EFDA Workprogramme 2013

Call for Participation

ITER Physics Support Projects

Deadline for Responses: 20. Dec 2012

This Call for Participation aims to implement the Work Programme for 2013 under Task Agreements as foreseen in the new EFDA Art. 5

Introduction

At its meeting in Marseille on the 3-4 October 2012, the EFDA Steering Committee approved elements of the EFDA 2013 Work Programme, including the ITER Support Projects programme. This includes the preparation and execution of experiments performed in the Associations and the subsequent coordinated analysis of experimental data in support of ITER.

The 2012 Work Programme was implemented under ITER Support Projects setup within 11 cross topical Research Areas (A01-A11) among the EFDA Topical Groups and the PWI Task Force. These Projects were planned as two year projects and so the 2013 EFDA Work Programme will be based around the continuation of these Projects with well-defined deliverables and milestones that advance the work in the light of the scientific progress achieved in 2012. No Projects will complete in 2012, and so all are expected to continue in the 2013 Work Programme should the budget be sufficient. The balance of effort, Tasks and Support will certainly change between them. Should the budget permit, three new Projects will begin in 2013. The elaboration of the 2013 Projects was performed by the EFDA Responsible Officers in collaboration with the Research Area Coordinators and with reference to the recommendations of the EFDA Steering Committee (Marseille, 3-4 October 2012). This strategy was agreed between the EFDA CSU and Research Area Coordinators at a meeting in April 2012. The implementation of the Projects will be done under EFDA Article 5 Task Agreements following a Call for Participation in the Projects and allocation of Priority Support. The Priority Support will be allocated to Projects where the EFDA co-ordination brings a significant added value, supporting Projects where individual associations are sub-critical and can only be carried out efficiently under a joint effort.

Programmatic Background

This Call is comprised of 11 Task Agreements: one for each of the 11 cross topical Research Areas, which remain as defined for the 2012 Work Programme. The Research Areas are listed below along with the names and email addresses of their EFDA Responsible Officers.

Research Area	Title	Responsible Officer	RO E-mail
A01	Prediction of Material Migration and Mixed Material Formation	Rudolf Neu	rudolf.neu@efda.org
A02	Shaping and Controlling Performance Limiting Instabilities	Mikhail Turnyanskiy	mikhail.turnyanskiy@efda.org
A03	Fuel Retention and Removal	Marie-Line Mayoral	marie-line.mayoral@efda.org
A04	Plasma Rotation	Darren McDonald	darren.mcdonald@efda.org
A05	Electron Heat Transport and Multi-Scale Physics	Darren McDonald	darren.mcdonald@efda.org
A06	Pedestal Instabilities (ELMs) Mitigation and Heat Loads	Darren McDonald	darren.mcdonald@efda.org
A07	Disruption Prediction, Avoidance, Mitigation, and Consequences	Marie-Line Mayoral	marie-line.mayoral@efda.org
A08	Physics of the Pedestal and H-Mode	Mikhail Turnyanskiy	mikhail.turnyanskiy@efda.org
A09	Fast Particles	Mikhail Turnyanskiy	mikhail.turnyanskiy@efda.org
A10	Particle Transport Fuelling and Inner Fuel Cycle Modelling	Denis Kalupin	denis.kalupin@efda.org
A11	Operation with metallic plasma facing components including High Power ICRH	Marie-Line Mayoral	marie-line.mayoral@efda.org

1. Prediction of Material Migration and Mixed Material Formation (Task Agreement WP13-IPH-A01)

1.1 Introduction

Research Area 1 encompasses two major fields of studies: *Prediction of material migration* and *Prediction of consequences of mixed material formation for ITER.*

Material migration occurs by erosion of plasma exposed material surfaces, subsequent transport of eroded atoms through the plasma and finally re-deposition of these atoms at plasma exposed surfaces. Erosion processes leading to wall material impurity flux to the plasma consist of sputtering, chemical erosion, erosion due to arcs and erosion by thermal overloading (melt release, evaporation, sublimation). Apart from plasma contamination, erosion processes may also lead to modifications of surface morphology. Re-deposition processes can be on the one hand **local**, by first gyro orbit loss after ionisation, escape of neutral molecule dissociation products or near-surface plasma flow. On the other hand, re-deposition will also occur on a **global** scale as a result of plasma exposed surfaces being subjected to erosion or deposition promoting plasma conditions and due to long range transport resulting e.g. from plasma flows in the boundary region.

Material mixing is, together and closely interlinked, with fuel co-deposition the most significant consequence of material migration processes. Formation of mixed material layers including chemical compounds and alloys occurs either by using different plasma facing materials in a device or by using chemically active elements as seeding impurities for mitigation of power loads to plasma exposed surfaces. To a lesser extent also residual impurities (most notably oxygen) will lead to formation of mixed material surface layers although they are usually insignificant compared to the former processes. In ITER, the wall material mix will consist of Be and W, possibly also adding carbon if a CFC divertor will be used in the non-nuclear phase. In addition, nitrogen might be present in the machine as seeding gas although noble gases (Ne, Ar) are more likely candidates.

1.2 Objectives

Material migration studies: The main short term R&D needs of ITER with respect to material migration processes arise from the uncertainties in the predictive capabilities of corresponding transport codes. Both simulations of local re-deposition (particularly into gaps of plasma facing components) and global impurity transport fail to describe present experiments with sufficient accuracy to allow reliable extrapolation to ITER conditions. Dedicated experiments are urgently needed to extend the data base for benchmarking and validation of existing codes. To resolve the current discrepancies between experiments and modelling predictions, new experiments are required to clarify if these discrepancies arise from deficiencies in previous measurements or if they are indeed indications for missing physics processes in the models. Emphasis should be put on all-metal wall material configurations relevant for initial (W&Be) and later (full-W) ITER operational phases. To this end trace impurities used for transport studies should not be subject to chemical erosion processes by D/T fuel species.

Material mixing: The main short term R&D needs of ITER with respect to material mixing processes are arising from the lack of data on the physics and chemistry of Be/W alloy formation and the corresponding erosion/deposition dynamics particularly in the divertor region of ITER. These data are crucial for the assessment of potential thermo-mechanical degradation and dust formation, which are of great significance not only for the operation but also for machine safety and licensing. Reactive seeding impurity elements (e.g. nitrogen) may also form stable mixed material layers influencing both recycling and erosion properties of plasma facing materials. There are still large uncertainties in the prediction of in-vessel tritium inventories, particularly because of the still largely unknown influence of mixed-material layers on tritium retention and removal. This holds not only for corresponding data on the mixed layers themselves but also for their influence on these processes in the bulk material underneath. Additional experiments are required to fill the gaps in the respective data sets.

Main efforts in Research Area 1 will be concentrated on:

- Identification of missing physics responsible for unresolved discrepancies between experiments and modelling predictions of main-wall/divertor material migration balance and of outer/inner divertor material migration balance, specifically for ITER-like all-metal wall configurations.
- Quantification of gross vs. net erosion and validation of local transport models for shaped and castellated metallic plasma facing components;
- Provision of key data (compound formation/dissociation rates, fractional erosion yields, release rates of volatile constituents) on formation and re-erosion dynamics of ITER relevant ternary and quaternary systems of mixed materials consisting of the constituents Be/W/N/O;
- Provision of quantitative data on fuel retention in (apart from co-deposition with single elements) and fuel release from mixed surface layers and covered bulk materials for ITER relevant mixed materials particularly those including Be.

1.3 Work Description and Breakdown

1.3.1 Structure

The Research Area A01 consists of the following Projects:

- WP13-IPH-A01-P1: Material migration and its consequences for ITER (continues from 2012, WP12-IPH-A01-1).
- WP13-IPH-A01-P2: Formation and re-erosion dynamics of ITER relevant mixed materials (continues from 2012, WP12-IPH-A01-2).
- WP13-IPH-A01-P3: Influence of mixed surface layers on fuel retention and release (continues from 2012, WP12-IPH-A01-3).

1.3.2 Work Breakdown

- **WP13-IPH-A01-P1 Material migration and its consequences for ITER**

Erosion of plasma exposed surfaces of the first wall, transport of eroded and subsequently ionised wall materials and their final re-deposition, which can be far away from their origin, leads to an overall migration of plasma facing materials. This has a strong impact on the life-time and thermo-mechanical properties of PFCs but also on the formation of fuel inventories. Re-deposition on small spatial scales leads to an effective reduction of gross erosion. This is particularly important for regions exposed to very high particle flux such as divertor target plates and limiters. Recent experiments have shown, however, that in the case of Be, net erosion is significantly higher than predicted by models using published data on erosion yields and sticking coefficients. A similar effect is seen in comparisons of local impurity injection experiments to local transport codes such as ERO, where generally re-erosion has to be assumed to be larger by one order of magnitude over literature values (or sticking of redeposited ions to be zero) to match experimental data. In the case of tungsten, gross erosion is expected to be reduced over that due to local plasma transport by prompt deposition of ionised W atoms within their first gyro orbit. Previous experiments only provided indirect experimental evidence.

Because PFCs in ITER are designed as castellated structures to reduce thermo-mechanical stress and electromagnetic forces by eddy currents, eroded material returning to the surface can end up at the side walls and bottom of corresponding gaps. In case of impurity species forming fuel inventories by co-deposition, this leads to T-inventories, which are not accessible to the presently planned cleaning procedures in ITER, specifically for Be which shows no or very low chemical erosion yields.

On a large spatial scale plasma facing materials are migrating from erosion dominated areas such as main chamber surfaces and the outer divertor target plate towards deposition dominated areas such as the plasma-shadowed side-faces of main chamber limiters and to the inner divertor plate. Whether a surface area is dominated by erosion or deposition is on the one hand determined by local plasma parameters, on the other hand by impurity transport, particularly in the boundary plasma. As yet, impurity transport predictions fail to quantitatively describe the experimentally observed net migration of wall materials to the inner divertor. The discrepancies are attributed mainly to the codes not recreating the generally observed strong plasma flows from outboard to inboard plasma boundary in the SOL and the private flux region. Discrepancies may also arise from the fact that due to topological restrictions the computational domain of fluid transport codes is not conforming to the wall contour of the main chamber.

- **WP13-IPH-A01-P2 Formation and re-erosion dynamics of ITER relevant mixed materials**

In devices with several different PFMs but also in devices using reactive seeding impurity species for radiative cooling, mixed material layers can form, even in erosion dominated areas because of the generally different fractional erosion yields of the respective species. At deposition dominated areas material from other PFCs can be continuously deposited forming closed layers, which might eventually disintegrate by thermal stress forming dust and flakes but can also diffuse into the bulk material as result of thermal excursions, forming alloys or compounds with generally degraded thermo-mechanical performance over the pure bulk material.

For plasma operation with seeding of external impurities for power load reduction to divertor plates, the use reactive species such as nitrogen, the formation of chemical compounds with the respective PFM can change its original properties. This can lead to a reduced fractional sputter yield but can also have adverse effects by uncontrolled release of the bound seeding species, by increased fuel retention due to formation of diffusion barriers or by changing the thermo-mechanical and electrical properties.

- **WP13-IPH-A01-P3 Influence of mixed surface layers on fuel retention and release**

Formation rates of bound tritium inventories in ITER are affected on the one hand by implantation and diffusion into the bulk of plasma facing components and on the other hand by co-deposition of tritium. The database for co-deposition fractions of T with Be and their dependency on deposition conditions, temperature and effects of additional residual and seeding impurities (W,O, N) should be refined.

Apart from directly formed T-inventories within co-deposited layers, such layers also have a strong influence on the retention and release of fuel isotopes in/from the bulk material. The parametric dependency of bulk retention and fuel release from bulk materials on layer composition and temperature are still to a large extent unknown. The usefulness of proxies for Be should be checked.

1.3.3 JET related activities

No JET related activities are meant to be implemented under this Task Agreement. JET related activities are implemented under EFDA Art.6. However some JET activities can be mentioned for information in this TA when they are closely related to the activity implemented under Art.5. JET data collected under the JET part of the EFDA WP can be brought together with other data under this TA when relevant for the progress of the work or used in multi- machine modelling activities under Art.5.

1.4 Scientific and Technical Reports

1.4.1 Reports

Report of achievements under Baseline Support: At the end of the Task Agreement during a Final Review Meeting the Task Coordinator - Project Leader shall present a report on activities under the Task Agreement. The EURATOM financial contribution will be made through the usual procedures for Baseline Support through the Contract of Association.

