Issue 2. 8 July 2013

WORK PLAN
FOR THE IMPLEMENTATION OF
THE FUSION ROADMAP
IN 2014-2018

Table of Contents

1. Description of the Proposal

Introduction

The European Commission proposal for the EURATOM programme in Horizon 2020 states the need for "an ambitious yet realistic roadmap to fusion electricity by 2050". A Roadmap to the realization of fusion energy was adopted by the EFDA system at the end of 2012[1]. The roadmap aims at achieving all the necessary know-how to start the construction of a demonstration power plant (DEMO) by 2030, in order to reach the goal of fusion electricity in the grid by 2050.

This proposal has the goal of implementing the activities described in the Roadmap during Horizon 2020.

ITER, the key facility in the roadmap. ITER is expected to achieve most of the important milestones needed on the path to a fusion power plant (FPP), notably robust burning plasma regimes, the test of the conventional physics solution for power exhaust and the validation of the breeding blanket concepts. ITER construction has triggered major advances in enabling technologies for the construction of the main components and of the auxiliary systems. The ITER licensing process has confirmed the intrinsic safety features of fusion and incorporated them in the design. Thus, ITER success remains the most important overarching objective of the programme and, in the present proposal the vast majority of resources in Horizon 2020 are devoted to ensure that:

1. ITER is built within scope, time and budget;
2. Its operation is properly prepared by addressing the R&D priorities pointed out by the ITER Organization in the ITER Research Plan; and
3. A new generation of scientists and engineers is properly educated and trained for its exploitation. Provisions for support at PhD and post doc level are described below.

The strategy to DEMO. In the European strategy DEMO is the only step between ITER and a commercial fusion power plant. Its high-level goals are:

1. Produce net electricity for the grid at the level of a few hundred MWs;
2. Breed the amount of tritium needed to close its fuel cycle; and
3. Demonstrate all the technologies for the construction of a commercial Fusion Power Plant, including an adequate level of availability.

To achieve the goal of fusion electricity demonstration by 2050, DEMO construction has to begin in the early 2030s at the latest, to allow the start of operation in the early 2040s. To minimize the risk of the DEMO R&D a pragmatic approach was chosen in the Roadmap that consists of relying on simple and robust technical solutions and well established and reliable regimes of operation2, as far as possible extrapolated from ITER, and on the use of materials adequate for the expected level of neutron fluence in DEMO. DEMO will rely on established

---

[1] *A roadmap to the realization of fusion energy* EFDA (12) 52/7.1.1a

[2] The choice of the DEMO regime of operation will depend on the ITER results. However, regimes based on advanced physics would require advanced technologies as well. For example, the heat-exhaust problem, more complex for advance regimes, and the need of considerable auxiliary power for plasma control, that requires high thermodynamic efficiency cycles, imply that advanced physics does require advanced technological solutions.

technologies for the main machine components, such as the magnet system and the vacuum vessel. Many of the technologies used for the heating and current drive systems of ITER will form the basis for DEMO, although extension of the capabilities and optimal reliability will be pursued through targeted R&D. The exploitation of DEMO will be performed in two phases: the first phase will be characterized by a system availability of around 30% and will require in-vessel materials qualified up to 30 dpa; in the second phase the availability will be progressively increased (with a target of 70% for a commercial fusion power plant) and in vessel components with materials qualified up to 70dpa will be used. Nevertheless, even with the pragmatic approach of the roadmap a substantial R&D activity is needed in a few areas to minimize the risks of technical failures and delays. Specifically, the areas of heat exhaust and tritium breeding will require a significant effort to develop risk mitigation strategies. Furthermore, cost optimization analysis will have to guide the DEMO design in order to ensure that the cost of the investment will be consistent with the target of an economic use of fusion power. For this reason, DEMO cannot be defined and designed by research laboratories alone, but requires the full involvement of industry in all technological and systems aspects of the design.

A goal oriented approach. The roadmap has been articulated in eight different Missions.

1. Demonstrate plasma regimes of operation (based on the tokamak configuration that increase the success margin of ITER and satisfy the requirements of DEMO.
2. Demonstrate heat exhaust system capable of withstanding the large load of DEMO.
3. Develop materials that withstand large 14MeV neutron fluence without degrading their physical properties.
4. Ensure tritium self-sufficiency through technological solution for the breeding blanket.
5. Implement the intrinsic safety features of fusion into the design of DEMO following the experience gained with ITER.
6. Produce an integrated DEMO design supported by targeted R&D activities.
7. Ensure the economic potential of fusion by reducing the DEMO capital costs and developing long-term technologies.
8. Bring the stellarator line to maturity.

For each Mission the critical aspects for reactor application, the risks and risk mitigation strategies, the level of readiness now and after ITER[3] and the gaps in the programme have been examined. High-level programmatic work packages (PWPs) for the roadmap implementation have been prepared and the resources evaluated. For each Mission a technical Annex has been produced with an attached Risk Register and list of >150 PWPs. The relatively high number of PWPs is motivated by the details of the deliverables in areas such as those related with the ITER preparation where the IO has produced a detailed list of the priorities for the ITER Research Plan. Thus, to make the analysis of the programmatic goals more easy the PWPs have been grouped under ~40 programmatic Headlines.

---

[3] Technology Readiness Levels (TRLs) are a systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology. The TRL approach has been used for example in NASA space technology. TRL Summary: **TRL 1** Basic principles observed and reported; **TRL 2** Technology concept and/or application formulated; **TRL 3** Analytical and experimental critical function and/or characteristic proof-of concept; **TRL 4** Component/subsystem validation in laboratory environment:**TRL 5** System/ subsystem/ component validation in relevant environment; **TRL 6** System/subsystem model or prototyping demonstration in a relevant end-to-end environment; **TRL 7** System prototyping demonstration in an operational environment; **TRL 8** Actual system completed and "mission qualified" through test and demonstration in an operational environment. Validation and verification completed. **TRL 9** Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience.

Education and training. The implementation of the fusion Roadmap requires a new generation of scientist and engineers to be formed. ITER will break new ground in fusion science and the best young scientists should be encouraged to participate in the ITER programme at an early stage of their career. Training will specifically involve strengthening the available engineering resources, with a marked change from non-nuclear to nuclear technologies. Training and education during Horizon 2020 will be supported at under-graduate and PhD level through Fusenet[4] to be followed by post-doctoral training programmes. Training in critical qualifications will be reviewed with industry and encouraged.

Basic research. In addition to the mission oriented work a programme aimed at promoting basic understanding and "curiosity driven" research will be implemented. Basic research is meant to address several areas in which fundamental understanding is required to reliably predict the integrated plasma behaviour in ITER and DEMO from first principles.

Opportunities for industrial innovation. In the coming decades the development of fusion will move from a science-driven, lab-based exercise to an industry-driven and technology-driven program. This requires that industry progressively shifts its role from that of provider of high-tech components to that of driver of the fusion development. This will be a step wise process with industry, possibly in the form of consortia including research laboratories and universities, working closely with research partners. During Horizon 2020 this process will be started in key area such as material development and efficient production of electricity.

How this proposal is structured. In the remainder of this section a description of the activities in each Mission is presented. This part, in conjunction with the Roadmap document and its technical Annexes, is aimed at summarize the scientific and technical objectives to be achieved in Horizon 2020 as part of the implementation of the Roadmap.
Section 2 presents the implementation Work Packages. The Work Packages associated with Missions 3-7 mirror directly the corresponding Headlines outlined in this section (see Traceability matrix below). For Mission 1 and 2 the approach is different. In this case the programmatic deliverables are strongly interlinked in the implementation and a precise quantification of the effort in each individual Headline is not possible. In the practical implementation, experiments on JET and on Medium Size Tokamaks operated as common facilities will have to be performed that will provide input to different Headlines and the goal of the implementation will be to ensure an efficient implementation of the programme, maximizing the run-time and so the cost effectiveness of the exploitation. Provisions are foreseen for the execution of joint experiments in different devices to maximize the return on the objectives of the Roadmap. Therefore, the work packages for Mission 1 and 2 are aligned with the exploitation of the common devices. Similar arguments can be applied for Mission 8.
Section 3 presents the management structure and the procedures for the allocation of activities to the Members and the peer-review process. This part includes the description of the function of the Programme Unit to ensure an effective coordination of the different Work Packages.

Section 4 describe the resources needed for the implementation

Section 5 summarizes the main milestones and decision points. A Gantt chart (covering the entire Roadmap) is provided separately to trace the implementation plan.

Francesco Romanelli 26/6/13 09:24
Comment: This will be the Gantt chart of the Roadmap

---

[4] Fusenet (the European Fusion Education Network) is the umbrella organizaisation under which all fusion education, from Master (and earlier) to PhD, is coordinated.

Mission 1: Plasma regimes of operation

The goal of this Mission is to demonstrate and qualify regimes that meet the needs of ITER and DEMO. Plasma regimes of operation (based on the tokamak configuration) for reactor application need to achieve high fusion gain, by minimizing the energy losses due to small-scale turbulence and by taming plasma instabilities. In addition, in order to comply with acceptable heat loads on the divertor (Mission 2) a large fraction of the heating power must be radiated from the confined plasma, whilst minimizing any adverse impact on fusion power production. Ideally, these regimes would need to be maintained in fully steady-state conditions. However, on the basis of the pragmatic approach described in the Roadmap, it may be sufficient, at least for DEMO, to maintain them for duration of a few hours (inductive regimes). Specific emphasis should be given to plasma control obtained with systems compatible with the harsh reactor conditions and avoidance/mitigation of disruptions and edge-localised modes must be ensured.

Mission 1 will be completed by ITER, providing the basis for the plasma regimes of operation in a fusion power plant (FPP). Its inductive regimes of operation will be demonstrated by 2030 and steady state regimes of operation by 2040. The main objective in Horizon 2020 is the mitigation of the high priority risks identified in the ITER Research Plan and Summarized in the Headlines 1.1-1.9 below (see Annex 1 of the Fusion Roadmap). The mitigation of these risks will allow a swift commissioning of ITER up to the maximum performance. On top of the risks identified by ITER, specific aspects of DEMO operation (as for example confinement and stability for operation at high-β and very high plasma radiation) will be an additional part of the program during Horizon 2020.

In Mission 1, the main risk mitigation measures are the preparation of ITER operation on JET (inductive regimes) and JT-60SA (steady-state regimes), the latter taking place after the period covered by the present Work Plan. Small and medium sized tokamaks (MSTs), both in Europe and beyond, with proper capabilities, will play a role on specific work packages. Besides JET, in Europe most of these capabilities are available in ASDEX Upgrade, which is expected to play an important role during Horizon 2020 for the preparation of the ITER steady-state regimes of operation.

Headline 1.1: Increase the margin to achieve high fusion gain on ITER

Roadmap PWPs: 1.3, 1.9, 1.10, 1.13

Inductive modes of operation (broadly classified as H-mode), with energy confinement adequate to meet the ITER needs, have been demonstrated and qualified during the 1990s. The goal in Horizon 2020 is to prove the compatibility of this regime with the constraints arising from the ITER first wall requirements and to extend its performance in order to provide extra margin for the achievement of the ITER objectives. As a risk mitigation measure and as an option to produce higher performance, the so-called improved H-mode (also known as *hybrid regime*) will be further developed. Optimization of H-mode confinement will involve three different lines. The results will be available by the end of Horizon 2020 to shape the strategy of the first part of ITER operation.

- *Operation with metallic Plasma Facing Components.* So far, the H-mode has been developed primarily in machines with carbon plasma facing components. The use of high-Z materials like tungsten or the combination beryllium and tungsten foreseen in

ITER requires special recipes for maintaining sufficiently high confinement. Results from JET and AUG show that both the edge confinement and the power required to access the H-mode change in the presence of a metal wall (with respect to carbon). These changes need to be further studied, understood and the relevant parameters re-optimised.

- *Improved H-mode ("hybrid" regime).* Tailoring the current density radial profile has been shown to lead to an increase up to 50% of the energy confinement time above the H-mode confinement scaling. This regime needs to be tested in condition as close as possible to those of ITER and a proper scaling law (supported by theoretical understanding) established for a confident extrapolation to ITER, including the dependence on the isotope mass.
- *High radiation*. Operation in ITER and even more so in DEMO will require high density and high radiated power using extrinsic impurities. In these situations, the conventional H-mode confinement scaling is known not to apply. Confinement optimisation and scaling in this part of the operating space will be a priority in Horizon 2020, including the integration with improved H-modes.

Headline 1.2: Operation with reduced or suppressed ELMs

Roadmap PWPs: 1.4 - 1.6

Strong reduction or complete suppression of edge-localised modes (ELMs) is assumed in all operating regimes of ITER to ensure a sufficiently long life time for plasma facing components. The compatibility of ELM mitigation methods with high-confinement operation will be studied and predictions for future devices improved with the support of a substantial theory and model validation effort. A related question is the isotope scaling of ELM mitigation methods with a view to optimising the information that can be obtained during the non-active phase of ITER. Two different development lines are envisaged here. Again they need to be completed by the end of Horizon 2020 to provide useful information for the ELM mitigation strategy of ITER and specifically for the work that will have to be done during the non-active phase to demonstrate adequate solutions:

- *Development of plasma regimes with intrinsic small or completely suppressed ELMs***.** Some have been identified but none is yet capable of spanning all of the operating parameters required for ITER. Indeed, some of these parameters can only be combined in an ITER-sized device. Effort will be allocated to further developing these regimes and to improving the theoretical understanding so as to identify which should be given priority in ITER.
- *Active ELM control.* Two methods are specifically foreseen here:
    - Resonant Magnetic Perturbations. During Horizon 2020, the goal is to improve understanding of the effects of RMPs in order to extrapolate to ITER (i.e. low normalized Larmor radius, high normalized density). Extrapolation of this technique to large machine size would require the installation of a set of coils in JET, an option possible only within the process of JET intenationalization as suggested by the Panel on *Strategic orientation of the fusion programme*.
    - Pellet Pacing. This method needs to be established as fully reliable in the conditions as close as possible to ITER and theoretical models need to be validated for a confident extrapolation to ITER.

Headline 1.3: Avoidance and mitigation of disruptions and runaway electrons

Roadmap PWPs: 1.1, 1.2

ITER can tolerate a few disruptions and the assumed disruption rate is in line with the present JET experience. A reactor should be almost disruption free. Thus, tokamak plasma scenarios must include specific provisions for disruption avoidance and their early detection, control and mitigation. Reliable disruption detection, avoidance and mitigation methods will have to be established during Horizon 2020 in order to support the initial ITER strategy in this area. The large transients associated with disruptions lead to three distinct issues:

- *Large energy loads on the plasma-facing components* are released in a few ms during the "thermal quench" leading surface temperatures above the melting threshold. The main risk-mitigation strategy here is the use of Massive Gas Injection (MGI) to radiate most of the thermal and magnetic energy. This needs to be demonstrated as a reliable method up to the highest plasma currents and the requirements for ITER need to be extrapolated from present data.
- *Electromagnetic loads* are generated during the "current quench". Control of the "current quench" duration to the minimum has to be reliably demonstrated. A full description of the "current quench" phase needs to be ensured with numerical simulation tools.
- *Beams of high-energy electrons* with the potential to damage the first wall can be generated during the "current quench" if sufficiently high electric fields are produced. This effect is exacerbated by the use of massive gas injection (which increases plasma resistivity) and is particularly important in large devices due to the secondary electron generation mechanism. Studies of runaway electron generation, control and mitigation are required in conditions as close as possible to those of ITER in order to provide adequate tools for the operation of ITER.

Headline 1.4: Integration of MHD control into plasma scenarios

Roadmap PWP: 1.15

The control of large-scale magneto-hydrodynamic (MHD) instabilities in present day tokamak operating scenarios is usually achieved by careful tailoring of the discharge trajectory to minimise the probability of their occurrence. Proof-of-principle experiments for control of core MHD instabilities such as sawteeth and neoclassical tearing modes (NTMs) have shown that active control is possible. Such control will be required in ITER as the threshold for these instabilities is expected to decrease with increasing machine size (although fusion alpha particles may provide some stabilisation) and because of the potential for redistribution and loss of fusion produced fast alpha particles, with negative consequences for self-heating and for first wall power loading. It is thus necessary to integrate these control tools routinely into the operating scenarios being prepared for ITER. In this regard, the main actuator being deployed (and planned for ITER) is high power electron cyclotron current drive (ECCD) combined with real-time control of steering mirrors. Testing the integrated control strategy and developing optimised control algorithms will be a priority in the first half of the period covered by this Work Plan. Extrapolation of these techniques to large machine size would require the installation of an ECCD system on JET. This requires the success of the process of JET internationalisation, as suggested by the Panel on *Strategic orientations of the fusion programme*, with a corresponding significant amount of resources made available for JET operation.

Non-inductive regimes, in order to self-generate a large fraction of the required plasma current, may need to operate at pressures above that at which the plasma is subject to global instabilities in the absence of a close-fitting conducting wall. For this reason, such a wall has been included in the design of several modern medium-size tokamaks and there are plans to retrofit or upgrade such walls in existing devices. The global instability is then reduced to one that evolves on the resistive time scale of the wall (resistive wall modes or RWMs) and is thus amenable to control. On the other hand, as an off-axis toroidal plasma current profile is required to maximise the plasma pressure, these regimes avoid sawtooth instabilities and low order NTMs by removing the corresponding resonant magnetic surfaces from the plasma (at the price of the requirement for significant off-axis current drive). The general development of non-inductive regimes is covered in Headline 1.9. Noted here is the specific need to define, in medium size devices, the system requirements for RWM control in large tokamaks (in this case, JT-60SA) and in ITER.

However, while RMW studies are an important long-term topic for ITER and JT-60SA and so a community needs to maintained, the NTM control work should take priority. This is due to the timeline of ITER were RWMs are only expected to play a role in the steady state scenarios explored after Q=10 operation is established.

Headline 1.5: Control of core contamination and dilution from W Plasma Facing Components

Roadmap PWP: 1.7

The use of metal plasma-facing components (PFCs) is required in ITER and DEMO to reduce the level of tritium retention in the machine (as compared to carbon walls). High-Z materials are required in order to reduce erosion in long pulse devices and thus to minimise the frequency of first wall exchanges. High-Z materials, on the other hand, have high radiation efficiency and thus the core contamination from such materials must be kept to a very low level, typically 10^{-5} times the plasma electron density. For this reason, ITER has chosen a combination of beryllium in the main plasma chamber and tungsten for the divertor whilst DEMO is expected to use tungsten armour throughout. A programme priority will be to demonstrate control of W concentrations to acceptable levels in the regimes of operation foreseen for ITER and a reactor, both for the ITER first wall materials and for all-tungsten machines.

Early in the 2020s, a decision on the JT-60SA enhancements will have to be taken. In particular, the use of an actively cooled tungsten first wall on JT-60SA or ITER will have to be assessed and a strategic decision taken. Operations with a tungsten wall do not need to take place before 2030. This leaves sufficient time for the design and R&D activities during the period 2020-2030.

Headline 1.6: Determine optimum particle throughput for reactor scenarios

Roadmap PWPs: 1.11, 1.12, 1.14, 2.I.5

Central peaking of the plasma density has the potential to increase the fusion yield in a reactor. On the other hand, increased density peaking facilitates the inward convection of plasma impurities and may lead to unacceptably high core dilution and radiative losses (Headline 1.5). Potential actuators to control central peaking are high-speed pellet injectors for increasing the core density and central electron heating, which has been shown to reduce density peaking.

ITER will operate with little or no direct neutral fuelling and thus relies on edge pellet fuelling. If an edge particle pinch exists, this may be unnecessary but would remove the attractive possibility of separately controlling the core and scrape-off layer densities. A test in similar low neutral penetration conditions can be made in JET high current H-modes. The exhaust from fusion plasmas is via pumping ports built into the divertor. The exact details of pumping efficiency depend on the divertor, plasma and pumping port geometry and particle transport in full and partially ionised plasmas. This applies not only to the primary fusion fuel components (D, T) but also to the helium produced by the fusion reaction. Efficient helium exhaust is required in order to minimise core fuel dilution. Models for plasma exhaust will be validated and tested in conditions that mimic the foreseen pumping capability of ITER. The impact of particle throughput on retention of fuel will be studied by changing fuelling and pumping rates.

Headline 1.7: Optimise fast ion confinement and current drive

Roadmap PWPs: 1.17, 1.22

The behaviour of energetic ions is fundamentally important in the study of fusion plasmas and the redistribution of fast ions and the degradation of their confinement caused by plasma instabilities is well known. Thus, understanding the complex nature of interactions between the plasma instabilities and fast ions and a potential deviation from classical transport requires further investigations.

The major goals during Horizon 2020 will be the validation of theoretical predictions against observations and the validation of existing models, understanding whether collective modes driven by energetic particles can reduce the fast ion confinement and the current driven by the injected fast ions and the assessment of the feasibility of installing fast ion diagnostics on ITER. Emphasis should be moved to the ongoing development of the new models allowing more meaningfull validation against present experimental observation. Realistic geometries, self-consistent mode structures and their interplay with suprathermal particle transports, along with kinetic description of thermal plasma components are all crucial ingredients that need to be taken into account for the development of a reliable predictive capability. Self-consistent numerical simulations must simultaneously test mode structures, amplitude, frequency spectra, and particle transport.

The fast ion distribution obtained in ITER will be different to that attained in all other present day devices, because the fast ion pressure is large enough to drive instabilities itself.

The investigations will focus on validating code/models for quantifying fast ion losses and redistribution in ITER-relevant regimes. In support of the experiments, close collaboration on diagnostic issues and interpretive modelling work is envisaged. Cross-machine studies will be undertaken to compare the effect of various plasma instabilities on the fast ion confinement and the saturation amplitude of internal Alfven Eigen modes with predictive codes as a nonlinear test of their capabilities.

Headline 1.8: Develop integrated scenarios with controllers

Roadmap PWPs: 1.16, 1.18, 1.19, DIA01

The goal in Horizon 2020 is to provide methods that will allow for safe and stable operation of ITER (and DEMO). This involves the development of controlling algorithms for discharge evolution including the control of MHD instabilities, disruption mitigation and the divertor operation control. Before a control scheme is accepted for ITER, its efficiency needs to be demonstrated on existing machines. The physics mechanism underlying the control algorithm will be validated through numerical simulations. Three different development lines are envisaged here and the work will involve experiments on divertor tokamaks of different size as well as the use of a numerical discharge simulator with integrated controllers/actuators:

- *Demonstration of the combination of individual control algorithms into integrated control scenarios.* In ITER, it will be necessary to combine algorithms for control of ELMs (Headline 1.2), sawteeth and NTMs (Headline 1.4) and disruptions (Headline

1.3) with control of core contamination (Headline 1.5), divertor detachment (Headline 2.1), fuel species mixture and fusion burn. Such a combination of many non-linear control loops requires preparation in present machines and the development of plant dynamical models based on physics-based simulation.

- *Development and test of measurement techniques for ITER and DEMO.* Advances in diagnostic techniques and interpretation are required if ITER is to reliably and routinely meet its measurement requirements. Tests of novel hardware and of interpretation algorithms are being made on present machines in order to prepare for ITER operation. Examples include the development and testing of first mirrors for ITER viewing systems, algorithms for compensating for reflections from metal walls and diagnostics for the detection of the fusion alpha particles.
- *Test of a DEMO-relevant minimum diagnostic and actuator set for control.* The harsh environment and very long pulse operation required for DEMO means that several diagnostic techniques used on present machines and foreseen for ITER will not be available on DEMO. As part of Mission 6, a review will be undertaken in order to identify DEMO measurement requirements and of options for making these measurements. A test of regime control using a DEMO-relevant set of measurements is foreseen.
- *Pre-qualification of complete ITER scenarios on present machines.* In the development of fusion plasmas, the regime of operation is often distinguished from the full, time-dependent operating scenario in which the regime is exploited. Indeed, the fusion performance and reliability of regimes of operation depend on robust scenarios. In ITER, there will be many technological constraints on scenario development, some of which are not normally faced by present machines. A programme goal will be to develop complete operating scenarios for each foreseen regime of ITER operation including plasma breakdown, current ramp-up, flat-top and termination.

Headline 1.9: Qualification of Advanced Tokamak regimes of operation

Roadmap PWP 1.20

To achieve truly steady-state operation in a tokamak, the plasma current must be driven without use of the central solenoid for inductive current drive. Limits on recycling power in a fusion power plant mean that a significant fraction of the non-inductive current drive must be self-generated. The self-generated current (referred to as bootstrap current) scales with the normalised plasma pressure gradient, whose radial profile must be to a large extent aligned with the required total current profile for the regime. Calculation and proof-of-principle experiments show that manipulation of the plasma current profile can be used to improve the core plasma confinement and thus the pressure gradient. There are several variants of plasma current profiles presently under investigation with the family of regimes collectively known as advanced tokamak (AT) regimes. Because of the required high plasma pressure gradient, the plasma in these regimes is subject to global instabilities (e.g. resistive wall modes or RWMs – see Headline 1.4) and is more prone to disruptions. Avoiding these instabilities and disruptions requires a number of sophisticated diagnostic, control and actuator mechanisms. Finally, even in AT regimes, part of the plasma current must be driven by external current drive methods. The efficiency of current drive increases with plasma temperature and decreases with density and thus is inversely proportional to the square of the plasma density at constant pressure. Divertor operation in a reactor, however, requires high edge plasma density values. Thus, a compromise must be found and the window of operation in plasma density for AT regimes in a FPP will be restricted.

