EFDA WORKPROGRAMME 2011

Call for Participation

(Part of the EFDA WP, H&CD and Fuelling TG)

H&CD and Fuelling Physics

Deadline for Responses: 14. Jan 2011

Contact persons: Marie-Line Mayoral (JET) Coordination Committees: Elizabeth Surrey (NBI), Laurie Porte (ECRH), Raymond Koch (ICRH), Alain Bécoulet (CCLH), Christian Day (Fuelling)
EFDA CSU contact person: Boris Weyssow

This Call for Participation aims to implement the EFDA Work Programme for 2011 on H&CD and Fuelling under Task Agreements as foreseen in the new EFDA Art. 5.

Introduction

At its meeting in Dublin on the 23rd June 2010, the EFDA Steering Committee approved elements of the EFDA 2011 Work Programme, among which the Heating, Current drive and Fuelling programme. This includes the preparation and execution of experiments performed in the Associations and the subsequent coordinated analysis of experimental data. This Call covers the Heating, Current drive and Fuelling programme implemented under Task Agreements on the basis of the provisions given in Article-5 of the EFDA Agreement.

No JET related activities are meant to be implemented as a result of this call. JET related activities are implemented under EFDA Article-6. However some JET activities are mentioned for information when they closely relate to the activity implemented under Article-5. JET data collected and analysed under the JET part of the EFDA WP can be brought together with other data under EFDA Article-5 Task Agreements when relevant for the progress of the work or used in multi-machine modelling activities.

The activities to be implemented following this call for participation will be organised in 5 activities as follows:

HCD-01-01: Experimental simulation of non-linear burning plasma
HCD-01-02: Reliability of ICRH and LHCD
HCD-01-03: Reliability of ECH and ECCD
HCD-01-04: Off-axis Current Drive and rotation
HCD-01-05: Fuelling Physics

The resources made available for the tasks amount to

Baseline Support: manpower 25 ppy

Priority Support: Ceiling of 130 keuro EC contribution

Programmatic Background

The EFDA Work Programme on Heating and Current Drive and fuelling covers the physics and technology issues related to the development of the Heating, Current Drive and Fuelling systems available for fusion plasmas and the integration of these technologies aiming at steady-state plasma operation. These include Neutral Beam Injection (NBI), both based on the acceleration of positive and negative ion beams; Ion Cyclotron Resonant Heating (ICRH); Lower Hybrid Current Drive; and Electron Cyclotron Resonant Heating (ECRH) and current drive (ECCD). The H&CD will address areas of direct ITER relevance, urgent needs, with a clear link with F4E and ITER; as well as longer term developments relevant for DEMO; and urgent needs in connection with fusion device upgrades already agreed or under consideration in the EU. Under areas related to the physics aspects, modelling development, support needs and requests towards the EU experimental program in the various devices will be carried out under the coordination of the respective co-ordination committees, while technology activities will include conceptual design studies, research and development needs among the EU fusion devices.

1. Experimental simulation of non-linear burning plasma:

Task Agreement WP11-HCD-01-01:
Experimental simulation of non-linear burning plasma

1.1 Introduction

Alpha particle heating can be experimentally simulated in a number of important respects using ICRH , by simulating in real time and in proportion as a 'substitute' for the DT reactivity. Similarly, the effect of bootstrap current can be experimentally simulated using ECCD and LHCD as substitutes. Predictive modelling of experimentally simulated burning plasma has been performed, based on the METIS code with simplified actuator models and simplified transport/deposition models and backed up by CRONOS simulations. First experiments, at reduced power, were performed on Tore Supra, showing a very good agreement with METIS simulations.

1.2 Objectives

Perform additional studies to ascertain plasma control capability of future fusion devices. This should be performed in X-point configurations and ITER-relevant conditions.

