Chapter IV: Coordinated Activities on Power Plant Physics and Technologies

IV.1 PROGRAMME FOCUS AND STRUCTURE

Following the establishment of a PPPT Department under EFDA, the approval of the Work Plan (see EFDA (10) 46/5.3.1) and the launch of the 2011 activities (see EFDA (11) 47/4.1.1), a preliminary timetable for the conceptual design activity for DEMO has been developed as illustrated in Fig. iv1.

The timetable foresees that a pre-conceptual design phase (estimated to last about 3 years from 2011 to 2013) will be required to select the DEMO options that can ensure the fastest realization of fusion. This choice will determine the priorities in physics and technology R&D to be pursued during the conceptual design phase of ~5 years (2014-2018). The engineering design activity is assumed to start in 2019, i.e. at the end of the ITER construction, and it will be able to make the best use of the engineers trained during the ITER and W7X construction.

The activities that were included in the EFDA PPPT Work Programme 2011 and which are now under implementation, are primarily aimed at revisiting the rationale and technology development assumptions that have led to the selection of some design choices in the past (e.g., in the frame of the Power Plant Study (see EFDA(05)-27/4.10 revision 1)) and at establishing reliable design tools and predictive modelling capabilities for the implementation of the design activities to be carried out later. At the time of the preparation of this document these activities are still in progress and findings and recommendations are expected to be available by the beginning of 2012. These findings will be taken into account in the context of the implementation of the 2012 Work Programme.

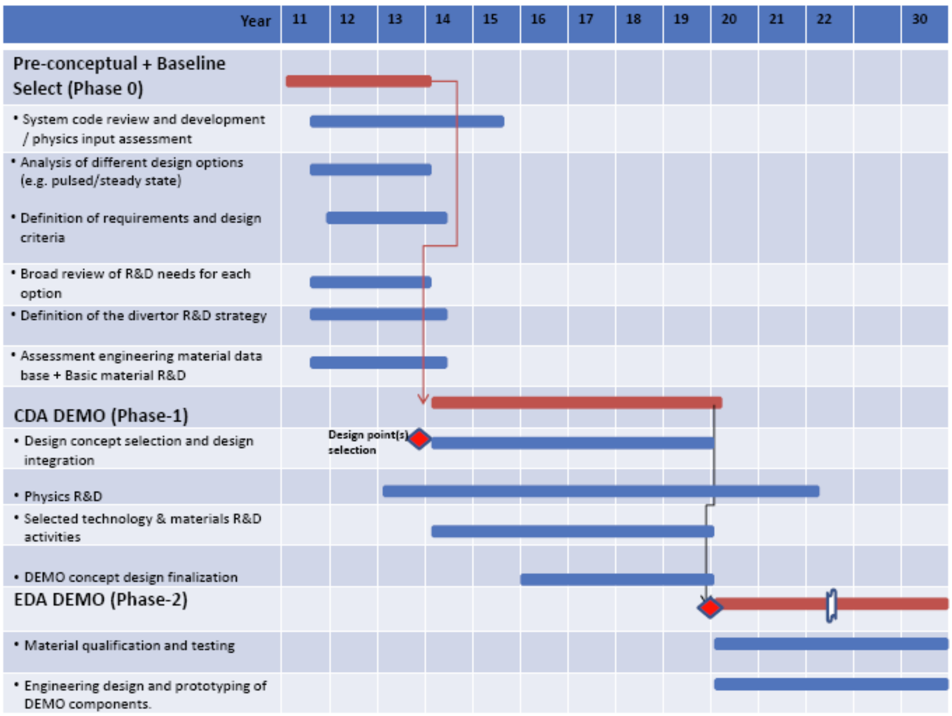


Fig. iv.1 Assumed timeline and main activities

IV.2 ORGANIZATION OF THE PPPT ACTIVITIES

The approach chosen for the design activities carried out in the context of the EFDA PPPT Work Programme consists in the formation of a multidisciplinary and distributed design team made up of personnel from the EFDA CSU, Associations and Industry.

The project organization is shown in Fig. iv.2. The core-team, located in the EFDA CSU of Garching, will be responsible primarily for the Project Control and the System Engineering and Design integration parts. The design and R&D activities will be carried out by a number of Projects distributed in the EFDA laboratories and led by a Project Leader from the Associates who respond to the PPPT Head of Department.

The organisation described in Fig. iv.2 will become fully operational at the beginning of the Phase-1 (see Fig iv.1), but the 2012-13 design and R&D activities will be organized in a way that reflects to the best extent possible this structure. A detailed WBS for Phase-1 will be produced in the context of the 2013 Work Programme on the basis of the results of the activities carried out in 2011-12.

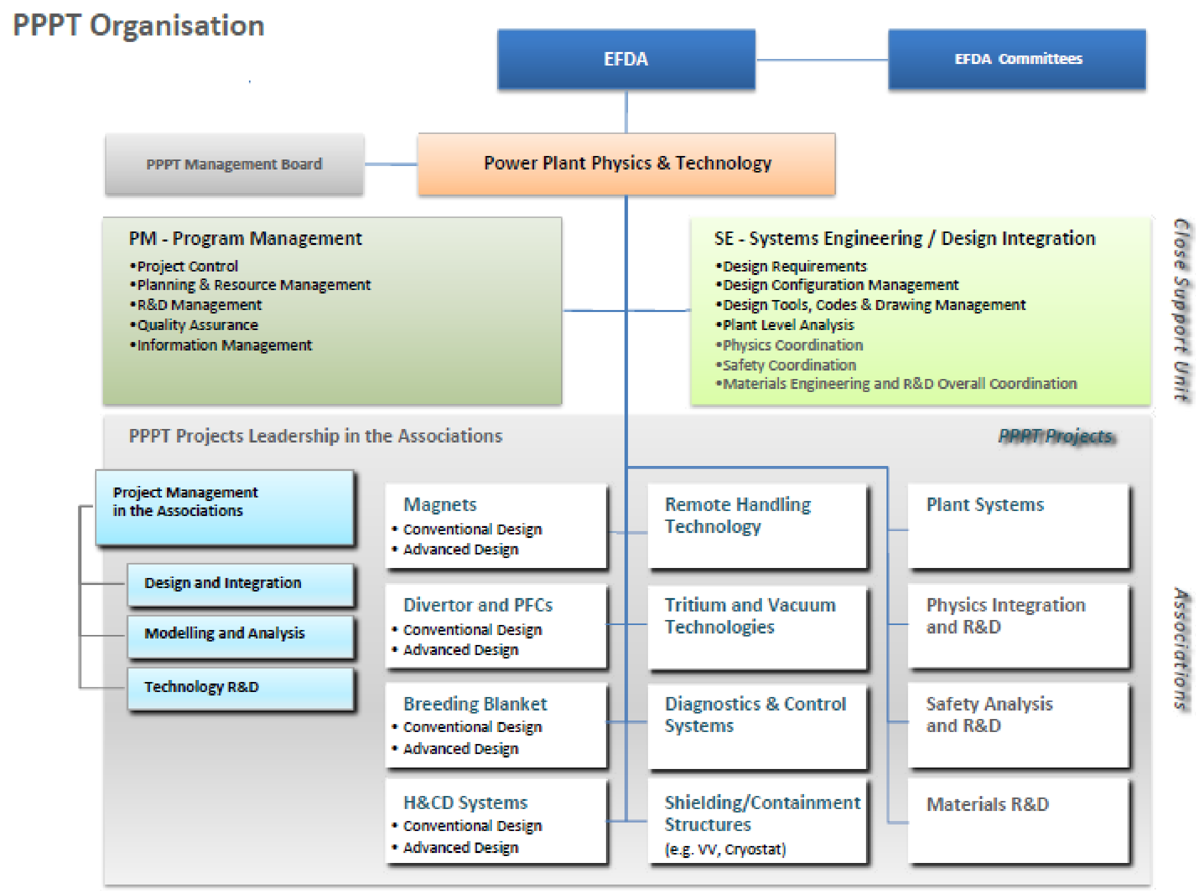


Fig. iv.2 PPPT Project Organisation

IV.3 DESCRIPTION OF ACTIVITIES OF THE 2012 WORK PROGRAMME

The activities of the EFDA PPPT Work Programme in 2011 were oriented along three main lines: development and application of system codes for the definition of main machine parameters (Cfp PPPT-WP2011-SYS); assessment of the problem of the DEMO power exhaust and preliminary definition of the R&D strategy for the divertor (Cfp PPPT-WP2011-PEX); and a number of design studies on important engineering topics that bear a strong impact on the future conceptual design activities. These topics were identified involving experts of Associations and Industry as well as EFDA Topical Groups and Coordinating Committees (Cfp PPPT-WP2011-DAS).

The major emphasis of activities in EFDA PPPT Work Programme during 2012 will be on:

- System code / physics input assessment;
- Analysis/ exploration of different design options (e.g. pulsed/steady state);
- Broad review of the R&D needs following DEMO WG recommendations;
- Definition of the strategy on divertor R&D and launch preliminary work;
- Assessment of engineering material data base.

The activities that are proposed for 2012 aim at the consolidation of the physics and technology basis in a specific design context. To this aim two design options are being explored. (i) DEMO Model 1: a "conservative baseline design" i.e. a DEMO concept deliverable in the short to medium term, based on the expected performance of ITER with reasonable improvements in science and technology; i.e., a large, modest power density, long-pulse inductively supported plasma in a conventional plasma scenario. (ii) DEMO Model 2: an "optimistic" design, i.e, a DEMO concept based around more advanced assumptions which are at the upper limit of what may be achieved during the ITER phase of fusion development, i.e., an advanced higher power density high CD steady state plasma scenario. It is clear that this can only be delivered on a longer term.

A preliminary set of technical parameters/ design features for these bounding DEMO design concepts are going to be available early 2012 as a deliverable of an activity underway with the system codes. It must be clear however, that this will certainly not represent the final selection for the DEMO reference design, but will, nevertheless provide a basis for more in-depth reactor design during the rest of 2012 and to develop and compare options for key reactor design features and selected technologies for the main components.

The activities of the PPPT in 2012 will be organised in 6 "Task Areas", including the activities on Socio Economic research in Fusion (SERF), which are currently part of the PPPT are at the end of this document (see Table iv.1). A number of activities are defined for each project as shown in Table iv.2 together with an estimate of the resources needed in 2012 .

The "Projects", as shown in Fig. iv.2, are expected to be gradually established starting in 2013 on the basis of the outcome of the work carried out in the next two years and they will include consolidated design and technology R&D activities based on the selected design options to be studied for the Conceptual Design Activity Phase.

A number of activities in 2012 are also launched to establish and/ or consolidate design tools and methodologies that are necessary for the implementation of the conceptual design activities. Table iv.1 PPPT projects for 2012.

1. System code activities (<u>SYS</u>)
2. Power Exhaust Physics Integration Studies (<u>PEX</u>)
3. Design Tools and Methodologies (DTM)
4. Design Assessment Studies (DAS)
5. Materials R&D and Engineering Database (MAT)
6. Socio Economic Research on Fusion (SERF)

Table iv.2 Task Areas and activities planned for 2012 (see details on resource allocation in the text).

