# 3. International Collaboration on Helical Fusion Research
# – IEA Stellarator-Heliotron Agreement –

## 1. Overview

The world stellarator-heliotron community has been promoting international collaborations under the auspices of International Energy Agency (IEA) Implementing Agreement on "Development of the Stellarator-Heliotron Concept". The present participating countries in this agreement are Australia, Germany, Japan, Russia, Spain, Ukraine and U.S.A. The Stellarator-Heliotron Executive Committee conducts arrangement of collaboration and endorses proposed activities. The 40th Stellarator-Heliotron Executive Committee was held in Canberra (Australia) in conjunction with the 18th International Stellarator-Heliotron Workshop. NIFS hosts the web page of this activity at http://iea-shc.nifs.ac.jp/. The summary of international collaboration on fusion research among helical systems is given in the following sections.

## 2. Joint Activity: Coordinated Working Group Meeting (CWGM) for Stellarator-Heliotron Studies

The Coordinated Working Group Meeting (CWGM) for Stellarator-Heliotron Studies has been continuously held since its 1st meeting in Kyoto in Sep. 2006. The main long-term goals of CWGM activity were specified as to identify critical issues for helical systems, to perform thorough and critical assessment of data, and to define a data base for system/reactor studies. These goals can be achieved through obtaining the comprehensive, complementary and deductive perspectives to provide highly reliable extrapolations. The helical system research by exploiting the diversity of the three-dimensional nature of magnetic configurations provides the best opportunity to achieve this through joint comparative studies. The CWGM has offered the appropriate forum to accomplish this, and has been held typically in between the major international conferences, such as the IAEA Fusion Energy Conference (IAEA-FEC) and the International Stellarator-Heliotron Workshop (ISHW), to facilitate collaborative research documented in joint papers.

The 9th Coordinated Working Group Meeting (CWGM9) was held in Jan. 28 at Australian National University. 15 experts participated.

The meeting was composed of 6 sessions including the ***Opening***, in which the evolution of CWGM and its highly-evaluated status in the International Energy Agency (IEA) Implementing Agreement for Co-operation in Development of the Stellarator-Heliotron (S-H) Concept (http://iea-shc.nifs.ac.jp/) as the programmatic international collaborations in S-H community. The list of joint papers originated from CWGM was introduced to stimulate joint activities towards systemization of physics understandings in S-H plasmas. The achievements in CWGM8 (Stellarator News, Issue 131, Apr. 2011, http://www.ornl.gov/sci/fed/stelnews) was also briefly mentioned.

Following the Opening, in the ***Energetic Particles*** session, *(D.A.Spong, ORNL)* initiated code benchmark study for linear growth rates of energetic particle driven Alfven eigenmodes (AE modes) in S-H plasmas was reported. Currently, 5 different models are participating (MEGA-R, AE3D-K, local analytic, CAS3D-K and CKA-EUTERPE) and two TAE modes that were observed in LHD were selected for analysis. At this stage both areas of similarity and difference have been found among the codes, depending on how the particle weights are evolved and which of the two modes are examined. As the study progresses, it is expected to sort out the differences and extend the study to observations from other devices. It was also pointed out that the impact of a large alpha-particle population in ITER on AE modes is a big issue, and S-H community has been anticipated for its contribution in discussions in the ITPA.

*(F.Castejon, CIEMAT)* The dynamics of fast ions coming from NBI heating is studied in 3D systems by means of Monte-Carlo codes, without any assumptions on the diffusive nature of transport, on the size of orbits or on the conservation of kinetic energy. The codes FAFNER2 and HFREYA are linked to ISDEP (Integrator of Stochastic Differential Equations for Plasmas) in order to study such dynamics in TJ-II and LHD plasmas. The steady state distribution function is obtained at several radial positions and, from it, several interesting quantities, like poloidal and toroidal rotation velocities, can be estimated. It has been found that the CNPA (Compact Neutral Particle Analyzer) spectra in TJ-II are in good agreement with the simulations. The slowing down time is obtained by NBI Blip experiments and simulations for TJ-II and LHD, with good agreement in both devices, showing also a good similarity with Spitzer formula in LHD and a strong difference in TJ-II, attributed to the radial size of ion orbits.

The importance of the validation of numerical codes against experimental results, and then, increasing accuracy for predictions (including towards ITER) for energetic particle issues was pointed out.

The ***Equilibrium in Experiment*** session was launched in CWGM9, reflecting the increased interests and activities on equilibrium reconstruction based on the progress of profile measurement, numerical code applications for the experimental analysis, and the extension of the International Stellarator-Heliotron Profile Database (ISH-PDB), to increase its usability, etc. *(J.Geiger, Max-Planck-Insitut für Plasmaphsik, Greifswald)* Function parameterization technique is to try to short cut the process for the interpretation of experiments (equilibrium reconstruction) by utilizing pre-calculated VMEC equilibria. In practice, reconstruction of flux surface shape, represented by Fourier components, $R_{mn}$ and $Z_{mn}$, were functionalized on, for example, $r_{eff}$ (radial coordinate), coils currents, plasma current and plasmas pressure etc.., in W7-AS. This approach has been in implementation for W7-X as a web-service. It will be utilized for mapping of diagnostics and simulations of diagnostic measurements. *(C.Suzuki, NIFS)* In LHD, real-time magnetic coordinate mapping (TSMAP) has been in practically applied to the experiments, which is based on searching a "best-fitted" coordinate mapping from wide-range pre-calculated VMEC equilibria to make the measured electron temperature (by Thomson-scattering) to be symmetric. The progress of ion-temperature (Ti) measurement by XICS (X-ray Imaging Crystal Spectrometer) in LHD, and related equilibrium reconstruction research was reported *(N.A.Pablant, PPPL)*. [XICS Ion-Temperature Profile Measurements] This diagnostic allows $T_i$ measurements to be made under plasma conditions where existing diagnosis (CXRS) cannot be operated. The system is now fully commissioned and can provide line integrated measurements of $T_i$ and $T_e$. Local profiles of $T_i$ and $T_e$ are found through Doppler tomography utilizing known plasma equilibrium. Initial comparisons against Thomson and CXRS show good agreement, demonstrating the applicability of this technique to helical geometries. There was discussion on how this diagnostic could be integrated into transport codes to provide $T_i$ profiles to study heat transport in LHD. [S-H Equilibrium Reconstructions] The code, STELLOPT, has been developed for S-H equilibrium reconstruction. It optimizes the VMEC input parameters to obtain a best match to diagnostic data using a modified Levenberg-Marquardt algorithm. Reconstructions were shown for several LHD discharges where optimization was done to match the following parameters: coil currents, stored energy, net toroidal current, and electron pressure. Work is in progress to add pitch angle measurements from the Motional Stark Effect diagnostic. Current development of STELLOPT is aimed at improving performance and user interaction to facilitate routine use. The codes PIES and SPEC were introduced that allow investigation of equilibria in the absence of good flux surfaces and complement work done using HINT2. Discussion surrounded the integration of STELLOPT results into diagnostic interpretation and transport studies. There were discussed that comparisons of STELLOPT equilibria with those determined though functional parameterization and VMEC database approaches as presented in this session could be used to examine the accuracy of these fast lookup techniques. The progress of the equilibrium registration attached to the registered experimental profiles in ISH-PDB was reported *(M.Yokoyama, NIFS)*, where an example of an LHD high-Ti discharge is explained. The TSMAP-defined (re-calculated by inputting parameters corresponding to "best-fit") VMEC equilibrium is registered as a test case. The process for utilizing the equilibrium is also explained. Those who have interests to analyze a registered discharge by their numerical codes can start the calculations either from registered VMEC input or output files. This should step up ISH-PDB from the "storage" phase to "utilization" phase.

It was noticed that various approaches for equilibrium reconstruction/specification have been in progress (session also formed in the following 18th International Stellarator-Heliotron Workshop), and it was pointed out that comparisons on these approaches would be beneficial to increase the validity and accuracy.

In the ***Transport Analysis*** session, *(M.Yokoyama, NIFS)* steady-state power balance analysis suite in LHD, TR-SNAP, which has now been linked to TSMAP, by establishing the interface to describe measured temperature and density profiles as a function of $r_{eff}$, and to acquire NBI energy/port through power, was introduced and also demonstrated. This suite is available to collaborators, and can replace TSMAP-defined equilibrium by the other equilibrium constructed in a different way as discussed in "Equilibrium in Experiment" session. This will provide an opportunity to test the impact of equilibrium properties on steady-state power balance analysis in an easy way. *(A.Wakasa, Kyoto U.)* The status of the TASK3D development was also reported for the predictive simulation on reachable temperatures (and those profiles) in LHD including the turbulent transport modelling in addition to the established neoclassical diffusion coefficient database, DGN/LHD. It was pointed out that the validation experiments in LHD should increase the accuracy of the prediction, and comparative study, module-to-module basis, with such as the predictive transport code developed in IPP would be valuable.

Rotation and momentum transport issues have gathered a lot of attentions recently. In the session of

***Rotation***, recent activity was presented from TJ-II *(J.A.Alonso, CIEMAT)*. Mass flows in (non-symmetric) S-H plasma are expected to be dictated by neoclassical (NC) ambipolarity and parallel force balance. These devices are, therefore, best suited for testing neoclassical predictions on flow damping. External biasing provides a controlled perpendicular force that is easy to quantify. TJ-II has recently pursued different experimental approaches to test the pre-eminent role of NC mechanisms in flow pattern regulation. In this CWGM9, there was only one presentation in this topic. However, similar lines have been or are being followed in other devices, and thus a coordinated action seems appropriate, which could as well help progressing our understanding of flows in symmetric configurations. J.A.Alonso will visit Heliotron J and LHD in Mar. 2012, and it could be an excellent opportunity to discuss and launch such a coordinated action.

We also had a session on ***Pellet (Fueling)*** *(G.Motojima, NIFS)* towards trying to start dealing with fueling issues in S-H power plant. The significance of a pellet injection for main fueling in S-H plasmas was discussed. Capability for higher-density plasma confinement in S-H provides us an attractive scenario for a power plant. The key to make this realize is a reliable pellet injection system, such as equipped and operated in LHD. The research on pellet fueling was introduced. It was mentioned that the pellet injection system for TJ-II has been in construction with US collaboration, and it has come to the final stage. The conceptual design for Heliotron J was also mentioned. Such installations will certainly enhance the collaborative research among several devices on physics and technological issues related to pellet injection towards future collaborative development.

"***Opportunities for collaborative research on H-1NF***" was also discussed *(D.Pretty, ANU)* at the occasion that CWGM was held in Australia. (1) In order to facilitate H-1NF data access for collaborators, a new data access system (H1DS) developed aiming at providing a data interface which is simple and intuitive for new users and collaborators. The H1DS design utilizes the HTTP protocol to provide an extensible web-service based application programming interface (API), which can interface with standard data analysis languages (Python, IDL, Matlab, Labview etc). A web-based MDSplus data viewer is now online at http://h1ds.anu.edu.au/mdsplus, providing simple navigation and basic processing of data. The new data system also includes a summary database, configurations database, and centralized documentation. A point of discussion was the possibility for the H1DS software to be deployed with datasets from other (non-MDSplus) S-H devices: currently the web-service only supports MDSplus but is not very tightly coupled to MDSplus, and would not take too long to implement on other systems (~ few weeks development time). (2) The progress towards an MHD Documentation Database (MDDB), occasionally discussed in previous CWGMs, was also introduced. This project aims to provide a reference documentation database of MHD modes using data mining techniques. Fluctuations are found by scanning Mirnov signals and 'fingerprinting' coherent fluctuations by the phase-difference between adjacent Mirnov channels; with clustering algorithms used for unsupervised identification of the same fluctuation across many shots. These techniques have been used to identify Alfven eigenmodes and other modes in H-1, TJ-II and Heliotron J for ~1000s of shots. In order to generate the MDDB database, processing has started on a larger dataset, with ~50,000 shots and including LHD and W7AS, and improved clustering algorithms capable of scaling to $10^7$ to $10^8$ data points are being explored. The discussion focused on what properties of fluctuations should be recorded when scanning Mirnov signals: for example, frequency spectral width may reveal growth rates.

Finally, it was pointed out that, in addition to widen the range of topics (~ range of the mountain), "flagship" topics (~ a peak of the mountain) to be intensively coped with, so that CWGM becomes more visible and relevant in the world-wide fusion research, through the outreach activities. Strategic discussions how to make CWGM evolve will be continuously made in the next 10th CWGM. The 10th CWGM is now under planning to be held from 6-8, June, 2012, in Greifswald. Your interests and participations are anticipated.

The materials presented in 9th CWGM are available at http://ishcdb.nifs.ac.jp/ (see CWGM9).

## 3. Australia

### 3.1 International Collaborations in 2011

The centrepiece of the Australian Plasma Fusion Research Facility at the Australian National University is the H-1 heliac. H-1 is a three-period helical axis stellarator with a flexible magnetic topology that allows fundamental studies in plasma confinement and stability, turbulence and flows, and confinement transitions at moderate heating power. Because of its coil-in-tank construction, the device is an ideal test bed for the development of advanced active and passive imaging diagnostic technologies from microwave through to optical frequencies.

2011 saw the completion of the first phase of the~US$7M upgrade of Facility. The funding, under the Australian Government's Super Science Scheme, is earmarked for infrastructure upgrades over the period 2010-2013. Enhancements to the Facility will enable future growth of Australian capability in fusion science and engineering, and as a focus for collaboration within the Australian community, will support the development of world-class diagnostic systems for application to international facilities in preparation for ITER.

Upgrades completed this year include a 2×200kW 4-20MHz radiofrequency heating system supplied by Thomson Broadcasting, a new cooled rf antenna, high speed cameras for imaging diagnostics, a helical Mirnov array and a precision current controller to provide a third magnetic configuration control parameter. A new single point of contact for data access, free of firewall restrictions has been established to provide simple access to the full range of H-1 data from summary and descriptive information to raw data (http://h1svr.anu.edu.au).

The rf upgrades increase heating power by more than a factor of five, allow magnetic field scans with minimal variation to the rf heating mechanism, and will provide more intense discharge cleaning. Improved configurational flexibility will deliver access to magnetic configurations suitable for development of divertor plasma diagnostics for future devices. H-1NF has allowed studies of large-device physics on a university-scale machine, including L-H mode transitions, magnetic island studies, and the characterisation of Alfvénic modes. While this year's activities were again dominated by implementation of the upgrade, extensive data was obtained from the upgraded 80 channel Mirnov array, and synchronous imaging of the radial structure of Alfvén modes.

As part of a longer term strategy that aims for an Australian involvement with ITER, upgrade funding is supporting the development of a small linear, high power-density satellite device that can utilize the H-1 heating and power systems. The Materials Diagnostic Facility led by Dr. Cormac Corr and developed in collaboration with Oak Ridge and the Australian Nuclear Science and Technology Organisation (ANSTO), will facilitate development of diagnostics for plasma wall interactions and for characterizing advanced high temperature materials. Diagnostics commissioned in 2011 include a movable optical CCD-based imaging diagnostic and an automated Langmuir probe.

Dr. Fenton Glass, previously from Tri Alpha, and Dr. Bernhard Seiwald joined the upgrade team working in diagnostic upgrades and the establishment of magnetic databases respectively. Dr. Graham Dennis joined the Plasma Theory and Modelling group under Dr Matthew Hole, funded by an Australian Research Council Grant.

- **Multilateral Collaborations**

Work on the international collaboration on MHD and configuration studies under the IEA agreement focussed on application of the new version of the analysis to recent configuration scans in Heliotron-J and extensive scans in H-1, combining two poloidal arrays and the new 16 element, 3 axis helical arrays. Results were presented at EPS.

One and two-dimensional coherence imaging (CI) systems developed by Prof Howard and his advanced imaging group at ANU underpin collaborations with the USA, EU members and Korea, which are supported by international agencies and the Australian Government. These include

- (EU) Collaboration between the ANU and IPP Greifswald on coherence imiaging in W7X and Asdex, and the FOM Institute for Plasma Physics (Netherlands) to undertake MSE imaging on the TEXTOR tokamak.

- (US) With LLNL and General Atomics, application of Doppler CI systems for imaging flows in the DIII-D divertor and scrape-off-layer. These static systems utilise novel spatial-heterodyne interferometric techniques to capture the 2-D Doppler information.

- (Korea) A 2D spatial heterodyne system installed on KSTAR has produced very encouraging MSE imaging data, proving a reconstruction of the magnetic field over most of the plasma, and interesting initial Zeeman data.

Collaboration between ANU, MPIPP (J. Svensson), and the Culham Centre for Fusion Energy (L. C. Appel) have complementary stellarator and compact toroidal components. The project, which is supported by an Australian International Science Linkages grant, aims to develop Bayesian techniques for the integration of various diagnostic data, building on pioneering development of the technique on W7-AS. In 2011 forward models were completed for Thomson Scattering and Charge Exchange Recombination Spectroscopy, a split-observation Bayesian force balance validation tool developed and implemented on MAST, and a technique on evidence based cross-validation, to remove rogue diagnostic data.

In an application to H-1, a set of MHD modes with low spatial resolution was generated using CAS3D: this is being used to implement a Bayesian approach to infer mode structure in H1 Modes were fitted to multi-chord data of optical emission brightness, synchronised in phase using Mirnov coil data. The residual of the line-integrated fit was ~10% using 4 modes, and less than 1% using 10 modes. The technique offers promise as a new form of fluctuation tomography. Work from this collaboration was featured in invited talks by Dr Hole (IAEA Technical Meeting on Energetic Particles, 2011; Asia Plasma Fusion Association, 2011), and contributed presentations by Dr von Nessi, (APS, 2011).

MRXMHD: A collaboration between the ANU (R. Dewar, M. Hole, M. McGann, A. Gibson, G. Von Nessi) and Princeton PPL (S. Hudson) on the development of a new variational principle - multi region relaxed MHD (MRXMHD) – was broadened through an Australian Research Council Discovery Grant. New partners include scientists from RFX-mod (Dr Dominique Escande), CCFE (Prof. Richard Dendy) and H1 (Dr Boyd Blackwell). In 2011 Dr Graham Dennis was appointed to the project, and spent 4 weeks at Princeton Plasma Physics Laboratory to acquire expertise and contribute to the development the new MRXMHD code SPEC.

The SPEC code, which was developed for application to stellarators, is being used by Dr Dennis compute helical states in RFX-mod, and thereby determines whether MRXMHD can describe quasi-single helicity and single helicity states of the reverse field pinch. In related work, a Masters student, David Barmaz from CRPP in Switzerland completed an MRXMHD ballooning mode stability calculation. ANU student Ashley Gibson is completing a Master's thesis on the mathematics underpinning MRXMHD, reconciling almost-invariant tori (imperfect magnetic surfaces) produced by the quadratic-flux-minimizing (QFMIN) surface method and the action-gradient-based ghost surface method Aspects of the project were featured in invited talks by collaborator S. Hudson (EPS, 2011; Intl. Workshop on Stochasticity in Fusion Plasmas, 2011 )

- **Collaborations with EU**

A collaboration between C. Nührenberg and Axel Koenies of MPIPP Greifswald, J. Bertram, R. Dewar, B. Blackwell, J. Howard, M. McGann, G. Von Nessi, M. Fitzgerald and M. Hole of the ANU is comparing the experimental observations of MHD activity with eigenvalue calculations using the CAS3D code and the wave-particle interaction code CAS3D-K. In 2011 J. Bertram completed a Master's thesis on the calculation of Alfvén modes in H-1 using scans of CAS3D and the 3D continuum code CONTI. These scans, which were performed on the ANU supercomputer node of the Australian Computing Infrastructure Facility, identified beta induced Alfven eigenmodes with frequency comparable to observations. The dependency of frequency with magnetic configuration suggests that these may provide a partial explanation for the characteristic "v" shaped structures in frequency with configuration. In October 2011 Dr Fitzgerald spent three weeks at MPIPP Greifswald working developing expertise with CAS3D-K, and computing wave-particle orbit resonances for H-1 plasmas. This activity was funded through a successful DAAD grant between the Group of Eight research intensive Australian Universities and German Academic Exchange Service.

Collaboration between CCFE (S. Sharapov, K. M$^{C}$Clements, S. Pinches) and the ANU (M. Hole, R. Dewar) in burning plasma physics, aim to non-perturbatively model the effect of energetic particles such as fusion alpha-particles on the equilibrium, wave-mode structure, and wave-mode induced confinement loss. In 2011 Dr Michael Fitzgerald's work focussed on the calculation of anisotropy in MAST plasmas, and computing the impact of rotation in high beta plasmas

- **Collaborations with JAPAN**

In addition to the multilateral datamining collaboration, the following were active in 2011:

1) Prof. Howard and Dr. Hatae (JAEA) on imaging birefringent interferometers for Thomson scattering.

2) Prof R. Dewar (ANU) and Prof. Yoshida (Tokyo) – MHD spectral theory and spheromaks

- **Collaborations with USA**

In addition to the multilateral MRXMHD collaboration, the following were active in 2011:

1) ANU and R. Goulding, J. Harris and P. Krstic of ORNL: development of the Materials Diagnostic Facility Prototype and ANU, and proposals for collaborative grants.

2) ANU, PPPL and DIIID – The effect of 3D magnetic perturbations on the edge plasma.

