PPPT PMU – Strategies, Achievements & Outlook

Draft v1.2

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1 Document Scope

The scope of this document is:

(1) To provide an overview of the key strategies that are being pursued by the PMU[1] in order to fulfill objectives listed in [1]. The document is not however, a formal status accounting report, but rather intends to provide orientation to the key strategic themes of the programme and to highlight some of the achievements and progress in these areas.

(2) To emphasize the importance of the design integration approach to explore the available design and operation space taking into account the high degree of system integration/ complexity/ system interdependencies and uncertainties and finally to strengthen the pivotal role of the central team (architect engineer) and to provide some examples of trade-off studies with multi-criteria optimizations.

(3) To concisely summarise some of the working issues that the PMU has identified in coordinating the activities, and bring attention to areas where there is concern that these issues may put some objectives at risk.

2 Referenced Documents

[1] Overview of PPPT implementation 2MMYSK,

[2] Overview of the design approach and prioritization of R&D activities towards an EU DEMO, G. Federici, et al., Fus. Eng. Des. (2016) in press, doi:10.1016/j.fusengdes.2015.11.050

[3] Report of the DEMO Stakeholder Group v1.1 2M6VKJ

[4] Briefing paper: Euro-Fusion / ASTRID & MYRRHA Programme Discussion outcomes as part of DEMO stakeholder process 2MWUA7. Revised DEMO Design and Development Plan (As part of the update of the EU Roadmap to Fusion Electricity) 2N2FJB

[5] On the EU Approach for DEMO Architecture Exploration and Dealing with Uncertainties, Coleman M., et al., Fus. Eng. Des. (2016) in press, doi:10.1016/j.fusengdes.2015.12.063

[6] Advances in the physics basis for the European DEMO design, R. Wenninger et al., Nucl. Fusion, Vol. 55, num. 6, April 2015.

[7] DEMO Stakeholder Group Meeting #2 Minutes v1.0 2LWRTQ

[1] In the reminder of this document the use of the word Programme Management Unit (PMU) refer solely to the part pertaining to the Power Plant Physics and Technology Department.

3 PMU Strategies & Achievements

The full scope of the PMU objectives are described in [1], whereas and overview of the design approach and prioritization of R&D activities towards an EU DEMO is described in [2]. The purpose of this section is to summarize some of the core strategies of the PMU that support the fulfillment of these objectives and the achievements in these areas. The strategies that are covered in this document are the following:

- Establishment of an integrated baseline plant concept
- Development strategies for coping with uncertainties
- Implementation of traceable decision making and management of design options
- Implementation of the programme management & coordination function

3.1 Establishment of an Integrated Baseline Plant Concept

Fundamental to the PPPT DEMO design development strategy has been the establishment of high level requirements, engaging a DEMO Stakeholder Group[2] [3,4], and the definition of a baseline architecture that integrates all the major DEMO sub-systems into a coherent plant concept, consistent with the present physics assumptions. The establishment of the baseline architecture, and the integration and coordination of the design activities in the distributed projects, has been the responsibility of the PMU, but has only been possible through the contributions of the distributed Work Programmes (WPs) and from industry. This philosophy, of developing systems design in a holistic, integrated fashion is a fundamental principle of the Systems Engineering approach.

The baseline plant architecture design is continually evolving, being updated as new information comes to light, but it represents the current 'best' option and acts as a central reference point to all contributors. In particular, work is focused to find robust integrated solutions to the problem of the power exhaust, power conversion and tritium breeding that all bear a strong impact in the selection of the technical features of the device and the operating conditions of the coolants and materials. The experience gained so far has shown integration is key. This was the original hypothesis and basis of the early PPPT progamme and the roadmap, and it has been more than confirmed by all the work done. By postponing integration assuming that it restricts innovation and inhibits an attractive DEMO plant is risky.

The processes that support the baseline documentation and evolution require further maturation, but progress to date represents a significant achievement over anything achieved previously. This philosophy of integrated design at an early stage has proved successful, in that it has encouraged a more 'systems orientated' way of thinking, and in the process brought major clarity to a number of critical design issues, and the overall integration challenge, as briefly summarized below:

- **Improved understanding of system context:** Integrating the systems in a baseline plant architecture has encouraged system designers to seek a more thorough understanding of the context of their systems, including interactions, interfaces and impacts on other plant systems.

