EFDA WORKPROGRAMME 2011

Call for Participation

(Part of the EFDA WP, PPP&T)

Initial Studies of the Problem of Power Exhaust in a Demonstration Fusion Power Reactor (DEMO)

Deadline for Responses: 24. Jun 2011

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This Call for Participation aims to implement part of the Power Plant Physics and Technology Work Programme for 2011 under Task Agreements as foreseen in the new EFDA Art. 5

Introduction

At its 47th meeting in Budapest (Hungary) on the 21st and 22nd of March 2011, the EFDA Steering Committee approved the amendment to the EFDA 2011 Work Programme concerning the activities associated to the newly established Power Plant Physics and Technology (PPPT) Department under EFDA. This Call relates to the preparation of a Task Agreement covering the initial studies on the Problem of Power Exhaust in a Demonstration Fusion Power Reactor (DEMO) included in the PPPT Work Programme [1] and to be implemented on the basis of the provisions given in Art. 5 of the EFDA Agreement.

Programmatic Background

The problem of power exhaust is among the most critical problems to be solved for a future fusion power reactor. Compared to the largest present fusion device, JET, the power to the Scrape Off Layer (SOL) in ITER increases by about a factor of 10 and by factors of 30-60 for a future fusion reactor, depending on the scenario chosen. However, the effective power deposition area in the divertor increases much less, by factors only of 2 -4 from JET to DEMO (the scaling of power decay length to larger future devices is still the subject of present R&D, but all data show only marginal or no dependence of the power decay length on size, thus the wetted area scales at first linear with the machine radius). To stay below the maximum acceptable power limit for the targets, which is set to about 10-20 MW/m2 at present, depending on the technology used (e.g., 10 MW/ m2 for helium and about 20 MW/ m2 for water-cooled solutions with copper), ITER and a DEMO reactor require radiated power fractions of 70 % and >90% respectively, together with controlled divertor detachment of both divertor legs as routine operation scenario. The present data show that already ITER-like radiation fractions of ≈ 70% are hardly compatible with the envisaged plasma parameters and performance. Radiation fractions of >90% as envisaged for DEMO are much more demanding and not realistically supported from the present tokamak experience to be achieved with adequate plasma performance.

In addition, stored energies in DEMO will increase by even larger factors (≈ 100) over the present largest values (≈ 10 MJ in JET), and largely exceed the ablation and melt limit of any wall material. Thus the ability to control and avoid ELMs and disruptions with high reliability is a mandatory prerequisite for operation of a DEMO reactor. However, a realistic concept of a DEMO reactor should consider a possible failure of the control of transients and the possible consequence for the integrity of the first wall, including repair scenarios.

This huge power density, coupled with the range of scrape-off-layer (SOL) projections, implies that acceptable divertor operation is, perhaps, the most serious roadblock in the march towards economically desirable power densities for fusion. A high SOL power flux leads to operation in the sheath limited regime, a highly undesirable regime associated with high plate erosion, low impurity shielding, low helium exhaust, low divertor radiation and high divertor heat fluxes. Attempts to dissipate excess heat via core radiation preclude good confinement, and probably high β. The low power density of ITER gives a P/R sufficiently low to allow a standard divertor (SD) to cope, but such SDs are not likely to extrapolate to power densities several times higher.
A number of activities need to be urgently started this year on the physics and technology side to pin-down the problem of the heat flux of the divertor in a DEMO device and the evaluation of limits of available or novel divertor technologies. They are seen as needed to complement the developments that have recently taken place in Europe on Helium cooled targets that can withstand ~ 10 MW/m2. These include: (i) the analysis and modelling of plasmas with a high fraction of radiated power; (ii) the assessment of power handling and design/ operation limitations for divertor concepts based on heat flux technology similar to that developed for ITER and potential prospects of optimisations; and (iii) the degree of realism and the development prospects of promising new ideas for improvement/ modifications to present-day divertors that may substantially improve their capability to disperse high-heat flux and perhaps provide control of ELMs. These new approaches include for example novel divertor configuration concepts e.g., the so-called snowflake divertor that produces a second-order null in the poloidal magnetic field at the X-point, or the so-called Super-X divertor that guides the near-separatrix SOL flux tubes to a larger major radius to increase the surface area available for power deposition, the use of liquid metals (Li, Sn, Ga) surfaces that can increase the power handling capability by flowing the heated material to a non-divertor cooling, and by eliminating most erosion concerns. All of these areas are only emerging concepts that require substantially more analysis and definitive experimental tests. Finally, (iv) an analysis of the gaps

