifswald, 14.03.–28.03.2006, Calculations for the influence of magnetic fields on the diagnostic injector and influence of bending magnets on the W7-X magnetic field, calculation of ion trajectories inside the diagnostic injector

8) Alexander Shalashov from Institute for Applied Physics, Russian Academy of Science, 04.05.–7.8.2006, Investigations on the joint research fellowship project Kinetic effects under the strong electron plasma heating in controlled nuclear fusion devices with magnetic confinement.

9) Mikhail Mikhailov from Kurchatov Institute Moscow, Russia, 20.5.–18.6.2006 and 24.09.–22.10.2006, Stellarator concepts

10) Visits to IPP Greifswald: A. Alexeev (Efremov) from 21.05.–27.05.2006, from 12.11.–19.11.2006

11) Visits to IPP Greifswald: A. Labusov (Efremov) from 14.05.–28.05.2006, from 05.11.–19.11.06

12) Visits to IPP Greifswald: A. Mikhaylov (Efremov) from 21.06.–24.06.2006

13) P. McNeely, T. Richert (IPP Greifswald) to Budker-Institute of Plasma Physics (BINP), Novosibirsk, Russia, 02.–07.07.2006, Development and construction of a diagnostic high energy neutral particle injector, Kick Off Meeting

14) N. Marushchenko visited Nizhny Novgorod, 02.07.–15.07.2006, Ray-tracing code benchmarking

15) M. Yu. Isaev (KIAE) to IPP Greifswald, 19.11.–17.12.2006, Benchmarking of the bootstrap current coefficient by numerical and analytical approaches

16) Rainer Burhenn (IPP Greifswald) with V. Yu. Sergeev (Technical University Applied Physics Ltd., Modelling of impurity pellet experiments at W7-AS, regular communication

17) Efremov to IPP Greifswald (Victor Bykov), 18.12.06– ..., Modification to the “Triple Connection FE Submodel” (NPC2Z2+NPC3Z2+NPC4Z2)

## - Collaborations with Ukraine

1) Alexander Zhezhera from IPP Kharkov / Ukraine, 13.02.–30.03.2006, Setup and test of HIBP diagnostic, optimisation of primary beam source and beam geometry in HIBP

2) Ludmilla Krupnik and Galina Deshko from Kharkov Institute, 27.03.–04.04.2006, Setup and test of HIBP diagnostic, optimisation of primary beam source and beam geometry in HIBP

3) Alexander Zhezhera and Oleksandr Kosachok from IPP Kharkov, Ukraine, 24.6.–18.7.2006, Installation and initial operation of a Heavy Ion Beam Probe

measurement system on the WEGA stellarator

4) S. Kasilov from Kharkov National University, Ukraine, 15.7.–16.8.2006

5) Alexander Zhezhera and Oleksandr Komarov from IPP Kharkov, Ukraine, 04.10.–30.10.2006, Installation and initial operation of a Heavy Ion Beam Probe measurement system on the WEGA stellarator

6) Yaroslav I. Kolesnichenko, Yuriy Yakovenko, Vadym Lutsenko (INP, STCU, Kiev), to IPP Greifswald, 28.10. –26.11.2006 (Yakovenko, Lutsenko), Cooperation on energetic ion destabilised Alfvén instabilities, energetic ion confinement in Wendelstein stellarators

7) Bizyukov from Kharkov National University, 05.11.–26.11.2006, Scientific collaboration

#### - Collaborations with USA

1) V. Decyk, J. Tonge and D. Dauger from UCLA, USA, 13.11.–21.11.2005, Modern Code Optimization Strategies

2) R. Schneider visited the Santa. Barbara/Emory University, Atlanta from 02.12.–15.12.2005, ICFRM/ Global Potential Energy Surfaces for Hydrocarbons

3) A.R. Sharma visited the Emory University, Atlanta from 20.11.–16.12.2005, Global Potential Energy Surfaces for Hydrocarbons

4) B. Braams from Emory University Atlanta, USA, 26.6.–30.6.2006. Potential energy surface for general hydro-carbons, Modelling of the edge and plasma-wall-interaction

5) Bas Braams (Emory University Atlanta) to IPP Greifswald, 26.06. –30.06.2006, Modelling of the edge and plasma-wall-interaction

6) Michael Zarnstorff from PPPL Princeton USA, 26.6.–5.7.2006, Progress in NCSX construction and plans for magnetic alignment of the coils

7) Alan Reiman, Michael Zarnstorff (PPPL, Princeton), to IPP Greifswald, 24.06.-5.07.2006, Study of beta induced equilibrium limit in stellarators

8) Allan Reiman from PPPL Princeton, USA, 28.6. – 6.7.2006, Equilibrium Flux Surface Calculations for the W7AS and NCSX

9) Jim Lyon (ORNL, Oak Ridge) to IPP Greifswald, 29.06–30.06.2006, Relation between US stellarator programme and W7-X, stellarator reactor issues

10) Stuart Hudson (Princeton) to IPP Greifswald, 07.07.–21.07.2006, Perturbed plasma equilibria and CAS3D transfer

11) Richard Sydora from University of Alberta, Canada, 16.07.–06.08.2006 and 16.09.–24.09.2006, Gyrokinetics

12) R. Schneider and A.R. Sharma visited the Santa Barbara/Emory University, Atlanta from 02.12.–15.12.2005 working on Global Potential Energy Surfaces for Hydrocarbons

13) R. Schneider visited Knoxville, USA, 13.05.–16.05.2006 for DAMOP/APS

14) Arthur Weller (IPP Greifswald), to PPPL, Princeton, Auburn University, 8.11.–15.11.2006, NCSX programme, equilibrium and stability of W7-AS high-beta configurations, diagnostics discussions (PPPL), CTH programme & X-ray tomography (Auburn)

15) R. Boivin (General Atomics), diagnostic developments at DIII-D, review/audit

#### - Collaborations with Australia

Daniel Andruczyk from University Sydney, 06.09.2006–06.01.2007, Preparation of the development of a new diagnostic to measure the electrical field at WEGA

#### 2.1.2 Conference participation

1) G. Kühner, Software Engineering, 28.03.–31.03.2006, Leipzig, Germany

2) Rainer Burhenn, Andreas Dinklage, Ralf König, Petra Kornejew, Ekkehard Pasch and Andreas Werner, Conference on High Temperature Plasma Diagnostics, 07.05.–11.05.2006, Williamsburg, VA, USA

3) V. Erckmann, H.P. Laqua, N. B. Marushchenko, 14th Joint Workshop on Electron Cyclotron Emission and Electron Cyclotron Heating, Santorini Island, 09.05.–12.05.2006, Greece

4) Ralf Schneider (IPP Greifswald), to Knoxville/Tennessee, 13.05.–18.05.2006, APS DAMOP

5) R. Haange, Jahrestagung Kerntechnik, 16.05.–18.05.2006, Aachen, Germany

6) Yühe Feng, Dieter Hildebrandt, K. Matyash, Francesco Sardei and R. Schneider, U. Wenzel, 17th Plasma Surface Interactions in Controlled Fusion Devices, 22.05.–26.05.2006, Hefei, China

7) A. Dinklage, D. Dodt, H. Dreier, J. Geiger, R. Preuss, G. Kühner, A. Werner, Data Validation Workshop, 29.05.–31.05.2006, Jülich, Germany

8) M. Drevlak, J. Geiger, G. Kervalishvili, T. Klinger, C. Nührenberg, J. Nührenberg, Y. Turkin, G. Warr, 33rd EPS Conference on Plasma Physics, 19.06.–23.06.2006, Rome, Italy

9) Harald Braune and Heinrich Laqua, German-Russian Workshop on ECRH and Gyrotrons, 19.06.–27.06.2006, Nizhny Novgorod

10) R. Preuss, D. Dodt, MaxEnt, 09.07.–13.07.2006, Paris, France



- 11) C. Sborchia, Applied Superconductor Conference, 27.08.–01.09.2006, Seattle, USA
- 12) D. Eremin, R. Kleiber, A. Könies, J. Nührenberg, to Varenna, 27.08.–01.09.2006, Joint Varenna – Lausanne International Workshop Theory of Fusion Plasmas
- 13) A. Kus, COMPSTAT, 28.08 - 01.09.2006, Rome, Italy
- 14) Ralf Schneider (IPP Greifswald), to Krakow/Poland, 11.09.–14.09.2007, Workshop on Edge Transport in Fusion Plasmas
- 15) H. Braune, D. Birus, J. Boscary, T. Bräuer, V. Bykov, A. Cardella, C. Damiani, A. Dudek, K. Egorov, H. Ehmler, J.-H. Feist, F. Füllenbach, D. Pilopp, J. Schacht, D. Hartmann, F. Hurd, M. Köppen, T. Koppe, H. Laqua, B. Petersen-Zarling, J. Reich, K. Rummel, F. Schauer, M. Schröder, M. Wanner, SOFT, 11.09.–15.09.2006, Warsaw, Poland
- 16) F. Wagner, 11<sup>th</sup> Int. Conference on Plasma Physics and Controlled Fusion, 11.09.–16.09.2006, Alushta
- 17) Georg Michel, IRMMW-THz, 18.09.–22.09.2006, Shanghai, China
- 18) Andreas Werner, 21<sup>st</sup> IAEA Fusion Energy Conference, 16.10.–21.10.2006, Chengdu, China
- 19) J. Nührenberg, A. Weller, European Fusion Physics Workshop, 03.12.–04.12.2006, Greoux-Les-Bains, France
- 20) R. König, N. Marushchenko, Toki Conference on Advanced Imaging and Plasma Diagnostics, 05.12.–08.12.2006, Toki, Japan

### 2.1.3 Participation in joint projects

#### - International Stellarator Confinement Data Base

Contributions from C.D. Beidler, A. Dinklage, A. Kus, H. Maaßberg, R. Preuss, Yu. Turkin, A. Weller, A. Werner (IPP Greifswald).

#### - International Stellarator Profile Data Base

Contributions from C.D. Beidler, A. Dinklage, H. Maaßberg, R. Preuss, Yu. Turkin.

#### - International H-Mode Confinement Data Base

Contributions from A. Kus

#### - International Design Review on W7-X Diagnostics

Reviewers: R. Boivin (GA, San Diego, USA), R. Barnsley (ITER/UKAEA, Culham, UK), J. Howard (ANU, Canberra, Australia), D. Johnson (PPPL, Princeton, USA), P. Martin (ENEA-EURATOM Consorzio RFX, Padova, Italy), W. Morris (UKAEA, Culham, UK), J. Neuhauser (IPP, ASDEX Upgrade team, Garching, Germany), G. Vayakis (ITER, Cadarache, France), C. Walker (ITER, Garching, Germany), S. Zoletnik (Association

EURATOM/HAS, Budapest, Hungary)

#### **2.1.4 Planning 2007**

##### **- Planning Stellarator Theory**

The planning for 2007 has not yet been detailed but the collaborations will comprise a similar extent with many of the researchers of the above list.

##### **- Diagnostic Developments**

1) T. Richert (IPP Greifswald), plans to visit the FZ-Jülich and the Budker Institute (BINP) in Novosibirsk, Russia to continue the collaboration on the development and construction of a diagnostic high energy neutral particle injector.

2) R. König, U. Neuner (IPP Greifswald) plan to visit KFKI Budapest, Hungary, to continue the design of the W7-X video diagnostic.

3) S. Zoletnik, G. Kocsis, A. Molnar, S. Recsei, A. Szappanos (KFKI-RMKI Budapest), plan several visits to IPP Greifswald of 1 week duration to continue the design of the W7-X video diagnostic.

4) Rainer Burhenn (IPP Greifswald) with Wolfgang Biel (FZ-Juelich), Development and test of the VUV spectrometer system HEXOS for W7-X, regular communication, several visits of 1 week duration in each direction planned.

5) Rainer Burhenn (IPP Greifswald) with Ireneusz Ksiazek (Institute of Physics, Opole University Poland, via Institute of Plasma Physics and Laser Microfusion (IPPLM) Poland), Development of a C-, O-Monitor System for W7-X, regular communication, several visits of 1 week duration in each direction planned.

##### **- Neutral Particle Diagnostics**

1) W. Schneider will visit the Culham Science Centre for 4 weeks for testing a compact neutral particle analyser and comparison of results with MAST neutral particle diagnostics. Further he will take part in the operation of an ACORD-24 analyser at TJ-II for about one month including the test of a new detection of scaler systems.

2) The development and construction of a diagnostic high energy neutral particle injector in collaboration with the FZ-Jülich and the Budker Institute (BINP) in Novosibirsk, Russia, will continue. Test of high voltage power supply is planned. Design of injector components will be closed.

##### **- Microwave Diagnostics**

1) P. Kornejew will visit interferometer devices at LHD (NIFS, Toki) and JT-60U (JAERI, Naka) on occasion of the workshop on laser aided diagnostics

2) M. Hirsch will visit TJ-II (CIEMAT, Madrid), Microwave diagnostic development, Comparison of ELM behaviour in W7-AS and TJ-II

3) Regular meetings with cooperation partners at Akademia Morska, Szczecin (MUS) and Szczecin University of Technology (SUT) are planned, about twice per year, Analysis of Microwave Propagation and Polarization effects in an inhomogeneous plasma aiming on the analysis of polarimetry in W7-X

4) P. Kornejew will visit the interferometer at TJ-II (CIEMAT), Cooperation contract on "Development and construction of a multichannel CO<sub>2</sub>-Interferometer for W7-X"

5) P. Kornejew will visit TEXTOR (Jülich), Dispersion interferometry as an option for W7-X

**- International Stellarator Profile Data Base**

1) R. Preuss (IPP Greifswald) plans to visit CIEMAT for scaling studies

2) R. Preuss (IPP Greifswald) plans to visit NIFS for implementation of the profile data base

3) Contributions from C.D. Beidler, A. Dinklage H. Maaßberg, R. Preuss, Yu. Turkin. Planning 2006

**- International Stellarator Profile Data Base and International Collaboration on Neoclassical Transport**

1) Topical Group Workshop

2) A. Kus plans to visit NIFS for data base implementation

3) C.D. Beidler, H. Maassberg, Yu. Turkin (IPP Greifswald) will visit NIFS/U-Kyoto, IEA implementing agreement topics and stellarator transport code development.

**- EMC3-EIRENE code for edge plasma modelling**

Y. Feng (IPP Greifswald), F. Sardei (IPP Garching) will visit NIFS: edge physics modelling

**- Collaboration on ECRH, ECCD and ECE**

1) H. Laqua (IPP Greifswald) to TCV-EPFL Lausanne (CH), 29.-30.1.07: Experiments for central power deposition with electron Bernstein waves

2) H. Laqua (IPP Greifswald) to TJ-2 Ciemat (Spain) 1 week: Initial experiments on 28 GHz heating at TJ-2

3) H. Laqua (IPP Greifswald) to IPP/CR., 1 week: interpretation of 3-dimensional ray-tracing calculation for Bernstein waves at Wega.

