EFDA Workprogramme 2013

Call for Participation

Design Assessment Studies

Deadline for Responses: 07. Feb 2013

EFDA CSU contact person: Gianfranco Federici

This Call for Participation aims to implement the Design Assessment Studies Work Programme for 2013 under Task Agreements as foreseen in the new EFDA Art. 5

Introduction

The Work Programme 2013 in Power Plant Physics and Technology (PPPT) aims at completing the selection of the key physics/technology prerequisites for DEMO, the definition of a set of technical characteristics for DEMO and the assessment of the R&D needs to establish its conceptual design.

Programmatic Background

This area of Design Assessment Studies includes in WP2013 nine topics:

1. Superconducting Magnets
2. Vessel/In-Vessel Components
3. Heating & Current Drive Systems
4. Diagnostics and Instrumentation Systems
5. Vacuum/Pumping and Fuelling Systems
6. Tritium Systems
7. Remote Maintenance
8. Balance of Plant
9. Stellarator engineering scoping studies

For further details please refer to the individual sections.

1. : Superconducting Magnets

Task Agreement WP13-DAS-01:

1.1 Introduction

Outline
Design assessment studies in the Superconducting Magnets area will be divided into two main activities: i) Nb3Sn Low Temperature Superconductors and ii) High Temperature Superconductors (HTS).

Nb3Sn Low Temperature Superconductors
In WP2012, the requirements for the DEMO conductors were defined and candidate prototype designs developed and analysed. In WP2013, the work on low temperature superconducting magnets will continue as follows:

- Perform manufacturing feasibility assessment of prototype conductors with industry
- Finalise the layout of both conductor options (RW and WR)
- Assess the implication for the coil technology of both conductor options (RW and WR)
- Define the test requirements for the conductor prototype phase
- Prepare to place contracts with industry for the manufacture of prototypes
- Identify the critical logistic and procurement issues of the DEMO superconducting coils

High Temperature Superconductors
In WP2013, a parallel R&D program into high temperature superconductors (HTS) shall also be continued from WP2012 focussing on the possible future application of HTS conductors to fusion. A number of testing / experimental activities are foreseen in 2013:

- Studies, testing and development of different HTS cable concepts i.e:
    - Roebel-Rutherford
    - Co-axial i.e. CORC
    - RACC
    - Twisted stack cables
- Development and tests of the jointing techniques of different HTS cable configurations
- Determination of change in properties after reactor irradiation of HTS samples to a fast neutron fluence

Scope
The scope of this activity is research, development and experimental testing of super conducting magnet technologies (both LTS and HTS) for a DEMO fusion power plant. The activity is performed as part of the EFDA PPPT 2013 work programme.

Acronyms
DAS Design Assessment Studies
EFDA European Fusion Development Agreement
PPPT Power Plant Physics and Technology Department (of EFDA)
WP Work Programme

TF Toroidal Field
CS Central Solenoid
PF Poloidal Field
QA Quality Assurance
DEMO Demonstration Fusion Power Plant
ITER International Thermonuclear Experimental Reactor
DC Direct Current
CORC Conductor On Round Cable
RACC Roebel Assembled Coated Conductor
LTS Low Temperature Superconductor
HTS High Temperature Superconductor
RW React then Wind
WR Wind then React

1.2 Objectives

The objectives for WP13-DAS01-MAG are:

1. To specify DEMO-relevant Nb3Sn conductor prototypes considering both react-then-wind (RW) and wind-then-react (WR) manufacturing processes and prepare these prototypes for the manufacturing and testing
2. Assess the implications for the DEMO superconducting coils of the:
    - proposed conductor designs
    - logistic and procurement issues (i.e. size, mass, transport, handling etc)
3. To continue to research high temperature superconductor technology and assess its application to fusion through testing and characterisation of HTS cables and joints under DEMO-relevant conditions

1.3 Work Description and Breakdown

WP13-DAS-01-T01

LTS Activity Coordination

The Coordinator shall be responsible for:

1. Producing and maintaining an Activity Management Plan as per [1]
2. Working closely with the WP13-SYS03 System Integration Study activity to ensure a bi-lateral flow of information between the individuals working on the WP13-DAS01 tasks
3. Ensure all deliverables / reports are produced and reviewed within the agreed timescales
4. Chairing and producing minutes for the kick-off, interim and final meetings
5. Calling any ad-hoc meetings as necessary for the purpose of discussion, clarification, communication, progress reporting etc

WP13-DAS-01-T02

Iteration of Conductor-Coil design for both RW and WR options

The results of the preliminary analysis carried out under WP12-DAS01-T04 for the two conductor layouts produced under WP12-DAS01-T03 shall be integrated into an updated conductor design. The size of the winding pack may also be the object of this design iteration. Other conductor iterations may include the copper and non-copper cross section, the helium channel size, etc.

If the results of the analysis of WP12 show substantial overdesign, the overall cross section of the TF coil may be reduced, with a feedback on the radial built indicated by the PROCESS code.

Before starting the work on WP13, the status of the System Code progress must be checked. If an updated reference from the PROCESS code is available, it should integrated in the conductor coil design together with the other iterations from the analysis.

WP13-DAS-01-T03

Iteration of the conductor analysis for both RW and WR options

The conductor layouts produced in WP13-DAS-T02 shall be assessed by a number of analyses, including electromagnetic, thermal-hydraulic and mechanical performance. For both conductor layouts, following analyses shall be performed:

- Iteration of Electromagnetic analysis
  - Magnetic field on each layer of the winding pack along the conductor length, from the helium inlet to the joint. Three values of magnetic field shall be calculated: the average field at the centre of the conductor; the peak field (average + self-field); and the effective field to be retained in the superconductor performance assessment.
- Iteration of Thermal-Hydraulic analysis
  - Pressure drop in each hydraulic channel (iteration from WP12).
  - Heat removal rate in each hydraulic channel (local operating temperature up to Tcs, fixed inlet pressure and inlet temperature, nominal mass flow rate)
- Iteration of Quench behaviour analysis
  - Calculation of the voltage rise up to the quench detection threshold of 100 mV, for a realistic case of quench initiation.
  - Hot spot temperature for a realistic case of quench initiation, including the above calculated time for voltage rise, a “delay time” of 2 s and a decay time constant of 23 s.
  - Maximum quench pressure for a realistic and extreme case of quench initiation.
  - Temperature Margin calculation
- Deepening of Mechanical Analysis
  - Global stress analysis at the inboard TF coil section (smeared properties for the winding pack).
  - Local stress analysis within the winding pack, including peak shear stress at the insulation and peak stress at the conductor conduit).

WP13-DAS-01-T04

Preparation for prototype manufacture of LTS conductors

The features introduced in the conductor layouts will need preliminary consultation with industrial manufacturers to verify manufacturing feasibility and the need, if any, of dedicated industrial R&D. To stimulate the involvement of the industry, small contracts can be placed with the related suppliers. Suggested R&D activities are given below:

- As the proposed DEMO Nb3Sn strand has a diameter larger than in the ITER conductors, a limited R&D at one strand manufacturer would aim at verifying the required parameter, e.g. by production of a trial small billet. The product of the trial, a strand with ø = 1.5mm and cu:non-cu = 1 should be evaluated by the manufacturer.

- As the cables proposed in the layouts have lower void fraction than ITER and a rectangular shape, a cabling company should assess the feasibility, required tools and necessary R&D.

- The jacketing of the proposed conductors is quite different compared to ITER: for the WR layout, the size and the deformation are much larger, for the RW longitudinal welding is required with related QA.

Based on the results of these studies, either small contracts or negotiations with the companies, the specification for manufacturing contract are drafted.

WP13-DAS-01-T05

HTS Activity Coordination

The Coordinator shall be responsible for:

1. Producing and maintaining an Activity Management Plan as per [1]
2. Ensure all deliverables / reports are produced and reviewed within the agreed timescales
3. Chairing and producing minutes for the kick-off, interim and final meetings
4. Calling any ad-hoc meetings as necessary for the purpose of discussion, clarification, communication, progress reporting etc

WP13-DAS-01-T06

Studies, testing and development of HTS cable concepts

Twisted Stack Cables

The next steps towards the development of a twisted stack cable are:

1. Up-scaling of the manufacture of a twisted stack cable to a length in the 5 to 10 m range
2. Demonstration of twisting for a cable length in the 5 to 10 m range
3. Demonstration of the soldering of a longer twisted cable (5-10 m)

In order to achieve the above steps, the following work shall be carried out:

- Planning and supervision of the manufacture of an 8 m long twisted cable to be made of 10 RE-123 coated conductors of 4 mm width. The expected Ic of the twisted cable at 77 K and self-field is around 600 A. The reduction of Ic as compared to the sum of the single tape critical currents of 1000 A is due to the self-field

- Procurement of the RE-123 coated conductor and the copper profiles
- Planning and supervision of the set-up for the twisting and soldering of longer cables
- Testing of the cable in LN2 and self-field.
- A piece of ~1 m length should be made available for test in the FBI facility.

Rutherford-Roebel Cables

Following the testing of twisted stacked cables, CORC Cable and Roebel cable and the detailed work on bending properties of Roebel Cable and the demonstration of Roebel Strands in a Rutherford Cable concept during WP12, the following work shall be performed:

- Investigation of resin or solder reinforced Roebel Cables in FBI to determine limits of degradation
- Improvement of existing Rutherford Cable concept with Roebel strands towards a Round Rutherford Cable
- Measurement of HTS cable produced from Versatile Round Strands in FBI
- Preparation of sub-cable tests in FBI with current, perpendicular field and defined strain

Strain characterisation of ReBCO tapes, joints and CORC Ic and AC loss

The following measurements and assessment shall be carried out on REBCO tapes and on some tape-joints:

1. Transverse stress, Ic(B,stress) and contact resistance @ 77 K
2. Controlled torsion and axial strain (combined) @ 77 K
3. Axial compressive and tensile strain, Ic (B,T,eps) @ T<77K

The following measurements and assessment shall be carried out on cables:

1. CORC AC loss, transverse cable compression (4 K), fusion relevant ramp rates
2. Twisted stacked tapes in copper wire AC loss (4K)

WP13-DAS-01-T07

Development and testing of HTS jointing techniques

1. Complete the WP12 task by:

- analysis of joints manufactured with lower temperature solder alloys (In-based alloys) and different commercial tapes:
    - Manufacturing of new joints
    - Electrical characterization of the joints in terms of Ic degradation and contact resistance at 77 K and self-field
    - Mechanical characterization of the joints in terms of Ic, contact resistance and N-exponent after tensile stress and bending
    - Analysis of magnetic behavior of joints
    - Mechanical modeling and analysis of the stresses distribution in the joints

2. Analysis of joints on a stack of tapes and Roebel cable (if available)
    - Manufacturing of new joints
    - Electrical characterization of the joints in terms of Ic degradation and contact resistance at 77 K and self-field
    - Mechanical characterization of the joints in terms of Ic, contact resistance and N-exponent after tensile stress and bending
    - Mechanical modeling and analysis of the stresses distribution in the joints of stacks

3. Produce a single scientific report of the findings with clear recommendations from the work performed

WP13-DAS-01-T08

Determination of HTS properties after fast neutron irradiation of HTS samples

In continuation of work performed in WP12, HTS tape test samples shall be subjected to neutron irradiation at DEMO-relevant fast neutron fluence.

HTS tape test samples shall be subjected to neutron irradiation up to DEMO-relevant fast neutron fluences (E > 0.1 MeV) of 3 to 4 x 1022 m-2 in the well characterized neutron spectrum of a fission reactor by sequential irradiation.

Tapes already investigated during the WP12 task will be irradiated to higher fluences and new tapes from the main commercial suppliers worldwide will be included in this year's campaign. In addition, the role of Sm or Gd substitutions for Y in 123-coated conductors will be clarified.

Characterisation of each HTS tape shall be carried out before and after irradiation. The following characteristics shall be measured:

a) Critical Temperature (Tc)
b) Critical Current (Ic), including angular dependence
c) Strain (testing of selected samples)
d) Homogeneity of supercurrent flow by magnetoscan

WP13-DAS-01-T09

Preparation of the SULTAN facility for testing of high-current HTS conductors at variable temperatures

The SULTAN facility of CRPP has been used to qualify all low-temperature superconductors to be used for the construction of ITER. HTS conductors to be developed for fusion magnets must be tested under fusion-relevant conditions (I > 10 kA, B > 10 T).

To allow the testing of HTS fusion conductors the following modifications of the SULTAN facility are required:

- Conduction-cooled HTS bus bars of high thermal resistance, which would connect the NbTi transformer of the SULTAN facility operated at a temperature close to 4.5 K with the HTS fusion conductor under test (4.5 K < T < 50 K). The envisaged heat flux between the HTS conductor under test and the NbTi should be less than 10 W.
- Counter flow heat exchanger for the supply of helium gas of intermediate temperature (20 K < T < 50 K) to cool the HTS test conductor

Design and supply of HTS Bus Bars

The following work shall be performed:

1. Design of HTS bus bars to connect a SULTAN HTS test conductor and the NbTi transformer including manufacturing drawings.
2. Comparison of RE-123 and AgAu/Bi-2223-based options (Magnetic field calculations, heat flux, tape arrangement).
3. Supervision of the manufacture of dummy bus bars (soldering trials and measurement of

contact resistance in LN2). A contact resistance sufficiently small to use the NbTi transformer to supply sample currents needs to be achieved.

4. Procurement of RE-123 or Bi-2223 tapes and other hardware.
5. Manufacture of a pair of HTS bus bars (Iop ~ 50 kA, T ~ 40 K).

Design of counter flow heat exchanger

The following work shall be performed:

1. Design of a counter flow heat exchanger for conductor test in SULTAN to return the helium gas used to cool the test conductor as "cold gas" (T ~ 20 K)
2. Consideration of available space, dimensions, mass flow rates
3. Integration with existing cryogenic system

Note: Manufacture of the heat exchanger not foreseen within WP13-DAS01-T09.

Resources

Resources for LTS tasks:

Task ID	Title	PS (ppy)	Hardware (k€)
WP13-DAS01-T01	DAS01 LTS Activity Coordination	0.1	
WP13-DAS01-T02	Iteration of Conductor-Coil design for both RW and WR options	0.2	
WP13-DAS01-T03	Iteration of the conductor analysis for both RW and WR options	0.8	
WP13-DAS01-T04	Preparation for prototype manufacture of LTS conductors	0.35	30
	TOTAL	**1.45**	**30**

Resources for HTS tasks:

Task ID	**Title**	**PS (ppy)**	**BS (ppy)**	**Hardware (k€)**
WP13-DAS01-T05	DAS01 HTS Activity Coordination	0.1		
WP13-DAS01-T06	Studies, testing and development of HTS cable concepts	0.8	0.4	85
WP13-DAS01-T07	Development and testing of HTS jointing techniques	0.2	0.2	10
WP13-DAS01-T08	Determination of HTS properties after fast neutron irradiation of HTS samples	0.2		35
WP13-DAS01-T09	Preparation of the SULTAN facility for testing of high-current HTS conductors at variable temperatures	0.25	0.15	40
	TOTAL	**1.55**	**0.75**	**170**

1.4 Scientific and Technical Reports

See deliverables section

Milestones and Deliverables

Milestones:

Milestone ID	**Title**	**Date**
WP13-DAS01-M01	Kick Off Meeting	End March 2013
WP13-DAS01-M02	Interim Review	Sept 2013
WP13-DAS01-M03	Final Review	Mid Dec 2013

Deliverables:

Task ID	**Deliverable ID**	**Deliverable Title**	**Required for Milestone**
WP13-DAS01-T01	WP13-DAS01-D01	LTS Activity Management Plan	M01
WP13-DAS01-T02	WP13-DAS01-D02a	Report: “Design Specification for RW prototype LTS conductor “	M03
	WP13-DAS01-D02b	Report: “Design Specification for WR prototype LTS conductor “	M03
WP13-DAS01-T03	WP13-DAS01-D03a	Report: “Electromagnetic and Mechanical Analysis of candidate prototype LTS conductors, winding pack and TF coil casing”	M03
	WP13-DAS01-D03b	Report: “Thermo-hydraulic analysis of candidate prototype LTS	M03

		conductors”	
	WP13-DAS01-D03c	Report: “Quench behaviour of candidate prototype LTS conductors”	M03
WP13-DAS01-T04	WP13-DAS01-D04	Report “DEMO Nb3Sn Candidate Superconductors: Manufacturing feasibility report”	M03
WP13-DAS01-T05	WP13-DAS01-D05	HTS Activity Management Plan	M01
WP13-DAS01-T06	WP13-DAS01-D06	Report: “Studies, testing and development of HTS cable concepts”	M03
WP13-DAS01-T07	WP13-DAS01-D07	Report: “Development and testing of HTS jointing techniques”	M03
WP13-DAS01-T08	WP13-DAS01-D08	Report: “Determination of HTS properties after fast neutron irradiation of HTS samples”	M03
WP13-DAS01-T09	WP13-DAS01-D09a	Manufacturing Acceptance / Component Test Report for SULTAN HTS Bus Bars	M03
	WP13-DAS01-D09b	Design definition document for SULTAN counter flow heat exchanger	M03

Activity	*Priority Support Deliverables*	*Due Date*
WP13-DAS-01-T01	WP13-DAS01-D01-"LTS Activity Management Plan"-M01 The WP13-DAS01-D01 Activity Management Plan shall be reviewed and approved by EFDA PPPT at or before M01.	01. Apr 2013
WP13-DAS-01-T02	WP13-DAS01-D02a- Report: “Design Specification for RW prototype LTS conductor “- M03 WP13-DAS01-D02b- Report: “Design Specification for WR prototype LTS conductor “- M03 The deliverables shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013
WP13-DAS-01-T03	WP13-DAS01-D03a-Report: “Electromagnetic and Mechanical Analysis of candidate prototype LTS conductors, winding pack and TF coil casing”-M03 WP13-DAS01-D03b-Report: “Thermo-hydraulic and temperature margin analysis of candidate prototype LTS conductors”- M03 WP13-DAS01-D03c- Report: “Quench behaviour of candidate prototype LTS conductors”- M03 The deliverables shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013
WP13-DAS-01-T04	WP13-DAS01-D04-Report “DEMO Nb3Sn Candidate Superconductors: Manufacturing feasibility report”-M03 The deliverable shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013
WP13-DAS-01-T05	WP13-DAS01-D05-HTS Activity Management Plan-M01 The WP13-DAS01-D05 HTS Activity Management Plan shall be reviewed and approved by EFDA PPPT at or before M01.	31. Dec 2013
WP13-DAS-01-T06	WP13-DAS01-D06-Report: “Studies, testing and development of HTS cable concepts”-M03 The deliverable shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013
WP13-DAS-01-T07	WP13-DAS01-D07-Report: “Development and testing of HTS jointing techniques”-M03 The deliverable shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013
WP13-DAS-01-T08	WP13-DAS01-D08-Report: “Determination of HTS properties after fast neutron irradiation of HTS samples”-M03	31. Dec 2013

	The deliverable shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	
WP13-DAS-01-T09	WP13-DAS01-D09a-Manufacturing Acceptance / Component Test Report for SULTAN HTS Bus Bars-M03 WP13-DAS01-D09b-Design definition document for SULTAN counter flow heat exchanger-M03 The deliverables shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013

References

[1] DEMO Activity Management Plan Template - EFDA_D_2LAWVX

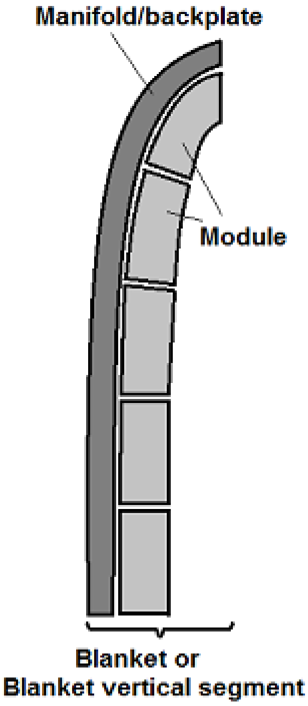
2. : Vessel/In-vessel Components

Task Agreement WP13-DAS-02:

2.1 Introduction

The design of the in-vessel components (IVCs) represents undoubtedly one of the greatest challenges for DEMO. While a number of related material questions are being addressed in the materials area, the in-vessel component area focusses on the further development of the design to allow for tokamak integration as well as system level analyses. The tokamak design driving role of the IVCs is recognized and it is therefore natural that their design must be developed early on accepting a high degree of uncertainty in the boundary conditions. Work in many other areas such as remote handling, neutron shielding and activation, plasma simulation, H&CD integration, tritium plant, hot cell and others depends on the availability of early divertor and blanket design details. The design progress of the IVCs will need to be subject to continuous review and verification.

<u>Definitions</u>
Ppy: Person per year
PS: Priority Support
BS: Baseline Support
RO: Responsible Officer
HW: Hardware
TPM: Task planning meeting
DEMO: A tokamak design based on conservative technology and plasma configurations with mainly inductive current drive whose construction could begin as early as 2030.
IVC: In-vessel component
FW: First wall
PF: Poloidal field
MHD: Magnetohydrodynamic
MMS: Multi-module segment
WCLL: Water-cooled lithium led
HCLL: Helium-cooled lithium led
HCPB: Helium-cooled pebble bed
HTC: Heat transfer coefficient [W/(m²K)]
PWR: Pressure-water reactor
DBTT: Ductile-brittle transition temperature
SIC: Safety-important class



2.2 Objectives

The activities in 2013 will focus on design and integration aspects and continue in many areas the work carried out in 2012. In the case of divertor target technology the tasks aim at clarifying a number of aspect expected to impact the future R&D plans and in particular the future irradiation campaigns and high-heat-flux tests as well as on the development of a DEMO divertor cassette. The basic design of three blanket concepts (WCLL, HCLL, and HCPB) continues while critical issues of the DCLL are being addressed in parallel. Particular focus in 2013 is on design and performance assessment of the water- and helium-cooled FW as well as on an initial development of a blanket attachment scheme.

<u>The activities foreseen in 2013 are:</u>

- Continuation and conclusion of the design study of the identified candidate divertor target concepts aiming at optimized designs for each concept.
- Further develop the design of the different blanket concepts WCLL, HCLL, and HCPB:
    - Considering as a reference a segmentation compatible with a blanket vertical remote maintenance scheme,
    - Optimizing thermal-hydraulic and n-shielding design characteristics,
    - Developing coolant channels and manifold layouts,
    - Studying different operating conditions, and
    - Defining preliminary of balance-of-plant-relevant parameters.
- Initiate the development of blanket and the module attachment concepts.
- Design and assessment of candidate water- and helium-cooled FW designs.
- Fabrication study to manufacture square-shaped multi-jet fingers using an alternative to WL10 as thimble material.

- Assessment of critical issues of a low-tech DCLL.
- Fabrication study of electrical insulating inserts for low-tech DCLL.
- Preliminary design of vacuum vessel upper port.

2.3 Work Description and Breakdown

WP13-DAS-02-T01

Coordination

The coordinator has the following tasks:

- Ensure all tasks are performed in a consistent manner and in accordance with the prescribed specifications.
- Provide expertise and advice to the owners of the single tasks.
- Collaborate with the System Integration Project to ensure the timely availability of the data required to perform the single tasks, e.g. DEMO geometry.
- Monitor the activities and check the results (includes the review of all final reports).

<u>Reference to this task:</u>

[1] DEMO Activity Management Plan template PPPT IDM direct access: EFDA_D_2LAWVX

WP13-DAS-02-T02

Water-cooled divertor target design study

<u>Background:</u> The DEMO divertor target is currently foreseen to be water-cooled, as the corresponding concepts offer potentially the highest heat flux capability. For a reliable performance assessment high-heat flux tests are foreseen following an irradiation campaign of mock-ups at operation temperature. As heat sink material Eurofer is considered as well as Cu-alloys (in spite of their higher activation levels). In 2012 different water-cooled concepts have been assessed and candidates been selected. In order to allow a direct comparison a design optimization of the individual concepts shall be undertaken. The respective performances shall be assessed based on consistent criteria.

<u>This task has two aims:</u>

1. To carry out a design study of the identified candidate divertor target concepts aiming at optimized designs (for each concept) recommended for fabrication, irradiation and high-heat-flux testing.
2. Preparation of an irradiation campaign with subsequent high heat flux testing including a detailed specification of the mock-ups to be fabricated.

<u>Task requirements and assumptions</u>

- 5200 heat cycles shall be assumed for the life of one divertor cassette (see EFDA_D_2LCY7A, pg. 3.2.2).
- The hold time of one heat cycle shall be considered to be 2 hrs (see EFDA_D_2LCY7A)

Task coordination

In close collaboration with WP13-DTM03 and WP13-MAT02 the types of failure against which the

different concepts need to be verified shall be defined. The corresponding criteria shall be defined to allow their consistent application across the different target concepts. Where uncertainties or gaps in required data exist assumptions shall be made to allow this task to be carried out. The structural feasibility criteria for the different parts of the concepts shall be based on the outcome of WP12-DTM03 and consider the progress of deliverable D4.
The proposed criteria shall be compared to experimental results of past high heat flux testing although it is recognized that this comparison cannot be fully conclusive. In particular the ITER test results (number of heat flux cycles to failure in un-irradiated and irradiated condition, e.g. [2]) shall be revisited. ITER assessments of the thermal stresses in the structure due to the heat flux shall be requested from ITER. The feasibility criteria proposed in WP12-DTM03 shall be compared to the stress levels and number of cycles to failure found in the experiments. If necessary additional thermal analyses shall be carried out consistent with the experiments. A discussion of feasibility criteria shall be made.

Target design optimization

- The following concepts shall be considered:
- The ITER monoblock concept using CuCrZr as heat sink and a copper layer between pipe and monoblock.
- The two alternative CuCrZr based concepts using Eurofer and a poorly conductive material for the interlayer respectively.
- The monoblock concept using Eurofer as heat sink and a copper layer between pipe and monoblock.

