WORK PACKAGE ENABLING RESEARCH

2015 scientific/technical report

Deadline: 31 December 2015

Project title *(as in Task Agreement)*	***Kinetic modelling of runaway electron dynamics***
Principal Investigator	Yves Peysson
Beneficiary of Principal Investigator	CEA-09
Project reference number *(as in Task Agreement)*	ER15-CEA-09

Filename should be of the format: ***WPENR_AWP15_interim_report_****Beneficiary-nn* *where* ***Beneficiary-nn*** *is, for example,* ***ENEA-01****.*

Purpose and use of report

This compact report is to report the progress on the deliverables, to justify payment. A brief summary of the scientific highlights is also requested. While the report will be available to STAC the performance will be assessed by the PMU unless there are issues which require the advice of STAC. The mid-term evaluation of the project, where relevant, is a separate activity but can refer to these reports. It will also be uploaded to the Enabling Research Wiki pages https://www2.euro-fusion.org/ERwiki/index.php?title=Main_Page), and thereby be available to the PMU and the relevant Work Package and Task Force Leaders.

The reports should be as brief and clear as possible, referring to publications and other information for details. However there should be enough information to support statements that deliverables have been achieved. As an indication **the full report should not exceed 4 pages excluding this title page**. Please keep to the report format and do not attach additional information. If there are one or two particularly significant figures that are needed to demonstrate the results, these can be included in the tables.

1. Main scientific output - summary

Summarise the main achievements of the project to date

1) The physics of synchrotron radiation reaction force, which is found to limit the runaway electron energy, and leads to significant modifications in the runaway electron distribution. Includes theoretical work and numerical implementation in kinetic solvers. This work is in the continuation of the previous enabling research project – 2014 – on runaway electron physics and is associated to kinetic modelling of runaway generation mechanism.
2) First theoretical calculation of the bounce-averaged knock-on collision operator for describing runaway avalanches in realistic magnetic configuration of tokamaks, and implementation in kinetic solvers

2. Project deliverables

Deliverable *(2015 deliverables as specified in the Task Agreement)*	**Achieved: Fully/Partly/Not**	**Evidence for achievement, brief reason for partial or non-achievement**
Kinetic modelling of runaway generation mechanisms : Quantify the effect of pre-existing fast electrons in the hot-tail formation and subsequent runaway production rate (2015).	Partially	*Participation to a dedicated experimental campaign on COMPASS tokamak as been performed. Preliminary simulations have been performed but still need to be continued. Ongoing simulations.* *Physics of synchrotron radiation reaction force on runaway electron dynamics* *First theoretical calculation of the bounce-averaged knock-on collision operator for runaway electron avalanches* *Procedure for obtaining the 'stochastic' transport coefficients (drift and diffusion), applicable in 1D codes like LUKE, that capture the effect that stochastic field lines have on runaway.*

Deliverable *(2015 deliverables as specified in the Task Agreement)*	**Achieved: Fully/Partly/Not**	**Evidence for achievement, brief reason for partial or non-achievement**
		electrons. Publication scheduled for 2016.
Kinetic modelling of runaway generation mechanisms: Include the effect of finite incident runaway momentum in the knock-on collision model for more realistic calculations of the secondary runaway generation (2015).	Partly	*Preliminary developments are underway. Numerical implementation has been done but further tests must be performed*
Kinetic modelling of runaway generation mechanisms : Design specific synthetic diagnostics for characterizing the runaway dynamics, especially in the early phase of their generation (2015).	Partially	*Preliminary developments are underway. Quantitative assessment is linked to the development of the self-consistent solver of the evolution of runaways with the electric field.*
Self-consistent evolution of runaways with the electric field: Validate the self-consistent solver obtained by coupling LUKE with the equilibrium/transport code METIS/CRONOS (2015)	Fully	*Numerical implementation completed and under testing. Conditions under which self-consistency between the runaway electron distribution function and the electric field is necessary have been identified. This work has been submitted to publication in November 2015 (Nuclear Fusion).*
Self-consistent evolution of runaways with the electric field: Compare with experimental runaway observations on Tore Supra (RF	Partially	*A detailed modelling of an Ohmic non-disruptive runaway discharge in Tore Supra (#40719) has been carried out, This*

Deliverable *(2015 deliverables as specified in the Task Agreement)*	**Achieved: Fully/Partly/Not**	**Evidence for achievement, brief reason for partial or non-achievement**
power drop, shot #28340) and TCV (density ramp-up, shot # 48195) (2015).		*work has been submitted to publication in November 2015 (Nuclear Fusion). Comparisons with experimental runaway observations on Tore Supra (RF power drop, shot #28340) and TCV (density ramp-up, shot # 48195) (2015) has been postponed to 2016, in the context of the development of the self-consistent solver.*
Code benchmarking : A complimentary proposal named " Global non-linear MHD modeling in toroidal X-point geometry of Disruptions, Edge Localized Modes, and techniques for their mitigation and suppression " will incorporate runaway electron dynamics in the MHD code JOREK using a PIC description. A benchmark of JOREK (using the PIC model for runaway electrons) with LUKE-METIS on axisymmetric cases will be considered. This collaboration will be coordinated by Yves Peysson and Cristian Sommariva.	Partial	*The work is in progress*

3. Publications/presentations

Those which have had a substantial component from the work of the project, marking those which are entirely from the work of the project.

Give title, first author, journal/conference/other venue

Articles

« Kinetic modelling of runaway electron avalanches in tokamak plasmas », E. Nilsson, J. Decker, Y. Peysson, R.S. Granetz, F. Saint-Laurent and M. Vlainic, *Plasma Physics and Controlled Fusion* **57**, 095006 (2015).

