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Report

Evaluation of fuelling requirements and transient density behaviour in ITER reference operational scenarios

Evaluation of fuelling requirements and transient density behaviour in ITER reference operational scenarios
Task Agreement

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Rossini C.**	**06-Jul-2012:signed**	**IO/DG/DIP/POP**
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Reviewers	**Loarte A.** **Pitts R.**	**06-Jul-2012:recommended** **06-Jul-2012:recommended**	**IO/DG/DIP/POP/SD/PLC** **IO/DG/DIP/POP/SD/DPWI**
Approver	**Campbell D.**	**06-Jul-2012:approved**	**IO/DG/DIP/POP**
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Change Log				
Title (Uid)	***Version***	***Latest Status***	***Issue Date***	***Description of Change***
Evaluation of fuelling requirements and transient density behaviour in ITER reference operational scenarios (AG36ER_v1_2)	v1.2	Approved	06 Jul 2012	corrected the typo (Monte Carlos to Monte Carlo) in page 5 and clarified the issue of the responsible officers in page 9. It now says Contractor/DA Task Responsible Officer.
Evaluation of fuelling requirements and transient density behaviour in ITER reference operational scenarios (AG36ER_v1_1)	v1.1	Signed	03 Jul 2012	page 4 under 1.5 the duration should be 24 months instead of 18 months) and page 6 an "r" was missing in Barrier
Evaluation of fuelling requirements and transient density behaviour in ITER reference operational scenarios (AG36ER_v1_0)	v1.0	Signed	03 Jul 2012	Technical Specifications
Evaluation of fuelling requirements and transient density behaviour in ITER reference operational scenarios (AG36ER_v0_0)	v0.0	In Work	29 Jun 2012	

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Evaluation of fuelling requirements and transient density behaviour in ITER reference operational scenarios

Technical Specifications

	Version 1	Date: 19/06/2012
	Name	Affiliation
Author	**A. Loarte**	**POP**
Reviewers	**R. Pitts/D. Campbell**	**POP**
Approver	**D. Campbell**	**POP**

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1 Abstract

This task intends to provide a physics-based assessment of the fuelling requirements for ITER operational scenarios during stationary and transient phases together with that of the transient density behaviour and its influence on power and particle fluxes to plasma facing components (divertor power flux density and total power to the main wall) during these phases. This assessment will be performed by application of models capable of simulating the time dependent plasma behaviour in ITER from the core through the pedestal to the SOL/divertor, including extrinsic impurities injected for power flux control required for ITER operation with a W divertor. The assessment will include scenarios foreseen for active (DD/DT) and non-active (H/He) operation in ITER.

2 Background and Objectives

1.1 ITER operation requires effective fuelling of the core plasma for conditions in which neutral penetration through the scrape-off layer plasma is expected to reduce significantly the efficiency of core plasma fuelling by gas puffing. On the basis of present analysis for stationary conditions, pellet fuelling is foreseen to provide core fuelling of reference high Q_{DT} scenarios [1]. Fuelling of H-mode plasmas during the non-active phase with He plasmas remains challenging, as it has to rely solely on gas fuelling due to non-applicability of pellet fuelling for these plasmas [2].

1.2 Although present experiments point out to the importance of the transient phases (after H-mode transition, for instance) in the build-up of the stationary density profiles, no appropriate modelling exists to date for ITER of such transient phases. Similarly, the decrease of the plasma density after the H-L transition is a key parameter to determine the power fluxes to PFCs during this phase and the decrease of the alpha heating and thus of the plasma energy, for which only upper (worst-possible case) values have been evaluated for ITER and incorporated into the Heat and Nuclear Load specifications [3].

1.3 The objective of this task is to perform an assessment of the fuelling requirements and expected transient density behaviour for non-active, DD and DT ITER plasma scenarios. The assessment will include an evaluation of : a) the fuelling requirements for gas-puffing and pellet fuelling for a range of operational scenarios for stationary and transient phases, b) a sensitivity analysis of these requirements to assumptions regarding edge and core plasma transport and pellet deposition (including the effects of the loss of pellet deposited particles by ELMs), and c) the power fluxes to PFCs during transient L-H and H-L phases and their control by the injection of extrinsic impurities with a W divertor.

1.4 The Tenderer, awarded and having signed the Contract shall be denominated as the Contractor.

1.5 The duration of the Task Agreement will be 24 months from the date of the signature by the last of the contracting parties, with the option of extensions to be agreed and defined by both parties. The ITER Organization explicitly reserves the right to decide whether or not to extend the Contract.