A comprehensive discussion shall be made for each concept regarding the pros and cons of different operating conditions. One operating condition shall be proposed for each concept. Amongst others the following points shall be addressed in the discussion of the operating conditions:

- Relevant material properties in the corresponding temperature range.
- Thermo-hydraulic performance (achievable heat transfer coefficient, pressure loss/m).
- Armour lifetime limitations.
- Requirements for integration into a cassette.
- Issues/feasibility for fabrication (if related to the operating condition).
- Cost.

All design studies shall include a number of parametric thermal and thermal-structural analyses. In addition more advanced analytical methods shall be used to predict for each concept the plastic behaviour of the material during the load cycles. The FE method shall be used to determine the temperature distribution and thermal-structural stresses in the structure. The heat flux onto the armour shall be increased to account for gaps between adjacent tiles. The following parameters shall be varied (and optimized) in the analyses:

- Coolant pipe inner diameter
- Coolant pipe wall thickness
- Interlayer thickness
- Monoblock 2D dimensions
- Monoblock thickness (third dimension)
- Water velocity

The maximum heat flux capability shall be determined for the optimized variant of each concept, i.e. the heat flux shall be determined that causes at least one parameter to reach the respective limiting criteria.

Experimental campaign
A review shall be made of past experiments regarding DEMO-relevancy, types of failure, fabrication, and conclusions drawn from results. A proposal shall be made for an irradiation and high heat flux testing campaign including test facilities, test parameters as well as estimated cost and time to perform the tests. The envisaged results of the tests shall be described and the conclusions that are planned to draw from these experiments shall be discussed.

References to this task:
[1] ITER Heat and Nuclear Load Specifications, EFDA_D_2LLJKL
[2] Rödig, HHF testing of different irradiated WC divertor target concepts, 2001, EFDA_D_2KYTVC

WP13-DAS-02-T03

Water-cooled blanket design development

Background: A number of other activities require the design of the blanket, e.g. neutronics or remote handling. It is therefore necessary to maintain a blanket design consistent with the evolution of the DEMO tokamak design. Experience also shows that issues of the design concept are often due to local characteristics of the component or the component integration and it is therefore that only through developing the design in all parts that such issues can be identified.

Aim of this task: To continue the basic design of the WCLL blanket started in 2012 developing also the design of the inboard blanket. The blanket design shall be modified according to the updated DEMO tokamak geometry and DEMO blanket requirements and under consideration of WP12 results.

Task requirements and assumptions:

- The design of one inboard and one outboard blanket shall be developed, both including the following parts:
    - Manifold and back-plate
    - The equatorial modules with external box and internal grid, designed for the module to withstand an internal pressure equal to the coolant pressure (as Class D loading condition)
    - FW and plasma-facing cover plate of the blanket box (the on-going work performed in task T09 (water-cooled FW) shall be considered).
    - Indicatively the breeding units.
    - Coolant routing.
- The design shall consider the stress allowables to withstand creep-fatigue damage, see recommendations in WP12-DAS02-T11: EFDA_D_2LM2AG.
- The blanket vertical segment supports shall be assumed not to constrain the thermal expansion of the blanket.
- The blanket vertical segment shall be considered to be attached directly to the vessel.

- The coolant routing shall be optimized in order to decrease thermal stresses and thermal deformation of the blanket vertical segment as well as of the single modules.
- In the choice of the number and size of modules the on-going work of WP13-SYS02-T03 shall be considered.
- The water cooling pipes shall be double-walled with Cu bridges for heat conduction.

Structural verification
The structural feasibility of the breeding module and manifold/segment shall be verified for the following load conditions:
Class A: Normal operation: Coolant pressure + temperature distribution during the flat-top plasma operational state.
Class D: Coolant leak inside breeding module: Coolant pressure on external walls of modules.
A steady-state thermo-hydraulic analysis shall be performed for the flat-top plasma operational state for back-plate with manifold. A subsequent thermal-structural analysis shall be performed to verify the structural feasibility of that back-plate with manifold for the normal operation state.
The thermo-hydraulic and thermal-structural analyses shall be reported and the related FE models and analysis macros be stored in the PPPT analysis database.

WP13-DAS-02-T04

Helium-cooled blanket design development

Background: A first basic design of the helium-cooled blanket was developed in 2012 for both concepts HCLL and HCPB. An important missing part of the design is the attachment of the modules to the manifold/backplate, which is developed in task T05. This task is a continuation of the 2012 tasks completing/further developing the design of the breeding unit and the manifold/backplate.

Aims of this task:

1. To further develop the design of the breeding units of the HCPB and the HCLL blanket concepts (considering in particular the different neutron wall load compared to the TBM).
2. To further develop the design of the manifold/backplate including thermal-structural assessment.
3. To assess the effect of convection and the heat transfer in the HCLL breeding unit.

WP13-DAS-02-T05

Design of module attachment to manifold/backplate

Background: In DEMO the blanket modules will be attached to the manifold/backplate of the blanket vertical segment (while in ITER they are attached to the vessel). In this task two attachment concepts shall be developed:

1. Using preloaded bolts and shear keys (similar as in ITER for the blanket modules).
2. Using welded plates at the sides of the module

The cooling and other pipe connections need also to be implemented in this interface.
Aim of this task: To propose, verify and discuss the two design concepts of the interface module – manifold/backplate.

Task requirements and assumptions:

- The assembly of the modules may take place prior to the transport of the blanket into the plasma chamber.
- Provision shall be taken in the attachment design to allow the replacement of a failed module in the hot cell under the assumption that the failure occurred before the reweldability limit (He-production in the pipe connections) was reached.
- An exchange of the modules in the vessel is not required.
- A helium-cooled outboard module shall be considered in this task, since the module thickness is greater on the outboard compared to the inboard and the attachment therefore more challenging.
- A reasonable module size shall be chosen prior to the attachment design. For this purpose a discussion shall be made with the task owners of task T04 (regarding cooling, breeding and module box design) and WP13-SYS02-T03 (regarding impact of the module size on the EM loads). A maximum category III (Class C) poloidal force acting on the module shall be considered of F_pol = 1.0 MN.
- Regarding the assessment of the thermal deformation during operation of the module and the manifold/backplate [3] shall be used as a basis (helium-cooled blanket).
- In the frame of this task the vessel temperature shall be assumed as in ITER (20°C during maintenance/shut-down, 100°C during normal operation, 200°C during vessel baking).
- Regarding the number and sizes of module feeding pipes [4] shall be used as a basis.
- The task owner shall interact with the task owner of T09 regarding the accidental temperature of the module.
- The task owner shall interact with the task owner of T08 regarding the dynamic amplification of EM loads.

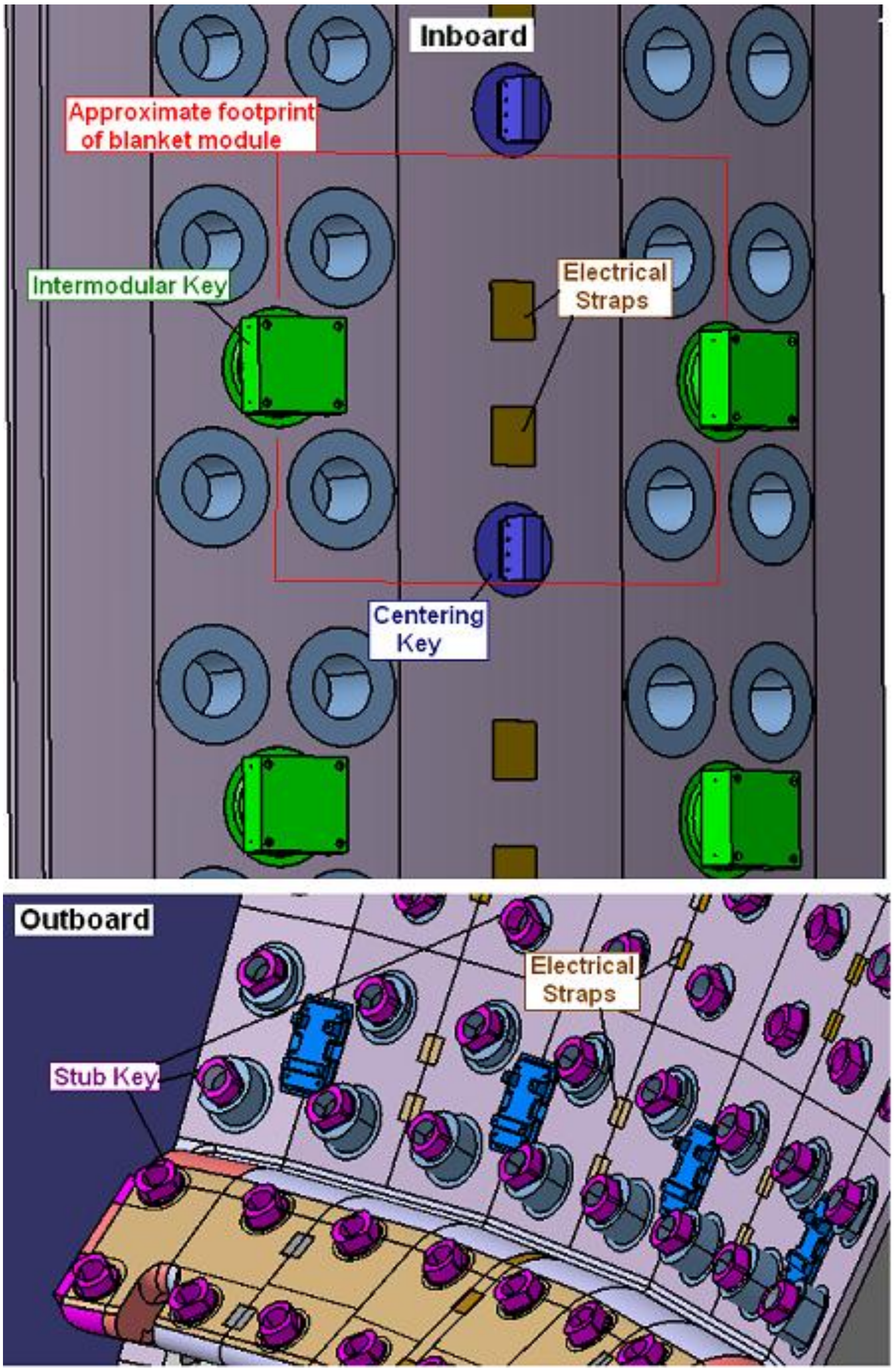
Attachment using preloaded bolts and shear keys
The design concept to be studied shall be similar to the ITER concept (see picture below) where pre-loaded bolts provide resistance against loads M_tor, M_pol, and F_rad. Shear keys provide resistance against loads M_rad, F_pol, and F_tor. Bolts and shear keys are electrically insulated. Pipe connections are in the centre of the module in order to ensure a single point of electrical connection and therefore prevent net current in and out of the module.
The design of the interface module – manifold/backplate shall include:

- The design of the bolts connecting the module to the backplate, including:
  - Choice of bolt material
  - Design of disks, nuts, inserts, and access holes
  - Choice of coatings
  - Design of electrical insulation
  - Structural verification of the bolted connection through hand calculations
- The design of the shear keys, including
  - Internal cooling channels
  - Coatings, electrical insulations
  - Gaps and possible wedges to close gaps
  - Access holes
  - Structural verification of the shear keys through hand calculations
- The implementation of the helium and purge gas/LiPb pipes
- Indicative: the design of electrical straps

The anti-seizure coatings chosen in ITER shall be discussed, see also [1] pg. 11.

The structural feasibility of the attachment shall be assessed by hand calculations:

- To demonstrate that in operation sufficient preload is maintained on the interface module-backplate to resist the EM loads M_tor, M_pol, and F_rad.
- To demonstrate that the bolted connection is able to cope with the thermal expansions occurring during operation and accidents.
- The shear keys shall be structurally verified against the EM loads M_rad, F_pol, and F_tor. The dynamic amplification study (T08) shall be considered in this assessment.
- To demonstrate that the shear keys are able to cope with the thermal expansions occurring during operation and loss of coolant accidents. A supporting thermal analysis of the module to provide information regarding its thermal deformation shall be carried out.



Attachment using welded plates at the sides of the module

The design concept to be studied shall consist of flexible plates welded to the sides of the modules to allow for the thermal deformation. These plates shall resist all loads and do not need to be electrically insulated. No constraints are therefore imposed regarding the location of the pipe connections. The design of the interface module – manifold/backplate shall include:

- The design of the welded plates connecting the module to the backplate, including location of welds and type of coatings (if used).
- The design of the shear keys (if included in the design), including
    - Internal cooling channels
    - Coatings

  - Gaps and possible wedges to close gaps
  - Access holes
- The implementation of the helium and purge gas/LiPb pipes
- Indicative: the design of electrical straps

The structural feasibility of the attachment shall be assessed by hand calculations:

- To demonstrate the structural feasibility of the flexible plates to resist the EM loads.
- If additional shear keys are implemented they shall be structurally verified against the EM loads. The dynamic amplification study (T08) shall be considered in this assessment.
- To demonstrate that the flexible plates and shear keys are able to cope with the thermal expansions occurring during operation and loss of coolant accidents. A supporting thermal analysis of the module to provide information regarding its thermal deformation shall be carried out..

References to this task:

[1] ITER Blanket DDD, EFDA_D_2AQ8R2
[2] WP12-DAS02-T07: Feasibility assessment of bolts and pins in irradiated environments, EFDA_D_2KVVWV
[3] WP12-DAS02-T04: Thermo-hydraulic and thermal-structural analyses report of the DEMO Helium-cooled blankets, EFDA_D_2M5RRE
[4] WP12-DAS02-T04: DEMO Helium-cooled blanket concept design description report, EFDA_D_2M7LQD

WP13-DAS-02-T06

Literature study regarding sliding on load bearing surfaces

Background: Large relative expansion will occur between vessel and in-vessel components in DEMO due to the large and changing temperature differences in different states, e.g. operation, maintenance, accident. Flexible attachments could be a solution; their very flexibility however often jeopardizes their load bearing capability. Sliding on the load bearing surfaces of shear keys could be an attractive solution since the stiffness of the shear key could remain high. Such sliding would occur only during the transition of the plant from one state to another, e.g. while the vessel temperature is increased to the baking temperature, or the vessel and the blanket temperatures are reduced to room temperature during a plant shut-down period. Also in an incident (e.g. loss of blanket coolant) the temperature difference between blanket and vessel can change compared to the normal operation scenario.

Aim of this task: A literature study shall be carried out to identify possible material solutions for in-vessel load bearing sliding surfaces. It shall indicate their limits of application on DEMO in-vessel component shear keys.

Task requirements and assumptions:

- The contact pressure shall be considered in the range [20…100 MPa].
- Number of sliding cycles to be considered: 500.
- Maximum irradiation does (in steel) at the shear key: ≤1 dpa.
- Environment: vacuum.

WP13-DAS-02-T07

Development of a blanket attachment concept

Background: The attachment of the blanket is an interface that drives very basic tokamak design choices. Although neither the DEMO blanket nor the DEMO vessel are sufficiently developed and assessed to allow a definite verification of any developed concept, the issue needs to be approached at this early point in the DEMO programme due to its tokamak-architecture-driving role:

- The DEMO plant architecture strongly depends on the blanket remote handling concept, which in turn depends on the blanket attachment scheme.
- Work in many other areas in particular H&CD integration and RH depends on the existence or non-existence of the semi-permanent shield inside the vessel. To provide reliable results also neutron shielding, plasma simulations, vertical stability assessments, and electromagnetic analyses require this information. Whether the semi-permanent shield is required depends on the suitability of a blanket-vessel attachment scheme for the large thermal mismatch between vessel and blanket.

Since the thermal deformation of the water-cooled blanket is expected to be significantly less severe than that of the helium-cooled blanket attachment schemes shall be developed for one helium-cooled concept.

Aim of this task: To develop and structurally verify possible attachment concepts for a helium-cooled blanket. A solution shall be attempted that avoids the semi-permanent shield considered in the PPCS studies. Instead a direct attachment of the blanket to the vessel shall be considered. This work shall identify major issues, provide feedback to the vessel and blanket designers, and list assessments needed for the further attachment development.

Task requirements and assumptions:

- Divertor cassettes are removed prior to the blanket replacement (according to WP11 RH studies)
- Blankets can be attached either to the vessel (@ 100°C) or to other blankets.
- Vessel baking scenario: vessel temperature: 200°C (uniform)
- Toroidally adjacent blanket vertical segments shall remain electrically insulated.
- Nearby blanket pipe connections electrical straps must be incorporated in the design unless a convincing argument is made.
- Except in the case of pre-loaded fasteners the support concept shall be designed such that the blanket is structurally determined (not over-constrained) to allow a first order prediction of support forces independently of structures' stiffnesses.
- In the definition of the attachments it can be assumed that RH access exists to all upper vertical and all lower divertor ports.
- The following load cases shall be considered in the attachment design:
    - EM loads and blanket dead weight to be defined at the kick-off meeting.
    - Supporting keys can be either part of the vessel (like the ITER inter-modular key) or part of the blanket.
    - The maximum uniform temperature of a blanket vertical segment to be assumed during a loss of coolant event (Category II, class B – tbd.) will be provided by task T09 (30.09.2013).

CAD model

A CAD model (Catia) shall be developed of the blanket attachments of the inboard and outboard helium-cooled blanket. The CAD models shall include:

- Movable elements like fasteners incl. nuts and discs, wedges, or uncooled plugs.
- Access holes through the vessel or blanket to the attachments.
- Those parts of the vessel and the blanket that react the forces transferred through the attachments.
- Shear keys including their internal coolant channels.

Technical feasibility and concept performance assessment

Feasibility assessment of the attachments including:

- It shall be demonstrated that the attachments can tolerate all occurring thermal deformations of the blanket vertical segment. The following cases of thermal deformation shall be considered:
    - Steady-state normal operation: The thermal deformation of the back-plate and manifold of the blanket vertical segment was determined in WP12-DAS02-T03. This shall be used as a basis in this task.
    - Vessel baking scenario.
    - Blanket loss of coolant scenario.
- Each fastener shall be judged regarding its feasibility for the irradiated environment, see also WP12-DAS02-T07.
- Structural integrity verification of each individual support. Maximum reaction forces on the individual supports due to weight, disruption EM loads (see WP12-DAS02-T09) and magnet fast discharge EM loads shall be estimated and specified. It is expected that the verification of some attachments' structural integrity can be carried out with text book formulae. The structural integrity of supporting keys shall be made using the FE method.
- Suitability verification for RH. How each attachment can be accessed and released by RH tools shall be described.

Heat loss calculation

An estimate shall be made of the heat [kW] conducted during normal operation from the blanket through the attachments into the vessel. This estimate shall consist of individual calculations for type of attachment considering the heat conduction from the blanket Eurofer through the support structure, contact surface(s), the vessel steel up to the vessel water-cooled surface.

WP13-DAS-02-T08

Dynamic amplification of blanket load caused by a gap at the supporting key

Background: At assembly of the blanket vertical segment a gap will be required at all supporting keys. Due to the higher operating temperature of the blanket compared to the vessel this gap will increase during operation. In order to close this type of gap after installation to operation a movable element would be required, which complicates the attachment design as well as the installation process.

EM loads due to fast disruptions occur on a short time scale and might accelerate the blanket significantly before contact at the supporting keys occurs, causing an impact of the blanket onto the keys. Depending on the stiffness of the blanket and its supports, the structure's natural frequency

might be similar to the time scale of the EM load, causing dynamic amplification. Both phenomena (impact and dynamic amplification) can cause stresses in the structure significantly higher than in the static stress state.
The ratio between static and dynamic stresses will indicate whether movable elements (e.g. adjustable wedges) are required in the design of the blanket attachment.

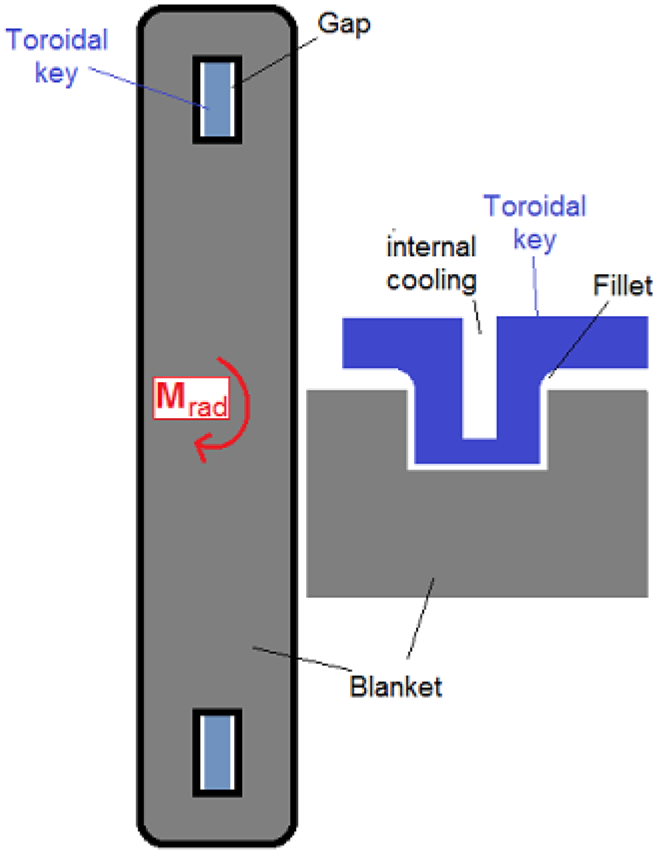
Aim of this task: To estimate the dynamic amplification factor of the radial moment acting on the blanket vertical segment due to a major disruption due to a gap at the supporting keys.

Task requirements and assumptions:

- Load:
  - In a first step the loading time function of the radial moment [1] acting on the HCPB blanket vertical segment due to a major disruption shall be assumed. In a second step a loading time function shall be considered that is three times slower. The peak radial moment shall be varied and the following values be used: 10 MNm, 20 MNm, and 40 MNm.
  - The radial moment Mr shall be considered to act distributed to the radial mid-plane of the blanket vertical segment (400 mm off the plasma-facing surface). A multi-point constraint (MPC) could be used in the FE model.
  - Two toroidal keys being part of the vessel (on top and bottom of the inboard wall) shall be considered to react the radial moment.
  - Definition: Toroidal keys react toroidal forces.
- FE models:
  - The vessel model shall be constrained on the poloidal edges
  - The blanket model shall be constrained at the contact surfaces of the toroidal keys.
  - In the calculation of the vessel stiffness the inner and outer shell, the key itself as well as the two adjacent poloidal ribs shall be considered. The poloidal length of the vessel comprising one toroidal key considered in the stiffness calculation shall be 2.4 m.
- Vessel and key design:
  - Poloidal distance of keys: 9 m (tbd)
  - Key toroidal width: 150 mm
  - Key poloidal length: 400 mm
  - Key design: 50 mm side walls, 50 mm internal cooling channel.
  - Vessel inner and outer shell thickness: 60 mm
  - Poloidal ribs' thickness: 40 mm
  - Key fillet: r = 10 mm
  - Radial dimension of key off the inner shell surface: 110 mm
  - Radial length contact area of key: 100 mm
  - Toroidal distance between centre of key and centre of poloidal ribs on either side of toroidal key: 260 mm
- Blanket design:
  - According to WP12-DAS02-T04: EFDA_D_2M7LQD. (The design can be simplified in the FE analysis.)
  - An adequate cut-out for the key shall be implemented in the design.

- The back-plate of the HCPB blanket vertical segment can be considered constrained against rotation about the poloidal axis.

- A gap size in the range [0…5 mm] shall be considered on either key.
- The mass moment of inertia of the blanket vertical segment shall be considered.
- I: mass moment of inertia (in kg per m^2)
- w: angular velocity (in radians per second)
- phi: rotation of blanket segment



Literature study regarding energy loss at impact: At the impact of the blanket with the key energy will be lost due to internal friction and shock waves. Typically the loss depends on the mass of the moving element (blanket) compared to the mass of the impacted element (key and part of vessel). In the blanket case where the impacting mass is large compared to the impacted mass only a small fraction of energy loss is expected (< 5%). Nonetheless this fraction of energy loss due to internal friction and shock waves shall be estimated quantitatively following a textbook and literature review.

Definition of Eurofer/316L(N) strength properties at impact loading: The more rapid the loading the higher the tensile and ultimate strengths of steels. The increased strength of Eurofer (blanket) and 316L(N) (vessel) corresponding to the impact of the blanket on its keys described above shall be defined following a review of the material assessment report.

FE analysis - stiffness of blanket and vessel: An FE analysis shall be carried out to determine the elastic rotational stiffnesses of the blanket and the vessel (Kblk and KVV) reacting a radial moment Mr (in Nm/radians). (The total rotational stiffness of the structure is K = 1/[1/Kblk + 1/KVV].)

Note: It may be possible to use the FE analysis of the blanket to calculate the mass moment of inertia of the blanket vertical segment.

Calculation of the maximum dynamic reaction force: Given the stiffness of the blanket + vessel structure, the static rotation of the blanket (load application region) shall be calculated for the peak radial moment. The related static strain energy in the structures shall be determined.
For the different gap sizes and loading durations specified the following entities shall be calculated over time and presented in graphs:

- The angular velocity of the blanket rotation: w
- The kinetic energy in the blanket: W_kin = 0.5Iw2, with I
- The strain energy in the blanket and vessel structure: W_ε = 0.5Kρ
- The work performed by the external load Mr: W_ext = int(Mr*dρ)
- The dynamic amplification factor shall be given in table form depending on gap size and loading duration.

References to this task:
[1] WP12-DAS02-T09: Electromagnetic analysis of the DEMO blankets, EFDA_D_2LJB6G

WP13-DAS-02-T09

Thermal analysis of accidental blanket temperature

Background: The temperature increase of a blanket vertical segment due to decay heat following a blanket coolant leak causing the blanket to be drained is an important parameter required in the design of the blanket attachment. The consequent thermal expansion therefore is a design driver for the blanket attachment concept.
Aim of this task: To determine the blanket temperature due to decay heat postulating a blanket loss of coolant event (blanket drained).