« Trapped-electron runaway effect », E. Nilsson, J. Decker, N.J. Fisch and Y. Peysson. *Journal of Plasm Physics* **81**, 475810403 (2015).

« Runaway electrons in non-disruptive scenarios in the Tore Supra tokamak », E. Nilsson, Y. Peysson, J Decker, J. F. Artaud, T. Aniel, M. Irishkin, D. Mazon and F. Saint-Laurent. Submitted to *Nuclear Fusio* (2015).

« Effective Critical Electric Field for Runaway-Electron Generation », A. Stahl, E. Hirvijoki, J. Decker O. Embréus and T. Fülop, *Phys. Rev. Letters,* **114**, 115002 (2015)

« Radiation reaction induced non-monotonic features in runaway electron distributions », E. Hirvijoki, I Pusztai, Decker, Embréus, Stahl and T. Fülop, *J. Plasma Phys.*, **81**, 475810502 (2015)

E. Hirvijoki, J. Decker, A. Brizard and O. Embréus, *J. Plasma Phys.*, 81, 475810504 (2015)

« Numerical calculation of ion runaway distributions », O. Embréus, S. Newton, A. Stahl, E. Hirvijoki a T. Fülop, *Phys. Plasmas,* **22**, 052122 (2015)

« Effect of bremsstrahlung radiation emission on distributions of runaway electrons in magnetized plasma », O. Embréus, A. Stahl, S. Newton, G. Papp, E. Hirvijoki and T. Fülop, submitted to *Phys. Plasmas* (2015)

« Energetic electron transport in the presence of magnetic perturbations in magnetically connected plasmas», G. Papp, Drevlak, G. Pokol and T. Fülop, J. Plasma Phys. 81 475810503 (2015)

« Status of research toward the ITER disruption mitigation system », E. Hollman et al, including T. Fülo and G. Papp, *Phys. Plasmas,* **22**, 021802 (2015)

« Numerical characterization of bump formation in the runaway electron tail », J. Decker, E. Hirvijoki, Embreus, Y. Peysson, A. Stahl, I. Pusztai, T. Fülop accepted to *Plasmas Phys. Contr. Fusion* (2015)

Conference contributions:

« Kinetic modelling of runaway electrons in non-disruptive Tore Supra plasmas », E. Nilsson, J. Decker Y. Peysson, J.F. Artaud, T. Aniel, M. Irishkin and F. Saint-Laurent., *42nd EPS Conference on Plasma Physics* (2015). [POSTER]

« Non-monotonic features in the runaway electron tail. » I. Pusztai, E. Hirvijoki, J. Decker, O. Embréus

A. Stahl and T. Fülop, *42nd EPS Conference on Plasma Physics* (2015). [ORAL]

« Towards self-consistent runaway electron modelling », G. Papp, A. Stahl, Drevlak, T. Fülop, E. Laube and G. Pokol,, *42nd EPS Conference on Plasma Physics* (2015). [POSTER]

« Numerical calculation of ion runaway distributions. » ,O. Embréus, S. Newton, A. Stahl, E. Hirvijoki T. Fülop: *42nd EPS Conference on Plasma Physics* (2015). [POSTER]
« Kinetic modelling of runaway electron dynamics », A. Stahl, O. Embréus, E. Hirvijoki, G. Papp, M. Landreman, I. Pusztai and T. Fülop,, *IAEA Energetic Particle meeting* (2015) [POSTER]
« Coupled kinetic-fluid runaway simulations », G. Papp, A. Stahl, T. Fülop, Drevlak, G. Pokol, E. Laub and A. Fehér,, *IAEA Energetic Particle meeting* (2015) [ORAL]
« Reaction of runaway electron distributions to radiative Processes » A. Stahl et al,, *APS conference Savannah* (2015) [POSTER]
« Conservative large-angle collision operator for runaway
Avalanches », *O. Embréus et al,*, *APS conference Savannah* (2015) [POSTER]
« Numerical calculation of ion runaway distributions », S. Newton et al,, *APS conference Savannah* (20 [POSTER]

Thesis report:

"Dynamics of runaway electrons in tokamak plasmas" by E. Nilsson
PhD thesis (Ecole Polytechnique Paris, France, September, 2015)
https://pastel.archives-ouvertes.fr/tel-01212017/
"Relativistic runaway electron simulations in 3D background" by Konsta Särkimäki
PhD thesis (Aalto University, Helsinki, Finland, 2015)

4. Managerial aspects (optional)

If you think there are any managerial issues to you project (*changes to personnel, cost issues, lack of communications and etc.*), which STAC and PMU shall take care of, please mention them here. (*1 page maximum*)

There is a need to do some changes in the personnel resources compared to the original plan.

The changes we would like to ask you to do are the following and concerns principally Chalmers university and CCFE. The total amount is unchanged compared to the original version for Chalmers University.

1) Newton Sara moved from CCFE to Chalmers University.
2) Eero Hirvijoki left Chalmers University and ER project on runaway electrons
3) For 2015, the budget (constant) is the following

   - Fülöp Tünde, 0.1 ppy *144 = 14.4 k€
   - Stahl Adam, 0.7 ppy * 61.6 = 43.12 k€
   - Newton Sarah, 0.16 ppy * 70.8 = 11.3 k€
   - Embreus Ola, 0.8 ppy * 56 = 44.8 k€

4) Newton Sarah is no more involved in the ER Projecton runaway electrons for 2016 and 2017