1.3 Work Description and Breakdown

Structure

Work Breakdown

WP11-HCD-01-01-01

Experimental simulation of alpha particles
It is proposed to extend the operational space of simulated alpha heating and self driven current in view of testing controllability of future fusion devices in burning conditions (i.e. in ELMy H-mode and advanced scenarios). The experimental and numerical simulation studies will consider devices with x-point capability and the influence of different fuelling/pumping capabilities. This will allow the study of the reaction of the different plasma parameters to the different actuators and control strategies, i.e. simulated burn control; anticipating in the most realistic conditions as possible any issues related to burn control and stability. The experiments should be carried out in the relevant range of beta normalised close to the values foreseen in the ITER scenarios, in order to study the effect of MHD instabilities and with the rho_star and nu_star as close as possible to ITER.

JET related activities

No JET experiments are foreseen to be implemented under this Task. However, should JET carry experiments in this area, a close coordination with the JET Task Forces will be sought.

Resources

1.4 Scientific and Technical Reports

<u>R&D Progress reports</u>

At the end of each calendar year, during the Topical Group annual meeting, the Task Coordinator shall present a report on activities under the Task Agreement to the EFDA Leader for his approval. These reports shall integrate the progress made by each Association on each activity, and they shall indicate the level of achievement of the objectives, the situation of the activities, the allocation of resources and recommendations for the next year when applicable. The EURATOM financial contribution will be made through the usual procedures for baseline support through the Contract of Association.

R&D Report of achievements under Priority Support

Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report (and intermediate reports marking substantial progress in the achievement of deliverables, if the EFDA Leader so requests) shall be prepared by the Task Coordinator and submitted to the EFDA Leader. Each participating Association will have to report in one subsection on the degree to which the deliverables of their Task have been achieved, and shall include a breakdown of expenditure. The Task Coordinator will collect the individual subsections into the final report for Priority Support activities addressing the milestones. The EURATOM financial contribution will be made after approval by the EFDA Leader of these reports.

Milestones and Deliverables

Milestones:

- Mid 2011 Activity Meetings: Collection and discussion of results obtained from the evaluation of theoretical work and experiments performed in 2010 and early 2011.
- End second trimester 2011 Annual meeting of the EU H&CD and Fuelling Topical Group: coordinated presentation of the results from the theoretical work and experimental campaigns in 2011.
- December 2011 Final report sent to EFDA-CSU.

Deliverables:

Activity	*Priority Support Deliverables*	*Due Date*
WP11-HCD-01-01-01	Perform experiments on simulated alpha particle heating on devices with x-point capability. Perform burning plasmas simulation experiments in conditions relevant to future device operations, i.e. ELMy H-mode and advanced scenarios.	

2. Reliability of ICRH and LHCD:

Task Agreement WP11-HCD-01-02:
Reliability of ICRH and LHCD

2.1 Introduction

The coupling of ICRH and LHCD power in fusion devices with respect to the H-mode edge conditions and the large distance between the antennas and the plasma expected in future devices requires further analysis since the extrapolation from present day devices is still unclear.

2.2 Objectives

The objective is to develop approaches to increase the level of reliable power density improving the present predictive capability for ITER. The long pulse operation of the RF systems also requires a better understanding and management of the various mechanisms leading to local heat loads and impurity generation.

2.3 Work Description and Breakdown

Structure

Work Breakdown

WP11-HCD-01-02-01

RF Coupling

The objectives of this task are i) to improve the knowledge regarding the ICRH and LHCD large distance coupling in fusion plasmas using results from experiments and numerical simulations, and by developing theoretical models of gas puffing experiments. Important results for the ITER LHCD have been obtained on Tore Supra with the validation of the ALOHA code calculations and the demonstration of low reflected power at low density close to the cut-off density in front of the launcher. Also, high power operation has been possible at a value equivalent to the ITER design. Activities to be carried out to further validate the ITER design in plasma regimes with higher current and density and different SOL density decay length. For ICRH the strong ongoing activity has demonstrated the positive role of particle seeding on antenna loading. Further activities, experimental and theoretical, focussing on the physics of gas puffing near an antenna could help, in particular with further measurements for resolving the poloidal sheath behaviour and modelling of the scrape-off plasma with improved tools, i.e. coupling state of the art of 2D modelling tools (e.g. B2-Eirenne) with RF coupling models (e.g. TOPICA); ii) to develop an overall understanding of the RF coupling mechanisms influencing the long pulse operation in particular by a detailed study of RF sheaths, convective cells, heat loads, impurity generation, combined ICRH-LHCD operation.

