EFDA WORKPROGRAMME 2011

Call for Participation

(Part of the EFDA WP, PPP&T)

System Design Code: Development and Applications

Deadline for Responses: 06. May 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 with the newly established Power Plant Physics and Technology (PPPT) Department under EFDA. This Call relates to the preparation of a Task Agreement covering the activities on Fusion System Code 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.The EFDA SC has agreed to conduct these activities under priority support within an overall ceiling of 96 k€.

Programmatic Background

For conducting the conceptual design and integrated performance assessment of a Demonstration Fusion Power Reactor (DEMO) the availability of a reliable and validated iterative system design code is essential. System design codes are computational algorithms with varying degrees of complexity that typically consist of physics, engineering and costing correlations/models or modules, that reflect the current knowledge with regard to physics and engineering assumptions and constraints, and determine the machine configuration, design parameters, associated performance and cost based on the selected plasma and engineering input parameters. It should be noted that a system code does not develop a detailed design but more a design parameter window and is essential to identify coherent design solutions that satisfy and meet the stringent plasma physics and engineering requirements. More specifically a fusion system design code is applied to satisfy simultaneously the constraints in all areas and hence delineate the sensitivity of performance and cost to design assumptions and constraints and their trade-off. It is used to compare different design concepts, identify critical design issues. Finally, it helps in producing preliminary design parameters, assess the impact of design changes and evolve design concepts.

Various system codes, with different degrees of sophistication and complexity, have been developed and used in the past to analyse/ evaluate various design concepts and to consolidate the design basis of all the devices that have been or are being built to date. Unfortunately, often most of these tools are not supported by a proper documentation and often the physics and engineering assumptions, which are used in the various models/routines, are known to the developers only, and need revisions in the light of new knowledge, which is available in several areas of physics and technology, thanks to the progress made in recent years.

1. :

Task Agreement WP11-SYS-01:
System Design Code: Development and Applications

1.1 Introduction

1.2 Objectives

The application and improvement of state-of-the-art system codes is recognised to be a priority for the PPPT activities. During the first phase the activity will be mainly centred to evaluate system codes available in Europe and, if possible, in the rest of the world, identifying specific strengths and weaknesses. An important aim is to revisit physics and engineering assumptions and models being used in system codes for designing fusion reactors. From the physics standpoint, special attention should be given to the modelling of impurity radiations, bootstrap currents, heat exhaust in the divertor, current drive efficiency and the analysis of trade-off between steady state and quasi-stationary regimes of operation. As far as the engineering is concerned, the modelling of superconducting magnets, blanket and divertor, as well as plant availability (or maintenance scheme), cost are expected to play a central role.

In particular, the impact of initial assumptions to be made for some of the systems, for example with regard to current drive efficiency and/ or modes of operation would need to be checked and analysed with the appropriate expert groups of the various systems and the implications arising on these assumptions on the requirements imposed on the systems and developments needs would need to be carefully evaluated in an iterative fashion. A limited number of baseline DEMO design concepts with various degrees of extrapolation from today's known underlying physics and engineering basis will be explored with the purpose of starting thorough and consistent technical assessments and compare systems modelling over a range of different conditions, provide base cases which can be modified to fit other assumptions as developments occur in the fusion programme, and provide the basis for wider interaction between DEMO design activities and the fusion programme.

Areas of necessary improvements of the code(s) will be identified, both in the areas of physics, engineering and costing to overcome some of the shortcomings of the specific tool to be used as identified in the first phase of this study. Some immediate improvements to the code will be implemented, but other, more substantial, modifications will be defined and developed and implemented in the systems code in a follow-up call, to be defined after collecting the results of these activities.

It is indeed to be expected that this activity will pick-up pace and continue after 2011 for (i) Design optimisation studies: to obtain minimum cost machine(s) with clearly defined design criteria and operation requirements and coupled physics, engineering and costing constrains. (ii) Cost –vs.- performance sensitivity studies: to perform cost-v-performance sensitivity studies around the design point. (iii) Operational flexibility: to assess operational flexibility of final design point using the capabilities of the system code. (iv) Design option trade-offs: to self consistently compare and contrast design options (e.g., steady-state vs. pulsed design configurations, etc.) under the same physics, engineering and cost assumptions.