**- International Collaboration on Data Validation**

Preparation of VALIDATION 5 with UKAEA Implementation of the HINT equilibrium code

- **VALIDATION workshop**

A. Dinklage is going to visit JET for joint organization of the workshop  
participation

- **Conference participation**

- 1) G. Kühner, Software Engineering, 27.03. – 30.03.2007, Hamburg, Germany
- 2) J. Schacht, IEEE NPSS 15<sup>th</sup> Real Time Conference, 29.04. – 04.05.2007, Fermilab, Batavia, Illinois, USA
- 3) V. Erckmann 17<sup>th</sup> Topical Conference on Radio Frequency Power in Plasmas, 07.05. – 09.05.2007, Clearwater, Florida, USA
- 4) M.Schröder, DGZfP-Jahrestagung, 14.05. – 16.05.2007, Fürth, Germany
- 5) S. Bosch, R. König, H. Viebke, M. Wanner, 5th IAEA Technical Meeting on Steady State Operations of Magnetic Fusion Devices, 14.05. – 17.05.2007, Daejeon, Republic of Korea
- 6) R. Vilbrandt, L. Wegener, Jahrestagung Kerntechnik, 22.05. – 24.05.2007, Stadthalle Karlsruhe
- 7) G. Croari, V. Tomarchio, T. Rajna, International Youth Conference on Energetics, 31.05. – 02.06.2007, Budapest, Hungary
- 8) J. Schacht, G. Kühner, 6<sup>th</sup> IAEA Technical Meeting on Control, Data Acquisition, and Remote Participation for Fusion Research, 04.06. – 08.06.2007, Inuyama, Japan
- 9) T. Richert, J. Reich, V. Bykov, P. v.Eeten, F. Hurd, 26<sup>th</sup> Symposium on Fusion Engineering (SOFE), 18.06. – 22.06.2007, Albuquerque, New Mexico, USA
- 10) J.-H. Feist, H. P. Laqua, M. Otte, R. Preuss, H. Thomson, Y. Turkin, A. Weller, D. Zhang, 34th EPS Conference on Plasma Physics, 02.07. – 06.07.2007, Warsaw, Poland
- 11) D. Dodt, MaxEnt (27<sup>th</sup> International Workshop on Bayesian Inference and Maximum Entropy...), 08.07. – 13.07.2007, Saratoga Springs, New York, USA
- 12) C. P. Dhard, R. Haange, M. Nagel, Cryogenic Engineering Conference 2007 (CEC), 16.07. – 20.07.2007, Chattanooga, Tennessee, USA
- 13) M. Laux, S. Marsen, VII IWEP Int. WS on Electrical Probes, 22.07. – 25.07.2007, Prague, Czech Republic
- 14) J. Baldzuhn, K. Riße, T. Mönnich, MT-20 Conference on Magnet Technology, 27.08. – 31.08.2007, Philadelphia, Pennsylvania
- 15) H. Braune, IRMMW-THz 2007, 02.09. – 07.09.2007, Cardiff, UK

- 16)H. Grote, Symposium on Vacuum Based Science and Technology, 05.09. – 07.09.2007, Greifswald, Germany
- 17)P. Kornejew, 13th Symposium on Laser-Aided Plasma Diagnostics, 18.09. – 21.09.2007, Takayama, Japan
- 18)R. König, International Workshop on Burning Plasma Diagnostics, 24.09. – 28.09.2007, Varenna, Villa Monastero, Italy
- 19)B. Hein, H. Jenzsch, B. Missal, 8<sup>th</sup> International Symposium on Fusion Nuclear Technology, 01.10. – 05.10.2007, Heidelberg, Germany
- 20)A. Werner, 10<sup>th</sup> IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems, 08.10. – 10.10., Kloster Seeon, Germany
- 21)A. Weller, Integrated Tokamak Modelling Task Force General Meeting, Cadarache, France, September13-15th, 2006
- 22)H. Dreier, M. Hirsch, R. König, P. Kornejew, H. Thomsen, F. Wagner, M. Ye, International Conference Plasma 2007 on Research and Applications of Plasmas, 16.10. – 19.10.2007, Greifswald, Germany
- 23)A. Weller, NCSX Program Advisory Committee Meeting, PPPL, Princeton, USA, November 9-10th, 2006
- 24)A. Weller, US-Japan Workshop on New Approaches in Plasma Confinement, Auburn, USA, November 13-15th, 2006
- 25)J. Boscary, 13<sup>th</sup> International Conference on Fusion Reactor Materials (ICFRM), 10.12. – 14.12.2007, Nice, France
- 26)A. Weller, 14<sup>th</sup> European Fusion Physics Workshop on Computational Plasma Physics for ITER and Beyond, Gréoux-les-Bains, France, December 4-6<sup>th</sup>

## **2.2 SPAIN**

### **2.2.1 International collaborations in 2005 using TJ-II at CIEMAT**

#### **- Collaboration with Russia**

- 1) K. Sarksyian and the ECRH IOFAN team were participating in the operation of the ECRH system of TJ-II during the 2006 experimental campaign and they participated in the high power experiments carried out to modulate the gyrotron power by a weak reflection.
- 2) M. Tereshchenko (form IOFAN) visited Ciemat and collaborated in the improvement and bench-marking of the ray-tracing code TRUBA (October – December 2006).
- 3) S. Petrov (IOFFE) (29 Oct – 26 Nov) and D. Makarin (St. Peterburg University) (12 – 26 Nov) visited Ciemat to participate in the development of ACORD-24 charge

exchange spectrometer control system. M. Pedrov (IOFFE) (14 – 26 Nov) visited Ciemat for general discussion of IOFFE – Ciemat collaboration.

4) N. Skvortsova (IOFAN) was participating in experiments with 2 mm scattering in TJ-II (Nov 2006).

5) A. Melnikov and L. Eliseev (Kurchatov Institute) were visiting Ciemat to investigate the structure of plasma potential in ECRH and NBI plasmas in the TJ-II stellarator as well as to discuss the possible up-grade of the HIBP diagnostic.

6) P. Deychuli, V. Kolmogorov and G. Abdrashito visited Ciemat in February 2006 to install and commission the Diagnostic Neutral Beam. The first injection of the neutral beam was made at the end of the same month and first charge exchange spectroscopy measurements were made in June.

## - Collaborations in Europe

### Germany

1) IPF (Stuttgart). G.Müller stayed at Ciemat during six months in 2006. He designed new modules to upgrade the control of the modulators of the gyrotrons and participated in the supervision of the design of the new high voltage power supply for the ECRH system.

2) IPP-Greifswald. D.Wagner visited Ciemat in December 2006 to work on the control of the polarization of the ECRH transmission lines. A polarization code was developed. The polarization measurements for the calibration of the software were discussed and prepared.

3) M. Sánchez was visiting IPP-Greifswald (October 2006) to collaborate in the Infrared Interferometry studies applied to the Stellarator W7-X.

4) P. García-Sánchez, mechanical engineer from CIEMAT was visiting IPP- Greifswald for six months (June-Dec). He was involved in the cryostat and vacuum vessel design activities.

### Portugal

1) C. Silva and Pedro Carvalho were visiting Ciemat to continue our collaboration on edge studies (biasing experiments) during 2006. Horacio Fernandes and André Netto have participated (November 2006) in the definition of control and software requirements for JET-EP2 diagnostic enhancement and test in TJ-II facilities (fast camera).

2) L. Guimaraes was visiting Ciemat (November-December 2006) to familiarise with the reflectometers installed at the stellarator TJ-II and to participate in the scientific exploitation of the reflectometer experimental data obtained in the 2006 experimental campaign.

3) Fernando Oliveira and André Sancho Guilhoto Duarte were visiting CIEMAT (November 13th – 24th) tuning the PAPI software running at IST. This software is part

of the PAPI federation established among CIEMAT, CEA and IST.

### **Hungary**

G. Kocsis and G. Petravich were visiting Ciemat (May / December 2006) to participate in the optical coupling design of the JET-EP2 diagnostic enhancement project and testing in TJ-II facilities.

### **Czech Republic**

H. Brotankova was visiting Ciemat (Nov – December) to participate in the analysis of edge plasma fluctuations.

#### **- Collaboration with USA**

1) J. Tsai and D. Schechter visited Ciemat between the 20<sup>th</sup> of June and the 30<sup>th</sup> of July. The NBI activities were organized around three main problems: Ion Source maintenance, Commissioning of injector #2, and High Voltage Power Supplies.

2) S. Combs (ORNL) used the visit to discuss progress on the pellet injection system for TJ-II. Pellet sizes and velocities were fixed.

3) J. Caughman (ORNL), who visited ciemat in December, met with the pellet injector team to outline the design for the microwave cavity detector to be installed on the pellet injector and to discuss the modifications needed for small pellets.

4) B. Carreras was visiting Ciemat in April and October 2006 to continue our long-standing collaboration between the CIEMAT, the University of Carlos III and Oak Ridge National Laboratory in the statistical description of turbulent transport in fusion plasmas and the physics of transport barrier.

5) John Caughman (ORNL) visited Ciemat in December 2006 to bring the antenna for measuring electron Bernstein emission. The antenna was mounted in its flange and the parameters were verified.

#### **- Collaboration with Ukraine**

1) The Heavy Ion Beam Probe team (led by L. Krupnik, Institute of Plasma Physics, National Science Center “Kharkov Institute of Physics and Technology”, Kharkov) has been fully involved in the characterization of radial electric fields in ECRH and NBI plasmas in the TJ-II stellarator during 2006 experimental campaign. An upgrade of existing HIBP system was started, with a significant improvement in power supplies. An up-grade in the diagnostics was agreed to provide two simultaneous sample volume capabilities.

2) S. S. Pavlov (Kharkov Institute of Physics and Technology) visited Ciemat to compare the finite Larmor radius effects in the fully relativistic plasma heating regime with the weakly relativistic case. (December 2006).

### - **Collaboration with Japan**

- 1) K. Nagasaki stayed in CIEMAT (March 2006) to participate in the ECCD experiments and to discuss comparative ECCD studies in Heliotron J, CHS and TJ-II.
- 2) A. Cappa visited Japan in January 2006 to participate in the ECRH experiments in Heliotron-J and to discuss comparative ECR studies with TJ-II.
- 3) L. Garcia was visiting Japan (October – December 2006) in the modelling of relaxation of flows and role of viscosity.
- 4) Masaki Osakabe (NIFS) visited CIEMAT in the period 15-19 March to discuss the participation of the TJ-II group in an international collaboration for the study of energetic particle transport in stellarators. Osakabe gave also a talk titled "Change of energetic ion transport by Alfvén Eigen-mode on LHD" on March 17.

### - **International collaborations: Stellarator working groups**

During 2006 we continued with the participation in the "International Collaboration on Neoclassical Transport" and in the activities of the International Stellarator Confinement Database and on profile database.

#### **2.2.2 Plans for 2007**

EURATOM-CIEMAT team will be involved in the area of concept improvement, through the scientific exploitation of the Stellarator TJ-II facility. In addition, we will strengthen and continue with our long standing tradition to extend our physics studies to different confinement concepts (tokamak / stellarators), looking for common clues as a fundamental way to investigate basic properties of magnetic confinement beyond any particular concept. Research activities in the TJ-II stellarator will be focussed in the following topics:

#### **Optimization of operational regimes for improved concepts:**

- Investigation of power threshold for core transition development with and without rationals. International stellarator confinement and profile data base and neoclassical transport
- International stellarator confinement and profile data base and neoclassical transport: Participation in the on-going activities of the ISCDB and ISPDB. The role of Global Neoclassical Transport in Stellarators (Development of Global Monte Carlo codes).
- Full lithium coating in TJ-II: Optimization of Lithium deposition set up by evaporation and Ne glow discharge in TJ-II (June 2007). First operation of TJ-II with full lithiumization.

#### **Understanding of plasma characteristics for improved concepts:**

- Influence of electric fields on transport and MHD stability. Including comparative studies (HIBP, probes, reflectometer, MHD activity) in ECRH and NBI plasmas: influence of magnetic configuration, heating power and plasma density.



- Edge and core Momentum transport studies, including the study of the influence on electric electric field on Reynolds stress driven flux and relaxation of flows and radial electric.
- MHD stability and plasma control: ELM physics
- Power and particle exhaust, plasma-wall interaction: Studies of de-tritiation methods.

#### **Development of plasma auxiliary systems:**

- **Heating:** Commissioning and start-up of the second NBI system as well as first plasma operation with two co/counter beams.
- **Diagnostics:** Further development of TJ-II systems including, installation of second channel hopping reflectometer, operation of fast particle detectors, fast particle detectors, first radial ion temperature and velocity measurements with the diagnostic neutral beam injector, operation of second reciprocating probe system: test active gas injection for turbulence visualization using fast cameras, test of optimised poloidal limiter and development and design of a new inner limiter and related diagnostics and transition from He–Ne to Nd-Yag second wave-length in the two color interferometer.
- **Plasma fuelling:** Distribution of the source and fuelling efficiency in normal and divertor configuration.
- **Real Time Measurement and Control:** Data mining techniques (Implementation of pattern recognition algorithms for TJ-II and JET). Test of the main power supply control system looking for vertical coil current modulation (aiming to dynamic control of magnetic well) and helical coil current modulation (aiming to dynamic control of low order rational location).
- **Remote participation:**
  - Development of an EFDA Federation (secure collaborative environment) based on a distributed authentication and authorization system: PAPI (Point of Access to Providers of Information). The Initial participants are CEA, CIEMAT, EFDA, IST, JET and KFKI/HAS.
  - Operation of SDAS (Standard Data Access) in TJ-II.
- **Theory and modelling:**
  - Modelling of kinetic effects on transport.
  - Statistical description of transport processes in fusion plasmas based on the use of probability distributions for individual particle motion.
  - Theoretical EBW studies in TJ-II: Beam diffraction effects related with O-X conversion efficiency in O-X-B scenarios. Kinetic effects of EBW heating,

Fokker Planck vs. Langevin dynamics. Fully and weakly relativistic effects on beam trajectory, current drive and absorbed power.

- Eirene code studies: Link of Eirene with particle transport, including relevant atomic physics mechanisms.

The following collaborations are planned during 2007:

**- Collaboration with Russia**

1) IOFAN ECRH group (K. Sarkisyan) will participate in the ECRH system operation. E. Bolshakov and A. Dorofeyuk will test the new developments for power measurements.

2) M. Tereshchenko will stay in CIEMAT to collaborate in further improvement of TRUBA: including a relativistic current drive module able for EBW. He will also collaborate in the developments of kinetic theory that are foreseen in CIEMAT. The important point is to deal with 3D geometry using models as exact as possible and to develop a Fokker-Planck code that can deal with plasma inhomogeneity.

3) N. Skvortsova (IOFAN) will continue her involvement in experiments with 2 mm scattering in TJ-II.

4) N. Petrov (IOFFE) and D. Makani (St. Petersburg University) will participate in the development / measurements with ACORD-24 charge exchange spectrometer in TJ-II.

5) A. Melnikov and L. Eliseev (Kurchatov Institute) will visit Ciemat to participate in the characterization of radial electric fields in the TJ-II stellarator and comparative studies with T-10 tokamak.

**- Collaborations in Europe**

1) IPF (Stuttgart). G.Müller will participate in the tests of the new high voltage power supply for the ECRH system and will continue with further improvements in the control system of the gyrotron anode modulators.

2) IPP (Greifswald): M Hirsch will visit CIEMAT (7.7. - 22.7) to discuss the Multichannel CO2 Interferometer Development for W7-X, the Euratom Fusion Training Scheme "Microwave Diagnostics Engineering in Preparation for ITER" and cooperation in the field of Doppler reflectometry: discussion of basics and numerical modelling (possibility for further optimization of W7-X antennas under design), development of improved antennas for TJ-II, possibility to use W7-AS equipment (fast multichannel spectrum analyzer ... ). M. Hirsch will also visit CIEMAT during fall 2007 to participate in interferometer and reflectometer operation as well as TJ-II physics studies (ELMs / edge transport).

3) M. Sánchez will visit IPP.Greifswald to continue the collaboration on infrared interferometry.

4) Czech Republic: M. Horn, I. Duran and H. Brotankova will participate in the test and development of TJ-II edge plasma diagnostics (electromagnetic probes).

IST-Portugal: C. Silva and IST team will visit Ciemat to continue our collaboration on edge studies during 2006. Continuing the collaboration in design and development of reflectometry in TJ-II (M. E. Manso, L. Cupido, L. Guimaraes and IST team).

5) H. Fernandes, Fernando Oliveira and André Sancho Guilhoto Duarte will visit TJ-II to continue our collaboration on the EFDA Federation and SDAS.

6) JET-UK: Andrea Murari will visit TJ-II to continue our collaboration on pattern recognition techniques.

#### **- Collaboration with USA**

1) J. Tsai and Phillip Ryan (ORNL) will visit in Ciemat in 2006 to participate in the beam conditioning of the injectors and to discuss beam transmission properties.

2) K. McCarthy will visit ORNL to perform test on the TJ-II pellet injector. S. Comb (ORNL) will visit Ciemat to commission the pellet experimental set-up.