Task requirements and assumptions:

- In this task the HCLL blanket concept shall be considered only.
- A VVPSS shall be assumed capable to limit the vapour pressure to 1.5 bar.
- The blanket activation shall be based on WP12-DAS06-T03 (which considers the HCLL blanket concept).
- The operating condition of the HCLL blanket shall be according to WP12-DAS02-T04.
- The decay heat produced within the blanket shall be estimated based on WP12-DAS06-T03 (where the heat is determined for the cases 1 day, 1 week, and 1 month after plasma shut-down). A discussion of the task owner of WP12-DAS06-T03 shall therefore be sought to estimate the heat produced during the quasi steady-state condition. The time frame of what is called quasi steady-state condition in the frame of this task (expected to be ~100-1000s after shut-down) shall be studied and the outcome reported, e.g. based on transient accident analyses performed for ITER, see [2], figure 3.2.1-5.
- More than one case shall be assessed regarding the FW temperature of the other blanket segments and divertor cassettes. One case shall be that these have a uniform temperature of 300°C; additional cases shall be discussed at the KoM.
- The vessel inner shell shall be considered to have a uniform temperature of 100°C.
- The emissivity of the vessel inner shell shall be assumed to be 0.35 (based on ITER thermal shield SRD, para. 2.1).

- The emissivity of all blankets' side walls shall be assumed to be 0.35.
- The emissivity of all plasma facing tungsten armour (divertor and FW) shall be assumed to be 0.35.

<u>Scenario description:</u>
The analysis shall assess the condition after plasma shut-down. In this condition it is assumed in the frame of this task:

- That the inertial effect of the blanket material thermal capacity on the increase of the blanket temperature has become insignificant (the decay heat to be assumed needs to be estimated based on the time it takes to heat up the blanket close to the maximum temperature).
- That the rupture disk of the vacuum vessel pressure suppression system has burst and pressure and temperature of the in-vessel (helium) atmosphere are quasi constant allowing the assumption of a constant thermal convection coefficient.

The damaged blanket vertical segment is assumed in this task to have a single cooling loop which is drained as a consequence of the failure. Hence no heat is removed from the entire blanket vertical segment by the cooling circuit.

<u>Analysis:</u> A steady-state thermal analysis shall be performed to determine the temperature in a drained blanket vertical segment due to the decay heat produced by the activated blanket material. The LOCA shall be assumed to have occurred on an outboard blanket vertical segment. A 3D FE model shall be developed including:

- The failed blanket vertical segment (assuming 8 modules with 10 mm gap between the modules) with reasonably simplified geometry.
- The side walls of the adjacent blanket vertical segments facing the failed one (the gap between the drained blanket segment and the adjacent blanket segments shall be assumed to be 20 mm.)
- The vessel inner shell surface behind the failed blanket.
- The complete FW of the DEMO tokamak, excluding gaps and strongly simplifying the divertor PFC.

Two ways of heat loss shall be considered:

- Radiation loss
- Thermal convection (due to helium inside the plasma chamber)

No conduction (at the supports) shall be considered in this task. It can be assumed that no heat is removed through the LiPb loop.

Three cases shall be analysed (using the same FE model):

	Case 1	Case 2	Case 3
Thermal convection coefficient [W/(m²K)], see [3] chapter 1.4 and 2.11	0	4	20
In-vessel helium temperature [°C]	-	300	200

<u>References for this task:</u>
[1] ITER accident analysis report Vol. II, EFDA_D_2JPAXD

[2] ITER accident analysis report – figures, EFDA_D_2M4LZ5
[3] ITER Cryostat - Thermal Structural Analysis for the Helium Leak Accident Scenario, 2011, EFDA_D_ 2JPWLT

WP13-DAS-02-T10

Water-cooled FW Design and Analysis

Background: The FW heat load in DEMO is difficult to predict during plasma ramp-up and discharge flat top. During the ramp-up the thermal loads on the first wall depend on whether or not limiters are implemented in the design. For design simplification reasons it is preferable not to implement limiters. However, in ITER where there are no limiters, the FW heat load during ramp-up is currently specified to reach at different poloidal locations between 2 and 5 MW/m² - much higher than the FW heat load considered in past DEMO and power plant studies: 0.5 MW/m². The maximum heat load capacity of a DEMO FW of reasonable cost may impact the decision of the implementation of limiters in DEMO; it will also be a factor in the comparison of water- and helium-cooled blanket concepts.
Even if direct contact with the plasma can be prevented through the use of limiters the FW heat load in DEMO will remain uncertain to a significant degree until ITER becomes operational. It is therefore necessary to identify the technology limit with a high level of confidence. Given the uncertainty of the Eurofer operating temperature window two Eurofer FW design shall be considered in this task and compared to the performance of an austenitic steel FW:

1. Water in super-critical condition: to comply with the recommendations of the material group.
2. Water in PWR condition: to allow the use of existing BoP technology and to reduce the required operating pressure.

Aim of this task: To develop and assess candidate water-cooled FW design solutions for PWR and supercritical operating conditions with Eurofer as structural material and compare their performance to an austenitic steel FW. The structural feasibility of the FW design solutions shall be assessed using the FE method and optimized following the analysis results.

FW design development
Requirements and assumptions:

- Optimized designs for three FW concepts shall be developed in this task for the following operating conditions:
    1. Eurofer: PWR condition
    2. Eurofer: super-critical condition
    3. 316L(N): outlet temperature/pressure 250°C / 6.5 MPa
- Two types of designs shall be developed for each of the three concepts:
    1. The tungsten-coated plasma-facing surface of the FW shall be waved (as in EFDA_D_2M5EY8 (150 MB!), figure 5.4).
    2. The tungsten-coated plasma-facing surface of the FW shall be flat (as in the EU TBM or as indicated in WP11-DAS-IVCC-05-CEA, EFDA_D_2JP9W2, figure 3-11 or in EFDA_D_2LF3JH, figure 3.2).
- The FW cooling channels shall be integrated into the module box front plate (continuous joint along their complete length) and in the modules sidewalls in the same way as shown in EFDA_D_2LF3JH, figure 1.1.

- The cooling channels shall be circular tubes with a 2mm tungsten coating on their plasma-facing surfaces.
- Maximum allowable Eurofer temperature: 550°C
- Maximum allowable 316L(N) temperature: 450°C
- A literature study shall be carried out assuming reasonable values of the HTC [W/(m²K)]. The task owner of deliverable D2 shall be approached to discuss the HTC values considered in each concept.
- The heat transfer to the FW cooling channels from the LiPb behind the module cover plate shall be considered in this task.
- Material properties at 20 dpa irradiation at the FW shall be considered.
- During the dwell time (time between two pulses) it shall be assumed that the blanket coolant is circulated at the operational coolant inlet temperature and at operational pressure.
- The fatigue assessment shall be made assuming 5200 plasma pulses of 2h duration (EFDA_D_2LCY7A) to occur during the life of the FW and considering the recommendation made in WP12-DAS02-T11 as well as the on-going work in WP13-DTM03-T04.

<u>3D Catia models</u> shall be developed individually for the three design concepts described above for both types of design (flat and waved FW panel), i.e. in total six designs, including:

- The FW cooling channel (assuming toroidal coolant flow in the plasma facing FW panel) with a module toroidal width consistent with the equatorial outboard module developed in task T03.
- The module box front plate, which integrates the FW cooling channels.
- The extensions of the FW cooling channels along the module sidewalls (approximately radially aligned) including the bends.
- The FW armour (2mm tungsten).
- Position and type of joints established during fabrication (e.g. HIP, weld).

The design shall be optimized iterating with the FE analysis regarding FW performance, i.e. each FW shall be designed to the limit of the critical criteria.

<u>FE thermal-structural analyses</u> of the FW design concepts described above (with individual FE models) to calculate:

1. The primary stress due to coolant pressure (Class A) and due to a pressurized module box due to internal coolant leak (Class D), and
2. The secondary stress range between flat top operation and dwell time. Secondary stresses shall include effects due to FW heat load and differential thermal expansion between cooling channels and module box.

<u>Water-cooled CFX assessment:</u>
One Catia model developed as part of deliverable D1 “FW design development” corresponding to design concept 2 (PWR condition, either with flat or with waved FW panel) shall be used as a basis for a 3D CFX assessment. Pressure loss and surface heat transfer coefficient shall be determined for a range of water velocities to be agreed with the task owner of deliverable D1.

For benchmarking purpose a He-cooled FW channel shall be assessed and the results be discussed with the task owner of task T11.

WP13-DAS-02-T11

Helium-cooled FW CFX AssessmentHelium-cooled FW CFX Assessment

Background: The FW heat load in DEMO is difficult to predict during plasma ramp-up and discharge flat top. During the ramp-up the thermal loads on the first wall and depend on whether or not limiters are implemented in the design. For design simplification reasons it is preferable not to implement limiters. However, in ITER where there are no limiters, the FW heat load during ramp-up is expected to reach at different poloidal locations between 1 and 5 MW/m² - much higher than the FW heat load considered in past DEMO and power plant studies: 0.5 MW/m². The maximum heat load capacity of a DEMO FW of reasonable cost may impact the decision of the implementation of limiters in DEMO; it will also be a factor in the comparison of water- and helium-cooled blanket concepts.
Even if direct contact with the plasma can be prevented through the use of limiters the FW heat load in DEMO will remain uncertain to a significant degree until ITER becomes operational. It is therefore necessary to identify the technology limit with a high level of confidence. The experimental campaign at HETRA, KIT has clearly shown the potential for improved heat removal in case of helium coolant. It is therefore the aim to develop a FW cooling channel with improved performance for DEMO. Such candidates could be selected for testing in the HOZ2020 programme.

Aim of this task: To assess with 3D CFX calculations the performance of three candidate FW cooling channel geometries regarding heat removal performance and pressure loss:

- A geometry with transversal ribs.
- Two different geometries with semi-parallel ribs.

Task requirements and assumptions (helium-cooled FW):

- Helium inlet temperature: 300°C
- Helium mass flow rate: To be chosen such that the average outlet temperature is 370°C.
- Helium inlet pressure: 8 MPa
- FW coolant channel structural material: Eurofer
- Maximum Eurofer temperature: 550°C

WP13-DAS-02-T12

Helium-cooled divertor design and fabrication analysis

Background: To facilitate the integration of helium-cooled target plates, straight target edges would be preferable to jagged ones. It was shown by analysis in WP12-DAS02-T06 that a square-shaped finger has very similar performance compared to a hexagonal finger. The next step in the development process should therefore be the fabrication and high-heat-flux testing of square-shaped fingers.
However, concern was raised regarding the embrittlement of the (structural) tungsten-alloy thimble below 750°C. It was therefore considered in WP12-DAS02-T05 to use a tantalum alloy for the thimble instead (e.g. T111: Ta-8%W-2%Hf or another commercially available substitute material with similar doping). This would allow reducing the operational temperature into a similar range as for the helium-cooled blanket (and hence avoiding the need for ODS steel). However there are other candidate material technologies, e.g. the recently presented ductile tungsten laminate.

Aims of this task:

1. To develop a design of an multiple-finger-unit with square-shaped fingers including the inlet and outlet manifold and assess the thermo-hydraulic performance of the unit for two thimble material options: WL10 and T111.
2. To perform fabrication studies to manufacture square-shaped multi-jet fingers using an alternative to WL10 as thimble material, e.g. T111 or another commercially available substitute material with similar doping, or tungsten laminate.

Task requirements and assumptions

- For the purpose of this assessment a uniform heat flux of 10 MW/m^2 shall be assumed.
- The helium outlet temperature shall be ~700°C (WL10 thimble) and ~500°C (T111 thimble).

Thermo-hydraulic assessment of multiple-finger-unit
Steady-state thermal-hydraulic analyses of the multiple-finger-unit shall be performed for both thimble material options WL10 and T111. The analyses shall be reported and the related FE models and analysis macros be stored in the PPPT analysis database. The determined temperature distribution shall be passed on to the task owner of WP13-DTM03-T05 for a further structural assessment.

Fabrication of specially formed multi-jet fingers
The square-shaped fingers shall be designed based on experience gained with the hexagonal-shaped fingers and based on the thermo-hydraulic study performed in WP12-DAS02-T06. Catia models of the designs shall be prepared.
Focus of the fabrication study shall be the thimble. The material options to be studied will be discussed and selected in a meeting addressing the design of divertor targets to be organized by EFDA around April 2013.

WP13-DAS-02-T13

DCLL blanket design

Background: The dual-coolant blanket is a candidate for fusion power plants and possibly for DEMO. A low-tech DCLL blanket (LiPb outlet temperature <500°C) could be a candidate blanket for DEMO without losing its fusion-power-plant relevancy. This low-tech DCLL is currently considered to have the following features:

- He-cooled FW, blanket box and grid structure
- LiPb outlet temperature ~470°C (driven by corrosion)
- Structural steel: Eurofer
- FW design: like HCLL and HCPB (no ODS steel necessary)
- Electrical inserts without thermal insulation function: Eurofer-Insulator-Eurofer sandwich (AlOxide is a candidate for the insulator, in between two layers of Eurofer without brazing). This sandwich technology is a candidate to replace the SiC inserts whose fabrication is more challenging.
- In the absence of high-temperature (HT) steel, co-axial pipes are highly desirable for the LiPb outlet pipe of a HT DCLL (LiPb exit temperature ~700°C). However, co-axial feeding pipes for LiPb are not mandatory for the low-tech DCLL since all the coolant temperatures are < 500°C, allowing the use of ferritic steel for all the piping.
- LiPb – water HEX (Brayton cycle not possible due to low LiPb temperature)

- Vacuum permeator (since the LiPb outlet flow has a temperature < 500°C and the T partial pressure is expected to be in the order of 1 Pa, steel pipes can be used to allow T permeation into a vacuum chamber)

The identified main technical issues to be addressed are corrosion and MHD effects in local non-regular geometries. As a first step in 2013 the design of the LiPb flow channels shall be initiated and the related MHD effects be assessed.

This task is defined under consideration of the current limitations regarding MHD modelling (manifolds for distribution to no more than three channels, rectangular flow channel geometries only). Although these limitations require studying designs with drawbacks in other engineering disciplines, apart from experiments this is currently the only way to determine the MHD effects in the selected locations. The need to improve the capabilities of MHD modelling tools is recognized.

<u>Aims of this task:</u>

1. To develop and discuss the design of LiPb channels in manifold and module of a DEMO DCLL outboard blanket with a single rectangular LiPb inlet pipe connection.
2. To analyse the liquid metal flow in essential parts of the DCLL blanket:
   - The module internal manifold distributing the LiPb from one feeder into three parallel channels.
   - The main poloidal channel behind the first wall considering the varying toroidal width of the channel.
3. Development and benchmarking of liquid-metal corrosion transport tool with experiments
4. To carry out a fabrication study of Eurofer-insulator-Eurofer electrical inserts for a main rectangular poloidal channel with a focus on the possibility to bend the sandwich sheets.

<u>Task requirements and assumptions:</u>

- The poloidal length of this module shall be assumed in the frame of this task to be 3.0 m.
- The outboard blanket size considered in this task shall be consistent with the DEMO CAD model provided at the KoM. To relax the requirements to the computer resources the outboard blanket is chosen in this task where the magnetic field is smaller. The extrapolation of the results to the inboard blanket is not expected to be an issue.
- Eurofer-insulator sandwich insulating inserts shall be considered in this task.
- LiPb inlet temperature: 350°C, outlet temperature: 470°C.
- As liquid metal LiPb at the eutectic composition shall be assumed with 90% Li6 in the Li part.
- The DCLL module shall be assumed to have a He-cooled FW, blanket box and grid structure.
- The strength of the toroidal magnetic field shall be: B_tor(R) = 7.1T * 9m/R. For simplification B_tor may be considered uniform across the module. However, it shall also be attempted in the analyses to increase the magnetic field as close as possible to the inboard condition.
- Three different poloidal field configurations shall be considered in the MHD assessments (assumed uniform across the module):
  - B_vert = 0.4 T, B_rad = 0.2 T
  - B_vert = 0.4 T, B_rad = 0
  - B_vert = 0.4 T, B_rad = -0.2 T

- The volumetric heat load [W/cm³] shall be estimated for the locations to be considered in this task. The following references may be useful in the definition of the heat load: WP12-DTM04-T06 (WCLL blanket) and [1].

References to this task: EFDA IDM: https://user.efda.org/?uid=2LJMUP
[1] Li Puma, Specifications of loading conditions for WCLL and HCLL blanket modules thermo-mechanical analyses, 2012, EFDA_D_2L3UJY

WP13-DAS-02-T14

Design of vacuum vessel ports

Background: The vessel upper RH port is an important constrain for the development of a blanket RH scheme. In particular the internal toroidal width needs to be maximized. The plan to develop this port therefore is to first attempt a design with single-walled toroidal sidewalls.
Aim of this task: To design the upper outboard part of one sector of the vacuum vessel including one upper RH port.

Task requirements and assumptions:

- The vessel and port structural material shall be 316L(N).
- Some poloidal ribs of the vessel shall be continuous and plane (to ease the control of manufacturing tolerances).
- The poloidal ribs shall have a thickness of 40 mm.
- The inner and outer shell thickness shall be chosen in the range 40 – 60 mm.
- The shells between the ribs shall be single-curved, i.e. the vessel shall be faceted in toroidal direction.
- At the sector field joint the centre line of the adjacent poloidal rib shall be 165 mm off the symmetry plane.
- Vessel design pressure (during baking): 2.6 MPa @ 200°C
- Vessel structural criteria: Maximum elastic membrane plus bending stress due to coolant pressure: 1.5 Sm.
- The overall vessel geometry will be provided at the kick-off meeting.
- The upper vertical port shall be double-walled on the poloidal sides but single-walled on the toroidal sides.
- The vertical inclination of the port axis shall be 0°.
- The radial inner clearance of the port shall be 5400 mm.
- All port shells shall have a thickness of 60 mm.
- In-wall shielding design is not required.

Resources

Task ID	Title	ppy		HW
		PS	**BS**	**k€**
WP13-DAS02-T01	Coordination	0.2		
WP13-DAS02-T02	Water-cooled divertor target design study	1.2		
WP13-DAS02-T03	Water-cooled blanket design development	0.35		
WP13-DAS02-T04	Helium-cooled blanket design development	0.4	0.3	
WP13-DAS02-T05	Design of module attachment to manifold/backplate	0.6		
WP13-DAS02-T06	Literature study regarding sliding on load bearing surfaces		0.3	
WP13-DAS02-T07	Development of a blanket attachment concept	0.7		
WP13-DAS02-T08	Dynamic amplification of blanket load caused by a gap at the supporting key	0.35	0.4	
WP13-DAS02-T09	Thermal analysis of accidental blanket temperature	0.25		
WP13-DAS02-T10	Water-cooled FW Design and Analysis	0.5	0.3	
WP13-DAS02-T11	Helium-cooled FW CFX Assessment	0.6	0.4	15
WP13-DAS02-T12	Helium-cooled divertor design and fabrication	0.55	0.3	15
WP13-DAS02-T13	DCLL + MHD	0.7	0.3	15
WP13-DAS02-T14	Design of vacuum vessel ports	0.2		
Total allocated resources		**6.6**	**2.3**	**45**

2.4 Scientific and Technical Reports

Task	Report	Included deliverables
T01	Executive summary report	T01-D1
	Activity Management Plan	T01-D2
T02	WCD design description report	T02-D1, D2, D3, D4
T03	Design description report	T03-D1
T04	Design description report	T04-D1
	MHD assessment report	T04-D2
T05	Design description report	T05-D1
T06	Task report	T06-D1
T07	Design description report	T07-D1
T08	Task report	T08-D1
T09	Thermal analysis report	T09-D1
T10	Design description report	T10-D1
	CFX analysis report	T10-D2
T11	CFX analysis report	T11-D1
	CFX analysis report	T11-D2
T12	Design description report	T12-D1
	Fabrication report	T12-D2
T13	3D Catia model	T13-D1
	Design description report	T13-D2

	Design description report	T13-D3
	Report on corrosion transport study	T13-D4
	Fabrication description report	T13-D5
T14	Design description report	T14-D1

Milestones and Deliverables

Milestones:

Milestone ID	**Title**	**Date**
WP13-DAS02-M01	Kick Off Meeting	18 April 2013 (tentative)
WP13-DAS02-M03	Interim Review Meeting	11 Sept. 2013 (tentative)
WP13-DAS02-M04	Final Review Meeting	11 Dec. 2013 (tentative)
WP13-DAS02-M05	Issue of draft final report for review	31 Dec. 2013
WP13-DAS02-M06	Implementation of review comments, request for approval.	28 Feb. 2014

Deliverables:

	ID	**Title**	**Required**
Task	WP13-DAS02-T01	Coordination	
Del.	WP13-DAS02-T01-D1	Executive summary report	31.12.2013
	WP13-DAS02-T01-D2	Activity Management Plan	01.04.2013
Task	WP13-DAS02-T02	Water-cooled divertor target design study	
Del.	WP13-DAS02-T02-D1	WCD design description report	31.12.2013
	WP13-DAS02-T02-D2	Design description report	30.11.2013
	WP13-DAS02-T02-D3	Design description report	30.11.2013
	WP13-DAS02-T02-D4	Design description report	30.11.2013
Task	WP13-DAS02-T03	Water-cooled blanket design development	
Del.	WP13-DAS02-T03-D1	In-work design description report	31.08.2013
		Design description report	31.12.2013
Task	WP13-DAS02-T04	Helium-cooled blanket design development	
Del.	WP13-DAS02-T04-D1	In-work design description report	31.08.2013
		Design description report	31.12.2013
	WP13-DAS02-T04-D2	MHD assessment report	31.12.2013
Task	WP13-DAS02-T05	Design of module attachment to manifold/backplate	
Del.	WP13-DAS02-T05-D1	In-work design description report	31.08.2013
		Design description report	31.12.2013
Task	WP13-DAS02-T06	Literature study regarding sliding on load bearing surfaces	
Del.	WP13-DAS02-T06-	Task report	26.07.2013

	D1		
Task	WP13-DAS02-T07	Development of a blanket attachment concept	
Del.	WP13-DAS02-T07-D1	In-work design description report	31.08.2013
		Design description report	31.12.2013
Task	WP13-DAS02-T08	Dynamic amplification of blanket load caused by a gap at the supporting key	
Del.	WP13-DAS02-T08-D1	In-work task report	31.08.2013
		Task report	31.12.2013
Task	WP13-DAS02-T09	Thermal analysis of accidental blanket temperature	
Del.	WP13-DAS02-T09-D1	In-work analysis report	12.07.2013
		Thermal analysis report	30.09.2013
Task	WP13-DAS02-T10	Water-cooled FW Assessment	
Del.	WP13-DAS02-T10-D1	In-work design description report	31.08.2013
		Design description report	31.12.2013
	WP13-DAS02-T10-D2	CFX analysis report	31.12.2013
Task	WP13-DAS02-T11	Helium-cooled FW CFX Assessment	
Del.	WP13-DAS02-T11-D1	In-work analysis report	31.08.2013
		CFX analysis report	31.12.2013
	WP13-DAS02-T11-D2	CFX analysis report	
Task	WP13-DAS02-T12	Helium-cooled divertor design and assessment	
Del.	WP13-DAS02-T12-D1	In-work design description report	31.08.2013
		Design description report	31.12.2013
	WP13-DAS02-T12-D2	Fabrication report	31.12.2013
Task	WP13-DAS02-T13	DCLL design	
Del.	WP13-DAS02-T13-D1	3D Catia model	31.05.2013
	WP13-DAS02-T13-D2	Design description report	31.12.2013
	WP13-DAS02-T13-D3	Design description report	31.12.2013
	WP13-DAS02-T13-D4	Report on corrosion transport study	31.12.2013
	WP13-DAS02-T13-D5	Fabrication description report	31.12.2013
Task	WP13-DAS02-T14	Design of vacuum vessel ports	
Del.	WP13-DAS02-T14-D1	In-work design description report	31.08.2013
		Design description report	31.12.2013

Activity	*Priority Support Deliverables*	*Due Date*
WP13-DAS-02-T01	WP13-DAS02-T01-D1: Prepare an executive summary report of the outcome of the WP13-DAS02 activity. WP13-DAS02-T01-D2: Produce an Activity Management Plan in accordance with [1] to be submitted to the PPPT RO at least 3 working days prior to the Kick Off meeting.	31. Dec 2013
WP13-DAS-02-T02	WP13-DAS02-T02-D1 task coordination (0.2 ppy PS): A design description report on water-cooled divertor targets shall be prepared including: • The criteria for the feasibility assessment of the target concepts studied in this task. • The comparison of the defined criteria to observations made in past high heat flux experiments. • The description of the target design optimization studies. • Proposal of irradiation campaign and high heat flux experiments. WP13-DAS02-T02-D2 (0.4 ppy PS): For the CuCrZr-W-monoblock concept a design description report shall be prepared and provided to the task coordinator by 30.11.2013, including: • Discussion of the operating conditions and the rationale for the selection. • Rationale for the selection of the dimensions of the optimized design. • Assessment and verification against the criteria of the optimized design. WP13-DAS02-T02-D3 (0.4 ppy PS): For the two alternative Cu-alloy based concepts a design description report shall be prepared and provided to the task coordinator by 30.11.2013, including: • Discussion of the operating conditions and the rationale for the selection. • Rationale for the selection of the dimensions of the optimized design. • Assessment and verification against the criteria of the optimized design. WP13-DAS02-T02-D4 (0.2 ppy PS): For the Eurofer-W-monoblock concept a design description report shall be prepared and provided to the task coordinator by 30.11.2013, including: • Discussion of the operating conditions and the rationale for the selection. • Rationale for the selection of the dimensions of the optimized design. • Assessment and verification against the criteria of the optimized design.	31. Dec 2013
WP13-DAS-02-T03	WP13-DAS02-T03-D1: A design description report shall be prepared including: • The rationales of the blanket design concepts, • The description of the individual design parts. • Attached to the report shall be the CAD models. • The structural verification analyses. • Any calculation models used in the task shall be uploaded to the EFDA Analysis Database: https://user.efda.org/?uid=2KW9Q3	31. Dec 2013