1.3 Work Description and Breakdown

Structure

The Work Programme 2011 is organised along seven activities:

- ***Coordination and code selection***

The aim is to identify the most suitable EU systems code to pursue the PPPT conceptual design activities and co-ordinate the necessary assessment and modifications of the system code.

- **Review the engineering model assumptions used in the system codes**

The aim is to review the overall approach and key technology assumptions of an existing systems code, with particular emphasis on the treatment of the additional heating systems, magnets, radial build, power flows, site and buildings, including costing algorithms, and how these system models interact with the plasma models.

- ***Review of the physics assumptions and the physics basis used in the system code***

The aim is to review the physics module within the systems code with particular attention paid to the radiation models (particularly impurity and synchrotron radiation), current drive efficiency calculations, bootstrap calculations.

- ***Analyse and compare the modelling of divertor physics within systems codes***

The aim is to review the main assumptions for the divertor modelling, and seek way of improving predictive capabilities

- ***Preliminary selection and analysis of DEMO baseline design concepts***

The aim is select an upper and lower limits for plausible DEMO design concepts, to compare systems modelling over a range of different conditions, provide base cases which can be modified to fit other assumptions as developments occur in the fusion programme, and provide the basis for wider interaction between DEMO design activities and the fusion programme. This should include 3 DEMO concepts derived from extensions of the ITER operating scenarios: a pulsed DEMO; a high current drive, steady-state DEMO, and an advanced tokamak version.

- ***Benchmark code calculations against equivalent Japanese calculations***,

Compare information on the systems code assumptions and on the derived DEMO conceptual designs with the equivalent work in Japan, through exchange of results and staff visits, and agreement and exploration of alternative benchmark cases as required.

- ***Identification of improvement needs and plans for implementation***

The aim of this activity is to identify areas where immediate improvements to the code are needed and these will be implemented under this Work Package. It is expected that other, more substantial, modifications will be indicated by external review, for instance a rewrite of a whole module such as the model of TF coils. These will be developed and implemented in the systems code.

Work Breakdown

WP11-SYS-01-ACT1

ACT1: Coordination of activities and code selection

The objective of this work package is to coordinate the following 6 Work Package activities and, on the basis of the associated work, recommend the most suitable EU systems code to pursue the PPPT conceptual design activities and co-ordinate the necessary identified modifications/improvements required to the system code.

More specifically, this activity should be aimed to the comparative evaluation of the potentially useful system codes available in Europe, identifying specific strengths and weaknesses, turnaround times, programming language, graphical user interfaces, etc. and specifying all the independent modules of which they are composed, all the assumptions made, all the involved approximations, the required computing platform and all the other specifications useful to judge the exportability and manageability of the code. This task should also give an overview and information on other codes available worldwide, with particular reference to USA and Japan, in order to assess critically the limits of the approaches proposed by the EU and rest-of-the-world.

Some test (benchmark) cases to cross-check the Japanese system codes, under investigation for use in the Japanese Design Activities that are part of the Broader Approach (BA) agreement should be planned – see ACT6. An outcome should be a recommendation of a future strategy – whether to adopt an existing code or to develop an entirely new code based on an existing or new philosophy.

WP11-SYS-01-ACT2

ACT2: Review of technology/ engineering assumptions/ models used in the codes

The purpose of this task is to document the overall approach and key technology assumptions of an existing systems code(s), and a comparative evaluation of the strength or weakness of an approach versus another one, with particular emphasis on the treatment of the additional heating systems, magnets, radial build, power flows, site and buildings, including costing algorithms, and how these system models interact with the plasma models.

WP11-SYS-01-ACT3

ACT3: Review of the assumptions and the physics basis used in the system code

Review the physics assumptions within the systems code with particular attention paid to the radiation models particularly impurity (see ACT4) and synchrotron radiation, current drive efficiency calculations, bootstrap calculations, etc. Where there are multiple options available, test, validate and recommend the most reliable options, and identify possible corrective actions. Where appropriate, use overall plasma models, external to the systems code, for comparison purposes, in collaboration with ACT5 below.

