# 3．International Collaboration on Helical Fusion Research – IEA Implementing Agreement for Cooperation in Development of the Stellarator-Heliotron Concept –

## 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 44th Stellarator-Heliotron Executive Committee was held in Greifswald (Germany) in conjunction with the 20th International Stellarator-Heliotron Workshop. NIFS and Max-Planck Institute for Plasma Physics (Germany) host the web page of this activity at http://iea-shc.nifs.ac.jp/ and http://www.ipp.mpg.de/sh-tcp.

## 2 COORDINATED WORKING GROUP MEETING (CWGM)

During 2015, 14th CWGM was held to continuously facilitate the joint activities.

The 14th Coordinated Working Group Meeting was held from 16 to 19, June 2015 at the Golden Tulip Warsaw Center, hosted by the Institute of Plasma Physics and Laser Microfusion (IPPLM, http://www.ipplm.pl/en/). This was the first CWGM in Poland, reflecting by the expanded coordinated collaborations based on EUROfusion, mission 8: Stellarator. The IPPLM has been especially known through its cutting-edge diagnostics development. Thus, a dedicated diagnostics session was held this time, to stimulate international collaborations on diagnostics developement and applications. Impurity transport session will become the standing session, as suggested and agreed in the Stellarator-Heliotron Strategy Workshop, Nagoya, March 2015 (cf., Stellarator News, No.147, April 2015). C.Hidalgo (CIEMAT) provided a kick-off talk remotely to raise critial issues in impurity transport.

Below, session summaries and formulated action lists are described. The presentation materials will be posted on the EUROfusion wiki page, soon or later.

<u>Strategic Collaboration</u> (A.Dinklage / F.Warmer)

- The EUROfusion Mission 8 activities focus on the exploitation of W7-X and actions to prepare a physics basis for a HELIAS Fusion Power Plant (FPP),
- International collaborations within the work package objectives can be supported by missions (mobility) and resources (within the WPS1 activities) – IEA Stellarator-Heliotron Implementing Agreement has proven to be the right frame for joint actions
- The CWGM is proposed to be a frame to prepare further input to strategic discussions towards reactor issues
- Common systems assessments
- Clarification of ‚road map‘ targets
- LHD (M.Yokoyama) is setting up TASK3D-a to provide confinement and profile data on a regular basis
- Update of confinement database with HSX data,
- interim responsible officer has been identified: F.Warmer (IPP-Greifswald), https://ishpdb.ipp-hgw.mpg.de/ISHPDB/public/

<u>Alfvén Eigenmodes (AEs) and Energetic Particles</u> (S.Yamamoto)

We mainly discussed what we should investigate of AEs aiming at stellarator/heliotron DEMO.

- Effect of ECH/ECCD on AEs for control of AEs
- TJ-II : “Impact of ECRH on the NBI-driven Alfvén activity in the TJ-II stellarator: experiments and data analysis” by Á.Cappa
- Heliotron J : “External Control of Energetic-ion-driven MHD instabilities by ECH/ECCD in Heliotron J Plasmas” by S.Yamamoto
- Fast ion generation by ICRF, “Fast-ion generation with ICRF at Wendelstein 7-X in high-density regimes” by Y.Kazakov

<u>Experiment</u> (S.Masuzaki)

- Status of Uragan 2M was presented by V.Moiseenko: Dedicated RF conditioning study has been conducted. Stellarator with embedded mirror configuration has been examined both experimentally and numerically. It is for the Stellarator-Mirror hybrid device for the fusion-fission hybrid device.
- Status of the development of 3D fluid code “Findif” for edge plasma modeling was presented by G.Pelka. Findif was applied to the edge plasma modeling in the TEXTOR DED and W7-X, respectively. Benchmark is necessary.
- S.Kumar presented the flow and electric field study in HSX. They are measured by using Pfirsch-Schlüter flows, and using MSE polarimetry. Measured field is compared to the numerical simulation data with PENTA code. It is

larger than the numerically expected values near the core. Benchmarking the Er calculated by SFINCS and FORTEC-3D to the PENTA results is underway.