Report of achievements under Priority Support (Final Reports): Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report will be prepared by the Task Coordinator and submitted to the EFDA Leader. Each participating Association will have to report to the Project Leader on the degree to which the Deliverables have been achieved. The Project Leader will collect the Associate contributions into the final report for Priority Support activities addressing the associated Deliverables defined. The EURATOM financial contribution will be made after approval of these reports by the EFDA Leader.

1.4.2 Milestones

1. June-July 2013: Submission of Interim Report for each Project (Activity) to EFDA Responsible Officer. Reports provided by each Task Coordinator and collected and submitted by Project Leader.
2. Final Review Meeting: coordinated presentation of the results of the theoretical and experimental work.
3. December 2013: Final Report sent to EFDA Leader.

1.5 Deliverables

Activity	*Priority Support Deliverables*
WP13-IPH-A01-P1	0. Project leader work 1. Combine the interim and final activity reports based on the task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with task coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Improve understanding of (enhanced) gross and net erosion 1. Provide reliable prediction of Be net-erosion rates expected in ITER. Clarify quantitatively, whether the unexpectedly high Be re-erosion rates are due to yields higher than published ion beam data and/or due to sticking

	coefficients smaller than published data; 2. Quantify possible enhanced re-erosion of re-deposited material, which has to be assumed in modelling observed local impurity transport patterns; 3. Quantify the influence of local plasma parameters, field geometry and microscopic surface morphology on local redeposition and on the corresponding relation between gross- and net erosion II. Improve understanding of material migration into gaps of plasma facing components 1. Provide quantitative data on the influence of plasma exposed surface and gap shaping on plasma properties and impurity (mainly Be) transport at gap entry and inside the gap volume of castellated plasma facing components. III. Improve understanding of material migration and of prediction of ITER material throughput 1. Measure global re-deposition pattern of injected 15N tracer in AUG and verify 2D/3D main wall/divertor distribution patterns predicted by DIVIMP/ASCOT. Measure N accumulation, erosion and release in laboratory experiments and compare to N-seeded discharges in AUG and to results provided by JET. Verify respective predictions by WALLDYN. Measure spatially resolved (impurity) SOL flow velocities in AUG and MAST to extend available data set for benchmarking of SOLPS/EDGE2D (including also JET data). 2. Finalize ERO predictive calculation of divertor erosion/deposition pattern in ITER for new ITER divertor geometry and including newly available gap transport module concentrating on Be as low-Z impurity. Validate ERO predictive calculation of main chamber limiter erosion/deposition patterns.
WP13-IPH-A01-P2	0. Project leader work 1. Combine the interim and final activity reports based on the task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with task coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Properties of material mixtures and corresponding formation / dissociation processes 1. Prepare and characterise samples with well-defined mixed material layers containing Be/W+N/O 2. Quantify Be chemical erosion under relevant plasma conditions 3. Calculation of D reflection and sputtering of BeW mixed surfaces using MD codes. Implementation of BeD and BeD2 molecule handling including MD computed material data into the ERO code 4. Identify phase formation and dissociation processes of Be with N and W with N (both in dedicated lab experiments and in tokamak discharges) and derive input data for modelling (reaction rates) 5. Identify and quantify the influence of O on Be/W erosion yields and determine material properties (including stability) of corresponding redeposited layers II. Deposition-erosion balance of W and/or Be particularly with respect to influence of N on these processes

	1. Determine the conditions and physics quantities governing the deposition-erosion balance of beryllium in particular under the influence of nitrogen 2. Determine the conditions and physics quantities governing the deposition-erosion balance of tungsten in particular under the influence of nitrogen 3. Prepare and characterise well defined sample layers for deliverables above.
WP13-IPH-A01-P3	0. Project leader work 1. Combine the interim and final activity reports based on the task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with task coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Extending knowledgebase on fuel release (and retention) of Be-containing mixed materials 1. Identify D trapping and permeation mechanisms in Be (bulk+surfaces) and quantify their role in fuel retention and release processes (activation energies) 2. Quantify the influence of seeded and intrinsic impurity species on D-retention/release. Prove the usefulness and application limits of Ti (Al) as a proxy for Be in these investigations II. Clarification of the influence of Be-containing redeposited layers on D-retention and release 1. Provide quantitative data on the influence of thickness and structure of Be-containing redeposited layers on D-retention and release. Provide quantitative data on the influence of oxide layers on D-retention of and release from W.

2. Shaping and Controlling Performance Limiting Instabilities (Task Agreement WP13-IPH-A02)

2.1 Introduction

The 2013 work-program in the area of "shaping and controlling of performance limiting instabilities" will be continuation of 2012 program and elaborated with the aim of advancing and fostering activities in the following main topics:

- Integrated real-time control with coils of MHD stability in high-beta scenarios;
- Impact of error fields and three-dimensional perturbations and their correction (including applied RMPs);
- Improving predictive capabilities for full simulations of MHD feedback control and
- Developing innovative measurement capabilities to better diagnose MHD with the aim of improving ITER plasma control.

This strategy recognizes the outmost importance of active control of three-dimensional MHD stability for the success of ITER and of the accompanying fusion program, and aims at exploiting the state-of-the-art EU expertise in this field by means of focused projects implemented with a net-based architecture. This means that cross-cutting, interdisciplinary projects need clear goals and have to be developed valorizing all experimental and theoretical resources present in the Associations.

The importance of 3D effects on tokamak stability and plasma control is now theoretically demonstrated. ITER is presently considering the option of installing internal active coils with the main goal of producing resonant magnetic perturbations (RMP), which are considered a viable tool to mitigate or even suppress Edge Localized Modes (ELM). These coils may be used also to control Resistive Wall Modes (RWMs) in high-beta scenarios. This would be a significant additional benefit, since it would allow access to a much broader operational range, in particular to achieve the Q=5 steady state goal. In both cases the basic principle is to produce and actively control a non-axis-symmetric magnetic field, which either:

- Changes the plasma edge magnetic topology, thus modifying transport in the pedestal region and therefore affecting ELMs, or
- Cancels the non-axis-symmetric edge radial magnetic field produced by the RWM.

This project therefore deals primarily with the physics and control of three-dimensional magnetic field and its scope is to contribute to the development of the internal coils for ITER, and to check the feasibility of their use as actuators for RWM control and more in general to make game-changing steps in the knowledge of the electromagnetic properties of the three-dimensional plasma edge. Being the final goal of the project related to ITER, it is necessary to take into account also those conditions, which are particularly important in ITER, like for example the robustness of the control system against noise and disturbances – also a safety issues – and the role of a significant population of fast ions

At present diagnostics and control systems do not present capabilities to diagnose and control the 3D structure of the MHD events which might have severe consequences (only partial control is achieved and/or MHD is detected with a time delay due to the measurement system).

2.2 Objectives

The objective of this work-program will focus on activities concerning

1. Three-dimensional aspects of experiments and modelling of MHD stability and its control
2. Developing measurement capabilities, control tools and associated real time infrastructures to better diagnose and control MHD with the aim of preparing ITER integrated plasma control.
3. Development of real-time infrastructures which is expected to remain under a conceptual level and only be "proof of principle" tested on today's machines since the implementation in ITER will only be done in the future on a different hardware (and probably also software) platform.

2.3 Work Description and Breakdown

2.3.1 Structure

The Research Area A02 consists of the following Projects:

- WP13-IPH-A02-P1 Development of real-time infrastructures (continues from 2012 WP12-IPH-A02-4) ➔ should remain under a conceptual level
- WP13-IPH-A02-P2 Shape and control the three-dimensional electromagnetic boundary of the plasma (continues from 2012 WP12-IPH-A02-2) ➔ due to lifeline of ITER operations work on NTM is preferential
- WP13-IPH-A02-P3 Development of new, control-oriented, diagnostic tools and plasma detectors (continues from 2012 WP12-IPH-A02-3) ➔ continue from 2012 with the assessment of system installed

2.3.2 Work Breakdown

- **WP13-IPH-A02-P1: Development of real-time infrastructures**

The development of diagnostics and /or imaging systems suited for the 3D reconstruction of MHD structures and their control is the main objective of this project. In order to achieve the first demonstration of 3D MHD modes analysis and control several aspects needs to be developed:

- Development of real-time techniques to improve the accuracy of the q profile reconstruction, a well-known ingredient for controlling the MHD.
- Development of real-time systems and infrastructure in order to acquire and treat the 3D information in a short time scale and insure a robust and fast feedback control.
- Provide integration of the measurements in a full real-time environment including RT treatment of the information and event handling for providing a robust control.
- Development of simulation tools of the full chain (measurement, treatment, MHD detection, MHD control and event handling).
- Experiments which investigates the possibility to control 3D modes structures and in which diagnostics are applied to characterize the MHD behaviour.

- **WP13-IPH-A02-P2: Shape and control the three-dimensional electromagnetic boundary of the plasma**

In order to achieve the ITER goals it is important to address and solve a number of MHD stability issues. Concerning the EFDA A02 Work Programme (i.e. excluding ELMs and disruptions treated elsewhere) the problems could be traditionally summarized as following:

- Neoclassical Tearing Modes and Sawtooth for the baseline scenario

- Resistive Wall Modes for advanced scenarios

In addition to that, both points are strongly influenced by the underlying topic of magnetic error field affecting plasma stability.

There is a growing amount of experimental and theoretical work on the role of the three-dimensional electromagnetic boundary for MHD stability.

a) MHD instabilities cause three-dimensional distortions of the MHD equilibrium (flux surface modifications and bulging, islands...), which may cause very severe localized plasma wall interaction, mode-locking (and consequent disruption). This forces to switch to a three-dimensional description of the equilibrium and stability, both to understand them and to find the ways to solve/mitigate the stability issue.

b) Three-dimensional magnetic geometries are expected to influence plasma stability. Addressing stability via 3D equilibria is a rapidly growing subject not only in the stellarators but also in tokamaks and Reversed Field Pinches

c) Active shaping of the three-dimensional boundary interacts with plasma stability and mitigates/suppresses dangerous instabilities. ITER for example is presently considering the option of installing internal active coils with the main goal of producing resonant magnetic perturbation (RMP), which is considered a viable tool to mitigate or even suppress the Edge Localized Modes (ELM). These coils might be also used to control Resistive Wall Modes (RWMs) in high-beta scenarios.

Switching to a three-dimensional view is therefore rather important for MHD studies and has a number of particularly important implications for ITER. For example, the robustness of the control system against noise, disturbances and other non-ideal effects as well as the role of a significant fast ion population may alter the MHD stability properties much more significantly than in present devices. In addition, three-dimensional magnetic perturbation may have an influence on plasma rotation, in particular on plasma braking – and in return, the plasma rotation has significant effect on MHD stability.

The strong European fusion program involvement in the JT60-SA experiment should also be considered where both MHD and the active control are going to be the high priority subjects with 3D skills needed to be further developed.

- **WP13-IPH-A02-P3: Development of new, control-oriented, diagnostic tools and plasma detectors**

The objective of this part of the project is to develop measurement capabilities to better diagnose and control MHD with the aim of preparing ITER integrated plasma control.

2.3.3 JET related activities

No JET related activities are meant to be implemented under this Task Agreement. JET related activities are implemented under EFDA Art.6. However some JET activities can be mentioned for information in this TA when they are closely related to the activity implemented under Art.5. JET data collected under the JET part of the EFDA WP can be brought together with other data under this TA when relevant for the progress of the work or used in multi- machine modelling activities under Art.5.

2.4 Scientific and Technical Reports

2.4.1 Reports

Report of achievements under Baseline Support: At the end of the Task Agreement during a Final Review Meeting the Task Coordinator - Project Leader shall present a report on activities under the Task Agreement. The EURATOM financial contribution will be made through the usual procedures for Baseline Support through the Contract of Association.

Report of achievements under Priority Support (Final Reports): Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report will be prepared by the Task Coordinator and submitted to the EFDA Leader. Each participating Association will have to report to the Project Leader on the degree to which the Deliverables have been achieved. The Project Leader will collect the Associate contributions into the final report for Priority Support activities addressing the associated Deliverables defined. The EURATOM financial contribution will be made after approval of these reports by the EFDA Leader.