[2] Key to the success of any technology development program is the early and continuous engagement of technology stakeholders to ensure that the work conducted is valuable to the eventual adopters of the technology. A DEMO stakeholder group was established with experts from industry, utilities, grids, safety, licensing and operators to focus early on fusion energy research and development needs to address utility, regulatory needs and to establish from the very beginning realistic top level requirements for the DEMO plant in order to embark on a self-consistent conceptual design approach. A Stakeholder Group report has been produced. This can be summarized as dictating the principle missions for the current DEMO programme as being: (i) safety and environmental sustainability; (ii) plant performance; and (iii) assessment of economic viability. Before embarking on a stakeholder engagement process, a number of meetings were held with advanced Gen-IV Fission projects such as ASTRID and MYRRHA and we are very grateful for the advice and observations that they have made [4]. The main lessons learned were that the plant design should essentially drive the R&D and that fusion is a nuclear technology and as such, will be assessed with full nuclear scrutiny by the regulator.

This more holistic design approach helps to reduce integration risks, and to reach the most advantageous compromises when requirements come into conflict.

- **Identification of critical interface issues:** The integrated design approach has enabled the identification and analysis of critical interfaces, where major technical risks have been identified that are now being addressed through exploration of alternative design concepts and supporting R&D. For example, analysis of the plasma first-wall interface has highlighted a significant risk that the first wall heat flux during normal operation and off-normal transients may be beyond the capability of current technology selected to enable tritium breeding on the largest fraction of the main chamber wall. This has motivated the start of the exploration of alternative plant architectures (e.g. double-null), in order to mitigate this risks that may radically alter the plant design architecture. Critical interfaces between WPs of both design (e.g. breeding blanket and remote maintenance) and programmatic/R&D (e.g. WPMAT and WPBB/WPDIV) nature are also coordinated and monitored by the PMU.

- **Establishment of an 'integration culture':** At the level of the major WPs, there is now a much greater appreciation of the need to understand interface requirements and the impact of design choices though engagement of systems designers outside of their local domain. There has been a progressive improvement in horizontal communication between WPs, and mutual understanding of issues. This is expected to improve further in 2016, through appointment of Systems Engineering Points of Contact (SEPOCs) in each WP who will become the domain expert in Systems Engineering and 'systems thinking'.

- **Plant Optimization studies:** DEMO is a highly interdependent system where there is strong coupling between plant and system parameters and design implementation. A number of optimization studies have been carried out (with support from tasks in the WPPMI) to investigate how some of the cardinal machine or physics parameters impact the performance of the overall architecture. The insight gained from these studies has provided more confidence in the design point, and has also motivated several design architecture changes that seek the optimal balance between competing design parameters. A summary of the current machine parameters and a list of recent optimization trade-studies is provided in Appendix A.

- **Assessing impact of technical risks and innovation**: Having an established baseline concept design allows a more complete understanding of how technical risks (or indeed, innovation) may impact the overall plant architecture. This enables the most high impact areas for design improvement to be targeted, and followed up with more detailed studies/feasibility investigations so that resource is allocated most effectively.

3.2 Developing strategies for coping with uncertainties

From the outset it has been recognized that one of the major challenges facing DEMO design is the ability to deal with significant parameter uncertainties that are characteristic of relying on unproven technology and plasma scenarios that cannot be fully validated. The PMU has therefore taken significant efforts to develop strategies for dealing with these uncertainties, but still allow the integrated design and supporting technology R&D to proceed independently, but still be relevant if design parameters change. A detailed explanation of this approach with supporting case studies is presented in [5], and a summary of some of the key elements to this strategy are presented below:

- **Plasma sensitivity studies:** plasma sensitivity studies have been carried out (with supporting tasks in the WPPMI) that have identified some of the plasma parameters that will most significantly affect the machine design parameters and magnetic configuration and plasma performance. This work has highlighted that relatively small changes in underlying physics assumptions for certain parameters can result in significant impact on the plasma and plant performance (e.g. divertor heat load, plasma elongation and triangularity, P_{LH},) [6]. The selection of the operating scenario is recognized to be an outstanding issue for a DEMO fusion power plant requiring a significant increase in experimental and theoretical effort to find a consistent solution with confidence in the performance and reasonable margins for the uncertainties.