The EU strategy for developing advanced, non-inductive regimes of operation is based on the joint exploitation with Japan of JT-60SA, where the first plasma is expected in 2019. Prior to JT-60SA operation, an adequate preparation of the advanced regimes of operation will be necessary during Horizon 2020 on existing MSTs with strong current drive capabilities and on JET. The main milestones will be the demonstration that advanced tokamak regimes can be reliably kept under control in conditions compatible with acceptable divertor/wall load and the definition of a preliminary confinement scaling law in medium sized tokamaks. Proof-of-principle size scaling of the current drive control requirements could be obtained during Horizon 2020 with the addition of an ECRH system to JET. It is expected that a decision to upgrade the current drive systems on JT-60SA and ITER will have to be made early in the 2020s and that the decision will be taken with little information on the requirements for non-inductive operation in these machines. A programme goal is thus to provide as much data as possible on present machines to inform these enhancement decisions.

Mission 2: Heat-exhaust systems

Heat-exhaust systems must be capable of withstanding the large heat and particle fluxes of a fusion power plant. The baseline strategy for the accomplishment of Mission 2 consists of reducing the heat load on the divertor targets by radiating a sufficient amount of power from the plasma and by producing “detached” divertor conditions. Indeed, if the SOL plasma is sufficiently collisional, a significant temperature gradient can be established and volume recombination of the plasma can take place, hence reducing the ion fluxes to the target. Such an approach will be tested by ITER, thus providing an assessment of its adequacy for DEMO. However, the risk exists that high-confinement regimes of operation are incompatible with the larger core radiation fraction required in DEMO when compared with ITER. If ITER shows that the baseline strategy cannot be extrapolated to DEMO, the lack of an alternative solution would delay the realisation of fusion by 10-20 years. Hence, in parallel with the necessary programme to optimise and understand the operation with a conventional divertor, e.g. by developing control methods for detached conditions, in view of the test on ITER, an aggressive programme to extend the performance of water-cooled targets to DEMO relevant condtions and to develop alternative solutions for the divertor is necessary as risk mitigation for DEMO.

The ITER baseline strategy will be pursued in existing divertor devices, preferentially with all metal plasma facing components, to secure acceptable ITER divertor operation in the detached regime. Control schemes will be qualified to establish stable detached conditions also in case of slow transients and avoid damage to the ITER divertor target. To optimise the radiated power, the injection of different impurity species will be tested together with control schemes to avoid excessive contamination of the plasma core. These activities will be supported by a strong modelling and validation effort. The milestone is the demonstration of full control of detached conditions compatible with high confinement regimes by the end of the period.

A risk mitigation programme will be defined to secure a viable solution for heat exhaust on ITER and DEMO. The technological feasibility and performance of water-cooled divertor targets concepts, which extend the ITER design and technology to DEMO relevant condition (e.g., higher coolant temperatures and pressures and higher n-dose), will be assessed. A short-list of possible alternative solutions to the baseline strategy will be completed by the beginning of Horizon 2020. Design, assessment of the adequacy for DEMO and proof-of-principle tests of innovative geometries/liquid metals should be completed. Specific milestones are the test of super X and snowflake configurations and of liquid metal targets in a number of small and medium sized tokamaks by the end of the period. The definition of the exact scope and technical specifications of a Divertor Tokamak Test (DTT) facility (either a new facility or the upgrade of existing facilities taking benefit of the opportunities for international collaborations) will have to be completed early in Horizon 2020 and, after a thorough review, a decision should be taken for its construction by 2016.

Headline 2.1: Detachment control for the ITER and DEMO baseline strategy

Roadmap PWPs: 2.I.1-4

Detached divertor conditions can be achieved by: reducing the power flowing to the SOL (P_{SOL}); increasing the SOL density and producing magnetic configurations with large connection length between the midplane and the divertor target (see headline 2.4). Decreased P_{SOL} can be achieved by radiating a large amount of power from the plasma edge (using extrinsic impurities). However, H-mode operation requires a minimum power to be conducted through the pedestal which will limit main chamber radiation specifically for ITER. Furthermore, detached conditions will have to be carefully controlled to ensure safe operation, requiring robust sensors, algorithms and actuators. ITER will play the ultimate role in proving the applicability of the "conventional" power exhaust scenario for DEMO, but it can provide this information only after the successful achievement of long pulse high fusion gain (Q~10) operation around 2030.

In preparation of a safe ITER start-up and to provide further input for a decision on a divertor test facility, the behaviour of detachment at high levels of heating power and radiation must be investigated during the first half of Horizon 2020. Specifically, the control of detachment, its compatibility with ELM mitigation and the behaviour close to the H-L threshold must be documented.

Although divertor detachment has been achieved on present day tokamaks, its behaviour cannot be described by the existing numerical codes in a predictive fashion necessitating also increased efforts for code development and modelling (see Headline 2.2).

Headline 2.2: Prepare efficient PFC operation for ITER and DEMO

Roadmap PWPs: 1.8, 2.III.1-3

In addition to the requirement of reduced steady state and transient power load, the erosion of the plasma facing components has to be minimized in order to maximise the availability of the device and to reduce the deleterious effects of hydrogen co-deposition and dust production. To optimize the material choice specifically in the main chamber, the temperature and flux of plasma filaments will be quantified. In parallel, improved plasma facing materials, also taking into account engineering requirements will be developed. The specific plasma wall interaction of seeding impurities with the respective armour material as well as the effect of material mixing will be determined. Since all conventional solutions foresee metallic PFCs, the effect of accidental melting on the plasma and on the performance of the component must be clarified.

Headline 2.3: Optimise predictive models for ITER and DEMO divertor/SOL

Roadmap PWPs: 2.II.1-2

Edge simulations are required for many deliverables under Mission 2. Therefore the activities subsumed under this headline shall increase the validation activities of edge codes, accomplished by their improvement towards more realistic geometries and closer coupling between different modelling tools. Also performance issues (such as CPU usage or code parallelization) will be addressed here. The work will involve edge transport and material migration codes and should finally deliver performance-optimized, fully validated codes providing predictive capabilities for ITER and DEMO in edge simulations with metallic PFCs.

Headline 2.4: Investigate alternative power exhaust solutions for DEMO

Roadmap PWPs: 2.IV.1-3

Two solutions are under investigation as alternatives for the conventional poloidal divertor: the "snowflake" configuration and the "super-X" configuration. Their benefit and limitations from the plasma physical point of view will be investigated during Horizon 2020 at a proof of principle level in small and medium size tokamaks.

The extrapolability of these solutions to DEMO needs to be assessed. Critical aspects are the complexity of the magnetic configuration and the necessity to avoid in-vessel coils in DEMO/FPP. Preliminary design activities are on going to understand whether these solutions can be realistically integrated in a DEMO/FPP design, including the constraints arising from neutron shielding and remote maintenance.

In addition to a new divertor concept, liquid metal-based solutions (Li, Ga, Sn) could provide the possibility for PFCs with a heat load capability of up to several tens of MW/m^2 and relieve the problem of surface damage. The problems faced by these solutions are that the evaporation of the liquid metal surface is often too high to be compatible with plasma operation and solutions that rely on evaporation probably cannot be used in a continuously operating device. Moreover, issues related to MHD effects for plasma transients and/or for sufficiently high flow velocity may lead to the necessity to avoid freely flowing metal surfaces.

In parallel to the investigations stated above a shortlist for the requirements of a possible divertor test tokamak as a tool for risk mitigation for the DEMO exhaust has to be set-up early during Horizon 2020 in order to provide input for the decision whether it should be built and for an eventual conceptual design phase which should start around the end of Horizon 2020.

Mission 3: Development of neutron resistant materials

The performance and reliability of structural and PFC materials for in-vessel components is among the foremost considerations for the successful development and deployment of DEMO and future fusion reactor systems. The very demanding operational requirements that the structural materials will experience in DEMO and FPPs are far beyond today's experience (including ITER)

An assessment of the state of development of neutron-resistant structural, high-heat flux and plasma-facing materials suitable for use in a Fusion Reactor was conducted in 2012-13 (MAG Report[5]). The MAG assessment has focused on the urgent R&D needs for material development for a DEMO starting construction around 2030. The assessment has defined a realistic set of requirements for the DEMO materials such as the capability of withstanding neutron damage up to 20dpa (for blanket front-wall steel) and 5 dpa (for copper-alloy-based divertor heat sinks). For the early DEMO concept being considered in the roadmap (e.g., 2 GWth, 2 hrs minimum pulse length with dwell times of few hundred seconds) this would allow the first set of DEMO in-vessel components operation for a period of ~ 1.5 fpy (~6000 fatigue cycles) or a ~4 year programme at around 30% availability.

On the basis of the MAG assessment the following strategy has emerged for the development of neutron resistant materials for DEMO:

- The selection of a limited number of baseline and risk-mitigation materials for structural steels, plasma facing materials and heat sink materials interfacing the coolants, during Horizon 2020 on the basis of the results of irradiation in fission reactors. This should include irradiaton of samples doped with special isotopes (i.e., Fe-54) to reproduce effects such as H/He production and with the support of an adequate simulation effort;
- The completion of the design of an accelerator-based 14MeV neutron source for the characterization of materials under a fusion neutron spectrum up to a level of damage typical of DEMO (although not of a fusion power plant). Options have been evaluated (such as a reduced specification version of IFMIF) to have the facility ready in 2022 and thus make available these data by 2027 in time for the completion of the DEMO engineering design.

A strong emphasis will be placed on the industrialization of the candidate materials, including issues of fabricability and joining techniques. Direct participation of industry as a full partner will be sought.

The main priorities of the programme over Horizon 2020 are summarized below.

Headline 3.1: Development and characterization of advanced steels: complete EUROFER baseline (Option 1) including, development for water-cooled lithium lead (Option2), develop advanced steels e.g., GEN IV EUROFER and ODS steels)

Roadmap PWPs→MAG

---

[5] Assessment of the EU R&D Programme on DEMO Structural and High-Heat Flux Materials Final Report of the EFDA Materials Assessment Group (December 2012) EFDA-IDM Ref: EFDA_D_2MJ5EU,

The baseline material choice for the breeding blanket structures is the Reduced Activation Ferritic Martensitic (RAFM) Steel EUROFER. It shows a good overall balance of mechanical properties, and there is broad industrial experience in its fabrication. However, its embrittlement at temperature < 300°C for samples irradiated after ~20dpa, coupled with the degradation in mechanical strength above 550°C, gives a relatively narrow temperature operating window and poses serious difficulties to design and develop breeding blanket concepts that rely on operation with water at pressurized water reactor (PWR) conditions (see below Headline 4.2) or with higher He temperatures to exploit, in the latter case, higher thermodynamic conversion efficiencies.

Over Horizon 2020 a focussed programme on characterisation, irradiation (including isotopic tailoring experiments) and modelling of EUROFER will be implemented with the goal of widening the temperature operating window. Furthermore, as a risk mitigation strategy, two advanced materials will be developed. These are:

- "Generation IV Ferritic-Martensitic steels", with improved high temperature creep strength (up to ~650°C) achieved using thermo-mechanical treatment (TMT) to improve the microstructure and density of radiation defect recombination centres. They will be investigated with the goal of bringing them to the level of reduced activation steels, as done in the 90s for EUROFER;
- Oxide Dispersion Strengthened (ODS) alloys with high temperature creep strength, in development for a decade but still at an early stage.

A down selection (for the baseline plus risk-mitigation options) is expected to generate by 2018 a prime candidate material list for prototyping, demonstration of welding and joining processes, and progressing towards industrialisation.

Headline 3.2: Development and characterization of high heat flux materials: complete HHF/PFC baseline for Cu alloys and W and risk mitigation options for HHFs/PFCs)

Roadmap PWPs ➔ MAG

The primary candidate material for plasma protection in DEMO is foreseen to be tungsten, whilst copper alloys remain the primary candidate as heat sink material for the divertor coolant interface. The use of copper alloys, like the CuCrZr pipes in the ITER divertor, has two major drawbacks for DEMO: the loss of ductility under neutron irradiation at low temperatures (T<180 °C), and the loss of strength at elevated temperatures in CuCrZr under irradiation. It should be noted that although the neutron damage of the divertor is limited to ~5dpa for the conditions typical of the first set of components of DEMO, the degradation of the physical properties of Cu alloys is observed already at a few dpa. Therefore improved Cu-based alloys need to be developed to meet the requirements for a DEMO divertor. During Horizon 2020 different alloys will be produced and irradiated. In parallel, a basic material properties database will be completed and mock-up fabrication & testing will be performed to evaluate fabricability and industrial processes. As a risk mitigation, the use of copper-based composites (fibre and foil reinforced copper pipes, tungsten-copper graded materials, and Cu-(W)-laminates) will be investigated. Further developments, including up-scaling of material production and the development of joining technologies at industrial level of these alloys will be done. The database of un-irradiated and irradiated samples must be delivered by 2020. In addition, the production capacity of self-passivation first wall tungsten alloys, which minimise the risk of volatilization of radioactive isotopes in a loss-of-coolant accident, will be enlarged by the end of this period.

A down selection of baseline and risk-mitigation materials will be completed by 2018.

Headline 3.3: Development and characterization of functional materials

Roadmap PWPs → MAG

The degradation of physical and mechanical properties of functional materials leads to severe limitations for their applications in DEMO. This includes for example Li-containing solid breeders and the Be multiplier used in some breeding blanket design options (see Headline 4.1), coatings for suppression or minimization of corrosion or tritium permeation through structures interfacing the coolants, and dielectric materials for diagnostic and H&CD applications. The investigation and characterization of the candidate materials will be extended to representative reactor conditions. R&D work on solid breeder characterization and corrosion/tritium permeation barriers is a specific design related item and is included in Mission 4.

Headline 3.4: Materials modelling and experimental validation

Roadmap PWP → MAG

Modelling of materials has made great progress over the last decade. This is partly due to the rapidly expanding availability of computer resources and partly due to the development of conceptually new numerical mathematical models. However, within Horizon 2020 a number of critical phenomena, requiring further vigorous R&D aided by modelling have been identified. They include: radiation “hardening” embrittlement, helium embrittlement, radiation swelling, thermal and irradiation creep, and fatigue of materials.

The priority areas for developing and applying modelling in the next five years are:

- The development of multiscale models for the accumulation of radiation defects and transmutation products, including helium and hydrogen, in complex microstructures and complex alloys;
- The investigation of fundamentals of radiation and helium embrittlement effects;
- The development of models for high-temperature phase stability and microstructural stability of materials, and the determination of factors limiting the compatibility of materials under high-dose irradiation;
- The problem of highly heterogeneous swelling, resulting from the highly spatially heterogeneous distribution of neutron flux;
- The integration of models for microstructural evolution with neutron transport calculations, and the development of capabilities for the computer-model-based assessment of the end-of-life conditions for components of a FPP.

Headline 3.5: Materials design data integration

Roadmap PWPs → MAG

In the DEMO design activity a programmatic link needs to be established between design progression and material development. This should facilitate:the rapid insertion of material technological and modelling advances into the conceptual design activity; and the prioritization of design needs and challenges within the other materials project areas

Main goals under this Headline will be:

- To develop design criteria, codes and standards (benefitting from the ITER experience) to meet the specific needs of DEMO and develop a material handbook to reflect the evolving needs of designers;
- To establish a link with component designers to understand the priority design needs in terms of material data and performance, identifying new work streams or focus areas for

the other material projects; there is also a need to identify key developments in the areas above (Headlines 3.1-3.4) and progress relevant to component performance, promoting this for insertion into the design concepts.

Headline 3.6: Early Neutron Source definition, design and construction

Roadmap PWPs ➔ MAG

The MAG report has confirmed that irradiation under a 'Fusion neutron spectrum' is necessary up to a minimum reasonable level of ~30dpa (for blanket structural steels), or 5dpa (for copper alloy-based divertor heat sinks) before the DEMO design can be finalized. Whilst a full performance IFMIF provides the ideal Fusion Neutron Source device, as already identified in the Fast Track approach, for testing materials up to dpa levels foreseen for a FPP, the schedule for DEMO is such that the tests must start earlier than currently foreseen for a full IFMIF. An early start of an IFMIF-like reduced specification 14MeV neutron source is advocated in Horizon 2020 and investigations on how to use the IFMIF/EVEDA hardware beyond the Broader Approach are presently being pursued. This could allow an early qualification of material at a DEMO-relevant level of neutron damage, thus strengthening considerably the basis for a DEMO decision in 2030.

The following options have been considered in the MAG report for the Early Neutron Source (ENS):

- Full recycling of many of the components developed for IFMIF-EVEDA by, e.g., reducing the accelerator voltage to 26 MeV, by omitting the final LINAC stage and by some reduction of the beam focusing systems, but maintaining the full accelerator current of 125 mA;
- A staged full-IFMIF option;
- The FAFNIR proposal based on a 40 MeV, 5-30 mA deuteron beam hitting on a carbon target.

A technical assessment of these and possibly additional options will be conducted in 2014, followed by a detailed design with the goal of taking a decision on the construction by 2017 so as to have the facility ready by 2022.

Mission 4: Ensure tritium self sufficiency

DEMO will burn about 0.4kg of tritium per full-power-day and robust technical solutions to ensure that an equivalent amount is bred and extracted must be in place from the beginning of operation. A number of different concepts have been developed based on different choices for the breeder (liquid or solid), the neutron multiplier (beryllium or lead) and the cooling fluid (water, helium or the liquid breeder itself).

ITER will address this mission through the Test Blanket Module (TBM) programme and will strongly contribute to the consolidation of the DEMO blanket design. However, for a DEMO starting construction in 2030 a number of technical decisions have to be made at the start of the Engineering Design Activity (EDA), foreseen at the beginning of the next decade. These decisions include e.g. the choice of the coolant which needs to be consistent with the goal of a net generation of electricity to the grid.

Thus, for Horizon 2020 the objective of this Mission is to strengthen and/or develop the technical basis and resolve all the remaining main technical issues to deliver a feasible, integrated concept design of the DEMO Breeding Blanket with an acceptable confidence level, and which can be shown to meet the DEMO requirements.

There are still uncertainties on the foreseen exploitation of the TBM programme, but there could be important opportunities for involvement of EU Fusion Laboratories. For example, it is planned to test the TBMs in two main phases, a first phase that can be called the "learning" phase and a second phase that can be called the "DEMO-relevant data acquisition" phase. In particular, involvement of specialists from the EU Fusion Laboratories could be foreseen to conduct specific TBM measurements during the operation campaigns. These measurements, in addition to confirm the integral performance of the TBM systems, including the demonstration of tritium breeding performance and verify on-line tritium recovery and controls systems would also be important for validating and calibrating the design tools and the database used in the DEMO blanket design process including neutronics, electromagnetic, heat transfer, and hydraulics. It is assumed that specific TBM instrumentations and data acquisition systems are going to be developed and procured as part of the scope of supply for the TMB concepts to be provided by Fusion for Energy.

A tentative definition of technology readiness level (TRL) for all these breeding blanket concepts is difficult but an attempt is made below to identify the main challenges that will be addressed during Horizon 2020. Tests in ITER are very important but large extrapolations will remain even after successful operation of ITER and supportive R&D activities must be planned to achieve the necessary system maturity.

- *Qualification of functional and structural materials*: Experimental results are available today only on tritium breeding in capsules/specimens irradiated in fission reactors (TRL 2-3). The TBM programme will provide the first integrated test of the helium-cooled pebble bed (HCLL) and helium-cooled lithium lead (HCPB) blanket concepts in a fusion environment and will help in advancing functional material qualification although at limited neutron fluence.
- *Tritium breeding optimization*: Good understanding and validated nuclear cross-section data is available today (TRL 3-4) on the tritium production in the blanket. Sophisticated 3D numerical models of neutron transport have been developed, and mock-up experiments using 14MeV neutron sources have validated these models. The ITER

TBM programme will provide the opportunity to further refine the models for tritium breeding in the presence of realistic effects (TRL 6 after ITER testing). However. design optimisation will still be required especially for blankets that provide marginal tritium breeding (e.g., HCPB).

- *Tritium recovery*: for most breeding blanket concepts, techniques for extracting tritium have been identified, and for some concepts, proofs of principle tests have been carried out (TRL 2-3). However, the extraction of tritium from LiPb is not yet fully established while the requirements for removal efficiency are high in order to keep the tritium concentration in the breeder low enough to meet permeation loss limits. In addition, efficient removal and processing of tritium from the breeder will not be fully addressed by ITER and only limited scale tests and partial validation are expected in ITER (TRL 4- 5 after ITER tests).
- *Fuel cycle and tritium accountancy*: In order to minimize the tritium inventory an efficient fuel cycle must be developed for DEMO that will have to process order of magnitude higher amount of tritium than in ITER. Experience is available from Tritium Labs in EU and in the US that began operations in 80's and contained all of the systems required to process DT fusion fuel. (TRL 4). Experiments such as JET and TFTR also contributed valuable operating experience in a prototypical system configuration, albeit with very small quantities of tritium involved and lower duty cycles. The level of control, reliability, and throughput expected in DEMO will be higher than in ITER. Overall, tritium processing has advanced to TRL level 4, and should approach level 6 following successful operation of ITER and, in parallel, conducting R&D on accurate dynamic tritium accountancy methods.

Making reference to Annex 4 of the Fusion Roadmap for all the technical background, during Horizon 2020 four blanket concepts will be investigated in depth with the aim of down-selecting the best breeding blanket concept including the selection of the coolant for the BoP:

- The two that are planned to be tested as part of the ITER TBM Programme (i.e., helium-cooled pebble bed (HCPB), helium-cooled lithium lead (HCLL);
- A water-cooled lithium lead (WCLL), whose investigation in Europe was abandoned several years ago for lack of funds, and
- An advanced blanket concept, e.g**.,** dual coolant lithium lead (DCLL).

As part of this project, the design and the preliminary qualification of a robust protective first wall concept in conjunction with the blanket concepts to withstand the plasma heat and particle loads (to be defined as part of Mission 2) shall be developed.

The main priorities of the breeding blanket R&D programme in Horizon 2020 are summarized below.

Headline 4.1: Design and R&D of HCLL/HCPB blanket concepts

Roadmap PWPs: HC01-11

The Helium-cooled pebble bed (HCPB) and helium-cooled lithium lead (HCLL) blanket concepts will be tested in ITER as part of the TBM programme. The fabrication of the TBM concepts will require the industrial qualification of a number of technologies (i.e. diffusion welding for the box fabrication) as well as the development and qualification of functional materials. All these activities are included in the TBM R&D programme conducted by F4E.

However, there are a number of issues that need to be resolved for reliable extrapolation of performance to DEMO. This includes for example:

- Efficient tritium extraction/purification system. The capability of these systems to achieve DEMO-relevant performance objectives, mainly in terms of maximization of tritium extraction efficiency (around 80%) and minimization of tritium inventory, is currently not considered as an aspect of primary importance in the TBM programme.
- Qualify behaviour of ceramic breeders and Be-multipliers under DEMO-relevant irradiated condition. This requires specimen irradiation of ceramic breeders and Be to > 20 dpa in fission reactors;
- Manufacturing feasibility and assessment of issues of industrial fabrication; corrosion of the pipes and blanket structures by circulating LiPb at high temperature (similar to DCLL),

Headline 4.2: Design and R&D of WCLL blanket concept

Roadmap PWPs: WC01-11

The water-cooled lithium lead (WCLL) concept relies on a liquid metal LiPb that acts as a breeder and water as a coolant. The main issues are the control of the LiPb water interaction in case of an accidental guillotine rupture of a cooling tube, the control/ minimisation of the tritium permeation from LiPb to water and the risk of embrittlement of the structural steel resulting from operation at temperature lower than 300-350^{o}C. The first two issues can be alleviated with appropriate counter-measures such as dimensioning the LiPb container to the water-pressure, using double-wall tubes as coolant pipes (increasing the blanket reliability and availability at the same time), and applying tritium permeation barriers on the cooling tubes. Some of these issues were partially addressed in an R&D program performed in the EU several years ago, but stopped for lack of funds.

The activities under this Headline in Horizon 2020 will be aimed at addressing the open issues described above.

Headline 4.3: Design and R&D of DCLL blanket concept

Roadmap PWPs: DC01-09

This dual coolant lithium lead (DCLL)concept relies on a LiPb breeder/coolant that is flowing sufficiently fast to remove both the bred tritium and the majority of the heat from the reactor. A second helium coolant is used to cool the structures especially the plasma exposed front part (i.e. the first wall). In this case, the MHD pressure drops in flowing LiPb are minimised by using insulating layers (e.g., SiC inserts). The concept to be investigated for a near term application sets a limit to the maximum allowable structural material temperature, which should be less than 550C, to enable use of the baseline steel option (EUROFER). Use of oxide-dispersion-strengthened (ODS) steels with their higher strength-based temperature limit would increase operation capabilities, but welding requirements would make the fabrication more difficult. Alternatively, the use of high temperature ferritic martensitic steel is possible provided a reduced activation version is produced. Open issues to be addressed in Horizon 2020 include:

- MHD effects in high velocity LiPb in all relevant geometries and reliability of insulating layers;
- efficient extraction and purification of tritium from LiPb flowing at a much higher velocity than HCLL and WCLL:
- corrosion of the pipes and blanket structures by circulating LiPb at high temperature (similar to HCLL);
- control of tritium leakage and minimisation of permeation to the He coolant of polonium and other transmutation products control in irradiated LiPb.

Mission 5: Implementation of the intrinsic safety features of fusion

From the very beginning, an integrated safety design approach should be followed for the DEMO design. A licensing framework based on safety goal policies will be developed to ensure that conceptual design and operation scenarios are consistent with safety performance goals. The approach followed by ITER of identifying the safety boundary with the vacuum vessel will be pursued also for DEMO. This approach allows decoupling of the licensing aspects from the R&D on materials since the vacuum vessel is a relatively un-irradiated component and can be fabricated with existing materials.