Impurities and Transport (N. Tamura)

- Kick-off for the new standing session: C.Hidalgo brought up important issues related to the impurity control. Question to be answered: "Optimum profiles for achieving high fusion gain without impurity accumulation (high & low Z) in Stellarator-Heliotron plasmas?"
- LHD: Existence of the impurity transport boundary layer inside the LCFS is suggested, which alter the accumulation of core-born impurity
- HSX: Laser blow-off (LBO) + 5 photodiode arrays are ready for the impurity transport study in HSX, and the collaborations (e.g. LBO system, STRAHL analysis) are highly welcome
- Uragan 2M/Uragan 3M: U-2M suffers from the impurities from the wall, and U-3M indicated the possibility of the control of impurities by the RF heating

Theory/Simulation

- Importance of parallel inertia force, which can cause impurity density variations in stellarator/heliotron plasmas, was highlighted
- Neoclassical-based impurity transport problem, such as a potential fluctuation on flux surface, etc. is being numerically (EUTERPE, FORTEC-3D, ...) analysed

Diagnostics (M.Kubkowska)

- W7-X: Limiter diagnostics: visible cameras and a low-resolution near infrared (NIR) camera for plasma monitoring, wall inspection and thermography, higher-resolution camera for scrape-off layer physics, set of Langmuir probes; pulse height analysis (PHA) system; light impurities monitor (for Carbon and Oxygen monitor) have been presented
- The following LHD diagnostics systems have been described:
- Density and temperature, radial electric field and rotational transform profiles: YAG Thomson scattering, Far Infrared (FIR) and CO2 interferometer, change exchange spectroscopy (CXS), heavy ion beam probe (HIBP), motional Stark effect (MSE)
- Impurity: Infrared (IR) imaging bolometer, vacuum-ultraviolet (VUV) spectrometer, extreme-ultraviolet (EUV) spectrometer, change exchange spectroscopy (CXS)
- turbulence: HIBP, phase contrast imaging (PCI), microwave frequency comb reflectometer, correlation electron cyclotron emission (CECE), beam emission spectroscopy (BES)
- For Heliotron J: Thomson scattering, CXS based on Czerny–Turner spectrometer, Langmuir probe, BES, 60-channels soft X-ray system and fast ion diagnostics have been listed and described.
- In the PHA system for W7-X - Si drift detectors will be used at the beginning - SiC or other detectors could be considered as a candidate for Deuterium campaign - tests at LHD during the Deuterium campaign possible?
- Application of gas electron multiplier (GEM) detectors for soft X-ray measurements with energy discrimination capability has been presented. This kind of detectors could be interesting for W7-X diagnostics.
- Scintillators for Gama-ray diagnostics have been detailed presented.

Fuelling and Particle Transport (K.McCarthy)

- 4 talks showing growing collaborations on pellet injection experiments and particle transport issues between LHD, W7-X and TJ-II
- Review of need to find means of avoiding hollow density profiles in stellarators that can lead to discharge termination (core pellet fueling, role of radial electric field, transport, need to be considered in detail).
- Reports on pellet injection systems and recent upgrades on LHD and TJ-II with capabilities and limitations of each system.
- Reports on pellet fueling experiments conducted on LHD and TJ-II that will provide input for presentation at the coming ISHW.
- Reports on data analysis by S.Cats and J.-L.Velasco (somewhat preliminary still) should be completed by ISHW.
- Discussion on pellet interaction in the different plasmas and on additional data that should be considered for analysis (e.g. plasma pressure in TJ-II, neutral beam particles, etc.).