WP11-HCD-01-02-02

Arc detection

Improve protection of ICRF systems against arcs, including characterisation of existing systems. The study includes the development of ICRH arc detection systems, design and R&D of new systems, and is expected to lead to recommendations for the arc detection systems of the future ICRH systems (ITER in particular).

SHAD and SMAD arc detection:

Address the problem of spurious detection, in particular during ELM’s, ICE, EMI, or even unknown ultra-short events and the issue of arcs that are still not detected.

Optical systems:

Analyse the behaviour of arcs using the spectra of metallic elements.

Guidar:

Hardware, transmission and data analysis software have been developed, and experiments have been performed on test-stands by inserting an inductance to simulate arc, demonstrating the functionality of this system. The system is very flexible with a wide range of possible carrier frequencies. Test hardware, transmission and data analysis software on dedicated simulators in Torino and on the MXP test-stand in Garching and development of the coupler.

WP11-HCD-01-02-03

Neutral Pressure in front of RF antennas

Experiments following upgrades of the diagnostics for the measurement of the neutral pressure in front of the RF antennas aiming at reconstructing the density profile in the scrape-off layer and edge in front of the antenna, ideally at different poloidal locations to allow for better understanding of sheath effects and convective cell generation by the RF and therefore the RF coupling. These activities will be carried out in collaboration with the PWI TF. The system for measurement of emission spectroscopy on thermal helium and lithium for determination of electron density and temperature, as well as spatially resolved Ha emission spectroscopy for neutral density profile measurements installed in TEXTOR near the bottom of an ICRH antenna will be used. Installation in TEXTOR of a second line of sight near the top of the antenna. This is an important improvement as some processes, like convective cells induced by the RF, may break the up-down symmetry.

JET related activities

No JET experiments are foreseen to be implemented under this Task. However, should JET carry experiments in this area, a close coordination with the JET Task Forces will be sought.

Resources

2.4 Scientific and Technical Reports

<u>R&D Progress reports</u>

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<u>R&D Report of achievements under Priority Support</u>

Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report (and intermediate reports marking substantial progress in the achievement of deliverables, if the EFDA Leader so requests) shall be prepared by the Task Coordinator and submitted to the EFDA Leader. Each participating Association will have to report in one subsection on the degree to which the deliverables of their Task have been achieved, and shall include a breakdown of expenditure. The Task Coordinator will collect the individual subsections into the final report for Priority Support activities addressing the milestones. The EURATOM financial contribution will be made after approval by the EFDA Leader of these reports.

Milestones and Deliverables

Milestones:

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- End second trimester 2011 Annual meeting of the EU H&CD and Fuelling Topical Group: coordinated presentation of the results from the theoretical work and experimental campaigns in 2011.
- December 2011 Final report sent to EFDA-CSU.

Deliverables:

Activity	*Priority Support Deliverables*	*Due Date*
WP11-HCD-01-02-01	Continue and extend the 2010 activities on coupling ICRH and LHCD power in fusion devices with respect to the H-mode edge conditions and the long distance between the antennas and the plasma as the new diagnostic systems become available. The proposal include - further gas puffing experiments, - further measurements for resolving the poloidal sheath behaviour, - modelling of the scrape-off plasma with improved tools, i.e. coupling state of the art of 2D modelling tools (B2-Eirenne…) with RF coupling models (TOPICA …). This activity may include a collaboration with the ITM, with adaptation of codes such as TOPICA and sheath analysis codes to the ITM framework aiming at providing reliable predictions that could be used e.g. to evaluate the performance in terms of coupling and sheath effects of ICRH antennas.	
WP11-HCD-01-02-02	*SHAD and SMAD arc detection*: Perform further work on arc characterization and SHAD signal filtering. Extend the scope of the SMAD to integrate into the signals consistency check other separately developed concepts like the VRAD (voltage ratio arc detection), the AWACS (Advanced Wave Amplitude Comparison System) and the customary arc detection technique relying on monitoring the VSWR (voltage standing wave ratio). *Optical systems*: Continue the analysis of optical systems by performing: - a more complete characterization of arcs, including the evaluation of the optical arc detection concepts; - observations of arc location and evolution using very fast cameras and test of the optical system on existing fusion machines.	