3) S. Zweben (PPPL-USA) will be involved on the characterization of turbulence in the TJ-II stellarator using high speed imaging. Comparative studies TJ-II NSCX (using similar analysis tools) are planned. In addition, a joint effort to investigate instabilities in JET is in progress.

4) B. A. Carreras (ORNL) will visit Ciemat to investigate statistical properties of turbulent transport.

5) I. Calvo will stay at ORNL (Feb- May 2007) for L/H transition studies.

#### **- Collaboration with Ukraine**

Further investigation of the structure of radial electric fields using HIBP diagnostic (Institute of Plasma Physics, National Science Center "Kharkov Institute of Physics and Technology).

#### **- Collaboration with Japan**

1) K. Nagasaki will participate again during 2007 in the ECCD experiments in TJ-II stellarator and will continue with the comparative studies in Helical systems.

2) A. Cappa will visit Heliotron-J in February 2007 to participate in the ECCD experiments.

3) Nagaoka and Yamamoto (National Institute for Fusion Science) will visit Ciemat in March 2007 to discuss fast ion flux measurements and the interaction of fast ions with MHD activity.

#### **- International Stellarator working groups**

Activities will continue with further analysis and presentations in the major conferences.

## 3 JAPAN

### 3.1 LHD team at NIFS.

#### 3.1.1 International collaborations by the LHD team at NIFS.

##### - Collaboration with EU

1) Y. Feng, Max-Planck Institute (IPP Greifswald), visited NIFS (H. Yamada and M. Kobayashi) from 19th Sep. 2006 to 22nd Dec. 2006 as a NIFS guest Professor to conduct 3D edge transport modeling of LHD. The analysis focused on the effect of magnetic structure in the ergodic layer on plasma transport, and of the impurity transport/radiation on thermal instability.

2) Ursel Fantz from the Max Planck Institute for Plasma Physics in Garching, Germany visited NIFS (K. Ikeda and Y. Takeiri) from July 18, 2006 to October 20, 2006 as a NIFS Guest Professor to work on the topic of "Cesium diagnostics with optical emission spectroscopy in cesium-seeded negative ion sources".

3) Yuri Igitchkanov (IPP Greifswald, Germany) is in NIFS from Apr. 17th (till Apr. 16th, 2007) as a NIFS guest professor to work on the topic of "Modeling of impurity transport in helical devices" and "Helical DEMO". He attended and presented his results at the 16th International Toki Conference.

4) M. Yokoyama (NIFS) visited Max-Planck Institut für Plasmaphysik (Greifswald, Germany) and continuously proceeded the international collaboration on Core Electron-Root Confinement (CERC) physics in helical systems such as LHD, CHS, TJ-II (CIEMAT, Spain) and W7-AS (Germany) based on the framework of the International Stellarator Profile DataBase. The collaboration results are reported as the oral talk in the 21st IAEA Fusion Energy Conference (Chengdu, Oct. 2006).

5) H. Maassberg (IPP-Greifswald), C.D. Beidler (IPP-Greifswald), Y. Turkin (IPP-Greifswald) and W. Kernbichler (Tech. Univ. Graz, Austria) visited NIFS to promote international collaboration on neoclassical transport code benchmarking and to initiate the benchmarking of the modules in the developing integrated transport code.

6) R. Preuss (IPP-Garching) visited NIFS to proceed the collaboration of International Stellarator Confinement DataBase. Parametric description of high beta plasmas has been investigated. The result was presented at the 21st IAEA Fusion Energy Conference (Chengdu, Oct. 2006) as a joint paper.

7) Luis Garcia-Gonzalo (Universidad Carlos III, Spain) stayed at NIFS during 4 Sep. 2006 - 4 Dec. 2006. He and K.Y. Watanabe applied the 3 dimensional resistive MHD stability analysis code "far3d" to LHD experimental data. Both the behaviors of the ideal MHD mode and the resistive MHD mode are analyzed. It is found that a collapse in the electron temperature profile is strongly related with the ideal MHD mode.

8) Collaboration of the plasma turbulence and structure formation was extended by inviting Klaus Hallatschek from the Max-Planck-Institut für Plasmaphysik to NIFS. Scientific issues, which were discussed, include the nonlinear mechanism of

meso-scale flow driven by microscopic turbulence, the nonlinear mechanisms for the saturation of the meso-scale flow, and the energy partition between the meso-scale structure and micro turbulence. Comparison between theory and simulation was analyzed, and a satisfactory initial result was obtained.

9) Collaboration of the plasma transport and transitions was extended by the visit of F.Wagner to NIFS. Scientific issues, which were discussed, include the recent development of experimental study of zonal flow and turbulence, physics of super-dense-core plasma (an improved confinement state that has been found by LHD recently), and future direction of fusion research and plasma physics.

10) Aleksandra Maluckov (Nis University, Serbia) visited NIFS (S.Ishiguro and M. M. Skoric) from Nov. 19, 2006 to Feb. 5 for the collaboration research for multi-scale simulation method. She has investigated development of equation-free projective integration method for plasma physics.

11) Milan Rajkovic of Vinca Institute, Belgrade (Serbia) from 28 Nov 2006 - 17 Feb 2007, worked with M.M. Skoric on multi-fractal characterization of L- and H-mode and scaling properties of fusion plasma turbulence. Major results, initially compiled in NIFS Report No. 833 (2006) will be presented at Stochasticity in Fusion Plasmas, March 2007, Juelich (and to be published).

12) H. Sugama and S. Ferrando i Margalet visited CRPP at Lausanne during Sep.1 through 6 in 2006 in order to have discussion with W.A. Cooper, L. Villard, and other staff members on gyrokinetic studies of plasma turbulence and zonal flows in tokomaks and helical systems.

13) T. Mito (NIFS) visited Forschungszentrum Karlsruhe (FZK) in Germany from Nov 6, 2006 to Nov. 8, 2006 for meeting concerning the research collaboration about the applied superconductivity and cryogenics based on the agreement on the academic exchange and collaboration between NIFS and FZK. T.Mito discussed with W. Fietz and R. Heller of the Institute of Technical Physics (ITP) in FZK about the actual collaboration theme such as development of HTS current leads, etc. According to the alternation of the director of ITP from P. Komarek to Noe, Mito wished to express his gratitude to P. Komarek for his distinguished contribution to the collaboration and asked to M. Noe as the continuous collaboration.

#### **- Collaboration with USA**

1) Masaaki Yamada (Principal Research Physicist, Princeton Plasma Physics Laboratory) stayed at NIFS (host: R. Horiuchi) from Nov. 16 to Nov. 20, 2006, for collaboration research on "Physics of magnetic reconnection in Space and Laboratory"

2) R. Kanno (NIFS) visited Institute for Fusion Studies, The University of Texas at Austin from 1 Nov. to 21 Dec. 2006 in order to collaborate with M. Kotschenreuther and J.W. Van Dam on Neoclassical transport in/around magnetic islands.

3) K. Ichiguchi (NIFS) visited Oak Ridge National Laboratory from July 16 to July 30. He collaborated with B.A. Carreras about the nonlinear MHD analysis of heliotron plasmas, particularly the interchange mode evolution in the beta ramp-up phase and the generation of flow and islands in the interchange mode saturation.

4) Grisham (PPPL) visited NIFS (Y. Oka) from 2007/2/28 to 2007/3/3. Collaborators from NIFS, PPPL, and JAEA observed successfully cesium neutral- and ion-lines with spectrometer during up to 10sec time variation from the LHD-negative ion sources for the first time.

5) N. Tamura (NIFS) visited PPPL from Mar. 12th to Mar. 26th to implement the TESPEL injection experiment on NSTX with H. W. Kugel (PPPL) and D. Stutman (Johns Hopkins Univ.). The TESPEL has been injected successfully into the NSTX plasmas during his stay.

6) J.H. Harris (ORNL) and D. Mikkelsen (PPPL) visited NIFS to promote international collaboration on helical system research. Several issues on experiment, theory and simulation were extensively discussed. The promotion of International Stellarator Profile DataBase was also highly recommended and supported.

7) K. Itoh(NIFS)visited Patrick H. Diamond University of California, San Diego CA, U. S. A.

8) J.H. Kim (IFS, U. Texas, USA) visit NIFS during Dec. 9-23, 2006 to collaborate with T.-H. Watanabe and H. Sugama on Application of the Fusion Theory to Space Plasmas. He implemented the gyrokinetic simulation code for Lone Star at UT.

9) H. Sugama and T.-H. Watanabe visited UCSD during Jan.9 through 14 in 2007 in order to attend the JIFT Workshop on "Gyrokinetic Simulation of Ion and Electron Temperature Gradient-Driven Transport" as its co-organizers.

#### - **Collaboration with Russia**

1)Collaboration with Russia A. V. Krasilnikov (Troitsk Institute for Innovating and Fusion Research, Russia) visited NIFS (M. Isobe) from Jan. 4 to Jan. 25, 2006. He has studied the mechanism of energetic ion production in hydrogen plasmas heated by ICRF by means of natural diamond detectors.

2) Miroshnikov (St. Petersburg Technical University, Russia) visited NIFS (S. Sudo and N. Tamura) from Oct. 29th to Dec. 10th in order to study the configuration of the pellet ablated cloud by measuring a Stark broadening with a spatial resolution on LHD.

#### - **Multi-lateral Collaboration**

H.Yamada (NIFS) and S.Murakami (Kyoto Univ.) coordinated the 1st Coordinated Working Group Meeting (CWGM) for Confinement Studies in Stellarators (19-22 Sep. 2006 at Kyoto Univ.) in cooperation with international collaborators. This meeting was conducted under the auspices of the IEA Implementing Agreement of Development of Stellarator Concepts and based on the preparatory discussion at the 15th International Stellarator Workshop in Madrid in 2005. The main issues for discussions were progress of the International Stellarator Confinement & Profile Database (ISCDB and ISPDB) activities, development of transport codes and their integration and validation, discussion on the working hypothesis "neoclassical optimization can suppress turbulent transport?". The participants from several countries covered almost all institutions where helical system research has been promoted. The further promotion of the international collaboration on these issues was agreed and the possibility of the 2nd

meeting was also discussed.

### 3.1.2 Plans for 2007

1) M. Yokoyama (NIFS) will continuously proceed International Stellarator Profile DataBase activity in collaboration with TJ-II and W7-AS. Quantitative understanding for ITB shot properties, such as the dependence of ECH power threshold on effective helicity and ripple trapped fraction, will be investigated based on a wide range of ITB

2) Yuri Igitchanov (IPP Greifswald, Germany) will visit NIFS from Oct. 1st, 2007 to continue the collaboration work of "Modeling of impurity transport in helical devices" and "Helical DEMO".

3) K. Ikeda will visit the NBI development facility in Garching (Germany) from 1st Feb. 2007 to 2nd May 2007 to study a long life RF negative ion source for NBI and an optical measurement method.

4) Grisham (Princeton Plasma Physics Laboratory) will visit NIFS (Y. Oka) for about 1 week in order to continue the work on spectroscopic observations of beam Doppler shifts and impurity behavior in the source and beam.

5) L. Grisham (PPPL) will join the NB injection experiments and discuss about the improvement on negative ion system for LHD and the spectrometry.

6) S. Toda (NIFS) will visit University of California, San Diego (Host: P.-H. Diamond) for about a month, in order to study the modelling of the role of zonal flows in the transport equations in helical and tokamak plasmas for the theoretical research of the internal transport barrier under the JIFT program.

7) K. Ichiguchi (NIFS) will continue the collaboration with B.A. Carreras (Oak Ridge) about the nonlinear MHD analysis of heliotron plasmas. The flow effect on the nonlinear evolution of the interchange mode, the interaction of the magnetic island and the interchange mode and various collapse phenomena will be studied.

8) N. Tamura (NIFS) will visit PPPL for 2 weeks in Mar. 2007 to continue the TESPEL injection experiment on NSTX with H. W. Kugel (PPPL) and D. Stutman (Johns Hopkins Univ.).

9) A. Ito (NIFS) will visit the Plasma Science and Fusion Center, Massachusetts Institute of Technology from Jan. 22 to 26, 2007 in order to collaborate with J. J. Ramos on Anisotropic Two-fluid Equilibrium.

10) Y. Todo (NIFS) will visit Institute for Fusion Studies, the University of Texas at Austin (H. L. Berk and B. N. Breizman) from Jan. 29 to Feb. 13 in order to advance a collaborative study of nonlinear MHD effects on Alfvén eigenmode evolution.

11) D. A. Spong (ORNL) will visit NIFS (N. Nakajima and Y. Todo) from Feb. 19 to May 18 as a NIFS Guest Professor as well as a JIFT exchange researcher in order to advance a theoretical and computational study of extended MHD models.

12) P. Diamond (UCSD) and T.S. Hahm will visit Nagoya during Jan.8 through 11 in 2008 in order to attend the JIFT Workshop on "Gyrokinetic Simulation of Plasma Transport" and have discussion with H. Sugama and T.-H. Watanabe as the co-organizers.

13) A. V. Krasilnikov (Troitsk Institute for Innovating and Fusion Research, Russia) will visit NIFS (M. Isobe) for 3 weeks on Jan. 2006 and work on fast neutral particle measurements by using natural diamond detectors in LHD.

14) V. Sergeev (St. Petersburg Technical University, Russia) will visit NIFS (S. Sudo and N. Tamura) for about one month, in order to continue the configuration study of the pellet ablated cloud by measuring Stark broadening with spatial resolution on LHD for the basis of high energy particle measurements with the pellet charge exchange.

15) I. Vinyar (St. Petersburg Technical University, Russia) will visit NIFS (S. Sudo and N. Tamura) for 2 weeks in Feb. 2007 for the collaboration of the TECPEL (Tracer-Encapsulated Cryogenic Pellet) injection experiment on LHD.

16) M. Isaev (Russia) will join the analysis of bootstrap current in LHD experiments. The main subjects are the effect of the bootstrap current on healing the magnetic surface and the radial electric field effect on bootstrap current in low density ECH plasmas.

17) Based on the successful 1st CWGM in 2006, the German party will organize the 2nd CWGM which has been proposed to have the meeting in late May, 2007 at Greifswald (IPP, Germany). The development after the 1st CWGM on several issues for confinement studies in helical systems will be the main topics for the discussion. Large contributions from NIFS researchers is highly anticipated.

## **3.2 CHS team at NIFS.**

### **3.2.1 International collaborations by the CHS-team at NIFS**

#### **- World-wide collaborations**

The experimental knowledge on the zonal flows at present has been systematized by the leadership of the CHS experimental group. The jointed institutes or laboratories of this activities are NIFS, JAEA, RIAM (Japan), ANU (Australia), SWIP (China), Max-Planck Institute, University Stuttgart (Germany), Kurchatov Institute (Russia), CIEMAT (Spain), UCSD and University Wisconsin (USA). The results were presented as a topical overview in the 21st FEC in Chengdu, China by A. Fujisawa.

#### **- Collaborations with US**

1) S. Okamura visited PPPL from March 28th to March 11th for the discussion of planned collaboration in NCSX experiment on physics topics of ECH plasma production and the electric field study using a heavy ion beam probe (HIBP). He also worked with PPPL people on the magnetic configuration optimization with auxiliary saddle coils.

2) S. Okamura visited PPPL from November 8 to November 11 to attend the program



advisory committee (PAC) meeting for NCSX experiment in place of O. Motojima who is a member of the PAC. He gave advices on NCSX program planning and also presented the cooperation proposal between NIFS and PPPL in NCSX experiment with HIBP diagnostic developed by NIFS.

### **3.3 Heliotron J team at Kyoto University**

#### **3.3.1 International collaborations by the Heliotron J team at Kyoto University**

##### **- Collaboration with Australia**

1) B. Blackwell (ANU) visited Kyoto Univ. for two weeks on January 9-26 to participate in the Heliotron J experiment. The MHD analysis by using such as SVD method and tomographic technique, ECH system and data acquisition was collaborated.

2) Discussions with H-1NF team (ANU) were kept along the same line as in 2005.