3 Scope of Work

The work in this task involves modelling of plasma energy and particle transport, particle sources and pumping as well as of the interaction of the plasma with PFCs in ITER for stationary and transient phases of ITER operational scenarios in the active and non-active phases. This requires models capable of simulating the core and edge plasma density evolution in the conditions expected in ITER including core particle sources from pellet injection, as well as those from neutrals recycled at the main chamber wall and divertor targets including their ionization in the SOL and divertor plasma. The studies carried out in this task require a coupled model of the core plasma with the pedestal plasma and the scrape-off layer/divertor capable of simulating consistently the time dependent interaction between these three regions of the plasma for transient phenomena down to the millisecond timescale. The models applied to ITER should have been previously utilized to model similar physics processes and compared with measurements from existing experiments, which shall include :

a) An adequate description of energy and particle transport in the core plasma including neoclassical and both theory-based and empirical models of anomalous transport for hydrogenic ions, helium and extrinsic impurities.
b) Time dependent modelling of the particle source in the main plasma by pellet injection including ablation and the effect of drifts.
c) Time dependent model of the pedestal plasma and edge transport barrier for energy and particles (hydrogenic ions, helium and extrinsic impurities) including the self-consistent triggering of ELMs and of their effects on the edge energy and particle transport.
d) Time dependent model of the edge and divertor plasma conditions (including a Monte-Carlo description of the neutrals) including hydrogenic ions, helium and extrinsic impurities and an appropriate description of neutral pumping by divertor cryo-pumps.

Modelling of W impurity behaviour as well as of the power fluxes to PFCs associated with plasma movements during the transients phases are outside of the scope of this task. The modelled plasma evolution during the transient phases will be utilized by the ITER Organization to evaluate the influxes of W from the divertor into the core plasma as well as the power fluxes on the first wall associated with radial movement of the plasma during these phases (caused by the changes of plasma energy) with separate models.

The study assessment will provide modelling results for :

i) Fuelling requirements for gas-puffing and pellet fuelling for a range of operational scenarios in H/He and D/DT for stationary and transient phases including L-mode, H-mode, post L-H and H-L transition plasmas.

ii) A sensitivity analysis of these requirements to assumptions regarding edge and core plasma energy and particle transport, pellet deposition (including the effect of drifts and of the loss of pellet deposited particles by ELMs), models of the L-H and H-L transitions (i.e. global versus local models) and the effects of controlled ELMs on the pedestal plasma.

iii) Extrinsic impurity seeding requirements to maintain control of the power fluxes to PFCs during stationary and slowly varying phases of the discharge (flat-top and current ramp up/down) and an evaluation of the transient power fluxes to PFCs during L-H and H-L phases and their possible control by the varying the rate of injection of extrinsic impurities with a W divertor during these phases.

The analysis will be performed for a range of plasma scenarios including the ITER reference inductive scenario at 15 MA for Q_{DT} =10 operation as well as lower current/high performance scenarios aiming at long pulse Q_{DT} = 5 with a W divertor. Other plasma scenarios regimes such as those foreseen in the initial phase of operation (i.e. 7.5 MA q_{95} =3 and I_p < 7.5 MA H-modes) will also be studied. A range of assumptions regarding pellet and ELM dynamics, pedestal parameters and core plasma transport for particles/impurities and energy based on experimental results and expectations for ITER will be considered in the simulations.

4 Estimated Duration

Starting date:	Signing of contract
Completion date:	24 months from the date of signature

5 Work Description

The work involved in this task involves modelling of the following physics processes that need to be assessed self-consistently for ITER :

1) Fuelling of the ITER plasma scenarios with gas fuelling and pellet fuelling during the various phases with emphasis in determining the range of applicability of gas fuelling to maintain the plasma density in L-mode and H-mode (within the various phases of each scenario and for flat top conditions) with a self-consistent model of the core plasma, pedestal plasma in the Edge Transport Barrier and SOL and divertor plasma/neutrals and divertor neutral pumping.
2) Sensitivity of the modelled fuelling requirements to assumptions on SOL, pedestal and core transport, pellet deposition (including drift and expulsion of pellet particles by ELMs) and effects of controlled ELMs on the edge plasma and of their associated particle outfluxes.

3) Modelling of core and edge plasma density evolution during slow (current ramp up/down) and fast confinement transients (L-H and H-L transitions) and of the associated power fluxes to PFCs with a self-consistent SOL/divertor plasma. This should include the evaluation of the feasibility of edge/core density control during these transients within the fuelling and pumping capabilities available in ITER.
4) Modelling of impurity seeding required for maintaining divertor power fluxes within the ITER engineering limits for stationary phases and slow transients and an evaluation of the possibility of the application of impurity seeding to control divertor power fluxes during transient L-H and H-L transitions.