- **Workshops and Conferences**

Preparations are well in hand and 132 abstracts have been received for the joint 18th International Stellarator-Heliotron Workshop and 10th Asia Pacific Plasma Theory Conference to be held in Australia from 29/1/2012 – 3/2/2012.

Japan will be host to the 9th Japan-Australia Plasma Diagnostics.

Dr Hole represented Australia at the 50th IFRC meeting and presented research highlights and summarised progress in upgrade of H-1 and the new materials diagnostic facility of the Australian Plasma Fusion Research Facility.

3.2 Future Research Plans

Enabled by the upgrade, configuration studies will focus on expanded configuration scans and magnetic field scans of Alfvén-driven instabilities. Multi-channel plasma density and polarimetry interferometers and multi-channel spectroscopic detectors will provide profile information for configuration studies and mode structure of Alfvénic instabilities. The original H-1 RF antenna will be made available for the excitation of Alfvén modes, and application of perturbation fields.

International collaboration on CI optical systems for spectro-polarimetric imaging will continue in 2012 and beyond. In the coming year, this work will embrace the following activities:

Following successful first data, a second Doppler imaging camera is planned for divertor studies on DIII-D, and a custom designed system will be permanently installed on KSTAR for imaging CXRS and MSE measurements.

Combined with fast, gated CCD cameras, newly developed passive spatial heterodyne CI systems will be deployed for synchronous detection of velocity distribution function perturbations associated with magnetic fluctuations in the H-1 heliac.

In the area of coherence imaging technology development and applications, the advanced imaging group anticipates a number of developments in coming years:

In future years there are plans to deploy CI imaging systems for edge physics studies in the W7-X stellarator. The recent success of Doppler imaging on the DIII-D tokamak divertor is a valuable guide in future planning

We are developing multiple-carrier spatial heterodyne CI systems that should allow extended capability for imaging of more complex spectral scenes and exploring Zeeman-assisted Doppler tomography of inhomogeneous magnetized plasma such as the tokamak divertor.

Utilizing the planned linear satellite device, we aim to trial imaging Stark effect and some new concepts in optical radar-based range sensing with the ultimate goal (subject to appropriate funding) to develop a prototype imager for monitoring tile erosion in high power fusion devices.

The expanded collaboration on MRXMHD project will apply the MRXMHD code SPEC to describe helical states in RFX-mod, determine whether ELM events can be described by MRXMHD relaxation, and investigate control of magnetic surfaces between different relaxed regions via external coils. In 2012 the burning plasma project will focus on computing the impact of anisotropy on global modes. A reciprocal visit from IPP to Australia is also funded to implement kinetic code CKA/EUTERPE on H1 plasmas.

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 optical coherence imaging (CI) spectroscopy systems for use in process control in steel production. A demonstration of new wireless communications technology to potential investors is planned for next year.

Finally, the Australian fusion science community will continue endeavours to secure funding to develop prototype diagnostic concepts using the new capabilities of the H-1 facility for one or more plasma diagnostics for ITER. The Australian fusion science community is currently revising the 2007 fusion science strategic plan, taking into account funding developments over the last five years and changes to research funding schemes.

## 4. EU

4.1 Germany

4.1.1 International Collaborations in 2011

- **Collaborations with EU**

1) A. Czermak (Institute of Nuclear Physics PAN, Krakow) to IPP, 05.01. – 07.01.2011
2) I. Ksiazek (Institute of Physics, Opole University, Opole) to IPP, 05.01. – 07.01.2011 and 20.07. –

30.07.2011: C/O-monitor diagnostic for W7-X

3) R. Kleiber (IPP Greifswald) attended the meeting of European Summer Schools in Gent, Belgium, 09.01. – 11.01.2011
4) C. Roach (Culham Centre for Fusion Energy, Culham) to IPP, 24.01. – 28.01.2011
5) J. Svensson (IPP Greifswald) visited Culham Centre for Fusion Energy, Culham, 28.01. – 01.05.2011
6) J. Baldzuhn, T. Richert (IPP Greifswald) visited RFX, Padua, 20.02. – 22.02.2011: exchange of experiences regarding the diagnostic injector
7) J. Connor (Culham Centre for Fusion Energy, Culham) to IPP, 27.02. – 12.03.2011
8) L. Esteban Hernández (CIEMAT, Madrid) to IPP, 27.02. – 01.04.2011
9) T. Feher (IPP Greifswald) visited Chalmers Universtity Gothenburg, 01.03. – 06.03.2011
10) G. Kocsis, T. Szabolics (KFKI, Budapest) to IPP, 21.03. – 25.03.2011
11) S. Zoletnik (KFKI, Budapest) to IPP, 22.03. – 24.03.2011
12) T. Klinger (IPP Greifswald) visited CEA, Cadarache, 13.04. – 15.04.2011
13) W. Schneider (IPP Greifswald) visited RFX, Padua, 02.05. – 18.05.2011
14) T. Johnsson, V. Bobkov, A. Lyssoivan, R. Koch, D. van Eester, A. Messiaen and J. Ongena (École Royale Militaire, Brussels) to IPP, 10.05. – 12.05.2011
15) L.G. Erikson (IAEA) to IPP, 10.05. – 11.05.2011
16) S. Brunner and T. Vernay (CRPP Lausanne) to IPP, 19.06. – 23.06.2011
17) A. Könies (IPP Greifswald) visited 5th ITER Summer School in Aix-en-Provence, France, 19.06. – 25.06.2011
18) T. Klinger (IPP Greifswald) visited University Szczecin, 20.06.2011
19) T. Klinger (IPP Greifswald) visited University Nyborg, 20.06. – 21.06.2011
20) S. Kasilov (TU Graz) to IPP, 01.07. – 31.07.2011
21) W. Kernbichler (TU Graz) to IPP, 10.07. – 31.07.2011
22) A. Mishchenko (IPP Greifswald) visited CRPP Lausanne, 17.07. – 22.07.2011
23) J. Urban (IPP, Prague) to IPP Greifswald, 24.07. – 30.07.2011
24) J. Preinhaelter (IPP, Prague) to IPP Greifswald, 24.07. – 20.08.2011 and 13.11. – 26.11.2011
25) J. Belloso (CIEMAT Madrid) to IPP, 14.08. – 03.09.2011
26) C. Hennig (IPP Greifswald) visited Culham Centre for Fusion Energy, Culham, 16.08. – 24.08.2011: DMV recommissioning JET
27) J. Baldzuhn, T. Richert (IPP Greifswald) visited COMPASS, Prague, 16.08. – 18.08.2011: exchange of experiences regarding the heating injectors
28) A. Hagberg Medin (Chalmers Gothenburg) to IPP, 04.09. – 09.09.2011
29) P. Helander (IPP Greifswald) visited Culham Centre for Fusion Energy, Culham, 24.09. – 01.10.2011
30) T. Szepesi (KFKI), Ch. Biedermann (IPP Greifswald) and M. Otte (IPP Greifswald) visited KIT Karlsruhe for testing camera in magnetic environment, 25.09. – 27.09.
31) D. Tskhakaya (TU Innsbruck) to IPP, 25.09. – 01.10.2011
32) D. Li (IPP Greifswald) visited CIEMAT Madrid, 25.09. – 07.10.2011
33) J. Svensson (IPP Greifswald) visited CIEMAT Madrid, 25.09. – 12.10.2011
34) C. Marini (University Milan) to IPP, 23.10. – 26.10.2011
35) C. Ham and S. Pinches (Culham Science Centre for Fusion Energy, Culham) to IPP, 31.10. – 04.11.2011
36) C. Biedermann, R. König (IPP Greifswald) visited IPPLM Warschau 03.11. – 04.11.2011
37) A. Mishchenko (IPP Greifswald) visited University of Oxford, 26.11. – 03.12.2011
38) J. Zajac (IPP, Prague) to IPP Greifswald, 04.12. – 10.12.2011
39) S. Bozhenkov (IPP Greifswald) visited Culham Centre for Fusion Energy, Culham, 04.12. – 10.12.2011
40) A. Cooper (CRPP Lausanne) to IPP, 05.12. – 07.12.2011
41) I. Predebon (Consorzio RFX Padua) to IPP, 11.12. – 17.12.2011

- **Collaborations with Japan**

1) P. Drewelow (IPP Greifswald) visited NIFS, Toki, 25.02. – 19.03. and 29.07. – 06.11.2011
2) A. Kus (IPP Greifswald) visited NIFS, Toki, 05.03. – 02.04.2011
3) M. Yokoyama (NIFS) to IPP Greifswald, 29.05. – 07.06.2011 and 04.12. – 10.12.2011
4) R. Seki (NIFS) to IPP Greifswald, 03.06. – 07.06.2011
5) H. Funaba (NIFS) to IPP Greifswald, 11.07. – 18.07.2011
6) M. Jakubowski (IPP Greifswald) visited NIFS, Toki, 23.07. – 30.10.2011: visiting professorship
7) M. Nunami (NIFS) to IPP Greifswald, 25.07. – 08.08.2011
8) A. Dinklage (IPP Greifswald) visited NIFS, Toki, 12.09. – 23.09.2011: LHD experiments
9) A. Könies (IPP Greifswald) visited NIFS, Toki, 06.12. – 16.12.2011
10) S. Murakami (NIFS) to IPP, 11.12. – 17.12.2011

- **Collaborations with Russia**

1) M. Mikhailov (Kurchatov Institute Moscow) to IPP Greifswald, 22.03. – 20.05.2011 and 26.10. – 23.12.2011
2) U. Herbst, T. Richert (IPP Greifswald) visited Budker Institute Novosibirsk, 16.04. – 21.04.2011:
3) J. Baldzuhn (IPP Greifswald) visited Budker Institute Novosibirsk,30.05. – 02.06.2011
4) J. Nührenberg (IPP Greifswald) visited Kurchatov Institute Moscow, 20.09. – 22.09.2011

- **Collaborations with Ukraine**

1) Y. Yakovenko and V. Lutsenko (Institute for Nuclear

Research, Kyiv) to IPP Greifswald, 07.05. – 28.05.2011

- **Collaborations with USA**

1) J. Lore and J. Canik (ORNL) to IPP Greifswald, 18.02. – 20.02.2011
2) A. Mishchenko (IPP Greifswald) visited University of Austin, 01.05. – 23.05.2011
3) A. Simakov (Los Alamos National Laboratory) to IPP Greifswald, 15.05. – 21.05.2011
4) G. Wurden (Los Alamos National Laboratory) to IPP Greifswald, 20.05. – 18.06.2011
5) T. Klinger (IPP Greifswald) visited University of Wisconsin, 30.06. – 02.07.2011
6) M. Rorvig (University of Madison) to IPP Greifswald, 10.07. – 24.07.2011
7) G. Plunk (University of Maryland) to IPP, 11.09. – 14.09.2011
8) T. Stoltzfus-Dueck (IPP Greifswald) visited MIT Boston, 19.11. – 23.11.2011
9) T. Stoltzfus-Dueck (IPP Greifswald) visited PPPL, 28.11. – 01.12.2011

### 1.1.2 Conference participation

1) T. Klinger, 40th FPCC Meeting, 01.02. – 04.02.2011, Paris, France
2) O. Grulke: PWA Workshop, 9.02. – 12.2.2011, London, Great Britain
3) G. Kuehner: Software Engineering Conference, 21.02. – 25.02.2011, Karlsruhe, Germany
4) N. Marushchenko: ITM Code Camp, 12.03. – 19.03.2011, Aix-en-Provence, France
5) H. Bohlin, C. Brandt, O. Grulke, P. Helander, T. Klinger, H. P. Laqua, D. Niemczyk, C. Rapson, T. Schröder, T. Stange, A. von Stechow, G. Stoppa and T. Windisch: DPG-Fruehjahrstagung, 13.03. – 18.03.2011, Kiel, Germany
6) H. Smith: European Geosciences Union General Assembly 2011, 05.04. – 09.04.2011, Vienna, Austria
7) Y. Feng: SFP 2011 Workshop, 10.04. – 14.04.2011, Jülich, Germany
8) A. Könies: ITPA Meeting on Fast Particles, 10.04. – 14.04.2011, Frascati, Italy
9) P. Drewelow, S. Marsen, M. Jakubowski, R. C. Wolf: 5th Workshop on Stochasticity in Fusion Plasmas, 11.04. – 14.04.2011, Juelich, Germany
10) J. Krom: ACCU 2011 Conference, 11.04. – 15.04.2011, Oxford, Great Britain
11) P. Helander, R. Kleiber and H. Smith: Heraeus Summer School, 17.04. – 21.04.2011, Bad Honnef
12) M. Laux: 13th PFMC Workshop/ 1st FEMaS Conference, 09.05. – 13.05.2011, Rosenheim, Germany
13) H. Braune, V. Erckmann, H. P. Laqua, G. Michel, T. Stange: 23rd Joint Russian-German Workshop on ECRH and Gyrotrons, 23.05. – 28.05.2011, Karlsruhe, Stuttgart and Garching, Germany
14) V. Erckmann: 19th Topical Conference on Radio Frequency Power in Plasmas, 01.06. – 03.06., Newport, RI, USA
15) C. Hennig, J. Krom, H. Laqua, M. Lewerentz, J. Schacht, A. Spring, A. Werner: 8th IAEA TM on Control, Data Acquisition, and Remote Participation for Fusion Research, 20.06. – 24.06.2011, San Francisco, USA
16) T. Klinger: SOFE 2011, 25.06. – 30.06.2011, Chicago, USA
17) M. Drevlak, Y. Feng, P. Helander, A. Kus, H. P. Laqua, N. Marushchenko, C. Nührenberg, J. Nührenberg, R. Reimer, J. Riemann, S. Schmuck, T. Stange, D. Zhang: 38th European Physical Society Conference on Plasma Physics, 27.06. – 01.07.2011, Strasbourg, France
18) O. Grulke: IPELS Workshop, 09.07. – 16.07.2011, Whistler, Canada
19) N. Marushchenko: ITM Code Camp, 10.07. – 17.07.2011, Prague, Czech Republic
20) A. Könies and J. Riemann: 12th IAEA TM and 7th ITPA Meeting on Fast Particle, 06.09. – 15.09.2011, Austin, USA,
21) P. Helander: Carolus Magnus Summer School, 06.09. – 07.09.2011, Weert, NL
22) C. Beidler, R. C. Wolf: MFE Roadmapping in the ITER Era, 06.09. – 11.09.2011, PPPL, Princeton, USA
23) R. Kleiber: 22nd ICNSP, 07.09. – 09.09.2011, Long Branch, USA
24) P. McNeely: 32nd International Electric Propulsion Conference, 11,09, - 14,09,, Wiesbaden, Germany
25) N. Marushchenko: ITM Code Camp, 12.09. – 17.09.2011, Garching, Germany
26) U. Neuner: 10th International Symposium on Fusion Nuclear Technology, 11.09. – 16.09.2011, Portland, USA
27) M. Krychowiak, M. Otte: Plasma 2011, 12.09. – 16.09.2011, Warsaw, Poland
28) J. Geiger and A. Mishchenko: 14th European Fusion Theory Conference, 26.09. – 30.09.2011, Frascati, Italy
29) Hans-Stephan Bosch, Thomas Sunn Pedersen, Heinrich Laqua, Ralf König, Petra Kornejew, Daihong Zhang, Antonio Cardella, Christoph Biedermann, R. Wolf, Dirk Hartmann, Nikolai Marushchenko, Jürgen Baldzuhn, Maciej Krychowiak, Alan Peacock, Henning Thomsen, Andreas Werner, Annett Spring, Heike Laqua, Thomas Rummel CEA: Andre Grosman, Roland Sabot, Marc Goniche, Jean-Marcel Travere, Philippe Jacques Moreau, Tuong Hoang, Ludovic Allegretti: 1st French-German Workshop "Aspects of Steady-state operation of fusion plasmas" 5th – 6th of October 2011, Greifswald
30) H. Braune, G. Michel: 36th International Conference Infrared, Millimeter and Terahertz Waves, 02.10. – 07.10., Houston, USA
31) J. Schacht: 6th Symposium on Automatic Control, 13.10. – 14.10.2011, Wismar, Germany
32) W. Schneider: Workshop Fast Neutron Detectors and Applications, 06.11. – 12.11.2011, Ein Gedi, Israel

33) O. Grulke, T. Stoltzfus-Dueck: APS DPP, 14.11. – 18.11.2011, Salt Lake City, USA
34) C. Beidler, A. Dinklage and R. Wolf: DEMO Workshop, 17.11. – 18.11.2011, Jülich, Germany
35) N. Marushchenko: ITM Code Camp, 27.11. – 02.12.2011, Innsbruck, Austria
36) M. Hirsch, R. C. Wolf: 21st Toki Conference, 28.11. – 01.02.2011, Toki, Japan
37) A. Dinklage, Y. Feng, M. Jakubowski, A. Könies, R. C. Wolf: 17th European Fusion Physics Workshop, 05.12. – 07.12.2011, Heringsdorf, Germany
38) T. Klinger: NIFS Peer Review Panel Meeting, 07.12. – 10.12.2011, Nagoya, Japan
39) T. Klinger: EPS PPD Board, 11.12. – 14.12.2011, Madrid, Spain

4.1.2 Participation in joint projects

- **International stellarator/heliotron confinement data base**

Coordinated Working Group: CWGM8, NIFS, 16.03. - 18.03.2011: contributions from A. Dinklage, J. Geiger,

- **International stellarator/heliotron profile data base**

Contributions from A. Dinklage, A. Kus, C. Beidler, H. Maaßberg, S. Marsen

- **ITPA diagnostics**

Contributions from R. König:

23.05 - 26.05.2011, Noordwijk, The Netherlands and 17.10. - 20.10.2011 Hefei, China

- **ITPA confinement and transport**

Contributions from A. Dinklage and M. Jakubowski

- **ITPA edge and pedestal**

Contributions from M. Hirsch

4.1.3 Plans for 2012

- **Planning stellarator/heliotron theory**

1) Ralf Kleiber and Matthias Borchardt plan to go to CRPP Lausanne to work on gyrokinetic PIC simulations.
2) Alexey Mishchenko plans to go to CRPP Lausanne to work on electromagnetic, gyrokinetic PIC simulations.
3) Michael Drevlak plans to go to Stockholm to collaborate with the KTH Stockholm on ICRH in stellarators.
4) Yuriy Turkin and Nikolai Marushchenko will go to TU Graz to work on neoclassical stellarator kinetics.
5) Joachim Geiger plans to go to NIFS to work on 3D MHD equilibrium problems.

- **Spectroscopic diagnostics**

1) Rainer Burhenn (IPP Greifswald) plans several visits at TEXTOR (FZJ) for (a) transferring the X-ray spectrometer to W7-X and (b) for installation of the calibration unit and successive calibration of the HEXOS spectrometer for W7-X
2) I. Ksiazek (Institute of Physics, Opole University, Opole) plans several visits (each about 1-2 weeks) to IPP Greifswald in the frame of the cooperation concerning the development of the C/O-monitor diagnostic for W7-X
3) A. Czermak (Institute of Nuclear Physics PAN, Krakow) plans a visit to IPP Greifswald for acceptance tests of the prototype detectors for the W7-X C/O monitor
4) Henning Thomsen (IPP Greifswald), plans a visit to IST Lisbon, Portugal in the frame of the collaboration on fast online tomography and data acquisition systems

- **IR/visible Imaging Diagnostics**

R. König and A. Rodatos plan several visits to Tore Supra (CEA) for software development for hot spot detection and image scene understanding within a common framework as part of the EFDA GOT WP10 "Imaging for Fusion".

- **IR diagnostics/collaboration with JET taskforce E1**

H. Thomsen (IPP Greifswald) will visit Culham Centre for Fusion Energy to continue the collaboration on the IR-camera data analysis within the JET EFDA-taskforce (~ 2 weeks at Culham).

- **Collaboration with NIFS**

1) M.W. Jakubowski will visit National Institute for Fusion Science, Toki to continue research on transport in stochastic boundary (1 or 3 months).
2) M. Krychowiak plans to visit NIFS Toki for Experiments with helium beam diagnostics (4 weeks)

- **Neutral particle diagnostics**

1) W. Schneider will visit RFX in Padova for about 2 ½ weeks in order to continue CX-NPA measurements with an ACORD22-analyser for plasma discharges in reversed field pinch configurations.
2) W. Schneider will visit Culham Centre for Fusion Energy to continue the collaboration with the MAST team, especially concerning measurements with neutral particle analysers in neutron fields (1 ½ weeks).

- **Neutron diagnostics**

1) Mutual visits (about 1 - 2 per year, each about for 2-3 days) in the frame of collaboration with PTB

Braunschweig on the neutron counter system for W7-X are planned to discuss the progress and the work plan of the project (involving A. Weller, R. Burhenn, R. König, W. Schneider). In addition, W. Schneider will visit PTB Braunschweig (about 6 - 8 times per year for 1 to 2 weeks) to engage in development of neutron monitoring systems and in MCNP calculations.
2) Mutual visit (for 2-3 days) in the frame of collaboration on the neutron activation system for W7-X after reactivation a new contract with IPPLM Warsaw and INP Cracow in the second half-year 2012 (involving A. Weller, W. Schneider).