##### **- Collaboration with EU**

1) J. Sanchez (CIEMAT) and E. Ascasibar (CIEMAT) visited Kyoto University on October 24 for concluding the scientific agreement between the Institute of Advanced Energy, Kyoto University and CIEMAT. The two institutes, recognizing the value of international cooperation, have agreed to continue their deeper cooperation. Extending the previous scientific agreement, the exchange of scientific cooperation includes the fields of plasma fusion science, fusion engineering/technology and related studies.

2) K. Nagasaki visited CIEMAT on March 26-30 in order to participate in the TJ-II experiment. He joined the ECCD experiment and compared the data with Heliotron J and CHS results.

3) A. Cappa (CIEMAT) joined the Heliotron J experiment on January 7-21. He analyzed ECCD experimental results on Heliotron J and compared them with TJ-II results.

4) F. Castejon (CIEMAT) visited Kyoto University on September 20, and discussed the ECH/ECCD physics on helical systems.

5) M. Henderson (CRPP, Switzerland) visited Kyoto University on September 24, and discussed ECH/ECCD system and physics in toroidal fusion devices.

6) N. Marushchenko (IPP, Greifswald) visited Kyoto Univ. on December 18-23, and applied his ray tracing code, "TRAVIS" to the Heliotron J configuration.

7) Collaborations with CIEMAT were continued along the same lines as in 2005.

##### **- Collaboration with China**

Z. Feng (Southwestern Institute of Physics, China) joined the Heliotron J experiment for one year. He studied the diagnostics such as CCD camera.

#### - Collaboration with US

1) The 2nd US-Japan workshop on “New approaches to advanced plasma confinement in helical system” was held on November 13-15 at Auburn University. The participants were F. Sano (Kyoto University), D. Anderson (University of Wisconsin), S. Okamura (NIFS), S. Kobayashi (Kyoto University), W. Guttenfelder (University of Wisconsin), T. Minami (NIFS), Y. Suzuki (NIFS), T. Rafiq (University of Wisconsin), D. Spong (ORNL), S. Kitajima (Tohoku University), K. Matsuoka (NIFS), M. Zarnstorff (PPPL), N. Pomphrey (PPPL), R. Maingi (ORNL), T. Mizuuchi (Kyoto University), T. Oishi (NIFS), K. Nagasaki (Kyoto University), G. Motojima (Kyoto University), T. Okada (Kyoto University), C. Deng (University of Wisconsin), J. Berkery (Columbia University), S. Knowlton (Auburn University), W. Reiersen (PPPL), A. Weller (Max-Planck IPP). The meeting covered new developments in the confinement of plasmas in helical systems, highlighting advanced helical systems exhibiting quasi-symmetry as well as heliotron/torsatron devices. The workshop was a forum in which recent progress in experiments, theory, design, and engineering of helical plasma confinement systems was presented and discussed.

2) J. H. Harris (ORNL) visited Kyoto University on August 28- September 1. He presented his topic at the International symposium of 21<sup>st</sup> COE program.

#### - Others

1) Confinement control of high energy particles by using optimizing field configuration based on the quasi-isodynamic concept was examined through Heliotron J NBI/ICRF experiments.

2) The details of the H-mode were studied experimentally and theoretically in Heliotron J.

3) Advanced ECH scenarios including EBW heating/current drive was examined through Heliotron J/CHS/LHD experiments.

4) Discussions with U-3M team (Kharkov) were kept along the same line as in 2005.

#### 3.3.2 Plans for 2007

1) Q. Yang (SWIP, China) will visit Kyoto Univ. as a guest professor for three months. He joined the Heliotron J experiment related to charge exchange spectroscopy, and will have lectures of plasma physics for graduate students.

2) F. S. B. Anderson will visit Kyoto Univ. for three weeks to participated in the Heliotron J experiment. He will analyze the MHD fluctuations driven by interchange instabilities.

3) A. Cappa (CIEMAT) will visit Kyoto Univ. for two weeks to participate in the Heliotron J experiment. The ECCD and EBW will be discussed.

4) A. Fernandez (CIEMAT) will visit Kyoto Univ. for two weeks to participate in the Heliotron J experiment. The ECCD physics will be discussed.

5) Research on confinement improvement in ECH plasmas and development of heating and current drive using electron Bernstein waves will be performed under the

collaboration with CIEMAT, IPP and NIFS.

6) Collaboration research will start among CIEMAT, Kharkov institute and ANU related to the physical understanding of fluctuation induced transport in core and edge plasmas and database for concept optimization of helical systems.

7) Confinement control of high energy particles by using optimizing field configuration based on the quasi-isodynamic concept will be examined through Heliotron J NBI/ICRF experiments.

8) Comparative studies on ECCD will be experimentally carried out among TJ-II, Heliotron J, CHS and LHD.

9) MHD activity control in higher beta plasmas through the field configuration optimization will be tested in Heliotron J.

10) The divertor study in the helical-axis heliotron configuration is to be started in Heliotron J.

11) The development of fast He beam probe is being developed under the collaboration with CIEMAT.

12) A heavy Ion Beam Probe will be designed for measuring the radial electric field and fluctuations in Heliotron J.

## **4 RUSSIA**

### **4.1 International collaboration in 2006**

#### **- Collaboration between General Physics Institute (GPI) and CIEMAT (Spain)**

Nine persons participated in joint GPI-CIEMAT works (total duration of visits: 12 month-persons):

In 2006 in accordance with agreed program of joint activity next tasks were fulfilled:

#### **1) Measurement of gyrotron power absorption in ECRH plasma on TJ-II along the toroidal direction.**

Measurements of microwave absorption in the toroidal direction of the TJ-II chamber were performed by using a system of diodes arranged along the TJ-II chamber. It was shown that, the absorbed power of microwaves propagating along the torus contributes, but insignificantly to the total energy balance, especially because absorption occurs in the edge plasma.

#### **2) Gyrotron Radiation Affected by Modulated Reflector: High Power Experiment.**

The high power experiment has confirmed the dependence of the gyrotron radiation characteristics on parameters of external non-stationary reflectors and the possibility of modulating the gyrotron power by a weak reflection at high power level was demonstrated.

### **3) Measurements of plasma density fluctuations on TJ-II by using of 2mm scattering diagnostic.**

The 2-mm scattering diagnostic was used in TJ-II to measure density fluctuations in the experiments with NBI, different magnetic field configurations, in the ECRH regime with additional current. The 2-mm scattering diagnostic was used for measurements long temporal time samples (more than  $10^5$  points with high frequency resolution) of amplitude of density fluctuations.

It is shown that fluctuations at the middle radius ( $r/a \sim 0.5$ ) of TJ-II can be attributed to drift-dissipative instability. The level of fluctuations in the ECRH/NBI regime decreases by a factor of 10-50 in comparison with the ECRH regime.

### **4) Participation in planned experiment on TJ-II with additional plasma heating by Bernstein waves.**

Theoretical task-further development of "TURBA" code.

### **5) Maintenance works on the Microwave Energy Measurement Device (MEMD) on TJ-II**

Maintenance development and improvement of MEMD for measurements of microwave power.

**As a result of this collaboration some joint papers were published.**

- **Collaboration between Kurchatov Institute and Max-Planck Institute( IPP) (Greifswald, J.Nuhrenberg group )**

Theoretical collaboration on different way of optimization of stellarator systems and development of corresponding numerical code. As a result two joint papers were published.

- **Collaboration between GPI and NIFS (Japan)**

Three persons participate in joint works (total duration: 2 month-persons) on microwave scattering diagnostic on LHD for high-k power measurements with the use of high power gyrotron radiation on LHD and L2-M. The corresponding scattering diagnostic was installed on LHD with using of 84GHz gyrotron and receive-transmitting quasi-optical system. The first measurements were performed.

## **4.2 Research plans for 2007**

- **GPI**

1) Adjustment of a new ECRH system for the L-2M stellarator, including a new supply

system and a new gyrotron with  $P = 0.8$  MW and  $f = 75$  GHz.

2) Carrying out the first experiments on plasma heating with a higher ECRH power.

3) Mounting and adjustment of a new submillimeter interferometer using a new two-frequency water-vapor laser.

4) Theoretical development of the modeling of transport processes in stellarators.

5) Continuation the collaboration between GPI and CIEMAT on a) Measurements of gyrotron second harmonic (for 53.2 GHz TJ-II gyrotron), for following use in scattering on TJ-II, and b) Consideration of the use of gyrotron first harmonic backwards radiation in scattering diagnostic, and between GPI and NIFS on microwave scattering diagnostic on LHD.

#### **- Kurchatov Institute**

In collaboration with IPP (J.Nuhrenberg group) develop the different way of stellarator optimization in order to reduce the particle and energy losses.

## **5 UKRAINE**

### **5.1 Institute of Plasma Physics of the National Science Center “Kharkov Institute of Physics and Technology” of the NAS of Ukraine (IPP NSC KIPT, NASU)**

#### **5.1.1 International collaboration of the NSC KIPT in 2006**

##### **5.1.1.1. International collaborations of the plasma theory division**

#### **- Collaboration with Technische universität Graz, Austria**

1) Optimization of stored energy in the  $1/\nu$  regime for URAGAN-2M started in 2005 is continued (V. V. Nemov, S. V. Kasilov and V. N. Kalyuzhnyj in collaboration with B. Seiwald and W. Kernbichler (Institut für Theoretische Physik, Technische universität Graz, Austria)).

2) Using new target functions (V. V. Nemov, S. V. Kasilov, W. Kernbichler, G. O. Leitold, Phys. Plasmas, 12, 112507 (2005)) which are related to collision-less  $\alpha$ -particle confinement and allow to save computer resources, a number of optimized stellarator configurations has been analyzed with respect to trapped particle confinement (V. V. Nemov, S. V. Kasilov in collaboration with W. Kernbichler, G. O. Leitold (Institut für Theoretische Physik, Technische universität Graz, Austria) and L.P.Ku (PPPL, Princeton)).

3) A numerical method for fast evaluation with the help of integration along the magnetic field lines of the bootstrap current and current drive efficiency in stellarators with arbitrary collisionality has been developed. (S. V. Kasilov, V. V. Nemov in collaboration with W. Kernbichler, G. O. Leitold and K. Allmaier (Institut für Theoretische Physik, Technische universität Graz, Austria)).

#### - **Collaboration with NIFS, Japan**

New methods of selective cold alpha-particles removal from the fusion helical plasma are being developed by A. Shishkin (with Kharkov National University team) in collaboration with O. Motojima and A. Sagara (NIFS).

1. "Use of Drift Resonances ( $iota^*=n/m$ ) of Removed Particle" [A.A. Shishkin, A.Yu. Antufyev, O. Motojima, A. Sagara "Removal of cold alpha particles from helical device for fusion" Fusion Engineering and Design, Vol.81, Issues 23-24, November 2006, pages 2737-2742]: The moving drift island of the helium ash ( $W=35$  keV) can be arranged in LHD by the change of poloidal field coil currents. The main ion orbits are not deteriorated.
2. "Small magnetic island structure at the plasma periphery" leads to the resonance structure of particle orbits. The penetration of the  $W=350$  keV alpha-particles through the magnetic islands takes place in the Force Free Helical Reactor [A.A. Shishkin, A. Sagara, O. Motojima, O. Mitarai, T. Morisaki, H. Ohyaabu. "Selective cold alpha-particles removal from fusion helical plasma" is being prepared for publication in Nuclear Fusion].

#### - **Collaboration with Russia**

The data base for the coils of the Uragan-2M magnetic system, which was used earlier for computations of magnetic surfaces taking into account the influence of current-feeds and detachable joints of the helical winding, is transformed to a new form which is suitable for the already existing Biot-Sawart code for computations of the magnetic field strength and its spatial derivatives (V. V. Nemov, V. N. Kalyuzhnyj, S. V. Kasilov, G. G. Lesnyakov in collaboration with N. T. Besedin (Kursk State Technical University, Russia)).

#### - **Collaboration with CIEMAT**

Study of influence of weakly relativistic effects on the Electron Bernstein Wave heating of plasma confined in the TJ-II stellarator near the fundamental electron cyclotron harmonic using TRUBA beam/ray tracing code. (S. S. Pavlov in collaboration with F. Castejon, A. Cappa, A. Fernandez (CIEMAT, Madrid, Spain) and M. Tereshchenko (General Physics Institute, Moscow, Russia)).

### 5.1.1.2 International collaborations of the plasma experiment divisions

#### - **Collaboration with NIFS, Japan**

During visit of V.Voitsenya to NIFS (90 days) the analysis was provided of the prospect to use a nitrogen-hydrogen mixture plasma for conditioning of large-scale fusion devices. On the results of the work a NIFS Report is prepared (accepted for publication) and the paper was presented at 11<sup>th</sup> Ukrainian Conference in Alushta (Sept. 2006), which was published in the Proceedings of the Conference.

#### - **Collaboration with Cadarache, France**

Problems of in-vessel mirrors in ITER (V.Voitsenya and V.Konovalov in collaboration with NIFS (Japan), Cadarache (France), RNC "Kurchatov Institute" (Russia)).

- **Collaboration with Argonne National Laboratory, USA**

Investigations of W-Pd bimetallic systems for hydrogen recycling control conformably to fusion devices were continued (G. Glazunov in collaboration with A. Hassanein and R. Causey (USA)).

- **Collaboration with CIEMAT, Madrid, Spain**

1) Calibration of the new HIBP secondary beam line system for TJ-II (L. I. Krupnik and IPP HIBP team in collaboration with C.Hidalgo and TJ-II team (CIEMAT)).

2) Studies of the radial electric fields, electron density and confinement in the TJ-II stellarator during ECR and NBI heating in variety of magnetic configurations (L. I. Krupnik and HIBP team in collaboration with C. Hidalgo and TJ-II team).

- **Collaboration with IPP, Greifswald, Germany**

1) The Heavy Ion Beam Probe (HIBP) diagnostic was installed on WEGA Stellarator. Calibration and tuning ionic gun, accelerator, and control systems was carried out (L. I. Krupnik and HIBP team (IPP NSC KIPT) in collaboration with M. Otte and WEGA team).

2) Experiments on primary and secondary probing beam passing through the system were carried out. Measurements of the secondary beam on the detector plates of the energy analyser during gas puffing were done (L. I. Krupnik and HIBP team in collaboration with Yu. Podopa and WEGA team).

- **Collaboration with Kurchatov Institute, Moscow, Russia**

Investigation of the radial plasma potential and density under the Internal and Edge transport barriers formation, biasing and Geodesic Acoustic Mode during ECR heating by HIBP diagnostic in T-10 tokamak. These results were compared with results in TJ-II stellarator (L.I.Krupnik and HIBP team (IPP NSC KIPT) in collaboration with A.V.Melnikov and T-10 team (Kurchatov Institute)).

### **5.1.2 Plans for 2007 of the IPP NSC KIPT**

#### **5.1.2.1. Plans for 2007 of the plasma theory division**

- **Collaboration with Austria (Institut für Theoretische Physik, Technische Universität Graz)**

1) Study of the  $1/\nu$  neoclassical transport for Uragan-2M with taking into account the influence of the current-feeds and detachable joints of the helical winding (V. V. Nemov, S. V. Kasilov and V. N. Kalyuzhnyj in collaboration with B. Seivald and W.Kernbichler (Institut für Theoretische Physik, Technische universität Graz, Austria)).

2) Elaboration of numerical tools for study of neoclassical confinement properties of real space stellarator magnetic fields produced by the HINT code (V. V. Nemov and S.V.Kasilov in collaboration with W. Kernbichler (Institut für Theoretische Physik, Technische universität Graz, Austria)).

3) Development of the delta-f Monte Carlo method for the computation of bootstrap current with improved convergence in the low collisionality regime. (S. V. Kasilov, V. V. Nemov in collaboration with W. Kernbichler, G. O. Leitold and K. Allmaier (Institut für Theoretische Physik, Technische universität Graz, Austria)).

**- Collaboration with Spain (CIEMAT, Madrid)**

Development of TRUBA beam/ray tracing code for the exact fully relativistic calculations (S. S. Pavlov in collaboration with F. Castejon, A. Cappa, A. Fernandez (CIEMAT, Madrid, Spain) and M. Tereshchenko (General Physics Institute, Moscow, Russia)).