**Action List**

Strategic Collaboration (A.Dinklage / F.Warmer)

- Research issues for τE documentation
- Assess global scaling of HSX data
- Renormalization factor, fren in the ISS04 (International Scaling) for LHD updates, HSX
- Assess impact of plasma size (minor radius)
- TJ-II NBI data to be provided
- Joint paper on configuration effects?
- Update of profile database for code validation purposes

Alfvén Eigenmodes and Energetic Particles (S.Yamamoto)

Short term:

- Effect of ECH/ECCD on AEs for control of AEs: LHD, TJ-II, Heliotron J

- should apply same method, target on similar mode for getting unified knowledge
- link to ITPA-EP (energetic particles) group, by S.Yamamoto and K.Nagaoka

Long term:
- Identification and parameter dependence of observed modes (excited by ions)
- high magnetic shear: LHD [EGAM, BAE, EPM, GAE/RSAE, TAE, HAE]: K.Ogawa, K.Nagaoka
- low magnetic shear, low iota, Heliotron J [BAE?, EPM, GAE]: S.Yamamoto
- low magnetic shear, high iota, TJ-II [GAE, HAE]: Á.Cappa, A.V.Melnikov, B.J.Sun
- Loss mechanism of fast ions caused by AEs using lost-ion probe (LIP)/fast ion loss detector (FILD)
- LHD, CHS, Heliotron J (currently Japanese domestic collaboration/joint experiment) : S.Yamamoto, K.Ogawa
- Prediction of AEs and their effect on a particle for stellarator/heliotron DEMO
- Experiment: parameter dependence of observed AEs such as observation region consisted of dimensionless parameters
- Simulation: development of numerical codes for the prediction of AEs in the DEMO (need collaboration with D.A.Spong, Y.Todo, A.Könies,,,)

<u>Impurities and Transport</u> (N. Tamura)

Short term
- Experiment: formulation of joint experiments
- Re-survey & Re-characterization of heating effects on the impurity accumulation
  (LHD, W7-X, TJ-II, Heliotron J, HSX, Uragan-2M/3M)
- Turbulence characterization focusing on the impurity transport (LHD, W7-X, TJ-II, Heliotron J, HSX)
- Theory/Simulation: Feasibility study of a joint paper regarding a non-uniform potential and density on flux surface to IAEA-FEC2016 (Kyoto)

Long term
- Experiment: Acquirement of an optimized heating scheme (power, deposition location) for the suppression of impurity accumulation
- Ensuring the compatibility between a power exhaust scenario (detachment) and an impurity handling scenario
- Theory/Simulation: Strategy of the impurity code validation (improvement in prediction accuracy)
- Production of an optimum profile from the viewpoint of impurity transport

<u>Fuelling and Particle Transport</u> (K.McCarthy)
- It was suggested that we perform simultaneous pellet/impurity injection experiments to determine how fueled particle/impurity confinement might be related.
- For ISHW presentation, K.McCarthy will need to know internal deadline in the LHD Experiment Group, and also need to consider EUROfusion deadline.
- Consider possibility for joint paper on pellet injection comparisons on LHD and TJ-II (after ISHW)

**Acknowledgements**

We sincerely appreciate all the efforts made by local organizers (IPPLM). The 14th CWGM was financially supported by Polish Ministry of Science and Higher Education within the framework of the National Contact Point Euratom-Fusion located in IPPLM. It was also supported by NIFS (National Institute for Fusion Science)/NINS (National Institutes of Natural Sciences) under the project, “Promotion of the International Collaborative Research Network Formation”. The participation of Arturo Alonso, Andreas Dinklage and Jose-Luis Velásco has been supported by EUROfusion. *This work has been partly carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission*.

## 3 END OF TERM REPORT (2010-2015)

On the occasion for the request of extension of the agreement, the activities for the term, from 2010 to 2015, was compiled and then submitted to the IEA.