The plasma conditions to be modelled will be selected from the scenarios below (to be defined in detail in the final contract specifications). The selection will be guided towards determining the range and limitations of the application of gas fuelling during the ramped and stationary phases of the scenarios below. This is expected to be determined by the value of the plasma density which is directly correlated with the plasma current for H-mode plasmas :

a) 15 MA/5.3T reference $Q_{DT} = 10$ H-mode plasma in DT.

b) 8-9 MA/5.3T reference $Q_{DT} \geq 5$ steady-state plasma in DT.

c) 12.5 MA/5.3T plasma hybrid scenario conditions for $Q_{DT} \geq 5$ with burn duration longer than 1000s in DT.

d) 7.5 MA/2.65T H-mode plasma in H, He, DD and DT, which is the foreseen scenario for development of ELM control methods in the non-active phase.

e) 10MA/5.3T H-mode plasma as representative of an intermediate development of the scenarios in ITER in from d) to a) that will be carried out in the non-active or active phase depending on H-mode access power requirements.

f) If gas fuelling of the 7.5 MA/2.65T H-mode plasma proves insufficient for the required plasma density, a lower I_p (2.65T) H-mode plasma in H, He, DD and DT will be studied.

The study will include :

i) Time dependent core, pedestal and 2-D edge plasma modelling (fluid approximation for plasma and impurities and Monte-Carlo modelling for neutrals) for selected L-mode, H-mode phases with controlled ELMs and transient L-H and H-L phases of the above a-f) scenarios.

ii) An exploration of the fuelling requirements for these selected cases by application of gas and pellet fuelling (within the specified design limits for ITER). This should include a sensitivity analysis to edge/core transport assumptions, pellet particle deposition and loss by the induced pellet-triggered ELM, the effect of controlled ELMs on particle outfluxes. For He

plasmas, the evaluation of plasma dilution by hydrogen pellets required for ELM control in H-mode regimes will be assessed.
iii) An evaluation of the density control level achievable by application of the ITER gas and pellet fuelling and pumping capabilities in the transient phases for a selected number of cases within scenarios a)-f) above. This should include a sensitivity analysis to assumptions on plasma/neutral recycling including the enhanced absorption or delayed release of particles stored on the PFCs during the confinement transients (L-H and H-L).
iii) An evaluation of the extrinsic impurity seeding requirements to maintain the divertor power flux under the 10 MWm^{-2} ITER divertor design limit for stationary and slow transient phases (current ramp-up/down) in the a)-f) scenarios above.
iv) An assessment of the power fluxes to PFCs during fast confinement transients (L-H and H-L) and their possible control by extrinsic impurity seeding. This should include a sensitivity study to the assumptions regarding changes of the SOL/edge/core transport across these transitions and the level of density evolution control that can be achieved in ITER from the studies under iii) above.

Before carrying out the integrated modelling studies described above, the models to be used in the task will be compared with existing reference stationary SOL/divertor plasma simulations provided by the ITER organization. A comparison for edge transients will also be carried out for a selected number of cases with simplified assumptions (i.e. sudden increase of the edge power flux, sudden increase of edge transport, etc.) to be also provided by the ITER Organization. The detailed conditions and scope of the consistency check will be agreed in detail between the ITER Organization Task Responsible Officer and the Contractor.

The ITER Organization will provide a set of reference equilibria and plasma parameters for the plasma conditions in a)-f) above to the Contractor to be used as a guideline for the studies.

The choice and range of modelling assumptions to be explored from those described above will be agreed in detail between the ITER Organization Task Responsible Officer and the Contractor.
The number of cases to be modelled will be agreed in detail between the ITER Organization Task Responsible Officer and the Contractor.

6 Responsibilities (including customs and other logistics)

ITER:

ITER will provide the needed information and access to the adequate ITER files for executing this work, such as geometry of PF coils, plasma facing components, equilibrium and reference plasma parameter files, etc., guidance regarding specifications for fuelling schemes (gas and pellets), specification for ELMs, transport assumptions, etc., as required by the implementation plan.

Contractor:

The Contractor appoints a responsible person, the Contractor's Responsible (C-R), who shall represent the Contractor for all matters related to the implementation of this Contract.

The contractor will provide results according to the scope of the work outlined above and will fulfil the implementation plan and conditions of present contract.

7 List of deliverables and due dates (proposed or required by ITER)

In each subtask, the deliverables are reports describing the statement of each problem, input data and approximations used in the studies and the results obtained. Reports will be delivered at approximately 6 months, 12 months, 18 months, and 24 months from the date of signature of the contract. Details on deliverables and priorities of the subtasks will be agreed between the Contractor/DA Task Responsible Officer and the ITER Organization Task Responsible Officer.