The output of this activity is to provide a document which lists the main physical assumptions in a given systems code and compares them with the most up-to-date knowledge, in term of experience and theory. A tentative list of the physics assumptions that are used in the codes and that should be reviewed are for example:

1) scaling laws of the energy confinement times,.

2) Current drive efficiency models

3) Models of the bootstrap current

4) Non-thermal particle densities and effects,

5) Scaling laws of the density limit

6) Scaling laws of the H-mode access power threshold

7) Compatibility of the radial profiles (density, temperature, pressure) with the present knowledge

8) Consistency of the He ash removal rate

9) Consistency between core radiation level, effective charge state and dilution

10) Consistency between the level of the radiated power and the H-mode access threshold

11) Consistency between the level of the conducted and radiated power and the maximum fixed power load on the targets

12) Assumed power removal rate from the divertor and maximum total load on the plates

13) Width of the energy flow channel in the SOL

14) Assumed ELMs magnitude

It is to be expected that the sensitivity of the results of the code with respect to some physics assumptions or physics modules is higher than others. The degree of confidence on the results/ assumptions/ approximations of such modules should be evaluated and a comparison should be made where more than one code is available. Example of some of the most critical physics models/approximations are:

- Calculation related to the radiated power, which is crucial for establishing the need for impurity seeding (see ACT4). This affects not only the dilution of the fuel and brings implication for the sputtering of the divertor targets, but also can concern the need to overcome the power threshold for maintaining a good H-mode. List of the admitted impurities and consistency of their radiation with the impurity transport physics should be provided, together with an assessment of the degree of reliability of the radiation radial profile. Information on the degree of reliability at which the codes are able to calculate the radiation outside the LCFS, either in the main SOL and in the divertor chamber should be provided. The confidence level for the calculated synchrotron radiation should be assessed. Corrections/improvements should be suggested.
- The basic assumptions on which the total amount of the driven current and its radial distribution are calculated should be listed and critically reviewed. Comparisons with the experimental data so far available should be made, mostly for the ability of off-axis CD and for the actual steadiness of the total current profiles. The same information should be provided for the self-generated bootstrap current, together with the degree of the consistency of this latter with the total current profile. In case more options for the calculation are available a ranking for them should be suggested. As for the previous one, this T.A. should also include to identify/suggest possible corrective actions and a relevant road map.
- The modelling of the divertor power load (see ACT4)

WP11-SYS-01-ACT4

ACT4: Analyse and compare the modelling of divertor physics within systems codes

This task consists of analysing how the problem of the divertor power exhaust is treated in the system code and in particular identify ways to improve predictive modelling capabilities and the differences and simplification with respect to the most common physics codes such as EDGE2D and SOLPS and identify corrective actions.

Initially, an as complete as possible database of existing relevant simulations, such as those in the highly radiating regime with seeded impurities needs to be established. With post processing of the results the development of parametric dependences of key parameters such as the edge and core radiation, and power scrape-off length for use in the systems code.

System studies should then be conducted to define tradeoffs and requirements on divertor heat flux.

In the longer term, and as part of a subsequent call, it is intended to validate the codes in the power plant regime using dedicated experiments in existing devices, and to conduct further runs to improve confidence in the extrapolations.

WP11-SYS-01-ACT5

ACT5: Preliminary analysis of baseline DEMO Concepts

In this phase of work it is proposed that up to 3 concepts of DEMO are proposed and analysed. It will be necessary to make improvements in systems codes before this can be pursued, depending on the outcome of the initial analysis, so this phase will be clarified during the initial phase of work.

It is proposed, however, that the 3 concepts are broadly as follows:

1) A DEMO concept which may be deliverable in the short to medium term, based on the expected performance of ITER in its pulsed scenario. With improvements in science and technology that may be reasonably anticipated this will define a pulsed version of DEMO and, by allowing high levels of current drive power,- a “baseline” steady-state design against which improvements can be compared.