- **Establishment of an adaptive design approach:** Acknowledging that the baseline design point may need to be modified as more information comes to light, the PMU's philosophy has been to create systems design teams that are capable of creating and analyzing consistent designs around any given point in the design space (with due consideration of technology constraints), and manage design changes efficiently.
- **Parallel development of alternative design solutions:** It has been a priority to benchmark performance limits and identify technical feasibility issues associated with particular technology or design options, and consider alternative designs that could be substituted if the baseline system performance is deficient to meet the overall plant requirements. For example, at systems level, in WPBB, multiple Breeder Blanket concepts are being developed in parallel for eventual down selection to the most promising concept. At plant level, the PMU is investigating Single Null and Double Null configurations to evaluate the respective advantages and risks on the overall integrated plant design.
- **Architecturally independent R&D:** many of the WPs are working on developing technological solutions for components and systems, the results of which are applicable to a wide variety of overall plant configurations and can, to an extent, be decoupled from the architectural and design investigations. Examples include breeding blanket module optimisation and manufacturing studies, divertor high-heat-flux target development, superconductors winding packs, tritium technologies.
- **Identification of critical R&D through plant concept development:** Recommendations that have emerged from consultations with the DEMO stakeholders and the GEN IV programme are being taken into account and the PMU is in the process of implementing an integrated risk management approach, whereby the design and R&D programme will be orientated to respond to major technical risks identified in the baseline. Qualification of critical design aspects through critical R&D (e.g., qualifying the RH concept) is recognized to be fundamental to the credibility of the machine architecture at the conceptual phase. The assessment of the attractiveness of candidate DEMO plant options must consider upfront the technical assumptions being made in plasma physics and technology and evaluate, with the support of industry their feasibility, technical readiness level, associated development risks, and development cost and schedule (see Sect. 3.3).

3.3 Traceable decision making & management of design options

The PMU as overall design integrator must undertake decisions with rigor and traceability, balancing numerous competing objectives and ensuring that the rationale is consistently recorded. Furthermore, through application of a Systems Engineering methodology, the logic of the design must be traceable from the high level Stakeholder requirements, through to the functional architecture, and the physical implementation of the design. Aligned to these philosophies some of the key strategies and achievements are presented below:

- **Establishment of Stakeholder Requirements;** establishing stakeholder requirements & objectives provide the basis through which the technical requirements of the design are derived and referenced against. The PMU (with support from the WPPMI) has therefore engaged a DEMO Stakeholder Group (SHG) to agree high level requirements for DEMO. These requirements and the supporting rationale have been recorded in a DOORS database (see below). Associated with this, will be the derivation of a stakeholder ‘value hierarchy’ which is the basis around which design & programme decisions should be orientated

- **Implementation of the DOORS requirements management database;** The implementation of the DOORS requirements database provides a single reference point for all technical requirements on the project for requirement traceability and clear allocation of requirements to logical systems. A further key advantage of formally recording all requirements in this database is that the rationale behind each requirement can be recorded, and that changes to requirements can be controlled and tracked.

- **Implementation of traceable decision making approaches;** The PMU is in the process of developing a decision making framework to assist in concept screening and down-selection at plant level, and ensure that decisions are aligned to stakeholder values. It should also be noted, that the projects should be commended for their proactive approach in implementing such methods in selecting their technology and design choices.

- **Industry technology maturity assessments;** The design implementation and technology decisions must take account the development risks associated with the technology. A first step is TRL assessments, but this must be interrogated further through identifying major technical risks, development costs, and schedule estimates associated with a technology option. The PMU have identified that this is a key area, where industry can play a crucial role, and has launched the first phase of a task in 2016 to invite industry to perform technical risk, cost and schedule estimates for selected technology options. This will form a key input into the integrated decision making process.

3.4 Programme coordination & management

It is true for any large engineering endeavor, that the project management and technical coordination of a distributed design team presents significant challenges to the central design and project coordinator. The challenge is further exacerbated in the case of PPPT due to a number of factors including; (i) the fundamental challenge of organizing design activities on a device that has little precedent or established example to follow; (ii) the need to balance design progress against innovative R&D; (iii) the need to lead the transition from an R&D to a more deliverables orientated project culture; (iv) the establishment of the project and technical management processes of a new coordinating organisation.