2.4.2 Milestones

1. June-July 2013: Submission of Interim Report for each Project (Activity) to EFDA Responsible Officer. Reports provided by each Task Coordinator and collected and submitted by Project Leader.
2. Final Review Meeting: coordinated presentation of the results of the theoretical and experimental work.
3. December 2013: Final Report sent to EFDA Leader.

2.5 Deliverables

Activity	*Priority Support Deliverables*
WP13-IPH-A02-P1	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Physics study 1. Improved real-time infrastructures in order to get in real-time an efficient and accurate reconstruction of the 3D structure of the mode and a robust control of the MHD. 2. First demonstration of 3D MHD control in an existing European tokamak. 3. Preparation of the integration of the measurements in a full real-time environment including RT treatment of the information and event handling for providing a robust control. 4. Development of simulation tools of the full chain (measurement, treatment, MHD detection, MHD control and event handling). 5. Full synthetic diagnostic and MHD control simulation. Assessment of the effect of 3D MHD on plasma stability both from the experimental and simulation standpoint.
WP13-IPH-A02-P2	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold

<table>
<tr><td></td><td>the activity coordination and progress meetings when necessary.

I. Breakthroughs in understanding three-dimensional magnetic and kinetic effects related to MHD stability by means of experiments and theoretical work and development of new scenarios based on three-dimensional equilibria to improve plasma stability.
1. Experiment and modelling dedicated to understanding the influence of three-dimensional magnetic fields on MHD stability (NTM, sawtooth, RWM).
2. Modelling and experimental research on RWM stability in presence of the fast ions
3. Modelling and experiment on the interaction between three-dimensional magnetic fields and plasma rotation.

II. A02-2-2: Development and optimization of active control tools designed to interact with plasma stability and error field, taking into account main ITER needs and addressing in particular non-ideal effects (e.g. noise, interaction with 3D mechanical features of the experiment, sidebands and unwanted resonant and non-resonant components….)
1. Assessment of the role of noise in MHD feedback control systems in support of the ITER internal coil design.
2. Development of modern feedback control algorithms and models in support of the ITER internal coil design.
3. Assessment of the influence of coil geometry and size on the effectiveness of stability feedback control.
4. Development of electromagnetic modelling integrating three-dimensional boundary structures and non-linear plasma evolution.

III. Error fields.
1. Experiments and modelling on the influence of error fields on plasma stability (NTM, ST, RWM..), with particular emphasis on conditions leading to plasma disruptions.</td></tr>
<tr><td>WP13-IPH-A02-P3</td><td>0. Project Leader work
1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary.

I. Physics study
1. New 3D diagnostics to better control diagnose and localize MHD instabilities in ITER</td></tr>
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3. Fuel Retention and Removal (Task Agreement WP13-IPH-A03)

3.1 Introduction

Results from the JET ITER-like wall, ASDEX-Upgrade and laboratories all clearly point to a much lower T **retention** for metallic (W /Be) plasma facing components (PFCs) compared with C-based PFCs but ITER metallic wall will face additional effects related to the high particle fluxes (both in steady state and transient conditions), material mixing (Be-W) and neutron irradiation. The dominant retention mechanisms are co-deposition and deep bulk diffusion. If co-deposition has been extensively studied for C, there are still open question for co-deposition with Be. Also, the dependence of deep diffusion in metals on particle fluxes and radiation damage is still limited and requires further research. The effect of the operational wall temperature should also be included.

The T retention in the ITER vessel is likely to require in-situ **fuel recovery (removal)** during operations or during the maintenance period (depending on the choice of first wall and divertor materials), or methods to actively control the inventory by limiting the T uptake during each pulse. Most of the past work concentrated on fuel removal from C (known as the main reservoir of the in-vessel accumulated hydrogenic species), however ITER will certainly have issues with T retention in Be, W and in mixed materials involving Be and W in conjunction with C and O impurities. Fuel removal methods belong to four basic categories: thermal, photonic, isotope exchange and chemical treatment by reactive gases and RF-assisted discharges (Ion Cyclotron Wall Conditioning – ICWC). For most of the techniques (e.g. photonic oxidative), the main advantages and limitations have been recognised but the following issues still need detailed investigations: efficiency of fuel removal and the recession rate of co-deposited layers; surface state of PFC following the treatment; applicability of the given method inside a tokamak and dust generation accompanying the disintegration of co-deposits. Special emphasis should be given to this latest issue. Indeed, the formation and accumulation of **metal dust** (W, Be) in a fusion reactor may create serious safety and operational problems, some of them connected to tritium retention. In addition, trajectories of dust along with estimation of the fuel content in the dust should be further characterised.

Finally, the assessment of ICWC for fuel removal and conditioning in ITER should be completed. The method is based on RF discharge breakdown using conventional ICRF heating antennas in the presence of permanent magnetic field and is part of the ITER Ion Cyclotron Resonance Frequency (ICRF) system functional requirements. Following the JET ITER-Like wall results, that have shown that inter-pulse conditioning might not be an issue in ITER, the method should be further develop focusing on the efficiency and uniformity of fuel removal from metallic surfaces and cleaning of metallic surface after use seeding and massive gas injection gases (Ne, N, Ar).

3.2 Objectives

The main objectives of this research area are:

- Extend data base on retention and scaling of the retention rate as a function of incident flux/fluence, outgassing and temperature;
- Study in tokomaks, the influence of material morphology, structure and radiation damage on H retention in metals;

- Assess fuel removal methods (priority to W&Be mixtures) in term of removal efficiency, determination of the stability of fuel-depleted layers, i.e. re-saturation effects
- Study of metal dominated dust morphology, motion, trajectories and generation by fuel removal techniques.

3.3 Work Description and Breakdown

3.3.1 Structure

The Research Area A03 consists of the following Projects:

- WP13-IPH-A03-P1: Fuel Retention and Predictions for ITER (continues from 2012, WP12-IPH-A03-1).
- WP13-IPH-A03-P2: Assessment of Fuel Removal Methods and Dust Generation (continues from 2012, WP12-IPH-A03-2).
- WP13-IPH-A03-P3: Assessment of Ion Cyclotron Wall Conditioning for Fuel Removal and Wall Conditioning (continues from 2012, WP12-IPH-A03-3).

3.3.2 Work Breakdown

- **WP13-IPH-A03-P1: Fuel Retention and Predictions for ITER**

The knowledge of the dependence of deep diffusion of H in metals on flux and radiation damage is still limited and requires further research. Post mortem analysis of exposed materials, either PFC or laboratory samples, is the most frequently used approach to determine the amount of trapped fuel. Until recently most data on retention have been obtained in all-carbon machines but more data from carbon-free devices (all-W ASDEX Upgrade, ITER-Like Wall in JET), limiters tests at TEXTOR and laboratory experiments with tungsten are needed to facilitate better predictions and extrapolation to ITER. Specifically, the effect of the operational wall temperature should also be included. The impact of seeding gases and impurities species (C & O) should be addressed especially by using markers techniques.

- **WP13-IPH-A03-P2: Assessment of Fuel Removal Methods and Dust Generation**

Preference will be given in the work programme to experiments aiming at the assessment of fuel removal method for Be (or a low-Z material of similar behaviour, e.g. B) and/or W and/or mixed materials such as Be-C, Be-W, C-W and Be-C-W and comparisons to C when appropriate. For all technologies, the removal rates should be quantified and its applicability to ITER should be assessed. The stability of the fuel-depleted co-deposits, i.e. re-saturation during subsequent exposure to plasma should also be quantified.

An important aim of activities is to improve the knowledge on dust generation and its characterization in different tokamaks. It also includes the development of dust generation and transport models in order to provide better predictions for ITER. Specific tasks are foreseen to investigate the appearance of dust in plasma discharges and, on the post mortem investigation of the dust morphology.

- **WP13-IPH-A03-P3: Assessment of Ion Cyclotron Wall Conditioning for Fuel Removal and Wall Conditioning**

In the past few years experiments performed on JET, ASDEX-upgrade, TORA SUPRA and TEXTOR have allowed the optimisation of the discharge particularly for fuel removal by isotopic exchange and wall conditioning and increase the confidence in the safe operation of the ICRF antenna when used for this purpose. Nevertheless, experiments still need to be supported by suitable modelling (plasma breakdown, RF wave propagation, transport) in order to extrapolate the results to ITER. Additionally, following the JET ITER-Like wall results, that have shown that inter-pulse conditioning might not be an issue in ITER, the method should be further developed finalizing the investigations on fuel removal efficiency and uniformity from metallic surfaces and further focusing cleaning of metallic surface after the use of seeding gases and massive gas injection (Ne, N, Ar).

3.3.3 JET related activities

No JET related activities are meant to be implemented under this Task Agreement. JET related activities are implemented under EFDA Art.6. However some JET activities can be mentioned for information in this TA when they are closely related to the activity implemented under Art.5. JET data collected under the JET part of the EFDA WP can be brought together with other data under this TA when relevant for the progress of the work or used in multi- machine modelling activities under Art.5.

3.4 Scientific and Technical Reports

3.4.1 Reports

Report of achievements under Baseline Support: At the end of the Task Agreement during a Final Review Meeting the Task Coordinator - Project Leader shall present a report on activities under the Task Agreement. The EURATOM financial contribution will be made through the usual procedures for Baseline Support through the Contract of Association.

Report of achievements under Priority Support (Final Reports): Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report will be prepared by the Task Coordinator and submitted to the EFDA Leader. Each participating Association will have to report to the Project Leader on the degree to which the Deliverables have been achieved. The Project Leader will collect the Associate contributions into the final report for Priority Support activities addressing the associated Deliverables defined. The EURATOM financial contribution will be made after approval of these reports by the EFDA Leader.

3.4.2 Milestones and Deliverables

1. June-July 2013: Submission of Interim Report for each Project (Activity) to EFDA Responsible Officer. Reports provided by each Task Coordinator and collected and submitted by Project Leader.
2. Final Review Meeting: coordinated presentation of the results of the theoretical and experimental work.
3. December 2013: Final Report sent to EFDA Leader.

3.5 Deliverables

Activity	*Priority Support Deliverables*
WP13-IPH-A03-P1	0. Project leader work 1. Combine the interim and final activity reports based on the task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with task coordinators and highlight/report to EFDA the

	problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Studies of metallic PFCs from tokamaks and materials (probes) 1. Determination by ex-situ analyses of retention in PFC after exposure to various levels of particle fluxes 2. Determination of spatial distribution of retention (surface and bulk) 3. Determination of sources of discrepancy between gas balance and ex-situ studies (long term outgassing). 4. Determination of retention in the main chamber and in the divertor II. Studies in High flux machines (linear plasma devices) 1. Determination and description of material damage (from neutron and high particle fluxes) 2. Determination of relation between material damage and fuel retention
WP13-IPH-A03-P2	0. Project leader work 1. Combine the interim and final activity reports based on the task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with task coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Fuel Removal: 1. Determination of fuel removal efficiency 2. Critical assessment of applicability of methods to a reactor-class device. 3. Determination of stability of fuel-depleted layers during subsequent exposure to plasma in tokamak. II. Dust 1. Determination of dust generation by fuel removal methods and surface uniformity. 2. Determination of dust migration (trajectories) and mobilisation in a tokamak and related modelling. 3. Determination of fuel content in dust in tokamaks. 4. Determination of dust properties (morphology) by unified dust analysis methods.
WP13-IPH-A03-P3	0. Project leader work 1. Combine the interim and final activity reports based on the task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with task coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Develop ICWC techniques 1. Determine through experiments and modelling, the role of the plasma species interaction with the metallic wall with emphasis on fuel removal efficiency and uniformity 2. Optimise through experiment and modelling, the RF parameters (frequency, voltage) and gas parameters (pressure, species) for safe plasma initiation 3. Investigate the cleaning efficiency of gases used for seeding and massive gas injection gases.

4. Plasma Rotation (Task Agreement WP13-IPH-A04)

4.1 Introduction

In the last few years great effort has been dedicated both on the experimental and theory sides to the understanding of the various ingredients that influence the rotation profile (toroidal and poloidal) in a tokamak. Although substantial progress has been made, we have not yet reached adequate understanding to be able to predict confidently what rotation profiles will be achieved in ITER. Improved knowledge on external torque sources, turbulent momentum transport and role of boundary conditions is needed. In addition, a better understanding has to be gained of the effects of the rotation profile on MHD stability and transport, in order to evaluate the impact on the performance of ITER scenarios. For these purposes, it is essential to have a close collaboration amongst different devices, including JET, and theory groups. The large number of physics questions, means that different devices and groups must tackle different questions in an organised way.