Four progress meetings will be organized as required to exchange information and to review the intermediate results of the task. In addition, two specialized meetings may be required to resolve technical issues related to the comparison of the models used in the task with existing results from the ITER Organization and on the modelling assumptions relevant to the ITER modelling in the this task.

8 Acceptance Criteria (including rules and criteria)

Quality plan shall provide work breakdown and list of check points at which ITER should review status of the work and make a decision for its continuation. ITER will also participate in reviewing the results of test and analysis.

The Contractor shall submit a draft of the deliverables foreseen in the Scope at completion of the work.

The IO-TRO shall review the deliverables and reply, within the time specified in the 15 following days, a commented version of the deliverables.

The Contractor shall perform all the necessary modifications or iterations to the deliverables and submit a revised version.

Contract will be considered completed after ITER has accepted the last deliverable.

9 Specific requirements and conditions

In response to this call for tender the following shall be provided:

- Schedule of deliverables
- Cost breakdown
- Payment schedule
- Profile of key personnel involved in execution of the work activity
- Implementation Plan for execution of the contract to demonstrate how the work will comply with the requirements of this specification. The Implementation Plan shall include list of points which need ITER to check and/or approve for continuation of the work

The official language of the ITER project is English. Therefore all input and output documentation relevant for this Contract shall be in English. The Contractor shall ensure that all the professionals in charge of the Contract have an adequate knowledge of English, to allow easy communication and adequate drafting of technical documentation. This requirement also applies to the Contractor's staff working at the ITER site or participating to meetings with the ITER Organization.

Documentation developed shall be retained by the contractor for a minimum of 5 years and then may be discarded at the direction of the IO.

The work shall require the presence of the Contractor's personnel at the site of the ITER Organization, Cadarache, 13115 St Paul-lez-Durance, France, for short time, for the purpose of meetings and data gathering.

For all deliverables submitted in electronic format the Contractor shall ensure that the release of the software used to produce the deliverable shall be the same as that adopted by the ITER Organization.

10 Work Monitoring / Meeting Schedule

Contractor shall also propose a list of meetings with ITER for progress monitoring in agreement with schedule proposed in § 4. At least the following meetings should be foreseen.

Scope of meeting	Point of check/Deliverable	Place of meeting
Kick-off contract	Work program	Contractor site, ITER site, or video conference
First progress meeting	Checking progress Submission of 1st report	Contractor site or ITER site or video conference
Second progress meeting	Checking progress Submission of 2nd report	Contractor site or ITER site or video conference
Third progress meeting	Checking progress Submission of 3rd report	Contractor site or ITER site or video conference
Closing contract meeting Contract completion	Checking final report	ITER site or video conference

11 Payment schedule / Cost and delivery time breakdown

Estimated cost of the contract is 0.9 PPY

12 Quality Assurance (QA) requirement

Prior to commencement of any work, a Quality Plan must be provided to IO for approval. This is a separate document which comprises:

1) a workplan with proposed time schedule and agreed preliminary dates for progress meetings,

2) a statement of those involved in the activity and their approximate role and contribution in time,

3) a statement of what work will be subcontracted and who will responsible for checking this.

13 References / Terminology and Acronyms

In the following table denominations and definitions are given of all the actors, entities and documents referred to in this Specification, together with the acronyms used in this document.

Denomination	Definition	Acronym
ITER Organization	For this Contract the ITER Organization	IO-
ITER Organization Responsible Officer	Person appointed by the ITER Organization with responsibility to manage all the technical aspects of this contract	IO-RO
Contractor	Firm or group of firms organized in a legal entity to provide the scope of supply.	C-
Contractor's Team	The Contractor plus all the sub-contractors/consultants working under its responsibility and coordination for the performance of the contract	C-Team
Contractor Responsible	The person appointed (in writing) by the legally authorised representative of the Contractor, empowered to act on behalf of the Contractor for all technical, administrative legal and financial matters relative to the performance of this contract	C-R
ITER Organization Task Responsible Officer	Person delegated by the IO-RO for all technical matters, but limited to one specific task order	IO-TRO
Contractor Task Responsible Officer	Equivalent to the IO-TRO in the Contractors team.	C-TRO

Referenced literature

[1] Kukushkin, A.S., et al., Jour. Nuc. Mat. **415** (2011) S497.

[2] Kukushkin, A.S., et al., Proc. 23rd Fusion Energy Conference, Daejeon, 2010, ITR/P1-33.

[3] Heat and Nuclear Load Specifications (2LULDH)