<table>
<tr><td></td><td>An in-work version of the final report shall be issued by Aug. 31. This version shall include:
Table of contents
Preliminary list of references
Pictures showing the status of the CAD models</td><td></td></tr>
<tr><td>WP13-DAS-02-T04</td><td><u>WP13-DAS02-T04-D1 (0.4 ppy PS):</u>
A design description report shall be prepared including:
The rationales of the blanket design concepts,
The description of the individual design parts.
Attached to the report shall be the CAD models.
Any calculation models used in the task shall be uploaded to the EFDA Analysis Database: https://user.efda.org/?uid=2KW9Q3
An in-work version of the final report shall be issued by Aug. 31. This version shall include:
Table of contents
Preliminary list of references
Pictures showing the status of the CAD models
<u>WP13-DAS02-T04-D2 (0.3 ppy BS):</u>
An MHD assessment of the HCLL breeding unit shall be carried out to study heat transfer and the effect of convection. Preliminary results for uniform neutronic heat load shall be developed by Sept. 2013. The results for the non-uniform neutronic heat load based on WP12-DTM04-T06, including a parametric study on the effect of wall electric conductivity shall be determined by the end of 2013.
An MHD assessment report shall be issued by 31.12.2013.</td><td>31. Dec 2013</td></tr>
<tr><td>WP13-DAS-02-T05</td><td><u>WP13-DAS02-T05-D1:</u> A design description report shall be prepared including:
The rationales of the two module attachment concepts
The description of the individual design parts including a discussion of strengths and weaknesses
CAD drawings of the two module attachment concepts
The calculations of the structural verifications
The description of the thermal analyses of the module.
All calculation models used in the task shall be uploaded to the EFDA Analysis Database: https://user.efda.org/?uid=2KW9Q3
An in-work version of the final report shall be issued by Aug. 31. This version shall include:
Table of contents
Preliminary list of references
Drawings illustrating the status of the design work</td><td>31. Dec 2013</td></tr>
<tr><td>WP13-DAS-02-T06</td><td><u>WP13-DAS02-T06-D1:</u> A literature study shall be carried out regarding the feasibility of (gravity) load bearing sliding surfaces in the vacuum vessel. Subject of the review is the identification of promising materials/coatings/material pairs, friction coefficient, tendency to seize, irradiation resistance. The study shall</td><td>31. Dec 2013</td></tr>
</table>

	conclude on the feasibility of the considered materials/coatings/material pairs and indicate their limits regarding irradiation, number of sliding cycles, friction coefficient, temperatures, and bearing pressure. A report of this literature study shall be prepared and all references shall be attached to the report on PPPT IDM. • An in-work version of the final report shall be issued by April 30. This version shall include: • Table of contents • Preliminary list of references • List of materials/coatings/material pairs considered	
WP13-DAS-02-T07	WP13-DAS02-T07-D1: A design description report shall be prepared including: • The rationale of the developed attachment schemes for both blanket concepts. • The description of the individual design parts including temporary fixations during removal/installation. • The sequence of the blanket removal and the description of the first motion of the blanket from its operational position. This shall be described in a table with the columns: action (e.g. release bolt), element (e.g. bolt #7), and description (e.g. release preload but keep engaged). • The feasibility assessment of the attachments. • The calculation of the expected blanket heat loss during operation. • A list of assessments needed for the further blanket attachment development. • Attached to the report shall be the two CAD models. • Any calculation models used in the task shall be uploaded to the EFDA Analysis Database: https://user.efda.org/?uid=2KW9Q3	31. Dec 2013
WP13-DAS-02-T08	WP13-DAS02-T08-D1: A task report shall be prepared describing the estimate of the dynamic amplification factor of the blanket radial moment reacted by toroidal vessel keys. This report shall include: • Summary and recommendations of the literature study regarding the energy loss due to shock waves at impact. • The Eurofer and 316L(N) strength properties at impact loading of relevant velocity. • Description of FE analysis of the structure’s stiffness (material properties, elements and mesh, contact definition, boundary conditions, load application, results). • The calculations of the maximum dynamic reaction force on the toroidal keys including intermediate results, e.g. the graph of the energy balance over time. • The FE models with input macros and results shall be uploaded to the EFDA Analysis Database: https://user.efda.org/?uid=2KW9Q3 An in-work version of the final report shall be issued by Aug. 31. This version shall include: • Table of contents	31. Dec 2013

	• Summary and recommendations of the literature study regarding the energy loss due to shock waves at impact. • The Eurofer and 316L(N) strength properties at impact loading of relevant velocity. • Description of FE model (material properties, elements and mesh, contact definition, boundary conditions and load application) • Preliminary list of references. • As attachment: FE model.	
WP13-DAS-02-T09	<u>WP13-SYS04-T09-D1:</u> A thermal analysis report shall be prepared by 30.09.2013 describing the thermal radiation analysis. All analysis models including their macros/routines shall uploaded to the EFDA Analysis Database: https://user.efda.org/?uid=2KW9Q3 An in-work version of the final report shall be issued by July 12. This version shall include: • Table of contents • Description of FE model (material properties, elements and mesh, boundary conditions including discussions) • Preliminary list of references • Conclusions	31. Dec 2013
WP13-DAS-02-T10	<u>WP13-DAS02-T10-D1:</u> A design description report shall be prepared, including • The 3D Catia models of the developed six FW designs. • Description of the different FW designs considered. • Description of the FE analyses (material properties, elements and mesh, boundary conditions, load application, results/results comparison). • The Catia models of all FW designs shall be attached to the report. An in-work version of the final report shall be issued by Aug. 31. This version shall include: • Table of contents • Design description of all FW design concepts proposed for study • Preliminary list of references • The FE models with input macros and results shall be uploaded to the EFDA Analysis Database: https://user.efda.org/?uid=2KW9Q3 <u>WP13-DAS02-T10-D2:</u> A CFX analysis report shall be prepared including: • Description of the two FW designs assessed. • Description of the FE analyses (material properties, elements and mesh, boundary conditions, heat application and water velocity range, results/results comparison). • The FE models with input macros and results shall be uploaded to the EFDA Analysis Database: https://user.efda.org/?uid=2KW9Q3	31. Dec 2013
WP13-DAS-02-T11	<u>WP13-DAS02-T11-D1 (0.6 ppy PS):</u> An analysis report shall be prepared including: • Description of the different FW designs considered	31. Dec 2013

	• Description of the CFX analyses (material properties, elements and mesh, boundary conditions, load application, results/results comparison, comparison with similar studies made in the past.).
	• The results of the CFX assessments shall include:
	Surface heat transfer coefficient at relevant locations in the cooling channel
	Temperature distribution in the pipe cross-section at the end of the plasma-facing part of the FW cooling channel.
	Coolant velocity in the pipe cross-section.
	Pressure drop in FW cooling channel.
	Energy loss due to pressure drop related to removed heat.
	• The CFX models with input macros and results shall be uploaded to the EFDA Analysis Database: https://user.efda.org/?uid=2M8R5L
	
	An in-work version of the final report shall be issued by Aug. 31. This version shall include:
	• Table of contents
	• The results for the design with transversal ribs.
	• Preliminary list of references
	
	<u>WP13-DAS02-T11-D2 (0.4 ppy BS):</u> An analysis report shall be prepared including:
	• Description of the two FW designs considered:
	  ○ The design with transversal ribs considered in D1.
	  ○ A design with semi-parallel ribs.
	• Description of the CFX analyses (material properties, elements and mesh, boundary conditions, load application, results/results comparison, comparison with similar studies made in the past.).
	• The results of the CFX assessments shall include:
	  ○ Surface heat transfer coefficient at relevant locations in the cooling channel
	  ○ Temperature distribution in the pipe cross-section at the end of the plasma-facing part of the FW cooling channel.
	  ○ Coolant velocity in the pipe cross-section.
	  ○ Pressure drop in FW cooling channel.
	  ○ Energy loss due to pressure drop related to removed heat.
	  ○ In the case of the design with transversal ribs the results shall be benchmarked against those obtained in D1.
	• The CFX models with input macros and results shall be uploaded to the EFDA Analysis Database: https://user.efda.org/?uid=2M8R5L
	
	An in-work version of the final report shall be issued by Aug. 31. This version shall include:
	• Table of contents
	• The results for the design with transversal ribs.	

WP13-	<u>WP13-DAS02-T12-D1:</u> A design description report shall be prepared that includes	31. Dec

<table>
<tr><td>DAS-02-T12</td><td>the rationales of the design choices and describes the thermo hydraulic assessment:

The description of the designs of the two fingers
The description of the assembly of the fingers to a target plate
The rationale for the chosen parameters of the design.
The rational for the choice of the materials for the parts of the fingers.
Description of the CFX analyses (material properties, elements and mesh, boundary conditions, load application, results/results comparison, comparison with similar studies made in the past.).
The CFX models with input macros and results shall be uploaded to the EFDA Analysis Database: https://user.efda.org/?uid=2LAPN4
The CAD models shall be uploaded to the EFDA CAD database: https://user.efda.org/?uid=2LCVSX

An in-work version of the final report shall be issued by Aug. 31. This version shall include:

Table of contents
CAD model and description of the design of the multiple-finger-unit

Preliminary list of references

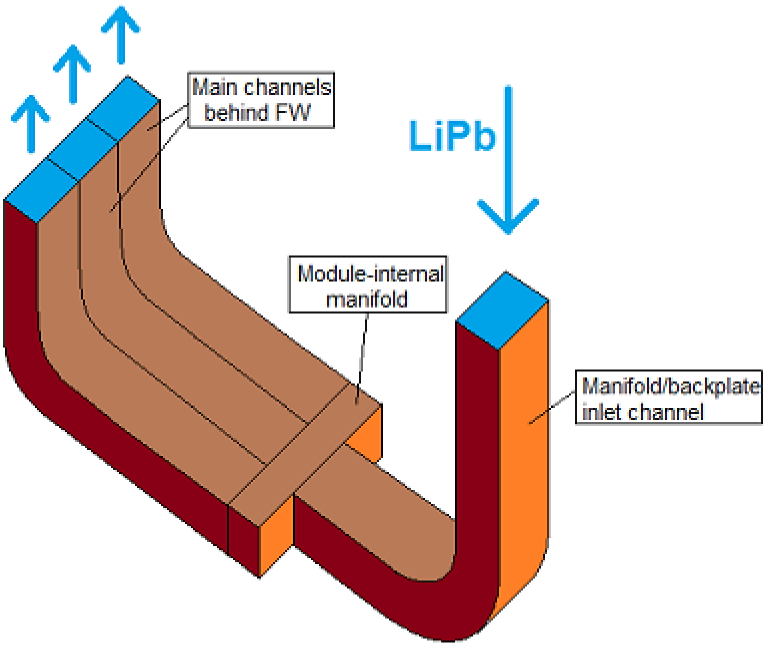
<u>WP13-DAS02-T12-D2:</u> A fabrication report shall be prepared including:

The description of the fabrication of the individual parts of the fingers
The description of the joining technologies
A proposal for future high heat flux testing of the candidate concepts including test facility, test parameters as well as estimated cost and time to perform the tests.
</td><td>2013</td></tr>
<tr><td>WP13-DAS-02-T13</td><td><u>WP13-DAS02-T13-D1 (0.15 ppy PS):</u> A design (3D Catia model) shall be developed of the LiPb flow channels routing the LiPb from the manifold/backplate into the module, distributing it into three parallel radial channels, which route it to the front of the module into the main poloidal channel behind the FW, see figure. The bottom module of the outboard blanket shall be considered in this task. The LiPb flow channels shall have rectangular shape to simplify the subsequent MHD analysis. A close contact with the task participant responsible for the MHD analysis is therefore required. The design development shall continuously be discussed with the task participant responsible for the MHD analysis.
The design development includes in particular:

A study based on assessments and DCLL designs done in the past regarding the required cross section of the LiPb manifold and the parallel LiPb main channels behind the FW.
The LiPb average flow velocity shall be defined under involvement of the other participants of this task and considering heat load as well as the inlet and outlet temperatures specified.
A survey of European and American DCLL designs shall be carried out. The bending radii of the liquid metal channels as well as the module-internal manifold shall be designed based on this survey as well as the module-internal manifold. The liquid metal pressure at inlet and in the main channels in the module shall be proposed based on this survey and be
</td><td>31. Dec 2013</td></tr>
</table>

discussed with the task participants responsible for the MHD analyses.

- The design shall comprise the following parts:
  - A part of the LiPb flow channel in the backplate/manifold
  - The LiPb flow channel entering the module
  - The module-internal manifold
  - Three parallel radial flow channels including the bends behind the FW
  - Three parallel poloidal flow channels over the complete length of the module
  - The insulating inserts in all LiPb flow channels
- The design shall be provided to the task participants responsible for deliverables D2 and D3 by 31 May 2013.
- A description of the design of the poloidal LiPb flow channels behind the FW as well as of the LiPb flow channel system shown in the figure below shall be prepared by 30.11.2013 and be provided to the task owners of D2 and D3 respectively for implementation in the task reports.
- The CAD models shall be uploaded to the EFDA CAD database: https://user.efda.org/?uid=2LCVSX



WP13-DAS02-T13-D2 (0.3 ppy PS): A MHD analysis of the shall be performed of LiPb flow channels routing the LiPb from the manifold/backplate into the module, distributing it into three parallel radial channels, which route it to the front of the module into the main poloidal channel behind the FW, according to the design developed in deliverable D1.

A design description report shall be prepared, including:

- The description of the LiPb flow channel system shown in the figure as provided by the task owner of deliverable D1
- A description of the MHD analysis, including all relevant parameters and boundary conditions as well as a description of the model geometry and

"mesh".

- The results of the MHD assessment shall include:
  - Liquid metal velocity profiles at relevant locations.
  - Liquid metal pressure profile at relevant locations.
- A graph of the average liquid metal pressure along the flow channel to illustrate where significant pressure losses occur.
- A discussion of the results and recommendations regarding:
  - The design of the module-internal manifold.
  - The possible consequences of having a module-internal manifold that distributed the LiPb not only to three but to 5 or 6 parallel channels.
  - The performance of the Eurofer-insulator-Eurofer sandwich insulating inserts.
  - The significance of the results to the inboard blanket.

<u>WP13-DAS02-T13-D3 (0.15 ppy PS):</u> A MHD analysis of the shall be performed of one poloidal LiPb flow channels behind the FW over the complete length of the module, according to the design developed in deliverable D1. The analysis model shall include the bend of the flow channel at the bottom of the module but does not need to include the bend at the top of the module.
A design description report shall be prepared, including:

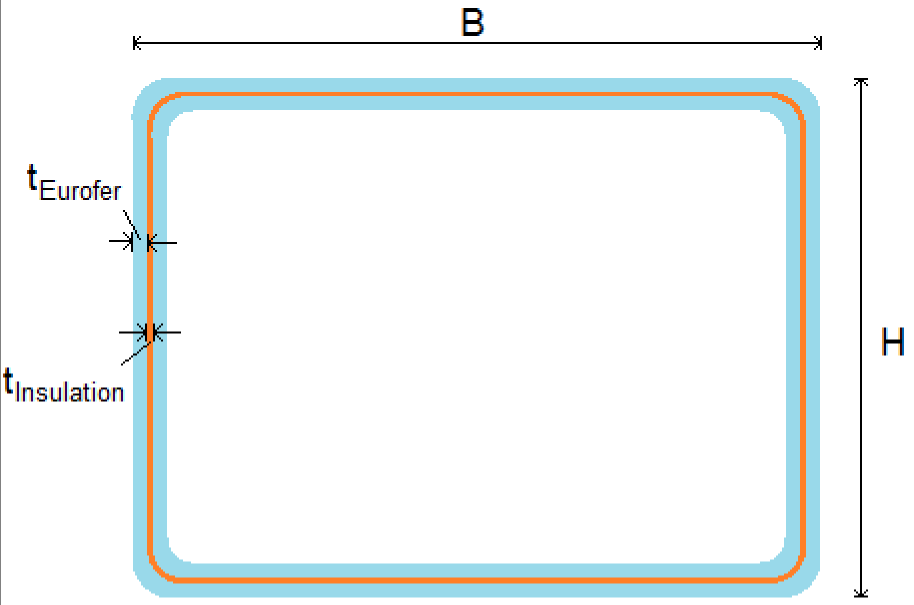
- The description of the design of the poloidal LiPb flow channels as provided by the task owner of deliverable D1.
- A description of the MHD analysis, including all relevant parameters and boundary conditions as well as a description of the model geometry and "mesh".
- The results of the MHD assessment shall include:
- A parametric study of the effect of the average LiPb flow velocity.
- A discussion based on the results of the effects of the increase of the channel toroidal width in flow direction.
- A discussion of the convection effects related to the non-uniform heat load distribution.
- A discussion of the significance of the results to the inboard blanket.

The analysis model(s) used in this assessment shall be stored on EFDA IDM: https://user.efda.org/?uid=2M5PTT

<u>WP13-DAS02-T13-D4 (0.3 ppy BS):</u> A tool shall be developed and benchmarked with relevant experiments for the numerical simulation of liquid-metal corrosion transport in a DCLL blanket. In accordance with the experiments, the simulations shall be performed for various geometric configurations, such as rectangular ducts, pipes, and concentric tubes, with velocities in the range of 0.01-0.3m/s (both laminar and turbulent flow regimes), temperatures 450-550°C, and magnetic fields up to 1.7T.
Finally, the feasibility and efficiency of various magnetic traps in a LiPb loop under DEMO conditions will also be examined by assuming that Fe is mainly dissolved.

<table>
<tr><td></td><td>A report on the described corrosion transport study shall be prepared by 31.12.2013.

<u>WP13-DAS02-T13-D5 (0.1 ppy PS):</u> A Eurofer-insulator-Eurofer electrical insert shall be fabricated for a poloidal flow channel behind the FW. The geometric dimensions shall approximately be:
• Cross section: B ~ 6cm, H ~ 5cm
• Poloidal length: L ~ 10cm
The geometry shall be discussed with the other task owners of this task regarding a possible future use of the insert in an MHD experiment. Focus of the study shall be the investigation of the process route to produce the bending radii at the corners of the cross section. Different means to improve the fabrication process shall be tested.



A fabrication description report shall be prepared including:
• The description of the intended and the achieved fabricated insert.
• The description of the fabrication process to fabricate the sandwich sheet.
• The description of the process chosen for the bending of the sandwich sheet.</td><td></td></tr>
<tr><td>WP13-DAS-02-T14</td><td><u>WP13-DAS02-T14-D1:</u> A design description report shall be prepared including:
• The rationales of the different parts of the design,
• The description of the individual design parts.
• Attached to the report shall be the CAD models.
• Any calculation models used in the task shall be uploaded to the EFDA Analysis Database: https://user.efda.org/?uid=2KW9Q3

An in-work version of the final report shall be issued by Aug. 31. This version shall include:
• Table of contents</td><td>31. Dec 2013</td></tr>
</table>

	• In-work CAD models • Preliminary list of references	

3. Assessment of the Heating and Current Drives (H&CD) Systems for DEMO Final Technical Specification WP13-DAS-03-HCD:

Task Agreement WP13-DAS-03-HCD:
Heating & Current Drive Systems

3.1 Introduction

The performance and reliability of the Heating and Current Drive (H&CD) systems is expected to play a strong role in the definition and analysis of well defined and self-consistent DEMO design points that balance physics and engineering requirements, which is currently in progress within the EFDA Power Plant Physics and Technology (PPP&T).

The activities on H&CD within the PPP&T in the last years have focused on the definition of the systems including a preliminary RAMI analysis for two versions of DEMO. The analysis, which has to be completed, shows that a long pulsed machine (DEMO-1) can be seen as an extrapolation of technologies used in ITER while the more advanced steady state machine (DEMO-2) requires fundamental studies for most of the H&CD systems in part due to more advance physics requirements (much higher installed powers requiring higher wall plug efficiencies).

The work to be conducted in 2013 is described in this document and takes into account the findings and recommendations of previous studies done within the EFDA PPP&T.

As the definition of the design and R&D needs for each system is strongly interlinked with the assumed DEMO H&CD requirements (e.g., assumed installed power, efficiency and operating parameter ranges such as beam energy, gyrotron frequencies etc.), the trade-off between a number of possible configurations involving various H&CD systems layouts (see table 1 below) must be analysed in detail in 2013, especially for DEMO-2. This study should provide a comparative evaluation of performance and design integration problems expected for each configuration layout, the knowledge gaps and R&D needs. In addition, this will be useful for defining the interfaces of the H&CD system with other systems e.g. remote handling and system integration and additionally there is some input from the other systems to the H&CD area e.g. the outcomes of tasks on magnets and neutronics.

As for last year, it is foreseen that all tasks of this activity are coordinated by one association representative (coordinating chair).

3.2 Objectives

The objective of this task is to consolidate the findings of activities conducted in 2011 and 2012 and to investigate the physics and engineering aspects of a number of possible configurations to satisfy physics and engineering requirements as emerging form the system code activities, assuming a number of consistent (albeit preliminary) plasma density and temperature profiles that have been studied in 2012. In view of the limitation of resources it is recommended to focus on the evaluation of H&CD aspects affecting the flat-top phase of the discharge, without precluding some possible considerations of plasma ramp-up and ramp-down issues.

A number of design cases need to be investigated in detail as part of this task in terms of performance, design integration, reliability, R&D requirements and costs. They are tentatively listed in the table below and they should be finalized after discussion with H&CD experts, taking into account information available to date on design option from systems code and work carried out in 2012 in DAS H&CD on profile assumptions and on preliminary scenarios on SYS-02. The advantages and disadvantages in terms of performance and integration of each option should be presented together with the R&D needed to fill the gaps. A risk register should be also prepared for each option pointing to the major risk and the available risk mitigation strategies.

Table 1: DEMO cases to be analyzed

	DEMO-1(A)	**DEMO-1(B)**	**DEMO-2(A)**	**DEMO-2(B)**
H&CD				
NBI or EC or both	50* MW	100* MW	200** MW	300** MW
MHD Control for (2,1) NTM				
· *EC*	~25*** MW	~25*** MW	~25*** MW	~25*** MW

Footnotes and Explanations
DEMO-1(A) only bulk heating foreseen, no CD
DEMO-1(B) CD assisted (longer) pulses
DEMO-2(A) CD assisted, steady-state plasma operation
DEMO-2(B) CD assisted, steady-state plasma operation with lower CD-efficiency
(For more details see /3/)

* to be confirmed by latest PROCESS calculations
** to be confirmed by PROCESS calculations
*** precise number to be evaluated in the first phase of the work package

The system integration of the possible DEMO H&CD system configurations is part of the PPP&T SYS-03 (system integration study). The several heating scheme options will be discussed regarding e.g. port size, injection angle, and port-power. This is here only mentioned but will be executed in the aforementioned SYS-03 assessments. These results must be reviewed and discussed after definition of the details in SYS-03 within the H&CD topical group again, possibly in several iterative steps.

3.3 Work Description and Breakdown

WP13-DAS-03-HCD-PC

PC

Physics activity coordination and basic physics heating & current drive simulations

Tasks

WP13-DAS-03-HCD-PC-T01 - Coordination

Since a number of Associations are expected to collaborate in this activity, a Coordinating Chair (Coordinator) shall be appointed to liaise with the EFDA RO and interact with the partner Associations within the activity to facilitate and control the work, to ensure that contributions are in line with the specification and to keep track of schedule. This includes in particular the definition of methodology to assess the H&CD capabilities of the systems for the various options to be analysed.

WP13-DAS-03-HCD-PC-T02 - Comparative analysis and final report preparation

The Coordinator is responsible for the preparation of the final report according to the agreed ToC (see appendix), which includes the evaluation of the contributions of all participating associations. Based on the outcome of the activity at least the following points shall be addressed in the summary:

a) The analysis of the capabilities of the H&CD systems for the various DEMO options. This should be done on the basis of kinetic, density and current profiles specified by PC-03 (see below).

b) The analysis of the technical readiness of the heating systems required to fulfil the H&CD tasks given above should be made. This should include an estimate of effort needed in development to arrive at the goal as well as an assessment of the risks in this development work.

WP13-DAS-03-HCD-PC-T03 - Basic physics simulations

FOR DEMO 1, analyses were made using flat and peaked temperature profiles. The simulations have to be finished to use them as input for the four candidate auxiliary H&CD systems.

For DEMO 2 a new 0-d case based on the so-called hybrid scenarios ' will be studied based on the 'improved H-mode scenario', also known as the 'hybrid' scenario, i.e. assuming flat elevated q-profile and a higher beta so that the bootstrap fraction is higher than in DEMO1.

For both DEMO1 and DEMO2, there should be a basic assessment of the CD requirements for (2,1) NTM stabilisation since both might be prone to (2,1) NTMs (it is assumed that other NTMs may be present, but do not have to be actively stabilised), as is the case in present 'improved H-modes'.

WP13-DAS-03-HCD-NB

NB

Technological maturity/development needs of Negative Ion Neutral Beam Injection Heating and Current Drive for DEMO

Tasks

WP13-DAS-03-HCD-NB-T01 - NBI Coordination

The coordinator is responsible for assembling, in accordance with the ToC, the final report on NBI general physics and technology, collating the results of the participating associations and ensuring adequate communication of information between participating parties to maximize the value of the physics and technology programme. It is expected that the coordinator will attend and use CCNB meetings as means to disseminate information.

WP13-DAS-03-HCD-NB-T02 - Source development: non-caesiated/alternative sources, oven, caesium management in multipole sources, power handling

Code development and theoretical work as well as practical investigations, to find a suitable test bed, since availability of BATMAN is expected to be low and ELISE fully occupied for ITER.

The drive to eliminate Cs is still strong. Alternative to Cs surface production materials, there should be investigations on other source designs and concepts such as the RF array, helicon and laser cluster. If it is not possible to eliminate Cs new strategies to manage it and minimize its use has to be developed. This requires understanding of its role and behaviour through experiment and modelling. Reducing the stripping loss is a strong driver for improving the efficiency and one way to achieve this is to reduce the operating pressure of the source. This could be pursued by a combination of the modelling codes developed in the past 3 years and experiment. Increasing the current density might be beneficial if there are no additional power handling issues introduced as a result. For the use of a RF source the power efficiency should be optimized and the problems associated with back-streaming investigated, since the power loading could reach 40 to 80MW/m2. This aspect will also benefit from reduced source pressure and improved accelerator pumping.

