Evaluation of runaway generation mechanisms and current profile shape effects on the power deposited onto ITER plasma facing components during the termination phase of disruptions

Technical Specifications

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1 Purpose

The purpose of this contract is to acquire the services of one Plasma Physicist to improve the physics basis for the evaluation of the integrated power fluxes to plasma facing components (PFCs) deposited by runaway electrons during plasma disruptions in ITER. This assessment will be performed by application of simplified models capable of simulating the current profile evolution of the plasma self-consistently with the generation of runaway electrons. The assessment will include ITER scenarios with plasma currents up to 15 MA and a range of assumptions concerning the generation mechanism for runaway electrons, in particular those expected during DT operation.

2 Scope

2.1. Due to the high plasma current at which ITER will operate, generation of large runaway plasma currents is expected during disruptions [Hender 2007]. The power fluxes expected on PFCs during the termination of these runaway plasmas are expected to cause, for the worst cases, melting of the first wall Be PFCs in ITER to a depth of few mm [Maddaluno 2003].

2.2. The magnitude of the integrated power fluxes deposited by runaway electrons on PFCs can be significantly increased above those expected from their plateau kinetic energy alone by the conversion of the magnetic energy of the runaway plasmas into runaway electron kinetic energy [Loarte 2011, Martín-Solís 2013]. This energy conversion process affects not only the magnitude of the runaway energy deposited on the PFCs but also the timescale over which these fluxes are deposited. Accurate modelling of the total energy balance and of the power fluxes deposited by runaways on PFCs in ITER requires an appropriate description of the current profile evolution at the runaway plateau formation and during the termination phase.

2.3. The objective of this contract is to perform an assessment of the expected runaway power fluxes onto ITER PFCs for non-active, DD and DT ITER plasma scenarios. The assessment will include an evaluation of : a) the effects of the type of mechanism for the generation of the primary runaway source, current quench rate, post-thermal quench plasma conditions and possible losses of runaways in the current quench phase on the kinetic and magnetic energy of the runaway plateau plasmas in ITER, b) an assessment of the power fluxes deposited by runaways on PFCs in ITER and of their timescales for the runaway plateau plasmas in a) for a range of ohmic plasma conditions and runaway loss characteristics (both spatial and temporal).

The work in this Contract involves modelling of the formation of runaway plateau plasmas in ITER and of their termination and the evaluation of the total power fluxes that will be deposited on the plasma facing components by runaway electrons and by the residual ohmic plasma and of the timescales for this deposition. This requires modelling of the ohmic and runaway plasma current profile evolution from the thermal quench to the runaway termination as well as of the evolution of the magnetic, thermal and kinetic energy of the plasma during this phase. The purpose of this study is to provide an initial assessment of the expected runaway power fluxes over a large range of initial (after-quench) plasma conditions in ITER and runaway production and loss assumptions. From the results of the studies in this contract, few conditions will be selected for detailed modelling for ITER with sophisticated models that include the required details of coil geometry, etc. These detailed modelling studies are outside the scope of this contract.

The assessment in this contract provides modelling results for the runaway formation and power fluxes deposited on PFCs during runaway termination. The two subtask/deliverables in this contract are:

i) Subtask 1 –Deliverable 1. Report on runaway plateau formation and dependence on modelling assumptions in ITER.

This report will provide an assessment of the formation of runaway plasmas and their characteristics (runaway plateau current level, runaway kinetic energy and current profile peaking) for a range of assumptions regarding the ITER pre and post thermal quench plasma, current quench timescale, primary runaway generation mechanism and possible losses of runaways during the initial phase of the current quench.

ii) Subtask 2 –Deliverable 2. Report on power fluxes to ITER PFCs and timescales during runaway plateau termination and dependence on modelling assumptions.

This report will provide an assessment of the total deposited power and energy onto ITER PFCs and their timescale during the formation and termination of the runaway plasmas for a range of assumptions regarding the loss processes leading to runaway plasma termination.

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. 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.

3 Definitions

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. Other terminology used is standard in the field of disruption and runaway electron physics.