- **Microwave diagnostics**

1) H. Oosterbeek (Technical University of Eindhoven) + student(s) will visit IPP: Measurement of the power flux density in a microwave stray radiation field

- **International stellarator/heliotron profile data base**

A. Kus will visit NIFS for Scaling Studies

C. Beidler, A. Dinklage and H. Maaßberg will contribute to transport model validation studies (LHD, TJ-II, W7-AS)

- **Collaboration on ECRH, ECCD and ECE Plans 2012**

1) H. P. Laqua (IPP Greifswald) will visit TJ-2 CIEMAT (Spain) for 2 weeks: Participation on heating experiments with electron Bernstein waves with the realigned transmission line.
2) T. Stange (IPP Greifswald) will visit TJ-2 CIEMAT (Spain) for 2 weeks: Participation on EBW-heating experiments.
3) Santo Gamino (INFN-LNS , Catania, Italy) will visit Greifswald for preparation of 14 GHz electron Bernstein wave heating experiments
4) H. P. Laqua (IPP Greifswald) will visit Tore Supra (France) (1 week) for collaboration on "Aspects of Steady-state operation of fusion plasmas"

- **Conference participation**

1) T. Klinger: FPCC Meeting, 23.01. – 25.01.2012, Paris, France
2) J. Geiger, M. Drevlak, T. Klinger, H. P. Laqua, T. Sunn Pedersen and R. C. Wolf: 18$^{th}$ International Stellarator/Heliotron Workshop, 29.01. – 03.02.2012, Canberra, Australia
3) A. Könies, IAEA and ITPA Meeting on Fast Particles, 05.03. – 09.03.2012, NIFS, Toki, Japan
4) Per Helander, A. Mishchenko, Pavlos Xanthopoulos and Josefine Proll: Gyrokinetic Theory Workhop, 19. – 23.03.2012, Vienna, Austria
5) A. Dinklage: VALIDATION, 26.-28.3.2012,Frascati, Italy
6) A. Dinklage, M. Jakubowski, ITPA TG Confinement and Transport Workshop, Hefei, China, 02.04 – 05.04.2012
7) R. König: High Temperature Plasma Diagnostics, 06.05. – 10.05.2012, Monterey, USA
8) W. Schneider: 39$^{th}$ European Physical Society Conference on Plasma Physics, 02.07. – 06.07.2012, Stockholm,
9) A. Dinklage: IAEA FEC, 8.-13.10.2012, San Diego, USA
10) A. Könies: IAEA and ITPA Meeting on Fast Particles, 15. – 16.10.2012, San Diego, USA
11) M. Jakubowski: 20$^{th}$ International Conference on Plasma Surface Interactions 2012, Aachen, Germany

4.2 Spain

4.2.1 International Collaborations in 2011 using TJ-II at CIEMAT

- **Collaborations with Russia**

1) K. Sarksyan and the ECRH IOFAN team have participated in the operation of the ECRH system of TJ-II during the 2011 experimental campaign (June-July 2011).
2) IOFAN Director was visiting Ciemat (July 2011) to discuss and expand Ciemat – IOFFAN long standing collaborations.
3) N. Kharchev (IOFAN) was visiting Ciemat in November 2011 to discuss possible designs to modify the gyrotron power by means of reflected power technique.
4) A. Melnikov and L. Eliseev and members of the HIBP Kurchatov Institute team were visiting CIEMAT to investigate the structure of plasma potential and plasma fluctuations in ECRH and NBI plasmas (in Lithium coated wall conditions) and measurements with two slit HIBP detector. The second HIBP system has been built for long-range (zonal flows) correlation studies and the commissioning is planned for 2012.

- **Collaborations in Europe**

**Germany**

1) E. Sánchez was visiting Greifswald (Germany) to work on gyro-kinetic theory and transport calculations using EUTERPE.
2) Y. Svensson and D. Li (Greifswald) visited Ciemat to work on Basesian analysis for tomographic reconstructions using arrays of soft-Xrays signals (September / October 2011).

**Portugal**

1) C. Silva and I. Nedzelskiy were visiting CIEMAT to continue our collaboration on edge studies (edge turbulence and transport studies and RFA development) during 2011.
2) D. Baião is working in her PhD thesis on soft x-ray based Te diagnostic for high density plasmas in the TJ-II

stellarator (including prototypes construction and testing).

3) Continuing the collaboration in reflectometry in TJ-II with S. Da-Graça and L. Cupido.

**Italy**

1) Collaboration with M. Spolaore and the RFXmod team to participate on edge diagnostic development and measurements in TJ-II including the design and development of electromagnetic probes to characterize the electromagnetic nature of plasma filaments in TJ-II; first measurements were done on June 2011.
2) B. Momo was visiting CIEMAT (July – September 2011) for studying transport in 3D magnetic confinement devices.

- **Collaborations with USA**

1) E. Hollmann (USCD) was visiting CIEMAT (June 2011) working on parallel / radial impurity transport studies.
2) Collaboration with R. Wilcox (UW) on the influence of magnetic quasi-symmetry on zonal flows, including comparative studies in TJ-II and HSX.
3) D. Carralero and A. Alonso were visiting HSX team (University of Wisconsin) to discuss joint activities on edge turbulence and flows.
4) K. McCarthy will visit Oak Ridge National Laboratory (December 2011) for testing the TJ-II pellet injector, which should be shipped to Ciemat at the beginning of 2012.

- **Collaborations with Ukraine**

1) The Heavy Ion Beam Probe team (leaded 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 2011 experimental campaign. The development of the second HIBP system has been design and and the injector system has been constructed and installed in TJ-II (July 2011).

- **Collaborations with Japan**

1) Keep in touch with N. Tamura, M. Shoji and K. Ida (NIFS, Japan) on non-local transport effects and diagnostic development (fast cameras, TESPEL and BES).
2) Y. Narushima visited CIEMAT during one week (2011) to work on island healing in stellarators.
3) K. Nagaoka (NIFS), S. Yamamoto (Kyoto Univ.), S. Ohshima (Kyoto Univ.) visited CIEMAT (March) to continue our joint experiments on fast particle studies.
4) T. Estrada has visited the Advanced Energy Laboratory at the Kyoto University (September – December 2011) working on reflectometry and participating in several conferences during her stay in Japan.
5) Based on previous discussions with T. Oishi (Nagoya University) who visited Ciemat in March 2010 to explore the viability of Beam Emission Spectroscopy in the TJ-II stellarator, the experimental set-up is now ready for first test in the TJ-II stellarator.

- **International collaborations: stellarator/heliotron working groups**

The 8th Coordinated Working Group meeting (CWGM) was held Japan (March 2011) to discuss joint activities. Ciemat staff has participated with remote access on different topics including L-H physics, edge transport, fast particle physics.

4.2.2 Plans for 2012

The main research activity of Euratom – Ciemat association will remain on concept improvement development and on the fusion technology programme with special emphasis on all the different aspects of fusion materials technology. 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.

1) Stellarator physics: confinement data-base, neoclassical transport, stellarator optimization and magnetic configuration effects on confinement. These activities are carried out within the framework of the international stellarator implementing agreement.
2) Plasma diagnostic development and engineering: Diagnostic developments for TJ-II will continue and in a wider context for JET, ITER (reflectometry, VIS-IR spectroscopy) and W7-X.
3) Plasma heating (NBI, ECRH and studying the efficiency of Electron Bernstein Waves).
4) Physics of advanced confinement scenarios: transport barrier physics, impurity transport and stability.
5) Theory and modelling of plasma transport, stability and equilibrium with emphasis on island dynamics and breaking of nested surface topology (3-D effects) and Gyrokinetic theory.
6) Plasma – wall studies, exploring plasma-wall interaction scenarios with Li coating and Li-liquid limiter concepts.
7) Data acquisition, control and advanced data analysis techniques.

- **Collaborations with Russia**

1) K. Sarksyan and the ECRH IOFAN team participated in the operation of the ECRH system of TJ-II during the 2012 experimental campaign.
2) S. Pavlov (Kharkov Institute of Ukraine) will visit Ciemat to work on ECRH theory.
3) S. Petrov (IOFFE) will visit CIEMAT to participate on charge exchange spectrometry measurements.
4) N. Kharchev (IOFAN) will visit Ciemat in September 2012 to continue the investigation of gyrotron-power control.

5) A. Melnikov and L. Eliseev and members of the HIBP Kurchatov Institute team will visit CIEMAT to investigate the structure of plasma potential in ECRH and NBI plasmas (in Lithium coated wall conditions) and measurements with two slit HIBP detector. The second HIBP system has been design for long-range correlation studies (zonal flows); the final analyzer installation and test is foreseen during 2012.

- **Collaborations in Europe**

**Germany**

1) J. L. Velasco and E. Sánchez will visit Greifswald (Germany) to work on Neoclassical transport and gyrokinetic theory respectively.
2) J. M. García-Regaña has joined Greifswald team in a pos-doc position to work on gyrokinetic theory.
3) A. Bustos will join the IPP-Garching team to work on the effect of turbulence on fast particle transport using GENE code.
4) T. Happel (IPP-Garching) will visit Ciemat to explore the viability of Doppler reflectometry as a tool to measure the radial correlation length of fluctuations
5) Y. Svensson will visit Ciemat to continue Bayesian analysis including TJ-II data (soft-X rays signals).

**Portugal**

C. Silva, L. Cupido and I. Nedzelskiy will visit CIEMAT to continue our collaboration on edge studies using arrays of Langmuir probes, Retarding Field Analyzers (RFA) and reflectometry.

**Italy**

1) Collaboration with M. Spolaore and the RFXmod team to participate on edge diagnostic development and measurements of electromagnetic turbulence in TJ-II.

- **Collaborations with USA**

1) I. Calvo will stay at MIT working on Gyro-Kinetic Theory (October 2012)
2) S. Combs and C. Foust will visit Ciemat for pellet injector commissioning on TJ-II (first semester 2012).
3) E. Hollmann (USCD) will visit CIEMAT (June 2011) to work on parallel / radial impurity transport studies.
4) A. Gómez will visit Oak Ridge National Lab to integrate DAB (distributed asynchronous bees) algorithm in STELLOP (stellarator optimization code).
5) A. Alonso and D. Carralero will visit UW to study driving and damping mechanisms of zonal flows and role of magnetic topology.

- **Collaborations with Ukraine**

L. Krupnik and HIBP team will visit TJ-II for investigation of the structure of radial electric fields using HIBP diagnostic (Institute of Plasma Physics, National Science Center "Kharkov Institute of Physics and Technology). The second HIBP system has been design for long-range correlation studies (zonal flows); the final injector installation and test is foreseen during 2012.

- **Collaborations with Japan**

1) M. Shoji (NIFS) will visit Ciemat (March) to investigate plasma visualization techniques of dust and plasma blobs.
2) K. Nagaoka (NIFS), S. Yamamoto (Kyoto Univ.), S. Ohshima (Kyoto Univ.) will visit CIEMAT to continue our joint experiments on fast particle / edge studies.
3) Keep in touch activities on BES in stellarators (TJ-II).
4) Based on the TJ-II experience with the pellet injector developed by ORNL, we plan to explore the viability of TESPEL system developed by NIFS (N. Tamura et al.,).

- **International stellarator/heliotron working groups**

Ciemat staff will participate in the forthcoming CWGM to be held along 2012.

## 5. Japan

5.1 International Collaborations by LHD at NIFS

- **Collaborations with EU**

1) Matsuyama (NIFS) visited Atominstitut, TU Wien in Austria from Feb. 1 to Feb. 11 for a collaborative research with Dr. Florian Koechl and Dr. Bernard Pégourié on the development of hydrogen pellet ablation-deposition code for magnetically confinement plasmas.
2) G. Kawamura (NIFS) visited Forschungszentrum Juelich GmbH (Juelich Germany) from 7th to 19th February 2011 for collaboration on simulation modeling of impurity transport and redeposition.
3) Yamada (NIFS) and R. Yasuhara (NIFS) will visit Culham Centre for Fusion Energy (U.K.) from 13st to 17th Feb. 2011 to discuss the advanced Thomson scattering system for LHD and MAST.
4) S.Yoshimura (NIFS) visited Ruhr-University Bochum (Germany) from 14th February to 19th March 2011 to conduct collaborative experiments on the spectral measurement of high-density argon plasmas and on the time-resolved electron-density measurement in afterglow plasmas using a microwave interferometer.
5) N. Tamura (NIFS) visited CIEMAT from February 23rd to March 6th, 2011 to join experiments regarding a nonlocal transport with a modulated biasing.
6) Peter Drewelow (Max-Planck Institute for Plasmaphysik, Germany) visited NIFS (H. Yamada and S. Masuzaki) from 26 Feb. 2011 to 19 March 2011 to divertor plates position measurement for the accurate measurement of divertor heat and particle flux profiles.
7) Torsten Bräuer (Max-Planck Institute for Plasmaphysik, Germany) visited NIFS (H. Yamada and S. Masuzaki) from 26 Feb. 2011 to 12 March 2011 to divertor plates position measurement for the accurate measurement of divertor heat and particle flux profiles.
8) Kus (IPP-Greifswald) visited NIFS from 7 to 19 Mar. 2011 to promote technical issues clarification and their

settlement on the International Stellarator-Heliotron Profile Database. He also joined the 8th CWGM (16 and 17 Mar. 2011 at NIFS) to present and discuss the technical issues on database.

9) Y. Suzuki (NIFS) visited Forschungszentrum Juelich GmbH (Juelich, Germany) from 7th to 11th March 2011 in the international collaboration on 3D modeling in the tokamak configuration with the resonant magnetic perturbation field. This collaboration results were reported at EPS2011 (Strasbourg, France, June 2011) and 13th H-mode workshop (Oxford, England, Oct. 2011).
10) G. Motojima (NIFS) visited Ghent university in Belgium to give presentations of "Helical systems" and "Technology progress and physics achievements in LHD" from 31 March to 3 April 2011 within a framework of Erasmus Mundus Program.
11) G. Motojima (NIFS) visited Max Planck Institute for Plasma Physics in Garching, Germany from 3 April to 6 April 2011 to discuss the high density H-mode plasma using pellet between Tokamak and stellarator/heliotron within a framework of Erasmus Mundus Program.
12) M. Goto (NIFS) stayed at Provence University in Marseille from 26th April to 5th June. He has discussed with Prof. R. Stamm and other members of his laboratory about the theoretical method for calculating the Stark broadening of various emission lines observed in LHD.
13) T. Tokuzawa (NIFS) visited Consorzio RFX, Italy from 4th to 6th May 2011 to attend 10th International Reflectometry Workshop organized in cooperation with the International Atomic Energy Agency (IAEA). He give a presentation about LHD and TST-2 Doppler reflectometer.
14) Andres Molina de Bustos (CIEMAT, Spain) visited NIFS (M.Osakabe) from 15 May 2011 to 4 June 2011to discuss about the modeling of NB-blip exp eriments on LHD in the ISDEP-code.
15) N. Yanagi (NIFS) attended the HTS4Fusion Conductor Workshop held at Karlsruhe Institute of Technology (KIT) from May 26 to 27, 2011 and gave an oral presentation titled "Innovative fabrication method of superconducting magnets using high-Tc superconductors with joints".
16) M. Yokoyama (NIFS) visited IPP-Greifswald from 29 May. to 6 Jun. 2011 to promote the extension and the usage of the International Stellarator-Heliotron Profile Database. Continuously, he attended the ITER-Integrated Modelling Expert Group Meeting (8-10 Jun., 2011) to present the status of integrated transport code, TASK3D in LHD, and have discussions with experts participating in meeting.
17) D. Kato (NIFS) visited Atomic and Molecular Data Unit in IAEA headquarter (host: B. Braams) in Austria from 30th May until 31st May 2011 to attend a consultant meeting on atomic data for fusion plasma-wall interaction.
18) D. Kato (NIFS) visited Malmoe University (host: P. Joensson) in Austria from 2nd June until 3rd June 2011 to discuss about atomic data evaluation of highly charged ions in plasmas and give a seminar on measurements of highly charged ion spectra by LHD and CoBIT.
19) Yu. Tolstikhina (P.N. Lebedev Physics Institute the Russian Academy of Sciences, Russia) visited NIFS (D. Kato) from June. 15 until July. 3, 2011 to collaborate on theoretical evaluation of isotopic effects on low-energy charge exchange processes of hydrogen collisions with carbon, beryllium and lithium atoms/ions.
20) Y. Suzuki (NIFS) visited Forschungszentrum Juelich GmbH (Juelich, Germany) from 20th to 24th June 2011 in the international collaboration on 3D modeling in the tokamak configuration with the resonant magnetic perturbation field. This collaboration results were reported at EPS2011 (Strasbourg, France, June 2011) and 13th H-mode workshop (Oxford, England, Oct. 2011).
21) Marcin Jakubowski (Max-Planck Institute for Plasmaphysik, Germany) visited NIFS (H. Yamada and S. Masuzaki) from 24 July 2011 to 28 Oct. 2011 to study the resonance magnetic perturbation effects on transport.
22) T. Morisaki (NIFS) visited Strasbourg Convention Center, Strasbourg, France to attend the 38th European Physical Society Conference on Plasma Physics from 27 June to 1 July 2011 to give a poster presentation entitled "Effect of Resonant Magnetic Perturbations on Super Dense Core Plasma in LHD". He discussed the relation between magnetic stochasticity and particle transport.
23) G. Motojima (NIFS) visited Culham Science Center in England from 17 July to 23 July 2011 to discuss the international collaboration about the imaging spectroscopy measurements of pellet ablation.
24) M. Nunami visited Max Planck Institute for Plasma Physics in Greifswalt from 24 July to 7 August 2011 to discuss benchmark test of two gyrokinetic simulation codes for stellarator, GKV-X (NIFS) and GENE (IPP).
25) Peter Drewelow (Max-Planck Institute for Plasmaphysik, Germany) visited NIFS (H. Yamada and S. Masuzaki) from 31 July 2011 to 3 Nov. 2011 to study the beta dependence of particle and heat flux profiles on the helical divertor in LHD. An infrared camera and a CCD camera were utilized for the study.
26) S. Takayama (NIFS) is staying Karlsruhe Institute of Technology (KIT) from September 1, 2011 to 31, 2012 for 7 months for a collaborative research with Dr. Guido Link and his group in IHM. He studies on the Investigation of interaction between microwave and materials.
27) Murakami (NIFS) visited Atomic and Molecular Data Unit in IAEA headquarter (host: B. Braams) in Austria from 7th Sep. to 8th Sep. 2011 to attend the IAEA Technical Meeting on Technical aspects of atomic and

molecular data processing and exchange (21st meeting of the A+M Data Centres).

28) X. Ding (NIFS) visited Queen's University Belfast in Belfast, UK, from Sep. 19th to Sep. 22nd to attend the 17th International Conference on Atomic Processes in Plasmas and made a poster presentation on "M1 transition energy and probability between the multiplets of the ground state of Ag-like ions with Z=47-92".
29) S. Shrarapov (Culham) visited NIFS from 20 Sep. to 1 Oct. 2011 for discussion on electron drag effects on nonlinear evolution of Alfven eigenmodes, and joined the LHD experiment for ITPA joint experiment EP2. The travel and staying expenses were supported by MEXT.
30) M. Yokoyama (NIFS) visited IPP-Greifswald from 5 to 9, Dec, 2011 to discuss and have joint analyses on the joint experiments performed in LHD (Sep. 2011) for transport model validation. The compilation for the invited talk presentation at 18th International Stellarator-Heliotron Workshop (Jan. 2012, Australia) was also done.
31) Matsuyama (NIFS) will visit IRFM, CEA Cadarache in France from Dec. 5 to Dec 15 for a collaborative research with Dr. Bernard Pégourié and Dr. Florian Koechl on the development of hydrogen pellet ablation-deposition code for additionally heated plasmas.
32) Könies (IPP, Greifswald) will visit NIFS from Dec. 6 to Dec. 17 to collaborate on code benchmark on energetic particle driven Alfvén eigenmode in LHD.
33) A.Dinklage (IPP-Greifswald) visited NIFS to participate joint experiments in LHD on transport model validation activity in CWGM. He also visited Kyuto University (Heliotron J) to promote Heliotron J's active participation to CWGM and Internatioal Stellarator-Heliotron Profile Database (especially, probe database issues) activities.
34) Jean Jacquinot, Tuong Hoang (CEA, France), Antoine Pochelon (Ecole Polytechnique Federale de Lausanne, Centre de Recherches en Physique des Plasmas, Switzerland), Hendrik Meyer (EURATOM CCFE Fusion Association, UK), Teresa Estrada (CIEMAT, Spain), Izuru Yonekawa (ITER Organization, France), Damian Hampshire (Durham University, UK), Gianfranco Federici (EFDA-CSU Garching, Germany), Mathias Noe (Karlsruhe Institute of Technology, Germany), Gerrit Maarten Dirk Hogeweij (FOM, Netherlands), Matthias Hirsch,Robert Wolf (Max-Planck-Institute for Plasma Physics, Germany) attended the 21th International Toki Conference, held in Toki, Japan from 28 Nov. to 1 Dec. 2011.