WP13-DAS-03-HCD-NB-T03 - HV development: improved voltage holding and stand-off distance reduction, breakdown management, other materials for bushings like ceramics, grounded source or other concepts with regard to the dark current

Reducing the system size is advantageous. Most of this arises from stand-off distances for HV. As breakdowns are inevitable it should be investigated how to manage them to minimise damage. Novel accelerator designs that improve the pumping of the grids should be investigated.

WP13-DAS-03-HCD-NB-T04 - System design: neutron shielding, duct materials, diagnostics, size reduction, CD/q-profile control implications, power handling

No work has been done so far on neutron shielding, duct materials, and cooling, diagnostics. The consequences of the CD/q-profile for NBI geometry needs to be reassessed in light of results from 2012, including the consequences of operating at optimized beam energies. If the system is smaller and the current density higher, power handling of components needs to be analysed. Cross reference to WP13-SYS-02-T07, for neutron streaming calculations.

WP13-DAS-03-HCD-NB-T05 - System efficiency improvements: feasibility of energy recovery (higher priority) and of photo-neutralizer schemes (lower priority)
Early studies on the feasibility of these systems prior to 2014-2020 programmes are required. The work should concentrate on the technological advances and engineering design requirements of such systems and, in particular, their integration onto a tokamak including consideration of the working environment. A preliminary development programme should be outlined that will answer the technological challenges and engineering issues. Comparative simulation should be done in the energy range from 1MeV to about 1.5MeV to show the drawbacks in CD efficiency when using lower beam energy.

WP13-DAS-03-HCD-NB-T06 - Data collection for comparison and benchmarking of modelling and simulation results with experimental data
To improve the impact of the various modelling programmes under way, it is desirable to provide validated experimental data for which the operating conditions are documented. The data collection will include information about the relevant source/plasma/beam conditions, the measurement method, the parameters measured and give references. It is particularly important that the data collection covers a historical period sufficient to encompass a wide experimental database to capture the initial tests of the features of negative ion systems now assumed commonplace (e.g. the suppression of extracted electrons).

WP13-DAS-03-HCD-EC

EC

Technological maturity/development needs of Electron Cyclotron Heating and Current Drive for DEMO

Tasks

WP13-DAS-03-HCD-EC-T01 - EC Coordination
The coordinator is responsible for assembling, in accordance with the ToC, the final report on EC general physics and technology, collating the results of the participating associations and ensuring adequate communication of information between participating parties to maximize the value of the physics and technology programme. It is expected that the coordinator will attend and use CCEC meetings as means to disseminate information.

WP13-DAS-03-HCD-EC-T02 - Modelling and physics activities: analysis of ECCD requirements for DEMO
Define the tasks of an ECCD system prescribed in table 1. For both DEMO-1 and for DEMO-2 this will include an estimation of the requirements for MHD control, current drive and heating. A first estimate of the launcher requirements and absolute power requirements should be obtained as well as requirements for power modulation in the case of MHD control. Of particular interest are the absolute power requirement and the power per launcher. It would also be beneficial to provide an estimate of the optimal power per gyrotron.

WP13-DAS-03-HCD-EC-T03 - Analyse development requirements of gyrotrons up to 250 GHz and investigate possible alternative generators

A moderate increase in frequency is needed but the exact value needs to be verified in order to find a reasonable compromise.
a) technology development required for high frequency mega-Watt gyrotrons
b) initial conceptual design work

From a technological point of view this topic is considered as the most important one for an EC system for DEMO. The RF generator will be the key element for any EC system. This task should also include numerical investigations and where necessary further numerical code development and improvements on existing codes towards gyrotron development. Existing codes have to be adapted to the DEMO-1 and DEMO-2 requirements. Basic activities which target on improvements and better understanding of components of gyrotrons, e.g. Magnetron Injection Guns (MIGs) has to be improved to achieve a higher efficiency, advanced concepts of emitter technologies and diagnostic tools for MIGs.
c) initial conceptual studies for alternative generators
d) Numerical code development and numerical investigations towards gyrotron development
e) Advanced concepts of emitter technologies and diagnostic tools for magnetron injection guns for gyrotrons

WP13-DAS-03-HCD-EC-T04 - Estimate the steering requirements of an ECCD launcher for use on DEMO
Assess remote steering and front end steering. In parallel with task on physics requirements of the EC system (WP13-DAS-HCD-EC-T02) a quantitative discussion of the relative merits of remote and front end steering should be provided. Issues to be addressed should include mechanical complexity and reliability and a clear RAMI analysis of the two types of steering should be provided.

WP13-DAS-03-HCD-EC-T05 - Step tuneable gyrotrons
Determine the relative merits of step tuneability vs. moving antennas. Both tuneability of gyrotrons and moving antennas can be used to change the deposition location of the EC power. An explanation of the flexibility provided by both solutions should be provided. In addition a development pathway and risk analysis of both potential solutions should be provided. Using this information a choice between frequency tuneability and antenna steering may be made.

WP13-DAS-03-HCD-EC-T06 - Additional physics studies
Coupling of EC waves to thermonuclear plasma is considered to be very efficient. However even a relatively small (of the order of a few %) fraction of uncoupled radiation can lead to machine damage and reduced efficiency. The goal of this study is to estimate the potential for machine damage and efficiency loss due to density perturbations near the plasma edge and due to mode impurity and non-ideal polarisation of launched EC waves.
a) density perturbations at the plasma edge
b) mode purity requirements and polarisation

WP13-DAS-03-HCD-EC-T07 - Feasibility and performance of broadband windows
Depending on the outcome of the assessment of step-tuneable gyrotrons, vs. moving antennas, launch initial work on broad band windows for gyrotron and transmission lines. Broad band windows can allow the operation, simultaneously, of gyrotrons operating at different frequencies which may be of consequence for an EC system that is to be used for EC breakdown assist, current

drive and MHD control. Broad band windows, however, are still at an early phase of development and their technical feasibility has still to be proven.

WP13-DAS-03-HCD-EC-T08 - EC assisted breakdown
With a view to minimising the electric field required to assure plasma breakdown in a DEMO machine it is required to estimate the power, frequency and polarisation requirement imposed by a DEMO like machine on an EC system designed for breakdown assist. Using the current coil set geometry and current distribution a first order estimation of power, frequency and polarisation should be obtained:

a) with a better understanding of the coil positions one can estimate the magnetic field contours in the vessel and find the flux null points
b) by finding the optimal frequencies
c) thru modelling effort to estimate power requirements and polarisation

WP13-DAS-03-HCD-IC

IC

Technological maturity/development needs of Ion Cyclotron Heating and Current Drive for DEMO

Tasks

WP13-DAS-03-HCD-IC-T01 - IC Coordination
The coordinator is responsible for assembling, in accordance with the ToC, the final report on IC general physics and technology, collating the results of the participating Associations and ensuring adequate communication of information between participating parties to maximize the value of the physics and technology programme. It is expected that the coordinator will attend and use CCIC meetings as means to disseminate information.

WP13-DAS-03-HCD-IC-T02 - DEMO-1 and DEMO-2 physics
In 2012, computations have been initiated to assess the heating and current drive potential of ICRH in DEMO-1. Further work is required in 2013 to address specific issues (such as the impact of the peakedness of the density profile, and the role played by the plasma composition). A similar exercise will be initiated for DEMO-2. The aim is to address coupling, wave propagation and damping in the usual (up to 100MHz) as well as the high (>100MHz) frequency ICRH range based on common input of a prescribed equilibrium provided to the modellers of the various auxiliary heating systems (NB, IC, EC, LH).

WP13-DAS-03-HCD-IC-T03 - Development of 2-D codes (with correct equilibrium)
At typical temperatures expected for DEMO, fast wave current drive with standard ICRH antennae becomes more efficient at higher frequencies. At such frequencies, several ion cyclotron layers simultaneously reside inside the plasma so that the parasitic absorption by fusion born alpha particles in a burning D-T-plasma becomes an issue as it reduces the current that can be driven for each Megawatt launched. To describe wave propagation and damping at arbitrary cyclotron frequency in a high density, high temperature plasma while fully accounting for the deformation of the externally launched wave spectrum caused by the finite poloidal magnetic field in the inhomogeneous plasma and for non-thermal populations is beyond the capabilities of present-day ICRH wave codes. The present task aims at developing tools enabling to ensure a sufficiently realistic description of the dominant wave modes.

In 2013, the focus is on hot but thermalized plasmas. On a longer time scale, more general tools need to be developed.

WP13-DAS-03-HCD-IC-T04 - Extension of the experimental data base
Experimental evidence of the current drive efficiency is available for DIII-D and Tore Supra, and a first assessment of JET current drive data was recently made in the PPP&T context. Compiling a more complete database and confronting it with numerical simulations is essential to get a better grasp on the potential of ICRH to drive current in DEMO.

WP13-DAS-03-HCD-IC-T05 - Understanding the voltage limits of the antennas
Present experiments are often limited by the voltage in the ICRF system. This will likely be the case also in ITER for certain edge plasma conditions. Understanding the theoretical reasons for those voltage limits would allow progress in increasing them.

Investigation antenna concepts that do not require operating near voltage limits

Certain antenna concepts promise much better coupling, thus allowing not to be limited by the maximum allowable voltage. We need to investigate if those antennas are viable for the next generation machines (e.g. distributed antenna-in-blanket concept).

WP13-DAS-03-HCD-IC-T06 - Investigations of the possibilities for an ICRF system to perform other functions than heating and current drive
Experiments on JET, among others have shown the effect on plasma rotation, transport of fast particles, influence on MHD (saw-tooth), etc. To what extend could the ICRF fulfil the functions that are needed during full discharge (pre-pulse, ramp-up, flat-top, ramp-down, post-pulse) in DEMO-1 and DEMO-2.

WP13-DAS-03-HCD-IC-T07 - Expanding the database on RAMI (reliability, availability, maintainability and inspectability) of ICRF systems
In the next machines reliability, availability, maintainability and inspectability will have an increased importance. Data is available on present experiments but not in a systematic way. This needs to be improved.

WP13-DAS-03-HCD-LH

LH

Technological maturity/development needs of Lower Hybrid Heating and Current Drive for DEMO

Tasks

WP13-DAS-03-HCD-LH-T01 - LH Coordination
The coordinator is responsible for assembling, in accordance with the ToC, the final report on LH general physics and technology, collating the results of the participating associations and ensuring adequate communication of information between participating parties to maximize the value of the physics and technology programme. It is expected that the coordinator will attend and use CCLH meetings as means to disseminate information.

WP13-DAS-03-HCD-LH-T02 - Conduct a deep self-consistent time dependent scenario analysis with LH helping the plasma ramp up and target formation prior to burning phase
Modelling of the ITER ramp-up by using all available former results of such studies may help to demonstrate the possible need in DEMO.

WP13-DAS-03-HCD-LH-T03 - Study very off axis LH CD during the burning phase for optimization of Bootstrap current
A careful analysis of LH damping on alpha particles, and their kinetics afterward, on these scenarios, will be necessary. At moment one can only guess on alphas profiles. Therefore these studies are necessary. Modelling of high density plasma should be taken into the focus.

Additionally a consequent final assessment of LH frequency has to be performed including assessing the efficiency. Parametric scans can be done to obtain the results.

WP13-DAS-03-HCD-LH-T04 - Evaluate parasitic fast electrons generated at the mouth of the antennas with proper SOL characteristics (or scanning its parameters)
The characterization of fast electron dynamics during LH experiments is a critical issue. Therefore fast electrons have to be investigated properly concerning their influence on coupling and wave propagation and therefore plasma performance.

WP13-DAS-03-HCD-LH-T05 - Identify needs for support for hardware R&D
More detailed work has to be done on basis of former work-programmes especially on:

- Windows (meet the RF-requirements e.g. power limits, neutron-resistance, number of windows, mechanical analysis, window-material {not necessarily CVD}, etc.)
- Klystrons (efficiency, frequency limits, market analysis of manufacturers etc.)
- Antennas / Launchers (neutron streaming, feeding, etc.)
- Main Transmission Line (optimisation, final choice, additional components like filters etc.)

For the antennas it is indispensable to investigate materials (which are neutron compliant) and to start studying the building procedure of the antenna front end with non-standard material.

WP13-DAS-03-HCD-LH-T06 - RAMI assessment/completion including analysis of existing data bases and extrapolation to DEMO LH System
On Basis of a former preliminary RAMI analysis the work has to be finished in a complete RAMI assessment for the DEMO LH system. The potential showstoppers for availability and/or reliability are of major interest for a DEMO fusion reactor.

WP13-DAS-03-HCD-LH-T07 - Assess the compatibility of LH CD with fuelling systems including pellets
Pellet injection for LH can be done by using ablation codes. This work has to be done by preventing overlapping of this activity with other PPP&T activities in Design Assessment Studies on Vacuum / Pumping and Fuelling Systems. A data exchange with the aforementioned activity is therefore a prerequisite to assess the LH CD opportunities.

Resources

Work breakdown:

Task ID	Title	Resource allocation [PPY] PS BS (foreseen)	
WP13-DAS-HCD-PC	PC: physics activity coordination and basic physics heating & current drive simulations	0.5	yes
WP13-DAS-HCD-NB	NB: common and specific physics studies; technology assessment	1.4	yes
WP13-DAS-HCD-EC	EC: common and specific physics studies; technology assessment	1.4	yes
WP13-DAS-HCD-IC	IC: common and specific physics studies; technology assessment	0.7*	yes
WP13-DAS-HCD-LH	LH: common and specific physics studies; technology assessment	1.0	yes
Total allocated resources		**5**	**-**

* In 2013 there will be cooperation between the ITER Physics Group (IPH) and PPP&T for the IC.

3.4 Scientific and Technical Reports

A monthly progress meeting (via videoconferencing) shall be organized by the coordinator covering the following points:

- Brief summary of activities carried out during the period
- Main problems / risks / opportunities encountered during the period
- Proposal of work for the next period
- Overview of schedule and resources if affected

Presentation(s) shall be submitted to the coordinator at least 1 working day prior to the meeting. Nevertheless a number of Review Meetings are foreseen during the course of the execution of the activity (see milestones) preferably by personal attendance. As a rule, interim and final review meetings have priority over progress meeting. The Interim and Final Review meetings shall concentrate on the detailed presentation of the deliverables due allowing sufficient time for discussion, while should also cover the above listed points of a general progress meeting.

Milestones and Deliverables

Milestones:

Milestone ID	Title	Date
WP13-DAS-HCD-M01	Kick Off Meeting *(to organize the work)*	Apr 2013
WP13-DAS-HCD-M02	Interim Review Meeting #1 *(to assess the status of the work and provide guidance for integration of the studies)*	Jul 2013
WP13-DAS-HCD-M03	Interim Review Meetings #2 (ditto)	Oct 2013
WP13-DAS-HCD-M04	Final Review Meeting *(to discuss the results)*	Dec 2013
WP13-DAS-HCD-P01 WP13-DAS-HCD-P02 WP13-DAS-HCD-P03	Additional Progress Meetings upon request mainly by videoconference *(to evaluate progress or potential problems)*	May 2013 Jun 2013 Nov 2013

Deliverables:

Task ID	Deliverable ID	Deliverable Title	Required for
WP13-DAS-HCD-PC: physics activity coordination and basic physics heating & current drive simulations	WP13-DAS-HCD-PC-T01	Activity Management Plan	M01
	WP13-DAS-HCD-PC-T02	Comparative analysis and final report preparation	M04
	WP13-DAS-HCD-PC-T03	Basic physics simulations	M02
WP13-DAS-HCD-NBI: common and specific physics studies; technology assessment	WP13-DAS-HCD-NB-T01	Coordination of NBI	M01
	WP13-DAS-HCD-NB-T02	Source development Code development and theoretical work as well as practical investigations	M04
	WP13-DAS-HCD-NB-T03	HV development and HV holding	M04
	WP13-DAS-HCD-NB-T04	System design	M03
	WP13-DAS-HCD-NB-T05	System efficiency	M03
	WP13-DAS-HCD-NB-T06	Data collection	M03
WP13-DAS-HCD-EC: common and specific physics studies; technology assessment	WP13-DAS-HCD-EC-T01	Coordination of EC	M01
	WP13-DAS-HCD-EC-T02	Modelling and physics activities	M02
	WP13-DAS-HCD-EC-T03	Analyse development requirements of gyrotrons	M03
	WP13-DAS-HCD-EC-T04	Estimate the steering requirements	M03
	WP13-DAS-HCD-EC-T05	Step tuneable gyrotrons	M04
	WP13-DAS-HCD-EC-T06	Additional physics studies	M03
	WP13-DAS-HCD-EC-T07	Feasibility and performance of broadband windows	M03
	WP13-DAS-HCD-EC-T08	EC assisted breakdown	M04
WP13-DAS-HCD-IC: common and specific physics studies; technology assessment	WP13-DAS-HCD-IC-T01	Coordination of IC	M01
	WP13-DAS-HCD-IC-T02	DEMO-1 and DEMO-2 physics	M02
	WP13-DAS-HCD-IC-T03	development of 2-D codes	M04
	WP13-DAS-HCD-IC-T04	extension of the experimental data base	M04

	WP13-DAS-HCD-IC-T05	understanding the voltage limits of the antennas	M04
	WP13-DAS-HCD-IC-T06	investigations of the possibilities for an ICRF system	M02
	WP13-DAS-HCD-IC-T07	expanding the database	M04
WP13-DAS-HCD-LH: common and specific physics studies; technology assessment	WP13-DAS-HCD-LH-T01	Coordination of LH	M01
	WP13-DAS-HCD-LH-T02	Conduct a deep self-consistent time dependent scenario analysis	M02
	WP13-DAS-HCD-LH-T03	Study very off axis LH CD	M04
	WP13-DAS-HCD-LH-T04	Evaluate parasitic fast electron	M04
	WP13-DAS-HCD-LH-T05	Identify needs for support for hardware	M04
	WP13-DAS-HCD-LH-T06	RAMI assessment	M04
	WP13-DAS-HCD-LH-T07	Assess the compatibility of LH CD with fuelling systems assessment/completion	M04

Requirements for Deliverables:

The deliverable is one document per HCD system plus one for the physics coordination produced according to the structure of the assessment report. The reports should be accompanied by an executive summary including the key findings and recommendations.
Deliverables (all except for the final report) shall be submitted three working days prior to the Kick-off (M01) or Interim Review Meetings (M02, M03) for review and shall be approved by the PPP&T RO at the meeting.

The presentations for presenting the outcome in a final review meeting shall be submitted (uploaded) lately one day prior to the Final Review Meeting (M04). The final reports shall be submitted until end of December 2013. After submission the RO is reviewing them and they shall be approved afterwards by the head of PPP&T.

Within the WP2013 it is requested from the Head of Department (HoD) to have at least one H&CD final report as mentioned above, the splitting in several reports is no longer promoted. The coordinators are responsible to deliver their single report which includes the outcome of their tasks and collecting all results of the associated members and contributors of their area. The coordinating chair should take responsibility for a summarizing report as executive summary with key findings and recommendations as mentioned above. This summary will help EFDA to define the next years work-programme. The template suggested from EFDA PPP&T can be found in [2].

For further details please see individual tasks.

Activity	*Priority Support Deliverables*	*Due Date*
WP13-DAS-03-HCD-PC	For further details see general description and individual tasks.	31. Dec 2013
WP13-DAS-03-HCD-NB	For further details see general description and individual tasks.	31. Dec 2013
WP13-DAS-03-HCD-EC	For further details see general description and individual tasks.	31. Dec 2013
WP13-DAS-03-HCD-IC	For further details see general description and individual tasks.	31. Dec 2013
WP13-DAS-03-HCD-LH	For further details see general description and individual tasks.	31. Dec 2013

References

[1] DEMO Activity Management Plan template PPP&T IDM direct access: EFDA_D_2LAWVX

[2] TEMPLATE_for_WP2012-Final Reports: EFDA_D_2L9TWS

[3] Kemp, Richard Summary parameter set for 2012 single-null DEMO1 design (refer to newest version available): DEMO1_July_12 (2LBVXZ)

4. : Diagnostics and Instrumentation Systems

Task Agreement WP13-DAS-04:

4.1 Introduction

DEMO diagnostics and associated control systems are besides other limitations constrained by the extreme environmental conditions, mostly due to the high neutron and gamma flux and fluence, and the stringent requirements on reliability, availability and maintainability. At the same time, plasma operation must be even more robust than in ITER since e.g. the pulse length is increased and disruptions have to be fully avoided.

The design of ITER diagnostics has progressed a number of issues, but it is expected that some of the systems used in ITER will not be adequate for DEMO.

Acronyms

Acronym	Definition
DAS	Design Assessment Studies
EFDA	European Fusion Development Agreement
PPP&T	Power Plant Physics and Technology Department (of EFDA)
WP	Work Programme
DEMO	Demonstration Fusion Power Plant
CDA	Conceptual Design Activity (2014-2020)
TRL	Technology readiness level
SXR	Soft X-ray
MSE	Motional Stark Effect
Marfe	Multifaceted Asymmetric Radiation from the Edge

4.2 Objectives

Scope

The activities related to the diagnostic and instrumentation system in DEMO should address specifically these systems that are essential for operating DEMO in a safe and reliable way. They need to have two essential general technical requirements:

1. Robustness with regards to the harsh in-vessel environment of DEMO (neutron fluence, temperature cycles, etc.).
2. Redundancy or rapid replacement capability to reduce the impact of failures during plasma operation.

The main diagnostic used in today's device for plasma positioning and shape control is the magnetics. However, other diagnostics could become alternatives and play a role in the plasma shape and control system.

A number of needed generic activities will be carried out during the pre-conceptual design activity phase:

- Building on the ITER analysis, assess diagnostics needs for machine protection, and basic control in DEMO.
- Selection of 'essential minimum diagnostic set' of diagnostic techniques and methodologies and identification of the required long lead diagnostics R&D.
- Assess and develop concepts for prospective novel approaches to feedback control of the DEMO burning plasma with 'sparse' data systems and robust actuators keeping in mind that burning plasma control is a new field with limited knowledge.
- Following the selection study, develop proposals for further hardened versions of key 'essential minimum diagnostic set'.
- Based on the results of the above control tool and sensor assessments, produce a plan for the development of appropriate diagnostic systems and data analysis tools.
- Assess general issues related with the integration of the diagnostics on DEMO.

The objectives for WP13-DAS04-DIAG are primarily:

1. Understanding the Diagnostics and Control requirements of DEMO.
2. Reviewing the current knowledge and availability of the diagnostics and control systems.
3. Reviewing the most relevant available technologies and their applicability to DEMO.
4. Proposing the necessary technology and Diagnostics and Control R&D programme to extend throughout the DEMO CDA phase.

4.3 Work Description and Breakdown

WP13-DAS-04-T01

Diagnostic Activity Coordination

The Coordinator shall be responsible for:

1. Producing and maintaining an Activity Management Plan as per [1].
2. Ensure all deliverables/reports are produced and reviewed within the agreed timescales.
3. Preparing an executive summary on the results of the overall activity incl. recommendations for the coming year(s).
4. Chairing and producing minutes for the kick-off, interim and final meetings.
5. Calling any ad-hoc meetings as necessary for the purpose of discussion, clarification, communication, progress reporting etc.
6. Participate in the planning and execution of the peer review meeting described in task T02 below.

WP13-DAS-04-T02

Review of DEMO Diagnostic Issues and Requirements, R&D plan for CDA

1. Review and determine the measurement requirements of DEMO in particular diagnostics and control needs to protect a DEMO divertor and first wall.
2. Review and determine the requirements and needs of controlling DEMO burning plasmas.
3. Review the overall diagnostics and control requirements for a DEMO plant. Assess the current status of technology and R&D in each of the relevant segments. The outcome shall be a requirements vs. TRL (Technology readiness level [2]) matrix.
4. Select the diagnostic technique and defining 'essential minimum diagnostic set' of diagnostic techniques (making it clear where any future R&D is necessary to make sure what is possible and what is not, using as a basis the existing diagnostics set of ITER/JT60SA and also considering novel techniques).
5. Review the issues associated with the neutron flux/fluence, gamma flux, dust accumulation and neutral particle deposition on optical surfaces, and the access requirements and the reliability for the application to DEMO of the ITER diagnostics for machine protection, and basic (advanced) control. Engineering aspects for system components and detectors like flow-meters and thermocouples should be included here as well.
6. Develop and propose a R&D plan for diagnostics and control systems (incl. technology specific issues) to be further investigated during the conceptual design phase (CDA) of DEMO.
7. Hold a peer review meeting engaging diagnostic experts from Associations and other fusion organisations, to gather comments and feedback so as to finalise the proposed plan with a high probability of general success. If possible involve organisations and individuals from outside Europe plus European industry.

WP13-DAS-04-T03

Plasma Periphery Magnetic diagnostics

1. Establish the measurement requirements that the plasma periphery magnetic diagnostics should fulfil in the plasma burn control of a DEMO reactor. This task is meant to provide the boundary conditions for the magnetic diagnostic in control of DEMO plasma scenario. Examples of missions usually attached to these diagnostics include: plasma shape control, vertical stabilisation system, MHD and disruption (Halo Current and Vertical Displacement Event forces) prevention. For all these missions the conceptual requirements should be clearly established. For each of these sensors the frequency response requirements should also be given since most of these detectors are likely to be installed in the shadow of the blanket.
2. Review the technology for ensuring reliable and lifetime of inductive type of detectors in DEMO. Review the technology for the manufacture of magnetic probes to be used in a harsh environment like that of DEMO. In present tokamaks, the magnetic probes have long been designed to cope with temperatures up to 300°C and resilience to vacuum conditions but in DEMO there are many radiation-induced effects to be considered. Electrical components such as wiring, insulation material, connections inside the vacuum vessel, etc. should be examined with respect to radiation induced conductivity, electrical and mechanical degradation and radiation-induced voltages Boundary limits for different material should be provided to give initial guidance to manufacturers.

3. Review the issue related to long steady state discharge on the inductive magnetic sub-system. This mission shall i) investigate novel techniques to convert steady state measurements into the measurement of an oscillating magnetic flux: rotating pick-up coils, coils with oscillating orientation, small local plasma oscillations, etc. These techniques should be reviewed and their advantage/drawbacks detailed. ii) Investigate alternative and novel non-inductive techniques such as metallic Hall probes or powered coils attached to resistive restrain gauges.
4. Faraday rotation techniques for measuring the edge magnetic field could be considered in optical fibres around the plasma as an alternative to the inductive sensors. Such measurement could be also used to monitor the currents in the metallic structures. Life time of optical fibres materials and their possible protections should be examined as well as part of the R&D.

