[redacted] and schedule to ensure that the [redacted] activities maintain coherence with the ITER exploitation and that there is adequate information from ITER and other supporting devices, to substantiate the DEMO design and physics basis at critical decision points whilst also respecting other external constraints and drivers on the schedule. This re-examination has also provided an opportunity to absorb lessons learnt from ITER in terms of project management, design maturity and the importance of a systems engineering approach to clearly establish system requirements, and manage systems integration during the Conceptual Design Phase. As such, the revised DEMO development strategy places strong emphasis on development of requirements, examination of systems integration aspects, traceable concept down-selection and assessment of design and project maturity through the implementation of a formal Gate Review Process.

This paper provides an overview of the development strategy, and also highlights the progress in the DEMO design and R&D activities since [2] in the Power Plant Physics and Technology (PPPT) Department of the EUROfusion Consortium by geographically distributed project teams involving many EU laboratories, universities, and industries in Europe. Section 2 provides an overview of the roadmap revision to adjust to the ITER delay, Section 3 describes the design approach. Section 4 describes the design choices under consideration. Finally, in Section 5 some of the recent technical achievements are highlighted.

2. Setting the DEMO ambition

2.1. DEMO in the EU roadmap

DEMO in Europe is considered to be the nearest-term reactor design [redacted] to follow ITER and capable of producing electricity, operating with [redacted] closed fuel-cycle and to be a facilitating machine between ITER and [redacted] commercial reactor. The main mission requirements of DEMO [redacted] Europe are summarized in Table 1.

It is a device which lies between ITER and First-of-a-Kind (Fo[redacted] Fusion Power Plant (FPP). In terms of where in relation to a power pl[redacted] it should be positioned, the Roadmap schedule sets the ambition [redacted] realize the DEMO objectives by the middle of this century – which h[redacted] strong bearing on this positioning. With this in mind, the overarc[redacted] principles of the DEMO development strategy include: (i) modest [redacted] trapolations from the ITER physics and technology basis to boun[redacted] velopment risks; (ii) robust design incorporating proven technologi[redacted] well as innovations validated through realistic R&D programmes; [redacted] safety features and design licencability by integrating lessons lea[redacted] from ITER licensing (and other existing nuclear facilities); (iv) a [redacted] cess orientated' approach of DEMO design development taking pla[redacted] parallel to ITER exploitation, but relying on design and physics [redacted] dation prior to construction; (v) harnessing the industrial base es[redacted] lished in bringing ITER to fruition.

Table 1
European DEMO goals [1].

- Conversion of fusion heat into electricity (~500 MWe)
- Achieve tritium self-sufficiency (TBR > 1)
- Reasonable availability/Several full power years
- Minimize activation waste, no long-term storage
- DEMO as a component test facility and pathfinder to a First-of-a-Kind (FoaK) Fusio[redacted] Power Plant (FPP).

[redacted] vised ITER schedule, as well as a gr[redacted] challenge' required to resolve al[redacted] architecture. These developm[redacted] DEMO development strateg[redacted] design activities will mai[redacted] that system integration[redacted] options are properly i[redacted] Engineering Design [redacted] ities.

The revised [redacted] production arou[redacted] pragmatic co[redacted] one hand an[redacted] on the oth[redacted] of DEMO[redacted] authoriz[redacted] of the [redacted] is the[redacted] ITER[redacted] the[redacted] O[redacted] i[redacted]

[redacted]

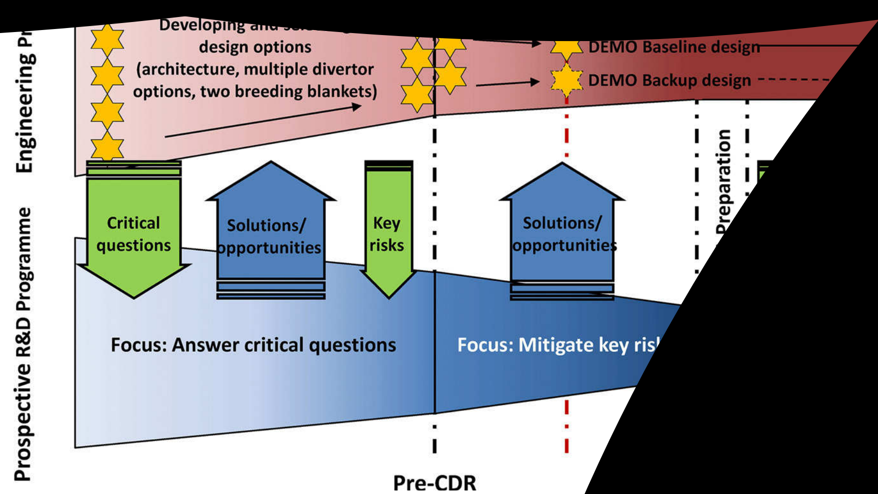


Fig. 1. DEMO staged-design [redacted]

Design Phase to mature and validate the baseline concept up to 2027; and (iii) an Engineering Design Phase beginning roughly around 2030[1] to develop the detailed design and prepare for the launch of major procurement activities.