- **Collaborations with Russia**

1) V. Yu. Sergeev (St. Petersburg Polytechnical University, Russia) visited NIFS (S. Sudo and N. Tamura) from February 17th to March 20th, 2011 for a collaboration research regarding the Tracer-Encapsulated Solid Pellet in the framework of the Invitation Fellowship Programs for Research in Japan by JSPS.
2) I.A. Sharov (St. Petersburg Polytechnical University, Russia) visited NIFS (S. Sudo and N. Tamura) from August 18th to September 19th, 2011 to study a spatial structure of the ablation cloud of the Tracer-Encapsulated Solid Pellet by measuring a Stark broadening with a spatial resolution on LHD.
3) B.V. Kuteev (National Research Center "Kurchatov Institute", Russia) visited NIFS (S. Sudo and N. Tamura) from October 7th to December 5th, 2011 for a collaboration research regarding the Tracer-Encapsulated Solid Pellet in the framework of the Invitation Fellowship Programs for Research in Japan by JSPS.
4) L.N. Vyacheslavov(Budker institute of Nuclear Physics, Russia) visited NIFS from October 23rd to November 11th. He made analysis of turbulence data measured by two dimensional phase contrast imaging. This is a collaboration work with K. Tanaka(NIFS)
5) Alexander Melnikov (National Research Centre Kurchatov Institute, Institute of Tokamak Physics, Russia), Inga Tolstikhina (P.N.Lebedev Physical Institute of Russian Acadamy of Sciences, Russia), Anatoly Nastoyashchiy (RF SRC Troitsk Institute for Innovation and Fusion Research (TRINITI), Russia), Leonid Eliseev (NRC Kurchatov Institute, Russian Federation) attended the 21th International Toki Conference, held in Toki, Japan from 28 Nov. to 1 Dec. 2011.

- **Collaborations with Ukraine**

1) Valentyn Tsisar (Physical-Mechanical Institute of National Academy of sciences of Ukraine), Volodymyr Mykhaylenko (V.N.Karazin Kharkov National University), Yuliya Stadnik (National Science Center Kharkiv Institute of Physics and Technology) attended the 21th International Toki Conference, held in Toki, Japan from 28 Nov. to 1 Dec. 2011.

- **Collaborations with USA**

1) C. C. Kim (Univ. Washington) visited NIFS from Jan. 11 to April 15 to develop energetic particle distribution analysis in phase space during the interaction with MHD modes.
2) M. Yokoyama (NIFS) visited University Wisconsin-Madison from 14 to 20, Feb. 2011 to promote CWGM activity and to enhance HSX-Group's interests and contributions to this international programmatic collaboration. During this visit, Core Electron-Root Confinement (CERC) plasma on HSX was successfully registered in the International Stellarator-Heliotron Profile database.
3) M. Isobe (NIFS) visited Princeton Plasma Physics Laboratory (Drs. D.S. Darrow and A.L. Roquemore) from Feb.16 to Feb.27, 2011 to participate in calibration experiment of neutron flux monitor by use of 252Cf fission neutron source in NSTX.

4) D.A.Spong (ORNL) visited NIFS from 27 Feb. to 4 Mar. 2011, to promote international collaborative research on Alfven eigen mode and energetic particle physics. He and his collaborators in NIFS had extensive discussions for successfully kicking-off "energetic particle session" in the 8th CWGM.
5) C. C. Hegna (Univ. of Wisconsin Madison) visited NIFS to attend the 8th CWGM. In this visit, he discussed with Y. Narushima the theoretical study to explain the LHD experimental observation.
6) C.Hegna (Univ. Wisconsin-Madison) visited NIFS from 14 to 18 Mar. 2011 to promote collaborative research on magnetic-island physics from the viewpoints of application of his theory to experimental findings in LHD. He also joined 8th CWGM to present the achievement made during his visit.
7) R. Kumazawa and Y. Yoshimura (NIFS) visited Newport (USA) from March 30th to June 5th 2011 to attend a meeting "Joint Meeting of the 19th Topical Conference on Radio Frequency Power in Plasmas and the US Japan RF Physics Workshop". They gave presentations about recent ICRF and ECRH results in LHD and discussed about RF Heating with the participants.
8) K.Tanaka (NIFS) visited General Atomic San Diego, USA and participate meeting of transport and confinement for International Tokamak Physics Activity from April 4th to April 5th. He made a presentation entitled “ELM and ELM free phase of H mode in LHD in comparison with tokamak”
9) K.Tanaka (NIFS) visited Bahia resort hotel San Diego, USA and participate EU-US Transport Task Force Meeting from April 6th to April 9th. He made a presentation entitled “Core turbulence and comparison with gyro kinetic simulation in high-Ti discharge of LHD”
10) David A. Gates (Princeton Plasma Physics Laboratory, USA) had stayed at NIFS from 1st July to 1st October 2011 as a guest professor. The technique of reconstruction of MHD equilibrium by using 3D MHD code was discussed.
11) Y. Todo (NIFS) visited Univ. Texas at Austin from Sept. 6 to Sept. 18 to discuss nonlinear MHD effects on Alfvén eigenmode evolution. He also attended and gave an invited talk at the 12th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems.
12) H.Yamada, A.Sagara and T.Goto (NIFS) attended the International Workshop "MFE Roadmapping in the ITER Era" held in Princeton, U.S.A. from September 7 to 10, 2011..
13) A. Sagara (NIFS) attended The 10th International Symposium on Fusion Nuclear Technology (ISFNT) held in Portland, US, from September 11 to 16, 2011 and made an invited presentation titled "Design activities on helical DEMO reactor FFHR-d1".
14) K. Ida (NIFS) visited DIII-D from 12th to 16th September 2011 to join experiments on heat pulse propagation experiment. He has investigated the heat pulse propagation due to the modulation electron cyclotron heating (MECH) near the plasma periphery in order to examine the magnetic topology.
15) Y. Suzuki (NIFS) visited General Atomics (San Diego, USA) from 12th to 16th September 2011 in the US-Japan collaboration on 3D modeling in the tokamak configuration with the resonant magnetic perturbation field. This collaboration results were reported at ITPA2011 (York, England, Oct. 2011).
16) M. Nunami visited Princeton Plasma Physics Laboratory (Princeton, US) from September 12-14, 2011, to discuss benchmark test between our gyrokinetic simulation code "GKV-X" and PPPL's code "GS2" in non-axisymmetric systems.
17) S.Lazerson (PPPL) visited NIFS from 20th to 22th September to discuss the reconstruction of 3D MHD equilibrium in the LHD. In this visit, the reconstruction using STELLOPT code was discussed.
18) A.Sontag (ORNL) visited NIFS from 20th to 22th September to discuss the reconstruction of 3D MHD equilibrium in the LHD. In this visit, the reconstruction using V3FIT code was discussed.
19) B. N. Breizman (Univ. Texas at Austin) visited NIFS from Oct. 1 to Oct. 15 to discuss continuum damping and nonlinear harmonics of Alfvén eigenmodes.
20) T. Mutoh and T. Shimozuma (NIFS) attended the US-EU-Japan RF Technology Workshop held in Austin (Texas) from 10 Oct. to 12 Oct 2011 and discussed ECH and ICRF technology related issues and the next year collaborations.
21) T. Tokuzawa (NIFS) visited Princeton Plasma Physics Laboratory (PPPL) from 1st to 15th November 2011 to discuss FDTD simulation study for microwave reflectometer diagnostics.
22) N. Tamura (NIFS) will visit the Salt Palace Convention Center, US from November 13th to November 20th, 2011 to join 53rd Annual meeting of the APS Division of Plasma Physics. He will give an invited talk entitled “Finding the Latent Structure in Non-local Electron Heat Transport Event”.
23) S. Nishimura, NIFS (Japan) visited the Department of Electrical and Computer Engineering, University of Wisconsin-Madison (Madison, WI, US) during Nov.27-Dec.15, 2011 for a collaboration on the transport analysis of the Helically Symmetric Experiment.
24) D.A. Spong(ORNL) will visit NIFS (K. Toi) from 1 Dec. to 15 Dec., 2011, for discussions on energetic ion driven MHD modes in LHD and energetic ion loss mechanisms on LHD. He will also discuss important issues related energetic particle confinement toward the next CWGM.
25) T.-H. Watanabe, H. Sugama, S. Satake, M. Nunami, and K. Ida (NIFS) visited Ocean Place Hotel to attend the The US-Japan Joint Institute for Fusion Theory Workshop on "Turbulent and neoclassical flow

generation and associated transport dynamics". They presented recent numerical and simulation results on plasma flows and related turbulent transport phenomena in toroidal configurations.

26) Michael Bell, G. Neilson, C. Chang (PPPL), Todd Evans (General Atomics), SYUNICHI SHIRAIWA, Seung Gyou Baek, Orso Meneghini (PSFC, MIT), Farrokh Najmabadi (UCSD), Viktort Decyk (UCLA), Steven Zinkle (ORNL), Francois Waelbroeck (University of Texas at Austin) attended the 21th International Toki Conference, held in Toki, Japan from 28 Nov. to 1 Dec. 2011.

5.2 Plans for 2012 in NIFS

1 ) K. Ida (NIFS) will visit DIII-D to continue the experiments on heat pulse propagation experiment. He will investigated the heat pulse propagation due to the modulation electron cyclotron heating (MECH) near the plasma periphery in the plasma with RMP field.

2 ) K.Tanaka (NIFS) will visit Australian National University Canberra, Australia from January 29th till February 3rd. He participate international stellarator/heliotron workshop and will made a presentation entitled ” Comparison of turbulence observed in LHD with gyro-kinetic simulation” as an invited speaker

3 ) M. Yokoyama (NIFS) will attend the 9th CWGM and 18th International Stellarator-Heliotron Workshop in Jan. to Feb. 2012, both held in Australia, to discuss international collobarative activity in CWGM and to make an invited-talk on joint experiments (LHD, TJ-II and W7-AS data as well) for transport model validation activity.

4 ) G. Motojima (NIFS) will visit Australian National University and Murramarang Beachfront Nature Resort, Canberra, Australia to attend the 9th Coordinated Working Group Meeting for Stellarator-Heliotron Research and 18th International Stellarator/Heliotron Workshop and 10th Asia Pacific Plasma Theory Conference from 26 Janualy to 4 Feburary 2012 to give a presentation entitled "Observation of Internal Distribution in a Pellet Plasmoid by High-speed Imaging Spectroscopy".

5 ) T. Morisaki (NIFS) will Australian National University, Canberra, Australia to attend the 18th International Stellarator/Heliotron Workshop from 29 January to 3 February 2012 to give an invited oral presentation entitled "Experimental Results of Closed Divertor Plasma in LHD". He discussed the initial experimental results of closed helical divertor partially installed in LHD.

6 ) G. Kawamura (NIFS) will visit Forschungszentrum Juelich GmbH (Juelich Germany) and Max-Planck-Institut fur Plasmaphysik (Greifswald Germany) on January 2012 for collaboration on simulation modeling of plasma-wall interaction and impurity transport.

7 ) M. Shoji (NIFS) visited to CIEMAT(Spain) from 12th to 22th March 2012 for attending the dedicated experiment for fast framing measurement of dusts from electrically biased electrode in TJ-II. He discussed stereoscopic measurement of the trajectory of the dusts by fast framing cameras with collaborators in CIEMAT.

5.3 International Collaborations by the Heliotron J team at Kyoto University

- **Collaborations with EU**

1) S. Yamamoto visited CIEMAT from March 2 to 13, 2011. In order to get a unified knowledge of energetic-ion-driven MHD instabilities such as Alfvén eigenmode (AE) in helical devices with low magnetic shear, He have experimentally and theoretically investigated the energetic-ion-driven MHD instabilities utilized by the iota scan in helical device TJ-II with magnetic shear. He has observed AEs in each magnetic configuration. He have obtained the data which can be compared the result of Heliotron J with low magnetic shear.

2) S. Ohshima visited CIEMAT from March 2 to 13, 2011 to have collaboration experiment for Alfven eigenmodes driven by energetic particles in TJ-II. He also discussed with Dr. M. A. PEDROSA and Dr. C. Hidalgo for details of the Langmuir probe systems such as probe head structure, circuit system and data acquisition system, and recent experimental results for long range correlation and turbulence in TJ-II.

3) A. Dinklage (Max-Planck Institute) visited Kyoto Univ. on Sep. 16 to discuss optimization of advanced helical systems. He presented report and outlook of the superconducting stellarator Wendelstein 7-X. A. Dinklage, M. Yokoyama, K. Nagasaki, S. Kobayashi and S. Ohshima had a discussion with M. Ramisch (Stuttgart Univ.) through satellite TV about turbulence database of TJ-K and Heliotron J.

4) T. Estrada (CIEMAT) visited Kyoto Univ. from Sep. 19 to Dec. 19 as a guest professor of Institute of Advanced Energy. She joined the Heliotron J experiment, developed a reflectometer system for density fluctuation measurement and analysed the fluctuation data. She also took a lecture on plasma turbulence to the graduate students of Graduate school of Energy Science, Kyoto Univ.

5) E. Ascasibar (CIEMAT) visited Kyoto Univ. from Sep. 14 to Sep. 17 and From Dec. 9 to Sep. 19 to make discussion about MHD modes including Alfven eigenmodes in Heliotron J and TJ-II. He also presented recent study on global confinement in NBI plasmas and dynamic magnetic configuration scans in TJ-II.

6) K. Nagasaki had a collaboration research on ECH/ECCD physics with N. Marushchenko (Max-Planck Institute). They have been developing a ray tracing calculation code "TRAVIS" for Heliotron J device to calculate the EC power deposition and EC driven current efficiency. The experimental results from Heliotron J are in quantitative agreement with the theoretical estimation. They published a paper in Nucl. Fusion Journal, entitled ""Influence of trapped electrons on ECCD in Heliotron J".
7) Discussions with W7 team (IPP) were kept along the same line as in 2011.
8) Collaborations with CIEMAT were continued along the same lines as in 2011.

- **Collaborations with Australia**

1) Discussions with H-1NF team (ANU) were kept along the same line as in 2011.

- **Collaborations with US**

1) Discussions with the US team (HSX (Wisconsin Univ.) team, CTH (Auburn Univ.) team, groups of ORNL and PPPL, etc.) were kept along the same line as in 2011.

- **Collaborations with Ukraine**

1) I. Pankratov (Kharkov Institute) visited Kyoto Univ. from Jan. 16 to 30, 2011. During his visit, the investigation of influence of plasma rotation on the shift of diverted plasma flux positions in the biasing experiment in Heliotron J was continued in collaboration with Tohoku University (Prof. S. Kitajima). The different plasma types ($H_2$, $D_2$, He) were used in experiments and strong shifts of diverted plasma fluxes were observed. The similar experiments should be suggested for LHD.
2) Discussions with Kharkov team were kept along the same line as in 2009 and also started the discussion about the collaboration in U-2M project.

- **Collaborations with Russia**

1) K. Nagasaki visited Nizhny Novgorod, Russia on July 8-17 to participate in 8th International Workshop on "Strong Microwaves and Teraherz Waves: Sources and Applications". He presented the physics study on ECCD in Heliotron J.

- **Others**

1) L. W. Yang (Southwestern Institute of Physics, China) visited Kyoto Univ. from July 1 to Sep. 30 as a guest professor. He had a collaboration research work on edge turbulence measurement and analysis especially the physics of zonal flow, geodesic acoustic mode and blob structure using Langmuir probes.
2) Confinement control of high energy particles by using the optimized field configuration based on the quasi-isodynamic concept was examined through ECH/NBI/ICRF experiments.
3) Details of bulk confinement properties were studied experimentally from the viewpoint of the bumpiness/toroidicity control, the toroidal current control, and the fuelling physics and theoretically in Heliotron J.
4) Advanced ECH scenarios including ECCD and EBW heating/current drive were examined through Heliotron J/LHD experiments. Temperature measurement in over-dense plasmas using 35GHz EBW diagnostics was also discussed. A waveguide switch which is available to the 70GHz ECH/ECCD system in Heliotron J was manufactured as a collaboration work between the Heliotron J group and the LHD group.
5) New gas fuelling by supersonic molecular beam injection (SMBI) was successfully applied to ECH/NBI plasma in Heliotron J. The collaboration of fuelling control studies are being discussed with TJ-II team and NIFS.

5.4 Plans for 2012 in Kyoto University

1) 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.
2) 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.
3) Collaboration research will be continued with H-1 staff, related to the upgrade of 28GHz ECH system and the plasma production/heating using this system.
4) Confinement control of high energy particles by using the optimized field configuration based on the quasi-isodynamic concept will be examined through Heliotron J NBI/ICRF experiments.
5) Details of transition phenomena related to the high confinement mode in NBI and ECH plasmas will be investigated through configuration control, plasma current control experiments.
6) SMBI experiments will be performed to investigate the confinement improvement in advanced stellarators/heliotrons, especially by the collaboration with TJ-II and LHD.
7) MHD activity control in higher beta plasmas, which is produced by assistance of 2.45 GHz 20 kW magnetron through the field configuration optimization will be performed in Heliotron J.
8) F. Sano, T. Mizuuchi, K. Nagasaki and H. Okada plans to attend 18th International Stellarator/Heliotron

Workshop & 10th Asia-Pacific Plasma Theory Conference, which will be held in Australian National University, Canberra on Jan. 29 – Feb. 3.

9) J. Thorsen (Max-Planck Institute) plans to visit Kyoto Univ. in 2012 for collaboration research on MHD mode analysis using multi-channel SX array measurement.
10) S. Darrow (PPPL) plans to visit Kyoto Univ. in 2012 for collaboration research on lost-ion probe diagnostic.
11) B. Blackwell (Australian National University) plans to visit Kyoto Univ. on March 2012 for collaboration research on MHD mode analysis in H-1 and Heliotron J.
12) S. Ohshima plans to visit CIEMAT and Stuttgart University on March, 2011 to discuss turbulence measurement by using Langmuir probe with C. Hidalgo (CIEMAT) and M. Ramisch (Stuttgart Univ.).
13) S. Yamamoto plans to visit CIEMAT on March, 2012 to investigate the helicity-induced AE (HAE) with multi helicity modes and global AE (GAE) with single-helicity mode and their effect on energetic ion transport using the dynamic iota scan experiments in TJ-II.
14) F. Volpe (University of Wisconsin) will visit Kyoto Univ. as a guest professor from June 1 to August 31, 2012. He will join the Heliotron J experiment, develop system on heating, current drive and diagnostic using electron Bernstein waves (EBW), and measure electron temperature using the EBW.

## 6. Russia

### 6.1 International Collaborations in 2011

1) M. Mikhailov (Kurchatov Institute Moscow) to IPP Greifswald, 22.03. – 20.05.2011 and 26.10. – 23.12.2011
2) U. Herbst, T. Richert (IPP Greifswald) visited Budker Institute Novosibirsk, 16.04. – 21.04.2011:
3) J. Baldzuhn (IPP Greifswald) visited Budker Institute Novosibirsk,30.05. – 02.06.2011
4) J. Nührenberg (IPP Greifswald) visited Kurchatov Institute Moscow, 20.09. – 22.09.2011
5) K. Sarksyan and the ECRH IOFAN team have participated in the operation of the ECRH system of TJ-II during the 2011 experimental campaign (June-July 2011).
6) IOFAN Director was visiting Ciemat (July 2011) to discuss and expand Ciemat – IOFFAN long standing collaborations.
7) N. Kharchev (IOFAN) was visiting Ciemat in November 2011 to discuss possible designs to modify the gyrotron power by means of reflected power technique.
8) A. Melnikov and L. Eliseev and members of the HIBP Kurchatov Institute team were visiting CIEMAT to investigate the structure of plasma potential and plasma fluctuations in ECRH and NBI plasmas (in Lithium coated wall conditions) and measurements with two slit HIBP detector. The second HIBP system has been built for long-range (zonal flows) correlation studies and the commissioning is planned for 2012.
9) V. Yu. Sergeev (St. Petersburg Polytechnical University, Russia) visited NIFS (S. Sudo and N. Tamura) from February 17th to March 20th, 2011 for a collaboration research regarding the Tracer-Encapsulated Solid Pellet in the framework of the Invitation Fellowship Programs for Research in Japan by JSPS.
10) I.A. Sharov (St. Petersburg Polytechnical University, Russia) visited NIFS (S. Sudo and N. Tamura) from August 18th to September 19th, 2011 to study a spatial structure of the ablation cloud of the Tracer-Encapsulated Solid Pellet by measuring a Stark broadening with a spatial resolution on LHD.
11) B.V. Kuteev (National Research Center "Kurchatov Institute", Russia) visited NIFS (S. Sudo and N. Tamura) from October 7th to December 5th, 2011 for a collaboration research regarding the Tracer-Encapsulated Solid Pellet in the framework of the Invitation Fellowship Programs for Research in Japan by JSPS.
12) L.N. Vyacheslavov(Budker institute of Nuclear Physics, Russia) visited NIFS from October 23rd to November 11th. He made analysis of turbulence data measured by two dimensional phase contrast imaging. This is a collaboration work with K. Tanaka(NIFS)
13) Alexander Melnikov (National Research Centre Kurchatov Institute, Institute of Tokamak Physics, Russia), Inga Tolstikhina (P.N.Lebedev Physical Institute of Russian Acadamy of Sciences, Russia), Anatoly Nastoyashchiy (RF SRC Troitsk Institute for Innovation and Fusion Research (TRINITI), Russia), Leonid Eliseev (NRC Kurchatov Institute, Russian Federation) attended the 21th International Toki Conference, held in Toki, Japan from 28 Nov. to 1 Dec. 2011.
14) K. Nagasaki visited Nizhny Novgorod, Russia on July 8-17 to participate in 8th International Workshop on "Strong Microwaves and Teraherz Waves: Sources and Applications". He presented the physics study on ECCD in Heliotron J.
15) Dr. L.I.Krupnik and HIBP team (IPP NSC KIPT) in collaboration with Dr. A.V.Melnikov and T-10 team (Kurchatov Institute)).
    - upgrade of the analyzer system of the Heavy Ion Beam Probe facility and measurement procedure on T-10.
    - Installation of the new modification of the energy analyzer.
    - Installation of the new modification of the injector extraction system.
16) Providing the experiments directed to investigations of

the Geodesic Acoustic modes and their features in the OH and ECRH regimes.