WP13-DAS-04-T04

'Conventional' laser Polarimetry and Motional Stark Effect polarimetry on 1.5MeV DEMO beams

Laser Polarimetry is one of the standard diagnostic systems used widely in today's fusion devices for the reconstruction of the current profile, working on the principle of the Faraday rotation and Cotton-Mouton ellipticity of polarised wave. This effect could be used in DEMO for estimating the current inside the discharge for current profile control.

1. Assess which wave length would be the most adequate for the use of the polarimetry for measuring current profile in DEMO. The wavelength is essential as it is a balance between sufficient Faraday Effect and wave refraction in the plasma by the density gradients. By considering typical DEMO plasma, this task should provide an assessment of the range of wavelength necessary and, in this range, which light source or laser could provide such a wave in a reliable way (i.e. on long duration).
2. Assessment of relativistic effects on plasma polarimetry as DEMO plasmas will have peak temperature higher (or of the same order of) ITER.
3. Assessment of the possibility of the measurements of plasma density through the Cotton-Mouton ellipticity and Faraday rotation.
4. Assessment of refraction effects in the propagation of the laser beam in DEMO plasmas.
5. Assessment of the use of recessed mirror plug in the DEMO blanket. Several devices in Europe (JET, AUG, Tore Supra) are using mirror plugs fitted on the inner wall of the machine to reflect the incoming beam of the interfero-polarimeter back to optical path. These mirrors are making possible the use of horizontal chords in these devices. For DEMO, an assessment should be done: i) whether metallic mirror or light extractor (reflective or diffractive) could be fitted on the in the range of wavelength assessed in point 1 or also for shorter wavelength for the benefit of optical diagnostics such as spectroscopy, ii) an assessment should be included about the life expectancy of such a device with regard to deposition, erosion, swelling and distortion., iii) the prospects for in-situ cleaning and polishing, recoating, or rapid replacement should also be assessed.
6. Taking into account the project already defined on ITER, make preliminary evaluations on the possibility of using a Motional Stark Effect (MSE) polarimetry system on one 1.5MeV heating beam of DEMO
7. Compare the difficulties of implementation of laser polarimetry and MSE and the relative merits of these diagnostics on DEMO.

WP13-DAS-04-T05

Microwave diagnostics including Reflectometry

Microwave techniques may also be feasible in DEMO without large modification from the present reflectometry system practice in today's tokamaks. So microwave reflectometry could be considered to second the magnetics and measure the position of a particular density layer in the edge region of the plasma. This technique is already planned in ITER. Reflectometry could therefore become a key diagnostics in plasma control in DEMO.

1. Review the possibility of using microwave diagnostics including reflectometry for diagnosing and controlling DEMO plasmas.
2. Review the frequency access to the edge density in DEMO using either O-mode or X-mode. X-mode reflectometer may require several frequencies depending on the magnetic field variation during plasma ramp-up etc. The best option for typical DEMO plasma should be examined.
3. Review the present understanding of the circumstances and extent to which the contours of electron density measured by the reflectometry do not always follow the magnetic flux surfaces, e.g. due to plasma rotation or Marfe phenomena.

WP13-DAS-04-T06

Neutron, gamma ray and Soft X-ray diagnostics

1) Neutron and Gamma ray diagnostics

Neutron and Gamma measurements (e.g. spatial distribution, etc.) in DEMO will play an essential role. It is therefore planned to conduct a preliminary study for the motivation and possibility of installation of neutron/gamma ray diagnostics on DEMO.

2) Soft-X ray diagnostics

Soft X-ray is a common diagnostic on tokamaks for physics studies, MHD identification, impurity transport etc. Here the possibility to use soft X-ray having many chords with fine spatial resolution, one can envisage a system of binary, 'knife-edge' SXR sensors that measure only where the plasma boundary is and how sharp the edge gradients are. Such sensors would be economical enough to be deployed at many poloidal and toroidal locations for control of plasma position and shape and for active mitigation of ELM activity. For achieving this, an R&D program on detectors is required.

- Investigate and review sensors in the SXR range insensitive to gamma/neutron and radiation resistant. High Z nano-structured photocathodes could be envisaged for example.
- Like for other optical instruments an optical diffractive extractor would be necessary. In connection with the R&D on reflective mirrors, research on diffractive solutions should be undertaken. Techniques like metal Fresnel plates or metallic gratings could be considered here if their reflection coefficient is sufficient.

Resources

Task ID	**Title**	**PS proposed effort (ppy)**
WP13-DAS04-T01	Diagnostic Activity Coordination	0.1
WP13- DAS04-T02	Review of DEMO Diagnostic Issues and Requirements, R&D plan for CDA	0.5
WP13- DAS04-T03	Plasma periphery magnetic diagnostics	0.1
WP13- DAS04-T04	'Conventional' laser Polarimetry and Motional Stark Effect polarimetry on 1.5MeV DEMO beams	0.1
WP13- DAS04-T05	Microwave diagnostics including Reflectometry	0.1
WP13- DAS04-T06	Neutron, gamma and Soft-X ray diagnostics	0.1
	TOTAL Priority Support (PS)	**1**

Note: Baseline Support will be granted as appropriate.

4.4 Scientific and Technical Reports

See section 'Deliverables" below.

Milestones and Deliverables

Milestones:

Milestone ID	**Title**	**Date**
WP13-DAS04-M01	Kick Off Meeting	Mid-March 2013
WP13-DAS04-M02	Interim Review	Sept 2013
WP13-DAS04-M03	Final Review	Mid Dec 2013

Deliverables:

Task ID	Deliverable ID	Deliverable Title	Required for Milestone
WP13-DAS04-T01	D01	Diagnostics Activity Management Plan	M01
WP13-DAS04-T02	D02	Report: "Overall DEMO Diagnostic & Control Requirements and associated issues"	M03
	D03	Report: "Diagnostics and control requirements vs. their maturity "	M03
	D04	Report: "DEMO Diagnostic and control development plan during a DEMO CDA"	M03
WP13-DAS04-T03	D05	Report: "Review and status of magnetic diagnostics for DEMO"	M03
WP13-DAS04-T04	D06	Report: "Review and status of Polarimetry and alternative Core Plasma Magnetic Diagnostics for DEMO"	M01
WP13-DAS04-T05	D07	Report: "Review and status of Microwave reflectometry for DEMO"	M03
WP13-DAS04-T06	D08	Report: "Review and status of Neutron and Gamma ray diagnostics for DEMO"	M03
	D09	Report: "Review and status of Soft X-ray diagnostic prospects for DEMO"	M03

- Reports within one task shall be, and reports across tasks can be, combined in one report.
- For each report a draft version shall be submitted to the task coordinator in advance of M03 for initial review.

References

[1] DEMO Activity Management Plan template

EFDA IDM direct access: https://user.efda.org/?uid=2LAWVX

[2] http://en.wikipedia.org/wiki/Technology_readiness_level

5. : Vacuum/ Pumping and Fuelling Systems

Task Agreement WP13-DAS-05:

5.1 Introduction

A thorough assessment of the available vacuum pumps for the use in the DEMO and later in fusion power plants resulted in the proposal of a pumping train consisting of three pumps as follows:
- liquid ring pump as a roughing pump
- diffusion pump as a high vacuum pump, ideally used only during dwell and for conditioning the vessel
- metal foil pump as a high vacuum pump and H isotope separator, ideally used only during operation

This set of pumps would provide the advantage of continuous work capability, avoiding power and time consuming regeneration, and as part of the DIR concept (Direct Internal Recycling) the separation of H isotopes close to the vessel and recycling into the fuel cycle to avoid heavy load on the T plant and too high inventory of T in the system. The proof-of-principle tests and the theoretical modelling of the proposed alternative set of vacuum pumps were started in 2012 and shall be continued during 2013.
Maintaining in parallel a backup solution, the theoretical investigation on cryopump with H isotope separation was started up to be able to present a feasible solution in case the above set of pumps would fail proof-of-principle testing. During 2012 promising results have been achieved with the modelling of a 3 stage cryopump, in which
- stage 1 is an 80K temperature bare metal surface
- stage 2 is a 15K temperature charcoal surface
- stage 3 is a 4K temperature charcoal surface

The cryopump could be regenerated in two steps, releasing the He at the temperature of about 30K and then releasing D and T at the temperature of about 110K providing a partially purified mixture of D and T, which might be suitable for Direct Internal Recycling.
The fuelling of DEMO requires a step change compared to existing machines. Earlier assessments proved, that neither the physics nor the technology can be regarded as mature at this stage. Report in 2011 recommends a way forward through several experimental steps investigating the most promising technologies further, such as the gas puffing, pellet fuelling and compact toroid fuelling.

5.2 Objectives

Vacuum pumping:
- Continuing the proof-of-principle testing of the candidate vacuum pumps (liquid ring pump)
- Experimental validation of the DIR concept and comparison experimental vs. modelling results
- Further investigating a 3 stage cryopump providing isotope separation through experiment
- Prepare a fundamental experiment to characterise the gas-sorbent interaction in the temperature range of interest for a 3-stage cryopump
- Investigating the DEMO relevancy of a cryo-mechanical pump

Fuelling:

- Updating preliminary fuelling requirements for the two DEMO design options currently investigated (Early DEMO and Advanced DEMO)
- Detailed planning of experiments based on a survey carried out on the future intention of other international parties involved (e.g. US in ITER fuelling)
- Crosschecking existing pellet fuelling experimental data of larger tokamaks for trend analysis

5.3 Work Description and Breakdown

WP13-DAS-05-T01

Investigation of candidate vacuum pumping systems

Proof-of-principle testing of pumps:

Tests were started up in 2012, but further testing is required to proof the principle of the metal foil pump.

Based on literature review and modeling work done in 2012 [ref. WP12-DAS05], the proof-of-principle testing of the liquid ring pump with T compatible liquid metal working liquid (mercury as a first candidate), shall be carried out. As a preparation a small size unit was ordered and the THESEUS facility at KIT (Karlsruhe, Germany) prepared to host the testing. This includes the implementation of a gas analyzing system to find out if the mercury content in the system is as low as expected. This is very important as it could be a serious problem of the concept.

With providing sufficient data on the liquid ring pump the overall alternative pumping concept could be evaluated and further R&D work identified.

Design development and infrastructure assessment for diffusion pumps:

Based on the successful proof-of-principle testing done in 2012, the development of a diffusion pump shall be continued. This includes a CAD design proposal, for which a linear shaped configuration with two integrated baffles and external boiler shall be studied. This information is important already in an early stage of the new pumping concept development as it is has strong consequences on the infrastructure needed for pump supply. For this work, the simulation code being developed under T1 will be used for optimization and design development.

Investigation of the metal foil pump:

In case of a positive outcome of the proof-of-principle testing, the metal foil module still needs significant further investigation as the maturity of this solution is still rather low. Therefore the theoretical investigation shall be continued.

Modeling activity:

Modeling of the pumps so as to have a design tool and to minimize experimental work afterwards has been started in 2012 and shall be continued and refined in 2013. The validation of the models to the proof-of-principle experiments shall be carried out.

WP13-DAS-05-T02

Further examination of isotope separation in a cryopump

Continuing development of cryopump with isotope separation:

In 2012, as a first step, the DSMC code has been validated against a known benchmark, namely the one in Sharipov's paper [1] through a very simplified test case [2]. The set up for the benchmark calculation was on a "flow through a short tube radius (R) length (L) connecting two infinite

reservoirs of gas at pressures p1 and p2 and temperatures T1 and T2 “.
Then the first calculations with the code resulted in a number of pumping speeds for He, D and T in case of different mixtures of fuelling gas [3]. In 2013 the theoretical investigation of a cryopump with isotope separation shall be continued reviewing all available information on the topic to be able to lay down a firm basis for the experimental validation.

Conducting an open panel experiment:
The molecular modelling work revealed the sensitivity of the final result on the value employed for the sticking coefficient between the hydrogen isotopes and the charcoal. This information would be needed for a varied temperature range and for pure gases as well as helium/hydrogen mixtures. This information is well known for the 4K stage from the extensive R&D done for the ITER cryopumps which have only one charcoal coated stage of 4K. On the other hand the information is missing for the intermediate temperature stage. This is especially problematic because the sticking coefficient of the hydrogen species is expected to vary significantly at this temperature. Moreover, the evolution of sticking with increasing sorbed amount is unknown but of major importance to design the pump such that prescribed inventory limitations are safely met. It is also known that these properties cannot be calculated. Therefore a rather simplified open panel test experiment shall be conducted to characterise the gas-sorbent interaction in the temperature range of interest. This shall be a fundamental experiment with simple geometries to keep the costs down despite being cryogenic. The ultimate goal of this testing is to validate the staged cryopump concept and to create a database of sticking coefficients of the related gases on charcoal surface in several temperatures, upon which the design of a real pump can be developed. The experiment itself shall be executed in the ITER cryopump test facility (KIT-TIMO2, Karlsruhe, Germany) to benefit from the existing and well calibrated vacuum and cryo-instrumentation and existing components.

WP13-DAS-05-T03

DEMO fuelling study

DEMO requirements:
The basic system requirements defined as part of the 2011 activity for fuelling DEMO (Early and Advanced) shall be updated based on the currently available information and assumptions (ranges). The goal of this task is to provide support in preparing the high level requirements of the DEMO fuelling system, which shall be part of the system integration project, a “live” document that would then drive the future development in the field.

Planning of supporting experiments:
In 2011 a literature review had been carried out and resulted in a few recommendations for the way forward, most of which consider the realization of experiments of different level of complication. The present subtask shall include a survey on future intention of international collaborators in fuelling, e.g. the US, which is heavily involved in the ITER fuelling system design. Based on this knowledge and the message of the European Fusion Roadmap (soon available at EFDA IDM with all the technical annexes), the description of the required experiments shall be carried out.

Crosschecking pellet fuelling experimental data:
A huge number of experimental data is available around the world in the field of tokamak pellet fuelling. Therefore the following activities are foreseen as part of this subtask:

- identification of relevant devices with pellet fuelling database (along with contact persons)
- collection of relevant data on ablation, drift and deposition of pellet material
- crosscheckng to theory

- analysing trends
- draw conclusions with special attention to DEMO relevancy

WP13-DAS-05-T04

Investigation of DEMO relevancy of a cryo-mechanical pump

An alternative backup solution to the non-cryogenic pumping train investigated in the frame of the Vacuum pumping activity in 2012 and continued in 2013 might be a cryo-mechanical pump (namely turbo-molecular and/or viscous stages working at cryogenic temperatures). The contributor(s) in the present task shall investigate the DEMO relevancy of this technology based on the key DEMO vacuum pumping requirements. The activity foresees the following steps:

- Collection of the relevant key requirements, presentation for discussion among all the contributors of the current activity and formal approval by the EFDA RO
- Relevancy analysis taking each requirements identified in the previous step into account following a logical pair structure: requirement – result of the investigation on the given requirement

Resources

Task ID	**Title**	**Resource allocation [PPY]**		**Hardware [kEuro]**
		PS	**BS**	
WP13-DAS05-T01	Investigation of candidate vacuum pumping systems	1.1	possible	70
WP13-DAS05-T02	Further examination of isotope separation in a cryopump	0.6	possible	55
WP13-DAS05-T03	DEMO fuelling study	0.3	possible	-
WP13-DAS05-T04	Investigation of DEMO relevancy of a cryo-mechanical pump	-	possible	-
Total allocated resources		**2**		**125**

5.4 Scientific and Technical Reports

N/A

Milestones and Deliverables

Milestones:

Milestone ID	Title	Date
WP13-DAS05-M01	Kick Off Meeting	Apr 2013
WP13-DAS05-M02	Interim Review Meeting	Jul 2013
WP13-DAS05-M03	Final Review Meeting	Dec 2013

Deliverables:

Deliverable ID	Title	Required for Milestone
WP13-DAS05-D01	Final report on "Investigation of candidate vacuum pumping systems"	M03
WP13-DAS05-D02	Final report on "Further examination of isotope separation in a cryopump"	M03
WP13-DAS05-D03	Final report on "DEMO fuelling study"	M03
WP13-DAS05-D04	Final report on "Investigation of DEMO relevancy of cryo-mechanical pump"	M03

Requirements for the Deliverable:
The findings of the overall activity shall be presented at the Final Review Meeting (Milestone 03) for review and discussion and the final report, internally approved (if required) shall be submitted (uploaded to EFDA IDM) by the 31st Dec 2013. It shall be then reviewed (by the EFDA PPP&T RO as a minimum) and approved by the head of EFDA PPP&T.

References

[1] F. Sharipov: Benchmark problems in rarefied gas dynamics; Vacuum 86 (2012) 1697-1700
https://user.efda.org/?uid=2LGC2F
[2] T. Shephard: Validating the DSMC code; 7th – 22nd August, 2012
https://user.efda.org/?uid=2M5UUH
[3] T. Shephard, M. Kovari: DSMC analysis of 3-stage cryopump (Note for discussion); 4th Sep 2012
https://user.efda.org/?uid=2HEHNY

6. : Tritium systems

Task Agreement WP13-DAS-06:

6.1 Introduction

The use of self-sufficient breeding blankets in DEMO will require the integration to a fuel cycle where large quantity of tritium will be extracted from the breeder and processed for fuel production. A challenge, which must be solved, will be upgrading the present fuel cycle technology to the requirements for DEMO because there are much higher tritium inventories and gas throughputs.

6.2 Objectives

- Identify tritium permeation control requirements through the improvement of the simple tritium migration model.
- Analyse tritium permeation control requirements through non-traditional tritium-handling equipment.
- Analyse the future potential of the different currently known tritium permeation barriers.
- Analyse DEMO relevancy of T extraction technologies from He and PbLi based on the ITER TBM program.
- Start the development of a fuel cycle simulator based on the application of the system code fuel cycle module.
- Scale the tritium plant of ITER up to DEMO relevant size and identify the impacting parameters.

6.3 Work Description and Breakdown

WP13-DAS-06-T01

T extraction and permeation analysis

T permeation control requirements:

The IVC task T15 “DEMO permeation study” (WP12-IVC) shall result in a comparison of the three different blanket concepts recently considered for DEMO (HCPB, HCLL, WCLL) using very simplified T migration model throughout the overall T cycle, highlighting some requirements in terms of permeation control. For 2013 it is foreseen to consider - keeping the same input data as last year – time dependency/ pulsed operation (burn time 2-4h, dwell time 0.5-0.8h) instead of steady state on one hand and more detailed models taking into account for example temperature and tritium generation profiles along the blanket that were considered as lumped parameters (mean value) in the 2012 study on the other hand. This could significantly impact the estimated permeation rates both from the breeder zone to the cooling zone and from primary cooling to secondary cooling zones. Special attention shall be given to non-traditional T handling equipment, such as the Balance of Plant components (heat exchangers; steam generators; large, high-temperature components; long high-temperature pipe runs; etc.). [1,2]

Outcome: Based on the results of the modelling - by the end of 2013 - a full set of control requirements in both traditional and non-traditional T handling equipment shall be proposed.

T permeation barrier:
Al coating is recently the most promising candidate for tritium permeation barrier for ITER [3]. Other candidate materials and methods were identified during the previous work therefore the DEMO (and reactor) relevancy of the candidate permeation barriers shall be assessed taking into account the following factors as a minimum:

- PRF - Permeation Reduction Factor (under DEMO like conditions),
- Size of operating temperature window for the given PRF,
- technology maturity,
- cost/ complexity of technology,
- etc.

Outcome:

- **Definition of DEMO like conditions for T migration.**
- **Identification of gaps in the currently available information on T permeability under DEMO like conditions.**

T extraction:
DEMO requirements for T extraction from the three candidate blanket options (WCLL, HCLL, HCPB) shall be defined. Then a thorough assessment of T extraction methods available and/ or needed from slow velocity PbLi and He purge gas – following a quantitative approach (multi criteria analysis) - shall be carried out concentrating on technical maturity (TRL), efficiency and future development potential. It is also foreseen, that the ITER relevant T extraction methods' potential for high performance is clarified considering DEMO requirements.

Outcome:

- **Identification of T extraction from blanket options.**
- **Quantitative assessment of T extraction methods from slow PbLi and He purge gas.**

WP13-DAS-06-T02

Fuel cycle simulator development

Current situation in T management at fusion experimental reactors is based on periodic reconciliation of "book" inventory versus "physical" inventory. Considering the much higher throughput and duty factor of Tritium in the future DEMO reactor, a real-time management system to track tritium between systems (accountancy) and determine chemical composition of tritiated streams is essential. Considering to establish such management system one first need to do the careful planning of the tritium flow over the entire fuel cycle system. For this purpose the present task shall accommodate the start-up of the development of a fuel cycle simulator based on the information of the system code fuel cycle module development reported in 2012 [see final report on fuel cycle module development in the frame of WP12-SYS01]. In 2013 the main focus shall be – relying on a carefully selected appropriate tool – to define the input and output parameters as well as the simplified operating equations of the modules of the cycle. Level of simplification is foreseen to be a large issue, therefore shall be agreed among the contributors and the EFDA RO.
For the schematic view of the fuel cycle module as proposed in the System code activity please see [4].

Outcome: The estimation of the necessary tritium start up inventory needed to operate a DEMO machine.

WP13-DAS-06-T03

DEMO preliminary T plant study

This work shall be based on the design of the ITER T plant considering the use of the ITER technology for both HCPB and HCLL blanket technology cases in a DEMO environment. A reasonable scale up of the plant shall be carried out along with the identification of all the parameters – both scientific and technological – that have an impact on it. The critical issues during this procedure shall be detected and presented for further future consideration.

Outcome: Comparison tables (1: HCPB, 2: HCLL blankets) between ITER and predicted DEMO T plant shall be assembled, in which all impacting parameters identified.

Resources

Task ID	Title	Resource allocation [PPY] PS	BS
WP13-DAS06-T01	T extraction and permeation analysis	0.6	Possible
WP13-DAS06-T02	Fuel cycle simulator development	0.4	Possible
WP13-DAS06-T03	DEMO preliminary T plant study	-	Possible
Total allocated resources		**1**	

6.4 Scientific and Technical Reports

See Deliverables

Milestones and Deliverables

Milestones:

Milestone ID	Title	Date
WP13-DAS06-M01	Kick Off Meeting	Apr 2013
WP13-DAS06-M02	Interim Review Meeting	July 2013
WP13-DAS06-M03	Final Review Meeting	Dec 2013

Deliverables:

Deliverable ID	Title	Required for Milestone
WP13-DAS06-D01	Final report on "T extraction and permeation analysis"	M03
WP13-DAS06-D02	Final report on "Fuel cycle simulator development"	M03
WP13-DAS06-D03	Final report on "DEMO preliminary T plant study"	M03

Requirements for Deliverables:
The findings of the overall activity shall be presented at the Final Review Meeting (Milestone 03) for review and discussion and the final, internally approved (if required) reports shall be submitted (uploaded to EFDA IDM) by the 31st Dec 2013. It shall be then reviewed (by the EFDA PPP&T RO as a minimum) and approved by the head of EFDA PPP&T.

References

[1] S. Tosti et al.: Analysis of tritium permeation in the steam generators of the SEAFP/ SEAL fusion power reactor; Fusion Engineering and Design 43 (1998) 29-35
IDM link: https://user.efda.org/?uid=2M8AJN

[2] P. Calderoni et al.: An overview of research activities on materials for nuclear applications at the INL Safety, Tritium and Applied Research facility; Journal of Nuclear Materials 417 (2011) 1336–1340
IDM link: https://user.efda.org/?uid=2M4ZMA
[3] F4E FPA-380/ lot3
F4E link: https://industryportal.f4e.europa.eu/Calls/SearchPublicCall.aspx

[4] C. Day et al.: Unified fuel cycle flowchart, EFDA PPPT WP12-SYS01
IDM link: https://user.efda.org/?uid=2M6YZY

7. : Remote Maintenance

Task Agreement WP13-DAS-07:

7.1 Introduction

Outline

In WP13, Remote Maintenance shall largely continue the work plan established in WP2012 in the following areas:

- RMS Requirements analysis: investigating the full context of the RMS within its operating environment; establishing top-level requirements and goals; establishing the main functions that the RMS must perform when the plant is in various operational states (e.g. assembly; commissioning; operational; planned maintenance shutdown; unplanned maintenance shutdown; upgrade; decommissioning; etc.)
- Plant architecture for Remote Maintenance: performing trade-off studies between the optimisation of plant maintainability and other tradable factors such as system performance, cost, structural efficiency, performance / configuration of other systems
- Radiation Dose mapping: utilising the radiation dose map produced in WP13 to understand the implications and constraints on remote maintenance operations and technology; implication of irradiation on re-weldability of EUROFER pipes; impact of maintenance port opening on ex-vessel environment; etc.
- Services joining technology: feasibility of various RH pipe connection technologies within the different zone of the plant; compatibility with overall remote maintenance concept; R&D planning for mock-ups etc.
- In-vessel component design for RH compatibility: exploration of the proposed in-vessel component attachment methods from a RH compatibility perspective, particularly with consideration of the in-vessel radiation dose level
- Pre-concept for in-vessel and ex-vessel RH equipment: investigation of the options for in-vessel and ex-vessel RH movers and manipulators in line with overall maintenance concepts; analysis of assembly tolerance; kinematics; rigid body dynamics / loading etc.; available sensing / feedback technologies
- Hot Cell handling and ex-vessel transport systems: logistics of maintenance operations (tokamak to hot cell)
- Decay heat and maintenance cooling systems: establish decay heating characteristics of in-vessel components following shutdown; establish requirements for a maintenance cooling system to manage decay heating; explore ideas for interfacing such a system to maintained components.

The vertical multi-module blanket segment (MMS) maintenance concept shall be further developed to check feasibility and to explore the main design options. This shall include: blanket segmentation; structural attachment (w.r.t. Remote Maintenance) and remote maintenance compatibility of in-vessel components; routing and connection of fluid services; assessment of in-vessel movers under expected radiation conditions; management of decay heating during shutdown; logistics of maintenance operations (tokamak to hot cell); impact on plant availability.