Limited developments are expected in the area of safety during Horizon 2020, with the analysis of the critical aspects for the licensing of DEMO on the basis of the ITER experience. In particular, in the area of radioactive waste management, R&D to identify efficient detritiation systems from solid waste should be started in advance of a possible test on ITER components. Feasibility studies of waste recycling and proof-of-principle demonstration of related technology will also be undertaken.

Headline 5.1: Definition of DEMO safety approach licensing regulatory requirements

Roadmap PWPs: 5.1-5.4

Key objectives are (i) to establish the safety approach and fundamental safety strategies such as to what extent safety credit may be given to in-vessel components; (ii) to set the safety criteria and to evaluate the safety impact of fundamental design choices (materials, coolant, etc.); and (iii) to review licensing regulatory requirements and the possible licensing regimes for DEMO.

Headline 5.2: Integrated safety analyses and demonstration of safety margins in the design

Roadmap PWPs: 5.5-5.7

The key objectives are (i) to determine accident scenarios to be taken into account in the safety analyses, using Functional Failure Modes and Effects Analysis(FFMEA); (ii) to determine needs for code development for safety analyses and the validation experiments that are required for these, and (iii) to assess the needs for source term development, dependent on fundamental design choices.

Headline 5.3: Radioactive waste management

Roadmap PWPs: 5.8-5.12

A review of clearance indices for radioactive material will be carried out to set an approach to defining a fusion-specific set of limits. A feasibility study of waste recycling will be launched to establish if viable and economic recycling processes are possible. Techniques for the detritiation of contaminated solid waste materials will be developed. Material composition limits will be established to minimize the radiological impact of activation, and strategies for minimization of the quantity of waste will be developed.

Mission 6: Integrated DEMO design and system development

The experience gained in the ITER construction will be used directly for the integrated DEMO design, but specific system development will be required in some areas. Above all, special emphasis will have to be given to the maintainability and reliability of components. Capitalizing on the ITER experience, modest targeted investments in the DEMO integrated design and system development are expected in Horizon 2020. Milestones are the definition of the optimum design configuration, the BoP (also on the basis of the results of Mission 3 and Mission 4), the development of prototypes of advanced low-temperature super conducting cables, the definition of the RH maintenance scheme and some R&D on H&CD and vacuum and pumping systems.

The DEMO Conceptual Design Activity (CDA) should be completed by the end of Horizon 2020. This should assess and integrate different designs of the breeding blanket and divertor concepts to be developed as part of Mission 4 and Mission 2, respectively.

Headline 6.1: Plant level system engineering & design integration

Roadmap PWPs: SE01-SE07

An integrated design-oriented approach is viewed as essential during the concept design stage: (i) to better understand the problems and evaluate the impact of uncertainties and technical risks of foreseeable technical solutions; (ii) to identify design trade-offs and constraints to address the most urgent issues in physics, technology and system engineering integration; and (iii) to prioritize the R&D needs. The highly interrelated nature of the DEMO development projects, in terms of system interfaces, performance trade-offs, sensitivity studies will require the rigorous application of systems engineering principles, methods and tools in order to effectively support the programme and ensure requirements, design, and decisions are analysed, verified and traceable. As part of this iterative process, holding of technical reviews is a prerequisite. In general, the progress assessment methodology should be similar to other fields and follow the approach of assigning a technical readiness level (TRL) to the reactor systems and updating that TRL as R&D tasks are completed. There are many examples of TRL scales and their application to systems of varying and evolving maturity. As the conceptual design and R&D activities progress there will be decision points at which potential design solutions will be evaluated and the most promising options selected. Systems engineering principles will be used to inform such a selection by clearly defining the potential issues associated with each option and by analysing their impact on the overall DEMO system.

The integration of the updates in the ITER physics into the DEMO conceptual design will be crucial in supporting its evolution. This will involve e.g. the use of system codes or other codes to address specific physics issues, scoping scenario studies with reduced models, possibly supported by comprehensive calculations to be carried out in the ITER Physics programme, input to the JET/MST experimental campaign definition.

Headline 6.2: Magnet system

Roadmap PWPs: MAG01-MAG06

The pragmatic approach advocated in the roadmap for the DEMO design calls for the use of existing or near term technologies for the design and construction of the DEMO magnets. Although technologies such as those based on the use of Nb3Sn are today established, their use for the DEMO magnet poses some challenge as the increased size and magnetic field above the ITER value will increase the stress on the superconducting cable and therefore the risk of degradation of performance and reliability loss.

The objective of the activities in this area is to deliver a feasible, integrated concept design of the DEMO Magnet System based on established technologies that, with an acceptable confidence level, can be shown to meet the Plant System Requirements. The concept design shall be substantiated and verified to an appropriate level for a plant-level Conceptual Design Review. This activity will be supported by a R&D programme to manufacture and test the performance of candidate conductor cables and assess conductor manufacturing and assembly feasibility in collaboration with industrial partners. As the magnet is expected to represent a significant fraction of the capital investment of a fusion power plant, a specific effort will be devoted at defining design solution and manufacturing routes that can keep the cost of the magnet system at a level sufficiently low to maintain the perspective of fusion as an economic energy source (see Mission 7 below).

Headline 6.3: Containment structures

Roadmap PWPs:

DEMO is expected to be at most 50% larger than ITER. Thus, the assumption is made that the DEMO vessel, cryostat and tokamak building will be designed and manufactured similarly to the corresponding structures in ITER and therefore no major R&D is expected to be required in the conceptual design phase. Apart from the feasibility verification, the integration of the design of the containment structures with the design of the other systems and the overall plant safety requirements will be the critical aspect.

Headline 6.4: Divertor

Roadmap PWPs:

The Divertor is a mission-critical component for DEMO. The R&D on the physics aspect of the baseline strategy (use of a conventional divertor configuration) and on alternative solutions is pursued under Mission 2. Due to the uncertainty on the technical solution to cope with the high heat exhaust loads in DEMO, the Conceptual Design Activity foreseen in Horizon 2020 will maintain sufficient flexibility in the design integration of the divertor cassette configuration within the overall DEMO plant. In addition, R&D will be pursued for high heat flux targets based on water-cooled technologies under the operating conditions (higher water coolant temperatures, and neutron doses) relevant for DEMO.

Headline 6.5: Heating & Current Drive systems

Roadmap PWPs: HCD-NB01-11, HCD-EC01-09

In a DEMO based on long-pulse/inductive regimes of operation, and not on fully steady state, Heating and Current Drive (H&CD) systems need primarily to provide heating power for H-mode access, capability of MHD instabilities suppression and increase of the pulse length whereas the detailed control of the equilibrium current density profile will not be the primary requirement. This choice will reduce the risks on the DEMO H&CD systems and is in line with the pragmatic approach advocated in the Roadmap. ITER will test the potential of different heating systems (Ion Cyclotron Heating, Neutral Beam Heating and Electron Cyclotron Heating, with Lower Hybrid Current drive as a possible upgrade to be decided at a later stage) from the point of view of their application to DEMO regimes of operation. The activities for the preparation of the ITER H&CD systems exploitation are dealt with in Mission 1. Therefore, the approach taken in the Roadmap in the H&CD area under Mission 6 is to pursue only specific developments to comply with the parameters of DEMO (e.g. higher magnetic field) and to ensure high system availability (e.g. by minimizing the need of maintenance outside the scheduled periods), reliability (e.g. by ensuring the modularity of the systems) and plant efficiency (e.g. by minimizing the re-circulating power). This will involve mainly R&D activities in the area of NB and EC technologies. These activities will be complemented by an analysis of the plasma regimes in DEMO to guide the final decision on the H&CD systems to be taken on the basis of the ITER experience.

Headline 6.6: Tritium, fuelling and vacuum systems

Roadmap PWPs: VP01-04

The long-pulse (a few hours) operation of DEMO requires a continuously operating pumping system. Furthermore, the goal of reducing the tritium on-site inventory and processing time calls for a fuel-cycle based on an effective tritium separation in the regions close to the divertor in order to minimize the throughput requirements of the tritium plant. These goals need an extension of the technologies used in ITER.

Headline 6.7: Heat transfer, balance of plant & site systems

Roadmap PWPs: BOP01-05

DEMO has to generate a net amount of electricity in the grid and this requires to maximize the conversion efficiency of the primary (blanket) and secondary (turbine) circuits still complying with the constraints determined by the structural materials of the blanket. In view of the pulsed nature of DEMO, an energy storage system might be required to buffer the thermal transients and reduce cyclic loading. Different solutions will be investigated with the direct involvement of industry.

Headline 6.8: Diagnostics and control systems

Roadmap PWPs: 1.16-19, DIA01

Diagnostics and associated control systems in DEMO will be constrained much more than in ITER by the extreme environmental conditions, mostly due to the higher neutron flux and fluence, and the more stringent requirements on reliability, availability and maintainability. In addition, the requirement of tritium self-sufficiency in DEMO (i.e., DEMO in contrast to ITER must produce its own fuel) places severe restrictions on port space for H&CD systems and sensors and diagnostics in DEMO.

The primary objective is to deliver a feasible, integrated concept design of the DEMO diagnostics and control systems that, with an acceptable confidence level, can be shown to meet the measurement requirements of the device. The concept design shall be substantiated and verified to an appropriate level for a plant-level Conceptual Design Review and minimum R&D development on radiation resistant diagnostic and actuators.

Headline 6.9: Remote maintenance

Roadmap PWPs: RMS01-RMS11

The development of the remote maintenance system for DEMO will be driven by the need of minimizing plant down-time and maximizing availability, the strongest driver to a low cost of electricity. The in-vessel radiation, activation and decay heat in DEMO will be more demanding than in ITER and specific maintenance schemes will have to be used that eliminate complex in-vessel operations. The vertical blanket maintenance scheme, presently considered the most promising option, will be taken as initial reference.

Mission 7: Competitive cost of electricity

In order to have a rapid market penetration, fusion will have to demonstrate the potential for competitive cost of electricity. Although this is not a primary target for DEMO, the perspective of economic electricity production from fusion has to be set as a target, e.g. minimizing the DEMO capital costs. Building on the experience of ITER, design solutions demonstrating a reliable plant with a high availability, serving as a credible data basis for commercial energy production, will have to be pursued.

Headline 7.1: Minimisation of reactor capital and operation costs

Roadmap PWPs:

Whilst ITER is a unique one-off design optimized for experimental goals within cost constraints, DEMO will move towards design choices suitable for series production. Design simplifications, easily scalable material production and well established industrial fabrication technologies are mandatory to minimize capital costs. At the same time, reduce complexity and high reliability of the technologies adopted for the fabrication of components and systems for the tokamak complex and the BOP as well as a demonstrated fast maintenance scheme will enable achieving high availability factors minimizing the cost of electricity.

Systems approach studies will be undertaken to explore all options to minimize the cost of a fusion power plant and to identify the innovations needed to make the transitions from DEMO to a fusion plant.

Socio-economic research activities on fusion energy will also be undertaken to maintain a long-term perspective and to optimize the strategies for market penetration of fusion.

Headline 7.2: Advancements for H&CD systems

Roadmap PWPs: HCD-PN01- HCD-PN03/ HCD-EC01-HCD-EC02

This includes primarily the development of technologies for better neutralization efficiency (in the case of NBI) such as the use of a photoneutraliser. The deployment of high efficiency (via multi-stage depressed collector) ECH systems is also considered under this area of development.

Headline 7.3: Development of high temperature superconductors

Roadmap PWPs: MAG-H01- MAG-H03

HTS magnets offer the opportunity for higher magnetic fields at higher operating temperatures and margins together with the potential design simplification (e..g, lack of a thermal shield). This in turn would lead to a higher overall efficiency from the fusion power plant due to higher energy density and lower cryogenic power requirements respectively. Design and R&D work should continue in Horizon 2020 with the goal to build and test full-scale HTS cables at relevant field, current and temperature conditions.

Headline 7.4: Advanced divertor heat removal technologies

Roadmap PWPs: DIV-HC01- DIV-HC03

R&D of He-cooled divertor concepts should be continued to further improve performance and durability of concepts developed so far. In addition, alternative heat flux enhancement techniques should be examined in more detail at DEMO-relevant parameters. These include improvements to jet impingement via cascade or surface roughness modifications as well as novel coolant and material selections.

Headline 7.5: Very advanced breeding blanket concepts

Roadmap PWPs: BB-01- BB-02

Activities included in Mission 4 aim at the development of a reduced performance DCLL design that uses EUROFER as a structural material (i.e. max temperature 500-550^{o}C) also leading to lower power conversion efficiency. Options included here consider instead more aggressive designs that push the LiPb outlet temperature to the compatibility limit of LiPb and SiC, perhaps even exceeding the creep strength temperature limit of the present generation of fusion steel structures.

Mission 8: Stellarator

In order to bring the stellarator configuration to maturity as a possible long-term alternative to tokamaks, the EU programme focusses on the optimised stellarator HELIAS line. Experimental work on other stellarator lines (Heliotron, Compact stellarators) will continue as part of international collaborations. For the period 2014-2020, the main priority should be the completion and start of scientific exploitation of the W7-X experiment in validating the energy and particle confinement of optimised stellarators and qualifying the island divertor. These activities will have also an impact on the progress of the basic understanding of plasma physics in support of Mission 1 and 2 and specifically in support of the ITER preparation.

Headline 8.1: Qualification of Helias optimised stellarator operation

Roadmap PWPs: 8.1, 8.2, 8.3

With regard to the reactor physics basis, the validation of the energy and particle confinement of optimised stellarators is one of the main objectives of the W7-X experiment. The neoclassic part of the physics underlying these optimisation goals is considered to be well understood and it is quite likely that the achievement of several of these goals concerning neoclassical behaviour can already be verified during the Horizon 2020. However, due to the power limitation in the early phase W7-X of operation, it is uncertain whether sufficiently high beta values will be reached in this phase of operation and whether the role of turbulent transport can be fully assessed.

Even after all optimisation goals of the W7-X experiment will have been demonstrated, advanced stellarators will only become attractive reactor candidates if they can maintain high-performance (high-β, low-ρ^*, low-υ^*) steady-state plasmas (discharges of several minutes. This is required to surpass all physical and technical time constants of relevance) with viable Divertor performance (high radiated-power fraction with at least partial detachment) without loss of density control and without impurity accumulation. As a superconducting device with 10 MW continuous (over 30 minutes) of ECRH and a high-heat-flux divertor capable of handling power loads of 10 MW/m^2 (following initial operation with an inertially cooled divertor), the W7-X experiment will possess the technical capabilities necessary to achieve such integrated reactor-relevant scenarios. The investigation of steady-state plasmas will be the main objective of the second phase of the W7-X experimental programme, probably starting only at the end or after Horizon 2020.

Headline 8.2: Theory development and modelling / stellarator optimisation

Roadmap PWPs:

The complexity and diversity of the stellarator configurations means that it is not feasible to investigate experimentally all possible options. Therefore, in addition to the foreseen collaboration on other stellarator lines with international partners, the search for the best stellarator configuration should be pursued in parallel through theoretical investigations and modelling. The optimization process will not only employ physics criteria but also engineering constraints and will capitalise on the advances in understanding and computational capabilities. These optimization exercises should provide a possible simplified engineering layout, optimised magnetic field configurations required for alpha particle confinement and possible divertor solutions different from the island divertor, in case it turns out that the W7-X divertor concept does not extrapolate to a reactor.

2. Implementing Work Packages

This section outlines the Work Packages in which the Work Plan will be implemented. For each Work Package, the top-level management scheme is given along with a description of the deliverables it addresses.

Theory and modelling is an essential part of the Work Plan. Theory and modelling activities are linked to and supported by the campaign or other Work Packages to which they relate – e.g. theory and modelling in support of JET work would fall under WPJET1, theory and modelling in support of JT-60SA would fall under WPSA1. Physics model development related to the code development work of WPCD1 falls under that Work Package.

To achieve the Work Plan's goals, an integrated approach is required in several important areas such as theory, modelling, experiment, hardware development and code development and the Task Force Leaders and Project Leaders of the different work packages are obliged to interact in order to ensure the adequate implementation of cross cutting projects and tasks. Equally important are the integration of the ITER and DEMO oriented parts of the Roadmap, and the integration of the campaigns on the common facilities. Integration is achieved through the combination of the goal oriented Headlines and the implementing Work Packages. Each implementing Work Package is organised explicitly in terms of the Headlines it addresses. The integrated nature of the work is reflected in the Headlines, and the deliverables within them, that are common to several Work Packages. The mechanisms and the responsibilities to ensure integration among the various areas are described in Section 3.

2.1 JET Department[6]

It is assumed that JET operation will be carried out over the entire period of the 5-year EURATOM programme, in agreement with the Roadmap strategy. A decision on the operation of JET beyond this frame will have to be taken in the context of the process of internationalization of JET as proposed by the *Panel for the strategic orientations of the fusion programme*.

WPJET1: JET Campaigns

Management:

Task force leaders

Description:

JET, as the machine closest to ITER in terms of size, its tritium capability and its use of the ITER first wall materials, will remain the focus of the European programme on tokamak physics. The experimental programme will primarily be used to address the programmatic goals of Missions 1 & 2. The JET programme will be complemented by experiments on medium-size tokamaks (WPMST1) and thus several of the milestones and deliverables are shared with that work package.

During the period 2014-18, a series of experimental campaigns and shutdowns are planned

---

[6] Note: in red the deliverables that will be implemented as joint experiments

that include experiments covering the entire range of working gases foreseen for ITER (H, D, T and He), culminating in an extensive DT campaign that is intended to provide the final demonstration of the compatibility of high performance inductive regimes of operation with the ITER wall materials.

A key element in the JET programme will be model validation to improve extrapolations to ITER (and beyond). Strong interaction is foreseen between the JET and MST task forces and the *Code Development for Integrated Modelling* Work Package (WPCD1). It is proposed that this interaction is facilitated by having one JET TFL as a member of the CD1 Project Board. In addition to validation of code modules, it is expected that the JET and MST task forces will provide input on the priorities and requirements for the integrated modelling package being developed in WPCD1.

Keys deliverables:

- **Headline 1.1: Increase the margin to achieve high fusion gain on ITER**
  - Study heat, particle and momentum confinement in conventional and improved H-modes (hybrid regime) and the dimensionless scaling towards ITER (2015)
  - Demonstrate compatibility of conventional and improved H-mode with ITER wall materials (2015)
  - Qualification of improved H-mode confinement at large machine size and at full machine performance (2015)
  - Characterise L-H threshold power and access to H_{98}~1 (e.g. power) in ITER-relevant conditions (2015; T & DT 2017)
  - Test isotope scaling of the improved H-mode in H, D, (2015) DT and T (2017)
  - Confinement scaling of regimes with high radiated power fractions (2020)
  - Confinement scaling near the density limit (2015; 2017 with isotope dependence)
  - Develop ITER ICR heating schemes (H non-activated phase, DT phase) (2017)
  - Develop physics models for the density limit (2018)
  - Map density limit in non-inductive regimes of operation (2020)
- **Headline 1.2: Operation with reduced or suppressed ELMs**
  - Quantify difference of ELMs, edge pedestal and L-H transition in H, D, T and He plasmas (2017)
  - Demonstrate high dynamic range ELM pacing and low accompanying fuelling thus minimising the impact on confinement (2015)
  - If agreed in 2013, design, procurement and installation of an ELM Control Coil set in JET (2017), allowing a subsequent test of the size scaling of this method of ELM suppression
  - Develop and understand ELM-free (e.g. QH-mode) / small ELM (e.g. Type II, Type III) scenarios (2015)
  - Establish scaling of small/no ELM regimes with high mantle radiation close to the density limit (2015; with DT & T 2017)
  - Construct empirical confinement scaling laws, as for the ELMy H-mode, for small/no ELM regimes (2018)
  - Theory & modelling development (2018)
  - Reproduce observed expansion of wetted surface during ELMs
  - Explain difference between inner/outer target and main wall
  - Explain fractional loss dependence of collisionality and on plasma impurity content
  - Predict dependence on ρ^*
  - Validate model for pellet pacing

- **Headline 1.3: Avoidance and mitigation of disruption and runaways electrons**
  - Develop robust operation of ITER scenarios and their safe termination (2015)
  - Quantify the efficiency of massive gas injection for disruption mitigation to high current (4 MA) (2015)
  - Extend studies of disruption avoidance and mitigation to conditions mimicking the hardware constraints expected on ITER (vertical stability capability, internal inductance, fast beta changes) (2015)
  - Determine disruption probability in non-inductive regimes of operation (2020)
  - Scaling of MGI efficiency in non-inductive regimes (2020)
  - Document conditions for run-away electron generation and mitigation (2015)
  - Test control of runaway electrons using non-axisymmetric fields (2014)
  - Validation of runaway generation model (2018)
    - Determine runaway heat loads and forces in case of loss of control
  - Develop disruption prediction methods that minimise the requirements for model training on ITER (2015)
  - Develop full 3D codes (plasma + vessel) to describe halo current formation and asymmetries (2020)

- **Headline 1.4: Integration of MHD control into plasma scenarios**
  - Demonstrate integrated and routine sawtooth control in high performance, inductive scenarios (2016)
  - If agreed in 2013, design, procurement and installation of an ECCD system in JET (2017), allowing a subsequent test of the size scaling of MHD control in inductive regimes
  - Define system requirements / control algorithms for non-inductive scenarios (2020)
  - Improve modelling of mode dynamics to take into account realistic wall geometries (RWM) (2018)
  - Develop first principles understanding and simulation capability for NTM dynamics including wave-particle absorption in magnetic island. Validate such models (2020)

- **Headline 1.5: Control of core contamination and dilution from W PFCs**
  - Demonstrate acceptable W concentration in the foreseen reactor regimes (H-mode, hybrid and non-inductive)
  - ITER wall materials and inductive operation (2015)
  - Investigate the effect of ELM suppression and mitigation on high-Z peaking (2015)
  - Develop high-Z accumulation avoidance by means of central electron heating (2015), eventually also alpha heating (2017)
  - Minimise heavy impurity sputtering and local heat loads by optimisation of plasma edge and reduction of ICRF sheaths (2015)
  - Develop and validate models for impurity transport in the foreseen reactor regimes (2020)

- **Headline 1.6: Determine optimum particle throughput for reactor scenarios**
  - Test of the influence of central alpha particle heating on core density peaking (2017)
  - Validation of models for core particle convective transport, pellet ablation and drifts (2015)
  - Demonstration of core particle fuelling in conditions of low neutral penetration (2015)
  - Optimisation of DT fuel mixture control and use of tritium (2017)
  - Validation of plasma exhaust models (2018)

- Test of particle throughput in conditions matching the foreseen ITER pumping capabilities (2015)
- Document He pumping in ITER regimes of operation (2015)
- Assessment of impact of particle throughput on fuel retention (2015)

- **Headline 1.7: Optimise fast ion confinement and current drive**
  - Preparation of burning plasma physics on ITER (2020)
  - Investigation of fast ion losses and their power scaling for various scenarios
  - Study the slowing down and losses of fusion alpha particles in JET during the 'after-glow' phase of high performance DT discharges (2017)
  - Benchmark codes and validate non-linear models for fast ion-MHD interaction
  - Systematically vary the plasma fast ion content to separate the dependence of confinement, stability and bootstrap current on thermal and fast ion pressure (2020)
  - Optimise pedestal and core density and temperature to maximise current profile control (e.g. propagation and damping of LH waves) in view of advanced regimes in ITER (2020)

- **Headline 1.8: Develop integrated scenarios with controllers**
  - Develop supervisory control algorithms. Combine avoidance of NTMs, possibly via sawtooth control, with control of ELMs, disruptions, core contamination, divertor detachment, fuel species mixture and simulated burn (2018)
  - Use first principle simulation and modelling of individual control requirements to develop simplified plant dynamical models and observers for use in control algorithms (2018)
  - Develop and test measurement techniques for ITER and DEMO (2015, DT-related 2017)
  - Test of a DEMO-relevant measurement set for scenario control (2018)
  - Pre-qualify complete ITER scenarios (breakdown, ramp-up, flat-top and termination)
  - Scaling with machine size and separation of collisionality and Greenwald density (2015)
  - Integration with DT operation (2017)

- **Headline 1.9: Qualification of Advanced Tokamak scenarios**
  - Demonstration of regime existence and of the feasibility of operation above the no-wall stability limit (2020)
  - Integration of the scenario with acceptable fast particle losses, density and divertor heat load (2020)
  - If agreed in 2013, design, procurement and installation of an Electron Cyclotron Current Drive system in JET (2017), allowing a subsequent proof-of-principle test of the size scaling of current drive requirements for non-inductive operation
  - Integrated model validation so as to define, in as much as possible without definitive large machine results, the current drive requirements for non-inductive operation in JT-60SA (decision ~2023) and ITER (~2024)

- **Headline 2.1: Detachment control for the ITER and DEMO baseline strategy**
  - Develop and test relevant sensors and actuators for detachment detection and control (2015)
  - Investigate/document confinement at detachment for different fuelling methods / locations (2015)
  - Document H-L threshold scaling up to Greenwald density limit at high auxiliary heating power (2015)

- Document influence of shaping on heat loads (steady state, ELMs) in the divertor (2015)
- Optimise impurity mix for divertor and mantle radiation (2015)
- Benchmark codes to predict detachment, particle and power loads in ITER and DEMO (2017) (linked to Headline 2.3)
- Document detailed conditions to reach detachment at highest available P_{sep}/R and close to Greenwald density limit and quantify particle and power loads to the main chamber (2015)
- Investigate the compatibility of W with extrinsic impurity seeding / optimize impurity mix for divertor and main chamber radiation (2018) (linked to Headline 2.2)
- Compare influence of different divertor geometry on heat loads (2018)
- Demonstrate low W sources and W core penetration for (partially) detached divertor conditions and relevant P_{sep}/R (2018)
- Demonstrate compatibility of detachment with ELM mitigation methods / ELM-free / 'small' ELM scenarios (2016)

- **Headline 2.2: Prepare efficient PFC operation for ITER and DEMO**

- Investigate evolution of melt layers of metallic surfaces, and their influence on the plasma behaviour (2014)
- Quantify isotope exchange with metallic walls (2015)
- Develop Ion Cyclotron Wall Conditioning techniques (2015, test for tritium removal 2017)
- Minimisation of divertor and main chamber erosion, quantify (and try to extrapolate) main chamber filamentary transport (expected particle flux and energy) (2015)
- Validate codes on plasma wall interactions (erosion, re-deposition and migration) (2016)
- Dust studies:
    - Qualify production mechanisms (2015)
    - Quantify dust production (2017)
    - Model and extrapolate production and transport (2018)
    - Model impact on plasma operation (2018)
    - Develop dust removal techniques (2018)

WPJET2: Investigation of Plasma-Facing Components for ITER

Management:

Project leader

Description:

The preparation of efficient PFC operation for ITER and DEMO (Headline 2.2) requires not only dedicated experimental time on JET but also post-mortem analysis of samples removed from the machine. Similarly, post-mortem analysis of dust generation and its characterisation provides important to the safety case for ITER and DEMO (Headline 5.1). Finally, control of ITER scenarios (Headline 1.8) and the definition of DEMO diagnostics (Headline 6.8) rely in part on measurements by viewing systems whose first mirror performance needs to be proven in present machines not only by operation but also with the support of post-mortem analysis and cleaning programmes.