**5.1.2.2. Plans for 2007 of the plasma experiment divisions**

**- Collaboration with NIFS, Japan**

1) Optimization of wall conditioning procedure for preparation of a fusion device to operation (V.Voitsenya and A.Shtan' in collaboration with S.Masuzaki and A.Sagara); the Uragan-2M torusatron will be used for the experiments (ECH + RF plasma in hydrogen and in mixture of hydrogen with nitrogen).

2) Investigation of environment effects on in-vessel mirrors exposed in LHD (V.Voitsenya and Konovalov in collaboration with S.Masuzaki, and N.Ashikawa); (the surface of mirror samples exposed in LHD will be analyzed).

3) Investigation of possibilities to decrease the oxygen concentration in LHD plasma (in collaboration with S.Masuzaki).

**- Collaboration with ANL, USA**

Continuation of investigations of hydrogen permeability and erosion behavior of the W-Pd bimetallic systems (G. Glazunov in collaboration with R. Causey and A. Hassanein (USA)).

**- Collaboration with Spain (CIEMAT, Madrid)**

1) Development and creation of the two sleet detector system of HIBP energy analyser for the TJ-II stellarator

2) Assembling and installation of a new high voltage power supply system for HIBP injector of TJ-II stellarator.

3) Calibration and test experiments with two sleet energy analyser in TJ-II.

4) Investigation of the plasma potential, electron density and their fluctuations in combined ECR and NBI heating regimes in TJ-II stellarator. Comparative study of the electric fields behavior in TJ-II stellarator (Spain) and T-10 tokamak (Russia).

**- Collaboration with Germany (IPP, Greifswald)**

1) Testing of the full control system and energy analyser, calibration of the Heavy Ion



Beam Probe (HIBP) diagnostic on WEGA Stellarator.

2) Measurements of the electric plasma potential by HIBP diagnostic in WEGA stellarator.

- **Collaboration with Russia (Kurchatov Institute, Moscow)**

Investigation of the plasma potential behavior during Internal and Edge barrier formation. Measurements of the plasma fluctuations. Comparative study of the plasma electric fields behavior in the T-10 tokamak and TJ-II stellarator during ECR heating.

- **The tasks to be solved at IPP NSC KIPT**

1) Measurements of magnetic surfaces in Uragan-2M torsatron being put in operation in 2006.

2) Optimisation of regimes of surface cleaning in Uragan-2M torsatron.

3) Optimisation of processes of radio-frequency plasma production and heating in Uragan-2M torsatron with the aim of plasma parameters increasing.

4) Development of a new type pumped limiter for Uragan-2M torsatron.

5) Investigation of processes accompanying the ITB and ETB formation in plasma of Uragan-3M torsatron under the RF plasma heating.

6) Investigations of divertor plasma flow characteristics in conditions of transport barriers formation.

7) Assembling of the test stand of heavy ion beam probe diagnostic for Uragan-2M torsatron. Development of the energy analyzer for HIBP diagnostic in Uragan-2M torsatron.

## **5.2 Karazin National University, Kharkov**

### **5.2.1 International collaboration in 2006**

- **Collaboration with MPIPP, Germany**

1) Impurity transport in 3D magnetic field for the stellarator Wendelstein 7-X (I. Girka (University) and A. Shishkin (NSC KIPT) in collaboration with F. Wagner, H. Wobig, R. Schneider, Yu. Igitchanov and C. Beidler (MPIPP)).

2) Sandwich Fellowship Program was established between the University and MPIPP since 2001. Sandwich PhD student I. Bizyukov had finished his study "Experimental study of tungsten sputtering by simultaneous carbon and deuterium bombardment at Dual-Beam Experiment facility" at MPIPP in Garching under the supervision of K. Krieger (MPIPP) and N. Azarenkov (University). Erosion of tungsten layers by deuterium, helium and carbon bombardment (single- and multispecies impact) was studied by I. Bizyukov (University) in collaboration with K. Krieger (MPIPP). The report by I. Bizyukov, K. Krieger, et al was presented at 17<sup>th</sup> International Conference on

Plasma-Surface Interactions, 2006.

One Sandwich PhD student more has started his course in 2006: A. Onyshchenko - at the Technology Division of MPIPP under the supervision of J.-M. Noterdaeme (MPIPP) and V. Bobkov (University). The device for carrying out the experiments for testing different protection composition coatings of the ICRF antennas for the plasma heating was made at the MPIPP by A. Onyshchenko (University) during his visit to MPIPP in collaboration with J.-M. Noterdaeme, V. Bobkov, W. Becker (MPIPP).

3) The device for the investigation of the collections of the D and He implanted particles in the composition thin films structures of the ICRF probes with the help of thermal desorption mass spectrometry was developed. Now this device is producing. This activity is carried out by Sandwich PhD student A. Onyshchenko, V. Bobkov (University) in collaboration with J.-M. Noterdaeme, V. Bobkov, W. Becker (MPIPP).

4) High-flux (up to  $10^{22}$  cm<sup>-2</sup>) keV range (up to 5 keV) ion source for experimental studies of influence of high particle flux from fusion plasma on plasma facing materials is being developed at the laboratory of high-current beams (O.A. Bizyukov is the head of the laboratory, University) for MPIPP.

5) High-flux (up to  $10^{21}$  cm<sup>-2</sup>) low-energy range (below 300 eV) ion source for experimental studies of the high particle flux interaction with the plasma facing materials in the fusion applications is developed by K. Pololzhii at the laboratory of Diagnostics of the Plasma-Technological Processes (University) for MPIPP.

#### - **Collaboration with NIFS, Japan**

New methods are being developed by Alexander A. Shishkin (Kharkiv Institute of Physics and Technology, UKRAINE and the University) in collaboration with Akio Sagara and Osamu Motojima (NIFS).

1) "Use of Drift Resonances ( $iota^* = n/m$ ) of Removed Particle" [A.A. Shishkin, A.Yu. Antufyev, O. Motojima, A. Sagara, "Removal of cold alpha particles from helical device for fusion", Fusion Engineering and Design, Vol.81, Issues 23-24, November 2006, pages 2737-2742]: The moving drift island of the helium ash ( $W=35$  keV) can be arranged in LHD by the change of poloidal field coil currents. The main ion orbits are not deteriorated.

2) "Small magnetic island structure at the plasma periphery" leads to the resonance structure of particle orbits. The penetration of the  $W=350$  keV alpha-particles through the magnetic islands takes place in the Force Free Helical Reactor [A.A. Shishkin, A. Sagara, O. Motojima, O. Mitarai, T. Morisaki, H. Ohyabu, "Selective cold alpha-particles removal from fusion helical plasma" is being prepared for publication in Nuclear Fusion].

#### - **Collaboration with Los Alamos National Laboratory, USA**

1) The development and investigation of radiation resistant materials for optical windows in devices of plasma diagnostics. Research was carried out by University group (V. Gritsyna, V. Kobayakov, Yu. Kazarinov) in collaboration with groups from Los Alamos National Laboratory (LANL), USA (K. Sickafus) and Colorado School of Mines

(CSM), USA (I. Reimanis).

2) The investigations were continued of radiation effects in magnesium aluminate spinel crystals and ceramics under influence of plasma factors. There were investigated the spectra of radio-luminescence (RL) in spinel specimens of different origin. It was revealed that luminescence comes from electron-hole recombination and from transitions in excited impurity ions, such as manganese and chromium. Kinetics of growth of RL and decay of phosphorescence indicated the existence of different traps of charge carriers formed during the preparation of optical materials. Temperature of RL and glow curves at thermo-luminescence indeed show traps of different depth leading to maxima of light emission at temperatures about 350 and 550 K. These data can be used for choice of optimal temperature to decrease the interference of RL emission and signal from plasma.

3) There were also investigated the optical properties of spinel crystals after bombardment with helium ions of 170 keV. The increased cationic disorder in ion-implanted specimens was demonstrated by measuring of RL. Optical micrographs show that at low ion fluencies the heterogeneous nucleation of bubbles takes place, but at fluence of  $1 \times 10^{21}$  ions/m<sup>2</sup> the homogenous formation of small bubbles of the higher density was obtained. Finally at the highest fluencies  $1 \times 10^{21}$  ions/m<sup>2</sup> the bubbles begin to grow by coalescence and become large enough to cause flaking of the implanted surface. This data gives the range of fluencies of helium ions leading to deterioration. Results of collaborative investigations were published in 3 papers in International Journals:

1. V.T. Gritsyna, Yu.G. Kazarinov, V.A. Kobayakov, I.E. Reimanis, "Radiation induced luminescence in magnesium aluminate spinel crystals and ceramics of different origin", Nuclear Instruments and Methods, **B 250** (2006) p. 342-348.
2. V.T. Gritsyna, Yu.G. Kazarinov, "Thermal stability of radiation-induced optical centers in non-stoichiometric spinel crystals", Nuclear Instruments and Methods, **B 250** (2006) p. 349-353.
3. V.T. Gritsyna, I.V. Afanasyev-Charkin, Yu.G. Kazarinov, K.E. Sickafus, "Optical properties of magnesium aluminate spinel crystals implanted with helium ions", Vacuum, **81** (2006) p. 174-178.

- and presented at the 17<sup>th</sup> International Conference on Physics of Radiation Effects and Radiation Material Science (Crimea, Ukraine, September 2006), the 13<sup>th</sup> International Conference on Radiation Effects In Insulators (Santa Fe, USA, August 2005) and 17<sup>th</sup> International Conference on Ion-Surface Interactions (Zvenigorod, Russia, August 2005).

### 5.2.2 Plans for 2007

1) Collaboration with Colorado School of Mines (Colorado, USA) will be continued on the development of methods for determination of point defects, impurities, and their complexes in spinel which influence on the formation of transparent ceramics in the wide range of spectral region by using radio-, photo-, and thermo luminescence methods.

2) A new numerical tool - 3D Impurity Transport Code, which will help to study impurity ion transport in 3-D plasma configurations with stochastic layers of the magnetic field in drift optimized stellarators, will be created in cooperation between the University and MPIPP.

3) Analytical study and numerical calculation of the flow trajectories of impurity ions near X-points and O-point of the island structure is planned to be carried out.

4) Plasma transport control with the use of drift resonances: drift islands transfer and estafette of drift resonances, - is planned to be studied.

5) The linear and nonlinear kinetic theory of the inhomogeneous plasma with magnetic field-aligned (toroidal) shear flow will be developed. The effect of the toroidal shear flow on the anomalous transport will be investigated (V. S. Mikhailenko, V. V. Mikhailenko, N. A. Azarenkov).

6) The theory of surface extraordinarily polarized electromagnetic waves propagating in fusion devices will be developed.

7) Simulation of W sputtering and C layer growth by bombardment of surface by C and C+D ion flux by Monte-Carlo codes using binary-collision approximation. Study of basic effects related to elemental modification of surface under simultaneous bombardment with gaseous and non-volatile ions.

8) Test of high-flux ion source operation generating D ion flux. Irradiation of W coatings with pure D ion beam and mixed D-C ion beam.

## **6 UNITED STATES**

### **6.1 International collaborations in 2006**

#### **- Collaborations with Australia**

S. Hudson (PPPL) visited Bob Dewar (ANU) to collaborate on developing a new 3D equilibrium code.

#### **- Collaborations with Japan**

1) PPPL hosted a US/Japan workshop on US/Japan JIFT Workshop on March 14-16 titled "Issues in the theoretical analysis of three dimensional configuration". The workshop was organized by N. Nakajima (NIFS) and S. Hudson and D. Monticello (PPPL).

2) Auburn University hosted a US/Japan Workshop on November 13-15 titled "2nd Joint Meeting of US-Japan Workshop and Kyoto University 21st Century COE Symposium on New Approaches In Plasma Confinement Experiments In Helical Systems". There were 26 presentations and approximately 30 registered attendees. The workshop attracted a large group of international participants, with half of the presentations made by Japanese visitors from NIFS, Kyoto University and Tohoku University, and one by Arthur Weller of the W7-X project in Germany.

3) C. Hegna (U. Wis.) and S. Hudson (PPPL) collaborated with N. Nakjima and Y. Nakamura (NIFS), publishing the paper "Boundary modulation effects on MHD instabilities in heliotrons," Nuclear Fusion 46, 177 (2006).

4) D. Mikkelsen participated in two stellarator meetings at Kyoto University in September: "Workshop on Kinetic Theory in Stellarators", and "Coordinated Working Group Meeting for Confinement Studies in Stellarators". His presentation at the second meeting was entitled "Topics for Cooperation in Stellarator Gyrokinetic Studies", and detailed discussions on this topic continued the following week at NIFS. Planning discussions with personnel from NIFS and IPP-Greifswald for collaborations on forming an International Stellarator Profile Database, and investigating impurity transport and gyrokinetic stability.

5) J. H. Harris (ORNL) visited LHD twice to participate in analysis and planning for experiments with super dense core (SDC) plasmas. These visits were backed up by calculations of MHD stability and simulations of ion flow properties in the LHD SDC regime with D. A. Spong and R. Sanchez. During Harris' visit to Japan, he and Sanchez also developed a target configuration for ballooning mode studies on Heliotron-J.

6) D. A. Spong continued collaborative work with M. Isobe and others at NIFS on the topic of simulation of energetic particle instabilities and fast ion losses in CHS and LHD.

7) O. Motojima, H. Yamada, and S. Okamura (NIFS) visited PPPL in March to sign an agreement between NIFS and PPPL on cooperation in fusion research.

8) S. Okamura (NIFS) visited PPPL in November to attend the NCSX PAC meeting and discuss collaboration on NCSX and LHD. He also continued to collaborate on the use of the optimization codes.

9) K. Ichiguchi (NIFS) visited ORNL in July to work on a multiscale code that combines the slow increase in plasma beta by heating with the stellarator equilibrium developing stable path to high beta. The main result was a paper "Multi-scale approach to the solution of the nonlinear MHD evolution of Heliotron plasmas" by K. Ichiguchi and B. A. Carreras, J. Plasma Physics 72, 1117 (2006).

#### **- Collaborations with Germany**

1) M. Zarnstorff and A. Reiman (PPPL) visited MPI-Greifswald and collaborated with A. Weller (IPP) and the W7AS group to continue the analysis of the W7AS high-beta data. This resulted in an IAEA paper and two other conference papers.

2) C. Lechte (U. Stuttgart) visited HSX to collaborate on the analysis of HSX edge-blob turbulence analysis.

3) R. Moyer (UCSD), T/ Evans (GA) and I. Joseph (UCSD) collaborated with A. Runov and R. Schneider of MPI-Greifswald to model heat transport in the boundary of DIII-D discharges with externally applied resonant magnetic perturbations. This work was featured in three presentations at the PSI Meeting, Chengdu, China in May, 2006

4) A. Weller of MPI-Greifswald visited PPPL in November to attend the NCSX PAC meeting and discuss further collaboration on Wendelstein and NCSX.

5) R. Wolf of MPI-Greifswald visited PPPL in December to attend the first NCSX Research Forum and discuss future collaboration opportunities.

#### - Collaborations with Spain

1) B. Carreras visited CIEMAT, Madrid, Spain for four weeks each in April and October to analyze experiments at TJ-II studying a transition at the plasma edge that creates the edge shear flow layer. A paper was published on this ["Critical transition for the edge shear layer formation: Comparison of model and experiment", B. A. Carreras et al., Phys. Plasmas 13, 122509 (2006)] and another paper was completed on pulse propagation using the CTRW transport model, which was presented at the IAEA meeting and will be published in Nuclear Fusion.

2) R. Sanchez and J. H. Harris (ORNL) visited TJ-II and J-A. Sanchez (CIEMAT/Madrid) visited ORNL to develop a TJ-II configuration with a low threshold for ballooning modes that might be explored in 2007 (and beyond) TJ-II experimental campaigns. R. Sanchez visited CIEMAT and Universidad Carlos III in Madrid for three weeks in May and June to work on application of stochastic models to neoclassical transport in TJ-II.