The feasibility of the divertor maintenance scheme shall also be progressed (using the ITER concept as a baseline) to optimise the segmentation; in-vessel attachment method and service connections with a view to maximising availability.

Scope
The scope of this activity is studying the Remote Maintenance System of a DEMO fusion power plant. The activity is performed as part of the EFDA PPPT 2013 work programme.

Acronyms

AMF	Active Maintenance Facility
CAD	Computer Aided Design
CS	Central Solenoid
DAS	Design Assessment Studies
DEMO	Demonstration Fusion Power Plant
EFDA	European Fusion Development Agreement
FBS	Functional Breakdown Structure
FFBD	Function Flow Block diagram
ITER	International Thermonuclear Experimental Reactor
LiPb	Lithium Lead
MMS	Multi Module Segment
NDT	Non-destructive Testing
PBS	Physical / Plant Breakdown Structure
PF	Poloidal Field
PPPT	Power Plant Physics and Technology Department (of EFDA)
QA	Quality Assurance
RH	Remote Handling
RHE	Remote Handling Equipment
RMS	Remote Maintenance System
TF	Toroidal Field
TWI	The Welding Institute
WP	Work Programme

7.2 Objectives

The objectives for WP13-DAS07-RM are to build on the work performed in WP12 to:

1. Further elaborate and understand the Remote Maintenance System requirements
2. Investigate the feasibility, trade-offs and design options with respect to:

a. Blanket maintenance
b. Divertor maintenance
c. Ex-vessel operations
d. Active Maintenance Facility
e. Service Connections

7.3 Work Description and Breakdown

WP13-DAS-07-T01

Activity Coordination

The Coordinator shall be responsible for:
1. Producing and maintaining an Activity Management Plan as per [1]
2. Working closely with the WP13-SYS03 System Integration Study activity to ensure a bi-lateral flow of information between the individuals working on the WP13-DAS07 tasks
3. Working closely with the WP13-DAS02 In-Vessel Components activity to ensure a bi-lateral flow of information with regard to in-vessel interfaces and attachments
4. Ensure all deliverables / reports are produced and reviewed within the agreed timescales
5. Chairing and producing minutes for the kick-off, interim and final meetings as per Table 3 1.
6. Calling any ad-hoc meetings as necessary for the purpose of brain-storming ideas, discussion, clarification, communication, progress reporting etc.
7. Producing a brief executive summary report of the main findings of WP13-DAS07 and recommendations for further work once all final task reports have been approved.

WP13-DAS-07-T02

Remote Maintenance System Requirements analysis

This task shall further develop the work previously performed in WP12. See the final report [2] for the outcomes and findings in this area. Furthermore, similar techniques will be employed in WP13-SYS03 to analyse requirements in other areas. It is suggested that strong collaboration is necessary between this task and WP13-SYS03-T06 to ensure a consistency of approach.

Using the "Initial Specification of Remote Maintenance System requirements" [2] as a basis, the DEMO Remote Maintenance System requirements shall be further analysed in order to develop a clearer picture of the problem to be solved. The following requirements analysis procedure is suggested:

1. Develop a Plant Breakdown Structure (PBS) for the Remote Maintenance System to an appropriate level of detail. The work performed in WP12 on System Integration provides definition of methodology in this regard – see [8].
2. Organise requirements specifications for each Remote Maintenance subsystem according to the PBS developed in the above step. Utilise a common specification format as described in [8]. The requirements capture for each subsystem should focus on:
    a. Functions: What the system has to do
    b. Performance: How well the functions have to be performed
    c. Interfaces: the environment in which the system will perform; classification of equipment for remote maintenance
    d. Design: what the system must be "build from" and "build to"
    e. Other requirements and constraints: i.e. materials; physical limitations; safety; reliability; codes & standards etc.
    f. Gap / Conflict analysis - Areas with no requirements; Areas with the most significant unresolved conflicts
    g. Requirements shall be cross-referenced with appropriate relationships i.e. derived from; decomposed to; interacts with; etc. using an appropriate requirements management tool.

3. List the set of assumptions that the requirements are based on
4. Once an initial requirements allocation exercise has been performed, the requirements shall be analysed using formal methods (as deemed applicable) such as:
    a. Context Analysis / Boundary Analysis
    b. States and Modes Analysis
    c. Functional Analysis
    d. Time Sequence / Scenario Analysis

Chapters 4 and 5 of the System Engineering Fundamentals handbook [9] provide some very good guidance on these practices. Furthermore, some DEMO relevant examples have been prepared by EFDA in [10]. Further useful guidance may also be available in section 4.2 of [12].

The deliverables shall consist of:

- The requirements presented in specification documents for each Remote Maintenance subsystem including the traceability and cross references between requirements
- The output from the requirements analysis activity i.e.:
    - Context diagrams
    - State Machine Diagrams
    - Function Flow Block diagrams (FFBDs)
    - Sequence diagrams

WP13-DAS-07-T03

Assessment of Remote Maintenance Operations, Sequence, Timing and Logistics

This task shall further develop the work previously performed in WP12. See the final report [5] for the outcomes and findings in this area.
The various functions and operations of the remote maintenance system shall be identified and evaluated in order to provide quantitate comparisons between the various operational concepts.

Furthermore, a method to classify systems and components within regard to maintainability requirements shall be proposed and adopted where appropriate (this shall be linked into to work performed in T02 above).

For each maintenance operation, a logical, time-based model shall be developed to analyse the sequence and timing of operational steps as components are removed from the tokamak and transported to the hot cell. This model shall include the conceptual remote handling equipment involved in the maintenance operation such as in-vessel movers, cranes, transfer casks, pipe connection equipment etc. and also the logistics of component/material/tool movements.

For each concept, the estimated time required to perform the following maintenance operations shall be evaluated:

1. Complete blanket removal and replacement
2. Removal and replacement of one MMS
3. Compete divertor removal and replacement
4. Removal and replacement of one divertor cassette

The above estimation shall take into account the following factors based on actual operational experience at a fusion facility:

- Human factors (such as shift-periods, breaks, human errors etc.)
- Radiological safety processes

- Remote Maintenance System availability
- Logistics of people, materials, equipment, transport, storage etc
- Failures of the remote maintenance equipment or operations

WP13-DAS-07-T04

Assessment of Radiation, Activation and Decay Heating implications on Remote Maintenance System

This task shall further develop the work previously performed in WP12. See the final report [3] for the outcomes and findings in this area. Note: The Activation and radiation dose map calculation is performed by WP13-SYS02-T08 [11].

An assessment of the radiation hardness of various components that are typically used in remote handling equipment shall be conducted. Some examples of these components are:

- Electrical connectors, insulators and wiring
- Sensing devices such as video cameras, load cells, position sensors, etc.
- Hydraulic seals, valves and other components
- Electrical motors and actuators

Within this task the following aspects shall be addressed:

1. Continue WP12 work to evaluate availability of radiation hard components
2. Development of a tool to link RadHard assessment to Radiation Map (with time dependent gradient)
3. Analyse proposed RHE for zonal applicability in terms of what tasks are to be performed (i.e. level of complexity) and how long the RHE will be exposed in executing the required tasks (a link to T03 is required here)
4. Effect of decay heating on handling, transport and storage of in-vessel components

WP13-DAS-07-T05

Blanket Segment Remote Maintenance System pre-concept study

This task shall further develop the work previously performed in WP12. See the final report [5] for the outcomes and findings in this area.

Within this task the following aspects shall be addressed:

1. Ideas and concepts shall be further developed for in-vessel blanket movers / transporters to include consideration of the in-vessel mechanical support of RH movers and the operations/tasks/functions to be performed. Integration with the proposed Divertor RHE (see T06) will be necessary to ensure compatibility.
2. Ideas and concepts shall be developed for blanket structural attachments to vacuum vessel from the RH point-of-view:
    a. Communication, knowledge and design development exchange with the WP13-DAS02-T07 “Development of a blanket attachment concept” task shall be necessary here to support component designers with implementation of RH requirements
3. Substantiation of a feasible of In-vessel RH equipment design
4. Ideas and concepts shall be developed for the remote connection / disconnection of other blanket segment interfaces such as earth bonding / electrical insulation, coolant pipes, tritium breeder fluid / purge gas, etc.

   a. Communication, knowledge and design development exchange with the WP13-DAS02-T07 shall be necessary here to support component designers with implementation of RH requirements

5. Ideas and concepts shall be developed for a Multi-Purpose Deployer (MPD) system that may be inserted into the vacuum vessel via an equatorial port. The main purpose of this system would be rescue or recover failed RHE or operations but may include other remote maintenance tasks as necessary.
6. Examine implications of LiPb vs Pebble bed breeder for maintenance efficiency

WP13-DAS-07-T06

Divertor Remote Maintenance System pre-concept study

This task shall further develop the work previously performed in WP12. See the final report [5] for the outcomes and findings in this area.

Within this task the following aspects shall be addressed:

1. Updated divertor RHE designs from the WP12 work (to include consideration of blanket handling, thermal expansion of blanket, cask plans, radiation and temperature levels)
2. Development of conceptual design of the telescopic radial transporter and its support
3. Development of conceptual design of the end-effector for central, left and right cassette
4. Detailed plan for the divertor service pipe replacement operations
5. Consider the implications of the requirement for an in-vessel transporter. Integration with the proposed Blanket RHE (see T05) will be necessary to ensure compatibility.
6. Detailed study of the cassette locking methods

WP13-DAS-07-T07

Ex-Vessel Remote Maintenance System pre-concept study

This task shall further develop the work previously performed in WP12. See the final report [5] for the outcomes and findings in this area.
Within this task the following aspects shall be addressed:

1. Development of remote handling equipment for opening and closing of vessel ports
2. Development of transportation cooling options based on decay heating values
3. Crane, casks and cask transport systems: further investigation and detailing
4. Ideas and concepts shall be developed for the remote maintenance of proposed:
   a. Heating & Current Drive Systems
   b. Vacuum Pumping Systems
   c. Diagnostic Systems
5. A preliminary study of the remote maintenance implications of the Balance of Plant (including Primary Loop Heat Exchangers, Circulators, etc.) shall be performed. It is suggested that the practices from fission power plants are reviewed in this regard (also refer to WP13-DAS08 “Balance of Plant” activity)

WP13-DAS-07-T08

Active Maintenance Facility (AMF) and transport systems pre-concept study

This task shall further develop the work previously performed in WP12. See the final report [5] for the outcomes and findings in this area.

Within this task the following aspects shall be addressed:

1. Start to describe the RHE that might be required within the Active Maintenance Facility
2. Increase the detail of the pre-concept AMF CAD model
3. Optimize the layout of the AMF to optimise for productivity
4. Study the maintenance operations and processes for individual components
5. Estimate the timing for AMF operations
6. Proposal of technology areas requiring R&D

WP13-DAS-07-T09

Services joining technology

An impact assessment shall be conducted to qualify the application of the candidate service disconnection/connection technologies (i.e. welding; mechanical connections; brazed connections) at the required locations (i.e. in-vessel; in-port; ex-vessel; etc.). This should include aspects such as access and space requirements; codes and standards; envisaged loads; etc.

In-bore cutting and welding

1. Evaluate related historical studies (e.g. J.A.E.R.I. 1999 – Yag Laser welding/cutting for ITER)
2. Contact commercial suppliers such as welding & cutting equipment suppliers and NDT specialists
3. Liaise with TWI for technical collaboration and knowledge sharing of similar parallel projects e.g. TWI/OC Robotics “LaserSnake”
4. Identify tooling required based on pipes mechanical forces
5. Risk assess to ensure failsafe and recoverable
6. Develop remote handling deployment solutions
7. Prepare an R&D plan (to be considered for WP14) for development of physical mock-ups

Mechanical Connections

1. Further development of Purex connection to include load handling capabilities and tritium permeation
2. Prepare an R&D plan (to be considered for WP14) for development of physical mock-ups

Brazed Connections

1. Further development and application assessment of brazed connector concept to include load handling capabilities and tritium permeation
2. Prepare an R&D plan (to be considered for WP14) for development of physical mock-ups

Resources

Task ID	**Title**	**Proposed PS Effort (ppy)**
WP13-DAS07-T01	Activity Coordination	0.1
WP13-DAS07-T02	Remote Maintenance System Requirements analysis	0.3
WP13-DAS07-T03	Assessment of Remote Maintenance Operations, Sequence, Timing and Logistics	0.4
WP13-DAS07-T04	Assessment of Radiation, Activation and Decay Heating implications on Remote Maintenance System	0.2
WP13-DAS07-T05	Blanket Segment Remote Maintenance System pre-concept study	1.4
WP13-DAS07-T06	Divertor Remote Maintenance System pre-concept study	0.6
WP13-DAS07-T07	Ex-Vessel Remote Maintenance System pre-concept study	0.6
WP13-DAS07-T08	Active Maintenance Facility (AMF) and transport systems pre-concept study	0.4
WP13-DAS07-T09	Services joining technology	0.3
	TOTAL	**4.3**

7.4 Scientific and Technical Reports

See Deliverables section

Milestones and Deliverables

Milestones:

Milestone ID	**Title**	**Date**
WP13-DAS07-M01	Kick Off Meeting	Early April 2013
WP13-DAS07-M02	Interim Review	Sept 2013
WP13-DAS07-M03	Final Review	Mid Dec 2013
WP13-DAS07-M04	Approval of final reports by EFDA	End Jan 2014

Deliverables:

Task ID	**Deliverable ID**	**Deliverable Title**	**Required for Milestone**
WP13-DAS07-T01	WP13-DAS07-D01a	Activity Management Plan	M01
	WP13-DAS07-D01b	Executive Summary of WP13-DAS07	M04
WP13-DAS07-T02	WP13-DAS07-D02a	Set of Requirements Specifications for the DEMO Remote Maintenance system and subsystems	M03
	WP13-DAS07-D02b	Report: “Remote Maintenance System Requirements analysis”	M03
WP13-DAS07-T03	WP13-DAS07-D03	Report: “Assessment of DEMO Remote Maintenance Operations, Sequence, Timing and Logistics”	M03
WP13-DAS07-T04	WP13-DAS07-D04	Report: “Assessment of Radiation, Activation and Decay Heating implications on Remote Maintenance System”	M03
WP13-DAS07-T05	WP13-DAS07-D05	Report: “Blanket Segment Remote Maintenance System Pre-concept study”	M03
WP13-DAS07-T06	WP13-DAS07-D06	Report: “Divertor Remote Maintenance System Pre-concept study”	M03
WP13-DAS07-T07	WP13-DAS07-D07	Report: “Ex-Vessel Remote Maintenance System Pre-concept study”	M03
WP13-DAS07-T08	WP13-DAS07-D08	Report: “Active Maintenance Facility (AMF) and transport systems pre-concept study”	M03
WP13-DAS07-T09	WP13-DAS07-D09	Report: “Services Joining Technologies for DEMO Remote Maintenance System”	M03

Activity	*Priority Support Deliverables*	*Due Date*
WP13-DAS-07-T01	WP13-DAS07-D01a-Activity Management Plan-M01 WP13-DAS07-D01b-Executive Summary of WP13-DAS07 -M04 The WP13-DAS07-D01a "Activity Management Plan" shall be reviewed and approved by EFDA PPPT at or before M01. The WP13-DAS07-D01b "Executive Summary of WP13-DAS07" shall be reviewed and approved by EFDA PPPT at or before M04.	31. Dec 2013
WP13-DAS-07-T02	WP13-DAS07-D02a-Set of Requirements Specifications for the DEMO Remote Maintenance system and subsystems-M03 WP13-DAS07-D02b-Report: "Remote Maintenance System Requirements analysis" -M03 The deliverables shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013
WP13-DAS-07-T03	WP13-DAS07-D03-Report: "Assessment of DEMO Remote Maintenance Operations, Sequence, Timing and Logistics"-M03 The deliverable shown shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT	31. Dec 2013
WP13-DAS-07-T04	WP13-DAS07-D04-Report: "Assessment of Radiation, Activation and Decay Heating implications on Remote Maintenance System"-M03 The deliverable shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013
WP13-DAS-07-T05	WP13-DAS07-D05-Report: "Blanket Segment Remote Maintenance System Pre-concept study" -M03 The deliverables shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013
WP13-DAS-07-T06	WP13-DAS07-D06 Report: "Divertor Remote Maintenance System Pre-concept study" -M03 The deliverable shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013
WP13-DAS-07-T07	WP13-DAS07-D07-Report: "Ex-Vessel Remote Maintenance System Pre-concept study" -M03 The deliverable shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013
WP13-DAS-07-T08	WP13-DAS07-D08 Report: "Active Maintenance Facility (AMF) and transport systems pre-concept study" -M03 The deliverable shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013

WP13-DAS-07-T09	WP13-DAS07-D09 Report: "Services Joining Technologies for DEMO Remote Maintenance System" -M03 The deliverable shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013

References

[1] DEMO Activity Management Plan Template - EFDA_D_2LAWVX
[2] WP12-DAS06-D01b: Initial Specification of Remote Maintenance System requirements - EFDA_D_2KXAVC
[3] WP12-DAS06-D02: Radiation hardness assessment of available components utilised in remote handling equipment - EFDA_D_2M4SZP
[4] WP12-DAS06-D03: Calculation of in-vessel and ex-vessel radiation conditions during shutdown periods - EFDA_D_2L4HB3
[5] WP12-DAS06-D04: Development of vertical MMS maintenance concepts including ex-vessel operations and design integration at plant level - EFDA_D_2LLTXY
[6] WP12-DAS06-D06: Study and recommendations of alternative pipe connection and non-destructive testing technologies for DEMO - EFDA_D_2L255D
[7] WP13-DAS-02 Vessel/In-vessel Components – Technical Specification - EFDA_D_2L86Z4
[8] WP12-DAS06-D07: System Integration of Remote Maintenance System with Magnets, In-Vessel Components, Heating & Current Drive Systems and Neutronics Analysis - EFDA_D_2LGSPZ
[9] US Department of Defense (Jan 2001), "System Engineering Fundamentals". Available on EFDA-IDM at EFDA_D_2KYEUP
[10] J. Harman (2012), "Selected Requirements Analysis Examples". Available on EFDA-IDM at EFDA_D_2M5EBV
[11] WP13-SYS02 System Level Analysis – Technical Specification - EFDA_D_2M8Y5S
[12] INCOSE (2010), "Systems Engineering Handbook – A Guide for System Life Cycle Processes and Activities"

8. : Primary Heat Transfer and Balance of Plant Systems

Task Agreement WP13-DAS-08:

8.1 Introduction

Outline

The DEMO primary heat transfer (PHTS) and balance of plant (BoP) includes the heat transfer system and associated electrical generation system. The design and performance of these systems will be affected by decisions made concerning the structural material of the in-vessel components (e.g. EUROFER) and the choice of coolant. The potentially viable options for both primary and secondary coolants are for the primary loops: Helium, pressurised water and lithium-lead (blanket); pressurized water and helium (divertor); for the secondary loop (Helium, water/steam, CO2, molten-salt).

The choice of helium as a coolant introduces various mechanical and materials issues that will have to be resolved through a development programme. Helium technology is a proven technology with experiences on different scales up to demonstrator power plants in different countries. Heat exchangers have been built in the past for Helium and CO2 gas at different scales and optimization is under way leading to high efficiency. Due to the narrow market, no "off-the-shelf" Helium to Steam heat exchangers are available but existing designs could be adapted for DEMO conditions. Furthermore, the Generation IV programme in Europe now focusses on building a demonstrator size plant in eastern European countries. (Belovsky, 2012)

As DEMO is likely to be a pulsed machine, this will also have implications for the PHTS and BoP in terms of thermal transients and fatigue due to cyclic loading. In order to prove the principle of connection of a pulsed energy system to the grid, it may be necessary to introduce a Thermal Energy Store to buffer the thermal transients and reduce the cyclic loading effect however which would further increase cost and complexity of the BoP.

Nuclear safety considerations are also paramount and it is expected that DEMO will have to employ an indirect cycle for the BoP architecture. Even so, the control of contamination and tritium transport will have to be carefully addressed from the beginning and the choice of a water coolant will introduce gamma doses from 16N decay and therefore additional shielding requirements.

Maintenance considerations are also very important and therefore the overall PHTS and BoP layout in terms of design integration; typical planned maintenance / inspection schedules (i.e. turbines, heat exchangers); and robust design and failure analysis will all be critical aspects in the development programme.
Strong industry involvement within this activity area is seen as highly desirable.

Scope

The scope of this activity is to investigate possible solutions for the primary heat transfer system and to elaborate the balance of plant for a DEMO fusion power plant. The activity is performed as part of the EFDA PPPT 2013 work programme.

Acronyms

BoP	Balance of Plant
CAD	Computer Aided Design
DAS	Design Assessment Studies
DEMO	Demonstration Fusion Power Plant
EFDA	European Fusion Development Agreement
HX	Heat Exchanger
ITER	International Thermonuclear Experimental Reactor
PCS	Power Conversion System
PHTS	Primary Heat Transfer System
PPCS	Power Plant Conceptual Design Studies
PPPT	Power Plant Physics and Technology Department (of EFDA)
WP	Work Programme

8.2 Objectives

The objectives for WP13-DAS08-BOP are:

1. To propose and evaluate potential architectural design options from the DEMO PHTS including the primary heat exchanger and BoP system in terms of efficiency, performance, cost, size, maintainability, risks etc.
2. To assess the impact of pulsed operation on the PHTS and BoP systems with further investigation into the necessity for Energy Storage Systems

8.3 Work Description and Breakdown

WP13-DAS-08-T01

Activity Coordination

The Coordinator shall be responsible for:

1. Producing and maintaining an Activity Management Plan as per [1]
2. Ensure all deliverables / reports are produced and reviewed within the agreed timescales
3. Chairing and producing minutes for the kick-off, interim and final meetings
4. Calling any ad-hoc meetings as necessary for the purpose of discussion, clarification, communication, progress reporting etc.

WP13-DAS-08-T02

Design, modelling and analysis of primary heat transfer and BoP options for integration with a DEMO fusion power plant

Scope of task

Figure 1 shows a schematic diagram of the primary heat transfer and electrical generation systems for a DEMO fusion power plant. The scope of this task is the study of the "Heat to Electrical Power Conversion System (PCS)" shown in the diagram. This includes both the primary heat transfer system and the secondary balance of plant system.

In a DEMO fusion power plant, a plasma pulse (Pfus) of typically 2 hours in duration will be generated by the tokamak system. A dwell period of approx. 0.5h is then necessary in order to prepare the tokamak system for the next pulse. Heat generated in the tokamak system by nuclear heating and plasma radiation processes is transferred from the blanket (Qblanket), divertor (Qdivertor) and vacuum vessel (Qvv) by primary coolants to the balance of plant system. Some of this heat will be converted to work in order to generate electrical energy (Pgross) – the rest is either rejected (Qreject) or lost to the environment. Some of the generated electrical energy is required by the tokamak system in order to sustain the plasma pulse for example, heating and current drive (PH&CD) systems and auxiliary systems (Paux) such as vacuum pumping, fuelling, cryoplant, etc. Furthermore, both primary and secondary coolants require power for circulation pumping (Ppump). The remaining balance of electrical energy (Pnet) can then be exported to the electrical grid for use by consumers.

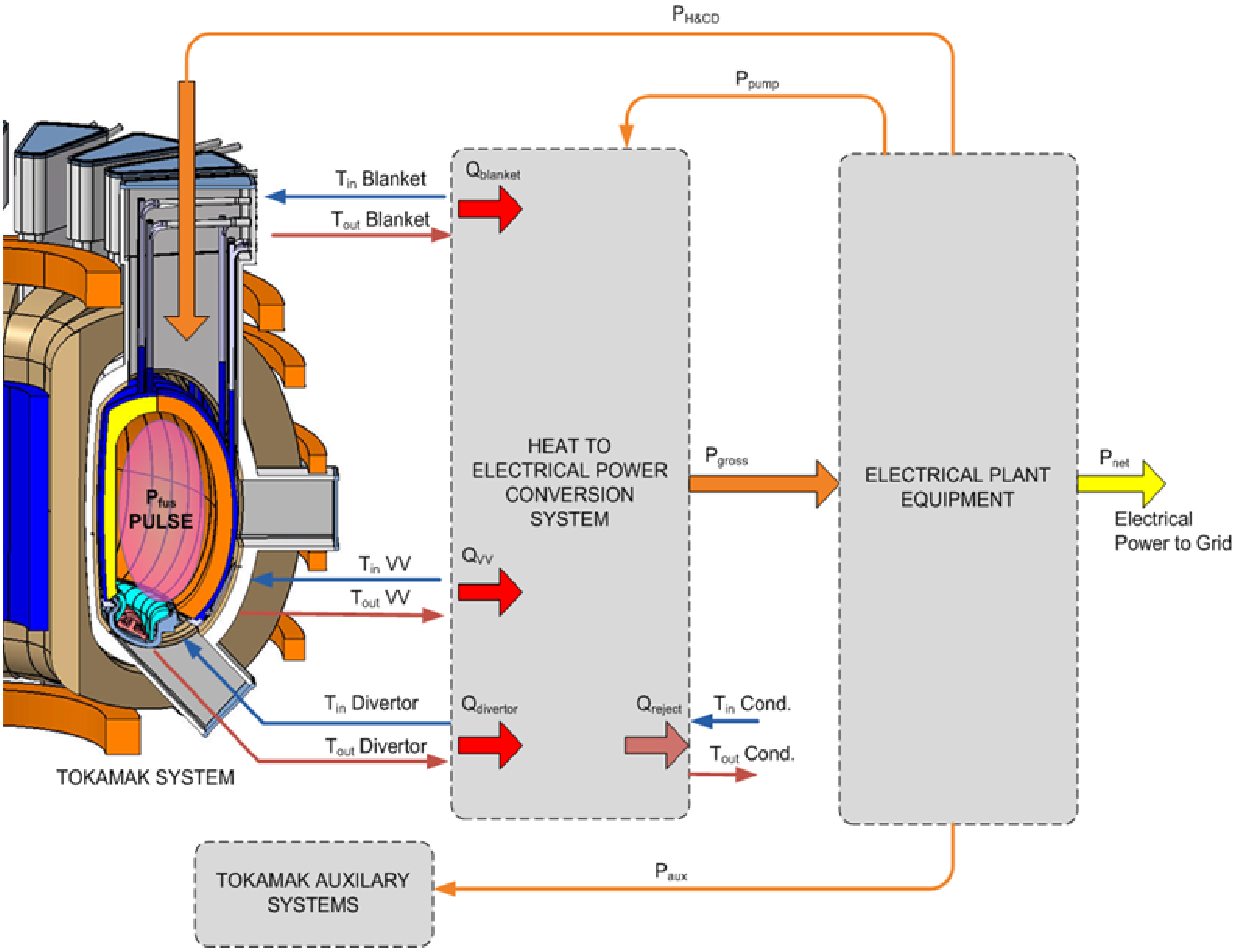


Figure 1: Schematic of DEMO Electrical Power Generation

Some typical parameters for the magnitudes of power under consideration for DEMO are given in Table 1. This is presented here for indicative purposes only and a set of parameters for calculation purposes will be provided at the KoM.