and dedicated facility needs to address the problems of power exhaust and extraction and the development of consistent physics scenarios and sound technological solutions for the divertor is proposed.

The aforementioned activities are to be intended as of initial preparatory nature and should be useful to provide input to a more comprehensive effort in this area expected to be launched under the Implementing Agreement starting from 2012.

1. :

Task Agreement WP11-PEX-01:
Initial Studies of the Problem of Power Exhaust in a Demonstration Fusion Power Reactor (DEMO)

1.1 Introduction

At its 47th meeting in Budapest (Hungary) on the 21st and 22nd of March 2011, the EFDA Steering Committee approved the amendment to the EFDA 2011 Work Programme concerning the activities associated to the newly established Power Plant Physics and Technology (PPPT) Department under EFDA. This Call relates to the preparation of a Task Agreement covering the initial studies on the Problem of Power Exhaust in a Demonstration Fusion Power Reactor (DEMO) included in the PPPT Work Programme [1] and to be implemented on the basis of the provisions given in Art. 5 of the EFDA Agreement.

1.2 Objectives

Five activities are proposed for implementation in 2011 in the area of power exhaust. They include:

- ***Divertor plasma edge modelling studies***
  The aim is to conduct using state-of-the-art plasma edge modelling tools (developed for and available from ITER) preliminary simulations and derive credible functional dependences for key quantities to be used as input to the systems codes. This activity complements a task being launched in the call of system codes.
- ***Feasibility study of a water-cooled divertor for DEMO based on the optimisation of the ITER W-monoblock design and technology***
  The aim is to determine realistic power handling limits for a plausible DEMO divertor design concept a based on the extrapolation of existing water-cooled ITER W-monoblock technology. The tolerable end-of-life neutron fluence of solutions using copper-alloys should be established based on reliable experimental data. At the same time a solution using alternative material as heat sink materials (e.g., ferritic steel) should be explored, including performance limit and feasibility issues, together with development needs (i.e., a design and a proposal for the realization and the testing of a mock-up).
- ***Preliminary assessment of alternative concepts for heat removal in future fusion reactors***
  The aim of this activity is to launch a preliminary study and ‘screen’ new advanced divertor geometries (based mainly on an increased divertor volume, such as long divertor legs), or alternative divertor target schemes based on moving or liquid targets (or hybrid systems of it). The strengths and shortcomings of the various concepts proposed should not be analysed in isolation but properly evaluated in a balanced design and integration contest, i.e., analysed within the frame of a possible realistic DEMO design.
- ***Assessment of the gaps and needs of new facilities for the development of divertor/ first wall and blanket systems for DEMO***
  The aim of this activity is to revisit work done in the past, mainly in the frame of the facility review [2,3], and to 1) identify gaps that exist in the development of consistent physics scenarios; and the knowledge of the problems of power exhaust and extraction; and the development/consolidation of sound technological solutions for the divertor and the first wall; 2) determine capabilities/options that exist to reduce the gaps with existing/planned machines. 3) Determine needs/ required features and capabilities of a possible dedicated DEMO divertor facility.

For the purpose of this assessment, an upper and lower limit for a plausible DEMO design concept should be considered, with parameters/ technical characteristics that are expected to be consolidated as part of the preliminary design oriented activities to be conducted this year as part of the call on the system code, i.e., a pulsed DEMO; a high current drive, steady-state DEMO.