3) P. M. Ryan and ORNL staff are working with the TJ-II NBI team to increase the available beam power. D. Schechter and J. Tsai (ORNL) visited CIEMAT to help in reconfiguration and tests of the beam units. An EBW emission viewing system was shipped to CIEMAT in November 2006 and J. Caughman visited in December to mount the system to the flange. The complete viewing system with a steering mirror will be installed on TJ-II in 2007.

4) S. Zweben (PPPL) continued the collaboration on gas-puff imaging of edge turbulence in TJ-II.

#### - International Stellarator Workshop

A. Boozer (Columbia U.), J. Canik (U. Wisconsin), K.L. Ku (PPPL), J. Lyon (ORNL), D. Spong (ORNL), and W. Reiersen (PPPL) gave invited talks at the 15th International Stellarator Workshop at CIEMAT in Madrid, Spain, and a total of twelve contributed papers were presented from all the US stellarator groups.

## 6.2 Program Plans for 2007

#### - CTH

The Compact Toroidal Hybrid (CTH) torsatron device at Auburn University is operating. Research activities will center on reliably generating stable torsatron plasmas with induced toroidal currents, and diagnosing the experimental equilibria primarily with passive magnetic diagnostics and soft X-ray arrays. Concomitant with this activity is the application of new 3-D reconstruction techniques to the CTH experimental results. Efforts during 2007 also include the continuing development of a mm-wave Faraday rotation diagnostic to measure the experimental plasma current profile, and the measurement of the edge plasma structure with Langmuir probes to assess transport in the presence of stochastic flux surface and islands.

- **HSX**

**HSX** activities for CY2007 demonstrated the reduction of thermodiffusion and electron particle and thermal diffusivity with quasisymmetry. These results were reported at the Chengdu IAEA conference, an APS invited talk, and have been accepted for publication in PRL.

- **NCSX**

Construction of the National Compact Stellarator Experiment (**NCSX**) will continue during 2007. The three vacuum vessel sectors will be instrumented with magnetic diagnostics and heating loops. Delivery of modular coil winding form deliveries will be completed in the spring, supplying the coil winding operations at PPPL. Delivery of the planar TF coils will begin. Assembly of the modular coils onto the vacuum vessel periods will start in late spring/early summer. The physics design of the external trim coils, magnetic alignment, and plasma facing component will be continued.

- **QPS**

The prototype casting of the modular coil winding form will be machined to the needed tolerance prior to winding the full-size prototype coil with the internally cooled cable conductor.

## **APPENDICES: TECHNICAL REPORTS ON 2006 ACTIVITIES**

### **APPENDIX 1: TECHNICAL REPORT ON 2006 ACTIVITY, GERMANY**

#### **Wendelstein 7-X**

In 2006, the project Wendelstein 7-X has continued with coil assembly. This, however, was slowed down by technical and quality problems with the non-planar coils. While the problems from the mechanical stability point of view to meet all forces with acceptable deviations and strain could be solved by strengthening the casing blocks, the problems with insulation failures due to fabrication faults required intensive investigations, repair and tests. By the end of 2006 29 coils (19 non-planar and 10 planar coils) were delivered for testing and 15 coils (10 non-planar and 5 planar coils) had been accepted after the cryotests at CEA Saclay, France. This allowed to restart assembly with full pace, and as of now work proceeds on two half-modules in parallel.

Design and manufacturing of the different machine components of the basic device has progressed considerably. All 299 ports have been completed and delivered, the first two modules of the outer vessel were accepted by IPP. Fabrication of the busbars started at FZJ and the first 6 conductors have been produced. The design of the support elements inter-connecting the coils progressed well and for the Narrow Support Elements the extensive R&D programme was concluded successfully.

The collaboration with FZJ, mostly in the field of the bus-bar system and the SC joint-housing for W7-X and diagnostic development and with FZK, predominantly in the area of ECRH and quench detection, continued successfully. New work packages, the design and manufacturing of the current leads as well as refurbishing of their coil test facility, TOSKA, and its operation as a second coil test facility for the W7-X coils have been agreed and work has started. The cooperation with CEA Saclay, where the coils are tested at low temperature, has intensified owing to the larger rate of coil production.

CEA and CIEMAT have sent personnel to W7-X/Greifswald to support the realisation of the project but also to train personnel for ITER.

The development of the diagnostics continued as planned. A significant increase in the number of cooperation contracts in the field of plasma diagnostic developments has been achieved in 2006 with the result that we now have collaborations on the following subjects: diagnostic neutral particle beam (Budker Institute), Heavy-ion-beam diagnostic (Charkov Institute), video diagnostic (KFKI-RMKI Budapest), thermal He-beam diagnostic, HEXOS and imaging X-ray spectrometer (FZ-Jülich), CO-monitor (Opole University, Poland).

The VUV spectrometer system HEXOS has been completed. The collaboration with FZJ concerning the development and test of the system at TEXTOR as well as the layout of the remote control and its integration into the W7-X vicinity continues successfully. A new collaboration (Opole University) on the development of a C-, O-Monitor diagnostic for W7-X starts in 2007.



## **Stellarator Theory**

In 2006, work of the stellarator theory division was concentrated on widening the scope of the theoretical work of the Greifswald branch institute and on further development of the stellarator concept. Main areas were

- 1) MHD theory of stellarators (progress with PIES equilibria, coil optimization at finite- $\beta$ , geodesic acoustic modes in general geometry, stability including kinetic effects)
- 2) Gyrokinetic simulations (progress with PIC simulations at small scales, gyrokinetic treatment of GAE modes, global itg modes in stellarators with radial electric field and TEM modes in stellarators) and
- 3) Plasma edge physics (progress with the code BoRiS for 3d but non-ergodized topology, benchmarking of the three lines of fluid codes being developed against each other).

## **WEGA**

The investigation of mode conversion heating for the 2.45 GHz microwave heating system was continued by means of modulation experiments. It was found that the location of the power deposition of a fast electron component strongly depends on the ambient magnetic field strength, which points on a resonant absorption in the overdense plasma. The setup and tests of the new 28GHz microwave heating system was continued. First plasmas were generated successfully for plasma discharges at a magnetic field strength of  $B=0.5T$  which will expand the operational regime of the machine. Fluctuation studies utilising Langmuir probes have shown a turbulent behaviour of the plasma. The new Heavy Ion Beam Probe Diagnostic foreseen for 0.5T operation was tested successfully in plasma operation. Within the framework of Wendelstein 7-X diagnostic development tests of a bolometer, a spectrometer, a neutral particle manometer and the data acquisition hardware for the magnetic diagnostics have been started or continued. Furthermore, the setup of a prototype installation of the W7-X control system has been started.

## APPENDIX 2: HIGHLIGHTS OF LHD EXPERIMENTS, JAPAN

During the 9<sup>th</sup> campaign, we have made significant progress in three areas, a discovery of an improved confinement mode, a long pulse discharge with nearly an hour duration and achievement of the average beta of 4.5 %. We discovered a new improved confinement regime, Super Dense Core (SDC) mode in diverted discharges in LHD. A SDC plasma develops naturally in LHD after a peaked, high density profile is generated by multiple pellet injections. With P (NBI absorbed power) = 10 MW,  $R_{ax}=3.75$  m, B = 2.64 T, a core density of  $\sim 4.5 \times 10^{20} \text{ m}^{-3}$  and temperature of  $\sim 0.85$  keV is maintained by an Internal Diffusion Barrier (IDB) located at  $\rho \sim 0.5$ . The discharges exhibit the highest fusion plasma performance achieved so far on LHD,  $n_0 \tau_E T_0 \sim 4.4 \times 10^{19} \text{ keV m}^{-3} \text{ s}$ . In the core region,  $\nabla T_e$  is small. In the outer region,  $\nabla T_e$  is relatively high, being determined by anomalous thermal diffusivity. We find that the observed  $T_e(0)$  and edge  $\nabla T_e$  increase with  $P/n_{edge}$ . And thus lowering  $n_{edge}$  leads to higher edge  $\nabla T_e$  and  $T_e(0)$ . The density profile outside the IDB behaves as usual with  $n \sim 6 \times 10^{19} \text{ m}^{-3}$  at the last closed flux surface ( $\rho = 1$ ). After the termination of a sequence of pellet injection,  $n(0)$  decays slowly with a time constant of  $\sim 1$  s for the case with B = 2.64 T, showing that the diffusion coefficient in the IDB is a very small value, less than  $\sim 0.02 \text{ m}^2 \text{ s}^{-1}$ . SDC plasma does not appear in discharges fueled by gas puffing alone because edge recycling results in a flat or slightly hollow density profile. The use of the LID in the SDC discharge increases pumping of edge-recycled particles and helps to maintain a low edge density and hence high edge  $\nabla T_e$ . The relatively low edge density also avoids the edge radiative collapse, which limits the operational density.

Steady state plasma operation experiment was carried out as one of the main subjects. The discharge duration was 54 minutes. The total injected heating energy reached 1.6 GJ. The plasma was mainly sustained by an ICRF heating of 380 kW in average power and an ECH power of 110 kW. Sparks were observed in the vacuum vessel during the long pulse discharge. Intensive sparks causes the plasma collapse and correlate with the ICRF power. Then, the long plasma discharge was realized by the fine control of the ICRF power with monitoring the sparks. Helium plasma mixed with the hydrogen minority ions was used for the minority heating of the ICRF heating scheme. A line-averaged electron density was  $0.4 \times 10^{19} \text{ m}^{-3}$  and the central ion and electron temperatures were about 1 keV. The magnetic axis is swept to spread the heat flux over the larger area on the divertor plates. The temperatures at the divertor plates saturated during the discharge and the maximum temperature increase was less than 300 °C. The discharge was terminated by influx of iron impurity and thus the most critical issue for achievement of further longer pulse discharge is to overcome the problem caused by the heavy impurity influx.

In LHD, the production of high beta plasma has progressed successfully with increasing heating power of neutral beam. In recent experiments, a scan of plasma-aspect-ratio,  $A_p$ , was mainly performed from 6.3 to 8.3 to investigate the configurational dependence of MHD characteristics of high-beta plasmas. Increment of  $A_p$  causes an increase in the central rotational transform and reduces the Shafranov shift. Large  $A_p$  is favorable for a heating efficiency and a transport because the outward shift of the magnetic axis leads to an increase in a helical ripple loss of particles. It is also suitable for raising an equilibrium beta-limit. However, a reduction of the plasma shift restricts spontaneous formation of magnetic well and thus violation of MHD

stability is concerned. The survey of the optimum operation provided the highest  $\langle \beta_{\text{dia}} \rangle$  value of 4.5 % at  $A_p = 6.6$ , and achieved  $\langle \beta_{\text{dia}} \rangle$  gradually decreases with increasing  $A_p$ .

### **APPENDIX 3: HIGHLIGHTS OF CHS EXPERIMENTS, JAPAN**

In 2006, CHS experiment had a last experimental campaign for its 17 years activities in the toroidal confinement physics study with a stellarator configuration. Major results from the last stage of CHS experiment were summarized in the four papers presented in 2006 IAEA fusion energy conference (FEC).

Turbulent transport study using two sets of heavy ion beam probe (duo HIBP) was continued to investigate the dynamics of the turbulence with the zonal flow components. The frequency spectrum of the turbulent particle flux was measured at the internal transport barrier (ITB). It was clearly shown that strong flux at about 70 kHz was suppressed by the formation of ITB. Simultaneous measurements of the time behavior of the high frequency drift turbulence and the low frequency zonal flow components showed the dynamic exchange of the turbulence energy between those two branches of fluctuations.

H-mode study was extended to high density plasma discharges ( $n_e \sim 1 \times 10^{20} \text{ m}^{-3}$ ) from the previous results with a middle range of density ( $3 - 5 \times 10^{20} \text{ m}^{-3}$ ). The combination of two confinement improving phenomena was obtained for the high density H-mode discharges. The 'reheat mode' was first appeared by stopping a strong gas puffing followed by the formation of an edge transport barrier. The edge electron temperature increased forming a high edge pedestal thermal pressure which was not observed in the previous middle density H-mode discharges.

The confinement of the high energy particle with the existence of strong MHD modes was studied. Direct loss flux of high-energy hydrogens from the heating beam ( $E \leq 40 \text{ keV}$ ) was measured with several methods of particle detectors, which are capable of measuring the particle energy and escaping trajectories. Energetic particle mode (EPM) and Toroidal Alfvén eigenmode (TAE) were observed and the synchronized energetic particle loss was analyzed.

Further data analysis and the physics interpretation work will be continued in 2007 in order to complete the documentation of CHS experiment program.

#### APPENDIX 4: HIGHLIGHTS OF HELIOTRON J EXPERIMENTS, JAPAN

Configuration control studies of Heliotron J have been carried out with an emphasis on the confinement improvement by the bumpy field which should play a key role in the neoclassical optimization of the helical-axis heliotron. Measurements of the enhancement factor,  $H_{ISS04}$ , of the experimental global energy confinement time,  $\tau_E^{exp}$ , with regard to the recent international stellarator scaling law,  $\tau_E^{ISS04}$ , have been made for 0.3-MW, 70-GHz on-axis ECH plasmas by changing the bumpiness,  $\epsilon_b$ , under the basically similar average magnetic axis position, minor plasma radius and edge rotational transform conditions. The experimental analysis suggests that the reduction in the “effective helical ripple”,  $\epsilon_{eff}$ , may introduce a beneficial effect on the improvement of  $H_{ISS04}$  not only in the L-mode but also in the transient phase of the H-mode.

A formation and confinement experiment for fast ions was performed using ICRF minority heating scheme with a proton minority and a deuteron majority. The role of one of the Fourier components, the bumpiness, is a key issue for the design principle of the magnetic field of Heliotron J, where the particle confinement is controlled by the bumpiness. Two loop antennas were installed on the low-field side of the corner section of Heliotron J. High energy ions were produced up to 10 keV by injecting an ICRF power into an ECH target plasma. Three configurations were selected; the bumpy ripple,  $\epsilon_b$ , was 0.01, 0.06 and 0.15 for the study of the configuration dependence of the fast particle confinement. The tail temperatures measured by a charge-exchange neutral energy analyzer were 1.04, 0.87 and 0.47 keV for the ripples of 0.15, 0.06 and 0.01, respectively. The heating efficiency of bulk ions was also better in the high bumpy case.

Non-inductive current of electron cyclotron heated (ECH) plasmas has been examined. The bootstrap and EC currents were separated by comparing the experiments with positive and negative magnetic field. The estimated bootstrap current was found to be affected by the magnetic field configuration. It increases with increasing bumpy component of the magnetic field spectrum, which agrees well with a neoclassical prediction using the SPBSC code. The EC current driven by oblique launch with respect to the magnetic field strongly depends on the field configuration and the EC power deposition location. The EC current was enhanced when the EC power is deposited on the magnetic axis. The maximum EC current is  $I_{EC} = -4.6$  kA, and current drive efficiency is  $\eta = n_e R I_p / P_{EC} = 8.4 \times 10^{16}$  A/Wm<sup>2</sup>, respectively. The EC current changes its flowing direction depending on the magnetic field ripple structure where the EC power is deposited.

A spontaneous shift of diverted plasma position during a discharge is investigated. The shift of a few cm was observed for discharges with a non-inductive plasma current < 3 kA and the plasma stored energy < 3 kJ. The observed shift was related to the change in the plasma current more closely than the stored energy. The most plausible mechanism for the observed shift is the change in the edge field topology caused by the plasma current. The three-dimensional finite- $\beta$  equilibrium calculations assuming profiles of plasma pressure and plasma current density profiles indicate that the effect of the plasma current depends not only on its direction but also on the current density profile. This experiment points out not only the importance of current control to fix the

divertor plasma position in a low shear helical device but also the possibility of "divertor swing" for reduction of the divertor particle/heat load by controlling a small amount of plasma current within a tolerable influence on the plasma performance.