Table 1: Typical DEMO Parameters (extracted from [3])

Parameter	Value
Fusion Power, P_{fus} (MW)	1943
Thermal Power, P_{th} (MW)	2227
Nuclear Heating in Blanket (MW)	1705
Nuclear Heating in Vessel (MW)	37.45
Power to Divertor (MW)	232.7
Gross Electrical Power P_{gross} (MW)	735*
Net Electrical Power P_{net} (MW)	≥500MW (requirement)
$P_{H\&CD}$ (MW)	50 (heating only)
P_{aux} (MW)	135
P_{pump} (MW)	TBC

* dependant on PCS efficiency (check assumptions used in PROCESS code)

The range of primary coolant options and parameters considered within the scope of this task are shown in Table 2. The values of coolant temperatures and pressures presented here should be taken as initial starting points based on material operating temperature limitations. Final values are to be agreed at the KoM.

Table 2: Primary Coolant Options

System	Coolant	Tin	Tout	P (bar)
Blanket	Helium	300	500	80
	Water	290	320	150
Divertor	Water	150	250	65
Vessel	Water	N/D	100	11

N/C: Not defined

Task Requirements

Review and synthesis of previous work

Much previous work has already been carried out looking into the question of coolant choice and the design of heat transfer and balance of plant systems for fusion power plants. The initial part of this task shall be to review and synthesise this previous work in order to check whether the approach and arguments are still relevant for DEMO (given the latest design philosophy) and capture any important technical issues highlighted by this work. The scope of some of this previous work is outlined below:

The STARFIRE design study considered helium and water as suitable primary coolants and found some clear advantages for the choice of pressurised water as well as identifying areas where development is required in order to utilise the potential advantages of helium. (Abdou & Graumann, 1980)

The European DEMO BOT Solid Breeder Blanket study (Dalle Donne, 1994) introduced a DEMO reactor concept based on helium cooled blankets. The Helium Coolant System (with 5 out of 6 operating cooling lines for redundancy) acts as Heat Transport System coupled with a water Rankine cycle power generation system. The conceptual design of the entire Cooling System (Helium and Water systems) was performed in collaboration with Siemens KWU.

The SEAFP reactor study also considered helium and water-cooled models for assessment purposes with a hybrid solution being proposed to cool high heat flux components with water and low heat flux components with helium. (Natalizio, Collen, & Vieider, Cooling System Design Options for a Fusion Reactor, 1997)

In the framework of the PPCS studies, both the water-cooled Model A and helium-cooled Model AB were used as reference designs for assessment of the BoP systems.
The following reports on PPCS Model A cover (with some overlap) the:

- Primary heat transfer system (Natalizio & Collen, Conceptual Design of Main Cooling System for a Fusion Power Reactor with Water Cooled Lithium-Lead Blanket (TW1-TRP-PPCS1-D8), 2002)
- Turbine and Generator (Chiesura, 2002)
- Full Balance of Plant System (Puente, 2002)

Two reports (Herrazti & Paule, 2006) and (Ward & Stainsby, 2006) focus mainly on the secondary power conversion cycles for the PPCS Model AB (Helium-cooled blanket) with supercritical steam and CO2 in the secondary loop.

The outcome of the PPCS studies in terms of power conversion are summarised by (Maisonnier, et al., 2007) and (Sardain, et al., 2009).

Finally, a design assessment study was performed by EFDA last year “Assessment of DEMO-relevant helium-cooled balance of plant technology” [4]. This looked in detail at the impact of using helium as the secondary coolant as well as various cross-cutting issues with helium BoP technologies.

Study of feasible design options of PHTS

1. Based on the scope described above and primary coolants options in Table 2, generate feasible designs (at the architectural level) for the complete heat transfer system (i.e. primary and secondary thermal power circuits). This shall include the physical layout (w.r.t. the tokamak system) and general sizing of components such as steam generators; pumps/compressors; heat exchangers; turbines; electrical generators; etc. To provide some orientation, Figure 2 shows a simplified layout of a possible blanket system heat transfer

system assuming a tokamak with 16 sectors. Note: the previous work performed in [4] should be included here.

2. For each design generated in step 1 above, produce a thermodynamic model to assess the cycle efficiency of each option
3. Study the integration of each BoP option within the overall DEMO power plant. E.g.
    - How physically large would the steam generators and circulators need to be? How many would be required? Where could/should they be positioned with respect to the tokamak?
    - Fault tolerance: what happens if one component develops a critical fault? Can the plant still operate? How do other power plants (fission, fossil, etc.) cope with this?
4. Identify and assess the risks associated with the balance of plant technology and propose potential mitigations.
5. Produce an indicative cost breakdown for each BoP option to include at estimate of the current capital acquisition cost range for each component (if possible, this should be performed in consultation with industrial contacts). Assess the possibility to use “off-the shelf” components are far as possible
6. Using the work performed in the steps above, assess the design options for the PHTS and BoP against a set of objective assessment criteria (where possible). Table 3 adapted from (Abdou & Graumann, 1980) provides a good starting point.
7. Report the findings of this task in a suitable report.

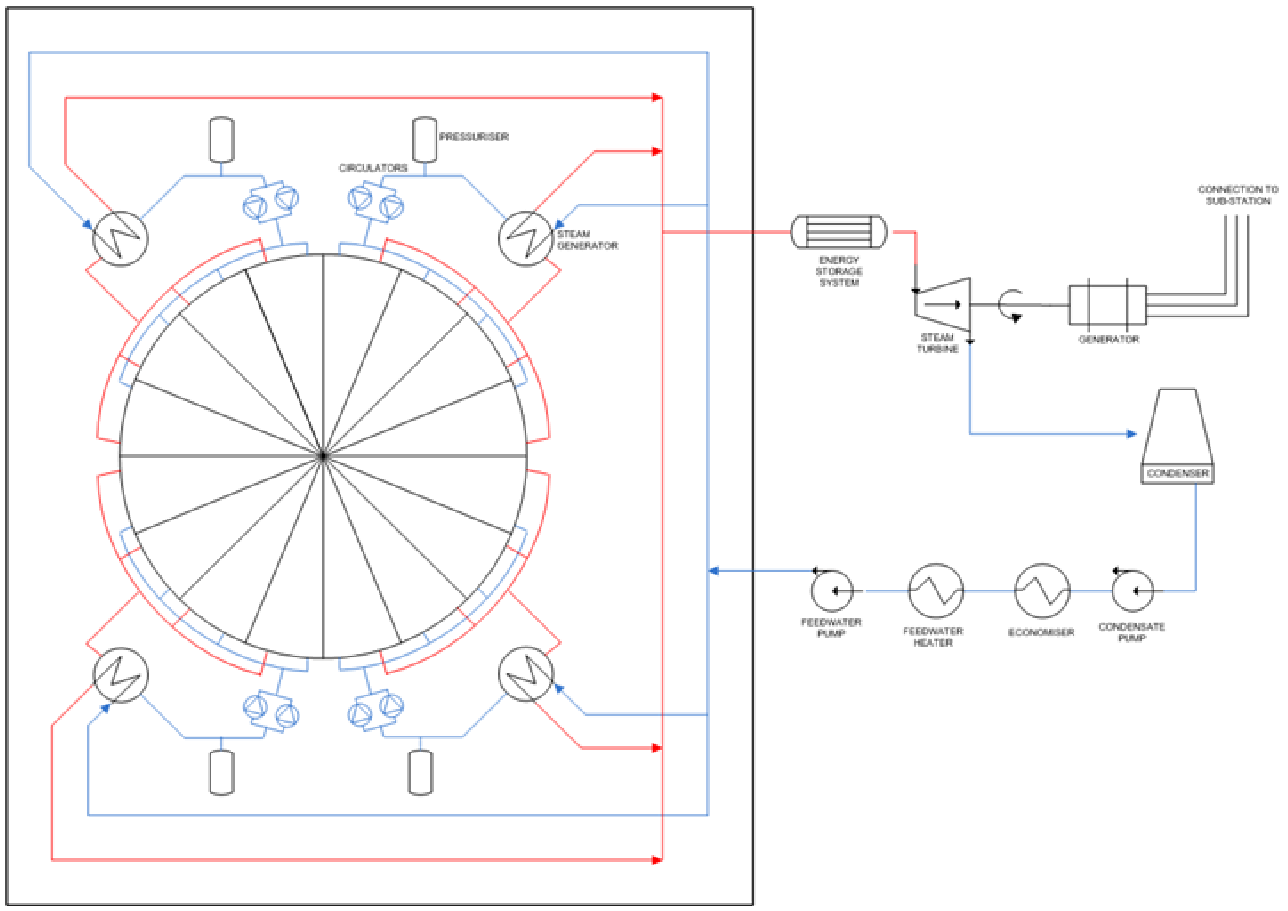


Figure 2: Simplified layout of a possible blanket heat transfer system

Table 3: Suggested PHTS and BoP assessment criteria

1. Gross thermal efficiency
2. Pumping power requirements
3. Cost of primary coolant loop including primary heat exchanger(s)
4. Impact of coolant selection on tokamak radial build
5. Control of tritium transport
6. Chemical reactivity
7. Maintainability of PHTS and BoP components
8. Integration of PHTS and BoP with rest of DEMO plant
9. Safety implications (overpressure; coolant leakage; chemical reactions etc.)
10. Cost and availability of coolant

WP13-DAS-08-T03

Development of a computer-based model to simulate the time-variant behaviour of a pulsed DEMO power plant

The intended pulsed operation of a DEMO fusion power plant is quite different from other types of steady-state electrical generation plant (e.g. coal, gas, fission). This pulsing introduces a number of time-variant effects that may have an influence on design, performance, technology, cost, reliability, etc. of DEMO.

In order to understand these effects further, a computer-based model shall be developed to simulate the time-variant behaviour of a pulsed DEMO power plant and the corresponding balance of plant system. The aim of this model would be to analyse and verify technical requirements and provide a basis for trade-off studies to inform technology choices. Suggested aspects that require integration within the model are:

a. Plant availability / Operational profile
b. Power cycle (Balance of Plant)
c. Energy storage / buffering
d. Tritium cycle

A useful modelling language for this application may be Modelica and/or Dymola. These codes are supported by plant modelling using TRACE, Relap5 or the SIM code. Here the type of the thermal buffer has to be included. Qualification of such a model is out of scope of that task but should be carried out later.

WP13-DAS-08-T04

Design assessment of pulsed power profiles in relation to Primary Heat Transfer and Balance of Plant systems

The intended pulsed operation of a DEMO fusion power plant is quite different from other types of steady-state electrical generation plant (e.g. coal, gas, fission). This pulsing introduces a number of time-variant effects that may have an influence on design, performance, technology, cost, reliability, etc. of DEMO.

A design assessment of pulsed power profiles in relation to Primary Heat Transfer and Balance of Plant systems shall be carried out to study:

1. Investigation (with industrial involvement if possible) the impact of pulsed power profiles on the durability and fatigue life of systems such as steam generators and turbines. Would a Thermal Energy Store be necessary to buffer the thermal transients and reduce the cyclic loading effect?
2. Exploration of the throttling principle for turbine generator sets (e.g. feasible dwell time limits, impact on primary cycle temperature evolution)
3. Further analysis of the functional requirements for Energy Storage to assess whether energy storage is required to:
   i. Provide a constant electrical power output to the grid?
   ii. Provide a controlled ramp-up and ramp-down power output?
   iii. Provide a buffer for smoothing internal DEMO system electrical power demands?
   iv. Provide mitigation for thermal transients on Heat Transfer and BoP plant?

Resources

Task ID	**Title**	**PS Proposed Effort (ppy)**
WP13-DAS08-T01	Activity Coordination	0.1
WP13-DAS08-T02	Design, modelling and analysis of primary heat transfer and BoP options for integration with a DEMO fusion power plant	1.3
WP13-DAS08-T03	Development of a computer-based model to simulate the time-variant behaviour of a pulsed DEMO power plant	0.3
WP13-DAS08-T04	Design assessment of pulsed power profiles in relation to Primary Heat Transfer and Balance of Plant systems	0.3
	TOTAL	**2.0**

8.4 Scientific and Technical Reports

See Deliverables section

Milestones and Deliverables

Milestones:

Milestone ID	Title	Date
WP13-DAS08-M01	Kick Off Meeting	Early April 2013
WP13-DAS08-M02	Interim Review	Sept 2013
WP13-DAS08-M03	Final Review	Mid Dec 2013

Deliverables:

Task ID	Deliverable ID	Deliverable Title	Required for Milestone
WP13-DAS08-T01	WP13-DAS08-D01	Activity Management Plan	M01
WP13-DAS08-T02	WP13-DAS08-D02a	Report “Modelling, analysis and architectural design of BoP options and integration with DEMO fusion power plant”	M03
	WP13-DAS08-D02b	Data files / tools for Thermodynamic models	M03
WP13-DAS08-T03	WP13-DAS08-D03a	Report: “Development of a computer-based model to simulate the time-variant behaviour of a pulsed DEMO power plant”	M03
	WP13-DAS08-D03b	Computer-based model to simulate the time-variant behaviour of a pulsed DEMO power plant	M03
WP13-DAS08-T04	WP13-DAS08-D04	Report: “Design assessment of pulsed power profiles in relation to Balance of Plant systems”	M03

Activity	*Priority Support Deliverables*	*Due Date*
WP13-DAS-08-T01	WP13-DAS08-D01-Activity Management Plan-M01 The WP13-DAS08-D01 Activity Management Plan shall be reviewed and approved by EFDA PPPT at or before M01.	30. Apr 2013
WP13-DAS-08-T02	WP13-DAS08-D02a-Report “Modelling, analysis and architectural design of BoP options and integration with DEMO fusion power plant” -M03 WP13-DAS08-D02b-Data files / tools for Thermodynamic models-M03 The deliverables shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013
WP13-DAS-08-T03	WP13-DAS08-D03a-Report: “Development of a computer-based model to simulate the time-variant behaviour of a pulsed DEMO power plant”-M03 WP13-DAS08-D03b-Computer-based model to simulate the time-variant behaviour of a pulsed DEMO power plant-M03 The deliverables shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013
WP13-DAS-08-T04	WP13-DAS08-D04-Report: “Design assessment of pulsed power profiles in relation to Primary Heat Transfer and Balance of Plant systems” -M03 The deliverable shall be fully reviewed by a suitable peer group, uploaded to IDM and approved by the EFDA PPPT.	31. Dec 2013

References

References

[1] DEMO Activity Management Plan Template - EFDA_D_2LAWVX
[2] DEMO Operational Concept Description –
[3] Kemp, R. (2012). DEMO Design Summary v1.0 – EFDA_D_2L2F7V
[4] Porton, M (2012). WP12-DAS08-BOP-T01 Assessment of DEMO-relevant helium-cooled balance of plant technology – EFDA_D_2M4XFP

Works Cited

Abdou, M. A., & Graumann, D. (1980). The Choice of Coolant in Commercial Tokamak Power Plants. Forth ANS Topical Meeting on the Technology of Controlled Nuclear Fusion. Pennsylvania.

Belovsky, L. (2012, 04 18). REZ private communication.

Chiesura. (2002). Technical Proposal for PPCS Model A BoP (EFDA 93-851 HJ). ANSALDO.

Dalle Donne, M. (1994). European DEMO BOT Solid Breeder Blanket, KfK 5429. Forshungszentrum Karlsruhe.

Herrazti, B., & Paule, A. (2006). Supercritical Power Conversion Cycles (EFDA Task: TW5-TRP-

006). CIEMAT / EFDA.

Maisonnier, D., Campbell, D., Cook, L., Di Pace, L., Giancarli, L., Hayward, J., et al. (2007). Power plant conceptual studies in Europe. Nuclear Fusion 47, 1524-1532.

Medrano, M., Puente, D., Arenaza, E., Herrazti, B., Paule, A., Branas, B., et al. (2007). Power conversion cycles study for He-cooled reactor concepts for DEMO. Fusion Engineering and Design 82, 2689-2695.

Natalizio, A., & Collen, J. (2002). Conceptual Design of Main Cooling System for a Fusion Power Reactor with Water Cooled Lithium-Lead Blanket (TW1-TRP-PPCS1-D8). Sweden: Studsvik Eco & Safety AB.

Natalizio, A., Collen, J., & Vieider, G. (1997). Cooling System Design Options for a Fusion Reactor. Journal of Fusion Energy Vol.16, Nos. 1/2, 149 - 153.

Puente, D. (2002). Conceptual Design of PPCS Model A BoP Specification (EFDA 93-851 HJ). IBERTEF.

Sardain, P., Maisonnier, D., Medrano, M., Brañas, B., Puente, D., Arenaza, E., et al. (2009). Alternative power conversion cycles for He-cooled fusion reactor concepts. Proceedings of the 2nd IAEA Technical Meeting on First Generation of Fusion Power Plants: Design & Technology. Vienna: IAEA.

Ward, D. J., & Stainsby, R. (2006). Final Report on Comparison between Power Conversion Cycles for DEMO (Task EFDA/05-1288). UKAEA Fusion; AMEC.

9. : Stellarator engineering scoping studies

Task Agreement WP13-DAS-09:

9.1 Introduction

Stellarators are still in a less-mature stage of development compared to Tokamaks, but their physics basis advantages, such as steady state operation, no occurrence of disruption, etc. are clearly recognized by the fusion community. A clear recommendation was made in the recent EU Roadmap Horizon 2020 (H2020) to bring the stellarator line to maturity as a possible long term alternative to tokamaks. However, the 3D geometry of the Stellarator poses a number of engineering challenges for the design and construction of the superconducting magnets, plasma facing components, blanket and shield. More specific engineering challenges are: tight space requirements for internal components such as the blanket/ shield required for tritium breeding, power extraction and protection of radiation damage sensitive superconducting magnets, integration and performance issues of a divertor, coil spacing, bend radius, superconductor type and properties; diagnostic and heating system port and space requirements, assembly and remote handling requirements and space needs.
Some effort was started last year to improve integrated optimization tools that involve in the loop both physics and engineering parameters. Some limited pre-conceptual engineering studies were initiated in 2012 as well, considering a 5 module HELIAS stellarator scaled up from W7X. This was deemed to provide sufficient space between the coils and the plasma for shielding and T breeding blanket, to concentrate on the magnet system reinforcement by structural analysis and a new, more feasible maintenance concept.

9.2 Objectives

- Apply physics design optimisation codes (e.g., Distributed Asynchronous Bees (DAB) code) to support the future engineering activities especially to optimise design layout of superconducting coils that bear a strong impact on the design and integration of the in-vessel components (e.g., blanket and divertor), on definition of machine assembly and remote maintenance schemes;
- Initiate a forward planning of the further engineering investigation among the interested parties to be able to implement an engineering based PPPT program from 2014 onwards;
- Review and improve the PROCESS code Stellarator module;
- Explore the physics and engineering requirements of an Intermediate device (ref: H2020 fusion roadmap);
- Provide engineering and physics support to the improvement of stellarator module in the PROCESS systems code and to the exploration of the requirements of the intermediate device.

9.3 Work Description and Breakdown

WP13-DAS-09-T01

Development of stellarator integrated optimization tools

The stellarator optimization to be undertaken is focused on the development of the Distributed Asynchronous Bees (DAB) code. Up to now, the reduction of the Bxgrad(b) drift plus the Mercier and the Ballooning stability criteria are considered [1]. The next steps are devoted to the inclusion of the coil design in the optimization process in order that it is possible to have simpler coils and room enough to accommodate diagnostics, remote maintenance and heating system ports. This task is targeting to provide physics support to the future coil design optimization, therefore assumes close interaction with T02.

Furthermore in the frame of the tasks T01 and T02 the optimization strategy shall be clarified and ranges for key variable parameters shall be defined wherever possible to reduce the unlimited number of combinations. Based on the above consideration a guideline for stellarator optimization steps shall be issued (common approach involving all contributors of the “Stellarator engineering scoping studies” activity through targeted meetings).

WP13-DAS-09-T02

Stellarator physics and engineering studies

Based on previous work [2] the engineering activity shall concentrate on providing support to the other tasks, such as to T03 on the PROCESS Stellarator module and to T04 on the exploration of technological requirements of the intermediate device foreseen by the Fusion Roadmap.

A planning activity shall be initiated among the interested parties to be able to provide the necessary human resources on one hand and a comprehensive program from 2014 onwards in the stellarator engineering field keeping in mind the following considerations:

- It is recognized, that future studies shall concentrate on the integration of in-vessel components such as the blanket and divertor.
- The accumulated knowledge on the European tokamak blanket concepts shall be applied to the stellarator device, calculation of blanket surface vs. blanket thickness requirement for self-sufficient T breeding (TBR: 1.05-1.10) and neutronic calculation to establish sufficient coil shielding requirement shall be carried out.
- Blanket segmentation and other integration issues satisfying remote maintenance requirements are key to the success to compete with tokamaks therefore shall be carefully examined.
- The integration of a divertor (ITER-like) will also need to be taken into account in future studies.

On the physics side, the further optimization of the magnetic field structure to improve alpha-particle confinement shall be continued and the resulting candidates shall undergo transport simulations of reactor-grade plasmas to verify that the expected bootstrap current in such a device would be small enough to allow application of the island divertor concept.

As mentioned under T01, the optimization strategy shall be discussed thoroughly and agreed upon to conclude in a set of guidelines for further studies.

WP13-DAS-09-T03

System code stellarator module review and improvement

The importance of the stellarator line as a potential long term perspective for providing low cost nuclear fusion generated electricity is recognized by the H2020 fusion roadmap [3]. Generally, without current drive and complex feedback systems, e.g. plasma stabilization, the stellarator promises to be more economic to operate as this lowers the re-circulating power. On the other hand, this advantage may be counterbalanced by the additional complexity of the stellarator design and a larger aspect ratio which leads to a larger size. Conversely, the larger aspect ratio results in a reduced neutron which would make maintenance less frequent.
Therefore it is important to review the status of the formerly developed stellarator module of the PROCESS code and make improvement to be able to assess the impact of the above trade-offs. The development work shall involve the following:

- review the current status of development of the existing stellarator module
- investigate if the several stellarator concepts could be accommodated in the module in a general way
- concentrate on the currently most developed 5 module HELIAS line and develop it further
- propose a set of input and output parameters
- analyse the future potential to attach other relevant code modules to the stellarator to avoid manual input of data (i.e. blanket, remote maintenance,…)

A close cooperation with System code activities is expected during execution [WP13-SYS01].

WP13-DAS-09-T04

Intermediate device requirements exploration

The main objective of Wendelstein 7-X is to demonstrate the reactor capability of the stellarator concept. However, the extrapolation of W7-X to a HELIAS in terms of dimensionless physics parameters shows a significant gap between W7-X and a HELIAS power plant. To bridge this gap an intermediate step device shall be considered (as requested by the Fusion Roadmap), which is designed for a burning fusion plasma, but with downscaled engineering requirements (e.g. with respect of dpa). The objective of such a device would be to prepare for a commercial power plant by providing the necessary physics information from a burning stellarator fusion plasma and basic technology developments while the remaining technology could be taken from the tokamak DEMO. Since the exploitation of the W7-X operation is planned for the late 2020s this subtask shall be a low profile exploration of the physics and technological requirements of an intermediate device.

Resources

Task ID	Title	Resource allocation [PPY]
WP13-DAS09-T01	Development of stellarator integrated optimization tools	0.5
WP13-DAS09-T02	Stellarator physics and engineering studies	0.3

WP13-DAS09-T03	System code stellarator module review and improvement	0.6
WP13-DAS09-T04	Intermediate device requirements exploration	0.1
Total allocated resources		**1.5**

Note: Total available resources might be up to 2.0PPY depending on overall use of resources.

9.4 Scientific and Technical Reports

See Deliverables

Milestones and Deliverables

Milestones:

Milestone ID	Title	Date
WP13-DAS09-M01	Kick Off Meeting	Apr 2013
WP13-DAS09-M02	Interim Review Meeting	July 2013
WP13-DAS09-M03	Final Review Meeting	Dec 2013

Deliverables:

Task ID	Deliverable ID	Title	Required for Milestone
WP13-DAS09-T01	WP13-DAS09-D01	Report on “Development of stellarator integrated optimization tools”	M03
WP12-DAS09-T02	WP13-DAS09-D02	Report on “Stellarator physics and engineering studies”	M03
WP12-DAS09-T03	WP13-DAS09-D03	Report on “Stellarator module review and improvement”	M03
WP12-DAS09-T04	WP13-DAS09-D04	Report on “Intermediate device requirements exploration ”	M03

Requirements for Deliverables:
The findings of the overall activity shall be presented at the Final Review Meeting (Milestone 03) for review and discussion and the final, internally approved (if required) reports shall be submitted (uploaded to EFDA IDM) by the 31st Dec 2013. It shall be then reviewed (by the EFDA PPP&T RO as a minimum) and approved by the head of EFDA PPP&T.

References

[1] F. Castejon et al.: Stellarator optimization under several criteria using Metaheuristics; for publication
https://user.efda.org/?uid=2LNLQ9
[2]F. Schauer et al.: HELIAS 5-B magnet system structure and maintenance concept; for publication
https://user.efda.org/?uid=2LMUQP
[3] H2020 Fusion Roadmap, Mission 8: Stellarator Research
Shortly available on IDM