Activities			Identifier	PPY	kEuro		Comments
1	**System Code**			**8**			
	a.	Code Development/improvements	WP12-SYS01	4			A
	b.	Analysis of design concepts	WP12-SYS02	3			A
	c.	Preliminary scenario analyses	WP12-SYS03	1			
2	**Power Exhaust Physics Integration Studies**			**12**			
	a.	DEMO conventional divertor solutions	WP12-PEX01	4	25		A,
	b.	Advanced divertor configuration studies	WP12-PEX02	2			
	c.	Novel PFC material solutions	WP12-PEX03	3	40		
	d.	Gap Analysis	WP12-PEX04	3			A
3	**Design Tools and Methodologies**			**6**			A
	a.	Evaluation/tests of CAD-based computation tools for engineering analyses	WP12-DTM01	2			I
	b.	Reliability Growth analysis	WP12-DTM02	2			I
	c.	Neutronics studies	WP12-DTM03	2			
4	**Design Assessment Studies**			**28**			
	a.	Superconducting Magnets	WP12-DAS01	2	80		
	b.	In-Vessel Component Design and Integration	WP12-DAS02	5			A
	c.	Heating & Current Drive Systems	WP12-DAS04	5			A
	d.	Diagnostics and Control Systems	WP12-DAS05	3			
	e.	Vacuum and Tritium Systems	WP12-DAS06	2	40		A
	f.	Remote Handling	WP12-DAS07	4			I
	g.	Stellarator engineering scoping studies	WP12-DAS08	2			
	h.	Additional topical studies	WP12-DAS09	5			
5	**MATERIALS**			**14**			
	Materials R&D		WP12-MAT01	12	220		A
	Materials engineering database		WP12-MAT02	2			A
6.	**SERF**		WP12-SERF01	2	5		A
TOTAL				**70**	**410**		

A=Initial work launched in 2011, I = involvement of industry sought

IV.3.1 INTEGRATED DESIGN ACTIVITIES AND PHYSICS STUDIES

IV.3.1.1 SYSTEM CODE

Development of a predictive capability for the DEMO main design and plasma parameters is envisaged to proceed along three different lines: a) code development and improvements, including a review of the physics and technology basis used in the codes to set the initial design basis for DEMO for later improvement; b) code analyses to explore the design parameters for concept studies of the two options (pulsed and steady-state) discussed above; c) preliminary plasma parameter and scenarios analysis.

A purely sequential strategy (code development, then successive exploitation from 0-D to 1.5-D codes) would of course be simple to implement. However, iterations among the various levels of simulations and R&D projects (e.g., divertor, H&CD systems) will be necessary. Therefore, a phased approach in which development and exploitation advance in parallel seems more appropriate. An example of this type of approach is shown in fig. iv.3.

a. CODE DEVELOPMENT/ IMPROVEMENTS

Work is underway in 2011 to analyze the status of existing systems codes in Europe, to assess the main assumptions and to make proposals for areas where improvements are needed. The assessments are to be carried out by a combined program of comparison of key models with the best present knowledge; benchmarking against other systems codes, both in Europe and in Japan; and by comparison with other codes carrying out more detailed calculations of specific aspects of the plant, such as MHD stability core confinement or divertor heat flux.

The expected outcome of these activities will be:

- the identification of the strengths and weaknesses of existing codes and the shortcomings of the models/ approximations being used
- the proposal of improvements to existing codes, the implementation of those that are relatively quick and the identification of a strategy for implementing those that are more substantial. In particular, analyse the needs and define a plan for the possible development of a European system code

In 2012, preliminary physics design guidelines and methodologies for projecting plasma performance in DEMO will be available and should be consistently implemented in the codes. Both "conventional" and "more advanced" operating modes will be considered. In particular, the highest priority for the physics in the system codes will be the problem of power exhaust and the model of the divertor heat flux, the problem of radiation, not just on the magnitude of bremsstrahlung, synchrotron and impurity radiation, but on the radial location and how this should feed into the power balance in different regions. the problem of high density operation and how to operate beyond the Greenwald limit, etc.

In the area of technology, the improvements will be focussing on the model of the superconducting magnets, the divertor and the blanket which are expected to have strong implications on the definition of the overall machine design parameters.

It should be noted that even in the case it concluded from this review that only a new systems code can fulfill the requirements of ongoing DEMO studies and work on such a new code would be urgently needed, it is likely that existing codes would still be used to define starting assumptions for wider DEMO studies – as it would not be feasible to wait for the implementation, testing and benchmarking of a new code before beginning other DEMO studies.

Estimated resources: 4 ppy in 2012.

b. ANALYSIS OF DESIGN OPTION

On the basis of the work described above, it will be possible to build on the existing work on DEMO conceptual designs and analyse preliminarily a range of options for DEMO and obtaining a starting set of machine design parameters. In 2011 it is anticipated that two main options for DEMO will be analysed as a focus for the assessment described above and the ongoing benchmarking of the systems codes. The output of this work will drive work in other areas which are ongoing in 2011 but that are expected to continue in 2012 (e.g., assessment on H&CD

systems, magnets, scenario development etc.) as the overall DEMO design will set very different requirements for key systems. These external studies, in turn, will feed back to further refine the DEMO models.

Analysis of DEMO design options will be continued in 2012 as the systems codes are improved, but also as new information becomes available on the appropriate assumptions to be made in the physics and technology (see above), and also on the decisions on the high-level requirements for DEMO such as electrical output, or pulse length. Sensitivity analysis to explore the effect of changing some important parameters, will be also conducted to determine trends and optimum, with a clear analysis of the uncertainties involved.

There are also likely to be other design options pursued, including work in collaboration with studies in Japan, which tend to rely on more aggressive assumptions on the physics (i.e., advanced tokamak operation).

Whether the strategy of improving existing codes or of developing a new systems code is pursued, the work in 2012 (and probably 2013) will have to be carried out with the existing, but improved tools.

Estimated resources: 3 ppy in 2012.

Total (system code)**:** 7 ppy in 2012.

c. SCENARIO ANALYSIS

In the context of the 2011 Work Programme the parameters of a pulsed and a steady-state DEMO will be produced. As part of the effort to consolidate the various machine design options (and possible variants) that will be available from the system code and to verify the consistency of the physics assumptions that were used for some of the essential system code modules, i.e., heating and current drive systems and of divertor, time-dependent evolution of the plasma parameters and radial profiles should be carried out at least in an approximate way. Development of predictive capabilities for DEMO plasmas parameters and test runs should include: i) fast time-dependent simulations with profile effects (0.5-D); ii) full integrated modelling simulations (1.5-D).

Fast time-dependent simulations with profile effects

For this type of analysis one needs codes that solve the current diffusion equation taking into account an approximate equilibrium evolution. Simplified treatment of the sources and of spatial dependences allow simulation of a discharge in a CPU time of the order of minutes, while keeping account of all the main non-linearities of the evolution. These fast computations can be obtained by using fully integrated codes with drastic simplifications of the sources and equilibrium modules (e.g., ASTRA), or by means of specific codes, also called 0.5-D, such as METIS.

Basic tools exist in Europe, however, specific developments may be needed in order to adapt their capabilities of simulating DEMO discharges (e.g., specific NBI modules, fast ray-tracing module for EC waves, fast MHD modules, etc.).

Specific activities to be carried out in 2012 are:

- start plasma parameter analysis by using existing 0.5-D codes as soon as some preliminary options are available from the systems codes, in order to test the time evolution aspects.
- conduct needed code adaptation and specific models update to adapt the 0.5-D codes for DEMO simulations, according to range of parameters provided by system codes.
- conduct sensitivity analysis to explore the effect of changing some important parameters. Determine trends an doptimum.

Estimated resources: 0.5 ppy in 2012.

Full integrated modelling simulations (1.5-D)

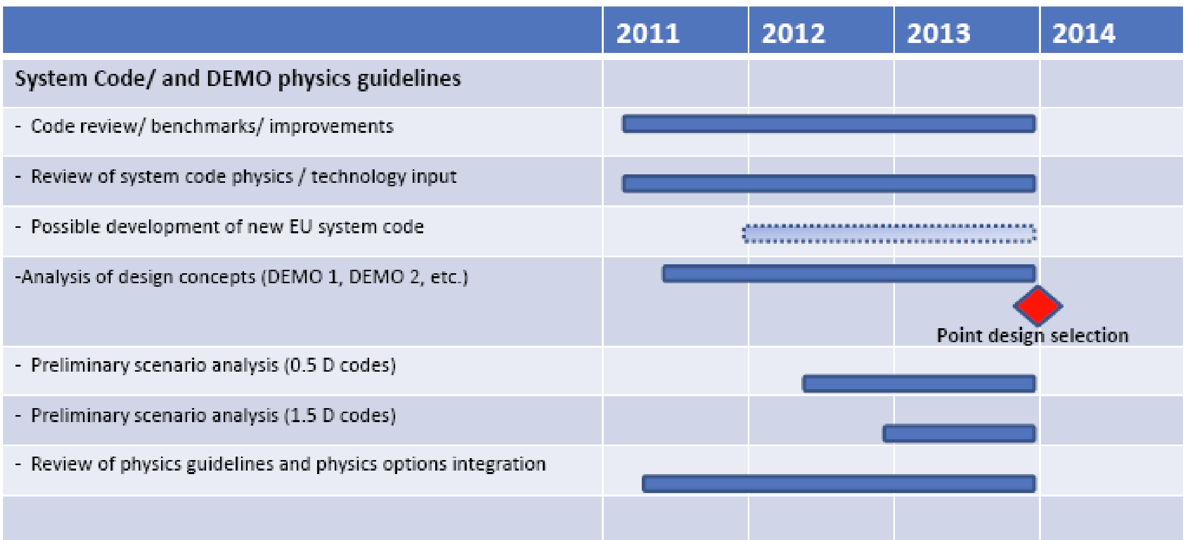
The objective of these analyses is to determine the time evolution of the radial profiles of plasma quantities (1-D) self-consistently with 2-D magnetic equilibria and with a realistic description of the sources. The equilibria can be computed either by fixed-boundary or by free-boundary codes. The edge and the pedestal can be treated as assigned boundary conditions or computed by appropriate codes. Some simple MHD stability prescription are sometimes included (e.g., sawteeth reconnection, effect of ELMs on the pressure gradient in the pedestal region). The constraints are mostly coming from physics, and consistency with technological constraints is usually checked *a posteriori*.

This activity will be carried out in close collaboration with the ISM Project in the ITM Task Force.

Activities to be carried out in 2012 are:

- as soon as some options are sufficiently developed start 1.5-D simulations. The MHD stability of the simulated scenarios should be checked systematically, at least at a linear level. The developments needed to adapt the 1.5-D codes to DEMO simulations should be carried out in 2013

Estimated resources: 0.5 ppy in 2012.



Fig, iv.3. Timeline for activities of system code and physics input consolidation.

IV.3.1.2 DEMO POWER EXHAUST PHYSICS INTEGRATION STUDIES

Irrespective of the basic operating regime which is ultimately selected for DEMO and subsequent power plants, the need to radiate a large fraction of the power so as to limit the peak power load on the divertor will be a key constraint and the Power Exhaust may ultimately determine the reactor size. Indeed, analysis carried out within the PPCS and DEMO studies shows that the tolerable divertor power loading is a significant driver for device size and cost of electricity (CoE).