6.2 Plans for 2012

1) K. Sarksyan and the ECRH IOFAN team participated in the operation of the ECRH system of TJ-II during the 2012 experimental campaign.
2) S. Pavlov (Kharkov Institute of Ukraine) will visit Ciemat to work on ECRH theory.
3) S. Petrov (IOFFE) will visit CIEMAT to participate on charge exchange spectrometry measurements.
4) N. Kharchev (IOFAN) will visit Ciemat in September 2012 to continue the investigation of gyrotron-power control.
5) A. Melnikov and L. Eliseev and members of the HIBP Kurchatov Institute team will visit CIEMAT to investigate the structure of plasma potential in ECRH and NBI plasmas (in Lithium coated wall conditions) and measurements with two slit HIBP detector. The second HIBP system has been design for long-range correlation studies (zonal flows); the final analyzer installation and test is foreseen during 2012.

## 7. Ukraine

7.1 Institute of Plasma Physics of the National Science Center "Kharkov Institute of Physics and Technology" of the NAS of Ukraine (IPP NSC KIPT, NASU)

7.1.1 International Collaborations of the NSC KIPT in 2011

**International collaborations of the plasma theory division**

- **Collaboration with Technische universität Graz, Ausstria**

1) Elaboration of numerical code for a direct computation of the α-particle losses in stellarators in real space coordinates.

The elaborated code is analogous to the code of W. Lotz et al., Plasma Phys. Control. Fusion, 34, 1037 (1992), which solves the guiding center drift equations in magnetic coordinates. Using the real space coordinates allows one to study an influence of magnetic islands and stochastic regions on the α-particle confinement in stellarators. (V.V.Nemov, S.V.Kasilov and V.N.Kalyuzhnyj in collaboration with Technische universität Graz, Austria).

2) Calculations of high energy particle losses for U-2M and W7-X.

Calculations with the elaborated code are performed for the life time of α-particles in the configurations of U-2M (Uragan-2M) and W7-X adapted to reactor plasma parameters.

For U-2M the magnetic field is calculated using the Biot-Savart law code with taking into account the influence of the current feeds and the detachable joints of the helical winding. Under the influence of these elements considerable island magnetic surfaces arise in the central region of the U-2M magnetic configuration. It is found that the presence of such islands has no essential influence on the life time of trapped α-particles in U-2M.

For W7-X a vacuum high mirror configuration obtained using the Biot-Savart law code (the case of $\beta=0$) as well as three-dimensional MHD finite β equilibrium high mirror configurations obtained with help of the HINT2 code ($\beta\approx2\%$ and $\beta\approx4\%$) are studied. It is found that the life time of trapped α-particles in W7-X is essentially better than in U-2M. For W7-X the obtained results for the life time of α-particles for the case of $\beta=0$ are in good agreement with those obtained formerly in magnetic coordinates (e.g., in W. Lotz et al.,). At the same time for finite β the life time of trapped α-particles found now is somewhat smaller than it was obtained formerly in magnetic coordinates. It is also found that confinement properties of stochastic regions in W7-X are insufficient. The results are published in V.V.Nemov, et al, $38^{th}$ EPS Conference on Plasma Phys, Strasbourg, 27 June-1 July 2011, P1.113. (V.V.Nemov, S.V.Kasilov and V.N.Kalyuzhnyj in collaboration with Technische universität Graz, Austria).

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

During 2011 year S.S. Pavlov in collaboration with F. Castejon, A. Cappa (CIEMAT, Madrid, Spain) and M. Tereshchenko (Instituto de Biocomputación y Física de Sistemas Complejos, 50018 Zaragoza, Spain, Institute of General Physics, RAS, Moscow, Russia) have finished the work on the modeling of waves in the inhomogeneous media, including thermonuclear plasmas.

**International collaborations of the plasma experiment division**

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

Dr. L.I.Krupnik et al (IPP NSC KIPT) in collaboration with Dr. C. Hidalgo and TJ-II team (CIEMAT).

1) upgrade of the first Heavy Ion Beam Probe system and performe measurements
of the electric fields and transport flows on TJ-II:
-installation and tuning of the new mode of the extration system to improve probing beam focusing
- development of the data acquisition system to increase the bandwidth.

2) Providing the experiments with the upgraded HIBP diagnostic of the TJ-II Stellarator. Experiments were directed to plasma trnsport processses investigations.

Potential and density coherent oscillations studied in the ECR and NBI plasma. The Alfven Eigenmode contribution into the bulk plasma coused by high energy electrons was found.

3) Installation of the second Heavy Ion Beam Probe diagnostic system on TJ-II stellarators. Possibilities of this system were significantly expanded.

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

Dr. L.I.Krupnik and HIBP team (IPP NSC KIPT) in collaboration with Dr. A.V.Melnikov and T-10 team (Kurchatov Institute)).

1) upgrade of the analyzer system of the Heavy Ion Beam Probe facility and measurement procedure on T-10.

   - Installation of the new modification of the energy analyzer.

   Installation of the new modification of the injector extraction system.

2) Providing the experiments directed to investigations of the Geodesic Acoustic modes and their features in the OH and ECRH regimes.

- **Collaborations with Japan Atomic Energy Agency, Japan**

V.S. Voitsenya et al. (IPP NSC KIPT) in collaboration with Drs. K. Isobe, T. Yamanishi and Dr. V.Kh. Alimov from Tritium Technology Group (Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan) together with Dr. B. Tuburska (Institute for Plasmaphysic (EURATOM Association, 85748 Garching, Germany) investigated the effects of irradiation of W mirror specimens with 20 MeV $W^+$ ions on the rate of reflectance degradation during subsequent long-time ion sputtering, as a simulation of behavior of in-vessel mirrors in ITER subjected to simultaneous impact of neutrons and charge exchange atoms.

- **Collaborations with Institute of Advanced Energy, Kyoto University, Japan**

During the visit of Dr. I.M. Pankratov to IAE in 2011 the investigation of influence of plasma rotation on the shift of diverted plasma flux positions in the biasing experiment in Heliotron J was continued (with Prof. T. Mizuuchi) in collaboration with Tohoku University (Prof. S. Kitajima). The first joint experiment was in 2009. In 2011 the different plasma types ($H_2$, $D_2$, He) were used in experiments and strong shifts of diverted plasma fluxes were observed. The similar experiments should be suggested for LHD.

- **Collaborations with Sweden**

1) V.E. Moiseenko visited Uppsala University 2 times, 16.12.2010-16.01.2011, 11.08.2011-11.09.2011 to participate in theoretical studies on fission-fusion hybrids.

- **Conference participation**

1) V.E. Moiseenko: Workshop on Fusion for Neutrons and Sub-Critical Nuclear Fission (FUNFI), Villa Monastero, Varenna, Italy September 12 - 15, 2011.
2) V.E. Moiseenko: Ninth meeting of the Coordinating Committee on Ion Cyclotron (CCIC-09), CEA Cadarache, 9-10 June 2011.
3) 16 participants: Ukrainian Conference on Plasma Physics and Controlled Thermonuclear Fusion, Kyiv, Ukraine, October 25-26.
4) I.E. Garkusha, L.I. Krupnik, M.S. Ladygina, V.A. Makhlaj, V.S. Taran, V.S. Voitsenya: PLASMA-2011, September, Warshaw

7.1.2 Plans for 2012 of the IPP NSC KIPT

**Plans for plasma theory division**

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

1) Calculations of the life time of α-particles for a number of optimised stellarator type configurations with help of the elaborated code (V.V.Nemov, S.V.Kasilov and V.N.Kalyuzhnyj in collaboration with Technische universität Graz, Austria).
2) Studies of the generalized Spitzer's function (current drive efficiency) in stellarator geometry with the help of NEO-2 code are planned (S:V.Kasilov in collaboration with Technische universität Graz, Austria, and IPP Greifswald, Germany).

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

To develop the fast method to evaluate the fully relativistic plasma dielectric tensor for EBW in fusion and astrophysical plasmas.

**Plans for plasma experiment division**

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

1) Completion of the hardware installation and launching of the control and data acquisition systems of the second HIBP system on TJ-II.
2) To develop the fast method to evaluate the fully relativistic plasma dielectric tensor for EBW in fusion and astrophysical plasmas
3) Tuning and start experiment of the second HIBP system

4) Investigation of the plasma potential and electron density during ECR and NBI heating in L-H transition. Study of the plasma potential evolution and its fluctuations in two cross-sections of plasma column by two HIBP systems on TJ-II stellarator

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

1) Tuning and start of experiment with new modified extraction system and new analyzer with 5-slit geometry.
2) Investigations of the behavior of plasma potential and fluctuations by upgraded HIBP system in regimes with high plasma density. Comparative study of the GAMs (and AEs) behavior in the T-10 tokamak and TJ-II stellarator during ECR heating with high intensity heavy ion probing beam.

- **Collaborations with Sweden**

V.E. Moiseenko will continue the collaboration with O. Agen from Uppsala University on theoretical studies on fission-fusion hybrids.

- **Collaboration with Plasma Physics Laboratory, University of Saskatchewan, Canada**

Comparative study of the SXR emissivity behavior and its fluctuations in STOR-M tokamak and URAGAN-3M stellarator.

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

1) Installation and adjustment of HIBP diagnostic system on Uragan-2M stellarator. Finishing the review paper on HIBP technique.
2) Investigations of the new supersonic sodium neutralyzer for Li0 diagnostic. Design and manufacture of the upgraded Li0 injector for TJ-II and Uragan-2M.
3) Experiments on RF plasma production and heating using 4-strap and recently manufactured "crankshaft" antennas on Uragan-2M device to study Alfven resonance heating.
4) Development of technique and technology of 24 hours per day RF wall conditioning. Further investigation of RF wall conditioning with the specially designed antennas.
5) It is planned to use the self-consistent numerical model for RF plasma production to explain Uragan-2M results.
6) Further development of the concept of a fusion-fission hybrid based on stellarator.
7) Theoretical and experimental investigations of the magnetic configuration of a stellarator with an embedded mirror with lowered magnetic field.
8) The test of equipment for providing the boronization procedure in the U-2M torsatron.
9) Continuation of investigations of the processes accompanying ITB and ETB formation in the plasma of the Uragan-3M torsatron under the RF plasma heating. Effects of transport barrier formation on divertor flow characteristics, in particular, on fast ion loss.
10) Elucidation of the nature of detail up-down asymmetry of characteristics of density and electric field fluctuations in the divertor region of the U-3M torsatron to check if this asymmetry is really connected with that of fast ion loss?
11) A search for RF plasma production and heating regimes in the U-3M torsatron without of production of fast ions.
12) Finishing the PhD thesis by A. Zhezhera, A. Prokopenko, M. Tarasov, and A. Beletskii.

7.2 V.N.Karazn Kharkiv National University, Kharkiv

7.2.1 International Collaboration in 2011

- **Collaborations with Institute of Space Research of University of Toronto, Canada, and Institute of Physics, Ernst-Moritz-Arndt University, Greifswald, Germany**

Roughness is an important factor that can increase the sputtering yield of the surface up to a factor of 5. To simulate the interaction of ions with rough surface, SDTrimSP-2D code has been developed and validated by comparison with experiments. In these experiments, energetic carbon ions bombard well known Si surface with pitch-grating structures. The evolution of the surface morphology predicted by SDTrimSP-2D code has been compared to the one, obtained experimentally by ex-situ secondary electron microscopy after the exposure; a good agreement has been found. The predictions of the model have been extended to the macroscopic parameters showing rather non-linear erosion of the structured surfaces.

**The results of this research were published:**

1) Schneider R., Mutzke A., Bizyukov I., Davis J. Bombardment of a Si pitch grating by C+ ions at an inclined incident angle parallel to the structure// Journal of Nuclear Materials, vol. 415, pp. S200-S203 (2011)
2) Mutzke A., Bizyukov I., Schneider R., Davis J. Nano-scale modification of 2D surface structures exposed to 6 keV carbon ions: Experiment and modelling// Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms. vol. 269, pp. 582-589 (2011)

- **Collaborations with National Institute for Fusion Science, Toki, Japan**

Last year we investigated the possibility to reduce the amount of T and $^3$He in D-T and D-$^3$He fusion plasmas respectively and at the same time to increase the fusion reactivity rates. On this purpose we applied selective ICRF heating to plasma minorities (T and $^3$He) to obtain catalyzed fusion.

New values for reactivity rates were calculated basing on the distribution function profiles for different RF heating scenarios. It was demonstrated that non-Maxwellian shape of the minorities distribution function played an important role for reactivity enhancement. The increase of reactivity rate is an important issue for the performance of fusion reactors.

**The results of the research carried out earlier were published this year:**

1) Shyshkin O.A., Moskvitin A.O., Moskvitina Yu.K., Yanagi N., Sagara A. Ignition Analysis for D Plasma withnon-Maxwellian 3He Minority in Fusion Reactors // Plasma Fusion Research 6, 2403064 (2011)
2) Yanagi N., Shyshkin O.A., Goto T., Kasahara H., Sagara A. Feasibility of Reduced Tritium Circulation in the Heliotron Reactor byEnhancing Fusion Reactivity Using ICRF // Plasma Fusion Research 6,2405046 (2011)

- **Collaborations with National Science Center «Kharkiv Institute of Physics and Technology », Kharkiv, Ukraine**

New approach is developed and applied to analyze a temporal evolution of drift ITG turbulence of inhomogeneous plasma flow across the magnetic field with time-dependent velocity shear in plane geometry. That approach allows strong time-dependent velocity shear rate to be treated, while retaining the effect of turbulence. In contrast to typical gyrokinetic treatment, a method of shearing modes (also named as 'nonmodal' approach) was used, which consists in transforming of Vlasov-Poison (V-P) system to sheared (in space and velocity) coordinates convected with shear flow and accounted for the effect of the waves stretching by shear flows. This transformation is followed by transformation to renormalized guiding center and Larmor orbit coordinates, which accounted for the effect of turbulent scattering of particles by ensemble of shearing modes with time dependent wave numbers. The renormalization procedure precedes the standard gyroaveraging and retains effect the gyration angle turbulent scattering in gyroaveraged V-P system. Developed theory reveals characteristic time scales and corresponding evolutionary processes, which display different statistic properties. It was obtained, that main nonlinear effect, which is absent in conventional gyrokinetic theory, but is responsible for extremely fast suppression of the instability, is effect of the gyration angle scattering by sheared perturbations.

The renormalized non-modal quasilinear equation, which accounted for the effect of ions scattering by ensemble of the sheared drift waves on the ion equilibrium distribution function, is obtained. It is applied to the investigations of the multistage processes of the temporal evolution of the anomalous transport of ions density and energy in plasmas with time dependent velocity shear. The time dependent diffusion and thermal conductivity coefficients, which display fast decay with time due to velocity shear, were obtained.

**The results of this research were published:**

Mikhailenko V.S., Mikhailenko V.V., Stepanov K.N. *Renormalized non-modal theory of the kinetic drift instability of plasma shear flows*// Physics of Plasmas 18, 062103 (2011)

**These results were reported on Conferences:**

1) Mikhailenko V.S., Mikhailenko V.V., Stepanov K. N. Non-modal renormalized kinetic theory of the drift turbulence of the non-stationary shear flow// The 5$^{th}$ IAEA Technical Meeting on the "Theory of Plasma Instabilities", Austin, Texas, United States of America, 2011
2) Mikhailenko V.S., Mikhailenko V.V., Stepanov K. N. Non-modal renormalized gyrokinetic approach for time-dependent plasma shear flow// 21st International Toki Conference (ITC-21) on Integration of Fusion Science and Technology for Steady State Operation, Ceratopia Toki, Toki-City, Gifu, Japan, 2011

7.2.2 Research within the University

In the KNU, comprehensive studies are continued of the interaction of ion beams with composite structures: the intermetallic alloy Zr50V50, yttrium iron garnet of different composition, as well as samples as witnesses for studies: stainless steel; single-layer coverings W; sandwich-layers coverings (Cu sub layer, ≈ 10 mcm.)

The following ion beams are used: $H^+$, $H_2^+$, $D^+$, $D_2^+$, $He^+$, $Ar^+$.

Range of energies of primary ions beam is: 0.5 - 10 keV.

Fluencies are applied: $10^{14}$ - $10^{18}$ $cm^{-2}$.

The following studies are carried out:
- Determination of coefficients of ions trapping (Mass-Spectrometry of Thermal Desorption) by the samples after fixed fluencies cumulating.
- Ion-photon emission (IPE) of sputtered particles during the samples irradiation.
- Changing of the composition of secondary ions (Secondary Ions Mass-Spectrometry) sputtered from the surface of the samples at cumulating of fluencies of primary ions with various chemical specifics.
- Surface topography during the accumulation of different fluencies of ions with various chemical specifics.

- Structural-phase transformations of a near-surface zone of a sample at the ion irradiation.

The results are reported at the conference «Ion-Surface Interactions 2011» (ISI-2011) in August 2011 in Zvenigorod, Russian Federation:

1) Bobkov V.V., Afanas'eva I.A., Gritsyna V.V., Gritsyna V.T., Shevchenko D.I. Characteristic features of ion-photon emission from yttrium-iron garnets.

2) Bobkov V.V., Starovoitov R.I., Tishchenko L.P., Zubarev E.N., Kovtunenko Yu.I., Logachev Yu.E. The influence of Deuterium and Helium implanted Ions on the Structure of condensed Tungsten coating.

3) Litvinov V.A., Koppe V.T., Bobkov V.V. SIMS investigations of Hydrogen interaction with the Zirconium getter alloy Surface.

The results are published:

Bobkov V.V., Tishchenko L.P., Onishchenko A.V., Zubarev E.N., Starovoitov R.I., Kovtunenko Yu.I., Logachev Yu.E., Gamayunova L.A. *Implantation of Helium and Deuterium Ions into Tungsten-Coated Composite Structures* // JOURNAL OF SURFACE INVESTIGATION. X RAY, SYNCHROTRON AND NEUTRON TECHNIQUES, Vol. 5, No. 8, pp. 806 - 811 (2011)

**8. United States**

8.1 International Collaboration in 2011

- **Collaborations with Japan (NIFS)**

1) D. A. Gates (PPPL) visited NIFS on for 3 months July 1- Oct. 1, 2011 as visiting professor working on equilibrium reconstruction, ion temperature measurements and high beta experimental analysis working with S. Sakakibara, Y. Suzuki, M. Goto, S. Morita, Narushima, K. Ida, and K. Watanabe.
2) D. A. Spong (ORNL) visited NIFS to give a talk at on Alfven Stability Theory at an energetic particle physics CWGM workshop Feb. 26 - March 5, 2011. Also worked with Y. Todo and others on developing a stellarator Alfven benchmark case.
3) D. A. Spong (ORNL) visited NIFS Nov. 28 to Dec. 16, 2011 for collaboration with Y.Todo, K. Toi, K. Ogawa, A. Konies (IPP-Greifswald) on stellarator AE stability benchmarks, modifications of the DELTA5D Monte Carlo code, and studies of acoustic coupling effects for AE modes seen in LHD.
4) D. A. Spong (ORNL) attended the JIFT (Joint Institute for Fusion Theory) U.S. – Japan Workshop on the Next Stage in the Progress of Simulation Science in Plasma Physics at NIFS (Toki, Japan) on Dec. 3, 4, 2011.
5) S. Lazerson (ORNL) visited NIFS in Toki, Japan from June 26 – July 2, 2011 to collaborate with Y. Suzuki and K. Ida on equilibrium reconstructions with STELLOPT and benchmarking of the PIES code with HINT2.
6) N. Pablant, M. Bitter, and K. Hill (PPPL) visited NIFS from May 13 – 30, 2011 to install and spatially calibrate a high resolution x-ray imaging crystal spectrometer for profile measurements of ion and electron temperatures and poloidal flow with S. Morita.
7) N. Pablant (PPPL) stayed at NIFS from July 19 – Nov. 7, 2011 to commission and to operate the IXCS diagnostic. During this trip Dr. Pablant also participated in experiments performed on LHD.
8) C. C. Hegna (UW-Madison) visited NIFS from March 12-19, 2011 to attend the CWGM and collaborate with Y. Narushima and K. Watanabe on magnetic island physics.
9) K. Tanaka visited PPPL in February to benchmark gyrokinetic codes in stellarator geometry.
10) M. Nunami visited PPPL in September to benchmark gyrokinetic codes in stellarator geometry.
11) K. Ida, S. Ohdachi and Y. Suzuki (NIFS) visited General Atomics to participate in the first half of a joint experiment on DIII-D and LHD during the week of September 12th.
12) T. Evans (GA), J. Harris (ORNL), E. Unterberg (ORNL) travelled to NIFS Sept. 19-23rd 2011 for the second half of the joint experiment on DII-D and LHD.
13) Throughout 2011, A. C. Sontag (ORNL) and J D Hanson (Auburn) began development of a version of the V3FIT rapid reconstruction code for LHD, based on the code now routinely used to reconstruct 3D equilibria for the CTH (Auburn Univ) and HSX (Univ. of Wisconsin) experiments. V3FIT uses data from external magnetic diagnostics with available profile measurements to calculate equilibria using VMEC. V3FIT is now being tested with agreed upon test data from LHD, and will be applied to shot sequences in LHD during planned visits to NIFS in 2012.
14) In September, 2011, K. Ida, Y. Suzuki, S. Ohdachi, T. Evans (GA), J. H. Harris, A. C. Sontag, and E. A. Unterberg (ORNL)participated in linked experiments to test the role of RMPs in transport on the DIII-D tokamak (GA) and LHD (NIFS).
15) S. Nishimura (NIFS) is visiting UW-Madison Nov. 28 – Dec. 13, 2011 to provide theoretical support for plasma flow measurements in HSX.