Keys deliverables:

- **Headline 2.2: Prepare efficient PFC operation for ITER and DEMO**
  - *Material erosion and deposition in the ITER-like Wall.* The erosion and re-deposition of first wall material in ITER is expected to be the dominant contribution to the amount of fuel trapped in the machine and is thus a key safety issue. In addition, the generation of mixed materials, particularly Be-W compounds, has the potential to reduce the performance of the PFCs. Post mortem analysis of tiles removed from JET will be used to quantify the rate of material erosion, transport and deposition and thus to validate models of these processes. In addition, the elemental and chemical composition of deposited layers will be studied.
  - *Dust.* The generation of dust in fusion reactors presents a safety risk for ITER, both in terms of dispersal of activated dust in a loss of vacuum accident and as a catalyst for the generation of hydrogen in a loss of coolant accident. Two main mechanisms are expected to contribute to the generation of dust: delamination of deposited layers and melting or layer destruction by transient events such as disruptions. JET shutdowns will be used to collect dust samples, which will be subsequently analysed for composition, size and fuel content. These data will be used to calculate conversion factors from layers to dust and to validate models for dust production.
- **Headline 1.8: Develop integrated scenarios with controllers**
  - *First mirrors*. Post mortem analysis of mirrors exposed to JET plasmas provides unique information on the expected lifetime of first mirrors in ITER (mirror coatings depend strongly on the plasma impurity content and thus on the plasma-facing armour material). The programme will investigate mirrors in geometries as close as possible to those foreseen for ITER and will assess potential mirror cleaning techniques.

WPJET3: Technological Exploitation of DT Operation for the ITER preparation

Management:

Project leader

Description and key projects:

Considerable added value can be obtained from the implementation of a package of technology projects in conjunction with a DT experiment on JET. Options for such a package have been developed in collaboration with experts from the ITER IO, Fusion for Energy and the European fusion laboratories. At present a list of potential sub-projects has been identified; for many, feasibility studies are underway with the goal of determining the required resources and schedule for implementation. Other than a sub-project for calibration of 14 MeV (DT) neutron measurements, which will be launched in 2013, other potential sub-projects include:

- Characterisation of neutron field, activation and dose rates (support activity)
- Experiments for neutron transport & activation code validation
- Activation measurements for ITER material characterisation and data validation
- Validation of calculations of activation corrosion products generation
- Functional material damage studies
- Measurement of T outgassing and airborne T
- T permeation and retention studies
- Test of detectors for tritium breeder blankets
- Operational experience on occupational dose
- Waste production and characterisation

- DEMO-relevant studies, including:
  - Erosion & T retention in neutron pre-irradiated materials
  - Fuel cycle

The activities described above are expected to contribute to a variety of programmatic headlines:

- Headline 1.8: Develop integrated scenarios with controllers
- Headline 2.2: Prepare efficient PFC operation for ITER and DEMO
- Headline 4.1: Design and R&D of HCLL/HCPB blanket concepts
- Headline 5.2: Integrated safety analyses and demonstration of safety margins in the design
- Headline 5.3: Radioactive waste management
- Headline 6.5: Heating & current drive systems
- Headline 6.6: Tritium, fuelling vacuum systems
- Headline 6.8: Diagnostics and control systems

WPJET4: JET Enhancements

Management:

Programme Unit through individual Task Leaders

Description and keys projects:

In order to complete the exploitation of the JET ITER-like Wall and to take full benefit from deuterium-tritium experiments on JET, it is necessary to carry out a small number of system refurbishments or upgrades. During 2013, the following upgrades have been or will be launched:

- *Re-installation of the JET ITER-like Antenna*. This will provide increased central electron heating and allow more complete tests of tungsten control (Headline 1.5). The system will be re-installed during a shutdown in 2104 and re-commissioned and exploited in deuterium plasmas in 2015 and in DT plasmas in 2017. Demonstration of reliable operation of the ILA is also viewed positively by the ITER IO as preparation for operation of their ion cyclotron heating system.
- *Re-location of the High Frequency Pellet Injector*. In its present location, delivery of pellets for ELM control (Headline 1.2) and core fuelling (Headline 1.6) is limited by losses in the transmission line between the injector and the tokamak. An alternate location has been identified with a shorter and simpler line. The injector will be re-located during the 2014 shutdown and exploited during 2015 in deuterium and in T and DT plasmas (with deuterium pellets) during 2017.
- *Upgrade of the JET viewing system*. Two or three of the JET visible and infrared views will be upgraded for compatibility with deuterium-tritium operation. These systems will be deployed during the 2014 shutdown so that operational experience can be gained in deuterium in 2015.
- *Refurbishment of the low energy neutral particle analyser*. This system is capable of measuring the plasma isotope mix (Headline 1.6) but requires a new generation of neutron-insensitive detectors and refurbishment of its data collection and control hardware. The upgrade system is only likely to be operational in time for the DT campaigns in 2017.

In addition, a small number of further diagnostic upgrades are being considered, focussing primarily on DT-related systems (neutron and gamma-ray detectors and spectrometers, alpha particle measurements, laser-based techniques for tritium monitoring, etc.), contributing to Headline 1.7 amongst others, depending on the exact range of diagnostic enhancements selected. The selection of which upgrades to pursue will be made in 2014.

Finally, the exploitation of JET beyond 2018, posited on a successful outcome of the process of JET internationalisation, as suggested by the Panel on *Strategic orientations of the fusion programme*, with a corresponding significant amount of resources made available for JET operation, is expected to include the implementation of one or two significant upgrades: an Electron Cyclotron Resonance Heating system (for Headlines 1.4 and 1.9) and/or an ELM Control Coil system (for Headline 1.2). Implementation of either of these systems would be accompanied by a small number of associated diagnostics in order to maximise the physics return of the extended programme.

2.2 ITER Physics Department

WPMST1: Medium-Size Tokamak Campaigns

Management:

Task force leaders

Description:

Experiments on medium-size tokamaks complement the work at JET (WPJET1) to provide a step-ladder approach for extrapolations to ITER and DEMO and in areas where the MSTs have superior experimental capabilities and flexibility.

During the period 2014-18, a series of experimental campaigns and shutdowns are planned in the European divertor tokamaks. ASDEX Upgrade with its all tungsten PFCs will play an important role as a medium-sized counterpart to JET specifically for experimental investigations which rely on all-metal PFCs. Towards the second half of Horizon 2020, a major upgrade of the ECRH power will allow ASDEX Upgrade to investigate current drive issues and physics questions related to AT scenarios. During 2014 TCV is undergoing a major upgrade in heating power, which will allow from 2015 proof of principle investigations on snowflake divertor configurations, amongst other issues. The super-X divertor can be investigated in MAST-U from 2016 after about 2 years of shut-down and initial commissioning. The set-up of this campaign-oriented work package is strongly dominated by the availability of the different devices and the evolution of their capabilities, in parallel with the requirements imposed by ITER and the decision processes for DEMO design options and DTT. The years indicated at the key deliverables denote the date by which they should be reached (not necessarily when the experiments will be performed). In order to keep the repetition to a minimum, the availability and major upgrades of the MSTs is given in the Annexes. In addition the tokamaks in the International Collaborators listed in the Annex 1 of the Roadmap will be exploited within the International Tokamak Physics Activity. Mobility will be used to support the participation of European scientists. Should other tokamaks become available, their use under the campaign-oriented approach will be assessed in a way similar to that done during the 2008 Facility Review and, in case of a positive assessment, included within this Work Package.

Keys deliverables:

- **Headline 1.1: Increase the margin to achieve high fusion gain on ITER**
  - Study heat, particle and momentum confinement in conventional and improved H-modes and hybrids and the dimensionless scaling towards ITER (2015)
  - H-mode and hybrid confinement scaling in regimes with high radiated power fractions (2018)
  - H-mode and hybrid confinement scaling near the density limit (2015; 2017 with isotope dependence)
  - Test scaling of confinement and L-H threshold of the improved H-mode in H and D (2017)
  - Develop physics models for the density limit (2018)
  - Develop gas puff technique and related modelling to maximise ICRF power in H-mode independently of the edge conditions (2017)
  - Map density limit in non-inductive regimes of operation (2018)

- **Headline 1.2: Operation with reduced or suppressed ELMs**
  - Quantify difference of ELMs & edge pedestal and L-H transition in H, D and He plasmas (2014).
  - Demonstrate ELM avoidance/mitigation by RMPs and pellet pacing at different collisionalities (2016)
  - Test compatibility between pellet pacing and ELM control coils (2014). Assess the collisionality affects (2015).
  - Develop ELM-free (e.g. QH-mode) / small ELM (e.g. Type II, Type III) scenarios (2015)
  - Establish scaling of small/no ELM regimes with high mantle radiation close to the density limit (2016)
  - Construct empirical confinement scaling laws (as for the ELMy H-mode) for small/no ELM regimes (2016)
  - Theory & modelling development (2018):
    - Reproduce observed expansion of wetted surface during ELMs
    - Explain difference between inner/outer target and main wall
    - Explain fractional loss dependence of collisionality and on plasma impurity content
    - Predict dependence on ρ^*
    - Validate model for pellet pacing

- **Headline 1.3: Avoidance and mitigation of disruption and runaways electrons**
  - Qualification of Massive Gas Injection as a mitigation method for heat loads and forces (fuelling efficiency, local peaking of radiation load as function of MGI parameters and plasma conditions) (2015)
  - Document conditions for run-away electron generation and mitigation (2015)
  - Alternative methods (use of non-axisymmetric fields) to control runaways beams (2015)
  - Real-time predictors methods optimised in term of model training, success rate, anticipation time, differentiation among different types of disruptions (2018).
  - Disruption probability in non-inductive regimes of operation (2020)
  - Scaling of MGI efficiency in non-inductive regimes (2020)
  - Validation of runaway generation model (2018)
    - Determine runaways heat loads and forces in case of loss of control
  - Full 3D codes (plasma + vessel) describing halo current formation and asymmetries (2020)

- **Headline 1.4: Integration of MHD control into plasma scenarios**
  - Demonstrate integrated and routine sawtooth and NTM control in inductive scenarios (2015)
  - Clarify role of low rotation in mode stability (2015)
  - Define system requirements / control algorithms for non-inductive scenarios (2017)
  - Improve modelling of mode dynamics to take into account realistic wall geometries (RWM) and actuators (NTM and RWM) (2016)
  - Develop first principles understanding and simulation capability for NTM dynamics including wave-particle absorption in magnetic island. Validate such models (2016)

- **Headline 1.5: Control of core contamination and dilution from W PFCs**
  - Demonstrate with all-W PFC wall, acceptable W concentration in the foreseen reactor regimes: H-mode (2015), hybrid (2018) and non-inductive (2020)
    - Investigate the effect of ELM suppression and mitigation on high-Z peaking

  - Develop high-Z accumulation avoidance by means of central electron heating
  - Minimise heavy impurity sputtering and local heat loads by optimisation of plasma edge
  - Develop and validate models for RF sheaths in order to minimise heavy impurity sputtering and local heat loads (2018)
- Develop and validate models for impurity transport in the foreseen reactor regimes. Link to the model development in Headline 1.6. (2020)

- **Headline 1.6: Determine optimum particle throughput for reactor scenarios**
  - Develop and validate models for core particle convective transport, pellet ablation and drifts. Link to the model development in Headline 1.5. (2015)
  - Validation of plasma exhaust models (2016)
  - Assess the impact of the metallic wall on the wall pumping. Compare tokamaks of different size. (2015)
  - Test of particle throughput in conditions matching the foreseen ITER pumping capabilities (2015)
  - Determine effect of pumping-/ divertor-geometries on He-pumping, including fuelling, pellets injection etc (2017)
  - Document He pumping in ITER regimes of operation (2015)
  - Assessment of impact of particle throughput on fuel retention (2015)
  - Determine technological and physics limits on density peaking (2016)

- **Headline 1.7: Optimise fast ion confinement and current drive**
  - Investigation of fast ion losses and their power scaling for various scenarios including MHD induced anomalous fast ion transport (2017)
  - Benchmark codes and validate non-linear models for fast ion-MHD interaction (2017)
  - Systematically vary the plasma fast ion content to separate the dependence of confinement, stability (for NTMs in the first instance) and bootstrap current on thermal and fast ion pressure (2018)
  - Investigate the effect of fast ion confinement on current drive(2015)
  - Assess and document off axis current drive performance (2018)
  - Development of ITER relevant fast ion diagnostics (2016)

- **Headline 1.8: Develop integrated scenarios with controllers**
  - Demonstrate combination of individual control algorithms into integrated control scenarios:
    - Develop supervisory control algorithms for combined ELM, NTM, disruption mitigation, divertor detachment and fuel species mixture control. Demonstration on MST (2018).
    - Use integrated modelling (IM) tools to develop simplified plant controllers and actuators for use in control algorithms (2018)
  - Test of minimum diagnostic and actuator set for control:
    - Optimization of the minimum set of realistic sensor / actuator by means of IM (2015).
    - Demonstration of operation in all candidate plasma scenarios with a reduced set of diagnostics (2018).
  - Pre-qualify complete ITER scenarios on present machines:
    - Qualification of the candidate plasma scenarios on the existing machines, including scaling with ρ^* and separation of collisionality / Greenwald fraction. The work should be supported by realistic numerical simulations (including controllers/actuators) (2016)

- **Headline 1.9: Qualification of Advanced Tokamak scenarios**
  - Demonstration of regime existence and of the feasibility of operation above the no-wall stability limit (2020)
  - Integration of the scenario with acceptable fast particle losses, density and divertor heat load (2020)
  - Integrated model validation so as to define, in as much as possible without definitive large machine results, the current drive requirements for non-inductive operation in JT-60SA (decision ~2023) and ITER (~2024)
- **Headline 2.1: Detachment control for the ITER and DEMO baseline strategy**
  - Develop and test relevant sensors and actuators for detachment detection and control (2015)
  - Investigate/document confinement at detachment for different fuelling methods / locations (2015)
  - Document H-L threshold scaling up to Greenwald density limit at high auxiliary heating power (2015)
  - Document influence of shaping on heat loads (steady state, ELMs) in the divertor (2015)
  - Optimise impurity mix for divertor and mantle radiation (2015)
  - Benchmark codes to predict detachment, particle and power loads in ITER and DEMO (2017) (linked to Headline2.3 on edge/SOL code development)
  - Document detailed conditions to reach detachment at highest available P_{SOL}/R and close to Greenwald density limit and quantify particle and power loads to the main chamber (2016)
  - Investigate the compatibility of W with extrinsic impurity seeding / optimize impurity mix for divertor and main chamber radiation (2018) (linked to Headline 2.2)
  - Compare influence of different divertor geometry on heat loads (2018)
  - Demonstrate low W sources and W core penetration for (partially) detached divertor conditions and relevant Psep/R (2018)
  - Demonstrate compatibility of detachment with ELM mitigation methods / ELM-free / 'small' ELM scenarios (2016)
- **Headline 2.2: Prepare efficient PFC operation for ITER and DEMO**
  - Investigate evolution of melt layers of metallic surfaces, and their influence on the plasma behaviour (2014)
  - Quantify isotope exchange with metallic walls (2015)
  - Develop Ion Cyclotron Wall Conditioning techniques (2015)
  - Minimisation of divertor and main chamber erosion, quantify (and try to extrapolate) main chamber filamentary transport (expected particle flux and energy) (2015)
  - Validate codes on plasma wall interactions (erosion, re-deposition and migration) (2016)
  - Dust studies:
    - Qualify production mechanisms (2015)
    - Quantify dust production (2017)
    - Model and extrapolate production and transport (2018)
    - Model impact on plasma operation (2018)
    - Develop dust removal techniques (2018)

- **Headline 2.3: Optimise predictive models for ITER and DEMO divertor/SOL**
  - Physics extensions, code validation, coupling of material migration code to the plasma code
    - Code validation for simple L-Mode cases in all metal (C-free) devices (2015); extension of validations to high power, high density impurity seeded H-modes (2017)
    - Validation of 3D migration codes (like ERO or ASCOT) and their coupling to plasma codes (like SOLPS) (2017)
- **Headline 2.4: Investigate alternative power exhaust solutions for DEMO**
  - Proof of Principle of detachment control in alternative divertor geometries
    - Document detailed conditions to reach detachment at highest available P_{SOL}/R and close to Greenwald density limit(2016)
    - Demonstrate removal of peak load
    - Assess effect of transients (β, l_i) on control of divertor geometry
    - Demonstrate divertor retention of eroded divertor material (2016)
    - Investigate He pumping capabilities (2016)
    - Test liquid metal PFCs in a high power divertor tokamak (plasma compatibility, effect of oblique magnetic field and transient power loads).
    - If possible, use of machines with different size to improve predictive capability to DEMO (2016)
    - Support analysis with modelling effort in view of assessment for DTT/ITER/DEMO (2016)
  - Proof of Principle of compatibility of detached operation with ELM mitigation/control in alternative divertor geometries
    - Investigate compatibility of the detachment with ELM mitigation methods / ELM-free / ‘small’ ELM scenarios (2016)
  - Proof of Principle of liquid PFC solutions
    - Demonstrate substantial power load capability of liquid metal PFCs ($\geq$ 10 MW/m^2) (2015)
    - Investigate conditions for acceptable plasma dilution/impurity content at high power loads (dominant PFC, ‘divertor impurity screening’) (2015)
    - Demonstrate ‘integrity’ of liquid surface during plasma instabilities (2014)
    - Demonstrate ‘integrity’ of liquid surface during substantial transient power loads (2015)
    - Quantify H retention (2014)
    - Investigate H removal (2015)
    - Characterize possible mixed material effects (main chamber PFCs/cooling structure) (2015)
    - Support analysis with modelling effort in view of assessment for DTT/ITER/DEMO (2015)

WPMST2: Preparation of Exploitation of Medium-Size Tokamaks

Management:

Programme Unit through individual Task Leaders

Description:

This work package comprises Tasks which are necessary for a successful exploitation of the MSTs along the headlines defined above. It is expected that during the execution of the Work Plan further Tasks will have to be defined. These Tasks include diagnostic development, work on test stands and modelling activities to develop efficiency of heating systems, complementary work on small size devices necessary for scaling laws, preparatory work on small size devices when the extrapolation of the result to MSTs is relevant (for example for safety reasons), off-line development of control algorithms and control tools before final real-time optimisation and validation, development of divertor/SOL predictive models.

Keys deliverables:

- **Headline 1.1: Increase the margin to achieve high fusion gain on ITER**
  - Improve arc detection systems during ELMs (work on test stands and RF systems) (2017)
- **Headline 1.3: Avoidance and mitigation of disruption and runaways electrons**
  - Development of ITER relevant disruption detection and avoidance schemes and Mitigation Systems (2018)
- **Headline 1.4: Integration of MHD control into plasma scenarios**
  - Define system requirements / control algorithms for non-inductive scenarios (2018)
- **Headline 1.5: Control of core contamination and dilution from W PFCs**
  - Develop understanding of RF sheaths effects (2016) (work on test stands, modelling and antennas design)
- **Headline 1.6: Determine optimum particle throughput for reactor scenarios**
  - Test of particle throughput in conditions matching the foreseen ITER pumping capabilities (2015)
  - Determine effect of pumping-/ divertor-geometries on He-pumping, including fuelling, pellets injection etc (2017)
- **Headline 1.7: Optimise fast ion confinement and current drive**
  - Development of ITER relevant fast ion diagnostics (2016)
- **Headline 1.8: Develop integrated scenarios with controllers**
  - Develop supervisory control algorithms and necessary control tools. Combine ELM, NTM and disruption mitigation with divertor detachment control, fuel species mixture control and simulated burn control (2016).
  - Develop reduced set of diagnostics for control (2016).
- **Headline 2.1: Detachment control for the ITER and DEMO baseline strategy**
  - Improve divertor and SOL diagnostics to allow new insight in underlying physics (ne, Te, Ti, flows, impurities) (2016)

WPPFC1: Preparation of efficient PFC operation for ITER and DEMO

Management:

Project leader

Description:

This work package comprises projects which are in support of the headlines and which should be carried out at non tokamak devices in order either to prepare further mission related work or to provide necessary information on plasma wall interaction for the extrapolation to ITER and DEMO. The subprojects have to align with the mission headlines and they will be defined by the Project Leader in close collaboration with PL of WPPFC1 and – where applicable – with the TFLs of WPMST1 and WPJET1. Specifically, subprojects such as experiments on linear devices for simulation of ITER/DEMO-like particle/power loads, laboratory work on plasma material interaction (power handling, erosion, H-retention) necessary for extrapolation to ITER and DEMO, the development and testing of improved DEMO relevant armour materials (W alloys, EUROFER, ...) and advanced DEMO relevant armour materials (liquid metals) will fall within this project. The investigations on liquid metals should only concentrate on solutions which do not rely on evaporation cooling and are compatible with low fuel retention.

Keys deliverables:

- **Headline 2.2: Prepare efficient PFC operation for ITER and DEMO**
  - Isotope-exchange experiments on ITER and DEMO relevant materials (2016)
  - Cross-check retention properties in heavy-ion (HI) damaged materials with that of neutron damaged material (2016)
  - Retention in neutron/HI damaged PFM as a function of irradiation temperature, preferentially for simultaneous (HI) and plasma irradiation (2017)
  - T removal from ITER and DEMO relevant materials (2018)
  - Model and extrapolate dust production and transport (2018)
  - Develop dust removal techniques (2017)
- **Headline 2.4: Investigate alternative power exhaust solutions for DEMO**
  - Demonstrate substantial power load capability of liquid metal PFCs (≥ 10 MW/m^2) (2014)
  - Demonstrate 'integrity' of liquid surface during plasma instabilities (2014)
  - Quantify H retention of liquid metal PFCs (2014)
  - Investigate H removal of liquid metal PFCs (2015)
  - Characterize possible mixed material effects (main chamber PFCs/cooling structure) (2015)
- **Headline 3.1: Development and Characterization of High Heat Flux Materials**
  - Laboratory tests of PFM foreseen for DEMO Divertor and First Wall applications (2018)

WPDTT1: Assessment of alternative divertor geometries and liquid metals PFCs

Management:

Project leader

Description:

This work package comprises subprojects which are in support of the Headline 2.4 which should provide the necessary information for the eventual preparation of the DTT. Specifically, the subprojects should explore the coil configurations for alternative divertor geometries, predict particle transport and power exhaust by modelling at different levels of sophistication and the exhaust capability of liquid PFC solutions. Before the conceptual design of a DTT can begin (see WPDTT2), integration issues and DEMO compatibility must be assessed within this Work Package. As for WPPFC1, liquid metal solutions should only be assessed if they do not rely on evaporation cooling and are compatible with low fuel retention.

Keys deliverables:

- **Headline 2.4: Investigate alternative power exhaust solutions for DEMO**
  - Assess requirements for physics model development (2014)
  - DEMO compatibility of alternative divertor designs
    - Assess Super-X divertor (2015)
    - Assess Snow Flake Divertor (2015)
    - Assess further geometries/techniques (2015)

- DEMO compatibility of liquid metal PFCs
  - Assess liquid PFC solution (2015)
  - Select best liquid metal, if viable (2015)

WPDTT2: Definition and design of the Divertor Tokamak Test facility

Management:

Project leader

Description:

This work package comprises subprojects which deal with the definition and the conceptual design of Divertor Test Tokamak. The conceptual design should only be started after review of the remaining gaps and the the possible solutions taking into account the results of the work packages WPPFC1 and WPDTT1 and the recommendations of the expert panel initiated by the EFDA SC in 2013. It must provide enough positive evidence that the investigated solutions could be integrated in a DEMO device in case the conventional divertor solution does not yield the necessary capabilities for power exhaust. The eventual DTT conceptual design activity should be performed in close coordination with the DEMO design integration project (WPPMI).

Keys deliverables:

- **Headline 2.4: Investigate alternative power exhaust solutions for DEMO**
  - Definition of DTT technical requirements (2015)
  - DTT conceptual design (new machine or upgrade of existing device) (2017, depending on outcome of the review)

WPSA1: Preparation of exploitation of JT-60SA

Management:

Project leader

Description:

This work package comprises subprojects which are in support of a European exploitation of JT-60SA within the broader approach and possibly beyond. The activities will run throughout the period 2014-2018.