Three different approaches can be anticipated for DEMO:
a) The use of conventional solutions for the plasma facing components; this requires the development of highly radiative regimes and leads to a relatively large size of the reactor;
b) The use of innovative divertor configurations;
c) The use of advanced plasma facing components (such as liquid metals); this requires the test on a dedicated device prior to any test in ITER.

a. CONVENTIONAL DIVERTOR SOLUTION STUDIES

a1. DEMO Divertor and Edge Modelling

Handling of the exhaust power from a tokamak power plant requires a high radiated power fraction combined with high confinement and sufficient of plasma purity. I the absence of impurity radiation, the power crossing the separatrix in a power plant plasma would be a factor of 5-10 greater than that in ITER, while the area of the divertor high heat flux components will probably differ by less than a factor of 2 from those of ITER. At present, the most favoured approach to power handling in a reactor combines tungsten plasma facing components, to ensure an acceptable interval between PFC replacements, with a highly radiating edge/divertor plasma to distribute the exhaust power over a sufficiently large wall area. Impurity seeding must therefore be exploited to generate sufficient edge and divertor radiation.

Although present day machines have demonstrated highly radiating scenarios, several differences compared to DEMO make the results difficult to extrapolate. Firstly, to achieve a similar radiated power fraction in the edge for DEMO parameters requires a much higher radiation power density, and associated steep temperature gradients. Secondly, power handling in DEMO is achieved by reducing the target power to an acceptable level which is of order 10 MWm^{-2}, not close to zero as in present experiments. This means that effects such as thermal instabilities, and changes in confinement cannot be directly extrapolated to DEMO.

It is essential that a good description of the power exhaust is included in the systems code for determining the global parameters of a power plant, as it is likely that it will be the determining factor for the machine size.

Some semi-integrated modelling has been done using both simple and state of the art edge and core models. However, such models still have difficulty in reproducing current experimental observations, and extrapolation of the input parameters is far from certain. In order to gain more confidence into the extrapolations it is intended to conduct a power plant specific validation of the codes by comparing with present experiments the incremental changes of adding impurity seeding, and approaching detachment. The “validated” codes can then be used with experimental scalings of transport parameters obtained from the multi-machine work in standard ELMing H-modes to model power plant scenarios.

Work has already started in 2011 to try to develop simple descriptions of the parametric dependences of the power exhaust from existing SOLPS-ASTRA integrated modelling and by running a range of conditions using less sophisticated integrated models, COREDIV. Also work has started to validate the incremental approach of extrapolation by preparing companion SOLPS runs for seeded and unseeded experiments in ASDEX-U and JET with metallic walls and divertor.

Over the next 2 years it is proposed to continue this work by:

2012

- Extending the range of conditions modelled using the simplified integrated and specific models, allowing to develop a more complete description of power exhaust for use in the systems code.(1ppy)
- Establishing that SOLPS correctly predicts the incremental changes resulting from the addition of impurity seeding to previously matched unseeded discharges in JET and ASDEX-U. (0.5ppy)
- Improve the experimental databases for the extrapolation of key parameters, under suitable conditions, including the promotion of experimental proposals to fill important gaps. This should include non-seeded plasmas as well as seeded. (0.3ppy)
- Run SOLPS using the range of extrapolations determined above, both directly and incremental, to derive more complete simplified descriptions of a highly radiating boundary for use in the systems codes, and compare the various methods.(1.2ppy)

2013

- Start a coherent modeling of erosion and redeposition, for DEMO relevant plasma operation parameters, which allows predicting quantitatively the life time of PFCs. Reactor studies carried out so far assume replacement of divertor module every two years and that the lifetime of breeding blanket is not affected by the need to replace its protective part, i.e., the first wall. The actual lifetime will be coupled to the power exhaust conditions and needs to be established by studies with significantly improved modeling of erosion/ redeposition for DEMO relevant conditions.(1ppy)
- Execute coupled edge and core models under conditions identified as a result of optimisations using the systems code, modifying the codes to reflect changes in understanding or regime.(2ppy)

Estimated resources: 2.5 ppy in 2012.

a2 . Confirm tungsten for PFCs in DEMO

In addition, a number of subsidiary activities should be launched in 2012 to confirm the use of conventional solutions using W-clad PFCs in DEMO. There is a widespread consensus that, in the absence of significant new developments in the technology of plasma facing components (PFCs) for fusion devices, considerations such as erosion lifetime, tritium inventory control indicate that DEMO will need to operate with high-Z PFCs, and tungsten appears at present to be the most suitable material for satisfying power plants requirements. This stem from the low sputtering rate which can be achieved with tungsten at low plasma temperatures in front of the surface as well as the possible use of enhanced operation temperatures for higher thermodynamic efficiency. Solid, low-Z elements like Be or C have to be excluded due to their high erosion rates and co-deposition. Liquid metals are still in their infancy for use as PFCs but the prospects of these solutions need to be clarified, and a proposal for work needed is made below.

The use of high-Z materials in a fusion device have profound implications on operation and requires an integrated plasma scenario with feedback-controlled impurity seeding and low plasma temperatures at the PFCs at high P/R (loss power divided by major radius), good energy confinement, high beta, acceptable ELMs and low PFC erosion rates.

A vigorous research program is in progress in Europe, involving the use of divertor tokamaks, like JET and ASDEX-Upgrade, to investigate the implications on machine operations arising from the use of tungsten. Work conducted on this topic is part of the ITER programme, focussed primarily with physics implications of using W at the strike points is of high relevance for DEMO. However, continued work is required to fully characterise the material, and define its operational limits at high power densities.

The following activities are proposed in 2012.

- Start a coherent modeling of erosion and redeposition, for DEMO relevant plasma operation parameters, which allows predicting quantitatively the life time of PFCs. Reactor studies carried out so far assume replacement of divertor module every two years and that the lifetime of breeding blanket is not affected by the need to replace its protective part, i.e., the first wall. This needs to be confirmed by studies with significantly improved modeling of erosion/ redeposition for DEMO relevant conditions.
- Quantify effects thermal transient overloads due to ELM and disruptions and determine constraints arising on the operational window of different plasma scenarios. Only scenarios which provide moderate ELMs and a very limited number of disruptions should be considered. 1) Establish acceptable ELMs and disruption load conditions for DEMO. 2) Establish disruption and ELM mitigation needs.
- As part of the characterization of new W-material grades being developed in the Material programme (see below), a number of thermal tests are foreseen by using e-beam (JUDITH facilities) and ion (H/He) beam (GLADIS).

Estimated resources: 1.5 ppy in 2012 + 25 kEuro for W thermal test in e- and i-beams.

b. ADVANCED DIVERTOR CONFIGURATION STUDIES

Innovations to improve heat flux handling and reduce surface erosion and in turn increase component lifetime, can have a profound impact on power plant optimisation. In addition to developing realistic high radiation scenarios (see activity above) it is also sensible to look into solutions using advanced magnetic configurations (e.g., higher flux expansion and expanded boundaries) which could reduce the radiation requirements. Work to be conducted in 2012 should take into account the findings and recommendations of a preliminary task launched in 2011. Emphasis should be on the heat exhaust capability of the solutions proposed during normal conditions, but also with a view to the occurrence of possible non controlled transients. More specifically it is proposed to conduct feasibility studies aimed at objectively and rationally determining and comparing the strengths and weaknesses of the various configurations (e.g., snowflake, X-divertor, super-X divertors, etc.). The assessment should include:

- an analysis of the case for potential gains in power exhaust from increased target area or radiation taking into account realistically achievable mechanical alignment and the geometrical stability of the equilibrium during plasma transients.

- an analysis of the implications of the target configuration on the mechanical integration and maintenance scenarios.
- an investigation of the design integration and engineering constraints arising from the use of large current coils in the divertor region for the case of the super-X divertor.
- an analysis of the layouts and currents of PF coils required to produce snowflake divertor configurations, and an analysis of the design implications.

Estimated resources: 2 ppy in 2012

c. NOVEL PFC MATERIAL SOLUTIONS

Finally, the prospect of using novel material, such as liquid metals (PFCs) should be seriously investigated.

c1. Explore the use of a bare-steel wall parts for PFCs in DEMO

The question of using a bare steel wall (i.e., without protective armour), at least partially in the main chamber, in a reactor has been often made in the past. Just from inspection of the sputtering yields and comparison to those of tungsten (where sputtering by impurities dominates), steel should be regarded as viable plasma facing material option. The main drivers are that W is expensive, joining of W to support structure (e.g., EUROFER) is difficult. Pure W is brittle, and its material properties degrade due to n-irradiation.

As part of the WP2012 one should conduct a meaningful modelling and experimental programme by means of laboratory and tokamak sampling experiments, to consolidate and determine the technical specifications of an experiment to be conducted preferably in a divertor tokamak.

- Review past operation experience with steel in fusion devices, including LHD. In particular, determine if the bad performance of steel as plasma facing material was caused, as suspected, by insufficient wall conditioning (e.g., too high oxygen content).
- Conduct accurate modelling calculations using available data for commercial steels, and consistent neutral and ion particle fluxes as from measurements in tokamaks.
- Define a coherent R&D programme that should involve introduction of steel-coated samples in a tokamak at a minimum number of poloidal and toroidal locations, thickness of coatings, type of steel, etc. Determine supporting modelling tools and resources needed
- Investigate the feasibility of installing in a step-wise approach raws of steel tiles for number of customized experiments in a tokamak, starting at the inner heat wall If no negative effects on plasma performance are observed, low field side PFCs could be exchanged in the course of the 'conducting wall' project. EUROFER is in particular challenging because it as a martensitic steel and magnetic. Plasma investigations may start with an austenitic steel, shifting the investigation of the magnetic perturbations by EUROFER tiles to a later date.
- Use available computational tools to study magnetic perturbations to be expected by the use of ferritic material.

Estimated resources: 1 ppy in 2012, 40 kEuro for procurement of tiles in 2012

c2. Liquid metals

A lot of R&D activities primarily related to the use of liquid lithium in fusion devices are underway worldwide and the results are promising (e.g., see proceedings of the 2nd International Symposium on Lithium Applications for Fusion Devices, that was held in Princeton, New Jersey, USA, on April 27 - 29, 2011. However, in general it is felt that there is a need for a better integration of research in both the PWI and plasma physics areas, which entail the use of liquid metals in fusion devices.

Two approaches have been developed using lithium that allow very high power handling. First approach (Red Star, Russian Federation, FTU Frascati) uses evaporation of lithium in a porous mesh target: i) Employs heat of evaporation; ii) Evaporating lithium provides vapor shielding of target. Second approach employs naturally generated (convective) flows in free surface liquid lithium for redistribution of heat (PPPL). Both approaches have issues for application in a tokamak. Lithium influx with evaporative technique may be prohibitive. High magnetic field may suppress self induced flows. But both techniques have demonstrated heat handling capability in excess of 50 MW/m^2 for short times

As part of the EFDA PPPT Work Programme 2012 it is proposed to start an assessment of the work carried so far in these areas and to determine the realistic prospects and relevance for fusion reactors. In particular the following activities are proposed.

- Review the rationale for liquid metals as PFCs and determine the implications on the plasma operation and performance.
- Identify candidate liquid metals and review recent experimental results
- Provide needed knowledge needed PFC components development with liquid metals. Determine power handling limits, erosion lifetime, and investigate effects of ELMs and off-normal transients.
- In parallel, investigate the design integration and engineering aspects of liquid metals divertor in a tokamak.
- An important part of this work should be the formulation of experimental proposals, including work in small tokamaks.

Estimated resources: 2 ppy in 2012.