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

1) D. A. Gates and H. Neilson (PPPL) visited Greifswald Feb. 19 – 23 to finalize plans for trim coils and to discuss future collaboration planning.
2) D. A. Spong (ORNL) worked with C. Beidler and H. Maassberg of IPP-Greifswald on neoclassical theory benchmarking for stellarators.
3) S. Bosch, K. Risse, and T. Rummel (IPP) visited PPPL

from July 6th-8th, 2011 to participate in the Final Design Review of the W7-X trim coils being constructed by the US.

4) K. Risse, and T. Rummel (IPP) participated in the Final Design Review of the W7-X trim coil services October 13-14, 2011 by remote connection.
5) K. Risse, and T. Rummel (IPP) visited PPPL from November 12-13 to discuss the contract that had been placed with Everson-Tesla and to tour the plant in Nazareth, PA, USA. The Manufacturing Process Outline was discussed.
6) M. Rorvig (UW-Madison) visited IPP-Greifswald for two weeks in June to learn to use the GENE code from P. Xanthopolous and F. Jenko.
7) D. Mikkelsen (PPPL) visited IPP August to benchmark gyrokinetic codes in stellarator geometry.
8) Glen Wurden visit to Greifswald May-June 2011 to begin diagnostics collaboration with W7-X, primary contact Marcin Jacubowski.
9) Andrei Simakov (LANL) visit to Greifswald, May 2011, to collaborate with Per Helander on analytic bootstrap theory work.
10) A. Lumsdaine and D. McGinnis of ORNL visited IPP-Garching and IPP-Greifswald for planning of the design activities for the W7X divertor scraper elements.

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

1) D. A. Spong (ORNL) collaborated with Sasha Melnikov on modeling AE activity and mode structures he has measured in the TJ-II stellarator (refs. J5, I2).
2) R. Wilcox (UW-Madison) collaborated with B. Ph. van Milligen (CIEMAT) on bicoherence measurements in HSX.
3) D. Carralero and A. Alonso (CIEMAT) visited UW-Madison and collaborated on Reynolds stress measurements in HSX, May 30 – June 3, 2011.
4) C. Cook (UW-Madison) is collaborating with R. Sanchez (Universidad Carlos III de Madrid) and S. Hirshman (ORNL) on the SIESTA equilibrium code.

- **Collaborations with Italy (Consorzio – RFX, Padua)**

1) D. A. Spong (ORNL) visited Consorzio-RFX in Padua, Italy from April 14-15, 2011 to work on application of stellarator Alfven wave theory to RFX and also gave a seminar "Recent results for energetic particle destabilized Alfven modes in toroidal devices."
2) D.Terranova (RFX) visited J.Hanson (Auburn University) from 13-22 Oct., 2011 in Boulder Colorado to discuss use of the V3FIT code on RFX.

- **Collaborations with France (IJL, Nancy)**

D. A. Gates (PPPL) visited University of Nancy, Institut Jean Lamour to discuss future collaborations on proposed ESTELLE stellarator and gave a seminar entitled “Fusion Research at PPPL”.

8.2 Planned Research Activities for 2012

Spong, Sontag, Gates, Harris, Pablant, Lazerson, Wurden, and Zarnstorff will attend the 2012 CWGM and ISHW in Canberra/Murramarang and give presentations.

**Alfven wave physics (D. A. Spong, ORNL):**

- Adapt the Landau-fluid closure Alfven instability model to stellarators

- Simulate Alfven instability observations on LHD and TJ-II, including acoustic coupling effects

- Work with Y. Todo and Axel Koenies on benchmarking Alfven instability codes

- Work with K. Ogawa on upgrading the DELTA5D energetic particle Monte Carlo code for fast ion confinement studies in LHD.

- Continue ongoing collaborations with L. Marrelli, Marco Gobbin, Matteo Zuin and others at Consorzio RFX on Alfven modes and neoclassical transport in helical RFX states.

**For the LHD IXCS diagnostic work (N. Pablant, PPPL)**

-Validate the analysis and inversion techniques used for the LHD XICS diagnostic

-An upgrade of the XICS system is planned for the 2012 run period. This upgrade will provide improved plasma coverage, calibrated poloidal rotation measurements and allow the XICS diagnostic to operate during steady state LHD discharges.

-N. Pablant will travel to LHD to implement the upgrade and to participate in the 2012 experimental campaign.

**W7-X Collaboration (PPPL, ORNL, LANL)**

-Four of the five trim coils will be completed and delivered to the W7-X.

-Design work on the power supplies will be completed and the first units will be ordered.

-Continue design of the W7X divertor scraper elements in collaboration with IPP

-Continue preparation of divertor diagnostic collaboration

-Development of solution for real-time image analysis at LANL

**LHD Island Physics (Hegna, UW Madison)**

-Plan to continue theory/experiment comparison - write paper on this subject

**Gyrokinetic benchmarks (Mikkelsen, PPPL)**

-Include studies of zonal flow damping in the NCSX, LHD, and W7-X configurations, and extend to nonlinear simulations of saturated turbulence.

-Apply the GS2 code to interpret experimental results on energy confinement and particle transport in the LHD high-Ti/'impurity hole' regime, and in an ECH plasma in W7-AS.

**Equilibrium Reconstruction (J. Hanson, Auburn, A Sontag, ORNL, S. Lazerson, PPPL)**

-Continue collaboration with RFX

-Visit Wendelstein 7-X for discussion on V3FIT reconstruction

-Visit RFX for discussions and further collaboration on equilibrium reconstruction

-Continue LHD reconstruction development for use in experimental analysis

- A.C.Sontag will visit NIFS several times to test the V3FIT reconstruction code on LHD experimental data.

- K. Likin (UW-Madison) will visit Kyoto in March to collaborate with S. Murakami on the application of the GNET code to HSX and visit NIFS to discuss potential collaborative opportunities on LHD.

- C. Cook (UW-Madison) will visit Madrid in the summer to collaborate with R. Sanchez (Universidad Carlos III de Madrid) on the SIESTA equilibrium code.

- Anderson, Briesemeister, Wilcox, Cook and Likin will attend the 2012 ISHW Conference in Canberra/ Murramarang and give presentations.

**Publications**

K. Toi, K. Ogawa, M. Isobe, M. Osakabe, D.A. Spong and Y. Todo, "Energetic- ion driven Global Instabilities in Stellarator/Helical Plasmas and Comparison with Tokamak Plasmas, " Plasma Phys. Control. Fusion 53, 024008 (2011).

C.D. Beidler, K. Allmaier, M.Yu. Isaev, S.V. Kasilov, W. Kernbichler, G.O. Leitold, H.Maassberg, D.R. Mikkelsen, S. Murakami, M. Schmidt, D.A. Spong, V. Tribaldos and A. Wakasa, "Benchmarking of the mono-energetic transport coefficients - results from the International Collaboration on Neoclassical Transport in Stellarators (ICNTS)," Nuclear Fusion 51, 076001 (2011).

D. A. Spong, "3D effects on energetic particle confinement and stability," Physics of Plasmas 18, 056109 (2011).

A.V. Melnikov, L.G. Eliseev, E. Ascasibar, A.A. Chmyga, C. Hidalgo, T. Ido, R.Jiménez-Gómez, I.A. Krasilnikov, A.D. Komarov, A.S. Kozachek, L.I. Krupnik, S.M.Khrebtov, A. Könies, Y.K. Kuznetsov, A. López-Fraguas, S.E. Lysenko, V.A. Mavrin, K. Nagaoka, J.L. de Pablos, M.A. Pedrosa, S.V. Perfilov, A.I. Smolyakov, D.A. Spong, M.V. Ufimtsev, S. Yamamoto and TJ-II team, "Alfvén Eigenmodes properties and dynamics in the TJ-II stellarator," submitted to Nuclear Fusion (2011).

P. Martin, J. Adamek, P. Agostinetti, et al. "Overview of the RFX fusion science program," Nuclear Fusion 51, 094023 (2011)

M. Gobbin, D. Bonfiglio, A.H. Boozer, A.W. Cooper, D.F.Escande, S.P. Hirshman, J. Lore, R. Lorenzini, L. Marrelli, P.Martin, E. Martines, B. Momo, N. Pomphrey, I.Predebon, M.E.Puiatti, R. Sanchez, G. Spizzo, D.A.Spong, D. Terranova and RFX-mod team. "Three-dimensional equilibria and transport in RFX-mod: a description using stellarator tools," submitted to Phys. of Plasmas (2011).

S. A. Lazerson, “A magnetic diagnostic code for 3D fusion equilibria” accepted for publication in Plasma Physics and Controlled Fusion.

N.A. Pablant, et. al., "Ion and electron temperature measurements from the x-ray imaging crystal spectrometer on the Large Helical Device", Review of Scientific Instruments, (submitted 2011).

C. C. Hegna, "Healing of magnetic islands in stellarators by plasma flow," Nucl. Fusion 51, 113017 (2011).

A.D. Turnbull, W.A. Cooper, L.L. Lao and Long-Poe Ku, “Ideal MHD spectrum calculations for the ARIES-CS configuration“ to appear in Nuclear Fusion (2011).

A. C. Sontag, J. D. Hanson, E. A. Lazarus1, S. Lazerson, J. H. Harris, S. Sakakibara, Y. Suzuki, "Evaluation of Magnetic Diagnostics for MHD Equilibrium Reconstruction of LHD Discharges," EPS Strasbourg, 2011

J.H. Harris, J. D. Lore, A. Lumsdaine, D. McGinnis, J.M. Canik, J. Tipton, A. Peacock, F. Hurd4,A. Peacock, J. Boscary, J. Geiger, "Design of Divertor Scraper Elements for the W7-X Stellarator," APS Salt Lake City, 2011

R.S. Wilcox, B.Ph. van Milligen, C. Hidalgo, D.T. Anderson, J.N. Talmadge, F.S.B Anderson and M. Ramisch, “Measurements of Bicoherence and Long-range Correlations During Biasing in the HSX Stellarator”, Nucl. Fusion 51, 083048 (2011).

S. P. Hirshman, R. Sanchez, and C. R. Cook, “SIESTA: A scalable iterative equilibrium solver for toroidal applications,” Physics of Plasmas 18, 062504 (2011).

**IAEA FEC Papers**

"Characteristics of Anomalous Transport and Losses of Energetic Ions Caused by Alfvenic Modes in LHD Plasmas," with M. Isobe, et al.

“Overview of the US collaborative program in stellarator experiments”, Gates, D.A., et al., 23rd IAEA Fusion Energy Conference, 11-16 October 2010, Daejon, Korea (IAEAF1-CN-180/FTP/P6-06).

"Alfven Eigenmodes properties and dynamics in the TJ-II stellarator," with A. V. Melnikov, et al.

**Conference presentations**

D. A. Gates, et al., “Overview of the US Collaborative Program in stellarators physics” at the 53rd Annual APS DPP conference in Salt Lake City from Nov. 13-18.

Glen Wurden, et al., “US-German Collaboration overview” at the 53rd Annual APS DPP conference in Salt Lake City from Nov. 13-18.

D. A. Spong, "Discussion/suggestions for CWGM energetic particle physics topics in stellarators: theoretical viewpoint," Coordinated Working Group Planning Meeting. (CWGM) and collaboration, Feb. 28 - March 4, 2011.

D. A. Spong, "Recent results for energetic particle destabilized Alfven modes in toroidal devices (RFP, tokamak, stellarator)," April 14-15, 2011 visit to the Consorzio/RFX laboratory, Padua, Italy.

D. A. Spong, "3D effects on energetic particle physics and Alfven instabilities," IAEA Technical Committee Meeting on Energetic Particle Physics, Sept. 7 - 9, 2011, Austin, Texas.

D. A. Spong, "Energetic particle physics in 3D configurations," 2011 Sherwood Theory Meeting.

D. A. Spong, "Recent development of energetic particle gyro-Landau fluid models," 2011 TTF Meeting

D. Spong, "Alfven instabilities and energetic particle physics in stellarators." 2011 APS/DPP Meeting, Salt Lake City,

D. Spong, "New simulation methods for energetic particle physics in toroidal devices." 2011 JIFT Workshop on the Next Stage in the Progress of Simulation Science in Plasma Physics at NIFS, Dec. 2-3, 2011,

2012 International Stellarator/Heliotron Workshop, D. Spong, "Energetic particle physics and Alfvén instabilities in 3D configurations."

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Pablant, N. A., Bitter, M., Delgado-Aparicio, L., Goto, M., Hill, K., Lazerson, S., Morita, S., Roque- more, A., Gates, D., Monticello, D., Nielson, H., Reiman, A., Reinke, M., Rice, J., and Yamada, H., “Layout and expected performance of the recently installed high-resolution x-ray imaging crystal spec- trometer on the large helical device,” in [Proceedings of the 38th EPS Conference on Plasma Physics], (2011).

A. Lumsdaine, et al., "United States Contributions to Wendelstein 7-X," proceedings of 23rd SOFE Conference, Chicago, 26-30 June 2011.

C. C Hegna, invited talk at Innovative Confinement Concepts workshop, Aug. 16, 2011

C. C. Hegna, invited talk at the 53rd Annual APS DPP conference in Salt Lake City from Nov.13-18.

D.Terranova, J.D.Hanson, S.P.Hirshman, L.Marrelli, A.H.Boozer, M.Gobbin, N.Pomphery, and I.Predebon, “RFP helical equilibria reconstruction with V3FIT-VMEC”, poster P5.084, 38$^{th}$ EPS Conference on Plasma Physics, 1 July 2011.

Todd Evans (GA) gave an invited talk entitled “Physics of Resonant Magnetic Perturbations in Toroidal Plasmas” Plasma 2011 Conference in Kanazawa, Japan

A. C. Sontag, J. D. Hanson, E. A. Lazarus1, S. Lazerson, J. H. Harris, S. Sakakibara, Y. Suzuki, "Evaluation of Magnetic Diagnostics for MHD Equilibrium Reconstruction of LHD Discharges," EPS Strasbourg, 2011

J.H. Harris, J. D. Lore, A. Lumsdaine, D. McGinnis, J.M. Canik, J. Tipton, A. Peacock, F. Hurd,A. Peacock, J. Boscary, J. Geiger, "Design of Divertor Scraper Elements for the W7-X Stellarator," APS Salt Lake City, 2011

Glen Wurden presented an invited talk on the US-German collaboration on W7-X at the ICC Workshop in Seattle, August 2011. Also a 4-page accompanying paper.

C. R. Cook, S. P. Hirshman, R. Sanchez, and D. T. Anderson, “Extending SIESTA capabilities: removing field periodic limitations,” 53rd APS DPP Meeting, Salt Lake City, UT (November, 2011).

S. P. Hirshman, C. R. Cook, and R. Sanchez, “Analysis of

the eigenspectrum of the MHD force operator in the SIESTA equilibrium code," 53rd APS DPP Meeting, Salt Lake City, UT (November, 2011).

S. K. Seal, K. P. Perumalla, S. P. Hirshman, C. R. Cook, and R. Sanchez, "Improved parallelization of the SIESTA magnetohydrodynamic equilibrium code using cyclic reduction," 53rd APS DPP Meeting, Salt Lake City, UT (November, 2011).

**Appendix 1: Highlights of LHD Experiments**

In 2011, the Large Helical Device (LHD) comes to its 15th experimental campaign. Remarkable progress in the physics parameters and understandings of net-current free heliotron plasmas has been made in LHD.

Baffle-structured helical divertor (active pumping system yet) installed in two toroidal sections of inboard side became in operation. It was demonstrated that the neutral gas pressure in baffle-structured divertor reached more than ten times higher than that in open divertor. Higher recycling of He compared to H was also identified. These findings obtained with this partial modification of divertor system certainly provide critical data to finalize the design of closed divertor.

Central ion-temperature exceeded 7 keV (previous record was 6.4 keV). The available heating power was unchanged from 14th campaign. This increase of ion-temperature has been understood to be attributed to the lowering the plasma density at peripheral region, then to make the heat deposition profile more centrally-peaked. Discharge cleaning (utilizing ICH long-pulse discharges) was recognized to be effective to reduce the recycling from the wall. The active pumping system for baffle-structured helical divertor will be in operation from 16th campaign (FY2012), which further increases the capability of the edge density control. High-beta plasmas in higher magnetic field strength were also extensively explored, to achieve 4.1 and 3.4 % (for $B$=0.75 T and 1 T), respectively, along with the study on relation between the increase of beta and magnetic field structure.

Detailed physics studies, for example, in the following topics have been also progressed: non-local transport, long-range correlation, off-diagonal term effects, stochastic magnetic field structure, energetic particles and its impact on instabilities, spontaneous change of the magnetic island, and atomic and molecular processes, etc.

LHD has provided flexible opportunities for international (as well as domestic) collaborations by providing plasmas in a wide range of parameters. International collaborative researches have been extended in the topics such as, impacts of magnetic perturbation on heat and particle control, 3D equilibrium reconstruction, validation of transport model, and new diagnostics.

The LHD Experiment board has established the procedure of application of experimental proposals, to further enhance smooth participation to LHD experiment. The forms of "Research Proposal" and "Data Usage and Publication Agreement" can be downloaded at http://www.lhd.nifs.ac.jp/en/. We hope this will be of your help to join the LHD experiment.

**Appendix 2: Progress Report on Wendelstein 7-X Construction**

*(from Stellarator News: Nov. 2011 )*

**W7-X Torus Completed**

On 16 November, 2011, the last of the five field-period modules which comprise the W7-X stellarator was placed on its foundation with millimetre precision. The entire procedure required only three hours although the assembly team had reckoned with a considerably longer process as it was necessary to avoid collision at both ends of the module for the first time. As little as 8 mm of clearance was available -- often at several points simultaneously -- in maneuvering the 120 tonne module into position.

In the coming months, each module will be connected to its two neighbours. The separate cryo-piping, instrumentation and bus systems of the individual modules will then be joined with the aid of superconducting joints. The sections of the central support ring will be bolted together, the thermal insulation joined at the seams and the plasma and external vessels will be sealed by welding.

At the beginning of 2012, assembly of the in-vessel components will commence by cladding the plasma vessel with stainless steel cooling panels. Regions which will be subjected to high thermal loads must be protected with carbon tiles.

**Ports Provide Access to the Plasma**

W7-X will begin its experimental programme in approximately three years. With all five modules in place in the experimental hall, the toroidal ring of 70 coils designed for improved plasma confinement is complete.

Before assembly of the numerous in-vessel components can begin, however, it is necessary to install the ports which will provide the links between the external and plasma vessels.

A total of 254 vacuum-tight ducts, some as long as 3 m, will provide these “windows” for plasma observation. Roughly half of the ports are devoted to diagnostic purposes, e.g. detection of signals in the microwave, visible and x-ray portions of the electromagnetic spectrum. One of the diagnostic goals is measurement of the plasma temperature which must reach approximately 100 million degrees Celsius to make a future fusion power plant a realistic possibility. The remainder of the ports provides access for plasma heating systems and for the vacuum pumps which are necessary for exhaust of the working gas as well as impurities. Also accommodated is the water-filled piping required for cooling of the plasma vessel.

The openings for the ports vary from circular with a diameter of 150 mm to approximately rectangular with dimensions of 1000×400 mm². The largest ports are reserved for the microwave and neutral beam heating systems and to provide physical access to the torus for maintenance.

Real and virtual perspectives: the photo on the left shows a module without ports in the experimental hall. On the right is a CAD view of the same (with external vessel removed) with the ports highlighted in red.

Placement of the ports is done from the outside of the torus. This involves insertion through the opening in the external vessel and maneuvering through the cryo chamber to the target position on the plasma vessel, after which both ends are welded into place.

To accommodate movement of the plasma vessel during experimental operation of W7-X, connection of the ports to the external vessel makes use of bellows. As the ports must pass through the extreme cold of the cryo chamber it is mandatory that they be carefully insulated.

As foreseen in the project timetable, port assembly is completed for three of the five modules. This was achieved in spite of the technical challenges faced during the process. Indeed, ports weighing as much as a tonne have been maneuvered and welded into place with millimetre precision.