Keys deliverables:

- **Headline 1.1-1.9**
  - Updates of the JT-60SA research plan
  - (Joint) modelling of physics issues in support of the design and operation of JT-60SA
  - Supporting experiments at European devices for exploration of operational procedures and domain
  - Specific investigations on diagnostics and hardware systems at JT-60SA
  - Development of concept for data access and exploitation at JT-60SA by European collaborators
  - Contribution to the Working Group on JT-60SA operations

WPS1: Preparation and Exploitation of W-7X Campaigns

Management:

Task Force Leader

Description:

This work package comprises subprojects which deal with a European exploitation of W7-X (Headline 8.1). W7-X will have its first campaign only in 2016 after a first phase with plasma at the end of 2014 in order to commission major technical systems. Until 2018, W7-X will operate with an inertially cooled divertor and a limited amount of auxiliary heating. Nevertheless first important results on scenario development, confinement and power / particle exhaust are expected in this first phase.

Keys deliverables:

- **Headline 8.1: Qualification of Helias optimised stellarator operation**
  - Scenario development
    - Pulsed operation: 8 MW / 10 s to 1 MW / 1 minute (2016)
    - Limited D-operation (2017)
    - Development of credible scenarios for steady state operation (2017)
    - Qualification of heating schemes up to very high densities (2017)
    - Edge-iota control including ECCD (2018)
  - Confinement studies
    - Verification of neoclassical confinement optimization (2016)
    - Study of impact of neoclassical optimization on turbulent transport (2017)
  - Power and particle exhaust
    - Tailoring of island configuration (2017)
    - Qualification of safe divertor operation (2017)

WPS2: Stellarator optimisation: Theory Development, Modelling and Engineering

Management:

Project leader

Description:

These work package deals with the optimization of the stellarator concept in view of a future reactor. The investigations are fully theory/modelling based and should put a strong emphasis on the integration of technical boundary conditions and limits. Reactor engineering studies should be performed with the same methology as those for DEMO performed under WPPMI. The activities will run throughout the whole period 2014-2018 and shall incorporate the experimental results provided by WPS1 from 2016 on.

Keys deliverables:

- **Headline 8.2: Stellarator optimization**
  - Include engineering constraints in the stellarator optimization together with advances in physics understanding and computational capabilities
  - Improve tools for predictive edge modelling for 3D geometries of stellarators
  - Include turbulent transport models in the stellarator optimization, in addition to the neo-classic optimisation
  - Develop new stellarator configurations, giving higher priority to fast ion confinement and less weight to aspects now deemed less crucial such as MHD stability.
  - Stellarator reactor engineering and technology studies, including systems code design optimisation and costing studies, requirements analyses for blanket / shield, coil spacing, bend radius, superconductor type and properties; space requirements

etc., diagnostic and heating system port and space requirements, RH requirements, remote handling space needs, etc.

WPCD1: Code development for Integrated modelling

Management:

Project Leader

Description:

Achieving the Mission 1 and 2 goals requires significant development of existing modelling codes with a particular focus on integrated modelling. This work package addresses this issue through a set of code and workflow development sub-projects which together provide a suite of codes that can be validated on existing machines and used for ITER and DEMO predictions. The codes and workflows shall be robust, user friendly and be flexible enough to model existing and future machines. The sub-projects build on the large body of existing modelling codes and the infrastructure, toolset and codes developed under the EFDA ITM Taskforce. They include the combination of codes into integrated work flows and the optimisation of codes by, for example, speeding up their run time.

Key deliverables:

- Extended linear stability chain (equilibrium coupled to MHD stability, edge instabilities, fast particle driven instabilities, RWM, ELMs) (in support of deliverables from: H1.4)
- Core transport simulator including various equilibrium and transport modules, turbulence modules, impurities, pellets, neutrals, sawteeth, NTM, Heating and Current Drive modules (extended to synergies, EC, NBI, IC, LH, fast-ions) with improved physics (in support of deliverables from: H1.1; H1.5; H1.6; H1.8, H1.9)
- Coupled feedback controlled free boundary plasma simulator and transport solver (in support of deliverables from: H1.8)
- Inclusion of the required synthetic diagnostics for comparison to experiment (in support of deliverables from: H1.8)
- Coupled Core and Edge transport simulators (in support of deliverables from: H1.2; H1.5; H1.6)
- Edge workflows modelling SOL and interaction with PFCs (in support of deliverables from: H1.5; H1.6)
- ELM control workflow – including ELM module/3D MHD non-linear code (in support of deliverables from: H1.2)
- Disruption workflow – including ELM module/RMP (in support of deliverables from: H1.3)
- Optimise predictive models for ITER and DEMO divertor/SOL (in support of deliverables from: H2.3)
    - Development of computational tools for edge transport extending up to PFC
    - Development of grids for all relevant devices up to the PFCs (2014)
    - Fully develop 3D code (for example EMC-3) for proper treatment of effects of Magnetic Perturbations, benchmark with 2D codes and experiments (2015)
    - Self-consistent coupling between core and edge transport codes using generic data objects developed by ITM (2015)
    - Interfacing to kinetic modules (neutrals, impurities). (2016)
    - Development of turbulence models for the SOL, divertor and pedestal (2017)
    - Physics extensions, coupling of material migration code to the plasma code

- Further development of 3D migration codes (like ERO or ASCOT) and their coupling to plasma codes (like SOLPS) (2016)
- Predictive capabilities for ITER and DEMO in edge simulations with metallic PFCs (2018)

WPISA Infrastructure support activities

Management:

Programme Unit through tasks (see Section 3.3 on implementation procedures)

Description:

Managing and supporting the codes and workflows which support the Horizon 2020 activities requires dedicated hardware and small teams of Software Developers and Computational Physicists. This work package will co-ordinate the preparation and execution of the activities in these teams which comprise the core programming team, the gateway (team) and the High Level Support Team. It will provide a link between these supporting teams and Code Development projects run under WPCD1 and activities within WPJET1, WPMST1 and WPMST2. The code development and implementation to be supported by the Core Programming Team and High Level Support Team requires a selection that has to be done by a committee such as the former HLST Project Board. The activities are foreseen throughout the whole period 2014-2018.

Structure:

- **Core Programming Team**
  - Functional maintenance of the Integrated Modelling platform and tools;
  - Implementation of new functionalities to the infrastructure;
  - Support to the integration of modules into workflows;
  - Provision of trainings on the Integrated Modelling infrastructure and workflows
- **Gateway**
  - Maintaining the hardware of gateway computer, support users on technical issues
- **High Level Support Team**
  - Support users on technical issues and code implementation on high performance computer, primarily the Helios supercomputer

2.3 Power Plant Physics and Technology Department

WPPMI: Plant Level System Engineering, Design Integration and Physics Integration

Management:

Programme Unit through tasks (see Section 3.3 on implementation procedures)

Description:

The overall technical management and coordination of the DEMO programme involve three distinct functions that will be managed by the Programme Unit:

- **Project management:**
  This function (planning and resource management, program control, QA and information management) are dealt with in Section 3 as part of the Programme Unit responsibility.
- ***System Engineering and Design Integration***
  This function involves the project requirements management, the configuration management, the design integration, the definition and maintenance of design tools and methods and the plant level system modelling. It will interface with the System Engineering activities in the individual Projects.
- ***DEMO Physics Integration***
  The DEMO Physics Integration has the function to manage the physics assessment in areas which have an impact on the overall DEMO design requirements and therefore cannot be managed at Project level.

Additionally, the following activities will be executed by Design Teams within member laboratories or Industry through specific Tasks:

- ***Requirements Analysis.***
  This will require modelling and calculations to substantiate the initial DEMO requirements and refine them as the DEMO concept develops. Examples of foreseen requirements analysis include:
  - System codes and 1-D plasma scenario modelling analysis to evaluate impact of changes coming from the individual projects. An example is the estimate of the burn time which is interlinked with assumed current drive efficiencies of the H&CD system and with plasma profiles, that affect plasma resistivity, as well as the design of the PF set, and in turn flux consumption during various phases of the discharge.
  - Divertor and first wall power load and erosion estimates, including modelling of radiation effects that impact the design approach through e.g. the presence of limiters, the design of the divertor target and armour erosion that impact frequency of divertor replacements.
  - Cost analysis, important itself but also to influence system-level studies of the overall optimum design choices.
  - Thermodynamic efficiency analysis and optimisation studies.
  - Plasma operation scenarios optimisation studies taking into account input from other Projects (e.g, WPDC).
  - In addition, a preliminary technical risk assessment shall be carried out and regularly reviewed. This risk assessment shall identify the level of technical

readiness of all the design options currently under investigation and include a system-by-system assessment of the impact and likelihood of each design option not meeting its performance targets. This should also reveal the major feasibility issues and available design margins to satisfy the most critical top level requirements (i.e. net electricity production, plant availability, tritium self-sufficiency, etc.).

• ***Plant System Modelling.***

This includes the production of plant-level system models in order to capture and analyse the overall purpose, form, structure, behaviour and performance of the DEMO Plant. Examples of these models are:

- Systems Code configurations, simultaneously satisfying the main constraints of all sub-systems to combine them in an optimum way.
- Reliability & availability models, and cost models, that should become a crucial part of systems level optimisation of DEMO.
- Plant behavioural models i.e. Thermodynamic models, Functional Flow Model, States/Modes Model, Operational Sequence Model, Control System Model
- Plant architectural models i.e. Plant Breakdown Structure, Functional Breakdown Structure, System Block Diagrams, Process Flow Diagrams etc
- Preparation and update of typical analysis models (e.g., neutronic models, structural models, ect)

These models will be used to ensure that requirements analysis activity is rigorous and systematic.

• ***CAD Configuration.***

This is a substantial part of the activity aimed at setting up the Interface Management process and tools in close coordination with Plant-level CAD Configuration models, CAD Database management and change/version control. Ensuring that system integration issues between projects/systems are identified, reviewed and resolved will be responsibility of the Programme Unit. The work in the Design Teams of the Members will include:

- Management / Control of CAD Data Packages i.e. implementation of PDM/PLM system
- Development and maintenance of large CAD model handling methods (i.e. CGR) for effective collaboration in a distributed teams
- Management and control of overall plant geometry
- Management and control of CAD models for multiple design options (i.e. Blanket options, BoP options, H&CD options, etc.)

• ***System Level Analysis & Simulation.***

These are analyses carried out to evaluate DEMO systems performance rather than the specific component performance. Examples of such analyses will be seismic structural analysis, neutronic analysis, global electromagnetic analyses, RAMI analysis etc. These analyses will be part of an iterative and recursive activity that will be needed to confirm the overall performance of the plant and that the design of the Projects evolves consistently with the plant-level requirements. Results of such studies should feed back on the overall system design from the earliest possible point, including, where possible, controlling the optimisation at systems code level.

Key deliverables

- **Requirements analysis**
  - Sensitivity / trade-off studies for key design drivers (i.e. blanket / coolant choice, pulse length extension, divertor configuration, etc)
  - Technical risk assessment reports.
  - Provide key input and verification of System Requirements Documents
  - Functional Anaysis Reports
- **Plant System modelling**
  - Reliability & Availability Model
  - Plant behavioural models i.e. Overall System Code (PROCESS), Thermodynamic model, Functional Flow Model, States/Modes Model, Operational Sequence Model, etc
  - Plant architectural models i.e. Plant Breakdown Structure, Functional Breakdown Structure, System Block Diagrams, Process Flow Diagrams etc
- **CAD configuration, interface control and design integration**
  - Plant level CAD configuration model that supports multiple design options (i.e. Blanket options, BoP options, H&CD options, etc.)
  - CAD data management processes and tools (i.e. implemented PLM system)
  - CAD modelling methodologies and tools
- **System–level analysis and simulation**
  - RAMI analysis reports
  - Seismic structural analysis report
  - Neutronic analysis reports
  - Global electromagnetic analysis reports

WPMAG: Magnet system

Management:

Project leader

Description:

The goal of the project is to deliver a feasible, integrated concept design of the DEMO Magnet system based on current or near term LTSC technology. A specific effort will be devoted to the analysis of design solution that minimizes the capital cost of the magnet system. A limited R&D programme on High Temperature Superconductor (HTS) technology is foreseen. The activities in this Work Package will involve:

- ***Magnet System Engineering.***

  This activity includes the provision of an overall systems engineering function for the Magnets Project including capturing and analysing of the Magnet System Requirements and maintaining CAD configuration models. Magnet System analysis models will be produced to simulate the expected electromagnetic, structural, thermal and quench behaviour. From this analysis, Load Specifications will be developed and iterated.

- **Conductor R&D, Concept Design & Analysis.**

  This activity will involve working with industrial partners in the manufacture and testing of prototype conductor samples to be used in the DEMO TF, PF and CS coil systems. Following the R&D phase, conductors will be selected based on agreed design criteria and the ability to meet the overall system requirements for each application. Lessons learnt from ITER shall be taken into account to mitigate the effects of cyclic degradation of performance.

- ***Coil Concept Design & Analysis.***

This work package will focus on the overall concept design of the TF, PF and CS coils including the structural casing; winding pack; structural support systems (gravity supports, pre-compression rings, intercoil structures, etc.); arrangement of power supply and feeders to the coils; control and quench protection systems and cryogenic supply system. Strong engagement with industrial partners is essential to avoid unnecessary complexity and cost into the design.

- ***Advanced Magnet Technologies (HTS).***

This activity will focus on the manufacture and testing of small-scale and full-scale HTS cables prototypes including jointing techniques and investigation of the response to neutron irradiation.

Deliverables and Milestones

- **Keys deliverables:**
  - Concept Design Description of DEMO Magnet System (i.e. TF, PF and CS coils; structural supports; power supply and feeders; control and quench protection systems; cryogenic supply system)
  - Design substantiation to include:
    - CAD models, engineering analysis reports, etc.
    - R&D of superconducting cable prototypes for TF, PF, CS coils to include performance and durability test reports;
    - Manufacturing feasibility studies for both conductors and coil structures and cost analysis;Risk analysis reports: RAMI analysis, Safety analysis, etc.

- **Keys milestones:**
  - Magnet System Model produced (2014)
  - Load Specification first issue (2014)
  - System Requirements Review (2015)
  - Testing prototype conductors complete (2016)
  - Conductor design selected (2017)
  - Manufacturing feasibility report (2017)
  - Preliminary cost report (2018)
  - Finalise conductor concept design (2019)
  - Finalise concept designs for PF, TF & CS (2019)
  - Magnets System Concept Design Review (2020)

Use of facilities

It is expected that a number of EU-based facilities will be employed through the course of the project. Namely, superconducting magnet facilities such as SULTAN (at CRPP) or FBI (at KIT) where conductor samples can be tested under representative field, current and temperature, are expected to be utilized. Furthermore, facilities for the mechanical testing of conductors under various strain regimes is also foreseen (such as those at the University of Twente). In the HTS area, facilities for the investigation of the effects of neutron irradiation on superconducting properties will also be necessary.

Opportunities for industrial innovation

Industrial involvement is mainly foreseen in terms of:

- Manufacturing of sample conductors for LTS research & development
- Providing manufacturing feasibility assessments for conductors
- Providing solutions for performance optimisation and cost minimisation of design solutions

- Assisting in the concept design definition for magnet casings (e.g. manufacturing processes, welding, etc)
- Providing HTS tapes (possibly manufacturing of sample cables)
- Providing key input in development of technology roadmap for HTS technology

Opportunities for Training & Development of Staff

A number of opportunities for training and development of staff such as graduate engineers have been identified:

- Superconducting technology (e.g. fusion application, conductor types/products, manufacturing processes, etc.)
- Tokamak Magnet System Engineering (e.g. system modelling & analysis, structural design, integration considerations, etc.)

WPCS: Containment structures

Management:

Project leader

Description:

The primary objective of the Containment Structures Project is to deliver a feasible, integrated concept design of the DEMO vacuum vessel, cryostat and tokamak building. No major R&D is expected to be required in the conceptual design phase based on the assumption that the DEMO vessel, cryostat and tokamak building will be designed and manufactured similarly to the corresponding structures in ITER. The design of the containment structures shall include provisions to allow the operation and maintenance of the auxiliary systems. A specific effort will be devoted to the analysis of design solutions that minimizes the capital cost of the containment structures. The activities in this Work Package will involve:

- ***Vacuum Vessel Concept Design.***
  This activity will capture and analyse the requirements for the Vacuum Vessel and produce an agreed Requirements Specification including a detailed Load Specification. A concept design description of the Vacuum Vessel shall be developed and substantiated by 3D CAD models and engineering analysis reports (e.g. structural, thermal, EM, neutronics, etc.). A preliminary manufacturing feasibility report including a basic cost analysis shall also be produced.

  An activity should also be launched to define a basic common port plug design, extrapolated from ITER that could be also adopted for DEMO.

- ***Cryostat Concept Design.***
  This activity will capture and analyse the requirements for the Cryostat and produce an agreed Requirements Specification including a detailed Load Specification. A concept design description of the Cryostat shall be developed and substantiated by 3D CAD models and engineering analysis reports (e.g. structural, thermal, EM, neutronics, etc.). A preliminary manufacturing feasibility report including a basic cost analysis shall also be produced.

- ***Tokamak Building Concept Design.***
  This activity will capture and analyse the requirements for the tokamak building and produce an agreed Requirements Specification including a detailed Load Specification. A concept design description of the tokamak building shall be developed and substantiated by 3D CAD models and engineering analysis reports (e.g. seismic,

neutronics, etc.). A preliminary manufacturing feasibility report including a basic cost analysis shall also be produced.

Deliverables and Milestones

- **Key deliverables:**
  - Concept Design Description of DEMO Containment structures (i.e. vacuum vessel, cryostat and tokamak building)
  - Design substantiation to include:
    - CAD models, engineering analysis reports, etc.
    - Risk analysis reports: RAMI analysis, Safety analysis, etc.

- **Key Milestones:**
  - System Requirements Review (2016)
  - Finalise concept design (2019)
  - Concept Design Review (2020)

Use of facilities

None currently foreseen.

Opportunities for industrial innovation

Under the assumption that the DEMO vessel, cryostat and tokamak building will be designed and manufactured similarly to the ITER correspondents it is not expected that trial mock-ups are required to qualify the manufacturing. During the DEMO conceptual design it is expected that important lessons will be learned from the manufacturing of the ITER vessel sectors and port extensions as well as from the manufacturing of the ITER and JT60SA cryostats in particular regarding achievable tolerances and the significance of issues with the chosen welding techniques. DEMO-specific manufacturing issues are planned to be addressed during the engineering design phase.

Industry involvement would be beneficial in the following areas, aiming at design simplification and cost minimisation:

- Manufacturing sequences, achievable tolerances and assembly issues.
- Welding processes and weld inspection techniques.
- Construction and licencing of large nuclear installations.

Opportunities for International Collaboration

None currently foreseen.

Opportunities for Training & Development of Staff

A number of opportunities for training and development of staff such as graduate engineers have been identified:

- Design integration (configuration control, system specification, requirements management)
- Manufacturing processes of large stainless steel structures and reinforced concrete buildings

WPBB: Breeding blanket

Management:

Project leader

Description:

The focus of the activities will be to develop and/ or to strengthen the technical basis and resolve all the main technical issues associated with the four blanket concepts that need to be investigated. The two that are planned to be tested as part of the ITER TBM Programme (i.e., helium-cooled pebble bed (HCPB), helium-cooled lithium lead (HCLL) a water-cooled lithium lead (WCLL) and an advanced blanket concept, e.g., dual coolant lithium lead (DCLL). The activities will develop and substantiate the design and qualify the underlying technologies of the various blanket concepts to an appropriate level for a conceptual design review. This will involve activities such as CAD modelling, engineering analysis, prototyping and testing of components, manufacturing feasibility studies, cost analysis, RAMI analysis, safety analysis, etc.The activities in this Work Package will involve:

- **Breeding Blanket System Engineering.**

This activity verifies and maintains the consistent integration of the blanket system in the DEMO plant. It will capture and analyse the blanket system requirements and maintain CAD configuration models. The relevant system analyses will be carried out and the required system specifications (e.g. load specification) will be developed and iterated. This includes in particular the definition of the essential acceptance criteria and the corresponding verifications, in particular of the blanket functions, its manufacturability, its structural integrity, and compliance with safety requirements. The design and R&D progress of the different blanket concepts will be harmonized to ensure that a comparable maturity level is reached.

- **HCPB Design and R&D.**

Focus of the technology R&D will lie on the following areas:

- Development and qualification of solid breeders (e.g., Li_4SiO_4, Li_2TiO_3**)** and Be multiplier under DEMO-relevant irradiated conditions (temperatures and doses with tests in fission reactors) to complement TBM Programme.
- Demonstrate fabrication feasibility of helium-cooled first wall concepts (HCLL, HCPB, and DCLL) including performance and durability tests.
- Demonstrate fabrication of small and medium-scale blanket mock-ups, including non-destructive examination, for representative geometries and thicknesses (in DEMO expected to differ from TBM, e.g., presence of first wall).

- **HCLL Design and R&D.**

Focus of the technology R&D will lie on the following areas:

- Demonstrate fabrication feasibility of helium-cooled first wall concepts (HCLL, HCPB, and DCLL) including performance and durability tests.
- Demonstrate fabrication of small and medium-scale blanket mock-ups, including non-destructive examination, for representative geometries and thicknesses (in DEMO expected to differ from TBM, e.g., presence of first wall).

- ***WCLL design and R&D.***

Focus of the technology R&D will lie on the following areas:

- Demonstrate Water/LiPb compatibility under relevant design conditions (e.g. safety and corrosion tests) and comply with reliability requirements (e.g. double tube containment).
- Development and qualification of double-wall tubes.
- Demonstrate fabrication feasibility of water-cooled first wall including performance and durability tests.
- Demonstrate fabrication of small and medium-scale blanket mock-ups, including non-destructive examination. Thermal cycling and endurance tests under relevant WCLL conditions (LiPb, pressurized water).

- **DCLL design and R&D.**

Focus of the technology R&D will lie on the following areas:

- Verify by means of simulations and tests the MHD effects in flow channels in relevant geometries.
- Development and qualification of flow channel inserts to suppress MHD effects arising from LiPb circulated at high speed.

• FW/limiter design and R&D.

This activity will develop and substantiate the design of the FW and qualify the related fabrication technology. In case plasma limiters are required in DEMO also the design and development of the DEMO limiters would be part of this work package. The FW and limiter requirements specification will be prepared including the heat load specifications. Focus of the R&D is on the development and qualification of the relevant fabrication processes and on the performance qualification of the high heat flux components.

• LiPb common technology development.

This activity will develop and qualify the LiPb technology required for the three blanket concepts HCLL, WCLL, and DCLL. This includes the characterization of the corrosion of EUROFER in low and high velocity LiPb and the development and qualification of mitigation technologies. In addition this work package will qualify the required auxiliary system of a LiPb loop, e.g. pumps, valves, or instrumentations. The processes required to purify LiPb from radioactive isotopes will be developed and qualified in this work package. Since the MHD effects in the HCLL and the WCLL are similar the related simulations and experiments are carried out in this work package. Blanket tritium technology development (e.g., permeation barriers, etc).

This activity will develop and qualify the technologies for tritium extraction and tritium permeation control for the four blanket concepts. The tritium transport within the cycle breeding blanket – extraction system will be simulated and the simulations will be validated through appropriate experiments in this work package in close collaboration with project P07. In addition the required tritium permeation barriers for the different blanket concepts will be developed and qualified. This includes testing under thermal cycling loads and neutron irradiation. In addition tritium extraction from low and high velocity LiPb as well as from helium purge gas will be investigated. The relevant technologies will be developed and qualified under DEMO relevant conditions complementary to the TBM development and experiments.

Deliverables and Milestones

• Deliverables common to all the concepts

- Concept Design Description of DEMO Breeding Blanket System (including the first wall)
- Design substantiation to include:
  - (CAD models, engineering analysis reports, etc.
  - Experimental R&D test reports, including code validation
  - Manufacturing feasibility studies for structural and breeding elements
  - Risk analysis reports: RAMI analysis, Safety analysis, etc.

• Keys Milestones:

- Blanket system model produced (2014)
- Load specification first issue (2014)
- System requirements review (2015)
- Selected technology R&D and testing to enable down-selection most promising design option for each breeding blanket concept (2016/2017).

- Manufacturing feasibility demonstration of key technologies, including performance tests, structural integrity reports, etc. (2019).
- Finalise breeding blanket concept design (2019)
- Breeding blanket concept design review (2020)

- **Concept specific milestones are:**

- HCPB/HCLL:
  - Performance and durability characterization tests of solid breeder candidates (e.g., Li_4SiO_4, Li_2TiO_3). This is complementary, but with strong interlinks to the TBM R&D Programme.
  - Down-selection of solid breeder material (2017), demonstrate industrial fabrication scalability (2019).
  - Fabrication feasibility demonstration of selected blanket box geometries for small and medium-scale mock-ups only (2019). Complementary to the TBM R&D Programme and focus on specific breeding blanket design configurations that satisfy DEMO neutronic, thermal and structural requirements.
  - Adapt and pre-qualify welding technologies and procedures for the candidate structural materials being considered (2018). Complementary to the TBM R&D Programme.
  - Feasibility demonstration of T-extraction from helium purge gas for DEMO relevant condition ranges (i.e., velocity, pressure, tritium concentration, etc.). Complementary to the TBM R&D Programme with focus on technology validation and efficiency improvement (2018).
  - Feasibility demonstration of T-extraction from PbLi at high temperature by gas-liquid contactors, permeation against vacuum (PAV) (2019).
  - Development/ characterisation of tritium permeation barriers required for HCLL and HCPB (no development foreseen in TBM Programme) including performance and testing under thermal cycling loads and neutron irradiation. Down selection among options (2016) and final selection of best technology (2019)
  - Design and feasibility demonstration of helium-cooled first wall concepts (HCLL, HCPB, and DCLL) including primarily high heat flux tests (2018/19)..