D. DEMO GAP ANALYSIS

This activity pertains with the analysis of the uncertainties and scientific R&D gaps that exist from existing knowledge, to the target goals in DEMO in the areas of divertors and thermonuclear breeding blankets.

d1. Divertor gaps -- An activity was launched as part of the PPPT WP2011 (PEX-01) to 1) identify gaps that exist in the development of consistent physics scenarios; and the knowledge of the problems of power exhaust and extraction; and the development/consolidation of sound technological solutions for the divertor and the first wall; 2) determine capabilities/options that exist to reduce the gaps with existing/planned machines. 3) Determine needs/ required features and capabilities of a possible dedicated DEMO divertor facility.

Depending on the outcome of this assessment, it is envisioned that further work will be needed and specific scientific and technical tasks will be launched along the priorities for the different options in order to

- consolidate the findings and to evaluate the impact of the recommendations.
- conduct in some cases a more in-depth assessment of the proposals especially concerning 1) use of existing fusion devices, after proper upgrades and/ or machine modifications. A precise estimate of the changes required and achievable must be documented together with an as accurate as possible estimate of the resources needed. 2) Use of a dedicated fusion device, which shall be capable of investigating as closely as possible, all of the issues and (non-nuclear) problems that PWI/PFCs would face in DEMO. These facilities should be available and operated well before the start of the construction of DEMO, in order to validate fundamental design choices and confirm their performance in a realistic environment.
- conduct feasibility studies of the options outlined above.

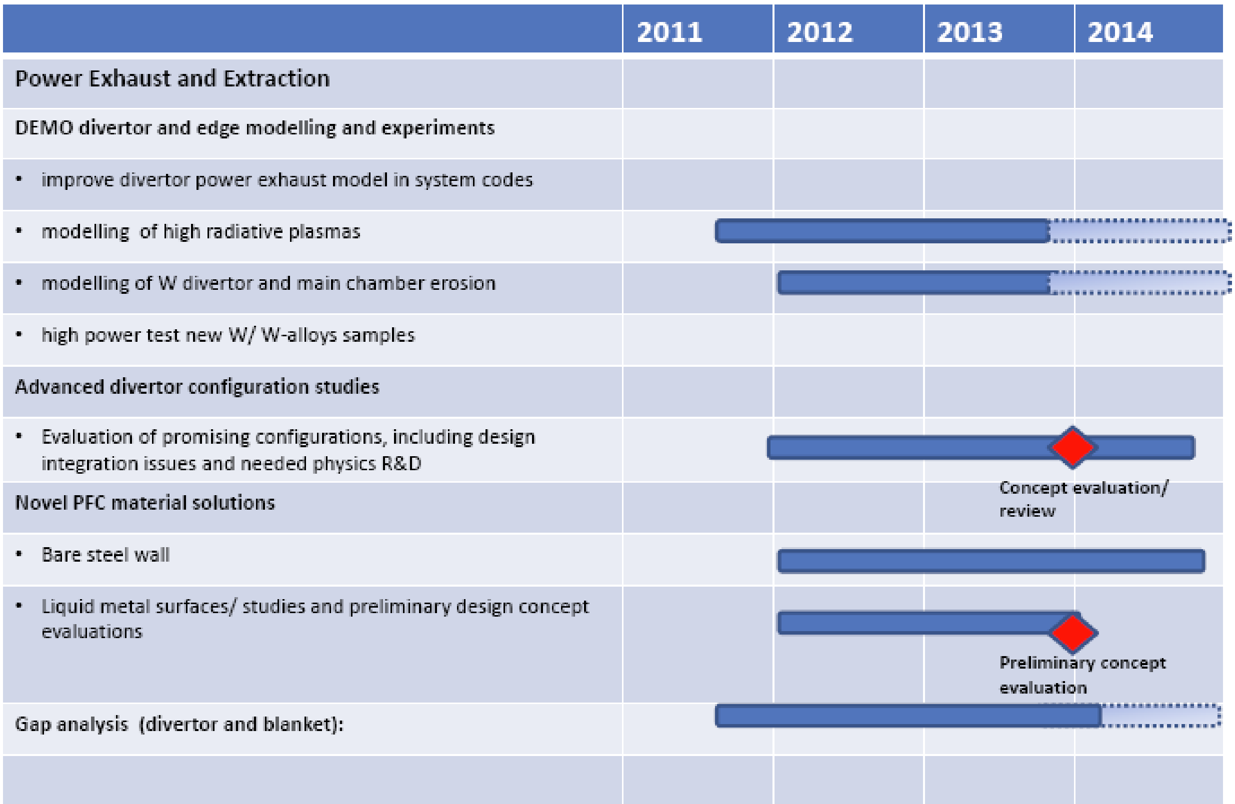
The findings are expected to be closely linked with the design requirements of DEMO and for the purpose of this assessment, an upper and lower limits for a two plausible DEMO design concepts should be considered, with parameters/ technical characteristics that are expected to be consolidated as part of the preliminary design oriented activities to be conducted in 2011-12, i.e., a pulsed DEMO; a high current drive, steady-state DEMO.

d2. Blanket design and R&D gaps – Main function of a pure-fusion blanket in DEMO are producing and recovering tritium sufficient to continuously refuel the plasma; capturing and exhausting part of the fusion power; and shielding other components as necessary to meet their lifetime, waste disposal, or reweldability requirements. There is a need:

- to study technology readiness and qualification issues for each concept
- to determine the testing capability and requirement needed to test components under prototypic conditions.
- to conduct a gap analysis to determine the risks arising from potential gaps and the required R&D including necessary test facilities and underlying test programs. Specific questions to be addressed are
  - What, in detail, is the fusion nuclear blanket development path to DEMO?
  - What are the important phenomena that are believed to drive the behavior of the fusion blanket? What are the relative time scales for these phenomena and are there important coupled or integrated effects that should be considered? Are there separable effects?
  - As part of the blanket development explain the incremental role of ITER and any other testing that would be required to qualify blankets for use in DEMO including: R&D to insert a blanket in ITER; results from ITER operation, given its current performance characteristics? What is the added value of a CTF?
  - What are the current types of experiments planned in the R&D leading up to the TBM? Do they capture the important phenomenological coupling identified as critical to blanket behaviour? Why or why not? Where is this R&D being carried out?
  - What will we learn from an ITER TBM in the overall context of FNT development that we could not possibly learn either by testing in existing plasma/fission devices for Neutronics and plasma effects supplemented with other separate effects testing?

This activity should be ideally carried out in collaboration with F4E.

Estimated resources: 3 ppy in 2012.



Fig, iv.4. Timeline for activities of power exhaust

IV.3.1.3 DESIGN TOOLS AND METHODOLOGIES

a. EVALUATION AND TEST OF TOOLS FOR CAD-CENTRIC COMPUTATION SYSTEM FOR ENGINEERING ANALYSES

During the past few years there has been a dramatic surge in simulation efforts relevant to fusion technology. Commercial software vendors have expanded the breadth of their offerings to include rapid physical modelling, smooth integration with CAD packages and convenient coupling across physical disciplines. Traditional neutronics modeling via MCNP has been extended to arbitrary geometries by providing CAD interfaces. Broadly multiphysical modelling efforts in the area of fusion plasma and structures under radiation have been initiated. These developments are very important as they have the potential to vastly improve and accelerate the design analysis process.

An activity is proposed to be launched in 2012, preferably with direct involvement of Industry to determine available tools, analysis procedure used today to perform engineering analyses of geometry complex components/ systems etc.); to evaluate the benefits to set out in the EFDA PPPT a computational system for integrated modeling process based on a CAD-centric computation system for engineering analyses. This should be devised in such a way to enable user groups to interoperate using a common modeling platform at various stages of the analysis and could be very useful to simulating the integrated behavior of components such as blanket, divertor and plasma facing components in a fusion environment.

Similar efforts has been recently conducted in the US [1] and one of the tasks should be that of critically evaluate the outcome of this work and explore possible opportunities for collaborations and synergies.

Also, platforms available today and used in ITER and/ or in other industrial fields should be considered, as this is clearly not a problem unique to fusion.

It should be noted that versatile commercial products are already available that perform some of the task mentioned above (e.g., ANSYS workbench) and the need to conduct some customisation to expand their applications with neutronic or electromagnetic solvers need to be evaluated.

In summary, in 2012 should be conducted with the help of Industry and have the following goals.

- Determine the needs and define requirements/ technical specifications for a CAD-based computational system for integrated modelling.
- Develop a procedure for managing a typical fusion component design modeling process
- Determine product availability/ potential vendors/ development needs
- Define and analyse a number of test cases
- Recommend implementation process.

For example there is the need to develop a design tool to assist the design, analysis and integration of the in-vessel components. This tool should assist the generation and management of the input for a system of programmes that are used in the analysis of the design (like CATIA, ANSYS, MNCP, RELAP5, MELCOR etc.). Activities related include the definition of the interface system/design codes, definition of the design workflow for in-vessel components, selection of a computational platform for the design code, selection and integration of a set of codes suitable for the different analyses.

Estimated resources: 2 ppy in 2012.

b. RELIABILITY GROWTH AND RISK MINIMISATION ANALYSIS FOR INTERNAL COMPONENTS

Reliability/availability analysis, reliability testing, and "reliability growth" programs are key elements in any engineering development. This structured process of finding reliability problems and monitoring the increase of the product's reliability through successive phases is called *reliability growth*.

Reliability/Availability is a challenge to fusion, particularly for the design and fabrication of the internal components (e.g., blanket/divertor and other plasma facing components). In contrast to other systems, the reactor core (blanket/PFC) will have little or no reliability data from ITER and other facilities. Estimates using available data from fission and aerospace for unit failure rates and using the surface area of a tokamak show: probable mean-time between failures (MTBF) for Blanket ~ 0.01 to 0.2 yr compared to required MTBF of many years. Therefore it is recommended to establish a vigorous reliability growth

[1] DOE SBIR – Phase-I Final Report "CAD-centric management system: VTBM" Phase-I SBIR FinalcReport HyPerComp Report Number: VTBM-2008-P1.

and risk minimization program for the design and development programme of internal components in DEMO (beyond obviously demonstrating their engineering feasibility).

As part of a programme aimed at improving the reliability of internal components of a tokamak, systematic risk analysis must be carried out at different stages of the design and R&D development by using state-of-the-art methodologies that are widely applied in other industrial fields. This includes for example Hazard and Operability studies (HAZOP), Failure Mode an Effects Analyses (FMEA/FMECA) that are used by nuclear, and aerospace industries to improve reliability of component and systems.

As part of the EFDA PPPT Work Programme for 2012 the following activities are proposed.

- Define Programs for Reliability Growth
  - Define a strategy and develop a plan
  - Identify synergies with ITER RAMI Program
  - Investigate what is done in other fields (e.g., nuclear, aerospace)
- Define Risk analysis methodologies and tools for reliability modeling and prediction
- Analysis Techniques– Statistical Test and Estimation
- Begin RAMI Process Document including on how to include RAMI in the design and fabrication process of components
  - Provide RAMI in the design and fabrication process of components
  - Assure RAMI in Design (RAMI processes in Design processes)
  - Qualify RAMI in Design
  - Feed Qualification lessons back into Design
  - Assure and qualify RAMI in Fabrication, Assembly, and Construction
  - Feed Qualification lessons back into Fabrication, Assembly, and Construction
- Concentrate early RAMI Process Document on content for:
  - Early Procedure – Survey the Past: Data from disparate experiments & studies
  - Developmental Procedure: Present Activities: Data from DEMO-Path experiments (e.g. ITER, etc.)