Determination of correct lengths and the complicated curves along which the ports must be cut to shape was also technically demanding. The initial approach involving a provisional placement of each port and subsequent cutting to achieve a satisfactory fit has now been replaced with a 3-D construction technology which not only accounts for the plasma vessel shape and the port orientation but also distortion which can be expected during the welding process. Once the port has been cut to the correct shape it must be thermally insulated. To prevent subsequent collisions in the construction and in the operation of W7-X, it is necessary that the insulation be applied with millimetre accuracy.

**Zero Tolerance -- Engineering Pushed to its Limits**

A handful of ports pose special challenges as they require accuracy at the level of technical feasibility. Although in most cases tolerances of a few millimetres are allowed, these special ports have tolerances which are essentially zero. The reasons for this include maximization of the port cross sections and the necessity of avoiding collisions with other components.

An example is the ports for neutral particle heating. Even a reduction of the port cross section by 1 mm would significantly increase the number of fast particles which never reach the plasma and instead deposit their energy in the port. An increase of port dimensions is impossible in this case due to the surrounding components, including the magnetic field coils. To improve such situations an iterative design and test procedure is used in which the orientation and welding properties of prototype ports are investigated with current results incorporated into each subsequent design.

This approach requires teamwork of the highest level as it represents an interplay of scientific calculations, modern CAD modelling, accurate 3-D measurements, cutting-edge engineering and a fine human touch.

**Appendix 3: Summaries of the Institute of Plasma Physics of the NSC KIPT, Kharkov**

**Plasma Theory**

***1) Calculation of current drive in plasma with finite collisionality***. In cooperation with ITP TU-Graz (Austria) and IPP Greifswald (Germany), studies of the effects of finite plasma collisionality on the efficiency of electron cyclotron current drive in toroidal fusion devices have been performed. At the first stage, tokamak geometry has been considered. A combination of drift kinetic equation solver NEO-2 (IPP Kharkov, ITP TU-Graz) and ray tracing code TRAVIS (IPP Greifswald) have been used for the study. For coupling of these codes, an interface has been developed which interpolates in 4D the generalized Spitzer's function precomputed by NEO-2 for a set of magnetic flux surfaces. It allows fast evaluation of current drive efficiency during the ray tracing. It has been shown that finite plasma collisionality effects visibly modify the local current drive efficiency in the mild long mean free path regime if the cyclotron resonance line in the velocity space touches or crosses the trapped passing boundary, namely, when Ohkawa effect becomes signficant. If the resonance line is located in the passing particle domain, results of NEO-2 agree with the results of a simple off-set model developed at IPP Greifswald for computation of collisional correction to the generalized Spitzer's function in the long mean free path regime. First results have been published in N.B.Marushchenko, et al, 38$^{th}$ EPS Conference on Plasma Phys, Strasbourg, 27 June-1 July 2011, P1.102.(S.V.Kasilov in collaboration with IPP Greifswald and ITP TU-Graz). Currently this study is being continued at IPP Greifswald.

***2) Power-flow formulation of a ray approach to the modeling of inhomogeneous waves*** / M. Tereshchenko, F. Castejon, S. Pavlov, A. Cappa / Physica Scripta **84** (2011) 025401. (It is given an analytical framework for the physically intelligible principle of a ray description of inhomogeneous wavefields on the basis of generic properties of active and reactive wave power flows. While being very close to the traditional geometric optics in the limit of lossless media, in substantially non-Hermitian systems this approach turns to be a distinct method capable of keeping up ray trajectories in a real-valued domain. It is demonstrated also that the ray method based on power-flow analysis is mostly free from standard limitations of geometric optics.)

***3) About parameter of reactor-stellarator in the conditions of ambipolarity of neoclassical transport.*** Parameters of reactor-stellarator in conditions of ambipolarity of neoclassical transport fluxes are calculated by using a one-dimensional spatio-temporal numerical code. The steady-state regimes of the self supported thermonuclear reaction are found when the pellets of DT-fuel are injected. It was shown that the fuel injection to the center of plasma promotes to the best confinement of particles and energy of plasma and optimization of reactor size. The variants of the magnetic system with the different values of helical field ripples are considered. The technical parameters of reactors look to be executable and can have a thermal power comparable with the power of already operating atomic power reactors. (V.A. Rudakov).

***4) The self-consistent model of RF plasma production*** is used for modeling of the plasma density ramp-up with four-strap $\pi$-phased antenna at Uragan-2M. It is assumed that initial plasma of density up to $10^{18}$ m$^{-3}$ is provided. Antenna is fed with the frequency below ion-cyclotron frequency and plasma production in the Alfvén resonance heating regime is realized. The model includes the system of the balance equations of particles and energy and the boundary problem for the Maxwell equations. The Maxwell's equations are solved at each time moment for current plasma density and temperature distributions. (V.E.Moiseenko, Yu. S. Stadnik, A.I.Lyssoivan)

***5) Fusion neutron generation computations in a stellarator-mirror hybrid with neutral beam injection.*** A linear kinetic bounce-averaged model for NBI is introduced and realized in the code KNBIM. The first calculations relate to the stellarator-mirror fusion neutron driver for a sub-critical fast reactor. In this scheme the hot tritium ions are sustained by the NBI at the local mirror trap embedded in a stellarator, and they interact with the warm Maxwellian background deuterium plasma. In the regime studied, the hot ion distribution is shaped by electron drag. The hot ion population depends only weakly on the confinement of the stellarator part. At the mirror part, it is sufficient to confine the hot ions for only a few hot ion-background ion collision times. The mirror ratio of the local mirror trap which is sufficient to avoid substantial ion losses is small, a value $R$=1.7 is adequate, and increasing it does not result in a considerable increase of the hot ion population. The fusion Q achievable within this scheme is less than unity. The calculated axial distribution of the neutron flux peaks at the injection points and has a noticeable magnitude at locations between the peaks. About 60% of the flux reaches the fission mantle if the NBI is made from both sides of the nuclear core. This amount rises to 80% for single-side NBI. It could be further increased by steeping the magnetic field profile near the injection area and making the field more uniform in the remaining mirror part. (V.E. Moiseenko, O. Ågren).

***6) Plasma heating and hot ion sustaining in hybrids with mirror cell.*** Possibilities of plasma heating and sloshing ion sustaining in mirror based hybrids are briefly reviewed. Sloshing ions, i.e. energetic ions with a velocity distribution concentrated to a certain pitch-angle, play an important role in plasma confinement and generation of fusion neutrons in mirror machines. Neutral beam injection (NBI) is first discussed as a method to generate sloshing ions. Numerical results of NBI modelling for a stellarator-mirror hybrid are analyzed. The sloshing ions could alternatively be sustained by RF heating. Fast wave heating schemes, i.e. magnetic beach, minority and second harmonic heating, are addressed and their similarities and differences are described. Characteristic features of wave propagation in mirror hybrid devices including both fundamental harmonic minority and second harmonic heating are examined. Minority heating is efficient for a wide range of minority concentration and plasma densities; it allows one to place the antenna aside from the hot ion location. A simple-design strap antenna suitable for this has good performance. However, this scenario is appropriate only for light minority ions. The second harmonic heating can be applied for the heavy ion component. Arrangements are similar for minority and second harmonic heating. The efficiency of second harmonic heating is influenced by a weaker wave damping than for minority heating. Numerical calculations show that in a hybrid reactor scaled mirror machine the deuterium sloshing ions could be heated within the minority heating scheme, while the tritium ions could be sustained by second harmonic heating. (V.E. Moiseenko, O. Ågren).

***7) Fuel for sub-critical fast reactor.*** The breed-and-burn concept could be applied to common technologies in which the burnout of the fuel is not deep and fuel is reprocessed after 5-10% of burnup. In connection to this, the idea is to find the transuranic elements composition to which depleted uranium is continuously supplied during frequent reprocessing, and the amounts of all other transuranic fuel component remain unchanged in time. Using a transuranic burnup model the composition of such a fuel is calculated. 3 isotopes constitute more than 99% of the fuel: $^{238}U$ (89%), $^{239}Pu$ (8.4%) and $^{240}Pu$ (2.3%). The effective neutron multiplication factor for the fuel is about 1.5. The fuel is highly radioactive, but only for a short time after taking it out from the reactor. Medium scale radioactivity is due to containment of the $^{241}Pu$ isotope. (V.E. Moiseenko, S.N. Chernitskiy, O. Ågren, K. Noack)

***8) Magnetic field of combined plasma trap.*** In the paper [V.E. Moiseenko, K. Noack, O. Ågren. "Stellarator-mirror based fusion driven fission reactor" [J Fusion Energy, 2010, vol. 29, pp. 65–69] a fusion neutron source for a sub-critical fast hybrid reactor, a combined magnetic plasma trap (CMPT), has been proposed. The essential parts of the CMPT magnetic system are a stellarator-type magnetic system and a mirror-type magnetic system. The numerical calculations were undertaken to study the magnetic field structure of one possible version of the CMPT magnetic system. The model comprises a magnetic system of an $l$=2 torsatron with additional toroidal magnetic field coils as the stellarator-type magnetic system. A single current-carrying turn coil is considered to be an element of the mirror-type magnetic system. The turn encircles the torsatron magnetic surfaces and produces a single toroidally-localized ripple of the resultant magnetic field. The calculations show the existence of magnetic surfaces acceptable for the above-mentioned proposal for extensive range of parameters. (V. G. Kotenko, V. E. Moiseenko, O.Ågren)

**Plasma Experiment**

***1) Continuation of investigations of the processes accompanying ITB and ETB formation in the plasma of the Uragan-3M torsatron under the RF plasma heating. Effects of transport barrier formation on divertor flow characteristics, in particular, on fast ion loss.***

Studies have been continued of plasma production and heating by RF waves in the multimode Alfven resonance regime ($\omega \lesssim \omega_{ci}$) with using a non-shielded frame-like antenna with the broad spectrum of parallel wavelengths. Time evolution has been studied of those plasma parameters that are important for a further production and heating of a denser ($\gtrsim 10^{13}$ cm$^{-3}$) plasma with the use of a shorter wave antenna and make a determinative effect on transition to the H-like confinement mode. Time variations are considered of line-averaged electron density and radiation temperature at different values of RF power fed in the antenna; generation of fast ions (FI) and their loss; edge radial electric field $E_r$ and edge turbulent transport.

With the RF power high enough and a certain combination of plasma parameters when optimum conditions are created for plasma heating with the presence of local Alfven resonances in it for wavelengths generated by the antenna, the H-like mode transition occurs.

Two states of discharge with the H-like mode are realized over the RF pulse, the H-like transitions being triggered by a short time enhanced FI loss. The H-like mode state is characterized, in particular, by a reduced edge turbulent transport which correlates with an enhanced $E_r$ shear at the plasma boundary. The initial, weaker $E_r$ shear is formed before the transition and is only amplified with transition and persists after the burst of FI loss, thus preventing the recovery of the pre-transitional higher level of the turbulent transport.

The paper "RF discharge dynamics with passing over L- and H-like states in the Uragan-3M torsatron" by V V Chechkin, I M Pankratov, L I Grigor'eva, A A Beletskii, A S Slavnyj, A Ye Kulaga, A P Litvinov, R O Pavlichenko, N V Zamanov, P Ya Burchenko, A V Lozin, S A Tsybenko, E D Volkov was sent for publication in "Plasma Physics and Controlled Fusion". At present is being revised after referees' comments.

***2) Continuation of investigations of divertor plasma flow characteristics in conditions of transport barriers formation in Uragan-3M.***

In the Uragan-3M torsatron with an open natural helical divertor and a plasma with the mean density up to several units $10^{12}$ cm$^{-3}$ produced and heated by RF fields in the multi-mode Alfven resonance regime ($\omega \lesssim \omega_{ci}$), a strong vertical asymmetry of plasma flows outflowing along the diverted field lines into the gaps between the helical windings ("diverted plasma flows" – DPF) has been observed recently. The asymmetry is displayed in the larger flow being recorded (by the ion saturation current to an electric probe) on the ion $B\times\nabla B$ drift side ("ion side"), with the ions dominating in the corresponding current (positive polarity) to the earthed probe. It was suggested on this basis that the asymmetry resulted from the direct (non-diffusional, collisionless) ion loss. The validity of such an explanation was confirmed by the results of numerical simulation of the direct charge particle losses in U-3M, a rising dependence of the asymmetry degree on the high energy ion content in the plasma and direct measurements of energies of ions escaping to the divertor on the ion and opposite ("electron") sides.

As a continuation of these works, studies of DPF time evolution were carried out in 2010-2011. In these studies a non-steady-state RF discharge regime with passing over the L- and H-like states was chosen and time variations were followed during the RF pulse of diverted plasma parameters, such as DPF magnitude, electron temperature and density, ion energies on the ion and electron sides. To do this, arrays of plain electric probes and grid ion energy analyzers placed in the divertor region in the gaps between the helical coils in symmetric poloidal cross-sections of the U-3M torus were used. The main result of the investigations is demonstration that the direct electron loss makes a more significant contribution to the DPF vertical asymmetry than the ion loss does. The recent conclusion has been confirmed that the H-like mode transition results in the loss reduction mainly through the electron channel.

The results are to be presented at 39th International Conference on Plasma Physics and Controlled Fusion (Zvenigorod, Russia, February 6-10, 2012) as
"Time evolution of plasma flows in the helical divertor of the Uragan-3M torsatron"
by A.A. Beletskii, P.Ya. Burchenko, V.S. Voitsenya, E.D. Volkov, L.I. Grigor'eva, N.V. Zamanov, A.Ye. Kulaga, A.V. Lozin, Yu.K. Mironov, V.Ye. Moiseenko, R.O. Pavlichenko, I.M. Pankratov, V.K. Pashnev, V.S. Romanov, A.S. Slavnyj, S.A. Tsybenko, V.V. Chechkin (registered by No. 160).

***3) Development of the soft X-ray diagnostics and its measurement techniques***

A novel soft X-ray (SXR) data analysis technique has been recently developed and applied to the SXR data from the STOR-M tokamak to determine the radial locations of rotating magnetohydrodynamic (MHD) modes by examining the difference signals between two neighboring SXR channels. The radial location of the 20-30 kHz MHD mode has been determined in the STOR-M tokamak by this technique. (M.Dreval, A. Hirose, C.Xiao)

***4) Cleaning of vacuum chamber wall by RF discharges in «Uragan-3M» torsatron.*** One of the main obstacles to obtain a dense high temperature plasma is the presence of light and heavy impurities. The main channels of inflow of the impurities into the discharge are usually desorption of atoms or molecules of impurities from the walls of the vacuum chamber and the erosion of the walls and other structural elements owing to the interaction with the plasma resulting in that the light (carbon, oxygen, etc.) and the heavy (the material of the walls) impurities come in the discharge. The plasma of the RF discharge with low electron temperature and density $n_e \sim 10^{12}\,cm^{-3}$ is used for cleaning of the vacuum chamber wall of Uragan-3M torsatron. At operating frequency $f_0 \sim 8\div9$ MHz the RF plasma is produced at magnetic fields $B_0 \sim 200\div300$ G and a hydrogen pressure $P_{H2}\sim10^{-4}$ Torr. Duration of the RF pulse was 50 ms with a pulse repetition rate 5 pulses per minute. In this case the RF power supplied to the antenna does not exceed 200 kW. The frame-type and three-half-turn antennas are used in the experiment. The frame antenna produces plasma and three-half-turn antenna is switched on 5 ms after. At these plasma parameters, an intense dissociation of hydrogen molecules proceeds. Atomic hydrogen is highly chemically reactive and, also, it is intensively bombarding the vacuum surface, which is covered by layers of oxides of the wall material and various carbon-containing films. After the cleaning cycle (more than 20,000 pulses) of the vacuum chamber wall by low-temperature plasma RF discharge:

- residual gas pressure in the chamber is lowered,
- a significant reduction of the intensity of the impurity line emission is observed,
- the mass spectrum analysis of the residual pressure at the chamber indicates a significant decrease of the amount of impurities,
- as a result of cleaning, the regular discharges with plasma density $n_e \approx 10^{12}$ $cm^{-3}$ and electron temperature $T_e \leq$ 1 KeV come to a quasi-stationary regime with a pulse duration up to 50 ms.

The proposed method of cleaning of the vacuum chamber wall by plasma generated by RF method with the fast magneto-sonic wave excitation uses the same antennas and RF generators as for plasma heating without any tuning of antenna and generator RF circuits. (O.B. Lozin, P.Ya. Burchenko, V.E. Moiseenko, L.I. Grigor'eva, A.E. Kulaga, Yu.K. Mironov, R.O. Pavlichenko, V.S. Romanov, S.A. Tsybenko, V.Ya. Chernyshenko, V.V. Chechkin).

***5) The measurements of the radial plasma potential and the electron density*** as well as their fluctuations by Heavy Ion Beam Probe (HIBP) diagnostic 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 of IPP NSC KIPT with CIEMAT (Madrid).

***5.1)*** HIBP diagnostic was upgraded to perform two point measurements to study directly the plasma electric potential and density, so as their fluctuations, poloidal electric field Ep=(φ1 - φ2) / Δ r [V/cm] and to extract radial turbulent particle flux $=\Gamma_{EpolxBtor.}=\Gamma_{ExB}$. Both mean potential and oscillatory components, including quasi-coherent and broadband oscillations, are available for HIBP measurements, which makes this diagnostic one of the key multipurpose tool to study directly plasma transport and turbulence phenomena.

***5.2)*** Both pure ECRH and NBI plasmas and also combined heated plasmas were studied in TJ-II. Low-density ECRH hydrogen or helium plasmas, $\bar{n}_e$=(0.3-1.1)×$10^{19}$ $m^{-3}$) are characterized by a positive potential. A minor area with negative potential may appear in the edge depending on the plasma density. The density rise due to gas puff or NBI fuelling is accompanied by the decrease of potential, which evolves to smaller positive absolute values, becoming fully negative if $\bar{n}_e > 1\times10^{19}$ $m^{-3}$. However, if the density approaches the value $\bar{n}_e$=1.7-2.5×$10^{19}$ $m^{-3}$, the growth of potential saturates at φ(0)= -600 V. The $E_r$ evolution for rising density, measured at the gradient area ρ=0.7, show that $E_r$ evolves from positive to negative values, crossing zero level at $\bar{n}_e \sim 1\times10^{19}$ $m^{-3}$. On the contrary, an increase in $T_e$ due to increasing ECRH power leads to an increase in plasma potential. The same effect is seen during ECRH power modulation. It is important to note that confinement degradation due to the increase of the ECRH power is associated with the positive trend of the central potential.

An analytical nneoclassical modeling was performed for the studied TJ-II regimes. Analytical expressions for the low collisional long mean-free path regime and for the high collisional plateau regime were used to simulate regimes with different collisionalities. The wide density range $\bar{n}_e$ = (0.3 – 4.5)×$10^{19}$ $m^{-3}$ was explored. The developed model satisfactorily explains the $E_r$ values and dynamics in the core plasma in the whole plasma parameters domain, obtained so far in TJ-II. Electron root solution of the ambipolarity equation dominates for low-density ECRH plasmas. Experimentally observed potential evolution from high positive towards the negative values with the density raise is explained by gradual changes from electron root (dominating electron losses in the low-collisionality regime) to the ion root (dominating ion losses in the high-collisionality regime).

***5.3) Study of oscillations***.

***5.3.1)*** *<u>Broadband turbulence and improved confinement</u>*

The L-H transition spontaneously happening in NBI heated plasmas in TJ-II is characterized by a potential drop, formation of the edge layer with a strong negative $E_r$~ -100 V/cm, and a strong suppression of the density fluctuations and turbulent particle flux $\Gamma_{E\times B}$ in the edge and core plasmas..

The regimes with improved confinement induced by edge biasing (limiter biasing in TJ-II) are characterized by formation of a strong edge $E_r$ and suppression of potential and density turbulence. In both spontaneous L-H and biased improved confinement regimes, the broadband turbulence was suppressed not only in the edge, but also in the core plasma, indicating a global improvement of the relevant transport processes.

Thus there is a clear link between the value of the electric potential, formation of an edge layer with strong negative radial electric field, turbulence suppression and increase in the plasma density and confinement.

***5.3.2)*** *Quasi-coherent oscillations*

Three types of the quasi-coherent potential oscillations were studied in view of the link with turbulence.

The core potential, density and $B_{pol}$ oscillations caused by Alfvén Eigenmodes (AE) were found in NBI heated TJ-II plasma, $\bar{n}_e$ = (1 - 4.5)×$10^{19}$ $m^{-3}$, $T_e(0)$ ~ 300 eV, $T_i(0)$ < 140 eV, $P_{NBI}$<0.9 MW. Oscillating potential due to AEs was found to have a range $\delta\varphi^{AE}$ = 10 V, giving an AE induced poloidal electric field $\delta E_{pol}$~10 V/cm. A long range radial correlation between core and edge plasma potential were found for some branches of AE. AE contribution to the bulk plasma turbulent particle flux $\Gamma_{E\times B}{}^{AE}$ for the observed wave vectors $k$ < 3 $cm^{-1}$ was found to be significant and directing outwards. There are also found examples where $\Gamma_{E\times B}{}^{AE}$ has negative (inward flux) or zero (no flux) value depending on the phase relations between $E_{pol}$ and $n_e$ oscillations.