4.2 Objectives

This task agreement aims at identifying the open issues and carrying out the experimental and theoretical work needed to achieve confident predictive capabilities of ITER rotation profiles in various regimes and of their effects on MHD stability and transport. Specific objectives are:

- Advance physics understanding of toroidal momentum transport, performing experiments to measure diffusivity, convection and residual stress and developing and validating theoretical models. This includes the assembly and exploitation of a EU database of intrinsic rotation profiles.
- Improve understanding of external torque sources besides NBI, namely RF and 3D resonant and non-resonant magnetic fields, validating models for Neoclassical Toroidal viscosity and plasma response. Evaluate the impact of MHD modes on intrinsic rotation.
- Investigate relation between SOL flow and core rotation. Determine which other effects play an important role in setting the value of the boundary rotation (non-zero particle flux, ripple, orbit losses, neutrals, pellets ...). Compare L and H-mode.
- Improve vpol diagnostics, to identify the existence of non-neoclassical vpol components in regions of high pressure gradients and resolve causality relation between the two, both for edge and core barriers. Develop and validate models for turbulent generation of poloidal flows.
- Understand the effect of rotational shear on ion and electron threshold and stiffness, with multi-machine experiments and model validation, in view of assessing how crucial rotation will be for ITER performance, in particular in Advanced Tokamak Scenarios.
- Determine the impact of rotation on threshold, triggering and saturation of NTMs and develop and validate modelling tools.

4.3 Work Description and Breakdown

4.3.1 Structure

The Research Area A04 consists of the following Projects:

- WP13-IPH-A04-P1: Achieve predictive capabilities of the plasma rotation profile (continues from 2012, WP12-IPH-A04-1)

- WP13-IPH-A04-P2: Understand effects of rotation on Transport and MHD stability (continues from 2012, WP12-IPH-A04-2)

4.3.2 Work Breakdown

- **WP13-IPH-A04-P1: Achieve predictive capabilities of the plasma rotation profile**

This Project aims at advancing physics understanding of momentum transport and torque sources and achieving a set of validated predictive tools of toroidal and poloidal rotation profiles.

- **WP13-IPH-A04-P2: Understand effects of rotation on Transport and MHD stability**

This Project aims to advance the physics understanding of the effects of rotation on MHD and on transport in different channels, and to produce a set of validated predictive tools.

4.3.3 JET related activities

No JET related activities are meant to be implemented under this Task Agreement. JET related activities are implemented under EFDA Art.6. However some JET activities can be mentioned for information in this TA when they are closely related to the activity implemented under Art.5. JET data collected under the JET part of the EFDA WP can be brought together with other data under this TA when relevant for the progress of the work or used in multi- machine modelling activities under Art.5.

4.4 Scientific and Technical Reports

4.4.1 Reports

Report of achievements under Baseline Support: At the end of the Task Agreement during a Final Review Meeting the Task Coordinator - Project Leader shall present a report on activities under the Task Agreement. The EURATOM financial contribution will be made through the usual procedures for Baseline Support through the Contract of Association.

Report of achievements under Priority Support (Final Reports): Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report will be prepared by the Task Coordinator and submitted to the EFDA Leader. Each participating Association will have to report to the Project Leader on the degree to which the Deliverables have been achieved. The Project Leader will collect the Associate contributions into the final report for Priority Support activities addressing the associated Deliverables defined. The EURATOM financial contribution will be made after approval of these reports by the EFDA Leader.

4.4.2 Milestones and Deliverables

1. June-July 2013: Submission of Interim Report for each Project (Activity) to EFDA Responsible Officer. Reports provided by each Task Coordinator and collected and submitted by Project Leader.
2. Final Review Meeting: coordinated presentation of the results of the theoretical and experimental work.
3. December 2013: Final Report sent to EFDA Leader

4.5 Deliverables

Activity	*Priority Support Deliverables*
WP13-IPH-A04-P1	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Predicting plasma rotation 1. Results from experiments, including perturbative studies, which identify toroidal momentum diffusivity and pinch and residual stress, and validation of theoretical models 2. Experimental results on the impact on rotation of RF heating and 3D magnetic perturbations (externally imposed or MHD driven) 3. An expanded EU database on intrinsic rotation and analysis of that database 4. Studies to validate models to predict toroidal rotation with and without NBI source, also in presence of RF and 3D magnetic perturbations (coils, ripple, TBM), addressing both pedestal and core 5. Results from the exploitation of newly built poloidal velocity diagnostics and the validation of models of turbulence driven poloidal velocity 6. Experimental results on the link between SOL flows and pedestal and core rotation
WP13-IPH-A04-P2	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Effects of rotation on Transport and MHD 1. Analysed experimental results on the impact of rotation on core ion and electron threshold and stiffness 2. Analysed experimental results on the impact of rotation and of poloidal asymmetries on impurity transport 3. Validated theoretical models that can represent a reliable set of predictive tools for Advanced Tokamak scenarios 4. Analysed experimental results on the impact of rotation on threshold, triggering and saturation of NTMs

5. Electron Heat Transport and Multi-Scale Physics (Task Agreement WP13-IPH-A05)

5.1 Introduction

Sources of anomalous (non-neoclassical) electron heat transport are multifarious and can occur at disparate scales. Theory of turbulent transport predicts that significant amounts of electron heat transport can be produced by both ExB and magnetic flutter transport, at both ion and electron Larmor radius scales. Various parameters determine the relative role of large and small scales, like the electron to ion temperature ratio and the electron collisionality. So far, many studies on electron heat transport focussed on the parameter domain where Te >> Ti. Studies of electron heat transport with Te = Ti are more limited, although they are of extreme relevance for ITER. In these conditions, the electron heat transport channel cannot be easily isolated, and these studies are definitely more challenging. In these conditions, electron heat transport can be expected to be produced not only at ion gyro-radius scales, e.g. by ion temperature gradient (ITG) and trapped electron modes (TEM), but also at intermediate scales and at electron gyro-radius scales, by electron temperature gradient modes (ETG). The role of electron gyro-radius scales is expected to become dominant in the presence of transport barriers, in conditions in which strong ExB shearing reduces or even suppresses the transport produced at large scales, while leaving the transport at small scales produced by ETG almost unaffected. ETG modes have been found to be unstable also in edge transport barriers. This opens the complex field of research of the identification of the relative role of large, intermediate and small scales in producing electron heat transport, which is the topic of the present research programme.

This is an extremely challenging research, which requires to push forward the frontiers in both diagnostics for small scale fluctuation measurements and turbulence simulations (multiscale with realistic mass ratio). Experimental investigations performed so far try to answer two critical points, to which the present research project aims at contributing:

1. Which is the source of observed amplitude of fluctuations at probed frequencies and wave numbers, in particular are they connected with the theoretically predicted strength of ETG turbulence, or do they have other turbulent origin.
2. Which is the relationship between the observed high-k fluctuations, the observed (power balance) electron heat transport, and the theoretically predicted level of ETG turbulence and transport.

At present these questions have received conflicting answers. High-k fluctuations have been observed in conditions both above and below the theoretically predicted linear ETG threshold, and electron heat transport has been observed to be both correlated or not-correlated in time with the amplitude of high-k fluctuations. Most recent investigations have clearly shown that multi-field (that is both density and temperature fluctuation) measurements are required to more convincingly identify the role of observed high-k fluctuations in producing the observed electron heat transport. This suggests that ideally one would like to have all possible diagnostics (large scale density and temperature fluctuations, intermediate and small scale density fluctuations) in all devices (or at least in one device), something which is practically hard to achieve. This strongly points to the need for a collaborative effort from the experimental side. In addition, a critical point to consider is that at intermediate and small scales only density fluctuations can be diagnosed, and therefore the role of connected temperature fluctuations in producing transport can be investigated only through simulations. This is one of the reasons why a close collaboration between experimental and theoretical research is crucial in this field.

5.2 Objectives

- Development or upgrade of diagnostics suited to the investigation of effects of multi-scale physics on electron heat transport
- Investigations inside and outside instability domain of ETG modes, search for multi-scale physics effects particularly producing electron heat transport

5.3 Work Description and Breakdown

5.3.1 Structure

The Research Area A05 consists of the following Project:

- WP13-IPH-A05-P1: Electron heat transport and multi-scale physics, experimental characterization through fluctuation measurements and related theoretical modelling (continues from 2012, WP12-IPH-A05-1)

5.3.2 Work Breakdown

- **WP13-IPH-A05-P1 Electron heat transport and multi-scale physics, experimental characterization through fluctuation measurements and related theoretical modelling**

The main aim of this work programme is to identify the turbulence that produces electron heat transport and develop models so that ITER behaviour can be predicted and optimised. In particular, it is important to identify which is the source of observed amplitude of fluctuations at probed frequencies and wave numbers, particularly at small scales, and whether they are connected with the theoretically predicted strength of ETG turbulence, or whether they have other turbulent origin; and which is the relationship between the observed high-k fluctuations, the observed (power balance) electron heat transport, and the theoretically predicted level of ETG turbulence and transport. A critical point is that, at intermediate and small scales, only density fluctuations can be diagnosed, and therefore the role of connected temperature fluctuations in producing transport can be investigated only through simulations. This is why to assess the role of high-k density fluctuations on electron heat transport, temperature fluctuation measurements at low-k are an essential element. Keywords in this research activity are multi-scale and multi-field. In addition, this shows that a close collaboration between experimental investigations using fluctuation diagnostics and theoretical studies on multi-scale turbulence is essential to make progress in this field.

5.3.3 JET related activities

No JET related activities are meant to be implemented under this Task Agreement. JET related activities are implemented under EFDA Art.6. However some JET activities can be mentioned for information in this TA when they are closely related to the activity implemented under Art.5. JET data collected under the JET part of the EFDA WP can be brought together with other data under this TA when relevant for the progress of the work or used in multi- machine modelling activities under Art.5.

5.4 Scientific and Technical Reports

5.4.1 Reports

Report of achievements under Baseline Support: At the end of the Task Agreement during a Final Review Meeting the Task Coordinator - Project Leader shall present a report on activities under the Task Agreement. The EURATOM financial contribution will be made through the usual procedures for Baseline Support through the Contract of Association.

Report of achievements under Priority Support (Final Reports): Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report will be prepared by the Task Coordinator and submitted to the EFDA Leader. Each participating Association will have to report to the Project Leader on the degree to which the Deliverables have been achieved. The Project Leader will collect the Associate contributions into the final report for Priority Support activities addressing the associated Deliverables defined. The EURATOM financial contribution will be made after approval of these reports by the EFDA Leader.

5.4.2 Milestones

1. June-July 2013: Submission of Interim Report for each Project (Activity) to EFDA Responsible Officer. Reports provided by each Task Coordinator and collected and submitted by Project Leader.
2. Final Review Meeting: coordinated presentation of the results of the theoretical and experimental work.
3. December 2013: Final Report sent to EFDA Leader

5.1 Deliverables

Activity	*Priority Support Deliverables*
WP13-IPH-A05-P1	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Transport studies 1. Testing of realistic multi-scale simulations against high quality experimental data. It is recognised that the work involved will be highly computationally intensive. 2. Synthetic diagnostics implemented in gyro-kinetic codes, and development of a close collaboration between theoretical groups, in particular those developing the codes strongly devoted to the study of multi-scale turbulence, and the experimentalists directly involved in making experiments in the various devices. 3. Improved fluctuation diagnostics and combined implementation of synthetic diagnostics in codes suitable to facilitate the design of the experiments, the analysis and interpretation of the experimental results, and eventually in a quantitative simulation of the observations. In particular the development of: new Doppler reflectometry systems allowing the measurement of density fluctuations at binormal wave numbers up to 10 inverse ion gyro-radii; tangential phase contrast imaging system expected to deliver fluctuations at wave numbers up to 25 inverse ion gyro-radii; correlation electron cyclotron emission systems to measure electron temperature fluctuations, attempting to increase the wave number spectrum resolution. These systems, when installed in the same device, will allow cross-validation of measurements

	obtained by different methods. 4. Studies of high k turbulence for electron heat transport in spherical tokamaks, and comparisons with experimental values of electron heat transport, including electromagnetic and ExB shearing effects. 5. Fundamental (and more long-term) theoretical / numerical research to find ways by which simulations for the investigation of multi-scale turbulence physics can become feasible with reduced computational costs. At a more fundamental level, an analysis of the characteristics of multi-scale turbulence and transport with a test particle approach, applied to multi-scale simulations of realistic plasma conditions, and/or direct experimental measurements of turbulent spectra.