Consequently, the PMU has invested significant effort to develop and instill a strong project management culture in the project, and to attempt to achieve consistency in project and technical management process. To fully realize and mature this approach will take time, but the PMU has made good progress with establishing the fundamentals, and insisting on strong project management from contributors at all levels. Some of the cornerstones to this approach are summarized below:

- **Establishment of a PPPT Management Plan (PMP):** This PMP contains a complete description of the processes and procedures employed by the PMU to execute project management and control across PPPT. It clearly defines the roles & responsibilities associated with all processes, to help ensure smooth implementation and accountability. This will serve as the key document to harmonise approaches across the programme.

- **Establishment of a PPPT Technical Management Plan (TMP):** This TMP defines how the engineering development of DEMO shall be managed during the Pre-Conceptual and Conceptual Design Phase (CDA). It describes the technical management processes to support the design and technology management & maturation process required within a Systems Engineering Framework. It elaborates in more detail the technical processes and principally describes the processes that control & manage the engineering activities.

- **Development of WP Project Management Plans:** The PMU invests significant effort to support WPs in development of their PMPs and overall project management approach, to encourage a deliverables orientated culture, and to harmonize project process across all WPs.

- **Development of an integrated schedule:** the PMU (with support from the PMI) has made progress towards establishing an integrated schedule, through asking each WP to provide high level milestones (such as key decisions) and schedules. In 2016, the schedules will be collated and harmonized to create the integrated schedule[3].

- **Engagement with Industry:** The PMU has identified that valuable lessons can be learnt in the management of large projects through direct consultation and engagement with industry. Several engagement have taken place to date, that have yielded important lessons in project management from interactions with the Gen VI Community and the DEMO SHG [3][4].

4 PMU Implementation Issues

In being accountable for the stewardship of the DEMO Design Development and supporting R&D, the PMU faces significant challenges in steering a geographically distributed R&D community towards a centralized and focused engineering effort. This presents the R&D community with a more constrained and requirement driven environment than it is perhaps familiar with. Additionally, the need to focus on the DEMO Design Development objectives will inevitably, at times, come into conflict with the objectives and interest of some of the Research Units, and yet without their support and contributions to the programme, it impossible to envisage how the programme will succeed. The PMU therefore has a difficult balancing act to follow between focusing on pursing the most pressing design objectives, and balancing the input and concerns of a multitude of stakeholders.

As a relatively young organization, it is natural that the PPPT organizational structure will need to be updated and evolved to respond to working difficulties, and to adapt to the changing nature of the design activities as the design matures. Presented below is an overview of some issues that are leading to working level difficulties, where there is emerging concern that come of the core objectives of the PPPT may be at risk.

- **Design direction:** The PMU has accountability for the integration of the full DEMO plant design, and must ensure that a consistent and credible DEMO concept design is developed taking into account the overall DEMO plant requirements and the findings that emerge through execution of the distributed Work Packages. The lack of a **clear project ownership** and **design authority** have however been perceived from DEMO SHG [4] as potential risks for the implementation of the DEMO design process being undertaken by EUROfusion. As DEMO is a very holistic system, the PMU must be able to steer the design direction at WP level – since system level design and technology choices have a major impact on the integrated plant design. In steering the design direction, PMU requires the input and assessment of independent technical experts who must perform a role of challenging and interrogating design assumptions, but the PMU must be able to mandate the agree design direction through to the WPs.

- **R&D direction:** The PMU as integrator of the plant design, must have oversight of the technical risks and key integration decisions across all elements of the plant – and it is this understanding that should enable the PMU to set the major R&D/feasibility studies and the levels of resource assigned to them. However, in certain instances, there is a misalignment between project needs and strategic interests of the involved RUs and an implicit influence exerted through from the RUs as to what R&D activities should be prioritized – hence it cannot be assured that these are the activities that are most critical for supporting the integrated plant design.