## APPENDIX 5: TECHNICAL REPORT ON 2006 ACTIVITY, RUSSIA

### 1) GENERAL PHYSICS INSTITUTE (GPI)

1. A series of experiments in the L-2M stellarator has been carried out for studying characteristics of an ECR heated plasma in the presence of an induction current producing variations of the magnetic field structure. A microwave beam (the second harmonic of the gyrofrequency, X-mode) with a mean power of  $P = 200$  kW was applied to a plasma with a mean density of  $n_e = (1-2) \times 10^{19} \text{ m}^{-3}$ . The plasma stability was studied in the range of induction currents  $\pm 4-14$  kA. At "positive" currents that produce a positive addition to the vacuum rotational transform, the plasma deviates from usual behavior when the current exceeds  $I_+ > 14$  kA and large-amplitude oscillations in the electron temperature are observed throughout the plasma column. Numerical simulation shows that, in this case, the rotational transform in the central region of the plasma column reaches  $\iota = 2\pi$ . At "negative" currents  $|I_-| > 10$  kA, intense fluctuations are observed in the Pfirsch-Schlueter currents, which is evidence of strong MHD perturbations in the core plasma. Magnetic probe measurements have revealed the excitation of MHD bursts of duration of 1-2 ms that are assigned to the zero toroidal mode and correlate with fluctuations in the Pfirsch-Schlueter current. The numerical simulation predicts that a multi-axis structure of magnetic flux surfaces with a zero rotational transform can form in this case.

2. In the latter part of the year, we have completed the construction of an ECR supply system which allows two high-power gyrotrons (of 800 kW each) to be operated independently. Our aim is to continue ECRH experiments with substantially higher energy release.

3. With the aim of upgrading interferometer measurements in the L-2M stellarator, a new laser has been developed and constructed in cooperation with the Institute of Physical Problems of the Russian Academy of Sciences. This water-vapor laser has two operating frequencies with orthogonal beam polarization. Modification of the interferometer measuring the electron density profile may do much to upgrade sensitivity, accuracy, and reliability of measurements.

4. A relatively simple model of transport processes in stellarators is constructed that is based on neoclassical theory and accounts for anomalous losses. The model is used to perform calculations for the L-2M, ATF, CHS, and LHD stellarators over a wide range of plasma densities and absorbed powers. The plasma energy lifetime calculated for these devices coincide to within factor on the order of unity with those obtained from the ISS95 and LHD empirical scaling.

### 2) KURCHATOV INSTITUTE

In 2006, integral optimization of quasi-isodynamical 12-period stellarator has been completed in full. The plasma boundary for optimized  $N=12$  stellarator was found; and using its form, the module coils, which provide the needed plasma boundary, have been calculated. Resulted free-boundary plasma equilibrium offers advantages of initial configuration, such as good confinement of fast particles and low neoclassical transport.

Research work on the optimization of quasi-isodynamical stellarators with different numbers of periods was continued. The form of new plasma boundary for N=6 stellarator with good plasma confinement, stable for high value of parameter  $\langle\beta\rangle = 0.2$ , has been calculated.

Possibility of strong reduction of the effective ripples at moderate values of  $\langle\beta\rangle = 0.05$  was investigated. The value of the effective ripples is shown to be reduced up to 0.001. At this value of the ripples, transport fluxes in the system for rare collision regime become in the factor of 500 -1000 less than in other optimized systems with the same averaged minor radius. Consistency of low neoclassical transport with high value of  $\beta$  is the subject of carrying researches.



## APPENDIX 6: SUMMARIES OF THE INSTITUTE OF PLASMA PHYSICS OF THE NSC KIPT, KHARKOV, FOR 2006

### Plasma Theory

1) Optimization of stored energy in the  $1/\nu$  regime for URAGAN-2M started in 2005 is continued (V.V.Nemov, S.V.Kasilov and V.N.Kalyuzhnyj in collaboration with B.Seiwald and W.Kernbichler (Institut für Theoretische Physik, Technische universität Graz, Austria)).

The fast field line tracing NEO code is applied for a realistic model of the magnetic field where magnetic field produced by the helical winding and its spatial derivatives are calculated on the basis of the Biot-Savart law. In the previous work regimes were analyzed with magnetic configuration well centered with respect to the vacuum chamber. Such a position of magnetic surfaces corresponds to somewhat under-compensated vertical field of the helical winding and enhanced  $1/\nu$  transport coefficients. Now, cases are considered with fully compensated vertical field of the helical winding. In these conditions magnetic surfaces turn out to be inward shifted with respect to the vacuum chamber. This leads to the reduction of the useful plasma volume because of its limitation by the vacuum chamber. Nevertheless, the decrease of  $1/\nu$  transport (by one order of magnitude) leads to an increase of the stored energy. The results have been published in the paper: B. Seiwald, V. N. Kalyuzhnyj, S. V. Kasilov, W. Kernbichler, V. V. Nemov, Fusion Science and Technology, Vol.50, 447-456 (2006).

2) Using new target functions (V. V. Nemov, S. V. Kasilov, W. Kernbichler, G. O. Leitold, Phys. Plasmas, 12, 112507 (2005)) which are related to collision-less  $\alpha$ -particle confinement and allow to save computer resources, a number of optimized stellarator configurations has been analyzed with respect to trapped particle confinement (V. V. Nemov, S. V. Kasilov (NSC,KhIPT) in collaboration with W.Kernbichler, G.O.Leitold (Institut für Theoretische Physik, Technische universität Graz, Austria) and L.P.Ku (PPPL, Princeton)),

In particular, it follows from the computations that for the N3ARAB configuration of NCSX the averaged radial  $\nabla B$  drift velocity is smaller than for an equivalent classical stellarator more than 5 times in total. This is the best result as compared with another optimized systems such as inward shifted configuration of LHD, high mirror configuration of W-7X, and optimized quasi-isodynamical stellarator configuration. 33<sup>rd</sup> EPS Conference on Plasma Physics, Italy, Frascati, June 2006, report P4.164.

3) The data base for the coils of the Uragan-2M magnetic system, which was used earlier for computations of magnetic surfaces taking into account the influence of current-feeds and detachable joints of the helical winding, is transformed to a new form which is suitable for the already existing Biot-Sawart code for computations of the magnetic field strength and its spatial derivatives (V. V. Nemov, V. N. Kalyuzhnyj, S. V. Kasilov, G. G. Lesnyakov in collaboration with N. T. Besedin (Kursk State Technikal University, Russia))

With the help of this code, using the transformed data base, computations are performed of the magnetic surfaces and the geodesic curvature,  $k_G$ , of the magnetic

field lines for few configurations of Uragan-2M. Because of the non-symmetric arrangement of current feeds and detachable joints the stellarator symmetry of the resulting magnetic field is violated. Therefore, a preliminary computation of the magnetic surface is necessary in order to determine starting conditions for  $k_G$  computation. The computations which have been performed are considered as a preliminary work for future transport computations. The results have been reported at 11-th International Conference and School on Plasma Physics and Controlled Fusion, Alushta (Crimea), Ukraine, September 2006, 1-33.

4) A numerical method for fast evaluation with the help of integration along the magnetic field lines of the bootstrap current and current drive efficiency in stellarators with arbitrary collisionality has been developed. (S.V.Kasilov, V.V.Nemov in collaboration with W.Kernbichler, G.O.Leitold and K.Allmaier (Institut für Theoretische Physik, Technische universität Graz, Austria)).

A numerical method for the solution of the linearized drift-kinetic equation in stellarator geometry using the integration along the magnetic field lines has been developed. The purpose of this method is computation of the matrix of transport coefficients (particle and heat diffusion coefficients and electrical conductivity coefficient as well as cross-coefficients such as bootstrap coefficient) and computation of the generalized Spitzer function (current drive efficiency). This method is applicable for finite plasma collisionality in the confinement regimes where plasma rotation due to the radial electric field is negligible. Method can be used for the stellarator magnetic fields given in magnetic and in real space (cylindrical) coordinates. In the latter case magnetic configuration may contain islands and ergodic magnetic field regions. The results in this case are obtained for the regions with existing magnetic surfaces. Method has been realized for the Lorentz collision model (this is sufficient for the computations of mono-energetic transport coefficients) and for the full linearized collision operator (this is necessary for the computations of the generalized Spitzer function). Method has been tested for the real space geometry of the Wendelstein-7AS stellarator where it well agrees with the asymptotical results for the transport coefficient in the one over nu regime. Computations of the generalized Spitzer function have been performed so far for the tokamak geometry. The results have been reported at 15-th Stellarator Workshop and the IAEA Technical Meeting (Madrid, October 2005), P2-15, at the 33rd EPS Conference on Plasma Physics (Rome, June 2006), P2.189 and at Combined Meeting of Kinetic Theory in Stellarator and Coordinated Working Group Meeting (Kyoto, September 2006).

5) New methods of selective cold alpha-particles removal from the fusion helical plasma have been developed. (A.Shishkin in collaboration with O.Motojima and A.Sagara (NIFS, Japan)).

Use of Drift Resonances ( $iota^*=n/m$ ) of Removed Particle. The moving drift island of the helium ash ( $W=35$  keV) can be arranged in LHD by the change of PF coil currents. The main ion orbits are not deteriorated. (A.A.Shishkin, A.Yu.Antufyev, O.Motojima, A.Sagara, Fusion Engineering and Design, Vol.81, Issues 23-24, November 2006, pages 2737-2742).

Small magnetic island structure at the plasma periphery leads to the resonance structure of particle orbits. The penetration of the  $W=350$  keV alpha-particles through

the magnetic islands takes place in the Force Free Helical Reactor. (A. A. Shishkin, A. Sagara, O. Motojima, O. Mitarai, T. Morisaki, H. Ohyabu, is being prepared for publication in Nuclear Fusion).

6) Study of influence of weakly relativistic effects on the Electron Bernstein Wave heating of plasma confined in the TJ-II stellarator near the fundamental electron cyclotron harmonic using TRUBA beam/ray tracing code. (S. S. Pavlov in collaboration with F. Castejon, A. Cappa, A. Fernandez (CIEMAT, Madrid, Spain) and M. Tereshchenko (General Physics Institute, Moscow, Russia)).

The result is that relativistic effects are not negligible and must be taken into account both on ray trajectories and in power absorption estimations.

### Plasma Experiments

7) At the end of 2006 the Uragan-2M torsatron after full revision was assembled and put into operation. The first results with RF produced and heated plasma were obtained with magnetic field of 0.5 T.

**8) ITB-associated processes at the plasma boundary.** On the Uragan-3M torsatron with RF produced and heated plasmas ( $\omega \lesssim \omega_{ci}(0)$ , the multimode Alfvén resonance regime), studies of effects associated with the internal transport barrier (ITB) formation were continued. It has been shown recently that a discharge mode spontaneously arises which is characterized by an increase of density, temperature, confinement time. According to estimates, the energy confinement time underwent an 1.2-1.3-times increase. This regime was attributed to ITB formation in the region of island chain with stochastized field lines (Volkov E.D. et al., Czech. J. Phys. **53** (2003) 887). Soon after, it was observed that in the process of ITB formation a layer with a strong shear of radial electric field  $E_r$  arose near the plasma boundary. In this layer turbulent fluctuations of density and electric field were effectively suppressed. Accordingly, the anomalous transport associated with the turbulence was also reduced, that is, an H-like confinement mode was also formed (Chechkin V.V. et al., Plasma Phys. Control. Fusion **48** (2006) A241).

**9) Studies of ITB development by microwave correlation reflectometry technique.** An efficient method of elucidation of effects resulting in transport barrier formation in U-3M is the microwave correlation reflectometry. This method is based on measurements of the shift of cross-correlation functions of two fluctuating microwave signals reflected from plasma layer sections which have the same density but differ by their poloidal and radial positions (A.I. Skibenko, O.S. Pavlichenko). In particular, it has been observed that oscillations of the reflected microwave signal arise at the discharge phase preceding the ITB formation. These oscillations correspond to a  $\sim 1$  cm radial shift of the reflecting layer with the frequency of  $\sim 400$  Hz and to corresponding oscillations of the plasma poloidal rotation velocity. These oscillations are damped with the ITB regime setting in. Such oscillations-relaxations may be result from localization of the reflecting layer in the region of stochastized field lines (so-called "oscillating islands" observed recently in the LHD heliotron).

It follows from observations of time evolution of the poloidal rotation velocity that ITB formation is accompanied by occurrence of a sharp velocity shear. With this, the ITB appears more stable in layers with the relative radius  $\rho \sim 0.1-0.3$  (counted from the

magnetic axis), that is, in the region of the island structure, where the ITB duration can attain ~10 ms. In more distant layers ( $\rho \sim 0.4-0.7$ ) the relaxations last longer and the stable regime sets in later and lasts for a shorter time (1-4 ms).

**10) Generation of fast ions and its effect on H-mode formation.** As it is known, the method of plasma production and heating in the U-3M torsatron (Alfven resonance in the  $\omega \lesssim \omega_{ci}(0)$  range of frequencies) results in a two-temperature ion energy distribution ( $T_{i1} \sim 50-80$  eV,  $T_{i2} \sim 250-400$  eV with  $T_e(0) \sim 500-700$  eV at  $\bar{n}_e \sim 10^{12}$  cm<sup>-3</sup>) with a minor (<1%) group of suprathermal ions with energies up to several keV. With this, the hotter and suprathermal ions (hereinafter, fast ions – FI) are in the long mean free path regime of neoclassical transport, which is typical for large-scale stellarator devices. Therefore, studies of mechanisms of FI generation and effects of FI on plasma confinement in a middle-size stellarator-type facility is of great interest, especially in the U-3M case where a specific method of plasma production and heating is used.

As recent research has shown, in U-3M occurring of H-transition due to hard bifurcation of  $E_r$  toward a more negative value is always preceded by a substantial rise of FI (>500 eV) content in the confinement volume and synchronized with a burst-like outflow of FI to the divertor region (spacings between the helical coils) on the ion  $\nabla B$  drift side. It has been observed that the peak of FI generation/accumulation in the confinement volume and the bursty-like rise of their loss occur at the same density, not depending on the RF power, and the magnitude of the burst depends resonantly on the magnetic field strength. On this basis, a conclusion is drawn that the FI ion generation is caused by an RF mechanism, the most possible one being a so-called local Alfven resonance in an essentially radially non-uniform plasma. Due to such a resonance, in a plasma layer where the relation  $\omega = k_{\parallel} V_A$  is fulfilled ( $\omega$  is the generator frequency,  $k_{\parallel}$  is the parallel wave number defined by RF current distribution in the antenna,  $V_A$  is the Alfven velocity) a strong enhancement of the RF field takes place. The fast ions may occur in the resonance layer due to cyclotron heating/acceleration. An additional RF field amplification can result from the coupling resonance between the exciting antenna and the toroidally and radially bounded plasma column.

An extremely important aspect of the effect of FI generation in U-3M is its influence on H-mode formation. The experimentally observed fact that the H-transition is always synchronized with an increase of FI loss may indicate that the  $E_r$  bifurcation toward a more negative value and occurrence of a transient layer between the  $E_r > 0$  and  $E_r < 0$  regions with a strong  $E \times B$  velocity shear at the plasma boundary where the anomalous transport is suppressed are driven by the ion orbit loss and by the radial flow of drift orbits of locally trapped ions (Shaing K.S., Crume E.C., Jr., Phys. Rev. Lett. **63** (1989) 2369; Shaing K.S., Phys. Rev. Lett. **76** (1996) 4364).

11) The measurements of radial plasma potential and electron density as well as their fluctuations with Heavy Ion Beam Probe (HIBP) diagnostics and study of their influence on the plasma confinement in helical axis Stellarator TJ-II with ECR and NBI heating were continued in the frame of the collaboration with CIEMAT (Madrid)

11.1. In most helical systems electron Internal Transport Barriers (e-ITB) are observed in Electron Cyclotron Heated (ECH) plasmas with high heating power density. In the stellarator TJ-II, e-ITBs are easily achievable by positioning a low order rational surface close to the plasma core, because this increases the density range in which the

e-ITB can be formed. Experiments with different low order rationals show a dependence of the threshold density and barrier quality on the order of the rational (3/2, 4/2, 5/3). In addition, during the formation of e-ITB quasi-coherent modes are frequently observed in the plasma core region. The mode can exist before or after the e-ITB phenomenon at the radial location of the transport barrier foot but vanishes as the barrier is fully developed

In TJ-II e-ITBs can be triggered by positioning a low order rational surface at the plasma core region. The rational surface contributes to the outward electron flux that creates a locally strong positive radial electric field. In this way, e-ITBs are achievable at higher plasma densities, reducing the ECH power per particle ( $P_{ECH}/n_e$ ) threshold.