- ***Task coordination for activity on gap analysis***
  The aim is to co-ordinate the last activity in case several associates are going to be involved in this study.

1.3 Work Description and Breakdown

Structure

Within the structure and the objectives defined above, the Work Breakdown will be as follows:

Work Breakdown

WP11-PEX-01-ACT1

Divertor plasma edge modelling studies

The power exhaust is among the most critical problems to be solved for a DEMO reactor. The maximum technical limit for the targets is set presently to about 10 MW/m2 for water cooled technologies, but can be less for He cooled concepts. This requires large radiated power fractions (70- >95% depending on the concept) together with controlled divertor detachment of both divertor legs as routine operation scenario. There is not enough confidence at present that such radiation fractions are compatible with the required plasma parameters and performance.

The main objective is to derive credible functional dependences for key quantities to be used as input to the systems codes. Such key parameters are: (i) the radiation profile; (ii) the peak power density at the target; (iii) the target plasma density and temperature; (iv) the core plasma contamination; (v) the helium density profile.

Tokamak edge modelling has developed over the last 3-4 decades, starting with analytic models such as those by Hotson, Harrison and Harbour, and developing into large fluid codes combined with multi-species neutral models, and linked to core transport models. However, it is still not possible to use such codes to model in a universal way results from existing experiments, let alone predict with any certainty the performance of the edge of a power plant type plasma. None the less these models can be used to assess incremental changes to the system, without being able to model all elements. An example of this might be to predict the radiation profile that would result from seeding impurities into a pre-defined plasma, whilst still permitting the radiation to modify the plasma parameters. In this way the modelling of the effect of impurity radiation can be separated from assumptions regarding the extrapolation of the underlying transport to a power plant, and the individual processes can be experimentally verified on existing machines. It is this type of combined experimental scaling and modelling which we propose would presently give the most credible predictions for a power plant.

The proposed activity consists of two parts, the first part to be conducted as part of this call and the second to be part of a subsequent call for 2012.

The first part (2011) consists of experimentally validating the incremental approach in the power plant relevant regime. The elements of this task are:

– Prepare low recycling attached scenarios matching experimental observations for existing divertor machines using a state of the art edge code (such as SOLPS) linked with a core simulation.

– Impose various levels of impurity seeding on top of the prepared scenarios, to determine the changes in the radiation profile, power to the target, and plasma parameters.

– Validate the model on existing data.

The second, to be covered by a subsequent call (2012), consists of using the validated approach from task 1 to determine parametric dependences to be used as input to a systems code. The elements of this task are:

– Use experimental data to obtain the range in extrapolation of key plasma parameters, including both conventional, and power plant relevant (impurity seeded) scenarios.

– Perform simulations using various combinations of extrapolated data to determine the range of parametric dependences of key quantities under power plant relevant conditions.

WP11-PEX-01-ACT2

Feasibility study of a water-cooled divertor for DEMO based on the optimisation of the ITER W-monoblock design and technology

The objective of this activity is the definition of a water-cooled W monoblock divertor that would be suitable for DEMO operation. Starting from the well proven technology developed for the manufacturing and testing of ITER monoblock plasma facing units, the heat sink material and the joining technologies will be explored in order to determine their potential to fulfil all DEMO requirements.

The end-of-life fluence of a solution using copper-alloys will be established based on reliable experimental data, in terms of thermal-mechanical and neutron damaging behaviour. At the same time a solution using an alternative material as heat sink materials (e.g., ferritic steel, other non ferritic alloy) will be explored, including performance limit and feasibility issues, together with development needs.

The key points of the feasibility study activity can be summarized as follows:

1. Review concepts of this kind proposed and analysed in the past;
2. definition of the DEMO engineering operational parameters needed for the design;
3. assessment of the material candidates that could be used in a monoblock configuration;
4. identification and assessment of the critical parameter for each proposed material;
5. thermal-mechanical analysis of the chosen water-cooled divertor configurations (copper alloys, ferritic steel) and comparison with DEMO specifications;
6. investigation on the possible technologies applicable to manufacturing;
7. identification of the critical parameters of the manufacturing processes (i.e. casting, coating, brazing, diffusion bonding, HRP, etc.) and definition of a experimental matrix to find the best solutions for the manufacturing of suitable W monoblock water-cooled divertor mock-upsolutions for the manufacturing of suitable W monoblock water-cooled divertor mock-up.