Between each of the major phases, it is proposed that a phase gate review shall be carried out. A gate review is a formal review of all aspects of the project, including the evaluation of technical feasibility/ risks associated with the design, but also aspects concerning cost, schedule, safety and any other aspects of importance to project stakeholders. The purpose of the gate reviews is for the project stakeholders [redacted] to assess and determine whether continued investment in the project i[redacted] warranted, considering the balance of risk/reward, and to assess th[redacted] investment necessary to execute the subsequent phase of the project.[redacted]

Once a phase gate has been passed, the activities of the project must [redacted] reoriented to focus on the core scope of the next phase – the project shou[redacted] not be permitted to revisit or make major modifications to the design t[redacted] were not planned for that phase and should have been resolved in [redacted] preceding phase. The proposed schedule of the gate reviews curre[redacted] comprises a pre-CDR review in 2020 and a CDR in 2027. The activit[redacted] define the gate exit criteria is currently ongoing. Preliminary ideas [redacted] structured methodology for taking technical design decisions withi[redacted] ceptable schedule and cost boundary limits is described in [7].

2.3. Overview of pre-concept design phase

During the Pre-Concept Design Phase, the focus is on establishin[redacted] system requirements through a top-down systems engineering pro[redacted] identifying the main technical risk/feasibility issues, and assessing [redacted] potential of a number of DEMO candidate system architectures and [redacted] sign concepts to meet the requirements. The supporting R&D progra[redacted] aims to respond to the critical questions and feasibility issues raise[redacted] the initial investigation of the options under study. As can be obse[redacted] from Fig. 1, during this phase, studies will continue to be focused on [redacted] baseline concept in order to ensure a thorough examination of integ[redacted] tion issues and a level of coherence across the PPPT Work Packag[redacted] (WPs) (see Section 5). Fortunately, many of the integration issues a[redacted] common across alternative plant concepts and so the work carried o[redacted]

wil[redacted] pr[redacted] i[redacted]

[1] Note that there is also a period between the completion of the CDR to allow fo[redacted] consolidation of the concept design before commencing the Engineering Design Phase.

[redacted]

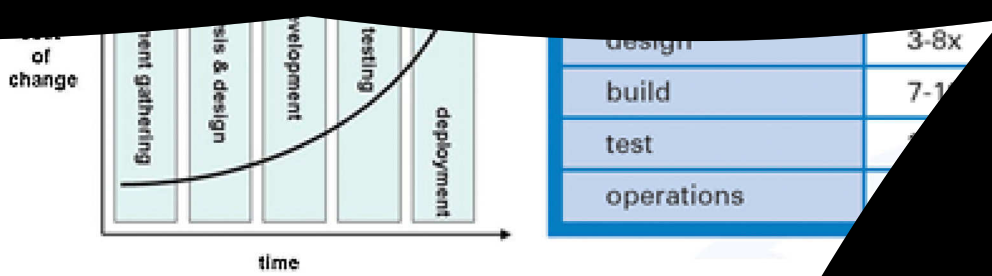


Fig. 2. Costs of change to a system increase significantly past the pre-conceptual design phase (req[redacted]

l) Building of relationships with industry and embedding industry experience in the design to ensure licensing, manufacturing and operational aspects are considered;

m) Preliminary cost estimates.

2.4. Overview of conceptual design phase

The objective of the Conceptual Design Phase is to bring the baseline concept to a complete integrated system design so that detailed assessments of technical feasibility, safety, licensing issues and life-cycle costs can be undertaken, and preparations can be made for major procurement and qualification activities foreseen during the Engineering Design Phase. It is paramount that system requirements and interfaces are validated to the extent that they can be frozen without a large risk of significant changes being required during Engineering Design Phase and procurement activities. The importance of validating requirements early in the programme, to avoid significant [redacted] and costly changes later is illustrated in Fig. 2 [8].

