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Coordinated Working Group Meeting (CWGM16) for Stellarator-Heliotron Research

The 16th Coordinated Working Group Meeting (CWGM16) was held 18–20 January 2017 in Madrid, Spain, under the auspices of the IEA Energy Technology Network (IEA Technology Collaboration Programme for Cooperation in Development of the Stellarator-Heliotron Concept).

Fig. 1. On-site CWGM16 participants.

Figure 1 shows the on-site workshop participants, representing CIEMAT (Madrid), IPP Greifswald and IPP Garching (Germany), IPPLM (Poland), IPT Kharkov (Ukraine), Kyoto University and NIFS (Japan), and ORNL, PPPL, and the University of Wisconsin-Madison (USA). Staff from the host institution, CIEMAT, attended many of the sessions, which brought the total number of those engaging in the meeting to about 30.

This was the largest CWGM participation in recent years, and it may have resulted from the great interest generated by the then imminent operational phase OP1.2 campaign at Wendelstein 7-X (W7-X) and the first deuterium plasma campaign at the Large Helical Device (LHD). Discussion of physics problems that could be addressed by these new experiments had a prominent place in all the sessions.

As in previous editions, a group of coordinators (Ascasibar, Dinklage, Gates, and Yokoyama) prepared the meeting by identifying topics for international cooperations. Colleagues from CIEMAT (Velasco, García-Regaña, Ascasíbar) took care of local organization. The list of topics and session coordinators was:

1. Core electron root plasmas (Felix Warmer).
2. Fueling; pellet injection (Kieran J. McCarthy).
3. Impurity transport (Novimir Pablant).
4. Turbulence, isotope effect (Teresa Estrada).
5. Divertor physics (Jeremy Lore).
6. Plasma wall interaction (Suguru Masuzaki / Ana Belén Martín-Rojo).

The materials presented at the 16th CWGM are available at http://fusionsites.ciemat.es/cwgm16/ and http://ish-cdb.nifs.ac.jp/. Here we provide a summary of each session of the meeting.

Fueling; pellet injection (Kieran J. McCarthy)

Three presentations were made by members of the Particle Transport and Fuelling Group. In the first report, Kieran J. McCarthy (CIEMAT) discussed recent pellet fueling efficiency measurements made on TJ-II. A significant database has now been built up, in particular for hydrogen pellets containing between 5×10^{18} and 1×10^{19} hydrogen

In this issue . . .

atoms injected from the low-field side (LFS) into plasmas heated with electron cyclotron resonant heating (ECRH) and/or neutral beam injection (NBI) in the standard magnetic configuration. The low efficiencies achieved with ECRH may reflect a strong outward drift of pellet particles. This needs further study and may be confirmed once the HPI2 simulation code is working for TJ-II.

A brief summary was made of Heavy Ion Beam Probe (HIBP) measurements on TJ-II during pellet injection in which low-frequency fluctuations (≤ 20 kHz) are seen to significantly decrease in the core immediately after an injection before recovering again.

In the second contribution, Nerea Panadero (CIEMAT) reported on her work at IPP-Greifswald, where she has successfully implemented the HPI2 code for W7-X. She reported on simulations made for OP1.2a, when a refurbished pellet injector will be used to make the first pellet injections. This pellet injector is limited to low velocities, ≤ 250 m/s; hence simulations were made for both LFS and high-field side (HFS) injection. It is predicted that higher fueling efficiencies will be achieved with HFS injections from AEK41. She also reported on simulations for injections with a new high-velocity pellet injector. In this case, only LFS injection is possible. Finally she reported on her efforts to implement HPI2 for TJ-II. This requires additional work due to difficulties arising because the number of particles in the pellet is similar to the number of particles in the plasma, etc.

In the third presentation, Gen Motojima (NIFS) reported on the new pellet injection system for Heliotron J. Pellets of ~1.1 mm diam will be produced for injection at a speed of several hundreds of meters per second. He informed the meeting about commissioning tests and about first injections. He reported that after a pellet injection, the density in the plasma peripheral region is suppressed to the same level as prior to injection. On the other hand, a steep density gradient (3 times higher than before the pellet injection) is formed in the plasma core. Further studies will be undertaken. A short contribution was also made by R. Sakamoto (NIFS) concerning the cryogenic pellet injection experiments planned for the 2017 deuterium campaign in LHD.

On the final day of the meeting, K. J. McCarthy presented a summary of the three presentations and of discussions. Given the successful implementation of the HPI2 code on W7-X, it was considered that the code should also be fully implemented on TJ-II and on Heliotron J so that comparative studies could be made. (The code has been implemented already on LHD.) It was mentioned that plasmoid drift is strongly affected by magnetic configuration, hence the need for significant effort to adapt the HPI2 to each device. it was also mentioned that A. Mischenko is looking into pellet ablation and cloud dynamics theory. However, the current status of this work is unknown.