### I. Executive Summary

The IEA Implementing Agreement for **Co-operation in Development of the Stellarator-Heliotron Concept** (SH-IA, the name Heliotron was added at the occasion of the last extension in 2010) has been operational since 1985 and, after the incorporation of Ukraine in 2002, it presently involves the participation of six parties, namely: Australia, the European Union, Japan, Russia, Ukraine, and the United States. The very successful and fruitful cooperation resulting in many important new scientific results during the period of 2010-2015 under the auspices of the SH-IA fully justify the extension of the Agreement.

Stellarator-Heliotron’s potentially unique feature, inherent favorable characteristics for steady-state operation, makes this concept an invaluable alternative to tokamaks in the development of future fusion power plants. Contrary to tokamaks, Stellarator-Heliotrons can create the magnetic field without requiring a net toroidal plasma current, which makes auxiliary current drive unnecessary and brings remarkable advantages for the plasma stability, in particular the absence of plasma current disruptions, and a significant reduction of circulating power in a power plant. In this way, steady-state operation would be intrinsically and safely achieved in a Stellarator-Heliotron reactor. Also, the enhancement of the understanding of three-dimensional physics in Stellarators-Heliotrons has greatly contributed to the progress of physics in tokamaks.

The SH-IA has pursued the advancement and coordination of the promising Stellarator-Heliotron concept towards a fusion reactor, which will provide environmentally friendly, safe and abundant energy. The Stellarator-Heliotron concept has allowed for the exploration of a wide range of physics and technological issues in the variety of topological configurations available to the parties. The exchange of knowledge and views, including joint participation in experiments and compilation of databases, as well as a coordinated strategy definition and planning, have greatly strengthened the research on the Stellarator-Heliotron concept over the past five years.

The collaborations within the IEA framework were very active and successful for the period of 2010-2015, evidenced by the fruitful collaborations summarized in this document. All participating countries have greatly benefited from these collaborations. Exploiting a leading large-scale experiment as the Large Helical Device (Japan) and Wendelstein 7-X (Germany), other experiments constructs a broader and firmer basis for the development of a Stellarator-Heliotron concept than before. These results and promising prospects as well as the large number of scientific collaborations in the coming years make the extension of the agreement highly desirable.

## II. Strategic Direction

The Stellarator-Heliotron concept has been an alternative confinement approach to the Tokamak concept for future fusion power plants. Significant progress of this concept has been made for the period of 2010-2015.

The SH-IA provides mechanisms to jointly investigate the properties of different Stellarator-Heliotron approaches and to compare them with the Tokamak concept. For example, a joint international Stellarator-Heliotron confinement (energy confinement time) and profile (measured profiles along with the corresponding three-dimensional equilibrium) database [ISH-C(P)DB] including experimental results from participating facilities is a representative activity under the SH-IA.

The Executive Committee (ExCo) has systematically guided coordinated activates such as the ISH-C(P)DB, the Coordinated Working Group Meeting (CWGM), and of course, the research community's regular workshop, the International Stellarator-Heliotron Workshop (ISHW, held every 2 years). In this way, the Executive Committee has compiled international joint programmes and strategic plans.

The collaboration programme includes jointly planned experiments for comparison purposes, mutual participation in experiments and theory/simulation activities, joint evaluation of results, and information sharing. Exploiting a larger number of devices provides a broader basis of experimental results, better progress on physics understandings and increases the reliability of the results from the various facilities, thus contributing to improve the design of next-step devices and the DEMO reactor towards realization of a fusion power plant.

Over the past five years, the flag-ship experiment has been the Large Helical Device (LHD) in Japan, which has significantly advanced the relevance of the Stellarator-Heliotron concept to a future fusion power plant in terms of steady-state (long-pulse) and high-performance (high-ion-temperature, high density) plasma confinement capability. Along with LHD's leading role in the Stellarator-Heliotron research, the SH-IA chair was served by Prof. Akio Komori (the Director-General of the National Institute for Fusion Science until March 2015).