To build the basis for demonstrating safety objectives can be me[redacted] the systems and components that are considered safety related or in[redacted] portant for investment protection will be designed, and the plant [redacted] censing strategy will be established. To enable this, remaining decisio[redacted] on sub-system design & technology options, and the reference phys[redacted] scenarios must also be settled. Some of the key decisions that are [redacted] pected to be made in this period include; selection of divertor con[redacted] uration and first wall protection strategy; breeding blanket concept [redacted] coolant selection; remote maintenance (RM) strategy for in-vessel [redacted] ex-vessel components; H&CD mix selection and plasma operating [redacted] nario selection.

R&D work during this phase is expected to aim predominantly a[redacted] validation and maturation of critical technology elements, to esta[redacted] confidence that the technology assumptions that underpin the D[redacted] baseline design are feasible. Large scale qualification and licen[redacted] demonstrations of systems and components are mainly foreseen du[redacted] the Engineering Design Phase. Nevertheless, system level solut[redacted] upon which the plant concept is dependent should be validated du[redacted] the Conceptual Design Phase, to mitigate the risks of significant o[redacted] haul once Engineering Design or procurement activities have [redacted] launched. In particular, the Remote Maintenance (RM) strategy is [redacted] to be pivotal in the definition of much of the physical layout of the [redacted] vessel components, vacuum vessel, magnets and the plant layout a[redacted] buildings design. As there are strong implications on plant design a[redacted] major front-end loaded procurements, it is important that the propos[redacted] RM strategy is confirmed through test-rig and trial demonstratio[redacted] during the Conceptual Design Phase.

Finally, by the end of the phase, the concept design must be matur[redacted] enough to develop credible development cost and schedule estimate[redacted] for the subsequent Engineering Design Phase. The Concept Design [redacted]

Phase will cul[redacted] configuratio[redacted] Design Pha[redacted]

3. Des[redacted]

3.1. [redacted]

[redacted] high degree of complexity in the overall system; (ii) the holistic, emergent behaviour of a tokamak; (iii) the large uncertainties in terms of physics and technology performance on which much of the design assumptions depend; (iv) the high level of integrity required of a design that must be subjected to nuclear licensing scrutiny; (v) the need to demonstrate maintainability, and high reliance on remote maintenance.

It has been identified that the implementation of a systems engineering approach led by a strong Lead Systems Integrator (LSI) is essential for the managing the development and integration of complex systems with a high degree of risk and novelty [7]. The systems engineering approach is not limited to only considering requirements traceability but also encompasses considering the spatial and physical integration between systems and components. In this regard, it is seen as a priority to develop a baseline configuration of the physical plant layout, to better understand the spatial/physical integration aspects from an early stage, to identify integration issues and improve coherency between system requirements. Experience with ITER indicates that it is important to initiate this activity early, so that major integration issues can be identified and resolved before critical aspects of the design are frozen, or major procurement activities are launched.

This philosophy of developing systems designs in a holistic, integrated fashion is a fundamental principle of the systems engineering approach. The baseline systems architecture and plant layout 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.

3.3. *The role of industry*

Lessons learnt from comparable projects, have highlighted the im[redacted] portance of involving industry during the early phases of the desig[redacted] development – especially for complex nuclear infrastructures. For i[redacted] stance, Gen IV Programs have leveraged impressive industry suppo[redacted] and engaged with industry as a partner from the outset. Work c[redacted] ducted in PPPT industry tasks to date, and interactions with Gen[redacted] projects, the Fusion Industry Innovation Forum (FIIF) and the DE[redacted] External Stakeholder Group (ESHG), have highlighted a numbe[redacted] areas where harnessing of industry competencies can have signifi[redacted] impact during the conceptual phases in areas such as: (i) suppo[redacted] establishing systems and project management processes to delive[redacted] project; (ii) translation of experience in obtaining construction[redacted] operational licenses for nuclear infrastructures, as well as pre-qu[redacted] cation of components and systems; (iii) assessments of design[redacted] technology maturity and prospects for licensing; (iv) experience i[redacted] dustrial plant design and integration; (v) development of concept[redacted] major components and systems that incorporate manufacturab[redacted] considerations; (vi) cost assessments.

Conversely, engaging industry in the DEMO design activities e[redacted] allows the possibility to build a familiarity within industry of the [redacted] ticular challenges associated with DEMO. Furthermore, it prov[redacted] some continuity for industrial suppliers in the interim period follow[redacted] completion of ITER procurements – but prior to the launch of ma[redacted] DEMO procurements – to maintain some interest and engagement[redacted] fusion. It also provides some opportunity for industry to steer the desi[redacted] direction, and encourages industry to participate not only as a supplie[redacted] but also as an important stakeholder within the project. Aligned to th[redacted] scope and strategy described above, a number of tasks have been u[redacted] dertaken with industry under the PPPT department. Some technica[redacted] highlights from these tasks are introduced in Section 5.