6. Pedestal Instabilities (ELMs) Mitigation and Heat Loads (Task Agreement WP13-IPH-A06)

6.1 Introduction

This topical area addresses one of the key fusion reactor issues, namely, how to maintain a burning fusion plasma without destroying the reactor walls ?! To answer this question, one in turn has to many others, which collectively can be labelled as plasma exhaust issues (these are listed below to provide the context to the work) namely:

- *What will be the SOL width & peak target heat loads in L-mode? and in H-mode? between ELMs? during ELMs (natural & mitigated)?*
- What will be the degree of divertor detachment?
- What will be the maximum achievable density in L & H-mode?
- What will be the impurity content?
- How useful can seeded impurities be in exhausting the plasma energy?
- What is the condition for the L-H transition?
- What is the effect of magnetic field (shape, topology) on the above Super-X divertor, Snowflake divertor, etc.
- What is the rate of PFM erosion by the plasma?
- What is the rate of fuel retention and material migration?
- What is the effect of plasma disruptions on plasma facing components?

This topical area address the first of these specific questions (printed in italics above), with the exclusion L-mode transport, i.e.

What will be the SOL width & peak target heat loads in H-mode between ELMs and during (both natural & mitigated) ELMs?

This question is addressed via two complementary projects, namely: (i) heat loads on plasma facing components (PFCs) during steady-state, inter-ELM and L-mode, and natural ELM phases and (ii) heat loads on plasma facing components during mitigated ELM phases.

6.2 Objectives

The goal of both projects it to achieve tolerable steady state and transient heat loads to the plasma facing components for the entire pulse, including ELM mitigation. This is reflected by its two main objectives:

- Quantify steady state, inter-ELM and L-mode, and ELM SOL transport and related PFC heat loads:
  - Obtain new inter-ELM SOL width data from existing tokamaks, including the influence of RMPs.
  - Develop a first principles SOL inter-ELM and L-mode width models and validate based on tokamak data.
  - Predict heat and particle (impurity) fluxes with and without ELM mitigation / suppression with respect to peak flux and distribution during ELMs or during full ELM suppression.
  - Obtain new L-mode SOL width data from existing tokamaks.
  - Predict heat and particle (impurity) fluxes during L-mode and compare with inter-ELM results.

  - Obtain new ELMy H-mode SOL width data
  - Develop a first principles SOL width model during ELMs and validate against tokamak data.
  - Predict heat and particle (impurity) fluxes with respect to peak flux and distribution during ELMs. Predict ELM related heat and particle fluxes in the divertor as compared to/from main chamber components.
- Quantify the transport of mitigated ELMs in the SOL and related PFC heat loads.
  - Obtain new ELMy H-mode SOL width data from RMP studies.
  - Develop a first principles SOL width model during mitigated ELMs and validate against tokamak data.
  - Predict heat and particle (impurity) fluxes with ELM mitigation / suppression with respect to peak flux and distribution during ELMs or during full ELM suppression. Predict ELM related heat and particle fluxes in the divertor as compared to/from main chamber components.

6.3 Work Description and Breakdown

6.3.1 Structure

The Research Area A06 consists of the following Projects:

- WP13-IPH-A06-P1: SOL transport and divertor heat loads in steady state and unmitigated ELMs (continues from 2012, WP12-IPH-A06-1, see note below)
- WP13-IPH-A06-P2: Active control of ELMs and the associated divertor heat loads (continues from 2012, WP12-IPH-A06-2, see note below)

Note: for 2013, the subtopic on unmitigated heat loads has been moved to A06-P1.

6.3.2 Work Breakdown

- **WP13-IPH-A06-P1: SOL transport and divertor heat loads in steady state and unmitigated ELMs**

The objective of the project is to develop a predictive model of SOL transport and divertor heat loads during steady state, inter-ELM and L-mode, and ELM phases. The importance of the inter-ELM exhaust has been recognized for a long time, but has only recently (last couple of years) become a major issue for ITER. This can be largely ascribed to infra-red measurements of inter-ELM heat loads on JET and ASDEX Upgrade, which have provided a predictive physics basis for the mid-plane SOL power width which has been found to explain data from a range of EU and US tokamaks and has almost no size dependence. These studies have also identified the importance of perpendicular diffusion on the SOL field lines in determining divertor heat loads. Further investigations, both experimental and theoretical, should focus on identifying the role of perpendicular diffusion and extend the analysis to L-mode plasmas. Additional effects, e.g. magnetic perturbation, and higher plasma density should also be considered.

The high peak divertor loads during ELMs predicted for ITER are incompatible with the ITER divertor design. Thus, the section of the project on heat load during ELMs is focused on building an understanding that can be applied to mitigated ELMs. This requires developing a phyiscs basis for SOL transport during ELMs and using it to build models to predict peak divertor heat loads.

Please note: the topic of ELM SOL is new to this Project (Activity) for 2013 and was included in the Project A06-P2 in 2012.

- **WP13-IPH-A06-P2: Active control of ELMs and the associated divertor heat loads**

Extrapolation from present devices to ITER shows that anticipated ELM power and heat loads are much too large and may result in too high erosion or damage of the divertor tiles. The transient power loss per ELM in ITER needs to be reduced by a factor of 10-20 in order to stay within safe operational limits. Various methods have been proposed among which the use of resonant magnetic perturbations (RMP) has shown a great potential. (Note: It is not clear whether the magnetic pertubations must be resonant or not. This Project applies to both resonant and non-resonant magnetic pertubations and, as is the convention, refers to both as RMPs.) On DIII-D and ASDEX Upgrade a complete stabilisation of ELMs by application of n=3 or n=2 RMPs, respectively, has been achieved. Experiments on JET using the error field correction coils in n=1 and n=2 configuration have shown that the frequency of ELMs could be increased by a factor of ~5. Application of n=3 RMPs on MAST have shown an increase in ELM frequency, too. At present there is a heuristic model that the edge ergodisation (expressed in terms of island overlap, Chirikov parameter) needs to be larger than 1 in a certain radial range. However, in the calculation no field shielding has been included and the resonant perturbation has been taken in its vacuum approximation. The theoretical interpretation uses the peeling-ballooning model and shows that due to the application of the RMP the edge pressure gradient decreases and the operational point moves into the ELM stable region. This raises the question why experiments on e.g. JET show a decrease of the edge pressure but an increase of the ELM frequency, and using specially tailored plasma conditions didn't achieve complete ELM suppression even in a case where the Chirikov parameter exceeded 1. Within Europe the tokamaks JET, ASDEX Upgrade, MAST, TEXTOR, and COMPASS are equipped with perturbation coil systems. This enables the systematic study and comparison of the influence of RMPs in various conditions (mode numbers, internal vs external coils). On the one hand this task aims to study and better understanding the conditions where ELMs are suppressed, on the other hand the physics of RMPs need to be better understood. One crucial question is what is the field penetration and shielding. Here smaller machines which allow better access to the plasma and more flexibility, and plasma configurations other than tokamaks can give valuable contributions to the physics understanding of specific questions in the area of field penetration. Other general questions address edge stability with and without application of RMPs and the underlying mechanisms for stabilisation / destabilisation of ELMs.

Please note: the topic of ELM SOL Transport has been moved to the Project (Activity) A06-P2 for 2013.

6.3.4 JET related activities

No JET related activities are meant to be implemented under this Task Agreement. JET related activities are implemented under EFDA Art.6. However some JET activities can be mentioned for information in this TA when they are closely related to the activity implemented under Art.5. JET data collected under the JET part of the EFDA WP can be brought together with other data under this TA when relevant for the progress of the work or used in multi- machine modelling activities under Art.5.

6.4 Scientific and Technical Reports

6.4.1 Report

Report of achievements under Baseline Support: At the end of the Task Agreement during a Final Review Meeting the Task Coordinator - Project Leader shall present a report on activities under the Task Agreement. The EURATOM financial contribution will be made through the usual procedures for Baseline Support through the Contract of Association.

Report of achievements under Priority Support (Final Reports): Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report will be prepared by the Task Coordinator and submitted to the EFDA Leader. Each participating Association will have to report to the Project Leader on the degree to which the Deliverables have been achieved. The Project Leader will collect the Associate contributions into the final report for Priority Support activities addressing the associated Deliverables defined. The EURATOM financial contribution will be made after approval of these reports by the EFDA Leader.

6.4.2 Milestones

1. June-July 2013: Submission of Interim Report for each Project (Activity) to EFDA Responsible Officer. Reports provided by each Task Coordinator and collected and submitted by Project Leader.
2. Final Review Meeting: coordinated presentation of the results of the theoretical and experimental work.
3. December 2013: Final Report sent to EFDA Leader

6.5 Deliverables

Activity	*Priority Support Deliverables*
WP13-IPH-A06-P1	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Inter-ELM and L-mode studies 1. Measurements of the edge-SOL in inter-ELM and L-mode target heat load profiles using appropriate diagnostics which enable the determination of a predictive scaling for the divertor heat load. The highest priority will be the determination of the effect of perpendicular diffusion on the SOL field lines. 2. Regression analyses of edge-SOL target heat profiles, including existing JET data, to determine a multi-machine scaling. An aim should be made for a single model which describes both the inter-ELM and L-mode scaling. 3. A simple, theory-based, model of edge-SOL transport for both inter-ELM and L-mode plasmas which has been compared with experiment. 4. Diagnostic upgrades in support of determining a predictive scaling for the divertor heat load. II. ELM SOL transport 1. Multi-machine measurements and analysis of divertor heat loads, modes, SOL plasma quantities, and SOL electric and magnetic fields in ELM filaments. Of particular interest are 2-D temperature profiles and

	measurements with W divertors. 2. Results from simple models for, or more detailed simulations of, ELM crash dynamics and their comparison with experiment. The focus should be on identifying divertor heat loads.
WP13-IPH-A06-P2	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. RMPs for ELM suppression / mitigation / control 1. Results from cross-machine experiments using RMPs in order to suppress / mitigate / control ELMs. The priority is to build an understanding of why some machines see complete suppression and some see only destabilisation of ELMs. 2. Comparison between experimental results on different machines to understand influence of coil configurations, mode numbers, target plasma parameters, etc. The priority is to develop the underlying physics of field penetration and surface deformation and to understand their relative importance. 3. Modelling to support the understanding of the issues of complete suppression versus destabilisation of ELMs and field penetration versus surface deformation.

7. Disruption Prediction, Avoidance, Mitigation, and Consequences (Task Agreement WP13-IPH-A07)

7.1 Introduction

Disruption mitigation has been identified as one of the very urgent ITER tasks that need to radiate more than 90% of the plasma thermal energy in order to prevent too high heat loads on plasma facing components. Disruption forces may cause serious damage to vacuum vessel, internal components, and supporting structure. In order to progress in our understanding and control of disruption, specific efforts have to be made in the following areas:

Development of disruption and runaway electron mitigation techniques (especially Massive Gas Injection). The main candidate for the ITER disruption mitigation system (DMS) in ITER is the so-called Massive Gas Injection (MGI) which system relies on the injection of very large amount of noble gas into the plasma when a disruption precursor is detected and the disruption cannot be avoided by other means. A radiative limit disruption is triggered and the stored energy of the plasma is radiated onto the plasma facing components (PFCs). At the same time forces due to vertical displacement events (VDE) are reduced. These effects were demonstrated on present machines, and MGI is already used as a real-time DMS (e.g. on ASDEX-upgraded and JET). Nevertheless, MGI should not result in a concentration of the radiation on a too small surface area that may lead to local melting of metallic walls, hence the development of multiple valves for MGI. Also, the current quench time should stays within acceptable limits as faster current quench could result in enhanced electromechanical loads. Additionally, in the disruption processes, runaway electrons potentially leading to significant wall damages can also be produced. Nevertheless, dominant runaway electron generation mechanisms in ITER are different than on smaller machines, and reliable extrapolation and prediction needs to be supported by validation of modelling. Finally quantification the density increase and characterisation of the plasma during and after the current quench following MGI, should be performed. If the current quench time becomes too short, this method may not be suitable for runaway electron suppression and other means have to be developed (e.g. RMP, runaway beam control and moderate gas injection). . Particularly, the critical density for runaway electron suppression has not been reached yet and further developments are needed.