WP11-PEX-01-ACT3

Preliminary concept studies of alternative concepts for heat removal in future fusion reactors based on moving or liquid targets, or hybrid systems of it

This activity should start with a review of the concepts and experimental data for alternative target systems proposed in the past with a focus on their prospects for heat exhaust in DEMO. The aim of this study is to deliver the basis for a possible EFDA R&D project for 2012 and beyond to qualify such concepts in more detail for their use in a fusion reactor.

In particular, the work in this task should judge the existing concepts and data with respect to:

– the heat exhaust capability with a main emphasis on steady state heat exhaust conditions, but also with a view on the occurrence of un-controlled transients

– the impact on the plasma contamination and performance

– the stability of liquid target concepts under steady state and non controlled transients

– the particle (hydrogen and helium) removal capability and the impact on the long term tritium inventory

– the compatibility of liquids with other material components and the neutronics of the materials used

A clear proposal should also be made for a design and R&D programme to further develop some of the considered solutions.

WP11-PEX-01-ACT4

Assessment of the gaps and needs of new facilities for the development of divertor/ first wall for DEMO

The aim of this activity is to revisit work done in the past, mainly in the frame of the facility review [2,3], and to 1) identify gaps that exist in the development of consistent physics scenarios; and the knowledge of the problems of power exhaust and extraction; and the development/consolidation of sound technological solutions for the divertor and the first wall; 2) determine capabilities/options that exist to reduce the gaps with existing/planned machines. 3) Determine needs/ required features and capabilities of possible dedicated DEMO divertor facilities. These facilities should be available and operated well before the start of the construction of DEMO, in order to validate fundamental design choices and confirm their performance in a realistic environment.

As a first step the technical/ scientific information to be expected by the Research Operation Programmes of ITER and JT60SA in determining or confirming the feasibility of divertor operation scenarios and design choices should represent the starting point.

The activity depends on the type of DEMO; two alternatives are considered: (i) a long-pulse inductively supported large plasma with modest power density in a conventional scenario and (ii) an advanced higher power density steady state plasma scenario.

In general the requirements for a pulsed device may be easier from the physics standpoint, essentially because we have already the well established H mode; however the scenario demands some minor extra capability for a more reliable start-up and termination, for some extra counter current drive capability, and, mainly, a very strong effort to moderate the ELMs strength.

As a key attribute of this approach, one would need to address (in a realistic and DEMO relevant experiment) in particular the level of flexibility that would be needed to accommodate for some of the innovative solutions being considered with regard for example to divertor geometry configurations (at least double null or snowflake type) or material options for both the first wall and divertor (e.g, solid W target, liquid metals, etc.). The contributing information expected from operation of ITER on these topics also need to be realistically evaluated together with the possibility to influence decisions for ITER enhancements of programme strategy.

In particular, the divertor assessment should be oriented to

• identify the common general features of a DEMO plasma edge with a particular attention to the divertor heat flux
• identify and prioritize the broad scientific and technical questions that need to be answered regarding DEMO and determine what can be provided by ITER and what can not. Possible list is: thermal loads expected during normal operation and transients, reactor relevant plasma edge conditions, particles target recycling effects, conditions of plasma detachment, divertor and edge power radiation levels and associated stability effects, plasma wall interactions for reactor relevant materials options, etc.
• assess available means, including all existing and planned facilities around the world, as well as theory and modelling, to address these questions.
• identify research gaps and how they may be addressed with existing/planned machines.
• Identify needs for new facility concepts (primarily integrated plasma experiments in non-nuclear fusion devices exploring aspects in an integrated fusion reactor relevant environment).