Input and involvement of Industry in this field is high recommended.

Estimated resources: 2 ppy in 2012.

c. NEUTRONICS STUDIES

d1. Neutronics tools – development, adaptation and extensions

The following activities should be launched in 2012:

- MCNP is the reference code for neutronics design calculations. However, very recently, severe restrictions have been imposed on its use, by US Government regulations linked to problems of export control, and especially it is very difficult to access the source code. Alternative Monte Carlo (MC) codes should be evaluated for use with DEMO neutronics, such as the European TRIPOLI and the Japanese PHITS code. Code must be suitable for fusion neutronics applications, must be benchmarked and validated. Source code must be available for a couple of analyses.
- Adaptation/extension of available tools for CAD geometry conversion and/or direct use of CAD data geometry data in MC neutronics calculations. This is a high priority activity and should be started in 2012 as different approaches are available, but not enough

matured; urgent need for further development related to the two items below for easy and error tolerant use.

- Coupling schemes for neutronics (MC) and thermal hydraulics calculations, both for fast 1d scoping and detailed 3D analyses. (High priority; should be started in 2012; next to nothing is available in this field – the nuclear fission community.
- Adaptation/extension of radiation transport and activation calculation schemes for evaluation of activity inventories, burn-up, transmutation and gamma dose rate distributions post irradiation. This is of high priority and should be started in 2012; important e. g. for radiation mapping during shut-down periods for maintenance assessment; promising tools are available but need to be extended for robustness and flexibility).

Further activities to be launched in 2013 are:

- Development of schemes for visualising nuclear responses (high resolution distribution data) on MC or CAD geometry. Requires coupling scheme to CAD/MC conversion tools.
- Adaptation/extension of suitable tools for sensitivity/uncertainty analyses of DEMO – e. g. TBR.

d2. Model development for DEMO

Most of the activities in this area are foreseen to be launched in 2013 only after scoping studies finished and DEMO parameters are stable.

- Plasma neutron source model/data to be elaborated on the basis of DEMO plasma physics. To be prepared for MC and deterministic calculations on mesh grid and/or parametric representation.
- Geometry model for DEMO reactor to be constructed on the basis of engineering CAD model for detailed 3D analyses (TBR, heating, radiation shielding, radiation damage, activation etc.). Requires to devise a clean neutronics CAD model and conversion to MC geometry representation.

d3. Nuclear Data for DEMO

The following activities should be conducted under F4E work programme:

- Sensitivity/uncertainty analyses to identify important nuclear reactions and cross-section data and assess related uncertainties for DEMO. This is of high priority and should be started in 2012.
- Review of nuclear data evaluations available for fusion neutronics (FENDL, JEFF, etc.) and assessment of further development needs including covariance data for uncertainty analyses and activation/transmutation data.
- Benchmark experiment for validating breeding and/or shielding performance at DEMO specific conditions will be required at a later stage.

d4. Nuclear analyses for DEMO

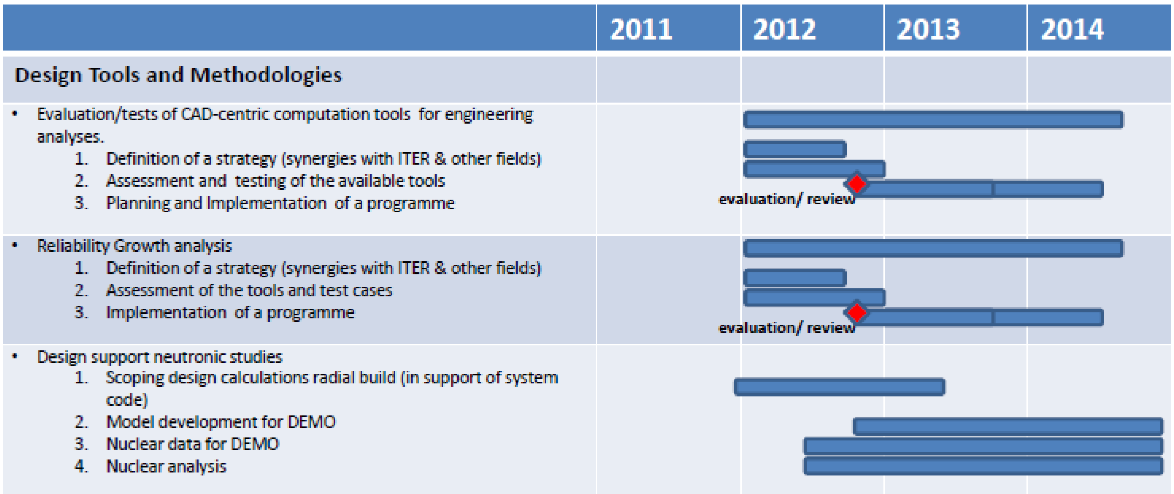
The following activities should be launched in 2012:

- Scoping analyses for blanket and shield optimisation to be iteratively performed with system code analyses.(2012)

The following activities should follow in 2013 after scoping studies are finished and DEMO machine parameters are fixed:

- Detailed neutronics analyses for optimisation of Tritium breeding and shield design. Assessment of global Tritium Breeding Ratio including port effects etc. Requires 3D DEMO model to be available.
- Dedicated 3D analyses for engineering design of in-vessel components.
- Specific analyses for design and integration of dedicated diagnostic components.
- Assessment of material and component activation and nuclear waste production.
- Analysis of TBR requirement for DEMO taking into account any potential tritium losses (fuel cycle), detrimental effects (e. g. burn-up, ports) and uncertainties (data, modelling).

Estimated resources: 2 ppy in 2012



Fig, iv.4. Timeline of activities for design tools and methodologies

IV.3.1.4 DESIGN ASSESSMENTS STUDIES

A number of design assessments have been launched in 2011 to review:

– Technological maturity/development needs of Heating and Current Drive and Fuelling and Pumping Systems for DEMO *(WP11-DAS-HCD)*;

– Status and prospects of high temperature superconducting magnets *(WP11-DAS-HTS)*;

– Current conceptual solutions for DEMO divertor and breeding blanket including an assessment of the coolants for in-vessel components *(WP11-DAS-IVCC)*;

– Material Database status and needs for DEMO conceptual design activities *(WP11-DAS-MAT);*

– Technology/engineering issues associated with pulsed tokamaks *(WP11-DAS-PLS);*

– Candidate remote maintenance schemes and solutions *(WP11-DAS-RH).*

The main objectives of these activities were: (i) to revisit the rationale and technology development assumptions that have led to the selection of some design choices in the past; (ii) to assess their technological maturity and/ or development prospects in view of recent factual information; and finally (iii) to provide a provisional roadmap for possible realistic developments in the various areas, with an estimate of the resources needed. At the time of the preparation of this document the design assessment studies launched in 2011 are still in progress and findings and recommendations are expected to be available by the beginning of 2012.

It is foreseen that these studies should be followed by more detail assessments of specific aspects of components and systems that will arise from these previous studies.

The activities for specific tokamak components and systems to be conducted in 2012 are described below, together with a number of more generic scoping engineering studies which are proposed for example on stellarators, CTFs. etc. It should be noted that these activities are not yet fully mature for a coherent definition of Projects, as teh work planned for 2012 and possibly in 2013 will consist primarily of the analysis of different design options available and the evaluation of R&D needs. Because of the limitation of resources available in 2012 and 2013, investment on hardware is expected to be rather limited in 2012 and to be oriented primarily to either proof-of-principle tests or qualification of small samples/ mock-ups. At the beginning of the conceptual design phase to be expected by 2014, most promising design concepts will be selected together with investment on design and selected technology R&D activities to confirm the feasibility of the solutions proposed and well defined Projects will be established in all areas.

a. SUPERCONDUCTING MAGNETS DESIGN

For the concept definition of DEMO since the magnet systems are the core of the basic machine, an early design activity is proposed to guide the analysis of different design options and R&D efforts. In general, the design of the magnets is going to be strongly interlinked with the selection of the main machine parameters, which are defined by means of a system code. Therefore, as part of the initial design activity on the magnets, an iterative design/ analysis process is expected to be needed to verify the consistency of the results of the system code and the underlying model of the magnets. Defining the mechanical and nuclear design criteria to be used for DEMO magnets as early as possible would be an advantage. At the beginning, the exact description of the winding pack is not necessary, as the definition of the magnet radial build in the equatorial plane from a give set of machine parameters, is essentially driven by the structures and not by the superconducting cable.

For a given ranges of design parameters that will be available from the system code calculations early in 2012 for at least two possible design concepts for a pulsed and a steady-state DEMO reactor, the design options and the conductor materials (low-temperature superconductor for a pulsed-device and low and high-temperature superconductors for a longer term steady-state device) should be analysed. One has to emphasise that high-temperature superconductors (HTS) have the potential to enable operation at higher magnetic field (> 14T) at much higher temperature (up to 50 K) in the fusion geometry than conventional superconductors. In particular, enabling operation at high magnetic fields with good temperature tolerance is perceived to be an important advantage in a DEMO reactor especially to compensate/mitigate potential performance shortfall risks that may arise from the fact that reliable operating scenario at high density (i.e., n> nG - Greenwald limit) could be difficult to be established, and this in the absence of compensating measure with coil design that operate at high fields would translate into the inability to achieve significant level of fusion power in a reactor.

The activities to be carried out in 2012 should take into account the findings and recommendations that will be available from a number of assessments launched in 2011, both for low-temperature as part of call and high-temperature superconductors as part of the call. No significant investments on hardware are expected in 2012 and 2013. In addition, the necessary information to start a DEMO magnet design, e.g. DC field, geometry, field scenarios, nuclear heat loads should available by mid-of 2012

The magnet design activities planned in 2012 are:

- Initial magnet design and analysis activities support to the system code (see above). Based on code results conduct some preliminary magnet design trade-off studies considering (i) different types of magnets refrigeration (e.g., bath associated with indirect cooling scheme; forced flow cooling like in ITER); different types of conductor design (e.g., cable in Conduit type, or Rutherford type with adjacent cooling channels). And depending on the maximum magnetic field, and for a given temperature margin, consider different kind of LT SC (NbTi, NB3Sn).
- Conceptual / feasibility effort, to extend initial work conducted in 2011 (as part of the DAS-01 task) to analyse conductor and coils design used for ITER and determine their strengths and weaknesses when extrapolated to DEMO.
- Define mechanical design criteria (e.g., stress limits in the TF and CS structures), nuclear design criteria (nuclear heat deposition in the coils and maximum tolerable irradiation on conductor insulation).
- Define criteria regarding the coils protection and the temperature margin in the conductors.
- Start analysis of practical LTS conductor designs (preferably two options) without significant investments in hardware.
- In the area of high-temperature superconductors (HTS), as a results of the design assessment conducted in 2011, the need to launch the following R&D activities is anticipated to advance knowledge in this area and will have to be confirmed following the completion of the 2011 deliverables: (1) Demonstration scalable cabling concepts; (2) Electrical stabilization & quench protection measurement & test of straight samples; (3) Demonstration of RE-123[2] fusion cable joints.

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Estimated resources: 2 ppy + 80 kEuro (for R&D on HTC) in 2012

b. IN-VESSEL COMPONENTS DESIGN AND INTEGRATION

In 2012 it is proposed to keep the activities of Divertor and Blankets combined as most of the proposed activities are of design integration nature, and involve questions related to remote maintenance, choice of coolants etc. These projects will be split as of 2013.