Real-time disruption prediction and classification. In ITER, any strategy for the mitigation of disruptions will strongly depend on the existence of high quality disruption predictors. The term ‘high quality’ refers to the following properties of the predictor: real-time applicability, enough anticipation time, high success rates and minimum number of false alarms. The development of such predictors implies a joint research effort to identify efficient models (both physics- and data-driven) in the prediction task. However, it should be noted that there are disruptions of different nature with different temporal scales and, therefore, the modelling activity can be extremely complex. It should be clear that the final goal of a predictor model is to provide an early enough identification not only of an incoming disruption but also of its specific class. Only after identification of the disruption type, it will be possible to undertake precise mitigation actions (it is known from JET that a wrong mitigation action can have detrimental consequences sometimes worse than a passive policy).

Note that in parallel, reliable disruption avoidance strategies should be developed, this means: exploring and developing reliable avoidance strategies for various types of disruption precursors (locked modes, NTMs, radiation, impurity influx, ...) on present machines and integrate in the ITER scenario development. Even when a successful disruption prediction and mitigation method is available, the total number of disruptions needs to be kept as low as possible. This is primarily a task for the scenario development and plasma control areas, but is strongly linked to the point of disruption prediction. Depending on the type of instability which is detected as a disruption precursor the controlled plasma shut-down should not be executed automatically but various means of counter action could be activated.

7.2 Objectives

R&D in support of an ITER disruption mitigation system should aim on achieving the following requirements:

- The disruptivity for major disruptions should not exceed 3%.
- The disruptivity for vertical displacement events should be below 1%.
- The prediction success rate has to be larger than 95%.
- 90% of the plasma thermal energy has to be radiated.
- Current quench time of mitigated disruptions should be between 50 ms and 150 ms in order to keep electromechanical loads within acceptable limits.
- Limit Runaway electron currents below the level for significant wall damages

7.3 Work Description and Breakdown

7.3.1 Structure

The Research Area A07 consists of the following Projects:

- WP13-IPH-A07-P1: Develop and Characterise Disruption and Runaway Electron Mitigation Systems (continues from 2012, WP12-IPH-A07-1)
- WP13-IPH-A07-P2: Development of Real-Time Disruption Prediction (continues from 2012, WP12-IPH-A07-2)

7.3.2 Work Breakdown

- **WP13-IPH-A07-P1: Develop and Characterise Disruption and Runaway Electron Mitigation Systems**

The following project will focus firstly on to the qualification of MGI for ITER. In particular, the local peaking of radiation load as function of MGI parameters and plasma conditions should be further studied focussing on the effect of using multiple valves for MGI and related density increase. The characterization of the the current quench time with different MGI and plasma parameters is also critical to make sure that electromechanical loads can be kept within acceptable limits. Secondly, runaway electrons suppression was not shown on present devices mainly because in ITER the generation of runaway electrons via the avalanche process is expected to be orders of magnitude larger. Nevertheless, there is a critical density above which the avalanche runaway generation mechanism is suppressed and work should aim to achieve this in present devices equipped with a MGI system. More experiments with larger valves need to be performed and the compatibility of plasma operation with that huge amount of injected gas needs to be shown. Alternative methods for runaway electron suppression (e.g. RMP, runaway beam control and moderate gas injection) should also be explored as if the current quench time becomes too short using MGI, the method may not be suitable for runaway electron suppression. Finally, more emphasis has to be put on a better diagnosis and understanding of the post-disruption phase when a runaway beam is present in the plasma. Conversion of magnetic energy into kinetic runaway energy and the build-up of a thermal plasma component during the runaway phase need to be characterised. Better knowledge of the physical processes during this phase may help to devise improved methods to control and mitigate the runaway electrons.

- **WP13-IPH-A07-P2: Development of Real-Time Disruption Prediction**

The first aspect of the project is related to the development of predictors for ITER focusing on data-driven which have been the main focus of recent predictor's developments. They are based on the estimation of useful relationships among several quantities with the aim of performing an accurate prediction and type classification. These relationships are typically obtained by applying machine learning methods. The second aspect of the project focuses on improving the set of diagnostics traditionally used for disruption prediction. For example, the relevance of imaging is increasing constantly but up to now no disruption predictor has ever included data from cameras, mainly for lack of adequate image processing algorithms. On the other hand it has become evident in the last years that there are some instabilities often leading to disruptions, such as MARFEs, that can be detected much better from cameras videos than with any other diagnostic.

7.3.3 JET related activities

No JET related activities are meant to be implemented under this Task Agreement. JET related activities are implemented under EFDA Art.6. However some JET activities can be mentioned for information in this TA when they are closely related to the activity implemented under Art.5. JET data collected under the JET part of the EFDA WP can be brought together with other data under this TA when relevant for the progress of the work or used in multi- machine modelling activities under Art.5.

7.4 Scientific and Technical Reports

7.4.1 Report

Report of achievements under Baseline Support: At the end of the Task Agreement during a Final Review Meeting the Task Coordinator - Project Leader shall present a report on activities under the Task Agreement. The EURATOM financial contribution will be made through the usual procedures for Baseline Support through the Contract of Association.

Report of achievements under Priority Support (Final Reports): Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report will be prepared by the Task Coordinator and submitted to the EFDA Leader. Each participating Association will have to report to the Project Leader on the degree to which the Deliverables have been achieved. The Project Leader will collect the Associate contributions into the final report for Priority Support activities addressing the associated Deliverables defined. The EURATOM financial contribution will be made after approval of these reports by the EFDA Leader Milestones and Deliverables

7.4.2 Milestones

1. June-July 2013: Submission of Interim Report for each Project (Activity) to EFDA Responsible Officer. Reports provided by each Task Coordinator and collected and submitted by Project Leader.
2. Final Review Meeting: coordinated presentation of the results of the theoretical and experimental work.
3. December 2013: Final Report sent to EFDA Leader.

7.5 Deliverables

Activity	*Priority Support Deliverables*
WP13-IPH-A07-P1	0. Project leader work 1. Combine the interim and final activity reports based on the task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with task coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Qualify through experiments and modelling, Massive Gas Injection as a mitigation method for heat loads and forces 1. Determine local peaking of radiation load as function of MGI parameters and plasma conditions 2. Use more than one MGI systems (where applicable) and characterise the increase in density and improvement of radiation load distribution 3. Determine scaling of current quench time with MGI and plasma parameters 4. Compare results from different machine and establish a common database in support to the ITPA disruption database II. Develop through experiments and modelling, runaway electron suppression by Massive Gas Injection Toward the Critical Density or other Means 1. Determine the achievable fuelling efficiency on present machines 2. Extrapolate the required amount of gas for reaching the critical density in ITER 3. Characterise wall heat loads and current quench times when using to avoid runaways, largest possible gas levels from MGI 4. Document potential of alternative methods for runaway electron suppression 5. Show compatibility and consequences of MGI with ITER cryopump operation III. Characterise post-disruption plasmas and devise options for runaway electron control and mitigation 1. Monitor the dynamic evolution of the runaway plasmas. 2. Explore plasma control methods and limits for runaway electron plasmas after disruptions 3. Determine runaways heat loads and forces in case of loss of control 4. Devise on alternative methods (RMP, pellets, gas puffs) to reduce runaway content of a stable runaway plasma 5. Use runaway plasmas in present machines to benchmark modelling
WP13-IPH-A07-P2	0. Project leader work 1. Combine the interim and final activity reports based on the task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with task coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Development of real-time disruption prediction 1. Combination of different real-time predictors (physics-driven and/or data-driven) to improve the predictions in terms of success rate, false alarms and anticipation time.

	2. Development of classifiers to distinguish among different types of disruptions. 3. Development of probabilistic disruption predictors as a way to improve either the real-time disruption predictors or the disruption types classifiers. 4. Improve data-driven predictors by identification of new physical quantities to measure (including images from visible cameras)”

8. Physics of the Pedestal and H-Mode (Task Agreement WP13-IPH-A08)

8.1 Introduction

In the 2013 programme some key elements of H-mode pedestal physics are expected to be addressed: 1) develop understanding of the H-mode barrier, 2) to study the L-H and H-L transition, 3) Confinement scaling of the H-modes and access to good confinement with H98,y2=1. In line with ITER operational time-line, accurate information is required to predict operation of ITER in the low activation phase, highlighting the importance of understanding of the H-mode pedestal, transition into H-mode, and H=1 access dependence of fuel specie (H/He/D/T). Improved predictive capability in all three areas will also require the availability of more sophisticated computational models that assemble the effects into a more complete physical description as well as better diagnosis of the plasma pedestal region. ITER operation with a Be/W wall, the influence of a metal wall on the H-mode pedestal and confinement is also an important topic of study

The pre-ELM pedestal profiles are found to be unstable with respect to Peeling-Ballooning modes, where the pedestal pressure gradient and edge current have reached a critical limit. However it is often observed that the critical gradients are reached long before the ELM occurs. Within the ITPA an activity has commenced to study the evolution of the pedestal pressure, density, temperature of ion and electrons as well as current density profile. Many European devices have joined this study and the topic has started to be addressed in the 2012 programme. As edge current profile measurements are not widely available, a diagnostic development task has been launched in 2012 for current profile diagnostics and will continue in 2013.

The L-H transition and the profile evolution towards good confinement H-mode are also important issues for ITER so we need to know how much input power is required to obtain H-mode and good confinement H-mode subsequently. The emphasis will be on the L-H trigger mechanism, The H-L back transition and the role of isotopes. The confinement scaling once steady H-mode has been achieved is also of upmost importance.

8.2 Objectives

The main objectives in this research area are:

- Understand the H-mode trigger mechanism
- Validate theories and models of L-H and H-L transitions
- Study H=1 access dependence and confinement scaling with fuel species (H/He/D/T)
- Understand pedestal structure and its transport including the reliable measurements with high spatial and temporal resolution of key uncertain plasma pedestal parameters with particular emphasis on the edge current density diagnosis
- Exploit synergies of H-mode study in different magnetic confinement devices (such as tokamak, stellerators) where meaningful

8.3 Work Description and Breakdown

8.3.1 Structure

The Research Area A08 consists of the following Projects:

- WP13-IPH-A08-P1: Construction of edge current density diagnostics (continues from 2012, WP12-IPH-A08-1)
- WP13-IPH-A08-P2: Multi device research to understand the pedestal stability through the study of the edge barrier evolution between ELMs (continues from 2012, WP12-IPH-A08-2)
- WP13-IPH-A08-P3: Access to and from high confinement modes in magnetic confinement devices for various fuel species (newly introduced).

8.3.2 Work Breakdown

- **WP13-IPH-A08-P1: Construction of edge current density diagnostics**

Direct measurements of the current density profiles with high temporal and spatial resolution.

- **WP13-IPH-A08-P2:Multi device research to understand the pedestal stability through the study of the edge barrier evolution between ELMs**

The H-mode pedestal in type I ELMy H-mode plasmas is thought to be limited by finite peeling ballooning (PB) MHD stability which limit the achievable pressure gradient for a given pedestal width. Pedestal width measurements are now well established.

Predictions of the pedestal performance in ITER depend on both accurate measurements of the pedestal properties in existing devices as well as the validity of the PB theory. Linear stability analysis codes have been developed over the last decades with Mishka and ELITE as two of the most advanced codes.

However some of the experimental ingredients to test the PB stability for a wide range of plasma parameters and devices are missing. Therefore a definite test of the PB stability is challenging because of either uncertainties or absence of plasmas pedestal parameters. Key parameters to measure with a spatial resolution of better than 1% of the plasma minor radius and a temporal resolution of ~1ms are:

1. Pedestal density and temperature of both electrons and ions. Thanks to an impressive development in electron profile diagnostics over the past decade these are well documented in most devices. The ion profiles are generally less well covered but the available measurements are still satisfactory.
2. Equally well resolved pedestal impurity and/or Zeff profiles are needed for the determination of the ion density profiles and the estimation of the edge current density if it is derived from the bootstrap current.
3. Better still is it to have direct measurements of the current density profiles again with high temporal and spatial resolution. Some pioneering work is ongoing, but this is an area where most of the development is required.
4. A poloidal and radial profile of the neutral particle density in the SOL as well as the pedestal region is required as it influences the edge density structure.
5. Turbulence measurements of n, T and B, covering the entire pedestal region. The extent of the pedestal region is thought to be set by a region of suppressed turbulence. Correlation length and fluctuation amplitude measurements are required to couple the turbulence characteristics and radial extent to the kinetic and current profile measurements
6. Next, an accurate determination of the magnetic equilibrium is needed for the stability analysis. This requires good magnetic diagnostics, generally available in most modern tokamaks, as well as an equilibrium solver that can be constrained with measured kinetic profiles as well as estimates or, better, measurements of the current density.