Finally several proposals for joint actions were made. These are summarized as:

7. Penetration depth database (IPADBASE): Request data for all devices to create a model as a function of T_e, N_e, V_p, and M_p. Create an intermachine comparison with NGS scaling model. Can we determine what additional factor(s) may be needed for stellarators? A basic comparison could act as a seed!
8. HPI2 code: Currently implemented for W7-X and LHD. It may be possible to benchmark W7-X version on TJ-II (to be done in 2017). Could HPI2 be adapted for Heliotron J?
9. Influence of fast electrons on ablation: Proposal for next campaign on W7-X (open to external collaborators). Will attempt to generate fast electrons in TJ-II ECRH plasmas. LHD sees fast electron ablation.
10. 19th LHD experimental campaign: Joint research proposal to study discharges with hollow N_e profiles (pronounced central heating, strong edge fueling, no central particle sources). A single pellet (or series of pellets) will be injected. Monitor N_e profile during and after injection to determine if such hollow profiles can be mitigated with single injections or a series of injections, and to what degree slow diffusive particle transport and fast transport mechanisms are important.
11. Intermachine comparison studies: Similar sizes and parameters (Heliotron and TJ-II; LHD and W7-X). Exchange of ideas for such studies between machines: Broadcast calls for proposals with due dates.
12. Transport of deposited material: Evolution of density profile after deposition; Transport studies by J. L. Velasco.

Impurity transport (Novimir Pablant)

Six presentations were made in the impurity session.

José Manuel García Regaña (CIEMAT) and Albert Mollén (IPP Greifswald) discussed several theoretical aspects of neoclassical impurity transport usually neglected in standard calculations: JMGR focused on the effect on radial impurity transport of the variations of the electrostatic potential on the flux surface, while AM commented on the effect of interspecies collisions.

Naoki Tamura (NIFS) presented ideas for the comparison study of impurity transport in helical plasmas. Thomas Wegner (IPP Garching) presented impurity transport studies using the laser blow-off system on ASDEX Upgrade and near-future plans for W7-X.

Aaron Bader (University of Wisconsin-Madison) commented on the impurity program at Wisconsin. Finally, Motoki Nakata (NIFS) showed neoclassical and gyrokinetic (GK) simulations of impurity transport and comparison with the experiment for LHD plasmas.

Several joint proposals were identified. In the first one (IT.1, Tamura), it was proposed to study the Z-dependence of impurity transport and impurity accumulation. The second one (IT.2 ,Velasco) is intended to develop an understanding of the physics underlying the impurity hole. The third one (IT.3, García-Regaña) focuses on investigation of the variation of the electrostatic potential on the flux surface and its effects on impurity transport. Finally, a fourth task (IT.4) would be the development of a general-purpose 3D stellarator impurity deposition/ionization/transport tool.

Turbulence, isotope effect (Teresa Estrada)

A session on isotope effect and turbulence was held for the first time in the CWGM series. GK simulations and experimental results were presented addressing the effect of the isotope mass on plasma turbulence and zonal flows. Isotope dependence was found in the GK simulations for LHD plasmas with a zonal flow enhancement in D plasmas as compared to H plasmas. These results will be verified in the LHD D–D experiments. Experimental results from Heliotron-J and TJ-II were also discussed. While no impact of the isotope mass on the L-H transition is found in TJ-II plasmas, an increase in the zonal flow amplitude is detected as the D concentration becomes dominant in Heliotron-J. This effect, however, depends on the magnetic configuration. Turbulence simulations for HSX plasmas were also presented with a detailed plan for experimental validation.

Several joint actions were discussed in order to study, numerically and experimentally, the effect of the isotope mass and magnetic configuration on zonal flow development and confinement.

Plasma-wall interaction (Suguru Masuzaki/ Ana Belén Martín-Rojo)

In this session, plasma-wall interaction studies in LHD, TJ-II, Uragan devices, and W7-X were presented. Material migration in vacuum vessel, liquid metal experiments, wall conditioning, in situ monitoring of wall condition, postmortem analyses of plasma-facing components, comparison between experimental observation and simulation, and other topics were discussed.

For a joint action, “material migration in helical devices” was proposed. In the action, long-term material probes on first wall and divertor and/or limiter tiles will be analyzed in helical devices. Isotope gas injection was proposed as a tool for studying material migration study. The effects of various magnetic configurations in a device should be considered. To understand the observed material migration, simulation is essential.