Another large-scale experimental device – Wendelstein 7-X (W7-X) in Germany – has been successfully commissioned and will start with experiment operations before the end of the year 2015. The start of W7-X experiments certainly indicates a new era of Stellarator-Heliotron research; a vigorously competitive and comparative collaboration is envisaged. Anticipating the active role of W7-X to further facilitate the Stellarator-Heliotron research, the ExCo has elected Prof. Robert Wolf (director of the Stellarator Heating and Optimization Division, Max-Planck Institute for Plasma Physics, Greifswald) as chair during the ExCo meeting in October 2015.

## III. Scope of Activities

The current strategic objectives of the SH-IA are (as formulated in the IA legal text):

– exchange of information;

– assignment of specialists to the facilities or research groups of the contracting parties;

– joint planning and co-ordination of experimental programs in selected areas;

– workshops, seminars and symposia;

– joint theoretical, design and system studies;

– exchanges of computer codes; and

– joint experiments.

These programmatic joint actions have facilitated the usage of experimental devices, numerical codes, obtained data etc. in participating institutions, and the systematization of academic outcomes.

To facilitate these activities in programmatic ways, the following actions have been taken in the past five years:

– International Stellarator-Heliotron Workshop (ISHW)

– Coordinated Working Group Meeting (CWGM)

– Executive Committee (ExCo) meetings

**Executive Committee Meeting**

ExCo-meetings have been held once a year and played a supervisory role for facilitating the programmatic joint actions for Stellarator-Heliotron concept development as documented in the IA legal text. One exception is 2011 due to the fact that the ISHW (the convenient opportunity for ExCo members to get together) was held in "fall" in Australia. ExCo members unanimously agreed to hold the ExCo for 2011 at the occasion of ISHW in January 2012.

The quorum (one-half of the members plus one) was satisfied at all ExCo-meetings. Russian representatives were absent from the 39th to the 43rd ExCo. On these occasions, the minutes were sent to them by e-mail, and their consent was obtained to reach unanimous agreement for important issues.

Now, two new Russian representatives, Prof. Boris Kuteev (National Research Center, Kurchatov Institute) and Prof. Viacheslav Ivanov (Prokhorov General Physics Institute of Russian Academy of Sciences (GPI RAS)) were endorsed by ROSATOM, and regular communications with Russia has been restored. Also, in October 2015, the European Commission nominated Lars-Goran Eriksson as an Euratom observer to the SH-IA ExCo.

**Annual Report**

The annual report is comprehensive and consists of an executive summary, the report on the CWGM (every year) and the ISHW in the year it was held, as well as the status of domestic and international collaborations, along with the detailed minute of the ExCo-meeting. It has been submitted to the IEA in a timely and complete manner every year. It is also publically available through the SH-IA website, http://iea-shc.nifs.ac.jp/annual_report.html (available are those from 2005 up to 2014). The IA delegate (chair or the substitute) has attended the FPCC every year to present the IA achievements/plans, and to have discussions with representatives from wide-range IAs.

**IEA Framework and IA Legal Document**

The IEA Framework for International Energy Technology is available as an appendix to the IA legal document. The IA legal document is also publically available at the IA website.

**Input to IEA Secretariat activities**

Energy Technology Initiative: The IA has contributed to editions

– 2013 (p.50: Densities, dynamics and 3-D physics), and

– 2015 (p.61: Super-dense cores and 3-D computations).

Testimonials for commemorating the 40th anniversary of the creation of the Implementing Agreement (IA) mechanism:

– CIEMAT, Spain

"The development of the stellarator as a concept for the steady state fusion power plant encompasses two thirds of the Spanish effort in Fusion research. The Implementing Agreement has been the basis of our international collaboration in this area and it has enriched our national research programme, leveraging experimental and theoretical capabilities and promoting scientific mobility."

Joaquin Sánchez, Director, CIEMAT National Fusion Laboratory, Madrid, Spain.