- WCLL:
  - Demonstration of water/LiPb compatibility under relevant design operating conditions. This includes establishing the needs for possible design amelioration (e.g., double tube containment), testing and validating of simulation tools (2015-18); finalise design guidelines (2018)
  - Preliminary development and qualification of manufacturing processes for double wall tubes using EUROFER (2016) or improved structural materials (2018).
  - Demonstrate fabrication of small and medium-scale blanket mock-ups, including NDT. Thermal cycling and endurance tests under relevant WCLL conditions (2017). Crack propagation tests on un-irradiated and irradiated samples 2018)
  - Feasibility demonstration, performance assessment of water-cooled first wall including high-heat flux tests. (2019)
  - Development and testing of performance and durability of tritium permeation barrier for WCLL coolant channels (see also HCLL) (2018).

  - Demonstration of T-extraction from LiPb under DEMO relevant conditions (velocity, pressure, tritium concentration, etc). (See also HCLL).
  - Hydrodynamic corrosion test of welded joints and DWT in LiPb under WCLL representative conditions (2016-2018).

- DCLL:
  - Development and characterisation of insulating layers to suppress or minimise MHD effects from LiPb circulated at high speed. Feasibility demonstration and performance report (2019)
  - Simulation and tests of MHD effects in high velocity LiPb in all relevant geometries. Code validation and design optimization (2015-2018). Final design concept (2017)
  - Development and qualification of tritium extraction process from higher speed LiPb (see also HCLL and WCLL).
  - Develop coatings for minimising LiPb corrosion. Feasibility demonstration (2019)
  - Analsysis and Development of LiPb Heat Exchanger and Power Conversion (see WPBOP)

Use of facilities

Facilities that could be engaged in the blanket concept development are:

- Tritium extraction from LiPb: without tritium TRIEX (Brasimone); with tritium TLK (KIT)
- T-extraction from helium coolant or helium purge gas: without tritium : HELOKA (KIT), HE-FUS3 (ENEA Brasimone), DIADEMO (CEA, Cadarache); with tritium TLK (KIT)
- T-extraction from water: TLK (KIT)
- T-permeation barrier applied to steel: experiments under thermal cycling conditions e.g. Vivaldi (ENEA), Corelli II (ENEA)
- Small-scale MHD experiments of slow velocity LiPb: MEKKA (KIT)
- Water-LiPb reaction: large leak: LIFUS-5 (ENEA); small leak: RELA III (ENEA)
- Qualification of WCLL double-wall tubes: un-irradiated: DIADEMO (CEA, Cadarache); irradiated: SCK/CEA or HFR FOM (irradiated)
- Aqueous corrosion experiments on EUROFER or CuCrZr: MELODIE (CEA), LECA (CEA, Saclay)
- Corrosion test on EUROFER or CuCrZr: hot helium or liquid metal: LECNA (CEA, Saclay)
- Un-irradiated blanket sub-elements testing including electrical heating and coolant flow: e.g. EBBTF (ENEA)
- Irradiation test facility: OSIRIS (CEA, Saclay)
- Helium gas purification tests / hydrodynamic tests of pebble beds: FLEX (KIT)
- Helium-cooled first wall channel high heat flux thermo-hydraulic experiments: HETRA (KIT)
- Isotope separation (TRENTA facility at TLK, KIT)

Opportunities for industrial innovation

Industrial involvement is foreseen in the following areas:

- Fabrication and manufacturing development and qualification, with emphasis on performance and cost optimization design solutions.
- Providing close support to the blanket project team in various fields, e.g. consulting, simulation tools development, analysis, design integration, and others.

Opportunities for International collaboration.

Involvement in the design of the CFETR facility in China or the FNSF in US is foreseen in order to allow the use of these facilities for EU component testing.

The sharing of know-how on the TBM programme with other ITER parties will be considered whenever a win-win situation is expected.

A collaboration with UCLA (US) is foreseen for the development of the DCLL blanket option.

Opportunities for Training & Development of Staff

A number of opportunities for training and development of staff such as graduate engineers have been identified:

- Manufacturing technologies (incl. EUROFER structures, corrosion qualification, solid breeder fabrication, FW manufacturing)
- Design integration and system engineering (configuration control, system specification, requirements management, design criteria)
- LiPb technology (fabrication and properties control, auxiliary systems, isotope separation)
- Tritium extraction technology (incl. permeation coating development and testing, extraction technologies development and qualification)
- Blanket analysis specialists (e.g. magnetohydrodynamic, electromagnetic, neutronics)

WPDIV: Divertor

Management:

Project leader

Description:

The Divertor Project will manage the design integration of the divertor cassette configuration within the overall DEMO plant and develop credible high-heat-flux targets through an in-depth R&D programme. This shall be substantiated and verified to an appropriate level for a conceptual design review by activities such as CAD modelling, engineering analysis, prototyping and testing of components, manufacturing feasibility studies, cost analysis, RAMI analysis, safety analysis, etc.. A limited R&D on advanced (e.g., He-cooled) divertor concepts will also be pursued. The activities in this Work Package will involve:

- ***Divertor design and integration.***

  This activity verifies and maintains the consistent integration of the divertor in the DEMO plant. It will capture and analyse the divertor system requirements and maintain the CAD configuration models. The relevant system engineering analyses will be carried out and the required system specifications (e.g. load specification) will be developed and iterated. The conceptual design of the divertor cassette will be also developed including the integration of the target.

- ***Water-cooled divertor target development.***

  This activity will develop and substantiate the design concept and qualify the fabrication technology of the water-cooled divertor target to an appropriate level for a conceptual design review. Strong links with WPMAT are foreseen.

- ***Advanced divertor target development.***

  This activity will develop an advanced He-cooled target concepts. This includes the development and qualification of the required fabrication processes and the development of design criteria. During the DEMO conceptual phase the high heat flux performance is foreseen to be demonstrated in un-irradiated condition. The advanced concept development is strongly linked to the material developments in project WPMAT.

Deliverables and milestones:

- **Keys deliverables:**
  - Concept Design Description of a number of feasible and performing divertor target concepts whose readiness is confirmed by a proper technology development and qualification program
  - Design substantiation to include: (a) CAD models, engineering analysis reports, etc. (b) R&D of target, including joining technologies; (c) Preliminary manufacturing feasibility studies and cost analysis; (d) Risk analysis reports: RAMI analysis, Safety analysis, etc.

- **Key Milestones:**
  - Produce a material qualification plan for armour and heat-sink materials including a plan for n-irradiation tests in fission reactors (2014)
  - System requirements review (2015)
  - Procure larger amount of candidate materials for testing (2015).
  - Prepare plan for high heat flux tests (2015).
  - Establish reference design and material specifications (2015).
  - Design and fabricate small mock-ups for thermal cycling tests (2015).
  - Initiate test programme for mechanical and thermal-physical properties (2016).
  - Determine failure mechanism(s) (2016).
  - Initiate high-heat flux test programme on small mock-ups (2016).
  - First results of conceptual design and integration analysis, including RH (2016).
  - Initiate demonstration of welding and NDE capability (2017).
  - Continue high-heat flux test program medium scale mock-ups (2017).
  - Optimization of design and manufacturing processes. (2017).
  - Continue demonstration of welding and NDE capability (2018)
  - Complete high-heat flux test programme on medium scale mock-ups (2019)
  - Manufacturing feasibility and RH demonstration (2019)
  - Concept design review (2020)

Use of facilities

The following facilities could be engaged in the divertor concept development:

- GLADIS (likely requires an upgrade for higher coolant pressure)
- HELOKA (for advanced He-cooled targets)
- Areva FE200, Le Creusot, France
- JUDITH, Jülich

Opportunities for industrial innovation

Industrial involvement will involve in the following areas:

- Fabrication and manufacturing development and qualification.
- Providing close support to the divertor project team in various fields, e.g. consulting, simulation tools development, analysis, design integration, and others.
- Identification of candidate advanced target technologies regarding reliability, cost and mass production.
- Possible use of the FE200 high heat flux facility in Le Creusot, France.

Opportunities for International Collaboration

None currently foreseen.

Opportunities for Training & Development of Staff

A number of opportunities for training and development of staff such as graduate engineers have been identified:

- Manufacturing of the high heat flux components including the various joining processes and metallurgical examinations, including NDT.
- Design integration (configuration control, system specification, requirements management, design criteria)
- Design engineer (incl. design development and specification, design assessment, design integration, experiment preparation).

WPHCD: Heating and current drive systems

Management:

Project leader

Description:

The activities in this Work Package will involve:

• *H&CD System Engineering.*
This activity will prepare initial CAD-configuration models and define the design and R&D strategies for the H&CD systems. It will capture and analyse the system requirements and contains a Load Specification (LS) including off-normal load conditions which may affect the NB- and EC- system itself (such as arcing etc.) or may have impact to the external components e.g. to the ports and launchers (such as VDEs, disruptions etc.).

• *Neutral Beam R&D.*
The key activities are the selection of Cs alternatives and develop new source technologies as well as the investigation of candidate energy recovery solutions to improve the efficiency of the NB system. A general analysis of power supply concepts for the accelerator taking into account energy recovery is a further goal. An ion source demonstrator should be developed. Finally the HV-bushing has to be developed further with regard to use of better geometries or other insulators (such as He-, oil-insulation etc.) and to prove the concept to avoid arcing failures or post arcing degradation.

• Electron Cyclotron R&D.
The key activities are the design and fabrication of a pre-prototype step tuneable high frequency (<250 GHz) gyrotron and the development of candidate high power broadband window solutions. After collecting and analysing the results, a pre-prototype design should be built and tested. As to the development of broadband windows, different technological solutions should be compared (Brewster angle windows, double-disc cavities, movable double disc arrangements etc.) and best concept selected. Thermo-mechanical design and a failure analysis are foreseen.

• H&CD Concept Design & Analysis.
This activity will focus on the design layout, integration and assembly of the H&CD systems.

• Advanced H&CD Technologies.
This activity will facilitate a parallel R&D programme focussed on advanced applications of H&CD technologies. The key activities within the work package are:

- *photoneutralizers*: this consists of the development of photo-neutralization by studying initially options or cavities and lasers, developing source geometry and cavity material and testing a scaled cavity with and without combination of beams,

starting with laboratory samples and finally with scaled cavities. Two concepts will be compared, the Fabry-Pérot concept and a Direct Drive concept.
- *high power multi stage depressed collectors*: initial design studies are foreseen followed with calculations and simulations of high power multi stage depressed collector gyrotrons. Concept fabrication should be followed by high power tests.

These activities will be complemented by design integration studies that encompass all the candidate H&CD systems including ICH, LH. This will allow identification of the space allocation and power transmission line requirements, etc. Similarly, integration studies should be conducted at an early stage to evaluate the impact and to understand the engineering requirements of long-term options e.g., with photo-neutralisation schemes for NBI.

Deliverables and Milestones

- **Key deliverables:**
  - Concept Design Description of a range of H&CD systems whose readiness is to be confirmed by a proper technology development and characterisation program
  - Design substantiation to include: (a) CAD models, engineering analysis reports, etc. (b) R&D on specific technologies; (c) Preliminary manufacturing feasibility studies and cost analysis; (d) Risk analysis reports: RAMI analysis, Safety analysis, etc.

- **Key Milestones:**
  - NB System
    - Requirements definition (2014/15)
    - System Requirements Review (2015) then continuing reviews and updates
    - Feasibility assessment of Cs alternatives, including small scale material studies (2014) and larger scale material studies (if required) (2016/2017)
    - Initial NB System Layout (2014)/ Optimisation of NB Layout + Design Integration (2017)
    - Preliminary Safety Analysis (2018)
    - Assembly & Maintenance Concept (initial 2016 but finalised by 2019)
    - Finalise NB System Layout + Design Integration (2020)
  - Heating & Current Drive: Electron Cyclotron
    - Initial Requirements Capture (2014)/ Functional Analysis and mapping of functions to PBS Identification & Specification of Interfaces (2014)
    - Initial ECH System Layout (2014)/ Optimisation of ECH Layout + Design Integration (2017)
    - Cold testing of various gyrotron parts (2016-2018)
    - High power testing of window (2015-2018)
    - Initial Gyrotron Concept Design Layout (2015)
    - Prequalification of gyrotron prototypes (2019)
    - Design Integration at System and Plant Level (2017)
    - Assembly & Maintenance Plan (2017)
    - Finalise ECH System Layout + Design Integration (2020)
    - Concept Design specification Review (2020)

Use of facilities

It is expected that a number of EU-based facilities will be employed through the course of the project. Namely, negative ion source test facilities such as BATMAN (IPP Garching), NIO1 project (Negative Ion Optimization phase 1 (Padova), or SNIFF (CCFE Culham) could be used to investigate Cs-alternatives or Cs-reduction. Use of further tests facilities, such as for example the Bulgarian Matrix Source Test Facility for other Cs-free source concepts and planar coil driven discharge could be envisaged.

To assess and develop the potential of neutral beam energy recovery it is mandatory to implement after some initial laboratory tests the developed high voltage and high power electronics into a real test bed. This could be done in one of the aforementioned facilities or in large-scale devices such as PRIMA (ENEA RFX/Padua).

For the development of gyrotrons existing test beds (e.g., the gyrotron test stand at KIT/Karlsruhe Forschungszentrum, which will have an upgrade in the next years for multi stage depressed collectors and the ITER test bed at CRPP/Lausanne) should be used. KIT and CRPP have also candidate facilities for testing broadband diamond windows, but additional facilities could be envisaged.

For the photo-neutralisation small scale experiments such as a cavity to measure the finesse (quality factor) and influence of temperature changings and laser instabilities are needed. Further test for material behaviour of the mirrors in long pulse or c.w. operation are to be developed in close collaboration with already mentioned facilities to be integrated there.

Opportunities for industrial innovation

Industry should be involved to investigate development and manufacturing of:

- Gyrotrons (the only European manufacturer is Thales in France)
- Subcomponents for Gyrotrons
- CVD diamond windows
- High voltage power supplies for energy recovery
- Launcher fabrication and assembly.

Further work involving industry will be defined at a later stage.

Opportunities for International Collaboration

None currently foreseen.

Opportunities for Training & Development of Staff

The training of physicists, engineers and other experts should be an important goal of this project. The strong R&D in the H&CD project will provide opportunities for Masters and PhDs as well. Also collaboration with ITER could be envisaged. A number of opportunities for training and development of staff such as graduate engineers have been identified:

- Heating & Current Drive System Engineering (e.g. materials selection under neutronics aspects, structural design, integration considerations, cooling etc.)
- Neutral Beam Technology (e.g. high voltage and structural FEM for accelerator and grids, RF simulations for drivers and circuits, electrostatic simulations with special numerical codes, diagnostics, designing of electrical circuits for high voltage etc.)
- Electron Cyclotron System Engineering (e.g. RF-simulations and engineering, mathematical description and simulation of resonances and parasitic cavity interaction, materials selection and brazing of diamond windows, designing of gyrotron components and testing and quality assurance (definition of quality standards) of gyrotron development processes.

WPTFV: Tritium, fuelling & vacuum systems

Management:

Project leader

Description:

The DEMO vacuum pumping system has to continuously provide the required vacuum conditions during the pulse and minimise the pump-down time in between the pulses. The fuelling system has to provide the required D-T fuel mixture to maintain the plasma as foreseen by the plasma scenarios. The tritium plant system shall purify the primary coolant to satisfy the safety and regulatory requirements on the tritium emission limits and to separate, collect and store the tritium isotope for refueling and minimising the tritium inventory held up in the fuel cycle. The activities in this Work Package will involve:

- ***Systems Engineering and Requirements Analysis***

  This activity will capture and analyse the tritium, fuelling & vacuum system requirements and maintain CAD configuration models.\

- **Vacuum Pumping Concept Development and Simulation.**

  This activity will focus on the development of the DEMO vacuum pumping concepts such as cryopumps with a separation function or continuously working pumps (i.e. diffusion, liquid ring, and metal foil pumps);

- **Fuelling System Concept Development and Simulation,**

  This activity will focus on the development of the DEMO fuelling system concept by reviewing the maturity and DEMO relevancy of the fuelling technologies adopted by ITER; and

- **Tritium Plant Systems Development and Simulation.**

  This activity will focus on the development of the tritium plant systems and specifically:
  - the coolant purification system (CPS), in connection with with the R&D on tritium extraction and permeation barriers development in the breeding blanket project,
  - the Tokamak Exhaust processing and isotope separation systems
  - the R&D of reactor relevant tritium accounting techniques. The development of a fuel-cycle simulator is also foreseen to provide a full parametric description of a conceptual fuel cycle of DEMO with recycling option.

Deliverables and Milestones

- **Key deliverables:**
  - Conceptual design of vacuum pumps concepts capable of hydrogen separation close to the vessel.
  - Conceptual design description of the DEMO fuelling system including the selection and further development of fuelling technologies to satisfy the requirements.
  - Conceptual design description of the DEMO tritium plant systems comprising of the following: a) coolant purification system concept developed for both He and water coolants; b) tokamak exhaust processing system; c) isotope separation system.

- **Key Milestones:**
  - Vacuum pumping concept development and simulation
    - Proof of principle of pump technologies complete (2014)
    - Small scale integrated test of candidate pumps complete (2015)
    - Technical scale test of candidate pumps complete (2017)
    - Selection of vacuum pumping technology(ies) (2018)
    - Design of vacuum pumping concept complete (2019)
  - Fuelling system concept development
    - Review of maturity of fuelling technologies for DEMO (2015)
    - Development report on fuelling technologies complete (2017)
    - Selection of DEMO fuelling technology (2018)

    - Design of fuelling system concept complete (2019)
- Tritium plant systems development and simulation
    - Design of He coolant purification system concept complete (2018)
    - Design of water coolant purification system concept complete (2018)
    - Selection of coolant purification system (2020)
    - Development of Tokamak Exhaust Processing system complete (2019)
    - Development of Isotope Separation System complete (2019)
    - Design and R&D of reactor relevant T accounting techniques complete (2019)
    - Fuel cycle simulator development review (2017)
    - Fuel cycle simulator GUI development complete (2018)
    - Provide a full parametric description of a conceptual fuel cycle of DEMO with DIR (2019)

Use of facilities

The use of the following is foreseen:

- THESEUS (KIT) – for testing and integration of an alternative set of vacuum pumps in DEMO relevant conditions (except tritium)
- TIMO (KIT) – for testing the cryopump with hydrogen separation (backup solution)
- Tritium laboratory TLK (KIT) – testing tritium measurement techniques.

A strong programmatic link is expected with the JET DT Programme.

Opportunities for industrial innovation

Industrial involvement is foreseen in the adaption of the tritium compatibility to commercially available pumps in terms of support to design and manufacturing.

Opportunities for International Collaboration

None currently foreseen.

Opportunities for Training & Development of Staff

There will be number of opportunities for training and development of staff such as graduate engineers, including:

- Vacuum engineer (theory, experiment)
- Tritium specialist (theory, experiment, handling, safety, etc.)
- Nuclear fusion fuel cycle specialist (theory, simulation)
- Fuelling technologies specialist (theory, experiment)

WPBOP: Heat transfer, balance-of-plant and site

Management:

Project leader

Description:

Water cooling is considered as the reference solution for the DEMO divertor as the divertor surface heat flux conditions prove to be beyond helium power handling capabilities. The choice of coolant for the breeding blanket and first wall systems requires work to be conducted to consistently analyse and resolve the associated technical issues especially considering both helium and water as primary coolants in order to make an informed selection by 2020. Different solutions will be investigated with the direct involvement of industry. In addition, the need of an energy storage system either to buffer the thermal transients (dwell times) or to reduce the effect of cyclic loading of some of the critical subsystems (e.g., heat exchangers) must be confirmed and the requirements defined. The activities in this Work Package will involve:

- **Primary Heat Transfer System (PHTS) & BoP System Engineering**

The provision of an overall systems engineering function for the project. System integration issues associated with attaching electricity generation equipment to a fusion reactor shall be investigated in-depth. Risks associated with efficiency; performance; pulsed operation; maintainability; reliability; redundancy; fault tolerance; cost; safety; etc shall be tackled at the system-level. This activity will capture and analyse the PHTS & BoP System Requirements and produce an overall System Requirements Specification. A CAD configuration model will be developed to consider options for Site Layouts. This activity will provide technology scanning and monitoring of PHTS & BoP technologies to identify opportunities from the Gen. IV programme and determine R&D needs for fusion power conversion systems. Evaluation the various design solutions proposed shall be made against agreed criteria in preparation for a concept design review. Because of the pulsed nature of DEMO, an energy storage system might be required to buffer the thermal transients and reduce cyclic loading. Different solutions will be investigated with the direct involvement of industry.

- **Modelling, analysis and concept design of PHTS & BoP.**

A number of possible architectures for the PHTS & BoP shall be designed, modelled, analysed and evaluated using appropriate tools and the involvement of industrial experts. This activity will focus on developing thermodynamic models and supporting analysis for Helium- and Water-based PHTSs and a range of primary/secondary coolant combinations. The assessment of available heat exchanger technology shall be undertaken including consideration of fusion-specific issues such as tritium containment and pulsed operation.

- **LiPb Heat Exchanger and Fluid technology.**

This activity shall develop and demonstrate the performance of a heat exchanger for the DCLL LiPb loop.

Deliverables and Milestones

- **Key deliverables:**
  - Conceptual design descriptions for the PHTS considering both Helium and Water as primary coolants
  - Conceptual design descriptions for the BoP system considering a range of viable secondary coolants and options for thermodynamic cycles
  - Conceptual design descriptions for the overall Site Layout options
  - System-level thermodynamic models and related analysis used to substantiate the concept designs and consider the effected of pulsed operation
  - Technology assessment for PHTS and BoP systems including findings from Gen IV fission programme and Tritium containment
  - Viable concept design for a LiPb Heat Exchanger with verification through prototype testing
- **Key Milestones:**
  - Draft System Requirements Document (2014)
  - System Requirements Review (2015/ 2017)
  - Initial concept designs for PHTS and BoP available (2015)
  - Feasibility / performance assessment of concept designs (2016)
  - Analysis of HEX technology inc. tritium containment (2017)
  - Selection of preferred PHTS & BoP concept (2019)
  - Concept Design of a LiPb heat exchanger to ~ 500°C (2017)
  - Manufacturing and building a LiPb HEX prototype and testing (2019)

Use of facilities

The in-depth use of proprietary thermodynamic modelling and analysis tools is foreseen, which could clearly be provided by industrial partners. The development of the LiPb heat exchanger and Tritium Permeation barriers would utilise that Breeding Blanket facilities (see WPBB for details).

Opportunities for industrial innovation

Power Plant systems such as Primary Heat Transfer and BoP are not areas of core technological competency held within the European Fusion community. However these technologies are very mature, with strong capabilities held within European industry and therefore strong industrial involvement is foreseen contributing to this project. In particular, the activities outlined above could all be performed by, or in close collaboration with, industrial partners to take advantage of their knowledge of: BoP modelling tools and techniques; system elements such as heat exchangers and turbo-machinery; opportunities to leverage developments foreseen from the Generation IV fission power plant programme.

Opportunities for International Collaboration

None currently foreseen.

Opportunities for Training & Development of Staff

Development opportunities exist for deepening knowledge of fusion-specific design issues relating to the application of electricity generation equipment to a fusion reactor. Bi-directional transfer of knowledge between the fusion community and industry is expected.

WPDC: Diagnostic and control

Management:

Project leader

Description:

The primary objective of the Diagnostics and Control Systems Project is to deliver a feasible, integrated concept design of the DEMO Diagnostics and Control System that, with an acceptable confidence level, can be shown to meet the Measurement Requirements of the machine. The concept design shall be substantiated and verified to an appropriate level for a plant-level Conceptual Design Review. This Work Package will involve:

- **Design Integration and System Engineering.**
  This includes the provision of an overall systems engineering function. The key activities within the work package are the preparation of initial CAD-configuration models and defining the design and R&D strategies.

- **Systems for Machine Protection.**

- **Systems for Basic Control & Specific Scenario Functions.**
  Starting from the measurement requirements, a diagnostics and control R&D plan will be developed which fulfils the requirements. Proof of principle both for adopted existing as well as for new systems will be performed, followed by a concept design and demonstration of their feasibility (in WPJET1 and/or WPMST1).
  A simulation tool for integrated plasma control will be developed to guide the R&D work for DEMO in this area. This implies:
    - Define the control parameters;
    - Develop an adequate set of control modules to carry out time-dependent simulations;

- Develop approaches to derive accurate and redundant physics quantities from sparse diagnostic raw data;
- Develop control scenarios based on DEMO actuators (slow, indirect, weak) for all phases of operation;
- Define R&D priorities for validation of DEMO control strategies on existing tokamaks;
- Optimisation of DEMO controllability in close feedback with system code design work.

Deliverables and Milestones

- **Key Milestones:**
  - Review of measurement requirements on DEMO (2013/14)
  - Assessment of the options for implementing the required measurements and definition of the requirements for new diagnostic development, e.g. plasma shape control without or with reduced magnetic measurements, alternatives to viewing systems with first mirrors close to the plasma (2014/2015)
  - Development of an adequate set of control simulation modules (2016).
  - Assessment of the options for actuators and control strategies compatible with use in a FPP. For example, beta control using additional power modulation will become more difficult at high fusion gain.
  - Development of optimised DEMO control scenarios (2018)
  - Selection of DEMO relevant concepts (2019) etc.

Use of facilities

The test of control schemes using a selected number of diagnostics and actuators will be performed under the JET and MST Work Packages (see Sec.3.2.1).

Opportunities for industrial innovation

Potential involvement of industry in specific areas to complement the R&D effort undertaken in research labs across Europe should be foreseen.