	Guidar: Perform tests of the Guidar in a tokamak environment; together with tests of the Guidar (hardware designed by ENEA-Torino) on the ITER prototype 1:4 mockup (LPP-Brussels) to demonstrate the capabilities of the system and to confirm (or infirm) the possibilities to apply this technology to arc detection in the ITER Ion Cyclotron (IC) system.	
WP11-HCD-01-02-03	Installation in TEXTOR of a second line of sight near the top of the antenna. Report on the results of the up-down symmetry of convective cells induced by the RF.	

3. Reliability of ECH and ECCD:

Task Agreement WP11-HCD-01-03:
Reliability of ECH and ECCD

3.1 Introduction

Reliability of long pulse ECH and ECCD requires feedback control and optimized polarization to avoid shine through (O2) or reflection (X1) interactions with the first wall and/or diagnostics.

3.2 Objectives

Techniques to measure these interactions and to minimize them need to be studied and documented, with test carried out in present devices.

3.3 Work Description and Breakdown

Structure

Work Breakdown

WP11-HCD-01-03-01

Real-time polarization control for ITER EC system

An extensive experimental campaign, using the feed-forward control of EC polarisation, as been started in ASDEX-Upgrade and TCV. The EC system on ASDEX-U is equipped with a remotely controllable (in principle real time controllable) universal polariser and low gain, homogeneous stray power monitors. Using these antennas the stray EC power can be measured in the vacuum chamber. Using feed-forward control of the universal polariser and changing the launched polarisation from X-mode to O-mode and back to X-mode a very clear rise and fall of the stray power was detected on the sniffer probe signals. In TCV, two fast mitre bend mounted polarisers, with their motors and controllers, have been purchased from General Atomics. Use of ECE temperature measurements, sniffer probe signals and infra-red camera signals as actuators for the controllable EC polariser in TCV and ASDEX-Upgrade, focussing on the relation between fluctuations and RF waves.

JET related activities

No JET experiments are foreseen to be implemented under this Task. However, should JET carry experiments in this area, a close coordination with the JET Task Forces will be sought.

Resources

3.4 Scientific and Technical Reports

<u>R&D Progress reports</u>

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Deliverables:

Activity	*Priority Support Deliverables*	*Due Date*
WP11-HCD-01-03-01	Report on the studies performed on the relation between fluctuations and RF waves Perform further studies on polarization, including beam tracing simulations	

4. Off-axis Current Drive and rotation:

Task Agreement WP11-HCD-01-04:
Off-axis Current Drive and rotation

4.1 Introduction

NBI and LH off-axis current drive efficiency

The capability of driving off-axis current drive is a key issue for the development of long pulse operation in ITER and DEMO. Further work is needed to characterise the NBI and LH off-axis current drive efficiency.

Fast wave off-axis current drive

High frequency fast-wave (HFFW) electron H&CD is envisaged in substitution to off-axis NBCD or in DEMO in substitution to LH off-axis CD. As the frequency of the HFFW would be substantially higher than the cyclotron frequency (up to somewhat below the LH) the coupling is expected to be much higher than for the present ICRH antennas. Some attempts and results from US (NSTX) are available.

4.2 Objectives

NBI and LH off-axis current drive efficiency

In addition to earlier experiments in ASDEX-Upgrade, proof of principle experiments on MAST showed evidence of off-axis current drive. The change in sawtooth behaviour in lower and upper single null discharges and lower solenoid consumption are indicative of a broadening of the current profile and efficient off axis current drive. In high Neutral Beam power discharges the measured neutron rate and stored energy, during n = 1 fishbone MHD activity, is in line with estimates from the nonlinear wave-particle interaction code, HAGIS. The work to be performed should allow extrapolation to the full pulse length of foreseen plasma scenarios in future fusion devices

Fast wave off-axis current drive

Develop a common understanding on the potential of fast wave for off-axis current drive by performing a detailed analysis of the fast wave current drive efficiency calculations, including the role of trapped electrons on the current drive efficiency.