The design of the in-vessel components represents undoubtedly one of the greatest challenges for DEMO. The demanding requirements coming from the problems of power exhaust and power extractions together with the requirement to breed tritium in sufficient quantities require robust and reliable technological solutions for the divertor, the first wall plasma facing

[2] RE-123 superconductor has the chemical composition of $ReBa_2Cu_3O_y$ (RE: rare earth elements and so it is called "Re-123".

components, and the breeding blanket, which must be confirmed and consolidated. The question of component reliability is clearly identified to be a priority in the PPPT and work is proposed to be initiated in 2012 in this area (see above). Similarly the importance of defining the R&D strategy for the DEMO divertor is well recognised and activities are described above

The activity for 2012 and (likely) 2013 should focus on design and integration aspects and extensive use will be made of on-going R&D activities in some of the associates.

- Collection and critical revision of requirements used in the design of the in-vessel components (i.e., blanket and the divertor systems, including the respective manifold, piping, supporting, attachment and shielding systems); the requirements used in different design studies should be accurately identified and the rational analysed. This includes design and safety requirements, standards, design inputs, design rules and their ranges of uncertainty. The requirements have to be organised in hierarchies and then managed under quality management during the development of the design. These should constitute the basis for the assessment of all the following items. The prospects of a water cooled divertor that has been investigated in 2011 (call Cfp PPPT-WP2011-PEX)

- Review of the maintenance studies for blanket and divertor in order to assess in more detail the feasibility of the proposed concepts (including e.g. feasibility of the attachment system and shield performances) and to compare the proposed solutions to select a number of most promising maintenance schemes. This should also take into account assembly of systems; definition of repair operations that should be foreseen in the reactors (e.g. re-welding requirements for the vessel). To avoid duplications clear interfaces must be agreed with activities under remote maintenance .

- Revision of the different proposed designs of the main components (Blanket and Divertor) in order to assess their limits, the feasibility, the development possibilities of these concepts and propose improvements and simplifications in their design. Assessment of the impact of the identified requirements in item 1) on the design in order to take decision on the adopted design criteria.

- Definition of criteria for tritium barrier and tritium concentration limits in coolant loops. A co-operation with the group of Fuel Cycle should help to develop a comprehensive model to assess this issue.

- Studies of the Tritium Transport after generation in the blanket systems. Extraction from the breeder, permeation in the structure, losses in the system, contamination of the cooling systems with possible release in the environment. Interfaces with the fuel cycle to determine the extraction and purification technology, their efficiency in the limiting the operational release of T in the buildings and in the environment and their impact on the costs of the plant (sizing of these systems).

Estimated resources: 5 ppy in 2012 (3 ppy divertor and 2 ppy blanket[3]).

c. HEATING AND CURRENT DRIVE SYSTEMS

A specific study has been launched in EFDA in 2011 to review the technological maturity/development needs of Heating and Current Drive and Fuelling and Pumping Systems for DEMO *(WP11-DAS-HCD)*. Emphasis of this study has been on evaluation of strengths and weaknesses of each system in terms of efficiency and of reliability availability maintainability and inspectability aspects. For this assessment two bounding cases were considered: a DEMO

[3] Additional work on blanket maintenance as part of activities in RH.

Model 1: a "conservative baseline design" i.e. a DEMO concept deliverable in the short to medium term, based on the expected performance of ITER with reasonable improvements in science and technology; i.e., a large, modest power density, long-pulse inductively supported plasma in a conventional plasma scenario. A DEMO Model 2: an "optimistic" design, i.e, a DEMO concept based around more advanced assumptions which are at the upper limit of what may be achieved during the ITER phase of fusion development, i.e., an advanced higher power density high CD steady state plasma scenario. It is clear that this can only be delivered on a longer term.

At the time of the preparation of this document these activities are still in progress and findings and recommendations are expected to be available by the beginning of 2012. Activities to be conducted in 2012 on each H&CD system will reflect the findings and recommendations of the assessment study conducted in 2011 as well as the outcome of the 0D and 1.5D calculation described above.

Only a generic description of the work needed is given here with a tentative allocation of needed resources, notwithstanding that the findings and recommendations of this study will be taken into account in the actual implementation of the work.

Neutral Beam (NB)

Based on past studies and the ongoing assessment, the following activities are identified to be of high priority and are therefore proposed for consideration in the 2012 work program:

- Development of photo neutralizer technology: feasibility study of laser technology, cavity design, etc. culminating in a technology readiness statement. The status of this technology is such that several steps to demonstrate the underlying feasibility are needed before going to the full experiment.
- Alternative to caesium/caesium management. Consolidating on work done under EFDA up to 2011 using modelling and experiments to understand basic physics of negative ion formation and relative roles of surface & volume, the effect of caesium, its management and its elimination.
- HV holding and breakdown investigation for injectors up to 2MV.

Electron Cyclotron Heating (ECH)

The following activities are proposed as high priority:

- Detailed assessment of a 1 – 2 MW, three-frequency coaxial-cavity gyrotron as a first step to a tuneable multi-frequency gyrotron with high unit power, including demonstration of usefulness in a DEMO type reactor.
- Report on efficiency enhancement of electron beam sources in particular by improvement of the quality of the helical electron beam and by energy recovery with multi-stage depressed collectors. Multi-staged depressed collectors do not exist for high-power gyrotrons, single-stage depressed collectors are state-of-the-art. Several advantages are foreseen in particular the improvement of gyrotron efficiency. The improvement of collector efficiency would reduce the thermal loading of the collector (which is a critical issue for long-pulse, high-power gyrotrons, true for existing gyrotrons, but very much more important for higher output power).
- Perform feasibility study for advanced antenna launchers for DEMO. The first effort would consist of checking qualification and availability of diamond windows, including broadband synthetic diamond window options and ideally in parallel consider what can

be done to improve diamond window reliability by surface engineering, stress and fatigue reduction. Regarding reliability the worst case failure mode would be a failing mirror causing the ECH heating power to be irradiated uncontrolled in the plug with consequences such as massive melting and a possible blocking of internal plug components or even the port plug in the vacuum vessel. The second effort would be on the analysis of EC concepts avoiding the use of mirrors close to the plasma. The high neutron fluxes in DEMO however require the mirrors to be protected by substantial shielding which is not compatible with the ITER ECH launcher design. The solution is to avoid angular steering by a tuneable ECH frequency, in this case the ECH frequency will be adjusted to the resonant magnetic flux surface. With this solution the ECH Launchers could be simple tubes/waveguides in the volume close to the plasma where the high neutron flux occurs. The design driver towards a frequency tuneable ECH is therefore not a performance issue, but a risk mitigation action. The idea of developing a frequency tuneable ECH requires the development and demonstration broadband diamond windows.

- In addition to the activities listed above, verification/benchmarking of ECCD/ECRH codes at elevated DEMO like temperatures is proposed in liaison with the ITM activities.

Ion Cyclotron Heating (ICH)

The activities to be performed in 2012 are intended to refine where deemed necessary the findings of the still ongoing assessment of the IC system in 2011: performance of H&CD scenarios, coupling issues, etc. In addition, further studies on transmission system, sources (with higher efficiency) and arc detection are foreseen to attain sufficient confidence in the selection of relevant technological solutions to initiate a conceptual design.

The DEMO model 2 could require additional investigations due to its higher complexity at least if 2 systems are needed,

1. IC1 similar to DEMO 1 (extrapolation from ITER) tuned for ion heating for (1) heating to H-mode and burn initiation (2) burn control.
2. IC2 tuned for broad profile full CD (but used also in the ramp-up phase) based on high frequency fast wave (HFFW)

Lower Hybrid (LH)

The 2011 assessment will attempt to clarify the role of LH in DEMO, addressing the problem of coupling and absorption with some details. However, time will not permit to explore all interesting plasma conditions (dependence on the magnetic field and plasma current) and important questions such as the parasitic absorption in the scrape off layer near the launcher will remain unanswered. Physics issues, considering refined constraints provided by the system code studies, are therefore considered fundamental in the 2012 program:

- wave accessibility and penetration
- analysis of absorption in the SOL
- verification of the physics scalings to DEMO

In terms of technology, R&D priorities are expected to be one of the outcome of the 2011 assessment but it is already foreseen that feasibility studies could be needed in different areas such as source (0.5 -1MW at about 5 GHz), transmission lines and windows adapted to DEMO conditions or launcher (new design).

Estimated resources: 5 ppy in 2012.

d. DIAGNOSTICS AND INTEGRATED CONTROL SYSTEMS

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

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

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

- Building on the ITER analysis, assess principal restrictions to diagnostics for machine protection, basic control and advanced control in DEMO.
- Screening of diagnostic techniques and methodologies and assess long lead diagnostics relevant R&D.
- Assess and develop novel approaches to feedback control of the plasma with 'sparse' data systems and robust actuators.
- Following screening study, develop further hardened versions of key 'essential minimum diagnostic set'.
- Following feedback control developments, develop novel diagnostic systems and data analysis tools
- Assess the issues related with the integration of the diagnostics on DEMO

The following activities are proposed for 2012.

- Review the issues associated with the neutron flux/fluence, the access requirements and the reliability for the application to DEMO of the ITER diagnostics for machine protection, basic control and advanced control.
- Assess the use of magnetic diagnostics in the shadow of the DEMO blanket for the control of plasma position and equilibrium reconstruction. Define possible R&D in this area.
- Investigate the use of different techniques for plasma position control such as X-ray imaging and microwave reflectometry, assessing their applicability in the DEMO environment (sensitivity to neutrons, reliability, etc.).
- Assess the use of polarimetry for current profile reconstruction and control.
- Review the status of the radiation hardened electronics for DEMO.

Estimated resources: 3 ppy in 2012;

e. VACUUM AND TRITIUM TECHNOLOGIES

Pumping system

The ITER torus pumping system is based on three stages: (a) discontinuous primary cryopumping system (stage 1); (b) discontinuous viscous cryo-compressor as roughing system (stage 2); and (c) dry piston pump for final compression (stage 3).

An attractive development path towards DEMO in this area is to consider a continuous / inherently tritium-compatible / non-cryogenic pumping system, which in addition would enable an important exhaust separation function to simplify the fuel cycle. Depending on the value of the neutral divertor pressure two options are possible:

(i) low neutral divertor pressure (ITER range), a liquid metal based continuous high vacuum pump shall be developed for stage 1, followed by a metal foil based system which provides a compression and separation function (stage 2).

(ii) high neutral divertor pressure (about 1 order magnitude higher than ITER), stage 1 would not be needed and stage 2 alone may be able to provide the full pumping performance.

Finally, the final stage 3 could be a ring pump which has to be characterized

- As part of the activities to be carried out in 2012, a proof of principle of all the stages above is needed to determine the viability of these concepts, who bear strong implications not only on the design of the pumps but also on the fuel exhaust and reprocessing system.
- Some associated modeling of the experimental results is also needed and this would reduce experimental efforts in the future.

If the aforementioned strategy proves not to work, one would need to reconsider the only alternative path available, i.e., a classical mechanical pump tritium compatible. It should be noted that this development has already been abandoned once in the past.

Fuelling system

It is commonly assumed that DEMO will require deep fuelling, and high velocity pellet injection is one promising technology, but requirements in terms of pellets size and velocity are still not available. ITER requirements on injected velocity are viewed to be inadequate and is clear that going to much higher velocity pellet injection, provided that this is feasible, and no other realistic method are available, would demand a significant R&D effort over several years. It is expected that the assessment conducted in 2011 (WP2011-DAS-01) on this subject will lead to further detailed evaluations and on the work to be done in this respect.