Opportunities for International Collaboration

All current ITER partners are more or less involved in diagnostic & control developments and procurements. As such this is an area in which international collaboration can be enhanced and could potentially lead to synergies. Although this might be true for most of the other tokamak systems as well, it is particularly true for D&C systems as the design of them is less dominated by the differences in DEMO design parameters as they are currently envisaged around the various ITER partners.

Opportunities for Training & Development of Staff

A number of opportunities for training and development of staff such as physicists, Post – Doctorates both in Physics and Engineering are envisaged. Diagnostic & Control is a well-known area for many of the participating institutes and vital for operating a machine or even a small facility.

WPRM Remote Maintenance Systems

Management:

Project leader

Description:

An overall availability target of at least 30% has been initially set for the DEMO plant. Therefore, the DEMO Remote Maintenance System shall be capable of supporting this requirement through achieving adequate performance in dependability and maintenance downtime. It is assumed that the multi-module blanket segment (MMS) concept will be employed to achieve an acceptable maintenance downtime with MMS blankets being remotely removed and installed via a vertical upper port in the tokamak. Due to the expected level of radiation both during and following plasma operations, in-vessel components such as Blanket and Divertor systems will require periodic removal and replacement by remote means. This Work Package will involve:

- ***Remote Maintenance System Engineering.***
  This activity will capture and analyse the requirements for the Remote Maintenance System subsystem; review and agree the requirements with all stakeholders and monitor / verify the satisfaction of these requirements throughout the CDA phase. Furthermore, it shall define and optimise the overall Remote Maintenance System CAD layout and closely manage the integration with interfacing subsystems. Aspects such as developing the overall concept for RM control and operation system; as well as defining the RM strategy for H&CD, Vacuum and Diag. Systems are also required.

- **In-vessel Remote Maintenance Systems.**
  This activity will interact with WPBB and WPDIV to develop the in-vessel components to ensure remote handling compatibility, addressing mechanical fixation, earth bonding, service connections etc. with prototyping and mock-ups required to substantiate the design. Furthermore, the development of concept designs of in-vessel transporters for the blanket and divertor systems with prototyping and mock-up trials of the transporter design concepts are required to substantiate the design.

- ***Ex-vessel Remote Maintenance Systems*.**
  This activity will develop the design concept and perform prototype testing of ex-vessel transfer casks and servo manipulators. RMS concept designs for H&CD, Vacuum and Diag. Systems will also be elaborated along with the concept design and layout of Active Maintenance Facility / Hot Cell.

- **Services joining technology.**
  This activity will focus on the development of service joining concepts for in-and ex-vessel components. Strong interaction with industry and prototype testing is foreseen including mock-ups and bench testing of remote service connection concepts with eventual testing of full-size service connections under relevant conditions.

- **DEMO Remote Maintenance Test Facility.**
  This activity will focus on the requirements definition and concept design of a fully equipped Remote Maintenance Test Facility to be built during the EDA phase.

Deliverables and Milestones

- **Key deliverables:**
  Concept Design Descriptions are required for:
  - In-Vessel Remote Maintenance System including Blanket Maintenance, Divertor Maintenance and Multi-purpose Deployer
  - Ex-vessel Remote Maintenance System including Upper Port Plug Maintenance (if required); Equatorial Port Plug Maintenance (inc. ECH, Diagnostics, etc.); Lower Port Maintenance (i.e. Vacuum Pumps, etc.); and NB Cell Maintenance
  - Active Maintenance Facility (inc. Hot Cell)
  - Transport Systems including Transfer Casks, Cranes, Conveyors etc.
  - Service Connections

- Remote Maintenance Control System

Physical proof-of-principle (scale) prototypes are foreseen in the following areas:
- Blanket & Divertor mechanical connections
- In-vessel transporters / actuators
- Ex-vessel transfer casks
- Service connections (i.e. in-bore welding, etc.)

• **Key Milestones:**
- Draft System Requirements Document (2014)
- System Requirements Review (2015)
- RM strategy defined for H&CD, Vacuum and Diag. Systems (2016)
- Proven remote handling compatible fixations (2016)
- Manufacture blanket module casks proof of principle (2016)
- Mock-up and bench testing of remote service connection concepts (2016)
- Construction of prototype in-vessel transporters for proof of principle (2017)
- Remote handling interfaces fully tested through mock-up trials (2018)
- RMS Concept Design Review (2019)

Use of facilities

Mock-up facilities with a fully equipped remote handling system to simulate the DEMO in-vessel and ex-vessel environment will be required along with a team to operate. The JET torus assembly building could be considered or alternative facilities with large capacity and ~150T crane.

Opportunities for industrial innovation

Industrial involvement is mainly foreseen in terms of:
- Manufacturing of mock-ups and prototype attachments
- Manufacturing of mock-ups and prototype in-vessel transporters
- Manufacturing of mock-ups and prototype transfer casks
- Remote pipe connection R&D i.e. in-bore welding, brazing, mechanical connections, etc.
- Remote Maintenance Control System Development.

Opportunities for International Collaboration

None currently foreseen.

Opportunities for Training & Development of Staff

A number of opportunities for training and development of staff such as graduate engineers have been identified:
- Remote Maintenance technology (e.g. fusion power plant application, radiation/environmental tolerance, etc.)
- Engineering design and analysis
- System Engineering (Hardware / Software / Operator integration)Logistics / Maintenance Planning

WPMAT: Materials

Management:

Project leader

Description:

The objective of the Materials Project is to develop advanced materials for the DEMO operating conditions. New lines of research will be pursued, irradiation campaigns will be undertaken and a direct interaction with designers will be set up to produce a materials database. This materials database will be used to support DEMO design activities together with the specific development of materials and joints to meet specific project design requirements. It is expect to be a part of the scope of the Materials Design Data Integration activity (see below), whose aim is to provide a strong, flexible programmatic link between design progression and material development. This should facilitate technology insertion via both: (i) the rapid insertion of material technological and modelling advances into the conceptual design activity; and (ii) prioritization of design needs and challenges within the other materials project areas. The activities in this Work Package will involve:

- **Materials Design Data Integration.**
  This activity will focus on the transfer of knowledge between/within design and material communities (designers/researchers interaction) over the whole project. A DEMO Materials Handbook will be created (data infrastructure and quality requirements) to be populated over the project with data generated in the previous described work packages. Codes and Standards Developments for structural and functional materials will start in 2014, with the final deliverable by the end of 2019. Design-Data Experimental Campaigns activities will start in 2014 preparing irradiation campaigns for EUROFER, and in 2015 for Cu alloys. These campaigns will include neutron irradiation, thermo-mechanical and environmentally-assisted tests.

- **Advanced Steels.**
  This activity will focus on: the development of EUROFER as baseline structural material option by reducing the ductile to brittle transition temperature after irradiation for water-cooling applications, the development (as risk-mitigation option) of a reduced activation versions of the High Temperature steels developed within the GEN IV programme and of Oxide Dispersion Strengthened (ODS) steels. The lines of development are common to all materials: definition, fabrication at industrial level, characterisation programme – database creation (including neutron irradiation data), and welding technologies.

- **High Heat Flux Materials.**
  This activity will focus on the R&D of armour and structural materials for low and high temperature heat sinks. Also, the development of materials technologies as joints, production and mass fabrication is in the scope of this area, as well as the fabrication and testing of preliminary mock – ups. Development of W and W composites, Cu alloys and Cu composites as divertor structural material for the different cooling concept and full characterisation will be part of the R&D in Horizon 2020 as well as fabrication technologies of self-passivation alloys at industrial level.

- **Functional Materials.**
  This activity will focus the development of optical materials for control and safety and dielectric materials for diagnostic and H&CD are within the scope of this work package. The investigation and characterization of the candidate materials will be extended to representative reactor conditions. R&D work on solid breeder characterization and corrosion/tritium permeation barriers is a specific design related item and is included in WPBB.

- **Integrated Radiation Effects, Modeling and Experimental Validation.**

This activity will focus on the study of (i) phase stability of fusion material under irradiation, (ii) defects production and microstructural evolution under irradiation, (iii) radiation stability of complex microstructures, including ODS steels and interfaces, (iv) changes in mechanical and physical properties under irradiation, and (v) transmutation under high – energy neutron irradiation, helium accumulation and embrittlement. The knowledge produced within this work package will be transfer to the other areas as an input to provide guidance in the development of high performance materials over the whole project.

Deliverables and Milestones

- **Key Milestones:**

- Advanced Steels
  - a) *Baseline option: EUROFER (Down selection 2016/2017)*
    - Basic material development, trial heats & screening (2014-2015)
    - Industrial fabrication of EUROFER heats with improved rad. resistance (2015/17)
    - Irradiation campaigns (200 - 400 °C) and full database production (2017-2019)
  - b) *Risk mitigation option: high temperature FM steels, ODS steels (Down selection 2018/2019)*
    - Optimise compositions/process conditions for a number of heats of ~9Cr reduced activation TMT FM steels and ~9Cr and 12-14Cr ODS alloys. Fabricate small heats (few tens of kg) of materials (2015)
    - Characterization tests including long-term thermal aging and thermal creep studies (2015-18)
    - Additional few 100 kg (in several batches) (2015-2018)
    - Joining R&D tests (2015-18)

- High Heat Flux Materials
  - a) *Baseline option: W alloys for armour applications, and Cu-alloys for heat sink applications (Down selection 2016/2017)*
    - W alloys: lab-scale material development and HHF test (2016)
    - W alloys: Production/Industrial Development and characterization >2015
    - Cu-alloys: Procurement/evaluation/comparison/basic characterization and selection of commercially available and promising alloys (2014-2015)
    - Cu-alloys: Production /Industrial Development, including development of joining technology (2016-2017)
    - Small divertor mock-ups components testing > 2017
    - irradiation fission neutrons + PIE (2014/ 2017)
    - Basic material properties database (2020)
  - b) *Risk mitigation option: W/Cu-based composite materials (Down selection 2018/2019)*
    - selection of material concept(s), lab-scale material development of W/Cu-based composite materials, proof-of-principle (2014-2016)
    - Production /Industrial Development (2017)
    - Prototype components testing (2018)
    - Material Irradiation database/ preparation of irradiation samples (2016) irradiation fission neutrons leading concepts (2017-2018) / PIE (2018-2020)

- **Functional materials**

  - Characterization test of available candidate materials for optical and dielectric applications. Identification of new materials with improved properties for optical and dielectric applications (Low RIA and RL, Low loss tangent) (2014/2015)

  - Analysis of the data for available candidate materials for optical and dielectric applications. Improvement of materials and assessment of the effects of radiation (progressions 2016/ 2018/ 2020)

  - Assessment of the impact of radiation on material properties for control, safety and H&CD systems applications.(2014/2015).

- **Integrated Radiation Effects, Modelling and Experimental Validation**

  - Understanding of changes in mechanical and physical properties under fusion irradiation conditions. Transmutation under high – energy neutron irradiation, helium accumulation and embrittlement. (Progressions 2016/ 2018/ 2020)

  - Assessment of phase stability, defects production and microstructural evolution under fusion irradiation conditions. Radiation stability of complex microstructures, including ODS steels and interfaces. Impact on materials properties. (Progressions 2016/ 2018/ 2020)

- Materials Design Integration
  - Design Criteria, Codes and Standards Development (Progressions 2016/ 2018/ 2020)
  - Materials Handbook Development 1st draft 2015/final 2019.
  - Planning and coordination of Design-Data Experimental Campaigns each year

Use of facilities

The use of the following EU facilities is foreseen:
- Materials Test Reactors (e.g. HFR, BR2, and in the future PALLAS and Jule Horowitz)
- Ion and electron beam irradiation facilities (eg. JANNuS, Van de Graaff accelerators, etc.)
- Microstructural characterisation equipment
- Characterisation equipment for Physical and Mechanical properties
- Thermal shock facilities (JUDITH)
- H/He beam loads facilities (GLADIS)
- Plasma linear devices to expose irradiated sample (i.e., Jules-PSI - FZJ)

Additional fission reactors outside of Europe must be used (see below).

Expected Role of Industry

Industry involvement is needed from the very first steps in some areas. This collaboration should play a major role in the case of the steels, and also the case of coatings and insulators.

Opportunities for International Collaboration

The issues related to the development of structural and functional materials for a DEMO – type reactor machine are worldwide investigated. Therefore, benefits can be taken from this situation, particularly in the use of complex and costly facilities out of Europe:
- Fission reactors in US (HFIR, ATR), Japan (JOYO), China (CEFR, CARR), India (FBTR), BOR-60 (Russia), etc.

- The Materials Research Laboratory built in the International Fusion Energy Research Centre (IFERC), Rokkasho, within the ITER Broader Approach Activities. This facility is equipped with most of the technology needed for testing of structural and functional materials for fusion, besides neutron irradiated materials can be studied.

Opportunities for Training & Development of Staff

A number of opportunities for training and development of staff such as physicists, Post - Doctorates in materials sciences and mechanical engineers have been identified:

- Production of materials: advanced steels, tungsten alloys, copper alloys, composites, insulators
- Modelling of radiation effects
- Database production: physical, mechanical and microstructural characterisation of all materials developed within this Programme.

WPENS: Early Neutron Source Definition and Design

Management:

Project leader

Description:

A minimum of 14 MeV neutron data should be provided to the Early DEMO programme by 2026 and, as indicated in the Roadmap and in the MAG report, this requires an accelerator based 14 MeV neutron source capable of irradiating a sufficient mission volume of critical materials to a level of 30dpa (to establish critical properties. This Early Neutron Source facility has not been identified yet, but three different proposals have been analyzed by the MAG. These, as well as other proposals will be reviewed early in Horizon 2020.

The foreseeable activities required to deliver a feasible, integrated concept design of the ENS includes: (i) A detailed technical and schedule risk assessment of the competing proposals should be carried out in 2014 to select the most promising option and (ii) conduct the required design and R&D (benefitting to the largest extent possible from the R&D outcome of the design and R&D outcome of the IFMIF EVEDA effort). This should include a study of the minimum mission capability including irradiation volume, factoring in the interactions with the outcomes of the isotopically-tailored fission irradiation campaigns.

Deliverables and milestones

- **Key deliverables:**
  - Evaluation report of the expert Panel assessing viable options, including rational for recommended selection.
  - Concept Design Description of ENS
  - Design substantiation to include:
    - CAD models, engineering analysis reports, etc.
    - R&D of the key facility elements;
    - Manufacturing feasibility studies
    - Risk analysis reports: RAMI analysis, Safety analysis, etc.
- **Key Milestones**
  - Technical review on accelerator and target (2014)
  - Concept design selection (2015)
  - Selection of site (2016)

- Design and qualification R&D (2017)
- Start of construction (2017)
- Commissioning and start of operation (2022)

WPSAE: Safety and Environment

Management:

Project leader

Description:

The objectives of the Safety and Environment Project are to ensure that the evolving DEMO conceptual design will fully respect the Fusion Power Safety Objectives and to perform required R&D and safety analyses in order to allow the demonstration of safety and environment performance for licensing purposes. An important aspect is the determination of the safety approach and safety design criteria, leading to a set of safety requirements to be documented in a Safety Requirements Document. This is one key deliverable; another is the Preliminary Safety Report which will present comprehensive safety analyses and justify that the conceptual design is compliant with the safety objectives and requirements. In addition to the specific deliverables within this project, a liaison will be maintained with every other Project within the Work Plan. The foreseeable activities within the Safety Project are expanded below:

- **Design and licensing regulatory requirements.**
  This activity will focus on the review of possible licensing processes and the definition of the safety approach to be adopted for the concept design activities, with priority given to the approach chosen for ITER with the vacuum vessel being the primary safety boundary.

- ***Integrated Safety Analysis/ Source terms/ Models and Codes.***
  This activity will focus on the R&D to improve quantification of DEMO source terms (design specific) and the development and validation of the required analysis tools. Safety analysis will be carried out (including bounding analysis sequences and analysis of beyond design basis) and the results documented including comprehensive identification of hazards, identification of safety functions and the corresponding safety credit to be given to systems, structures and components. This will include transient and accident analysis, including demonstration of ultimate safety margin in arbitrary beyond-design basis scenarios, and the assessment of environmental releases in normal operation and the provisions needed to minimize these.

- **Radioactive waste management.**
  This activity will focus on the definition of clearance limits; required infrastructure and requirements to make recycling a viable option. Following the feasibility assessment of waste recycling options, activities will focus on the development and demonstration of technologies for large-scale recycling and efficient detritiation systems for solid waste treatment.

Deliverables

- Definition of DEMO safety approach
  - Define safety approach and determine impact of design choices (Dec. 2014)
  - Complete Safety Requirements Document (Dec. 2016)
  - Draft/final Preliminary Safety Report (June 2019/ Dec. 2020)
- Integrated safety analyses and demonstration of safety margins

  - Complete FFMEA and accident sequences (Dec. 2015)
  - Complete safety analyses based on main design choices (2019)
  - Complete quantitative source term determination (2018)
- Radioactive waste management
  - Establish fusion-specific clearance indices (2015)
  - Review feasibility of waste recycling (2015)
  - Determine technologies (PoP) for waste recycling (2017)
  - Demonstrate detritiation techniques for solid waste treatment (2018)

Use of facilities

A number of facilities will be used for the experimental aspects of the programme. These relate mainly to the validation of codes used for safety analyses, and the demonstration of detritiation technologies both for limiting tritium releases in gaseous and liquid forms and for the treatment of tritiated solid radioactive waste.

A strong link is expected with ITER safety and with JET, especially in areas of neutronics, activation and tritium.

Opportunities for industrial innovation

There are important roles for industry in the execution of this programme, in particular in radioactive waste management. Industrial input is needed to determine criteria for clearance and recycling of radioactive material and for the development of viable process for this recycling.

Opportunities for International Collaboration

Collaboration with other countries that have fusion safety programmes could bring added benefits, particularly where R&D results can be shared to establish a wider database of results, for example for the validation of safety analysis codes.

Opportunities for Training & Development of Staff

The training of nuclear safety specialists with a strong understanding of the specifics of fusion safety should be one outcome of this programme. This could be done by the involvement of graduate science & engineering students in some parts of the programme.

2.4 Socio Economic Studies

WPSES: Socio Economic Studies

Management:

Project leader

Description:

While the technical aspects of DEMO are approached by other projects, the objective of Socio-Economic Studies Project is to assess the social and economic viability of fusion energy. Research in fusion economics will be carried out to understand the internal and external costs of fusion energy. The possible role of fusion power on the future energy markets and its competitiveness under different conditions will be analyzed with the employment of the global energy system's model generators such as EFDA TIMES and TIAM. The level and the conditions of the social acceptance of fusion energy will be studied periodically, including the public and stakeholders' reasoning on the power plant safety. Understanding these elements is crucial for fusion technologies successful integration into the global and European electricity system, especially in the situation in which the nuclear energy image suffers from the Fukushima accident's consequences and in the consideration of the fact that fusion energy market chances depend strongly on fusion power plant costs. The foreseeable activities within the Socio-Economic Studies Project are expanded below:

- **Economic aspects.**

  This activity will deliver updated fusion energy cost assessments relying on the outputs of other Projects dealing with the physics and technology of DEMO and FPPs and on a European System Code. It will also assess the external costs of fusion energy by means of the Life Cycle Analysis of DEMO. The internal and external costs of fusion energy will be implemented to EFDA TIMES, together with the costs of other energy technologies in the global system, which will make it possible to better understand the role of fusion in various future energy scenarios. The Fusion Energy module in the EFDA TIMES will be kept updated and made available to other TIMES models and to other modelling communities.

  Systems approach studies will be carried out regularly to explore all options to minimize the cost of a fusion power plant and to identify the innovations needed to make the transitions from DEMO to a commercial fusion plant.

- **Social aspects.**

  Social support for fusion in Europe can no longer be taken for granted after the Fukushima accident, which tainted the nuclear energy image. In the context of DEMO design and siting debate; fusion safety aspects (addressed in WPSAE) will gain ever more attention of the public and stakeholders. Therefore, apart from research and design work addressing these topics, a dialog with the European civil society on the environmental, socio-economic and safety aspects of fusion energy is a necessary prerequisite for successful DEMO implementation and its social recognition. This activity will periodically monitor the level of social acceptance of fusion energy and identify the critical factors on which the social support for fusion depends.

- **Outreach activities**

  Outreach activities will foster fusion recognition in the context of the European energy policy debate and fusion understanding among the European civil society. They will be fed by the results of the socio-economic research conducted within this Project and by other Projects' outputs. Especially, the intensity and quality of fusion community participation in the global scientific energy & environmental debate (mainly, with EFDA TIMES scenarios), and the improvement of fusion energy presentation in mass media, will be faced.

Deliverables

- Assessment of fusion energy cost basing on (alternative) DEMO design features as delivered by projects dealing with physics and technology of the fusion power plant, and on a European System Code
- Assessment of fusion power socio economic and environmental impacts (e.g. in terms of GHG emission reduction) and external (environmental and non-environmental) costs, based on DEMO characteristics
- Implementing of the updated fusion cost module to EFDA TIMES and to other global models
- Sets of scenarios showing the contribution of fusion to the global electricity generation in the long term and analyzing fusion energy competitiveness under different conditions
- Periodical assessment of the level and critical requirements of fusion energy social acceptance in Europe
- Outreach activities, founded on the research results achieved within this and other Projects, fostering fusion recognition in the context of energy policy debate and fusion understanding among the European civil society

Opportunities for industrial innovation

Not applicable.

Opportunities for International Collaboration

Collaboration with energy system modelling communities on the world would be desirable (e.g. IPCC, WETO, ETSAP, TIAM)

2.5 Public Information

WPPI: Public Information activities

Management:

Programme Unit

Deliverables

- New Fusion Expo
- Public Information Network
- External communication (web presence, the newsletter, brochures, video clips)

3. Management structure and procedures

3.1 Governance

[This part will be written following the WG report]

3.1.1 General Assembly

3.1.2 Bureau

3.1.3 Coordinator

3.1.4 Scientific and Technical Advisory Committee

3.1.5 Programme Leader

3.2 Implementation

This section describes the different approaches for the implementation of the roadmap work packages.

3.2.1 Campaign oriented implementation

Work on tokamak and stellarator devices with the relevant capabilities to cover a significant part of the programmatic headlines (see Annex 1 of the Roadmap) will be exploited through a Campaign oriented approach. Each Annual Work Programme shall indicate the headlines that will be addressed and the number of experimental days that need to be devoted to the common programme.

Task Forces and Task Force Leader role.

"Task Forces" means groups established to execute tasks linked by a common S/T objective identified in the Consortium Annual Work Programme. The Leadership of each Task Force is appointed by the General Assembly upon proposal of the Programme Leader and is responsible to the Programme Leader for the scientific and technical coordination of the corresponding Task Force. The Terms of Reference for a Task Force Leader are given in Annexes.

Implementation of joint experiments and multi machine comparison.

Joint experiments among different devices will require a special coordination among different Task Forces. The following procedure will be used:

- The (annual) programme is set-up through independent General Planning Meetings (JET / MSTs) with the participation of both JET and MST Task Force Leaders in both cases
- A specific session during the General Planning Meetings is devoted “Joint/multi machine” experiments.
- The amount of time on each machine is decided jointly by the Task Force Leaders. The implementation schedule is decided by each machine Task Force in consultation with the others.
- The Scientific Coordinator and the experimental teams running the experiment at one device are invited to play a strong role also for the experiment at the other device(s). The same Scientific Coordinator will be selected preferentially for experiments in different devices.

Campaign work in support of DEMO projects.

Activities in support of the DEMO related project can be included in the Campaign work foreseen in the Work Programme under request of the relevant Project Leader. The selection, definition, execution and analysis of the corresponding experiments will be under the responsibility of the relevant Task Force Leaders.

3.2.2 Project implementation

Design work, specific R&D and realization of components and specific S/T work on facilities will be implemented in the form of Projects. For each Project, a Project Leader is appointed for the technical responsibility of the activities.

Project Leader role.

The Terms of Reference for a Project Leader are listed in the Annexes

3.2.3 Tasks

Tasks can be established with member laboratories to execute specific support and S/T work as part of the DEMO integration activities and the Infrastructure Support Activities. Task will be managed directly by the Programme Unit.

3.2.4 Basic research

In addition to the mission oriented work, a programme aimed at promoting basic understanding and "curiosity driven" research will be implemented. Basic research involving devices funded under the common programme will have to be incorporated into the respective Work Package. Although the basic research programme should be curiosity driven and be judged for its excellence, only topics with relevance for fusion research will be eligible for joint programme funding. With this respect, the Keep-in-Touch activities to the complementary approach of the inertial fusion energy (IFE) are of significance and will be eligible with a maximum percentage of xx%.

To ensure excellence of the basic research programme, an evaluation system will be set up that is similar to the well-known ERC procedure. For the activities to be carried out beyond 2014, a Call for Proposals will be issued each year for multi-annual projects (preferably 3 years). The budget of the annual call for proposals should not vary too much between the years. The funding rate for proposals in the area of basic research will be 50%, for personnel and 40% for hardware.

After a screening of the proposals by the Programme Unit on the basis of the eligibility criteria (submission within the deadline, completeness of the proposal, etc) the incoming proposals will be evaluated by a panel consisting of excellent scientists. In the refereeing process the panel may also invite additional experts as referees, including experts from outside Europe. For activities to be carried out beyond 2014 the evaluation panel will be set up by the General Assembly.

The evaluation procedure shall guarantee excellence of basic research. Evaluation criteria will be, e.g.

a) Curriculum Vitae and Track Record of the Principal Investigator and participants in the project, and their commitment to the proposal,

b) Importance for Fusion, feasibility and the capability of addressing important challenges,
c) Scientific excellence, innovation potential - going beyond the state of the art,
d) Adequateness of the resources to meet the proposed goals,
e) Collaborative Aspects. (collaborative projects of several consortium members are encouraged)

The outcome of the evaluation process will be proposals

- Rated A: to be funded within available funds,
- Rated B: not to be funded under the present Call "rejected", but submission in subsequent Calls allowed.
- Rated C: Rejected, no resubmission possible.