7. Finally, experimental profile measurements and equilibrium solvers typically have an accuracy of 1-2% of the minor radius in the position calibration of the profiles and the location of the last closed flux surface, respectively. For the stability analysis an accuracy of well within 0.5% in the relative position of the measured profiles and magnetic equilibrium is required. For this reason additional edge modelling is used to lock the kinetic profiles to the equilibrium.

The test of the PB theory requires static stability analysis of the 'unstable' pre-ELM experimental profiles as well as dynamic analysis of the evolution of the individual spatially resolved ne, Te, ni, Ti, pe, pi, Jped, and zeff . The static analysis determines the closeness of experimental profiles to the PB stability boundary, while the dynamic analysis shows the development timescales of various plasmas properties. The latter gives indicators as to which plasma parameter saturate first and which parameter determines the crossing of the stability boundary and subsequent occurrence the ELM.

- **WP13-IPH-A08-P3: Access to and from high confinement modes in magnetic confinement devices for various fuel species**

The main objectives identified are to understand the H-mode trigger mechanism to the access to steady ELMy H-mode with regular ELMs and H98(y,2)≈1 for various fuel species.

L-H and H-L transition; validation of theories and models. Studies should explicitly aim at validating existing theoretical or empirical models of the transition or underlying physical mechanisms contributing to it. The trigger mechanism that drives rotation in the pedestal remains to be resolved (Reynolds stress, ion orbit loss, Stringer spin-up, neutrals). Improved predictive capabilities will require the availability of sophisticated computational models that assemble the effects into a more complete physical description. This demands a focussed effort on the theoretical understanding as well empirical modelling for the L-H and H-L transitions. Perform L-H vs. H-L dedicated experiments on various European magnetic confinement devices (tokamaks and stellerators) including detailed measurement of:

- local radial profiles as rotation and Er, including kinetic effects
- poloidal and toroidal asymmetries
- correlations in turbulence
- isotope effects
- magnetic configuration effects:

H=1 access dependence of fuel species (H/He/D/T) Access to steady ELMy H-mode with regular ELMs and H98(y,2) ≈ 1 is important for ITER in order to achieve a stable H-mode without large Pa fluctuations. So far, the H=1 access as a function of fuel species has not been studied in great detail. As physics of isotope effects remains as open question and crucial for the initial low activation ITER operations, perform the physics study of the access to so-called H=1 operation for different fuel species (H/D/HE/T) obtained at a certain fraction above PL-H under various conditions in European magnetic confinement devices (tokamaks and stellerators).

8.3.3 JET related activities

No JET related activities are meant to be implemented under this Task Agreement. JET related activities are implemented under EFDA Art.6. However some JET activities can be mentioned for information in this TA when they are closely related to the activity implemented under Art.5. JET data collected under the JET part of the EFDA WP can be brought together with other data under this TA when relevant for the progress of the work or used in multi- machine modelling activities under Art.5.

8.4 Scientific and Technical Reports

8.4.1 Reports

Report of achievements under Baseline Support: At the end of the Task Agreement during a Final Review Meeting the Task Coordinator - Project Leader shall present a report on activities under the Task Agreement. The EURATOM financial contribution will be made through the usual procedures for Baseline Support through the Contract of Association.

Report of achievements under Priority Support (Final Reports): Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report will be prepared by the Task Coordinator and submitted to the EFDA Leader. Each participating Association will have to report to the Project Leader on the degree to which the Deliverables have been achieved. The Project Leader will collect the Associate contributions into the final report for Priority Support activities addressing the associated Deliverables defined. The EURATOM financial contribution will be made after approval of these reports by the EFDA Leader.

8.4.2 Milestones

1. June-July 2013: Submission of Interim Report for each Project (Activity) to EFDA Responsible Officer. Reports provided by each Task Coordinator and collected and submitted by Project Leader.
2. Final Review Meeting: coordinated presentation of the results of the theoretical and experimental work.
3. December 2013: Final Report sent to EFDA Leader

8.5 Deliverables

Activity	*Priority Support Deliverables*
WP13-IPH-A08-P1	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Physics study 1. Demonstrate feasibility of the diagnostic system including obtaining the necessary temporal and spatial resolution 2. Construction of edge current density diagnostics. 3. Calibration and validation of the measurement
WP13-IPH-A08-P2	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Physics Study 1. Multi device study of the pedestal profile dynamics of electron and ion P, T, n and J in type I ELMy H-modes.

	2. Exploitation of new diagnostic capabilities developed under A08-P1. 3. Use of the obtained experimental pedestal profiles to test theory(for example PB) and linear stability analysis 4. Isotope, low and high impurity effects on the pedestal evolution and stability.
WP13-IPH-A08-P3	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Physics study 1. Study on L-H/H-L-transitions including their dynamics on various magnetic confinement devices (tokamaks and stellerators) explicitly aiming at testing existing theoretical or empirical models or underlying physics mechanisms. 2. Study of confinement scaling and H=1 access dependence on fuel species (H/He/D/T) including the role of low and high Z impurities.

9. Fast Particles (Task Agreement WP13-IPH-A09)

9.1 Introduction

This work in this area is motivated by the desire to address such questions as:

• What will be the fast particle stability properties of a burning plasma? Steady-state amplitude saturation or explosive nonlinear evolution?

• What will be the consequences of these instabilities? Moderate fast redistribution (changes to heating/current/stability) or extensive transport and loss (concern for first wall)?

• How will we diagnose the fast ions in ITER?

9.2 Objectives

Building upon the strengths within the EFDA Associations, two clear programmatic goals have been defined and form the basis of the two projects within the area of fast particles:

- To understand and predict the alpha particles behaviour in a burning plasma
  - Quantify a potential fast ion losses in ITER to allow confident performance predictions based on theoretical models expandable to ITER relevant regimes and assessment of risks such as wall loading in future devices.
  - Understand and separate the underlying processes responsible for anomalous levels of fast ion diffusion reported at high power. Assess potential implications for the current drive efficiency and location of driven current.
  - Perform cross machine comparison of above topics
- To be able to diagnose fast ion behaviour in ITER
  - Share the technical expertise among association to maximise exploitation of presently available diagnostics as well as identifying needs and supporting developments of innovative concepts for better understanding and diagnosis of the fast ion behavior on ITER.

9.3 Work Description and Breakdown

9.3.1 Structure

The Research Area A09 consists of the following Projects:

- WP13-IPH-A09-P1 Behaviour and consequences of alpha-particle driven modes in ITER (continues from 2012, WP12-IPH-A09-1)
- WP13-IPH-A09-P2 Diagnosing Fast Ion Behaviour in ITER (continues from 2012 WP12-IPH-A09-2) ➔ includes synthetic diagnostic (modelling)

9.3.2 Work Breakdown

- **WP13-IPH-A09-P1: Behaviour and consequences of alpha-particle driven modes in ITER**

The fast ion distribution obtained in ITER will be different to that attained in all other present day devices, bar that obtained during the D-T operation of JET. There are open questions about the behaviour and consequences of fast ion driven modes in ITER based on the observed behaviour of modes driven by super-Alfvénic slowing down beam ions which exhibit a highly nonlinear evolution.

- **WP13-IPH-A09-P2: Diagnosing Fast Ion Behaviour in ITER**

Despite being the first machine to ignite a burning plasma in which the D-T fusion produced alpha particles heat the plasma in a self-sustaining way, no fast ion loss diagnostics are foreseen in the ITER baseline plan.

9.3.3 JET related activities

No JET related activities are meant to be implemented under this Task Agreement. JET related activities are implemented under EFDA Art.6. However some JET activities can be mentioned for information in this TA when they are closely related to the activity implemented under Art.5. JET data collected under the JET part of the EFDA WP can be brought together with other data under this TA when relevant for the progress of the work or used in multi- machine modelling activities under Art.5.

9.4 Scientific and Technical Reports

9.4.1 Reports

Report of achievements under Baseline Support: At the end of the Task Agreement during a Final Review Meeting the Task Coordinator - Project Leader shall present a report on activities under the Task Agreement. The EURATOM financial contribution will be made through the usual procedures for Baseline Support through the Contract of Association.

Report of achievements under Priority Support (Final Reports) : Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report will be prepared by the Task Coordinator and submitted to the EFDA Leader. Each participating Association will have to report to the Project Leader on the degree to which the Deliverables have been achieved. The Project Leader will collect the Associate contributions into the final report for Priority Support activities addressing the associated Deliverables defined. The EURATOM financial contribution will be made after approval of these reports by the EFDA Leader.

9.4.2 Milestones

1. June-July 2013: Submission of Interim Report for each Project (Activity) to EFDA Responsible Officer. Reports provided by each Task Coordinator and collected and submitted by Project Leader.
2. Final Review Meeting: coordinated presentation of the results of the theoretical and experimental work.
3. December 2013: Final Report sent to EFDA Leader

9.5 Deliverables:

Activity	*Priority Support Deliverables*
WP13-IPH-A09-P1	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold

	the activity coordination and progress meetings when necessary. I. Physics study 1. Quantified measurements of fast ion redistribution due to measured fast ion driven modes supported by interpretive modelling which is capable expanding to the ITER operating conditions. 2. Benchmarking of the existing code modelling (such as HAGIS, ASCOT etc) for ITER relevant scenarios as well as existing experimental data.
WP13-IPH-A09-P2	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Physics Study 2. Designed and tested diagnostics for fast ions, capable of delivering information on the fast ion behaviour on ITER. 3. Modelling of predicted energy, time, space, signal to noise ratio in gamma, neutron, CTS NPA FI diagnostics on ITER.

10. Particle Transport Fuelling and Inner Fuel Cycle Modelling (Task Agreement WP13-IPH-A10)

10.1 Introduction

Understanding and controlling particle and impurity transport is very important for a variety of reasons. Fuelling of tokamaks with gas puffing or pellets relies on details of the particle transport from the SOL through the edge into the very core. While fuel ions should be refuelled, ash and impurity ions should leave the core plasma. An integrated view of fuelling and pumping systems and other actuators (source and sink terms) of the inner fuel cycle is essential to make the next step in modelling and predictive plasma control.

The penetration of impurities and their profiles impacts on the possibility of operational scenarios which rely on impurity seeding in the edge for radiative pooling of this region.

Understanding of particle transport processes, the parametric and geometric (especially with respect to poloidal angle) dependence of these and the transport behaviour under different heating schemes needs a consistent effort. The inner fuel cycle including a detailed balance of particle and impurity transport as well as a characterization of in vessel inventories, pumping capabilities and plasma wall interactions is a large and in many aspects not yet fully addressed field, where plasma physics and engineering problems meet. It has been recognized that in order to progress very specific parts of the larger problem have to be addressed.

Fuelling strategies for ITER demand knowledge of particle transport in the edge/SOL region. The interaction between transport events (blobs/ELM filaments) and the wall with the interplay on impurity sources should be understood so far as to allow predictive modelling. This area will connect edge turbulence with SOL physics.

10.2 Objectives

The main objectives are:

- Develop a consistent and physics-based description of all fuel cycle elements (actuators, sub-systems, sink and source terms).
- Support ITER with summarizing knowledge about fuelling cycle (fuel cycle simulator).
- Develop a module-based SOL turbulence code to assist particle transport, source and sink terms.

10.3 Work Description and Breakdown

10.3.1 Structure

The research area A10 consists of following activities:

- WP13-IPH-A10-P1 Comprehensive investigation of fuelling and pumping operation properties of tokamaks (continues from 2012, WP12-IPH-A10-1)
- WP13-IPH-A10-P2 Development of a turbulent SOL code (newly introduced)

10.3.2 Work Breakdown

- **WP13-IPH-A10-P1: Comprehensive investigation of fuelling and pumping operation properties of tokamaks**

It has been noted that operation of fuelling and pumping on fusion machines often relies on "kitchen recipe" style soft knowledge, often gained by trial and error. This project aims to set a validated knowledge base for the design and operation of these systems and to identify the most prominent interdependencies between operational parameters as well as control and variability of system performance on one side and the relevant, most influential plasma parameters on the other side. Ultimately, it will result in a predictive modelling of the complete fuel cycle with all its actuators in the four subsystems plasma chamber - divertor pumping – tritium plant – fuelling, programmed in such a way that the outer fuel cycle can be included in a later stage.