Fuel Cycle Development:

The use of self-sufficient breeding blankets in DEMO will require the integration of an outer part to the ITER type fuel cycle where large quantity of tritium should be extracted from the breeder and processed for fuel production. A challenge, which must be solved, will be upgrading the present fuel cycle technology to the requirements for DEMO because there are much higher tritium inventories and gas throughputs. The latter is a special challenge for fuelling and vacuum pumping systems.

Some effort has been devoted to in the past to understand the impact to adopt a complex the fuel cycle proposed for ITER in DEMO and the benefit to implement simplifications in order to mitigate the needs to process huge amount of exhaust. The possibility to develop pumps that allow for exhaust separation would mitigate the requirements on the tritium reprocessing plant.

Work in 2012, an effort should be made to organize initial work in this area vis-a-vis design requirements to be discussed and agreed. It is expected that the assessment conducted in 2011 (WP2011-DAS-01) on this subject will lead to further detailed evaluations and on the work to be done in this respect.

Estimated resources: 2 ppy in 2012 + 40 KEuro for pumping hardware.

f. REMOTE MAINTENANCE

The development of remote maintenance schemes for DEMO and future fusion power plants is driven by the following key requirements: (1) feasibility and reliability of the maintenance schemes, (2) high machine availability, resulting in a maximum duration for the execution of the various maintenance operations and/or the need to carry out several maintenance operations in parallel. This work is particularly crucial because the ITER maintenance scheme for in-vessel components is not reactor-relevant, so that novel maintenance concepts must be developed and validated for use in DEMO. Although not directly relevant, several important lessons will be learned from RH activities in ITER and in JET. It will therefore be essential to establish and to maintain close links between the persons involved in the DEMO remote handling activities and their colleagues in JET and in ITER.

A preliminary assessment has been launched on remote maintenance for DEMO in 2011, mainly to revisit the rationale and technology development assumptions that have led to the selection of some design choices in the past; and to assess their technological maturity and/ or development prospects. More detailed assessment of the proposed schemes are envisioned in 2012-2013. At the time of the preparation of this document these activities are still in progress and findings and recommendations are expected to be available by the beginning of 2012. Therefore, here a generic description of the work needed is given with a tentative allocation of needed resources, notwithstanding that the findings and recommendations of this study will be taken into account in the actual implementation of the work.

The activities to be conducted in the WP2012 and hereafter will include:

- Detailed assessment of the schemes for fusion reactor divertor and blanket maintenance proposed in the past (e.g., divertor cassettes, blanket with larger segmentation than ITER, “banana” blanket handlings concept). Identify strengths and weaknesses and development needs.
- Consider possible alternative schemes to arrive as early as possible at the conceptual definition of DEMO maintenance schemes which may take into account completely different maintenance schemes (e.g., upper divertor and extraction of blanket segments from the bottom of the machine relying on transfer gallery below ground level, easier draining of components, no huge loads suspended during in-cask etc.), with a view to achieve more effective maintenance schemes.

- Carry out preliminary design and R&D work on the problems of connections of in-vessel components (mechanical, hydraulic etc.) following findings/recommendations of studies in 2011.
- Begin studying the ex-vessel and hot-cell maintenance operations and the logistics aspect following findings and recommendations of studies in 2011.
- Begin studying the preliminary definition of the DEMO port plugs. Significant differences are expected between the pulsed and the steady-state devices, so that these 2 options ought to be considered separately.
- Produce radiation map in DEMO (by scaling from similar radiation maps available for ITER) during a plasma pulse and at different points in time after termination of a plasma shot (1hr, 1d, 1w, 1m, 6m). carry out work to refine the radiation map, as per recommendations of studies in 2011.
- Establish RAMI guidelines for all major sub-systems. This activity will be carried out in 2012, and a first interaction with experts in the various fields is foreseen in 2013.
- Define a methodology for the definition of standards. The work to be carried out in 2012-2013 shall be clarified by the assessment in 2011.

Estimated resources: 4 ppy in 2012.

g. STELLARATOR ENGINEERING SCOPING STUDIES

An activity is proposed for 2012 to start a systematic analysis of the following reactor engineering aspects:

- Space requirements for blanket / shield.
- Coil spacing, bend radius, superconductor type and properties; space requirements etc..
- Diagnostic and heating system port and space requirements.
- Remote handling considerations, including remote maintenance requirements and classification of components, remote handling space needs.
- Costing algorithms for stellarator components.

In addition, concepts should be identified that make qualitative improvements to reactors.

Estimated resources: 2 ppy in 2012.

h. ADDITIONAL TOPICAL STUDIES

New studies are also foreseen on the following topics.

- Plant availability
- Thermal efficiency and balance of plant::
- Engineering scoping studies of a Component Test Facility. The concept of a Component Test Facility (CTF) has been proposed in order to alleviate the qualification testing requirements in DEMO and to speed up the fusion development schedule. As was recommended in the Facilities Review Panel Report, and the DEMO ad-hoc Group a study of a CTF should be considered focusing on the most critical issues, which include:

- an evaluation of the mission of a CTF in the programme, aimed at risk reduction and acceleration in the DEMO phase;
- the analysis of the technical characteristics of a CTF and a feasibility study, in particular on the problems of power handling (divertor in particular), current drive requirements, need for tritium breeding availability and maintenance.
- Remote handling considerations, including remote maintenance requirements and classification of components, remote handling space needs.
- A comparison of different CTF design concepts available should be conducted to identify: strengths/ weaknesses of the various options.

Estimated resources: 5 ppy in 2012.

IV.3.1.5. MATERIAL R&D AND MATERIAL ENGINEERING DATABASE ACTIVITIES

The activities on materials in 2012 are oriented toward the start of a compilation of a material database, primarily on structural materials, for engineering assessments and design studies and material R&D activities. The latter, as in the previous year will remain focussed along the following four main lines: 1. Tungsten and Tungsten alloys; 2. Oxide-dispersion-strengthened ferritic steels (OFDFS); 3). Silicon-carbides; and 4. Modelling

It is also assumed here that the development and qualification of EUROFER ferritic-martensitic steel for in-vessel components are carried out by F4E as part of the ITER TBM Programme.

The breadth of the structural material program for DEMO needs to be carefully reviewed at the end of the pre-conceptual design phase to determine the actual material qualification needs, and in particular the material irradiation programme needs and facilities available.

a. MATERIAL R&D

a1. Tungsten and Tungsten alloys

In order to optimise the output of the program, some investigation areas are considered to be completed and others have to be intensified as follows:

Fabrication

Machining parts by standard mechanical as well as by electro-chemical methods has been demonstrated as possible for all tungsten materials and therefore, further investigations are not necessary. Mass fabrication process development (powder injection moulding, deep drawing/bending) are promising and shall be continued. The joining process development (W to W and W to steel) has not been successful so far with respect to low activation brazing materials. Therefore, the low activation criterion will be released as much as necessary. Diffusion bonding (W to steel) has been shown to be feasible with a vanadium layer at maximum 700°C which is the end result for this task. Explosive bonding and gradient materials seem to be too difficult to be applied to structural components. Therefore, these topics are not further followed. Pulse plasma sintering, however, is a promising alternative to brazing and has to be developed and investigated more in detail.

Divertor mock-up

Up to now, the finger module with helium jet cooling (steel pipe, tungsten thimble and armour on top) was used as reference/test case for the whole program. Due to many open questions and a still missing general divertor design, a concentration to such a specific part could be a constraint which would then probably prevent the follow-up of other possible options. Therefore, the 2012 program works without a specific test case. This should open the way for more or different joining solutions.

W as structural material

Here, the improvement of ductility is still one of the most pressing issues. Three methods were followed so far: (1) alloying (solid solution), (2) nano-structuring, and (3) composite materials. The improvement by alloying was not successful so far. The remaining options will be tested in 2012. From the nanostructuring processes only the powder-metallurgical route could be upscaled to industrial fabrication. Up to now, only Kurishita (Japan) was able to produce a more ductile tungsten alloy. Therefore, the only remaining and promising method which needs more investigation efforts is the development of composites. Missing data for the structural tungsten materials still include long-term recrystallization/grain growth, long-term creep, and low cycle fatigue.

A specific decision point is recommended by the end of 2012 to continue or not the activity in this area.

W as protection material

High power test of new tungsten alloys in e-beams and i-beams are planned and are described above.

To promising self-passivating alloys. Has been identified as part of the development programme. In 2012 the application of these materials will be demonstrated after production of larger amounts by intensive material tests.

Irradiation performance

The key point in using tungsten for structural components is in knowing its irradiation behaviour depending on temperature (DBTT shift and annealing). Unfortunately, no data are expected in 2012 from external programs.

Material science and modelling

The plasticity studies for the case of W-Re are almost finished and have delivered important answers. Micromechanical tests are further applied to study irradiated specimens.

The multiscale approach to simulate irradiation damage is continued as well as the validation experiments (JANUS, etc.). The refinement of transmutation/activation codes is also continued and applied to specific topics (brazing, divertor components).

a2. Oxide-Dispersion-Strengthened Ferritic Steels (OFDFS)

The main objective of the effort in this area is to produce optimized ODSFS material with a well defined chemical composition, fabrication route and a set of thermo mechanical treatments.
The following activities are proposed for 2012:

- Production and characterization of batches (laboratory and Industrial fabrication) of up to 15-20 kg of nano-structured ODSFS. The main goal is to identify the optimal chemical composition, fabrication route and thermal mechanical treatments combination.
- Irradiation and post- irradiation characterization of produced nano-structured ODSFS. The main goal is to investigate the effect of dose and temperature on hardening and the stability of oxide particles in the grain boundaries.
- State of art of nano – structured ODSFS: Bibliographical review. The main goal is to review and to evaluate the results obtained by USA and Japan in developing this kind of materials

a3. MAT- SiC_f/SiC Composites

The objective of the R&D in this area is to develop a reference SiC/SiC -based composite focusing mainly on porosity, gas permeability and thermal conductivity at high temperature.

As indicated in the EFDA 2011 Work Programme (EFDA (10) 45/4.1.1), activity on SiC/SiC composite will be assessed by the end of 2011 and a decision should be made to continue or not R&D in this area under the EFDA PPPT Programme,

In view of this decision, and with the sole scope to anticipate resources that would be needed, the activities to be foreseen for 2012 are:

- Definition of a fabrication route for an optimised SiC –based composite The main goal of this activity is to find a fabrication route and preliminary manufacturing trials to be able to produce a dense, SiC-based composite with closed porosity using elements with low neutron activation and potentially low irradiation effects
- Optimization of thermal conductivity of SiC fibres to be able to reach working temperatures around 1200 °C
- Understanding basic defect formation mechanisms in SiC.
- Radiation effects in EU reference SiCf/SiC and 3D WSiCf/SiC composites. This would consist of evaluating the results of the FURIOSO irradiation experiment.

This is expected to require ~15 kEuro in addition to 1-2 ppy under priority support,

Material modelling

In 2012 MAT-REMEV will focus on two main objectives: (1) modelling microstructural evolution of EUROFER under neutron irradiation *and* (2) modelling more general radiation damage effects in general. The specific questions to be addressed are:

- The origin of low-temperature radiation embrittlement, and the transition to no-embrittlement microstructural evolution mode, which occurs in the temperature interval from 300 to 400°C.
- Development of a model for radiation-induced swelling of EUROFER, where the peak swelling rate in pure iron corresponds to the same temperature range: 300 to 400°C.
- Development of a model for quantitative assessment of helium embrittlement effects, including the development of a model for helium segregation at grain boundaries and dislocations, assessment of critical dose, and quantitative assessment of experimental data (spallation sources etc) on helium-assisted fracture.