For proposals rated B or C, a reason for the decisions shall be given, for proposals rated B suggestions for possible improvements will also be provided.

For activities to be carried out beyond 2014, principal Investigators are required to send scientific reports to the programme unit (mid-term, if required, and at the end of the project). Specific outputs from the project should be included (e.g. publications). The scientific reports may be subject to review by a pertinent scientific review panel. These reports could be used in the evaluation of subsequent applications for the continuation or extension of the project.

The full evaluation procedure will not be in place in time for the implementation of the 2014 programme, so a step-wise implementation is foreseen, as a special provision to deal with the transitional period:

- For activities to be carried out in 2014, a Call for Proposals will be sent out by the EFDA Leader, and the proposals will be evaluated by the EFDA STAC.
- Positively evaluated, projects will be funded for 2014 and the duration of the projects is limited to one year. Only personnel costs will be supported in 2014, with a funding rate of 50%. A reasonable distribution of resources among the various labs should be aimed at.

For activities to be carried out in 2014, a single final report on the outcome of the project, outlining the main results should be submitted at the end of the project. This report could be used in the evaluation of subsequent applications for the continuation or extension of the project.

3.2.5 Education and post doctoral fellowships

[This part will be written following the WG report]

3.2.6 Industrial involvement

[To be written afer discussion with the FIIF]

3.3 Implementation procedures

3.3.1 Task Force Leader and Project Leader selection

The Task Force Leaders and Project Leaders are proposed by the Programme Leader and appointed by the General Assembly. A Call for the nomination of Project Leaders and Task Force Leaders is issued by the Programme Leader to all the members and, with the previous agreement of the General Assembly, to International Collaborators. The Call will indicate the criteria for the selection, the Terms of Reference for the Project Leader/Task Force Leader, the scope and deliverables of the Project and the duration of the appointment. For each appointment, an interview panel, adapted to the post in question, will be formed. The panel will assist the Programme Leader in the evaluation the candidates based on the criteria for selection.

3.3.2 General Planning Meeting/Technical Planning Meeting

In connection with the launch of a Call for Participation the Programme Unit will organize an information meeting with the Members to explain the activities covered by the Call and to receive feedback. Whenever applicable the relevant Task Force Leaders and Project Leaders will attend the meeting and lead the discussion.

3.3.3 Call for Participation

Calls for participation will be launched by the Programme Leader for the implementation of the Work Packages described in Section 2. The Call shall include:

- The scope of the activity to be implemented;
- The deliverables;
- The criteria for the selection of the participation;
- The resources involved in the activity.

The replies to the Call will be evaluated by the Task Force Leader/Project Leader and the Programme Unit and a proposal for the distribution of resources elaborated and submitted by the Programme Leader to the General Assembly.

3.3.4 Monitoring of the activities

Monitoring of the activities will be done in each Work Package on a regular basis. For each Project (or group of Projects, if appropriate) the Programme Leader will form a Project Board with one representative of each of the Member participating in the Project. The Project Boards will decide on any issue arising with availability of resources, change of schedule and technical decisions that do not impact on other Projects. The Project Boards will be chaired by the Programme Leader.

3.3.5 Reporting

Reports on the execution of the activities will have to be submitted by the member laboratory in connection with the achievement of a deliverable. Reports will be evaluated by the TFL/PL and the Programme Unit and approved by the Programme Leader for the release of the corresponding payment.

3.3.6 Call for Proposal (basic research)

[This part will be written following the WG report]

3.4 Programme Unit

The Programme Unit supports the Programme Leader in the implementation of the Programme of the Consortium and ensures that common standards based on good project management practice are followed in all the projects for the selection of the participation, the management of the activities, the documentation and the evaluation of the results.

The structure and size of the Programme Unit is decided by the General Assembly under proposal of the Programme Leader. The members of the Programme Unit are selected by the Programme Leader, advertising the positions among the members of the Consortium and the European Commission.

The role and responsibilities of the Programme Unit are described below.

NOTE: THE ROLE OF THE ADMINISTRATION NEEDS TO BE DEFINED IN CONNECTION WITH THE ROLE OF THE COORDINATOR

3.4.1 Implementation

3.4.1.1 Information meetings (GPM/TPM)

In advance of the launch of a Call for Participation, the Programme Unit organizes a General Planning Meeting (for the Campaign oriented implementation) or a Technical Planning Meeting (for the Projects) ensuring adequate participation of the Members to explain the activities covered by the Call and to receive feedback. The Programme Unit supports the Task Force Leader/Project Leader in incorporating the feedback of the discussion in the Call.

3.4.1.2 Preparation of the Calls for Participation and evaluation of the reply

The Programme Unit Responsible Officer (RO) prepares the documentation for the Call for Participation on the basis of the timeline of the experiments or the PMP. The documentation for the Call is reviewed and endorsed by the Project Leader/Task Force Leader and approved by the Programme Leader.

The Programme Unit RO supports the TFL/PL in the review process and ensures that any necessary additional information is supplied by the Members.

3.4.1.3 Preparation of the Task Agreement

The Programme Unit Responsible Officer (RO) prepares the Task Agreement in which the activity to be executed by each Member is described. The Task Agreement is reviewed by the Project Leader / TF Leader and approved by the Programme Leader.

3.4.1.4 Evaluation of the work performed by the members

The Programme Unit RO collects and prepares the documentation for the evaluation of the work performed by the members and for the endorsement of the deliverables by the PL / TFL, and for the final approval by the Programme Leader.

3.4.1.5 Technical management of JOC

The Programme Leader will manage the execution of the JET Operation Contract between the European Commission and the United Kingdom Atomic Energy Authority ensuring its coherency with the priorities of the activities to be implemented on JET.

3.4.1.6 Support to Experimental Campaigns

The Programme Unit shall manage and optimise the experimental programme, optimise the use of scarce resources and provide support to the Task Force Leaders and the member staff for the participation in Campaign.

3.4.2 Integration

3.4.2.1 Coordination of tokamak operations

The Programme Unit shall ensure appropriate coordination among the tokamak devices operated as common facilities for an effective implementation of the programmatic objectives. This involves monitoring and discussing the operation schedule of the devices run through the Campaign oriented approach in order to:

- Facilitate the participation of scientists
- Execute joint experiments in the correct sequence

The Programme Unit shall ensure the integration of the Projects related with the operation of the devices and the diagnostic enhancements and in particular an adequate planning to allow their timely implementation in connection with the needs of the experimental programme.

3.4.2.2 DEMO design and physics integration

The Programme Unit shall ensure the integration of all the projects related with the DEMO Conceptual Design Activity and in particular:

- Identify and manage interfaces among project work packages into a plant system
- Ensure effective communication among projects.
- Facilitate a system-level decision and solution selection process
- Coordinate requirement analysis, and system modelling and plant-level analysis.
- Ensure that the physics R&D needed in order to consolidate the DEMO Physics basis is pursued in the relevant Work Packages.

3.4.3 Programme planning (maintaining level-1 schedule)

The Programme Unit shall ensure that the level-1 schedule of the Roadmap is maintained.

The Programme Unit should produce and update the Project Schedule on the basis of the information of the projects, monitor the progress and determine the corrective actions.

3.4.4 Project control

3.4.4.1 Budget control

The Programme Unit shall ensure that the overall budget is in line with the commitment and expenditure profile and in case of significant changes propose to the General Assembly adequate corrective measures.

3.4.4.2 Progress monitoring and performance metrics

The Programme Unit shall propose and implement a set of (as much as possible) common criteria for monitoring the performance of each Work Package and regularly update the report on the evolution of the implementation.

3.4.4.3 Review

The Programme Unit shall ensure that each project is regularly monitored and that review meetings are held as appropriate.

3.4.4.4 Reporting

The Programme Unit shall ensure that the quality of the reporting from each Member is adequate and that uniform standards are applied.

The Programme Unit shall prepare in liaison with the TFLs and PLs the annual report on the execution of the programme.

3.4.4.5 Quality Assurance

The Programme Unit shall ensure that quality control and quality assurance practice is applied in each project.

4. Resources

The following Table details the amount of resources foreseen in each Work Package for the period 2014-2018. The financial resources of the Commission are in line with what presented in the Roadmap.

The assumptions behind the resource estimate are similar to those employed for the Roadmap. The cost of the professional is estimated in 100k€ for the members and 150k€ for industry. The share of contribution of the Consortium is 40% for hardware costs (except for JET), 50% for all the manpower costs[7], and 100% for JET hardware, TFL/PL work and for support tasks[8]. A Joint Fund as proposed in the roadmap is assumed here[9].

The breakdown of resources among the members of the Consortium will be presented following the Calls for Participation in October.

Work Package	Manpower (ppy)	Resources (M€)	Of which hardware (M€)	EC resources (M€)
JET operation Contract (p.m.)		*280.000*		*210.000*
JET Campaigns	489	48.880	0	31.730
Analysis of JET ITER-like wall plasma facing components	66	7.560	1.000	4.400
Technology exploitation of DT operations	60	6.560	0.540	4.050
JET enhancements	48	6.250	1.500	4.070
Medium size tokamak campaigns[10]	260	103.500	75.000	73.000
Preparation of exploitation of Medium Size Tokamaks	105	15.500	5.000	7.500
Preparation of efficient PFC exploitation of ITER and DEMO	109	17.400	6.500	8.300
Assessment of alternative divertor geometries and liquid metals for DEMO	20.75	4.075	2.000	1.875
Definition and design of the Divertor Tokamak Test facility[11]	62.75	126.275	120.000	51.275
Preparation of the JT-60SA exploitation	40	4.100	0	2.200
Preparation and exploitation of W7X	107.5	70.750	60.000	18.550
Stellarator optimization	21.25	2.125	0	1.125
Integrated Tokamak Modelling Code	105	10.500	0	5.500
Infrastructure support activities for modelling and high-performance computing	70	37.000	30.000	19.000
Plant level system engineering, design integration and physics integration	145	15.300	0	8.190
Magnet system	34	7.100	3.500	3.350
Containment structures	16	1.800	0	1.050

---

[7] Cost of personnel for personnel under Campaigns will be determined following the decision on the Joint Fund.

[8] Education share to be presented following discussion with Fusenet

[9] This will be updated following the discussion in the Working Group

[10] HW include use of tokamak and linear PWI facilities

[11] Hardware includes also manpower for the project

Breeding Blanket	241	70.950	46.650	30.960
Divertor	42	13.400	9.000	5.950
Heating and Current Drive systems	80	16.800	8.600	7.690
Tritium Fuelling and Vacuum Systems	24	3.950	1.350	1.990
Diagnostic and control	25	4.500	2.000	2.050
Remote Maintenance system	94	19.600	10.000	8.950
Balance of Plant	14	3.600	2.000	1.750
Materials	339	85.500	48.500	39.460
Early Neutron Source definition and design	112	81.200	70.000	33.600
Safety	52	10.200	4.800	4.770
Socio Economic studies	34	3.550	0.150	0.740
Public Information activities		1.000		1.000
Basic research		70.000		35.000
Education		TBD		45.000
Training	200	75.000	0	35.000
Administration + mobility	250	49.000	0	49.000
TOTAL (without JOC)		**992.925**		**547,335**
TOTAL		***1.272.925***		***757.335***

5. Reviews and decision points

The programme proposed in this Work Plan is based on a few assumptions that need to be consolidated at the beginning of Horizon 2020.

The decisions with the largest impact on the proposed Horizon 2020 programme are:

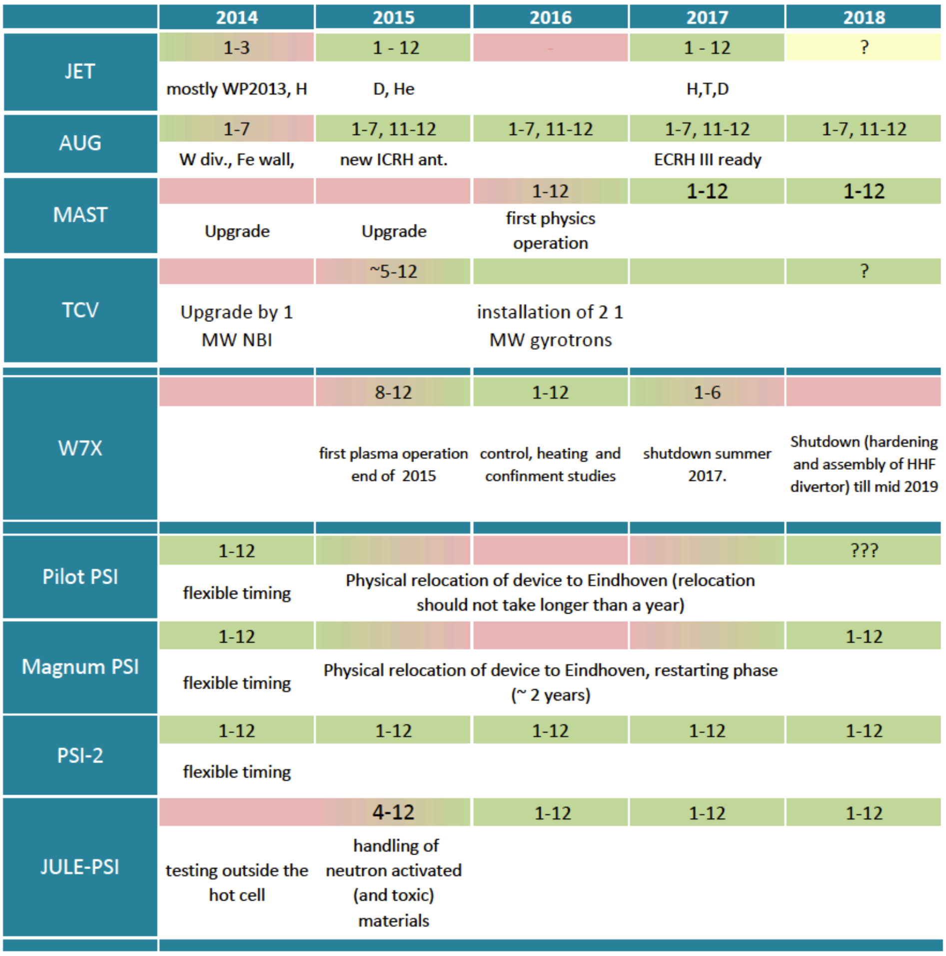
- The decision on the internationalisation of JET. The elements for this decision are expected to come by the end of FP7;
- The decision to extend and possibly enlarge the scope of Broader Approach activities to be undertaken with Japan (which may in turn include the items below);
- The decision on the implementation of the programme for Mission 2; and
- The decision on the Early Neutron Source.

A review should be made early in Horizon 2020 (say by 2015) when the elements to take decisions on the above points will be available.

Annex 1: Traceability matrix between headlines and implementing work packages

		Implementing Work Packages																												
Missions & Headlines		WPJET1	WPJET2	WPJET3	WPJET4	WPMST1	WPMST2	WPPFC1	WPSA1	WPCD1	WPISA	WPDDT1	WPDDT2	WPDIV	WPMAT	WPENS	WPBB	WPPMI	WPMAG	WPCS	WPHCD	WPTFV	WPBOP	WPDC	WPRM	WPSAE	WPSES	WPS1	WPS2	WPPI
1. Plasma regimes of operation	1.1 Increase the margin to achieve high fusion gain on ITER	🟩				🟩	🟩		🟩	🟩	🟩																			🟩
	1.2 Operation with reduced or suppressed Edge Localized Modes	🟩			🟩	🟩			🟩	🟩	🟩																			🟩
	1.3 Avoidance and mitigation of disruption and runaway electrons	🟩				🟩			🟩	🟩	🟩																			🟩
	1.4 Integration of MHD control into plasma scenarios	🟩			🟩	🟩	🟩		🟩	🟩	🟩																			🟩
	1.5 Control core contamination and dilution from W PFCs	🟩			🟩	🟩	🟩		🟩	🟩	🟩																			🟩
	1.6 Determine optimum particle throughput for reactor scenarios	🟩			🟩	🟩		🟩	🟩	🟩	🟩																			🟩
	1.7 Optimise fast ion confinement and current drive	🟩			🟩	🟩	🟩		🟩		🟩																			🟩
	1.8 Develop integrated scenarios with controllers	🟩	🟩	🟩		🟩	🟩		🟩	🟩	🟩																			🟩
	1.9 Qualification of Advanced Tokamak regimes of operation	🟩			🟩	🟩			🟩	🟩	🟩																			🟩
2. Heat-exhaust systems	2.1 Detachment control for the ITER and DEMO baseline strategy	🟩				🟩	🟩							🟩																🟩
	2.2 Prepare efficient PFC operation for ITER and DEMO	🟩	🟩	🟩		🟩		🟩						🟩																🟩
	2.3 Optimise predictive models for ITER and DEMO divertor/SOL					🟩	🟩							🟩																🟩
	2.4 Alternative power exhaust solutions for DEMO					🟩		🟩				🟩	🟩	🟩																🟩
3. Development of neutron resistant materials	3.1 Development and characterisation of advanced steels														🟩															🟩
	3.2 Development and characterisation of high heat flux materials							🟩						🟩	🟩															🟩
	3.3 Development and characterisation of functional materials														🟩															🟩
	3.4 Materials modelling and experimental validation													🟩	🟩															🟩
	3.5 Materials design data integration													🟩	🟩															🟩
	3.6 Early neutron source definition, design and construction														🟩	🟩														🟩
4. Tritium self sufficiency	4.1 Design and R&D of HCLL/HCPB blanket concepts			🟩													🟩													🟩
	4.2 Design and R&D of WCLL blanket concepts																🟩													🟩
	4.3 Design and R&D of DCLL blanket concepts																🟩													🟩
5. Intrinsic safety of fusion	5.1 Definition of DEMO safety approach licensing regulatory requirements																									🟩				🟩
	5.2 Integrated safety analyses & demonstration of safety margins		🟩	🟩																						🟩				🟩
	5.3 Radioactive waste management			🟩																						🟩				🟩
6. Integrated DEMO design and system development	6.1 Plant level system engineering & design integration																	🟩												🟩
	6.2 Magnet system																		🟩											🟩
	6.3 Containment structures																			🟩										🟩
	6.4 Divertor													🟩																🟩
	6.5 Heating & Current Drive Systems			🟩																	🟩									🟩
	6.6 Tritium, fuelling vacuum systems			🟩																		🟩								🟩
	6.7 Heat transfer, balance of plant & site systems																						🟩							🟩
	6.8 Diagnostics and control systems		🟩	🟩																				🟩						🟩
	6.9 Remote maintenance																								🟩					🟩
7. Competitive cost of electricity	7.1 Minimisation of reactor capital and operation costs																										🟩			🟩
	7.2 Advancements for H&CD systems																				🟩									🟩
	7.3 Development of high temperature superconductors																													🟩
	7.4 Advanced divertor heat removal technologies													🟩																🟩
	7.5 Very advanced breeding blanket concepts																🟩													🟩
8. Stellarator	8.1 Qualification of Helias optimised stellarator operation																											🟩		🟩
	8.2 Theory development and modelling / stellarator optimisation																												🟩	🟩

Annex 2: Availability of the devices to be exploited through the campaign-oriented approach and of the linear PWI devices[12]



	2014	2015	2016	2017	2018
JET	1-3	1 - 12	-	1 - 12	?
	mostly WP2013, H	D, He		H,T,D	
AUG	1-7	1-7, 11-12	1-7, 11-12	1-7, 11-12	1-7, 11-12
	W div., Fe wall,	new ICRH ant.		ECRH III ready	
MAST			1-12	1-12	1-12
	Upgrade	Upgrade	first physics operation		
TCV		~5-12			?
	Upgrade by 1 MW NBI		installation of 2 1 MW gyrotrons		
W7X		8-12	1-12	1-6	
		first plasma operation end of 2015	control, heating and confinment studies	shutdown summer 2017.	Shutdown (hardening and assembly of HHF divertor) till mid 2019
Pilot PSI	1-12				???
	flexible timing	Physical relocation of device to Eindhoven (relocation should not take longer than a year)			
Magnum PSI	1-12				1-12
	flexible timing	Physical relocation of device to Eindhoven, restarting phase (~ 2 years)			
PSI-2	1-12	1-12	1-12	1-12	1-12
	flexible timing				
JULE-PSI		4-12	1-12	1-12	1-12
	testing outside the hot cell	handling of neutron activated (and toxic) materials			

---

[12] In addition the tokamaks in the International Collaborators listed in the Annex 1 of the Roadmap will be exploited within the International Tokamak Physics Activity. Mobility will be used to support the participation of European scientists. Should other tokamaks become available, their use under the Campaign oriented approach will be assessed in a way similar to what done during the 2008 Facility Review and, in case of a positive assessment, included within this Work Package.

Annex 3. ToR of Task Force Leaders

With the other TFLs, relevant PLs and the Programme Unit, create a programme and team that address the highest priority issues for the creation or development of the tools and capabilities needed to ensure rapid exploitation of ITER on the one hand and credible plasma designs for DEMO on the other. Use the main EU facilities and theory and modelling capabilities to achieve this. This programme should be in line with the programmatic headlines of the Work Plan. The TFL should:

- In collaboration with the Programme Unit, propose scientific priorities (Headlines) for the Work Programme.
- Liaise actively with related activities across all three elements of the programme, JET, ITER Physics and Power Plant Physics and Technology.
- Stimulate proposals for specific experiments to be carried as part of the Work Programme.
- Stimulate proposals for theory and modelling activities and projects to complement and guide/confront the experiments.
- Organise peer review of these proposals via the Task Forces.
- Recommend the experiments to be incorporated in the experimental schedule as well as of the level of necessary contingency.
- Propose combined experiment, theory and modelling work to exploit the output of the experiments to the Roadmap objectives.
- In response to Calls for Participation in the Work Programme, propose Scientific Coordinators for the individual experiments and tasks defined in the Call. Identify areas where the response to the Call is insufficient for the programme's needs and where the response is in excess of these needs.
- Co-ordinate the preparation, execution and analysis of the experiments and tasks.
- Work with the scientific co-ordinators to develop detailed experimental proposals and present them for approval at the Programme Execution Committee (PEC) of the facility.
- Report on the experimental results to the PEC.
- Organise peer review of experimental results and analysis, both via the task forces and via Science Meetings.
- Promote, review and endorse publications resulting from the analysis of experiments and the related theory and modelling.
- Prepare and monitor a plan for publications and conference presence to ensure dissemination of all key aspects of the programme.
- With the rest of the leadership team, maintain a task force web site and wiki pages.
- Report the results and analysis to the broader scientific community, as appropriate.

Provide a summary report of the scientific highlights achieved as input to the annual monitoring report.

Work, under request of the Programme Leader, for more general support to the programme, for instance in the definition of longer-term priorities.

Annex 4. ToR of the Project Leader

The Project Leader (PL) should develop a project to address the needs of the Work Plan as effectively as possible. This will involve identifying the challenges and stimulating creativity and innovation in the project team to meet them, where necessary pursuing more than one path. The PL will need to attract and motivate a capable team of scientists and engineers.

The PL has the overall responsibility for the successful planning, execution, monitoring, control and closure of the project in accordance to the objectives specified in the Work Programme/Workplan.

The PL has the full responsibility of the overall management of the project, and shall design and apply an appropriate project management framework for the project using the tools made available by the Programme Unit (e.g. documentation management and planning). The PL is the leader of all activities performed within the project scope, defined at the outset of the project and approved by the Project Board (PB).

The PL writes, executes and monitors the Project Management Plan (PMP) where all the technical, financial and management specifications are described, according to the PMP description (Annex 5).

The PL has to develop an appropriate documentation and reporting system, usually using the tools made available by the Programme Unit, able to retrieve information whenever required. Such a system has to be coordinated among the various projects by the Programm Unit.

The PL is assisted in his task by a member of the Programme Unit, who is in particular in charge of the duties concerning the project, and helps in the overall management of the project.

The PL is assisted in his task by a Project Sponsor, in particular when resources issues arise. The Project Sponsor (typically from the home lab of the PL) will ensure that the PL is provided with adequate support in order to fulfil his/her duties (e.g. back office work such as planning, organisation and general support)

The PL is responsible for the preparation and execution of the industrial contracts, in accordance with the Consortium rules.

The PL shall conduct regular project evaluations to assess how well the project is being managed, prepare a ‘Lesson Learned’ report and implement any corrective actions/recommendations as required

Any decisions which affect the overall objectives or financial boundaries of the project need to be endorsed by the Project Board.

Annex 5. Project Management Plan description

The project management plan (PMP) is the reference document for the management of the project.
It is the responsibility of the project leader to write this document, to up-date it, and to use it as a management tool with the project team and as a reporting tool to the Project Board.

The general requirements for such a document are as follows:

- It should be fully in line with the Consortium Work-plan and Work-programme.
- The PMP should be written at the outset of any project
- The PMP must be approved by all the stakeholders who should sign the PMP
- It should be endorsed by the Project Board
- It will be revised at least each year and as needed, at the request of the Project Leader or the Programme Leader
- The PMP will be used as a basis to write the Task Agreements placed with the members.
- The PMP must be an official document referenced and archived via the project documentation management system.

The mandatory key features of the PMP are listed below. This list is not exhaustive and can be extended at the project team's discretion:

- Scope of the project
- Technical description of the project
- Technical objectives
- Organisation and management scheme (including the roles and responsibilities of all the members involved)
- Work breakdown
- List and description of the milestones and deliverables
- Time plan
- Cost breakdown
- Resource plan (manpower and procurement)
- Procurement policy
- Boundaries and interfaces
- Risk management
- Change control