Experiments with different low order rationals show a dependence of the threshold density (and also of the barrier quality) on the order of the rational. The island width may be the relevant parameter in the modification of the radial electric field induced by the rational surface. e-ITB triggered by the 4/2 rational produces an increase in the electron temperature at the plasma centre of about 25% at relatively high line densities:  $0.7-0.9 \cdot 10^9 \text{ m}^{-3}$ . Comparatively, the increase in the central electron temperature in e-ITBs triggered by the 3/2 rational is less pronounced -close to 15% -at similar densities:  $0.7-0.8 \cdot 10^9 \text{ m}^{-3}$ .

11.2. Previous experiments in the TJ-II stellarator have shown that the generation of spontaneous perpendicular sheared flow (i.e. naturally occurring shear layer) requires a minimum plasma density. Plasma density and heating ECR power have been systematically modified in TJ-II to control the shear layer development. A biased electrode has been also used to externally change the edge radial electric field. Sheared flow development/damping occurs in time scales of the order of the turbulence time scale (typically 10-50  $\mu\text{s}$ ). The statistical properties of edge fluctuations have been also investigated during the shear layer development.

Quasi-coherent modes are observed with maximum amplitude close to the foot of the e-ITB, where the  $E_r \times B$  shear flows develop at the e-ITB formation. The mode can exist before or after the e-ITB phenomenon at the radial location of the barrier foot but vanishes as the barrier is fully developed. A possible cause of the reported quasi-coherent mode may be attributed to MHD instabilities. In that case, the sheared radial electric field developed at the e-ITB formation may act as the stabilizing mechanism of the mode.

11.3. In the TJ-II stellarator there is a threshold density to trigger the development of edge shear flows. Density ramp experiments show that sheared flows can be driven in a time scale of tens of microseconds. These sheared flows appear to be organized near marginal stability with fluctuations in TJ-II. The universality of this property is easily understood assuming that edge sheared flows are controlled by turbulence

Transition from the positive potential to the negative one starts at the edge when the line averaged density exceeds a threshold value.

11.4. MHD activity in TJ-II depends on the heating methods using ECRH or NBI. The effect of low order rationals inside the rotational transform profile on MHD activity and transport properties has been studied experimentally. The appearance of low

frequency modes (some tens of kHz) in ECRH plasmas depends on the potential transform profile and plasma density. In NBI plasmas, high frequency (150-300 kHz) modes have been found in plasmas with line density range  $0.6\text{-}3 \cdot 10^{19} \text{ m}^{-3}$  and heated with on/off-axes electron cyclotron heating.

12) Comparative study of the plasma electric fields behavior in the T-10 tokamak and TJ-II stellarator during ECR heating.

The evolution of the electric potential in a wide range of regimes of ECR heating using upgraded Heavy Ion Beam Probing diagnostic in T-10 and TJ-II was investigated. On both devices the potential in SOL plasma were measured by multipin Langmuir probes. Comparison of the plasma potential behavior in both devices showed the clear link between the core plasma potential and ECRH power: The stronger power leads to the higher (more positive) absolute potential.

In tokamak the electric potential follows the electron temperature similarly to its behaviour in stellarator. Potential in the plasma core and edge depends on plasma density. The negative plasma potential was observed when  $n_e$  is above some threshold value.

It is possible to modify global confinement and plasma parameters with biasing, illustrating the direct impact of the radial electric fields on stellarator and tokamak confinement properties.

13) The Heavy Ion Beam Probe (HIBP) diagnostic for WEGA Stellarator have been tested. The probing  $\text{Na}^+$  beam with intensity up to  $20 \mu\text{A}$  and energy up to  $60 \text{ keV}$  was obtained (L.I.Krupnik and HIBP team in collaboration with Wega team). The optimized probing scheme for C+C- port combination was found. The radial range of volume (for  $0.5 \text{ T}$ ,  $40 \text{ keV}$ ) is  $0.3 < \rho < 1$ , the geometrical limitations were not permit to reach the plasma column center. Toroidal focusing of the secondary trajectories will lead to necessity to construct rather complex secondary beam line. The secondary beam of  $\text{Na}^{++}$  with intensity up to  $0.3\text{-}0.1 \text{ nA}$  reach energy analyzer detector plates with gas puffing. The first measurements of the secondary particles from plasma volume were carried out.

### List of Publications

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## APPENDIX 7: SUMMARIES OF KARAZIN NATIONAL UNIVERSITY, KHARKOV FOR 2006

1) Science and Technology Center in Ukraine Project # 3685 "Impurity transport in 3D magnetic field for the stellarator Wendelstein 7-X and tokamaks" (manager I. Girka) has started on May 1, 2006.

The effect of the finite plasma pressure on the magnetic field configuration of the stellarator Wendelstein 7-X (the second chain of the islands excitation, overlapping of adjacent island chains and stochastization of the magnetic field lines) was studied.

New numerical tool, which will help to study impurity ion transport in 3-D plasma configurations with stochastic layers of the magnetic field in drift optimized stellarators, was developed by Oleg Shyshkin (University). The following databases were included into the 3D Impurity Transport Code to describe geometric parameters of the Wendelstein 7-X stellarator, vacuum magnetic field data for the Wendelstein 7-X stellarator in Boozer coordinates, magnetic field data for the Wendelstein 7-X stellarator in Boozer coordinates under finite plasma pressure, background plasma density and temperature profiles (finite plasma pressure profile) and the correspondent magnetic field data for the Wendelstein 7-X stellarator in Boozer coordinates, and atomic data for the molybdenum atom.

The results of the studies were published in 3 journal papers and were presented in 4 reports on scientific conferences:

1. I.O. Girka, "The reversed effect of the electromagnetic wave spatial multimodality on Alfvén wave heating in helical magnetic field", *Physica Scripta*, 2006, vol. 73, issue 5, p. 490-498.
2. V.O. Girka, I.O. Girka, "ECR plasma heating caused by absorption of surface flute modes in a bumpy magnetic field", EC-14. 14<sup>th</sup> Joint Workshop on Electron Cyclotron Emission and Electron Cyclotron Resonance Heating. Santorini, Greece. May 09-12, 2006. Program & Abstracts. P. 23. ID:1
3. V.O. Girka, I.O. Girka, "Surface flute modes in a rippled magnetic field", *Plasma Physics Reports*, 2006, vol. 32, No. 9, p. 750-758.
4. I.O. Girka, O.I. Girka, V.O. Girka, I.V. Pavlenko, "Effect of a noncircularity of a cross – section of the outer magnetic surface on the dispersion properties of surface flute modes", 11<sup>th</sup> International Conference – School on Plasma Physics and Controlled Fusion. Book of abstracts. Alushta (Crimea), Ukraine, September 11-16, 2006. 4-1. P. 78.
5. I.O. Girka, V.O. Girka, I.V. Pavlenko, "Effect of eigen surface wave absorption on edge temperature profile during ICRH", *Ibid*, 2-3. P. 69.
6. I.O. Girka, O.I. Girka, V.O. Girka, "Theory of surface flute modes propagating along plasma-metal interface in the presence of an external axial magnetic field", *Ibid*, 4-2. P.79.

7. I.O. Girka, V.O. Girka, "Additional ECR Heating of a Radially Inhomogeneous Plasma via the Absorption of a Satellite Harmonics of the Surface Flute Modes in a Rippled Magnetic Field", Plasma Physics Reports, 2006, vol. 32, No. 12, p. 1047-1051.

Three manuscripts more were submitted to journals.

2) Kinetic theory of the inhomogeneous plasmas with inhomogeneous shear flow (V. S. Mikhailenko, V. V. Mikhailenko),

It is found that the inhomogeneity of the velocity shear of the flow across the magnetic field is a source of the new mechanism of the resonant damping of drift and ion cyclotron waves across the magnetic field due to their interaction with ions, which is akin to the finite-beta resonance in the curved magnetic field. The condition of that resonance is  $\omega(k) - k_y V_0(x) - \frac{k_y V_0''(x) v_\perp^2}{4\omega_{ci}^2} - n\omega_{ci} = 0$ . This resonance is particularly important for drift modes with a frequency equal to  $\omega(k) \approx k_y v_{de}$ . In that case resonance condition does not depend on the wave number  $k_y$  and fulfils for the total spectrum of drift waves. Linear and renormalized nonlinear theory of the drift and ion cyclotron instabilities in the plasma shear flow across the magnetic field was investigated. It was proved, that shear flow across the magnetic field has stabilizing effect on the development of the instabilities considered.

3) The investigation of the processes that take place in the composition thin films structures (stainless steel + Cu + W) in consequence of radiation treatment by the D and He ions with average energy is continued at the University:

- the collections of the D and He implanted particles in the composition thin films structures
- structurally-phase changes of the irradiated materials
- influence of the radiation disturbances, that arise in the composition thin films structures, to theirs sorption and desorption properties

These works were carried out by the Sandwich PhD student A. Onyschenko, L. Tishchenko, V. Bobkov (University).

Head of Council on Plasma Physics and Controlled Fusion  
of the National Academy of Science of Ukraine

Prof. K. Stepanov

Director of IPP NSC KIPT  
Deputy Head of Council on Plasma Physics and Controlled Fusion  
of the National Academy of Science of Ukraine

Prof. V. Tereshin

## APPENDIX 8: TECHNICAL REPORT ON TJ-II ACTIVITIES IN 2006

The results achieved in the TJ-II stellarator during 2006 were obtained in plasmas created and heated by Electron Cyclotron Resonance Heating (ECRH) (2 x 300 kW gyrotrons, at 53.2 GHz, 2<sup>nd</sup> harmonic, X-mode polarisation) and Neutral Beam Injection (NBI). Beams of 400 kW port-through (H0) power at 30 kV, were injected into target plasmas created using one or both ECRH lines. Recent improvements in plasma diagnostics have led to a better understanding of the confinement properties of TJ-II, including a test of the collisional-radiative model by a supersonic He beam, the development of a dedicated neutral beam injection system and charge-exchange diagnostic, two-colour infrared interferometer and spectroscopy. The main conclusions can be summarized as follows:

- 1) The investigation of plasma potential profiles reveals a direct link between electric fields, density and plasma confinement. The smooth change from positive to negative electric field observed in the core region as density is raised is correlated with global and local transport results, showing a confinement time improvement and a reduction of electron transport. The statistical description of transport is emerging as a new way to describe the coupling between profiles, plasma flows and turbulence.
- 2) TJ-II experiments show that the location of rational surfaces inside the plasma can, in some circumstances, provide a trigger for development of core transitions. TJ-II findings provide critical test for different models proposed to explain the appearance of ITBs linked to magnetic topology.
- 3) The investigation of momentum transport mechanisms in the core and edge region is emerging as a key area of research in the TJ-II stellarator. In the plasma core, perpendicular rotation is strongly coupled to plasma density, showing a reversal consistent with neoclassical expectations. Contrarily, spontaneous sheared flows appear to be strongly coupled to plasma turbulence in the plasma edge, consistent with expectations for turbulence-driven flows.
- 4) The local injection of hydrocarbons through a mobile limiter and the erosion by plasmas with well-known edge parameters opens the possibility of carbon transport studies relevant to co-deposit formation in fusion devices. The erosion pattern of the resulting hydrocarbon films was studied and compared to that of bulk graphite.

## Minutes 35<sup>th</sup> Stellarator Executive Committee meeting

Chengdu, October 19th 2006

### Attendees

Carlos. Alejaldre	<a href="mailto:carlos.alejaldre@ciemat.es">carlos.alejaldre@ciemat.es</a>	(chairman)
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Hutch Neilson	<a href="mailto:hneilson@pppl.gov">hneilson@pppl.gov</a>	(substitute for M. Zarnstorff)
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Carlos Hidalgo	<a href="mailto:carlos.hidalgo@ciemat.es">carlos.hidalgo@ciemat.es</a>	(secretary)

### **WELCOME AND APPROVAL OF THE AGENDA**

C. Alejaldre welcomed all the participants to the 35<sup>th</sup> Stellarator Executive Committee (SEC) meeting. The draft agenda was approved.

### **APPROVAL OF THE MINUTES FROM THE PREVIOUS MEETING**

The minutes of FPC63 were approved with minor corrections suggested by O. Motojima (a copy of which is attached to these minutes).

### **CHAIRMANSHIP SEC**

C. Alejaldre explained that due to his new duties in the ITER project, he cannot continue as a chairman of the Stellarator Executive Committee (SEC). O. Motojima (present vice-chairman) was suggested as a new chairman, being the proposal accepted by SEC members. The new secretary will be H. Yamada. O. Motojima showed his appreciation to C. Alejaldre for his work in the SEC and wished him the best in his new position in ITER.

### **APPROVAL BY THE EXECUTIVE COMMITTEE OF THE AMMENDMENTS TO THE STELLARATOR IA**

The Executive Committee resolved unanimously to approve in its entirety the document entitled "Amendment No. 1 Implementing Agreement on Co-operation for Co-operation in Development of the Stellarator Concept as prepared by EURATOM and dated 29 September 2005, which amends Articles 3, 9, 10 and 11 of the Implementing Agreement.

### **STATUS INTERNATIONAL COLLABORATIONS**

C. Alejaldre invited the members to make brief reports. H. Yamada reported the

formation of International Network for Scientific Collaborations by NIFS. This initiative promotes the development of interdisciplinary research (including interlink of astrophysics, material and fusion science). He also provided a list of visiting scientists to NIFS 2006-07. J. Sánchez explained recent collaborative efforts of Ciemat with NIFS, IPP, ORNL, PPPL, IOFFAN and Kharkov. H. Neilson explained that first plasmas in NCSX are expected in July 2009 and the project is opened to the whole international community. R. Haange reported the status of W7-X. Time delays due to problem with coils will be intended to be balance accelerating the machine assembly. This action is pending of budget approval. C. Alejaldre mentioned that Australia wishes to become involved in ITER and asked about the possible impact on the Australian stellarator community. M. Hole replied that some impact is foreseen.

## **DEVELOPMENT OF STELLARATOR WORKING GROUPS AND LINK OF STELLARATOR COMMUNITY WITH ITPA WORKING GROUPS.**

Dr. H. Yamada reported on the International Collaborative Activity in Helical Devices, including Confinement Data-Base and Profile Data-Base working groups. He mentioned the physics oriented database activity (including core electron-root confinement, operational limit related issues and integrated code developments). This activity is fully welcomed by the committee.

At the last meeting of the IEA Stellarator Executive Committee, it was agreed to start the discussion of possible additional IEA Stellarator Working Groups on new topics. M. Zarnstorff has collected all suggestions of the Executive Committee members including topic and proposals for working group leaders. In subsequent discussions and email, interest was indicated by members and groups for the following topics:

- 1) 3D Divertors
- 2) 3D Alfvénic Mode Stability
- 3) Momentum transport
- 4) Extreme edge events: ELMs and Collapse characterization

C. Hidalgo mentioned that it would be important to promote stellarator working groups with parallel activities in the ITPA groups (e.g. momentum transport, ELMs) as well as key stellarator issues (e.g. 3D divertor). The proposed topics are considered of great interest by the committee. Due to the quite significant absence of committee members, C. Alejaldre encouraged continued e-mail discussion to identify priorities as well as leading people before any SEC decision is taken.

There was a general agreement that stellarator representatives in ITPA should have an active role (e.g. identifying links tokamak-stellarator) including reporting activities to SEC.

## **MISCELLANEOUS AND FINAL REMARKS**

Dr. O. Motojima explained that the organization of the 16th International Stellarator Workshop is in progress (in Toki side, Japan). He suggested C. Hidalgo as chairman of the International programme committee (IPC). C. Hidalgo explained that 4900 Euro were left over from the 2003 Stellarator Workshop in Greifswald and 1.200 from 15<sup>th</sup> SW (Madrid) with a resulting positive global balance of 6.100 euros.