[3] Accounting for impacts of the revised roadmap

- **Lack of a project culture:** Many investigators are not fully familiar with a deliverables-oriented project culture, as they originate from an R&D oriented environment where 'best efforts' is a typical culture. This leads, in some cases, to inefficiencies in task completion as well as in task coordination leading to scope creep causing; (i) delays to progress in critical areas of design; (ii) major areas of technical uncertainty left unresolved; (iii) unsatisfactory quality of the deliverables. Additionally the lack of familiarity with project and technical management processes that are necessary for the PMU to implement effective project and technical control, places additional strain on the ROs of the PMU as they have to invest significant time and effort in coaching project contributors to comply.
- **Fragmented resource pool:** The WP leaders must utilize resources from a fragmented resource pool, where skills and capabilities are distributed in the various RUs. There are gaps in the resource pool and there are also areas of overlap in capability and strategic interests between RUs. This leads to problems including; (i) there are not the skills available to support some activities (ii) in trying to satisfying the interests of all the RUs, there is duplication between tasks; (iii) the WP leaders must try to coordinate tasks that are split amongst multiple institutions – significantly increasing the administrative and coordination efforts and increasing the risk of divergence or inconsistencies in the design.
- **Lack of resources in the PMU and WPPMI:** The PMU currently does not have adequate resource to perform *both* physics & technical design integration *and* project control effectively[4]. This leads to a situation where PMU ROs spend the majority of their time focusing on project control, at the expense of their technical integration responsibilities. As a result, the integrated plant design & technical coordination of the projects suffers, increasing the risk of inconsistent definition of boundary conditions for the system design and uneven levels of progress in each system design. Furthermore, the PMU has very little in-house design or analysis capability compromising the guidance in overall technical direction that PMU should be able to provide to the projects. Whilst having a small central PMU office goes some way to integrating and coordinating the work being carried out, this approach pales in comparison to the capability and efficiency that a single design team hosted under one roof would have.
- **Difficulties in securing industrial involvement**: The need for industrial engagement in the various DEMO design and development phases, from pre-conceptual design to construction have been identified in the Roadmap. However, to date there have been difficulties in securing industrial involvement in DEMO activities and acquiring relevant industrial effort in a timely manner in order for it to have meaningful impact. This is due to a number of reasons including; (i) a convoluted 'double-tiered' tendering process that adds time and cost overhead; (ii) a piecemeal annual allocation of small lots of industry tasks; (iii) restrictive contract conditions that are not of interest to established industrial organizations of the required competence. This must be resolved through more streamlined contract award processes, and employing more appropriate contract instruments (e.g. a professional services framework contract).

[4] It should be noted that the PMU is accountable for the development of the DEMO physics basis. However, significant gaps and uncertainties exist in DEMO physics, which need to be closed to substantiate DEMO design evolution. Manpower for DEMO physics integration in the PMU at the moment is very limited and the PMU is reliant on external physics expertise. This leads to relatively long turnover times between the definition of the problem and the presentation of the results of analysis and or experiment. A solution to this problem and more in general a solution to improve the focused involvement of the fusion community to address the priority physics issues for DEMO is required.

5 APPENDIX A - Summary of current machine design options and examples of design integration trade-off studies

In ref. [3] we present some preliminary design choices/sensitivity studies to explore the design space, identify attractive design points and understand the implications on technology requirements and plasma physics basis development needs (see Fig. 1). These are not intended to represent fixed and exclusive design choices but rather “proxies” of possible plant design options to be used to identify and address generic design interface issues that need to be resolved in future fusion reactor systems.
Design features now incorporated in the initial conceptual design work are listed in Table 1. Open design choices where a decision is expected to be made at a later stage are shown in Table 2.

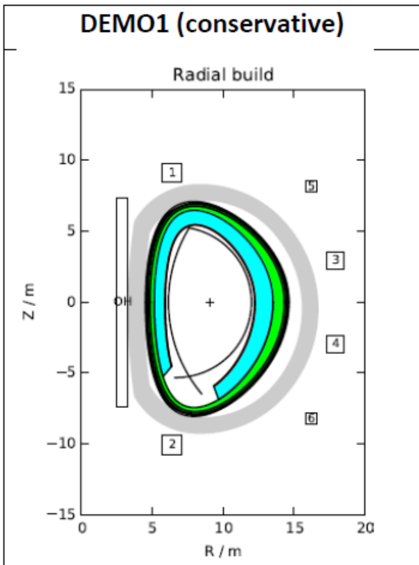
Table 1 Preliminary design features (EU DEMO 2015):

- 2000 MW_{th} ~ 500 MW_e
- Pulses > 2 h
- Single-null water cooled divertor; PFC armour: W
- LTSC magnets Nb3Sn (grading)
- B_{max} conductor ~12 T (depends on A)
- EUROFER as blanket structure and AISI 316 for VV
- Maintenance: Blanket vertical RH / divertor cassettes
- Lifetime: starter blanket: 20 dpa (200 appm He); 2nd blanket 50 dpa; divertor: 5 dpa (Cu)

Table 2 Open design choices where a selection is expected to be made by the end of the concept design work

- Operating scenario
- Breeding blanket design concept
- Protection strategy first wall (e.g., limiters)
- Advanced divertor configurations and/or technologies
- Energy conversion system
- Specific safety features, e.g., # of PHTS cooling loops
- Diagnostics and control systems

The integration of our expanding physics knowledge into the DEMO conceptual design will play a crucial role in supporting the design evolution. Incorporating lessons learned from the ITER design and construction, together with early involvement of industry in the design and monitoring process, are needed to ensure early attention is given to industrial feasibility, costs, nuclear safety and licensing aspects.