2) A DEMO concept based around more advanced assumptions which are at the upper limit of what may be achieved during the ITER phase of fusion development, either in ITER steady-state operation or in other devices - an “optimistic” design.

By choosing what is considered here to be the upper and lower limits for plausible DEMO design concepts, the work will drive a comparison of systems modelling over a range of different conditions, provide base cases which can be modified to fit other assumptions as developments occur in the fusion programme, and provide the basis for wider interaction between DEMO design activities and the fusion programme. In particular, these studies should help guide the operational scenarios for ITER, JT60-SA and for the wider fusion programme. These reference DEMO conceptual designs will also form the basis for interactions with materials and technology programmes.

WP11-SYS-01-ACT6

ACT6: Benchmark code calculations against equivalent Japanese calculations

A benchmark code calculation against equivalent Japanese calculations is requested through a controlled benchmark calculation and through modification of the DEMO design concepts developed in ACT5; testing the systems code capabilities against those in Japan across the range of possibilities for DEMO. The progress in this work will depend on the level of progress in Japan so collaboration and flexibility will be key to success of this work.

An important part of this work will be to further identify improvements in systems modelling and to begin the process of making the improvements. Depending on the outcome of this work, improvements in key aspects of the modelling may be carried forward into later work. It is expected that staff interchange between EU and JP will be necessary in this phase of work.

WP11-SYS-01-ACT7

ACT7: Identification of improvement needs and plans for implementation

In carrying out tasks 1 to 6, some immediate improvements to the code will be identified and these will be implemented under this Work Package. It is expected that other, more substantial, modifications will be indicated by external review, for instance a rewrite of a whole module such as the model of TF coils. These will be developed and implemented in the systems code

JET related activities

Not applicable

Publications

A list of publications produced on the basis of results of the 2011-WP, will be compiled after the completion of these tasks.

Resources

The estimated resources for 2011 for the PPPT- SYS research project are 4 ppy under Priority Support

Table 2: WP-2011: Human Resources and Expenditures proposed for Priority Support

2011 Priority Support	PPY	Expenditure	Comments
Coordination and code selection	0.5		
Review the engineering model assumptions used in the system codes	0.5		
Review of the physics assumptions and the physics basis used in the system code	0.5		
Analyse and compare the modelling of divertor physics within systems codes	0.5		
Preliminary analysis of DEMO baseline design concepts	1		
Benchmark code calculations against equivalent Japanese calculations	0.5		
Identification of improvement needs and plans for implementation	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

<u>Milestones:</u>

The results obtained will be presented and discussed during a number of progress review meetings held every two months. On this basis the progress accomplished by the contributing Associations will be reported by the Coordinator to the Head of the PPPT Department.

<u>Deliverables:</u>

The report on the Association activities under Priority Support will be prepared by the Coordinator to be presented to the EFDA Leader.

The final and technical report will be submitted to the Head of the PPPT Department for approval and uploading in the IDM database.

Activity	*Priority Support Deliverables*	*Due Date*
WP11-SYS-01-ACT1	The deliverables for this activity are: - An interim report by November 2011. - A final report by March 2012.	31. Mar 2012
WP11-SYS-01-ACT2	The deliverables for this task are: - A draft final report by November 2011 - A final report, for publication by March 2012	31. Mar 2012
WP11-SYS-01-ACT3	The deliverables for this task are: A reference report where the approach and key assumptions used in the code are coherently documented. - A draft final report by November 2011 - A final report, for publication by March 2012	31. Mar 2012
WP11-SYS-01-ACT4	The deliverables for this task are: - A draft final report by November 2011 A final report, for publication by March 2012	31. Mar 2012
WP11-SYS-01-ACT5	The deliverables for this task are: - A draft final report by November 2011 - A final report, for publication by March 2012	31. Mar 2012
WP11-SYS-01-ACT6	The deliverables for this task are: - A draft final report by November 2011 - A final report, for publication by March 2012	31. Mar 2012
WP11-SYS-01-ACT7	The deliverables for this task are: - A draft final report by November 2011 - A final report, for publication 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*