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

4 References

[Hender 2007] T.C. Hender et al., Nucl. Fusion **47** (2007) S128

[Loarte 2011] A. Loarte et al., Nucl. Fusion **51** (2011) 073004

[Maddaluno 2003] G. Maddaluno et al., J.Nucl.Mater. **313-316** (2003) 651

[Martín-Solís 2013] J.R. Martín-Solís et al., "Inter-machine comparison of the termination phase and energy conversion in tokamak disruptions with runaway current plateau formation and implications for ITER", to be submitted to Nucl. Fusion

5 Estimated Duration

Starting date: Signing of contract.
Completion date: 12 months from the date of signature.

Number of working days required to complete the work-scope within the 12-month period : 24 days

6 Work Description

The assessment will be performed by application of simplified models capable of simulating the current profile evolution of the plasma self-consistently with the generation of runaway electrons, and induced currents in the vacuum vessel, from the thermal quench to the runaway plateau termination in ITER disruptions for a range of scenarios from those described below. In these simulations, movement of the plasma column during the disruption thermal and initial current quench and runaway termination will not be considered.

For subtask 1, an assessment of the formation of runaway plasmas and their characteristics (runaway plateau current level, runaway kinetic energy and current profile peaking) will be evaluated for the following assumptions :

i) A range of post-thermal quench plasma conditions (n_e) and impurity compositions (n_Z) leading to current decay rates consistent with acceptable forces on the ITER vessel and in-vessel components for each pre-disruptive current level studied.

ii) A range of assumptions regarding impurity radiation during the current quench phase including corona equilibrium will be considered.

iii) Several primary runaway generation mechanisms will be considered. These will include Dreicer generation as well as other mechanisms expected to play a role in ITER (hot tail, fast electrons produced by T decay, activation of in-vessel components, etc.). The key parameters (from i-ii) leading to runaway generation for the various primary runaway generation mechanisms will be identified.

iv) Several levels of runaway losses during the initial phases of the current quench will be considered.

For subtask 2, an assessment of the power fluxes on ITER PFCs and of their timescales during runaway plateau termination will performed for a relevant set of runaway conditions selected from subtask 1. This will include:

i) A range of assumptions regarding the overall timescale of runaway loss as well as the “type” of runaway loss event, e.g. the runaways are lost in a single event with a given loss timescale or in a series of very short events spaced in time over a given time interval.

ii) A range of assumptions regarding the spatial characteristics of the runaway loss event, e.g. the runaways are lost at a uniform rate across the runaway beam cross section or dominantly from a particular region of this cross section.

The plasma conditions to be modelled will be selected from appropriate time-slices of the scenarios below, to be defined in detail by discussions between the Contractor Responsible Officer and the ITER Organization Responsible Officer. The selection will be guided towards determining the range of power fluxes to PFCs and their timescales during the termination of runaway plateau plasmas in ITER and possible mitigation strategies by influencing plasma parameters during the initial current quench and the runaway termination :

a) 15 MA/5.3T reference $Q_{DT} = 10$ scenario in DT.

b) 9 MA/5.3T reference $Q_{DT} \geq 5$ scenario in DT.

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

d) 5.0 and 7.5 MA/5.3T H-mode plasma scenario representative of initial H-mode operation at high field in DT.

e) 5.0 and 7.5 MA/2.6 T H-mode plasma scenario representative of initial H-mode operation in H, He, DD, and DT, which is the foreseen scenario for development of ELM control methods in the non-active phase.

The present technical specification description defines the overall contents of the two subtasks/deliverables in this contract. Details of each subtask will be agreed/refined through communications between the corresponding Responsible Officers. Frequent communications between the IO-RO and the C-RO are therefore envisaged to discuss and agree on details of the calculations and priorities.

7 Responsibilities

ITER:

ITER will provide the needed information and access to the adequate ITER files for executing this work when needed following the implementation plan.

Contractor:

The contractor will propose an Implementation Plan for the execution of the contract, to be approved by the ITER Organization, to demonstrate how the work will comply with the requirements of this specification.

The contractor will provide results according to the scope of the work outlined above and will fulfil the agreed Implementation Plan and conditions of present contract.

The majority of the work will be carried out at the Contractor's site. The work may require the presence of Contractor's personnel at the site of the ITER Organization, Cadarache, 13115 St Paul-lez-Durance, France, for the purpose of meetings and data gathering. The presence of the Contractor's personnel at the site of the ITER Organization will be of, at most, five working days within the 12 months period of the Contract. The associated cost for travel and subsistence expenses for the Contractor's personnel should be included in the Contract Cost (see Section 12). The Contractor will take care of all administrative formalities required for the presence of the Contractor's Personnel at the IO site with the authorities concerned (obtaining visas, etc.).