Divertor physics (Jeremy Lore)

Edge and divertor physics in 3D systems were discussed, with presentations including results from LHD, W7-X, and HSX. A common theme was a focus on simulation and validation using the EMC3-EIRENE code, including the need to compare the results to simple models based on field line following. Specific aspects that can be explored through experiments and modeling across various devices include simultaneous matching of upstream and downstream parameters, characterizing impurity transport and radiation in boundary islands, the transition to high-recycling and detached divertor conditions, and up-down flux asymmetry. A desire was expressed for advanced code capabilities such as additional atomic and molecular physics including volume recombination and cross-field drifts to better capture these effects.

The upcoming W7-X OP1.2 campaign with island divertor configurations and the deuterium campaign at LHD offer excellent opportunities to investigate physics critical to future 3D reactors, with a wide range of collaborative areas identified. Divertor physics–related goals of the OP1.2 campaign include characterization of the power loads (e.g., heat flux width), heat transport in stochastic regions, impurity transport, and access to the high-recycling regime. Multi-machine comparative studies in these areas are of high importance, with several topics identified as active projects, in particular detachment, impurity screening, and stochastic boundary transport. Many of the listed problems cut across topical areas, as exemplified by the scraper element divertor components to be installed during OP1.2. These components are designed to address an issue that arises because the toroidal current evolution in certain long-pulse scenarios is predicted to modify the edge topology, resulting in a shift in the heat flux on the order of centimeters.

The topic of designing future devices with optimization criteria related to divertor and edge physics was also discussed. Calculations intended to quantify divertor resilience were presented, with residency defined as the capability of a magnetic configuration to have divertor loads that are insensitive to plasma current and beta evolution. Developing cost functions related to divertor physics suitable for introduction into an optimizer such as STELLOPT remains an open research area.

Core electron root plasmas (Felix Warmer)

With the start of W7-X and extended diagnostic capabilities in smaller devices like Heliotron J, interest in the core-electron-root-confinement (CERC) regime has been revived after being dormant for several years.

Because W7-X was heated in the first operation phase solely by ECRH at low densities, a clear CERC regime was observed with peaked, high electron temperatures and flat, low ion temperatures. The detailed investigation of the CERC regime in W7-X is currently ongoing, including comparison to neoclassical predications, in particular for the critically important radial electric field. Further, a magnetic configuration scan was carried out in OP1.1 and the impact on the CERC regime is being studied.

W7-X and LHD have about the same plasma volume, magnetic field strength and ECRH capabilities, so it is intriguing to compare the CERC features in both devices and the behavior and impact of the positive radial electric field. A preliminary look at W7-X and LHD shows that very similar electron temperature profiles (also in magnitude) develop at comparable density and heating power. A more detailed study is planned once W7-X data has been analyzed more thoroughly.

In this context, the combined CERC investigations in W7-X and LHD are a prime example of the international collaboration activities in the frame of the CWGM. For both experimental devices, many proposals have been submitted for the next experimental campaigns (W7-X OP1.2 and LHD deuterium campaign) to study specific aspects of the CERC regime in a comparative manner, including impurity transport, particle transport, bootstrap current, and the role of the radial electric field, to name only a few. Further, a multi-machine scaling shall be derived for the CERC threshold in the frame of the ISHCDB. As reported at the last CWGM, the ISHCDB is to be integrated in a common EUROfusion infrastructure. The new CERC data should serve as a test case for the implementation in this system in the near future.

Concerning the CERC regime, not only are the large stellarators of interest, but also the helical devices which have been operated for longer times and thus have accumulated extensive experience. In particular, electron internal transport barriers (eITB) have been observed recently at Heliotron J and previously at TJ-II. The degree to which eITB and CERC are different (or similar) transport regimes has been a topic of discussion. It was pointed out that at TJ-II a transition from CERC to an eITB with a stronger positive electric field has been observed. Future work is needed to clarify the degree to which these regimes exhibit different features and how they are established. This is especially of importance for the planned CERC threshold scaling.

In that context it was reported that the magnetic configuration has a strong impact on the transition phase from ion-root to electron-root. In particular, in Heliotron J it was observed that a higher effective helical ripple can reduce the density threshold at fixed power. It is hypothesized that an emerging core magnetic island may be responsible for this behavior due to the faster loss of electrons. Similar observations have in the past been made in TJ-II, but more work is required to understand these observations.

Beyond a brief follow-up meeting within the next International Stellarator/Heliotron Workshop in Kyoto (Fall 2017), it was agreed to continue the Coordinated Working Group Meetings in Spring 2018 at PPPL in Princeton.

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