4.3 Work Description and Breakdown

Structure

Work Breakdown

WP11-HCD-01-04-01

NBI and LH off-axis current drive efficiency

Simulations with the TRANSP/NUBEAM, ASCOT models and experiments on MAST with off-axis NBI, together with experiments to validate current understanding of the LHCD PAM current deposition on Tore Supra. The aim is to integrate the physics knowledge, including momentum transport and its role in controlling the rotation profile, and information for a consistent extrapolation to future fusion devices.

Experiments to test methods to drive off-axis current with NBI in devices where Collective Thomson Scattering measurements of ion beam distributions is available.

WP11-HCD-01-04-02

Fast wave off-axis current drive

Development and adaptation of the numerical tools required for describing off-axis fast wave current drive in ITER will be carried out, including the use of ANTITER, TOPICA, EVE + CRONOS and FDTD and further developments of Fokker-Planck solver treating correctly long range correlations. The efficiency of FWCD should be assessed for ITER long pulse scenarios.

JET related activities

No JET experiments are foreseen to be implemented under this Task. However, should JET carry experiments in this area, a close coordination with the JET Task Forces will be sought.

Resources

4.4 Scientific and Technical Reports

R&D Progress reports

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Deliverables:

Activity	*Priority Support Deliverables*	*Due Date*

WP11-HCD-01-04-01	Report on the experiments to test methods to drive off-axis current with NBI including Collective Thomson Scattering measurements of ion beam distributions, together with modelling of the origin and scaling of the fast ion transport process. Report on the validation of LHCD PAM current deposition through further experiment and modeling. Report on the applicability of the methods for driving current and rotation in future devices.	
WP11-HCD-01-04-02	Perform further theoretical investigations on the potential of fast wave off-axis current drive; and identification of the type and characteristics of the antenna and RF power sources required. If such a scheme would look promising, test experiments could subsequently be proposed on existing machines.	

5. Fuelling & Pumping physics:

Task Agreement WP11-HCD-01-05:
Fuelling & Pumping physics

5.1 Introduction

A better description of the fuelling and pumping systems used in present machines is needed to validate the solutions for ITER, and for the future machines. For instance, the fuelling in ITER by slow pellets injected from the high field side relies on the grad B drift to increase core fuelling efficiency, but the associated physics is not yet fully understood. Also, the integrated modelling between the fuelling and vacuum gas systems and the main transport codes is still not available. In 2010, some of these problems are considered by the development of a pellet database, by performing fuelling simulations and comparison of experimental results with pellet loss models. The pellet physics modelling will be further developed aiming at a more consistent description of ablation and penetration due to the drift in magnetic field. The objective is to characterise the various injection paths (low/high field side).

5.2 Objectives

It is proposed to focus the study on particle sources and on the fuelling systems, in particular, the physics of pellet injection and neutral particle flow characteristics of gas injection and the sinks by modelling the exhaust gas vacuum systems starting from the under-dome region of the divertor cassettes in ITER.

5.3 Work Description and Breakdown

Structure

Work Breakdown

WP11-HCD-01-05-01

Development of a pellet fuelling database

Strengthening the effort in the area of pellet fuelling for future fusion devices is needed as few fuelling alternative methods are available. The efficiency analysis of pellet fuelling requires the continuation of the development of a pellet fuelling database for extrapolation to ITER. No reliable methods for extrapolating the fuelling efficient of pellets in ITER exist; therefore, a cross machine experimental database is key in providing grounds for more accurate predictions.

WP11-HCD-01-05-02

Modelling of pellet physics

Pellet physics modelling shall be further developed to aim at a consistent description of ablation and penetration due to the drift in magnetic field to characterise the various injection paths (low/high field side). The models shall be extended to cover and characterise deep fuelling. This ongoing work shall be compared with the results of a more rigorous theory-based model (resistive MHD code). A 2-D+1 code has been developed to describe the interaction of moving pellets with hot plasmas, when injected into a Tokamak. The 2-D resistive MHD equations supplemented by Maxwell's equations, Ohm's generalized law, and a number of rate equations are solved for the symmetry plane. This work shall be continued and further elaborated, aiming to provide a description of complete scenarios, suitable to be compared with other modelling approaches.