Depending on the outcome of this assessment, a facility which will be capable of investigating as closely as possible, all of the issues and (non-nuclear) problems that PWI/PFCs would face in DEMO, should be proposed. The feasibility study of this facility should be the subject of a further tasks to be launched next year pending the outcome of this activity.

WP11-PEX-01-ACT5

Coordination of studies conducted in Activity 4

The aim of this activity is to coordinate the study to be conducted in Activity 4 on the assessment of the gaps and needs of new facilities for the development of divertor/ first wall for DEMO, in the case that there are more than one associate involved in this activity.

More specifically, this activity should be aimed at the coordination/ overview of the assessment to ensure, in particular, the adoption of reasonable assumptions, dissemination of information, and to review the different findings that may be emerging from different studies. Best effort should be made to facilitate dialogue between potential different groups engaged to avoid unnecessary overlapping duplications. A comprehensive final report, with a clear overview of the findings and their implications should be prepared including a review of potential proposals for further work in this area in the future.

JET related activities

Not applicable.

Resources

The estimated resources for 2011 for the PPT- PEX research project are 3.5 ppy under Priority Support.

WP-2011: Human Resources and Expenditures proposed for Priority Support

2011 Priority Support	PPY	Expenditure	Comments
Preliminary DEMO divertor plasma edge modelling studies	0.5		
Feasibility study of a water-cooled divertor for DEMO based on the optimisation of the ITER W-monoblock design and technology	0.5		
Preliminary assessment of alternative concepts for heat	0.5		

removal in future fusion reactors			
Assessment of the gaps and needs of new facilities for the development of divertor/ first wall and blanket systems for DEMO.	1.5		
Coordination of assessment of the gaps	0.5		

1.4 Scientific and Technical Reports

Report of achievements under Priority Support (final report and, when appropriate, intermediate reports):

The progress of tasks undertaken under Priority Support and the status of deliverables will be reported separately to the Head of the PPPT Department. A final report (and intermediate reports indicating any substantial progress in the achievement of deliverables,) shall be prepared by the Task Coordinator and submitted to the Head of the PPPT Department. These reports shall include specific sub-sections for each of the Associations involved. They shall document the degree to which the deliverables outlined have been achieved, and shall include a breakdown of expenditure for each Association. The EURATOM financial contribution will be made after approval by the EFDA Leader of these reports.

Milestones and Deliverables

Milestones:

Deliverables:

Activity	*Priority Support Deliverables*	*Due Date*
WP11-PEX-01-ACT1	The deliverables for this activity are: - An interim report by November 2011. - A final report by March 2012.	31. Mar 2012
WP11-PEX-01-ACT2	The deliverables for this activity are: - An interim report by November 2011. - A final report by March 2012.	31. Mar 2012
WP11-PEX-01-ACT3	The deliverables for this activity are: - An interim report by November 2011. - A final report by March 2012.	31. Mar 2012
WP11-PEX-01-ACT4	The deliverables for this activity are: - An interim report by November 2011. - A final report by March 2012.	31. Mar 2012
WP11-PEX-01-ACT5	The deliverables for this activity are: - An interim report by November 2011. - A final report by March 2012.	31. Mar 2012

References

[1] Power Plant Physics and Technology activities under EFDA DRAFT Work Programme 2011, STAC 34/3.2.1 - Issue 2, 24 November 2010.

[2] The European Fusion Research Programme: Positioning, Strategic outlook and need for infrastructure towards DEMO, Part II. Facilities, Input to the Facilities Review Panelprepared by the EFDA Leaders, the EFDA Associates and F4E, 6 May 2008

[3] E. Ascasibar, D. Borba, F. Crisanti, A. Fasoli, R. Giannella, W. Morris, J. Ongena, J. Pamela chairman, P. Pavlo, V. Pericoli, V. Philipps, M. Rubel, B. Saoutic, T. Tala, R. Zagorski, H. Zohm, CCE-FU working group on JET funding and future directions of the accompanying programme - Group of experts on Satellite Tokamak, First Stage Report