DEMO1 (conservative)	Parameters	DEMO2 (optimistic)
9, 2.9	R_0, a (m, m)	7.5, 2.9
3.1	A	2.6
5.7	B_T (T)	5.6
20	Ip (MA)	22
1.6, 0.33	k_{95} / δ_{95}	1.8, 0.33
13.0	$<T_e>$ (keV)	18.1
0.80	$<n_{e,vol}>$ ($10^{20}m^{-3}$)	0.87
2.6	Z_{eff}	4.7
4.2, 1.1	t_E, H (s,-)	4.0, 1.4
2	t_{burn} (hrs)	St.-state
35	f_{bs} (%)	61
50	P_{aux} (MW)	133
154	P_{div} (MW)	150
133	P_{LH} (MW)	128
2040	P_{fus} (MW)	3255
500	$P_{e,net}$ (MW)	953
1.1	Av_{NWZ}(MW/m^2)	1.9

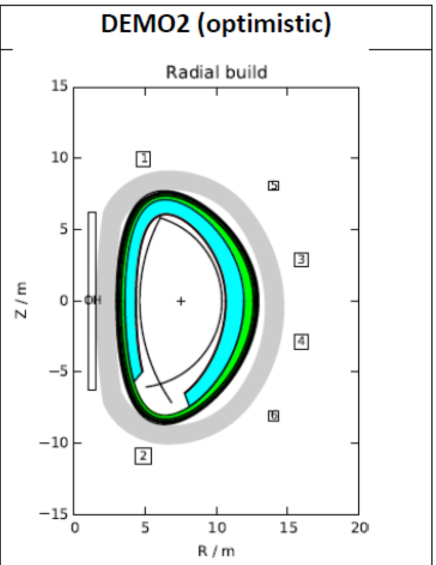


Fig. 1 Preliminary DEMO Design Choices under Evaluation. Both machines assume Nb_3Sn superconductor. Physics performance, divertor heat loads, NBI energies, and structural stress limits are higher for DEMO2.

A number of studies that have strong implications on machine parameter selection and architectural layout have been initiated [3]. They include

- Aspect ratio scan for a fixed P_{el} of 500 MW_e and a pulse duration of 2 h.
- Investigation of the impact of increasing plasma elongation, k, constrained by vertical stability, through optimising for example PF coils layouts and current distributions.
- Investigation of divertor configurations with a lower X-point height and larger flux expansion.
- Assessment of first wall power handling design limits near the upper secondary null point and assessment of the technology and maintainability requirements of the solutions proposed.
- Investigation of the potential of a double null (DN) configuration: advantages (e.g., higher plasma performance with improved vertical position control, and reduced machine size) and disadvantages (e.g., T-breeding, compatibility with proposed blanket vertical maintenance scheme, integration of upper divertor, etc.).
- Investigation of divertor strike-point sweeping, including technology issues such as thermal fatigue of the high-heat-flux components, AC losses of the adjacent PF coils, etc.
- Optimise blanket shielding design to minimise vacuum vessel activation.
- Tritium Breeding Ratio (TBR) sensitivity study.
- Investigation of magnetic field ripple: trade-off between RM access, coil size, and NBI access.
- Estimation of the minimum achievable dwell time and evaluate impact of trade-offs on central solenoid design, BoP, pumping, etc.

Emphasis of current work is on engineering and operational challenges that affect the physical layout of the in-vessel components, vacuum vessel and magnets and more in general the overall plant layout. These include: (1) the assessment of reactor relevant divertor solutions that consistently address the problems of power exhaust and associated first wall protection; (2) the definition and study of attractive remote maintenance schemes; (3) important safety analyses (e.g., in-vessel and ex-vessel loss of coolant accident) to understand the advantages and limitations of the current coolant candidates (i.e., helium and water), etc.