WP11-HCD-01-05-03

Integration of particle control in ITER plasma scenarios simulations

Bring the modelling communities together in the area of neutral flows in the divertor, pumps and ducts in an effort to advance accurate modelling of vacuum gas flow configurations. The objectives are to enhance understanding and quantitative prediction of the influence of the pumping solutions for ITER (including wall conditioning effects on the particle balance) on the divertor and edge particle control as well as their compatibility with additional fuelling for ELM or disruption mitigation. It is also proposed to extend the assessment towards a general understanding with regard to scale to machines beyond ITER. Finally, the contribution of experiments and modelling to validate ITER scenarios and controllability of burn parameters (D-T mix, burn-up fraction, He content) with relevant fuelling conditions, in particular pellet fuelling.

WP11-HCD-01-05-04

Pellet fuelling experiments to validate ITER scenarios

Pellet fuelling experiments need to be developed to cross-check existing pellet models and to improve predictive modelling, focussing on ITER scenarios. An emphasis is to be given to the scenario of H-pellet injection in He H-mode plasmas which is considered to be most relevant for the first years of ITER operation and reliable extrapolation needs to be developed in order to prepare the non-active phase of ITER operation.

WP11-HCD-01-05-05

Modelling of non equilibrium phenomena of vacuum flows

Complements the work done under particle control for pressure driven flows, including flow phenomena due to temperature and mixture composition gradients as well as transient flows due to starting or ending pumping/fuelling operation or due to plasma unsteadiness.

JET related activities

No JET experiments are foreseen to be implemented under this Task. However, should JET carry experiments in this area, a close coordination with the JET Task Forces will be sought.

Resources

5.4 Scientific and Technical Reports

<u>R&D Progress reports</u>

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Milestones and Deliverables

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Deliverables:

Activity	*Priority Support Deliverables*	*Due Date*
WP11-HCD-01-05-01	Further develop the pellet fuelling database including pellet size, velocity and launching geometry, discharge geometry, magnetic field and q-profile, pre- and post pellet density and temperature profiles.	
WP11-HCD-01-05-03	Propose activities integrating particle control in ITER plasma scenarios simulations. Develop the ITER gas injection system including simulation of flows and definition of injection location by plume evolution simulations in the form of an input to ITER plasma scenarios simulations. This activity shall also include assistance to the problem of gas puffing foreseen to be used to improve ICRH coupling, which is an ongoing issue (see WP11-HCD-01-03). Develop predictive integrated modelling software for gas flow coupling the divertor, pumping, and duct systems. Accurate simulation of vacuum gas flow phenomena shall be provided in the whole range of the Knudsen number (e.g. low and high speed flows through piping elements, leaks through openings and associated pumping efficiency, diffusion effects, unsteady flows related to pumping and plasma scenarios). The required information shall be provided in form of boundary conditions to the main transport codes.	
WP11-HCD-01-05-02	Improve the modelling capability of pellet physics: drift, dispersion and evaporation (pedestal). Describe complete scenarios (obtain scaling laws) for self consistent ablation rate with varying the key parameters (such as pellet velocity, pellet size, magnetic field, plasma temperature, and plasma density). Compare the cases of initial plasma being uniform and non-uniform (taken from other codes). The use of pellet injection is discussed for ELM pace-making at ITER. The modelling of this is using some assumptions which shall be studied in further detail. Aspects to be included are the definition of the critical pellet size and penetration depth for ELM triggering and a consistent characterisation of the induced ELMs.	
WP11-HCD-01-05-	Improve the modelling capability of non-equilibrium phenomena under any vacuum conditions in order to be able to include transient operations.	

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WP11-HCD-01-05-04	Define and possibly perform pellet fuelling experiments required to validate ITER scenarios (in collaboration with Transport and MHD Topical Groups).	