- **WP13-IPH-A10-P2: Development of turbulent SOL code**

Codes used at present for calculating SOL properties and its interaction with plasma facing components and the first wall are fluid and transport codes assuming quiescent plasmas. The plasma in the SOL is turbulent and characterised by large fluctuation levels that even render the description by distinction between time averaged profiles and fluctuations difficult. No present code can address the large parameter variations across the SOL and magnetic field lines which span orders of magnitude in typical parameters which include effective mass, effective beta and resistivity.

10.3.3 JET related activities

No JET related activities are meant to be implemented under this Task Agreement. JET related activities are implemented under EFDA Art.6. However some JET activities can be mentioned for information in this TA when they are closely related to the activity implemented under Art.5. JET data collected under the JET part of the EFDA WP can be brought together with other data under this TA when relevant for the progress of the work or used in multi- machine modelling activities under Art.5.

10.4 Scientific and Technical Reports

10.4.1 Reports

Report of achievements under Baseline Support: At the end of the Task Agreement during a Final Review Meeting the Task Coordinator - Project Manager shall present a report on activities under the Task Agreement. The EURATOM financial contribution will be made through the usual procedures for baseline support through the Contract of Association.

Report of achievements under Priority Support (Final Reports): Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report will be prepared by the Task Coordinator and submitted to the EFDA Leader. Each participating Association will have to report to the Task Coordinator on the degree to which the deliverables have been achieved. The Task Coordinator will collect the Associate contributions into the final report for Priority Support activities addressing the associated milestones defined. The EURATOM financial contribution will be made after approval of these reports by the EFDA Leader.

10.4.2 Milestones

1. June-July 2013: Submission of Interim Report for each Project (Activity) to EFDA Responsible Officer. Reports provided by each Task Coordinator and collected and submitted by Project Leader.

2. Final Review Meeting: coordinated presentation of the results of the theoretical and experimental work.
3. December 2013: Final Report sent to EFDA Leader

10.5 Deliverables

Activity	*Priority Support Deliverables*
WP13-IPH-A10-P1	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Investigation of fuelling and pumping operation properties of tokamaks 1. Develop a physics-based understanding of the ITER divertor neutral gas exhaust 2. Simulations of plasma exhaust, taking into account the link between divertor plasma detachment, X-point MARFE formation under high density conditions. 3. Study the influence of fuelling parameters on core plasma composition close to ITER conditions 4. System integration of the fuel cycle
WP13-IPH-A10-P2	0. Project Leader work 1. Combine the Interim and Final Report for the Project (Activity) based on the Task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with Task Coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Development of turbulent SOL code 1. A 3D global turbulence SOL code module in simple geometry including sheath boundary conditions ready for benchmarking with 1D and 2D SOL fluid codes. 2. Defined standardized benchmark cases.

11. Operation with metallic plasma facing components including High Power ICRH (Task Agreement WP13-IPH-A11)

11.1 Introduction

When ITER will operate with a full metallic wall, restrictions will be imposed on the plasma operational space in order to ensure safe operation. This research area will first concentrate on studying the compatibility of plasma operation with the given metallic materials (W and Be) under normal and off-normal (disruptions, ELMs etc.) power load (=> melting/cracking) and particle load (=> erosion/cracking). Secondly, the possibility to expand the operational window by external impurity seeding will be investigated. Experiments in tokamaks with metallic walls (full W AUG) or limiting elements (TEXTOR, FTU), and in laboratory devices (plasma simulators facilities and ion/electron beam facilities) with associated modelling, fall in the scope of this topical area as benchmark with JET-ILW results. The third goal is to develop our understanding of the interaction between ICRF antenna/wave and plasma edge in term of wave coupling/absorption and RF sheaths in order to maximise the RF power output while minimising any impurity increase. Finally, as recently confirmed by results from JET-ILW unfuelled plasmas, heavy impurities can reach the plasma centre and deteriorate the plasma performance. Ways to control this impurity peaking and potential subsequent impurity accumulation should be further investigated both experimentally in tokamaks and through modelling.

11.2 Objectives

Study the influence of high and excessive heat flux to metallic plasma exposed surfaces:

- Quantify the role of plasma exposure on damage threshold during transients.
- Characterise morphology changes (fuzz/blisters) as function of temperature, impinging surface integrity and ultimately melt damage by repeated high heat flux exposures. flux and impurity composition (ITER-grade metallic surfaces (technical finish)).
- Develop surface integrity and ultimately melt damage by repeated high heat flux exposures.

Extend the operational window of high-Z PFCs by external impurity seeding:

- Optimize operational scenarios in respect of impurity control and confinement.
- Clarify PFC compatibility (e.g. influence of seeding impurity on wall materials).
- Quantify of W sputtering with and without impurity seeding (role of nitrogen vs. argon and neon).
- Use dual seeding techniques to induce radiative mantel in main chamber and cold divertor operation

Maximise ICRH Power in metallic environment:

- Mitigate impurity generation and heat loads at antennas. As a first step, this requires improving the understanding of RF sheaths both experimentally and theoretically. This includes improving diagnostics (or developing new ones), testing new concepts and advancing the non-linear theory of the RF-edge plasma interaction.
- Improve coupling by appropriate edge plasma / neutral gas pressure modifications, e.g. by gas injection, and development of related diagnostics.

Develop understanding behind High-Z impurity peaking and accumulation avoidance techniques

- Investigate the effect of ELM suppression techniques on high-Z impurities penetration and peaking
- Develop high-Z accumulation avoidance by means of central electron heating (ICRF, ECRF)
- Modelling of high-Z impurities transport and the effects of accumulation suppression
- Influence of the heating methods on the high-Z 2D asymmetry

11.3 Work Description and Breakdown

11.3.1 Structure

The Research Area A11 consists of the following Projects:

- WP13-IPH-A11-P1: Qualification of tungsten as plasma-facing material for the ITER divertor (continues from 2012, WP12-IPH-A11-1)
- WP13-IPH-A11-P2: Integrated scenarios high-Z PFCs power handling by external impurity seeding (continues from 2012, WP12-IPH-A11-2)
- WP13-IPH-A11-P3: High Power ICRH operation with metallic plasma facing components (continues from 2012, WP12-IPH-A11-3)
- WP13-IPH-A11-P4: High-Z impurity peaking control and accumulation avoidance (newly introduced)

11.3.2 Work Breakdown

- **WP13-IPH-A11-P1: Qualification of tungsten as plasma-facing material for the ITER divertor**

This project aims in the qualification of W as divertor material for the ITER divertor, in particular under impact of high transient heat and particle loads. The variation or reduction of the damage threshold of once damaged W armour material needs to be studies in order to set the technical damage threshold for operation properly. Moreover, the knowledge can be used for optimal plasma-facing design (castellation) and has direct impact on the new shaped W divertor foreseen for ITER. For day one ITER operation with a W divertor, also He-induced effects on W such as nano-structures or bubbles and their impact on the damage threshold are of particular interest and need to be investigated. Two work packages are proposed:

- ✓ Determine the reduced damage threshold of pre-damaged W plasma-facing components.
- ✓ Determine the impact of He-induced material defects on the performance of realistic W plasma-facing components.

- **WP13-IPH-A11-P2: Ways to extend the operational window of high-Z PFCs by external impurity seeding**

This project aims in the extension of the operational space with W as plasma-facing material. As impurity seeding is mandatory for divertor operation under ITER-relevant plasma conditions, particular emphasis is on plasma operation with seeding gases as radiator in the divertor. The use of nitrogen as seeding gas needs to be qualified for ITER in view of performance and plasma-wall interaction (formation of nitrides, volatile ammonia derivates), and compared to those with Ne or Ar seeding. Furthermore, modelling associated with impurity seeding needs to be benchmarked. Basically, two work packages are proposed:

- ✓ Explore and extend the operational space with N seeding and W plasma-facing components. Compare with Ar and Ne seeding.
- ✓ Study the plasma-surface interaction with N, Ar and Ne in term of material erosion, retention, surface modification and exhaust gases.

- **WP13-IPH-A11-P3: High Power ICRH operation with metallic plasma facing components**

In order to maximise ICRH power in ITER, several issues have to be tackled. Firstly, RF sheath effects (in term of heat loads and impurities generation) should be further investigated both experimentally on existing tokamaks and test facilities and theoretically, via modelling development. Secondly, if the effect of gas injection seems to have beneficial effect on the ICRF coupling, the technique is neither mature nor well understood. For both issues, the development of specific diagnostics is essential and should provide measurements of neutral pressure and RF and DC electric fields in front of antennas.

- **WP13-IPH-A11-P4: High-Z impurity peaking control and accumulation avoidance**

Heavy impurities can accumulate in the plasma centre and deteriorate the plasma performance. Ways to control the peaking and accumulation of impurities should be further investigated both experimentally and through modelling. The effect ELM mitigation techniques on the impurities penetration and peaking as well as the role of central heating should also be further assessed. The strong 2D asymmetry as recently observed on JET should be investigated also in other devices and confronted to the latest theory.

11.3.3 JET related activities

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11.4 Scientific and Technical Reports

11.4.1 Reports

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11.4.2 Milestones and Deliverables

1. June-July 2013: Submission of Interim Report for each Project (Activity) to EFDA Responsible Officer. Reports provided by each Task Coordinator and collected and submitted by Project Leader.
2. Final Review Meeting: coordinated presentation of the results of the theoretical and experimental work.
3. December 2013: Final Report sent to EFDA Leader.

11.5 Deliverables

Activity	*Priority Support Deliverables*
WP13-IPH-A11-P1	0. Project leader work 1. Combine the interim and final activity reports based on the task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with task coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Qualification of tungsten as plasma-facing material for the ITER divertor 1. Characterise W plasma-facing material damage threshold and its evolution under high and repeated heat fluxes (and plasma) exposures in different devices. 2. Benchmark material damage codes in view of ITER predictions (also for repeated melting) 3. Diagnostic development for better interpretation of power load data on W 4. Clarify relevance of W nanostructure (“fuzz”) formation for ITER grade W, technical surfaces under realistically high transient heat loads 5. MD simulation of W nanostructure formation (including with seeding gases)
WP13-IPH-A11-P2	0. Project leader work 1. Combine the interim and final activity reports based on the task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with task coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. Integrated scenarios of high-Z PFCs power handling by external impurity seeding 1. W divertor qualification with respect to plasma compatibility with impurity seeding and W erosion (N, Ar, Ne) 2. ERO benchmark Code validation for predictions of ITER divertor physics. 3. Quantification of nitrogen content in W material in seeded discharges and ammonia production. 4. Dual seeding techniques to induce radiative mantel in main chamber and cold divertor operation.
WP13-IPH-A11-P3	0. Project leader work 1. Combine the interim and final activity reports based on the task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with task coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary.

	I. High Power ICRH operation with metallic plasma facing components 1. Improved understanding of RF sheath by using appropriated diagnostics on tokamaks and test-facilities 2. Improved understanding of RF sheath phenomena through modelling 3. Understand processes responsible for ICRF coupling improvement during gas-puff, quantify edge plasma / neutral gas pressure modifications and develop related diagnostics
WP13-IPH-A11-P4	0. Project leader work 1. Combine the interim and final activity reports based on the task reports and submit them to the EFDA RO responsible for the Research Area. Communicate with task coordinators and highlight/report to EFDA the problems, delays and achievements in the project managed activity. Hold the activity coordination and progress meetings when necessary. I. High-Z impurity peaking control and accumulation avoidance 1. Investigate the effect of ELM suppression and mitigation techniques on high-Z peaking 2. Develop high-Z accumulation avoidance by means of central electron heating (ICRF, ECRF) 3. Quantitative modelling of high-Z impurities transport (peaking, accumulation), its effect on plasma properties and the role of different heating methods. 4. Study high-Z 2D asymmetry experimentally and by modelling (influence of the heating method, plasma response)