8 List of deliverables and due dates

The deliverables of this contract are reports describing the statement of each problem, input data and approximations used in the studies and the results obtained. Two intermediate reports shall be delivered at 4 months and 8 months from the date of signature of the contract. The Final Report shall be delivered at 12 months from the date of signature of the contract. The overall content of the deliverables in this contract are detailed below:

Deliverable	Content	Time

First Intermediate Report	• Initial evaluation of the formation of runaway plasmas in ITER for 1-2 levels of plasma current and a range of runaway generation/loss mechanisms and post-quench plasma conditions. • Initial evaluation of the dependence of power fluxes on ITER PFCs and of their timescales during runaway plateau termination on the loss characteristics for the runaway formation conditions modelled above.	4 months after contract signature.
Second Intermediate Report	• Continue the assessment of the formation of runaway plasmas in ITER with emphasis in the critical areas identified in the First Intermediate Report. • Continue the assessment of the dependence of power fluxes on ITER PFCs and of their timescales during runaway plateau termination with emphasis in the critical areas identified in the First Intermediate Report.	8 months after contract signature.
Final Report	• Complete assessment of formation of runaway plasmas in ITER within the scope of the contract. • Complete the assessment of the dependence of power fluxes on ITER PFCs and of their timescales during runaway plateau termination on the loss characteristics within the scope of the contract.	12 months after contract signature.

9 Acceptance Criteria

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.

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

10 Specific Skills and Competencies

A Plasma Physicist providing the service should meet the following requirements:

- University PhD degree or equivalent in plasma physics,
- At least 10 years of proven experience in plasma physics R&D,
- At least 5 years of proven experience on runaway electron physics R&D.
- Knowledge/skills/practical experiences in the following are an advantage:-
  o Modelling of the formation and dynamics of runaway plasmas in tokamaks including ITER-specific physics processes.
  o Modelling of the termination phase of runaway plasmas in tokamaks.

The official language of the ITER project is English. Therefore excellent knowledge of English is required because all input and output documentation relevant for this Contract shall be in English.

11 Work Monitoring / Meeting Schedule

The contractor will participate in a series of meetings with the ITER Organization for progress monitoring in agreement with the schedule for deliverables proposed in § 8. At least the following meetings should be foreseen :

Scope of meeting	Point of check/Deliverable	Place of meeting
Kick-off contract	Work program	ITER site or video conference.
Five Progress meetings	Checking progress of deliverables every two months	ITER site or video conference
Closing contract meeting Contract completion	Checking final report	ITER site or video conference

12 Payment schedule / Cost and delivery time breakdown

The ITER Organization will pay per each deliverable as described in Section 8 of these Technical Specifications. Payments are subject to proper approval of the deliverables by the ITER Organization. The contractor will include the cost for each deliverable in their proposal.

The foreseen payment schedule is the following:

List of Deliverables	Estimated Schedule
Deliverable 1: Intermediate Report 1	4 months from the signature of the Contract
Deliverable 2: Intermediate Report 2	8 months from the signature of the Contract
Deliverable 3: Final Report	12 months from the signature of the Contract

Prices are inclusive of all costs, including but not limited to the cost of labour, material, taxes, management, daily transport, preparation, overheads, profit and fee, and those associated with the presence of the Contractor's Personnel at the IO site as detailed in section 7, as applicable.

13 Quality Assurance (QA) requirement

The general requirements are detailed in ITER Procurement Quality Requirements (ITER_D_22MFG4).

Prior to commencement of the task, a Quality Plan must be submitted for IO approval giving evidence of the above and describing the organisation for this task; the skill of workers involved in the study; any anticipated sub-contractors; and giving details of who will be the independent checker of the activities (see Procurement Requirements for Producing a Quality Plan (ITER_D_22MFMW)). 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.

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 use of computer software to perform a safety basis task activity such as analysis and/or modelling, etc., shall be reviewed and approved by the IO prior to its use, it should fulfil IO document on calculation code for safety analysis.