A new type of instability mode, interpreted as suprathermal (ST) electrons excited mode, was found in the extremely low-density ECRH plasma: $\bar{n}_e$ = (0.2 - 0.5)×$10^{19}$ $m^{-3}$, $T_e(0)$ ~ 1 keV, $T_i(0)$ < 80 eV, $P_{EC}$<0.6 MW. In such conditions the mean energy of suprathermal electrons tail corresponds to 3-4 times higher the thermal velocity. Moreover, a population with much higher energies up to 90 keV was detected. The quasi-monochromatic density and plasma potential oscillations in the frequency range 20-120 kHz tend to have several “branches” with constant frequency shift between them. The typical amplitude of the mode induced potential oscillations $\delta\varphi^{ST}$ = 20 V was estimated. The mode branches have individual finite radial extent. Unlikely to AEs, the ST mode contribution to the turbulent particle flux $\Gamma_{E\times B}{}^{ST}$ for the observed wave vectors $k_\theta$ < 3 $cm^{-1}$ was found to be small in comparison with broadband turbulence, indicating no mode coupling with bulk plasma rather with suprathermal population.

The properties, driving force and the nature of the third type of the quasi-coherent mode are under study now. Empirically the mode occurs in the outer slope of density profile ρ>0.5 and presents the dominant modulation in local density, with a typical frequency about 20-40 kHz . The mode was found in the wide range of both ECRH and NBI plasmas with various densities. Surprisingly, it tends to be more excited in a resonance with some specific values of line-averaged density $\bar{n}_e$ = 0.6, 1.7, 2.7, 3.6 $\times 10^{19}$ $m^{-3}$, when it presents quite large density modulation, measured by HIBP, up to 100% of the local value. Such large modulations are also seen in the line-averaged density measured by the central chord of interferometer, exciting its root mean square fluctuations at the resonance densities. Unlikely to the other modes discussed here, this density resonance mode is much less pronounced in the plasma potential, presenting mainly density and poloidal field $B_{pol}$ perturbation measured by HIBP and other diagnostics.

***6) The measurements of radial plasma potential and electron density*** and also their fluctuations by Heavy Ion Beam Probe diagnostic and study of their influence on the plasma confinement in tokamak T-10 with ECR and OH heating were continued in the frame of the collaboration of IPP NSC KIPT with Kurchatov Institute (Moscow).

***6.1)*** Various regimes with OH and ECRH were investigated in T-10 with HIBP diagnostics. Parameters of studied regimes were significantly improved by injection of energy and current intensity increasing. OH and ECRH deuterium plasmas ($n_e$=1.0-4.1$\times 10^{19}$ $m^{-3}$) in T-10 are characterized by a negative potential up to φ(0.2)= -1600 V in the central area at $T_e(0)$ ~ 1 keV. As a rule, the potential profile is monotonically increasing towards the plasma edge. On the contrary, the rise of $T_e$ due to increase of the Ohmic or additional ECR heating leads to decrease of the absolute value of negative potential.

Neoclassical (NC) evaluation of the ambipolar electric field for T-10 was performed for this high-density regime, where $T_i$ data measured by CXRS and density were available.

The edge potential profile presents a challenge for HIBP due to the reduction of signal-to noise ratio in low-density edge plasmas. Continuous efforts were done to get the edge profiles with increased probing beam intensity, obtained with advanced ion emitters and extract system. Now the potential profile is sensitive to the ECRH up to the limiter. In the far edge the NC collisional mechanism unlikely plays a dominant role in the $E_r$ formation. Comparison of the HIBP and Correlation Reflectometer (CR) data was done.

***6.2)*** The electrode biasing of T-10 improved confinement regimes, the broadband turbulence was suppressed not only in the edge, but also in the core plasma, indicating a global improvement of the relevant transport processes.

Geodesic Acoustic Modes (GAMs), high-frequency counterpart of zonal flows, may be the possible mechanism of the turbulence self-regulation. In T-10, the mode, identified as GAM, presents a dominant peak in the power spectral density of potential. In some cases a higher frequency satellite appears. The mode is more pronounced during ECRH, when the typical frequencies are seen in the band 22-27 kHz over some radial extent. GAM amplitude decreases with plasma density rise. With the density increase, first the satellite and then the main peak consequently disappear. The amplitude of GAM-induced potential perturbations in T-10 may be quite significant, up to $\delta^{GAM}$ = 100 V; they exhibit a high correlation with density oscillations. It was found that GAM modulates the high frequency broadband density turbulence.

**7) *Progress report in the HIBP diagnostic.***

***7.1)*** It has been Installaed of the second Heavy Ion Beam Probe diagnostic system on TJ-II stellarators. Possibilities of this system was significantly expanded. Ingector system with new extraction and focusing systems significantly improved the primary beam parameters: their intensity, stabilisation and focusing. In registation system of the secondary beam there was used two elecrostatic energy analyzers. As a result, this year on the TJ-II will be used for plasma investigation two separate HIBP diagnostic systems displasemented on 90°.

***7.2)*** HIBP diagnostic system has been installed on special Uragan-2M stend deviece.

High voltage and eletronic control and data aquisition systems were completed and tested. It was obtained high spatial energy resolution of the analyser of $10^{-4}$ during calibration experiment.

***8) Imitation of neutron irradiation on behaviour of W mirror specimens under long term sputtering.*** The experiments on simulation of synergetic effects of irradiation with neutrons and sputtering with charge exchange atoms on behavior of W mirrors were provided in cooperation of IPP NSC KIPT, Japan Atomic Energy

Agency, Tokai, Ibaraki, Japan, and the Institute for Plasma physics (EURATOM Association, Garching, Germany). Two type of W were tested: recrystallized at high temperature (2070 K) and ITER-grade. One pair of W mirror specimens were irradiated up to 0.3 dpa, and other – up to 3 dpa. The neutron irradiation did not lead to any significant reflectance change. The repeated sputtering procedures were carried out using $Ar^+$ ions with energy 600 eV. The weight loss and measurements of reflectance were provided after every sputtering procedure, thus the dependence of reflectance on thickness of sputtered layer was obtained. It was found that both specimens, irradiated with 20 MeV $W^+$ ions and not irradiated behaved similarly. Thus, approximating to first mirrors in ITER, one can made an important concluion that neutron irradiation will probably not influence the behavior of in-vessel mirrors.

Surprisingly, the reflectance of mirror specimens made from recrystallized tungsten practically saved their initial reflectance, whereas the reflectance of those made from ITER-grade tungsten strongly degraded (all 4 specimens were sputtered to the depth ~3 μm.

***9) Investigation of resistance to long-term sputtering of fine-grain W and Mo mirror specimens.*** The joint experiment of V.S. Voitsenya et al. (IPP NSC KIPT) with Drs. Jun Tan and Zhou Zhangjian from University of Science and Technology (Beijing China) was provided with an aim to clear up the prospect for fine-grain tungsten and molybdenum to be the material of the first mirrors for optical plasma diagnostics in ITER. To shorten the experiential time, the long-term sputtering of W and Mo mirror specimens was provided with $Ar^+$ ions (600 eV). The results were reported at the 12th International Young Scientists Conference "Optics & High Technology Material Science - SPO 2011", Kiev, Ukraine, 27-30 October 2011.

***10) ECE experiments for optically thin Uragan-3M torsatron plasmas.*** Radial profile of second harmonic X-mode (X2) electron cyclotron emission (ECE) was observed for optically thin plasma produced by Alfvén resonance heating in Uragan-3M (U-3M) torsatron. The radiation was detected from the low field side. Heterodyne one channel and narrow bandwidth (10 MHz video BW) radiometer receiver measures a radiation at a single frequency per every plasma shot. The channel was absolutely calibrated at all frequencies by the 1.5 eV noise lamp radiation. For the ECE frequency range 31-37 GHz the reconstruction of electron temperature profile was done for several consecutive shots with the assumption that plasma parameters do not vary from shot to shot. Radial electron temperature profile was derived from "radiation temperature" profile using approximation formula for the plasma optical thickness. The applied conversion procedure ignores multiple reflections from the walls (due to "open magnetic system" of the U-3M device) of the vacuum chamber: according to estimation it gives sufficiently small errors. For special plasma production conditions (additional gas-puffing) an ECE "cut-off" phenomenon (rapid signal drop) due to the overdense plasma is clearly observed. Thus, it is possible to estimate the value of the local "threshold" electron density. In the absence of Thomson scattering system, the temperature data were cross-checked with other electron temperature related diagnostics (SXR, optics, etc.). For low density plasma $n_e \sim (1.5\text{-}2)x10^{18}m^{-3}$ strong "afterglow radiation" was observed after switching off the RF pulse. The measured ECE spectra are modelled using a bi-Maxwellian describing the bulk and the suprathermal electron populations. (R. Pavlichenko and URAGAN-3M team)

***11) Microwave plasma diagnostics.*** A new 140 GHz, 40 mW compact interferometer system has been installed on Uragan-3M to measure line-averaged electron density of the bulk plasmas. To minimize signal loses a new optimized waveguide transmission line have been installed. System is equipped with I-Q detection system with phase deviation accuracy of 0.1 degree, that corresponds to minimal detectable relative density fluctuations level of 0.001 percent (test experiments for reflection from flat metallic mirror). Experimental data for various U-3M plasma scenarios shows good system characteristics and measurement capabilities of average densities $n_e \sim 10^{15}\text{-}10^{19}$ $m^{-3}$ (with errors less than $0.2x10^{15}$ $m^{-3}$).

A new six channel superheterodyne radiometer operating within frequency range 57-74 GHz which is optimized for the X2 ECE radiation (central magnetic field 0.95-1.15 T) is under installation for the Uragan-3M plasma experiments. As an initial phase, the experiments for observing optically thin X3 ECE radiation from low field side (central field of 0.68-0.72 T) will operate next experimental campaign. (R. Pavlichenko, A. Kulaga, N. Zamanov and URAGAN-3M team)

*12)* ***Preparation of equipment for in-situ measuring the efficiency of wall conditioning.*** A thermal desorption method was suggested and preliminary test was provided as a part of in situ diagnostic of the Uragan-2M torsatron vacuum chamber surface state during wall conditioning procedure.

*13)* ***Modification of microwave plasma diagnostics***

***Stellarator U-2M***. A simple (and inexpensive) homodyne interferometer for operation in 36-50 GHz. With it in use there is a possibility appears to obtain an electron plasma density in a real-time mode. The new method of phase shift measurement is based on solution of a integral equation in contrast to the widely applied method with the use of inverse trigonometric functions and some logical operations. The new method was approved during experiments on optimization of RF methods of plasma production and heating. The preliminary results were presented at the Ukrainian Conference on controlled fusion and plasma physics (Kiev, 25-26 Oct. 2011).

***Stellarator U-3M***. With taking into account the constructive peculiarities of U-3M torsatron, the microvave complex was developed for operation at this machine.
(V.L.Berezhnyi, V.V.Philippov)

**Appendix 4: Technical Report on TJ-II Activities in 2011**

TJ-II is a medium-size Heliac-type stellarator operating at low magnetic shear. The results achieved in the TJ-II stellarator during 2011 were obtained in plasmas created and heated by Electron Cyclotron Resonance Heating (ECRH) (2×300 kW gyrotrons, at 53.2 GHz, 2nd harmonic, X-mode polarisation) and Neutral Beam Injection (NBI). Two beams of 400 kW port-through (H0) power at 30 kV, were injected on TJ-II.

They have continued with the characterization of plasmas under Li-coating walls, which has allowed to enlarge the operational density range and to reach H-mode customarily. Low order rational values of the rotational transform can be introduced anywhere in its plasmas causing modifications in the electric potential and, consequently, radial structures in the radial electric fields that can be used to alter transport and stability in an externally controllable way. The ability of TJ-II to perform dynamic configuration scans has been used to illustrate these aspects and find practical realizations, like exerting control on the L-H transition. Furthermore, the spatio-temporal behaviour of the interaction between turbulence and flows has been studied close to the L-H transition threshold conditions in the edge region of TJ-II plasmas. The temporal dynamics of the interaction displays an oscillatory behaviour with a characteristic predator-prey relationship. The spatial evolution of this turbulence flow oscillation-pattern has been measured, for the first time, showing both radial outward and inward propagation velocities of the turbulence flow front. The results indicate that the edge shear-flow linked to the L-H transition can behave either as a slowing down, damping mechanism of outward propagating turbulent flow oscillating structures, or as a source of inward propagating turbulence-flow events.

Long-distance correlated floating potential structures are seen to modulate not only the high k spectral power of the local turbulence but also the particle transport into the unconfined Scraped-Off Layer, providing the first direct evidence of global transport modulation by broadband frequency flows (zonal-flow like structures). The ability to select spontaneous flux-surface-collective rotation attempts opens up the possibility to study effective viscosities in stellarators and tokamaks unperturbativelly. By means of a Bayesian technique, and using different plasma diagnostic signals, density profiles are reconstructed in the outer half of the plasma. Together, a comprehensive picture is obtained of the evolution of various key global plasma profiles and parameters across forward and backward transitions associated with the formation of an edge sheared flow layer.

The properties of fast ion confinement have also been investigated from both theoretical and experimental points of view, including the appearance of Alfven modes and the dynamics of the fast ions created by Neutral Beam Injection.

**Appendix 5: Technical Report on Heliotron J Activities in 2011**

Effects of the confinement configuration on the fast ion confinement, the bulk thermal confinement, the plasma current control, and the particle fuelling control have been investigated in Heliotron J, a flexible helical-axis heliotron, with special regard to the optimization study of the helical system with a spatial magnetic-axis and a vacuum magnetic well. To attain the drift optimization of the $L$=1 helical-axis heliotron, the bumpiness control is essential to reduce the neoclassical transport (or the effective helical ripple). The experiments have been performed by changing the bumpiness with keeping plasma volume, plasma axis position, and edge rotational transform almost constant. The Heliotron J activities in 2011 are summarized as follows:

1) Optimization of gas-fueling scenario has been studied to improve the plasma performance in Heliotron J. Localized fueling with a short pulse of supersonic molecular beam injection (SMBI) can increase the core plasma density avoiding the confinement degradation. Microwave AM reflectometer data and fast camera image analyses suggest the change of particle transport and the edge plasma turbulence characteristics during/after SMBI, respectively. We have observed that a large increment of stored energy after turning off a high intensity short pulse GPF (HISP-GP) in a high power NBI plasma. By applying an HISP-GPF, the store energy initially increases with an increase of the density and then decreases, as usually observed in a case of excess GPF. If the intense GPF is stopped at a proper timing during the NBI pulse, the stored energy started to recover and finally reached to a much higher value than the first peak. The similar recovery discharge is realized also by using SMBI.
2) The physics of edge fluctuation has been studied using

multi-channel Langmuir probe systems installed at different toroidal/poloidal positions. It was found that low-frequency fluctuation less than 100 kHz is dominant in the fluctuation induced particle flux evaluated from the probe measurement. Statistical approach using probability density function (PDF) clarified that the shape of PDFs for the probe signals were distorted depending on the radial location, which may be relative to the intermittent transport known as blob transport. In addition, characteristic coherent fluctuations, correlated with broadband fluctuations, were observed inside LCFS.

3) Filament features in edge plasma turbulence has been studied using a combination of fast video cameras and a hybrid probe system. Applying a SMBI to Heliotron J plasma the stored energy in the plasma increased beyond the saturation level in the conventional gas puff condition. A change in the edge plasma turbulence (ex. dynamics of a filament structure in the turbulence) might be related to the observed difference in the plasma performance between the SMBI and the conventional gas puff cases. The behaviour of edge plasma turbulence during SMBI was studied using a combination of the fast camera with GPI, Langmuir probes and a set of magnetic probes in Heliotron J. Filament structure which was enhanced during the SMBI has been analysed.

4) 2.45 GHz 20kW microwaves has been applied prior to NB injection, and an NBI plasma has been successfully produced without either fundamental or second harmonic ECH. A low electron density plasma generated at the ramp-up phase of a poloidal coil increased its density to more than $1\times10^{17}$ m$^{-3}$ during 2.45GHz microwave turn-on, and then an additional gas-puffing increases the electron density to over $1\times10^{19}$ m$^{-3}$ during NBI. The operational magnetic field is widely extended to $B$>0.63 T, expecting further physics studies such as MHD stability of high-beta plasmas and B dependence of global energy confinement and high-energy particles. An ECE measurement shows that there is a critical threshold in radiation temperature for successful startup, indicating that suprathermal electrons should be produced for ionization of the neutral beam. The critical power for density build-up increases with decreasing the magnetic field strength.

5) Fast ion velocity distribution in the low density region has been investigated using fast protons generated by ICRF minority heating in Heliotron J with emphasis on the effect of the toroidal ripple of magnetic field strength and heating position. The high bumpiness was preferable for the fast ion confinement as expected. The effective temperature of the minority proton in on-axis heating was higher than in the inner-side heating; however, the bulk deuteron temperature was lower. One of the possible explanations of the resonance-position change experiment is that the fast ions in the inner-side heating are localized in the off-center region, then, fast ions cannot be fully detected. The wider range observation (about 25% in the poloidal cross section) of fast ions is performed by changing the line of sight of the CX-NPA vertically for three bumpinesses. The difference of the energy spectra is very small for the on-axis heating condition except for the high bumpiness. The largest change in the vertical scan is found in the inner-side heating for the medium bumpiness. In the higher part of the plasma, more fast ions are observed. A Monte-Carlo simulation is under progress to interpret the difference in the energy spectra of fast ions and bulk heating.

6) Control of rotational transform profile is studied by using ECCD. The experimental results show that the EC driven current can be controlled by the resonance layer position and the poloidal injection angle as well as $N_{||}$ and the magnetic configuration. The experimental results including the $B$ and $N_{||}$ dependences agree with ray tracing simulations using the TRAVIS code in which the parallel momentum conservation with trapped particle effect is considered. Modification of the rotational transform profile is estimated by using the EC current calculated by the TRAVIS code. The calculation shows that the EC current profile is localized at the resonance position and the peak position can be changed from on-axis to off-axis. The time evolution of rotational transform is estimated by solving the following one-dimensional current diffusion equation. At the initial phase of ECCD, the electric field is induced at the magnetic axis, reducing the rotational transform. It takes the current diffusion time to reach the steady state.

7) Density fluctuation and its radial structure have been measured with a Beam Emission Spectroscopy (BES) in Heliotron J. The BES system installed in Heliotron J has 16 sightlines which observe the beam emission at the position from $r/a$=0.07 to 0.94 with a good spatial resolution. Some coherent modes, which may be induced by energetic-ion-driven MHD activities, have been observed. The mode with a frequency of $f$~90kHz spread widely in the whole plasma region. In the case of the mode with $f$~65kHz, the fluctuation is observed in the core region, while the mode with $f$~27kHz is localized in the peripheral region. The phase difference between the BES intensity and the magnetic probe signal also has radial structure depending on the modes.

8) The MHD stability of Heliotron J plasmas has been

experimentally investigated by scanning rotational transform and magnetic well/hill in order to demonstrate the advantage of our concept with low magnetic shear and magnetic well in whole plasma region. Two kinds of MHD instabilities are observed in Heliotron J plasmas. One is the low-$n$ ($n$: toroidal mode number) pressure driven resistive interchange mode. The $m/n$=2/1 ($m$: poloidal mode number) and $m/n$=5/3 MHD instabilities having intense magnetic fluctuations have been observed in the plasmas with low order rational surface $\iota/2\pi$~0.5 and 0.6. When these MHD instabilities are observed, the bulk plasma parameters such as plasma stored energy and electron density are saturated and/or decreased indicating that they affect global energy confinement. No coherent mode has been observed in the plasma without low order rational surface. The other mode is the energetic ion driven MHD instabilities including global Alfvén eigenmodes (GAEs) and/or energetic particle modes (EPMs). In NBI heated plasmas, MHD instabilities in the frequency range of the Alfvén eigenmode are typically observed. They might affect the energetic ion transport from the result that some plasma parameters such as $H_\alpha$ and $T_e$ are simultaneously modulated with the bursting GAEs.

9) A new Nd:YAG Thomson scattering system is under development to measure the time evolution of the plasma profile on Heliotron J. Two high repetition Nd:YAG lasers (>550 mJ at 50 Hz) realize the measurement of the plasma profile with ~10ms time intervals. The system has 25 spatial points with ~10 mm resolution by 25 interference polychromators and an optical fiber bundle. These specifications are enough to study the confinement improvement of the Heliotron J plasma. To keep out of a support structure and coils of Heliotron J, the laser beam is injected from obliquely downward to upward, therefore, and obliquely back-scattered light is detected (scattering angle is 20 degree). A model simulation of the polychromator shows that the system can measure the electron temperature of 10eV-10keV and the density range of $>5\times10^{18}$m$^{-3}$ within 2% error.

10) To deepen the understanding of the configuration effects on confinement, the following new diagnostics are designed and/or installed; an improved CXRS system for the measurement of ion temperature and toroidal rotation, far-infrared interferometer for density profile, upgraded Langmuir probes and magnetic probes and fluctuation measurement by using an SX tomography and a reflectometer for density fluctuation. Advanced wall conditioning method using a Li coating is under development.

(Yamada, H. for the IEA Implementing Agreement for Co-operation in Development of the Stellarator - Heliotron Concept)