In particular the following points must be clearly addressed

– *Interatomic bonding and phase stability.* This requires modelling vacancy-mediated high-temperature α′ and σ-phase precipitation, including the competing effects of radiation mixing and phase decomposition in high-Cr alloys.

– *Radiation damage accumulation and evolution of microstructure.* This requires a model for the segregation of helium to the grain boundaries and dislocations and a model for following the microstructural evolution of dislocations under irradiation and thermal recovery.

– *Deformation and plasticity.* This includes the development of a model for dislocation plasticity of irradiated iron, FeCr alloys, and steels. Model for fracture of irradiated materials, including effects of α´ precipitation and interaction with ODS precipitates.

– *Experimental validation of models*, by means of dual/triple ion beam variable temperature/dose rate irradiation experiments, and *in-situ* electron microscope examination of microstructure, thermal recovery experiments, helium migration analysis, related to segregation of helium to grain boundaries, dislocations, and free surfaces, atom probe tomography on irradiated model alloys and steels.

Estimated resources: 12 ppy and 220 kEuro in 2012.

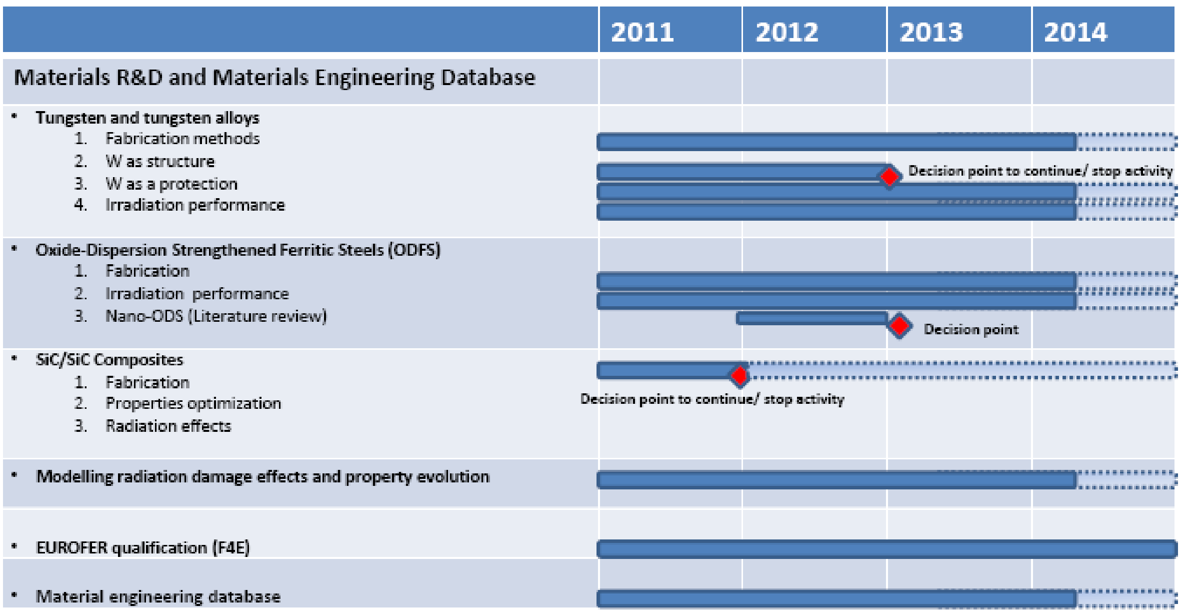
b. MATERIAL ENGINEERING DATABASE ACTIVITIES

An activity has been launched as part of the EFDA Power Plant Physics & Technology Work Programme 2011 to review the material database status and need for DEMO Conceptual Design Activities. The main goal of this activity is the preparation of a preliminary DEMO material assessment report, which gives the justifications and includes the recommended properties to be used for the design analysis and identify areas of uncertainties and conditions (relevant to the design) where data are instead either missing or unreliable.

This activity should be continued in 2012

- to consolidate the findings of the report, to continue the review the database in areas where uncertainties where identified in 2011 and provide guidance to the R&D to fill the gaps, especially in areas and materials which are important for the conceptual design activities.
- In addition, some effort is anticipated to establish a dialogue with International Partners to arrive at a common database, including also materials, where in Europe knowledge is rather limited (e.g., Vanadium).

Estimated resources: 2 ppy in 2012.



Fig, iv.6. Timeline for activities on Materials

IV.3.1.6. SOCIO-ECONOMIC RESEARCH ON FUSION (SERF)

Socio-Economic Research on Fusion aims (i) at increasing the visibility and credibility of fusion energy as a sustainable energy source, (ii) at developing tools in support to the governance of such a complex project as fusion technology development for energy generation, as well as (iii) at understanding social (cultural, organisational, political etc) factors which constraint this project successfulness. In line with the recommendations of SERF AHG endorsed by EFDA SC in 2008, the SERF programme should have clear objectives, increasing level of coherence, multi-years goals, more collaborative actions among associations and increased links to universities as well as increased integration of the new EU members.

In 2012, similarly to what has been done in precedent years, the SERF activities will be structured in two parts (even if some activities initiated under 2011 successfully integrated both parts): Sociological and anthropological studies (1) and Energy scenarios (2)

a. SOCIOLOGICAL AND ANTHROPOLOGICAL STUDIES.

Some new lines of research implementing the above programmatic objectives and entailing collaborations with universities, contemplated as multi-year activities, were launched under 2010 WP. Scoping studies have been completed between March and June 2011 and their appraisal and discussion are in progress. The Task Agreement regarding the activities proposed for 2011 will be finalised by August.

In this situation, the description of the activities to be implemented in 2012 can only be of preliminary nature, and will have to take into account that both the objectives previously established and the associations capacities to reach them will have to be weighted up in the light of the 2010-11 achievements. New research questions will also likely be formulated as the result of this assessment.

It must be stressed also that (as it results from proposals submitted to the recent Call (WP11-SER-AIF) and from numerous communications with the responsible officers) the Associations have problems with implementing SERF activities which always require external experts' participation (EURATOM associates rarely have sociologists or anthropologists among their staff) under baseline support only, especially in the situation in which also this support is currently restricted. In fact, many activities successfully initiated under 2010 in collaboration with universities risk to be ceased due to lacking resources, which put in risk the programmatic goals achievement. This especially is the case of collaborative projects requiring scientific coordination by university researchers – the activities considered to be the most valuable.

This part of SERF has two branches: (1.1) activities in support to communication and stakeholders engagement and (1.2) activities addressing socio-material networks of fusion RTD with the special focus to ITER.

a.1 Studies in support to communication and stakeholders engagement

The objective of these studies is to enhance the social representation of fusion energy by providing the evidence-based advice for EFDA communication strategy. The following activities are foreseen:

- An activity aiming at exploring and enhancing fusion awareness among informed members of civil society with the special focus on stakeholders belonging to the research-policy interface. It will be a continuation of the ISAF project (however, not necessarily focused on "integrated sustainability assessment") which, under 2011 WP is performing a policy supportive study examining the usefulness of EFDA TIMES model as the decision support tool in the context of energy governance and policy designing. This activity will employ the action-research approach which combines exploration of the reality with social intervention.

- Analysis of the public discourse on fusion energy diffused through various channels (press, internet) and creating the public image of fusion energy, ITER and its "social field" (actors, their interrelationships, goals, interests etc). This will be a continuation of 2010-11 tasks (which confronted the "externally" and "internally" generated discourse on ITER), employing the same methodology to allow comparative analysis, including new data bases, analysis of trends and in depth studies of selected topics. This activity will allow critically discussing fusion community communication effort and indentifying untapped communication resources.

- Assessment of the social impact of the selected EFDA communication actions' with a special focus on Fusion Expo. This activity, following the example of many museums and science centres and aiming at both scholarly and practical goals, will be carried out in various places where the Expo is going to be deployed, in order to enable inter-national comparative analyses. An assessment tool – a standard research protocol will be proposed to allow a relatively easy Fusion Expo impact assessment in various locations.

a.2 Studies addressing Fusion RTD networks

The fusion energy success depends on not only scientific and technological but also on social (organisational, cultural, political) constraints. The studies belonging to this branch of SERF, following the topics and methodologies of the Social Studies of Science, aim at understanding these constraints.

Special attention is addressed to ITER organisation: the scoping study conducted within 2010 WP showed that that, being a meeting point of many different national, organisational and professional cultures, the social reality of ITER is very intricate and the processes of creating its structure and identity are problematic. This activity will address these processes, employing both ethnographical and sociological research tools.

Studies in other organisations collaborating to ITER and addressing distributed cognition and problem solving, as well as the resources which are mobilised to cope with their complexity, are also foreseen. This will allow monitoring the socio-material network of fusion research and development from many points of view.

Estimated resources: 1 ppy PS + (7 ppy BS) in 2012.

B. ENERGY SCENARIOS - EFDA TIMES (ETM)

The long term objectives of this activity are:

- develop long-term energy scenarios containing fusion as an energy option and showing the potential benefits of fusion power as an emission free energy source;
- gain visibility, credibility and recognition by contributing with these scenarios to the international scientific energy debate;
- bring the fusion option into other long-term energy models, by making available the latest technical, economic and environmental dataset on future fusion power plants;

- Exploring the conditions that make fusion a successful contributor to sustainable energy systems; and
- provide domestic and European decision makers with analyses and arguments in support of the potential benefits of ITER and longer term fusion R&D.

These objectives will be pursued by the exploitation of the EFDA TIMES model that now can be considered an established modelling tool and the major part of improvements to the model proposed in the multi-year programmatic guidelines (presented together with 2011 ETM WP) are in progress.

Within 2012 it will be desirable to complete the model enhancements foreseen in the above mentioned guidelines, namely:

- introduce Risk Parameter and Risk Indicator variants to EFDA TIMES to allow identification of the technology combinations which achieve acceptable compromise between risk and cost and to prepare trade-offs scenarios; introducing of the Myopic Variant and the Cost-Benefit Analysis (value-flow) routine - all these options already available in TIMES;
- switch to a final energy demand driven model (instead of having a model driven by energy services demands) which would simplify the model, enable to analyse more scenarios, and make it possible to run more complex variants
- introduce Endogenous Technology Learning variant, which will allow to fully exploit the power of a technology rich model like EFDA TIMES, making it easier, for ex. to analyse the competition between fusion and renewable energy sources.

Further model exploitation requires assistance for software updating and management to be achieved by mean of a contract with Kanors - the developer of the software (a similar contract has been set up in the past by EFDA); this agreement would guarantee immediate assistance to all the partners related to new functions introduced to the software as well as the immediate support in modelling problems related to the completion of current tasks.

Apart from the above improvements, it is necessary to enhance the ETM results' diffusion, and 2012 efforts should be focused in the first place on the model exploitation and the diffusion of its results among other modelling communities, potential end-users of the model and among the selected segments of civil society. This activity will again integrate the two parts of SERF.

Estimated resources: 1 ppy PS and 7 ppy BS in 2012 + 5 kEuro for software updating and management.