– IPP-Greifswald, Germany

"The optimized stellarator Wendelstein 7-X is one of the most prominent fusion experiments worldwide. Its objective is to demonstrate power plant capability of the stellarator concept. Strong international support was and will continue to be essential for its success. The Implementing Agreement facilitates this support by providing an effective framework for the global exchange of expertise and personnel. It is therefore an indispensable asset for international scale projects such as Wendelstein 7-X."

Robert Wolf, Director at the Max-Planck-Institute for Plasma Physics, Greifswald, Germany

– NIFS, Japan

From 1992, the National Institute for Fusion Science (NIFS) has been a leading member of the implementing agreement for co-operation in development of the Stellarator-Heliotron concept for realizing fusion energy. It has provided sound basis for long-standing international collaborations, to establish world-standard plasma confinement and profile database, and to leverage scientific and technological achievements of the world-largest superconducting fusion experiment, Large Helical Device (LHD). Now, IA-bridging steady-state operations co-ordination group (SSOCG) has been launched and co-chaired by NIFS upon LHD's record-breaking progress on this issue.

Akio Komori, Director-General, National Institute for Fusion Science, Toki Japan

A delegate from the SH-IA, A. Dinklage, attended the Energy Technology Network meeting on 18 September 2015.

**IV. Contribution to Technology Evolution / progress**

Joint actions such as joint experiments or joint simulation code benchmarking efforts conducted under the auspices of the IA have facilitated the academic understanding and systemization to lead the improvement of the performance of high-temperature plasma confinement.

Some examples for significant publically recognized “success stories” (e.g. cites in scientific journals, awards etc. ) are as follows:

– "Research on high-ion-temperature plasmas through the advanced heating methods foreseeing the nuclear fusion", O.Kaneko, Y.Takeiri and M.Osakabe (National Institute for Fusion Science)

– Prizes for Science and Technology, The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, Japan

– ”Flow damping due to the stochastization of the magnetic field” K.Ida, S.Inagaki et al., and the LHD Experiment Group, National Institute for Fusion Science and Kyushu University, Nature Communications (Jan. 8, 2015)

– IEEE Fusion Technology Award 2014 to Felix Schauer, head of the Wendelstein 7-X engineering division, in recognition of his outstanding contributions to fusion research and superconducting magnet technology.

– Overwhelming recognition of the successful construction of the superconducting optimized Stellarator W7-X in international media.

– Mitigation of NBI-driven Alfvén eigenmodes by electron cyclotron heating in the TJ-II stellarator, K. Nagaoka, T. Ido, E. Ascasíbar, T. Estrada et al., 2013 Nucl. Fusion 53 072004.

– Collaboration between groups under the Stellarator/Heliotron and Reversed Field Pinch Implementing Agreements resulted in a new understanding of the formation of a helical state in the Padua RFX device. Minimally Constrained Model of Self-Organized Helical States in Reversed-Field Pinches – G. Dennis G, S. Hudson, D. Terranova, et al., Physical Review Letters 111 (2013) 055003.

– Small size RF antenna (14x14 cm2) with operational frequency 135 MHz and RF power of a few kW has been installed into U-2M vacuum chamber. It was shown that the antenna is able to produce and maintain plasma with parameters suitable for providing wall conditioning in a wide range of magnetic field (0.1-1.0 kG). V.E. Moiseenko, V.L. Berezhnyj, V.N. Bondarenko et al. Nucl. Fusion 51, 083036 (2011).

– A simple method has been suggested and realized for suppression of runaway electrons appearance during ramp up/down stages of magnetic field at torsatrons Uragan-2M and Uragan-3M; the results were explained theoretically. V.E.Moiseenko, V.B.Korovin, I.K.Tarasov et al. Letters to J. Phys. Reports, 40, #15, pp.80-96, 2014.

Also, the list of the highlighted scientific/technological achievements of SH-IA over the past five years can be given as follows:

– At the Large Helical Device, National Institute for Fusion Science, Japan, the own world record of the total injected energy onto the steady-state plasmas was broken (also one of highlights in SSOCG activity)

– Successful commissioning of Wendelstein 7-X and first measurement of closed flux surfaces, proving the precise alignment of the superconducting magnet system.

– Comprehensive approach to the problem of MHD stability. MHD stability was analyzed with the help of three-dimensional numerical code and analytically. The results of calculations are in reasonable agreement with experimental data. M.I Mikhailov (Kurchatov institute), S.V. Shchepetov (GPI), C. Nührenberg and J. Nührenberg (IPP), L-2M Experimental Team, Prokhorov Institute of General Physics of the Russian Academy of Sciences, Plasma Physics Reports (2013-2015).

– Prepare the physics basis for controlling fast particles (joint NIFS/Japan-CIEMAT / Spain collaboration): The mitigation effect of electron resonance cyclotron heating on fast particle driven modes reported in TJ-II stellarator suggests an attractive avenue for a possible control tool in reactor relevant conditions...

– Improving confidence in impurity transport predictions (Joint IPP/Germany – CIEMAT/Spain collaboration): Direct experimental evidence of plasma potential variation on magnetic flux surfaces in the TJ-II stellarator consistent with neoclassical simulations.

– Core plasma fueling experiments (Joint ORNL/US – CIEMAT / Spain): Successful core plasma fuelling experiments using a cryogenic pellet injector system and associated diagnostics in the TJ-II stellarator.

– New gyrotron complex was installed and tested for L-2M stellarator (Prokhorov Institute of General Physics of RAS). Possible plasma effects were calculated and predicted.

– In a multilateral collaboration, Australian data mining techniques have been successfully applied to four stellarator/heliotron experiments. This work will feed into the Stellarator/Heliotron Coordinated Working Group databases...

– (Ukraine) In cooperation with ITP TU-Graz (Austria), IPP Greifswald and IPP Garching (Germany) the codes NEO, NEO-2, NEO-MC have been benchmarked within the International Collaboration on Neoclassical Transport in Stellarators against other solvers, and the NEO-2 version was applied for modelling of some effects in Wendelstein-7X and ASDEX-Upgrade.

– (Ukraine) It was found that the transition to regime of better plasma confinement in Uragan-3M correlates with a short-time ejection from plasma confinement volume of high energy ions. V.V. Chechkin, I.M. Pankratov, L.I. Grigor'eva et al. Problems Atomic Sci. Technol., series "Plasma Physics", No. 6 (82) 2012, pp. 114-116.

– (Ukraine) The first plasma experimental data were obtained demonstrating the possibility to have a combined stellarator-mirror configuration in torsatron Uragan-2M. These experiments were carried out after such feasibility was proven by calculations and by measuring magnetic surfaces via electron-beam-luminescent-rod-technique.

– (Ukraine) The conditions for excitation of quasi-coherent fluctuations in the frequency range 20-400 kHz in Alfvén-wave-heated plasmas of the U-3M torsatron were studied; appearance of modes correlates with the presence of both suprathermal electrons and high-energy ions in the plasma body.

– (Ukraine) It was shown that runaway electrons are possible trigger for enhancement of MHD plasma activity and fast changes in runaway beam behavior in EAST tokamak (I.Pankratov, R.Zhou, L.Hu, 2015 Phys. of Plasmas, 22, 072115).

## V. Policy Relevance

The activities conducted in the SH-IA have been well communicated to policy makers in the participating countries.

– Australia

The Australian representative reports to Government on Implementing Agreement presentations to the Fusion Power Coordinating Committee.

– Europe

The European Roadmap to the Realization of Fusion Energy (2013) quotes as one of eight missions to bring the stellarator line to maturity, while focusing on the optimized Helias line. The Roadmap supports the international collaboration on other stellarator lines which are mainly pursued under the umbrella of the Implementing Agreement.

The EUROfusion work plan for the implementation of the Fusion Roadmap in 2014-2018 includes two specific stellarator work packages on the "Preparation and Exploitation of W7-X Campaigns (WPS1)" and "Stellarator optimisation: Theory Development, Modelling and Engineering (WPS2"),

– Germany

Fusion research in general and specifically research on the Stellarator-Heliotron concept was included in the 6. Energy Research Program of the Federal Government of Germany (Research for an environmentally sound, reliable and affordable energy supply, Federal Ministry of Economics and Technology, 2011).

– Japan

Annual report and minutes of ExCo have been submitted to the Ministry of Education, Culture, Sports, Science and Technology (MEXT). These have been taken into account in policy making, in particular on Heliotron research.

– Russia

Annual reports are sent to Presidium of Russian Academy of Sciences, the latter submit the Joint report to the related ministries. These materials are taken into account in scientific policy making.

– Spain

The EU stellarator program is focused on the optimized Helias line as pointed in the EU Fusion Roadmap to the realization of fusion energy. Work on other stellarator lines is part of international collaboration under the umbrella of the Implementing Agreement.

– USA

The US Department of Energy has greatly raised the awareness for Stellarator-Heliotron research by providing grants to US-Universities, earmarked for the collaboration on the superconducting stellarator experiments LHD and W7-X, and through substantial hardware contributions for W7-X.

**Relevance to IEA analysis**

The SH-IA has contributed continuously on IEA analysis (upon request from the Secretariat). (cf. Sec. 4.5). Progress on scientific understandings on the three-dimensional magnetic confinement in Stellarator-Heliotron research were reported and used in the IEA Energy Technology Initiatives (2013), and progress of steady-state operation research in LHD and the advancement of Wendelstein 7-X assembly were reported and used in the IEA Energy Technology Initiatives (2015).

**Relevance to other high level events**

Below is the list of Implementing Agreement's contributions to high level events over the past five years.

– Japan (NIFS and universities) - Spain (CIEMAT) collaboration, a part of the SH-IA, was picked up on the agenda in the 1st (Jul. 2012, Madrid) and 2nd (September 2014, Tokyo) Japan-Spain Joint Committee on Science and Technology Cooperation, as in http://www.mofa.go.jp/page1e_000029.html

– Japan (NIFS and universities) - Germany (Max-Planck Institute for Plasma Physics), a part of the SH-IA was picked up on the agenda of the 21st Meeting of the Japan-German Joint Committee on Cooperation in Science and Technology (March 2013, Tokyo).

**VI. Contribution to Environmental Protection**

Fusion research, including the Stellarator-Heliotron concept, has been still under development and is still distant to a fusion power plant. However, in the long-term, the SH-IA indeed expects to make a significant contribution to environmental protection, through the realization of fusion power plant.

**VII. Contribution to Information Dissemination**

During the past five years, the SH-IA tried to develop its information dissemination as follows:

– Outreach of three-dimensional research conducted in SH-IA to ITPA (International Tokamak Physics Activity) was made several times to introduce and facilitate the viewpoints of "3D physics" in tokamaks.

– The established strong link between SH-IA and SSOCG has been a good example for communication between experts on steady-state plasma confinement research, and similarly the connections that were made between the SH-IA and the RFP-IA, resulting in a joint conference, and collaborations on the 'helical state'.

The SH-IA website, http://iea-shc.nifs.ac.jp/, has been continuously updated. The website is currently hosted by NIFS. The most recent update was made on 17 April 2015. Other regular updates include the upload of the annual report and reports on the CWGM. Along with the transfer of the chairmanship of the SH-IA, the website will be hosted by IPP Greifswald.

Contracting Parties, SH-IA legal text (Written Agreement), Annual Report (from 2005 to 2014, including End of Term Report 2005-2009 for the last extension), Stellarator news (community journal), information on CWGM and ISHW, are all available at the SH-IA website, http://iea-shc.nifs.ac.jp/.

(Takeiri, Y., Morisaki, T., Yokoyama, M.)