[redacted] gineering approach. Therefore, a [redacted] velopment strategy has been th[redacted] tecture that integrates all the [redacted] plant concept. This is not [redacted] design choices but rather a[redacted] to identify design/mater[redacted] fusion reactor systems[redacted]

Work continues t[redacted] a pulsed baseline [redacted] and resolve desi[redacted] native configu[redacted] Double-Null ([redacted] being studie[redacted] [10]) to ev[redacted]

The p[redacted] technica[redacted] ments [redacted] tritiu[redacted] betw[redacted] iou[redacted]

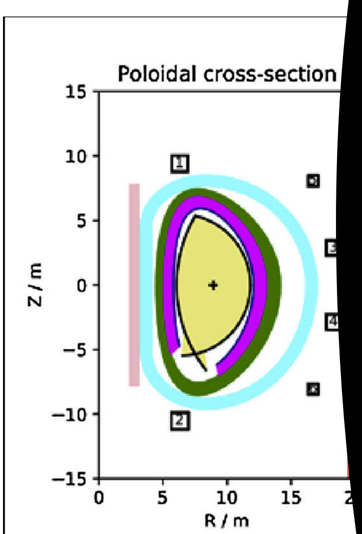
[redacted]

[redacted]

- Plasma current (MA)	18.0
- Elongation/triangularity (95%)	1.59/0.33
- Toroidal field, axis/coil-peak (T)	5.9/ > 12.5
- Auxiliary heating power – flat top (MW)	50
Performance	**Value**
- Fusion power (MW)	2000
- Electric Output (MW)	500
- Neutron wall loading (MW/m^2)	1.04
- Burn time (s)	7200
- Dwell time (s)	< 600
- Volt-sec capability/Volt-sec for burn (Vs)	728/365
- Loop voltage (V)	0.048
- $\beta_{N,tot}$	2.5%
- Av electron temperature (keV)	12.6
- Av. electron density/Greenwald density limit ($10^{20}\,m^{-3}$)	0.73/0.67
- Z_{eff}	2.2
- Plasma stored energy (GJ)	1.181
- Divertor challenge quantifier $P_{sep}B/qAR$ (MWT/m)	9.2

Table 4
Current EU DEMO design assumptions.

– Single-null water cooled divertor; PFC armour: W
– Low Temperature Super Conducting magnets Nb_3Sn (grading)
– B_{max} conductor ~12 T
– EUROFER for IVCs, AISI ITER-grade 316 for VV
– In-vessel RH: vertical (blanket)/horizontal (divertor)
– DEMO plant lifetime (design) ~7–8 fpy
– Neutron wall loading (average) ~1 MW/m^2
– Thermal conversion efficiency > 30%
– Tritium fuel cycle: self sufficient
– Blanket lifetime
- Starter blanket: 20 dpa
- Second blanket: 50 dpa
– Reactor availability: a scenario is assumed in which the availability of a DEMO plant during its initial years of operation (starter blanket) is relatively low and increases (in stage II) to about 30% or more.



(i) [redacted]

Fig. 3. (i) Elevation view of the tokamak as generated by PROCESS; (ii) Tok [redacted] (outboard); d) divertor; e) lover port; f) (equatorial port; g) upper port; h) to [redacted]

[redacted] certainties that bear a strong imp [redacted] kamak system and the design an [redacted] rounding the plasma. There [redacted] systematic treatment of unc [redacted] establish their impact on th [redacted] impact and converge tov [redacted]

4.2. Supporting studie [redacted]

A number of [redacted] technical chara [redacted] tions on plant [redacted] have been ca [redacted] studies tha [redacted] tional cha [redacted] its perfo [redacted]

- Se [redacted] p [redacted]
- [redacted]

[redacted] the subject of computer modelling using established safety codes [18]. Inventories of tritium and activation products, potential source terms for these postulated accidents, have been re-evaluated [19], supported by neutronics and activation analyses [20] and assessments of sputtering [21] and activated corrosion products [22]. Experimental studies are also being performed to validate some of the codes and models in use, where existing data is inadequate [23–26]. Other safety and environmental issues being addressed include the minimization of routine tritium releases during normal operation, by comprehensively identifying the potential sources, and seeking to minimize these and restrict their pathways for release. A provisional study of the potentially largest contributors to occupational radiation exposure is also in progress, with the aim of influencing design choices to minimize potential doses. All these topics, together with others, are chosen to address a full range of safety issues [27], and to ensure that safety is fully taken into consideration in the conceptual DEMO design.

- Preliminary assessments of radioactive waste have been performed, focused on the influence of design options on the quantity and classification of waste [28]. R&D has been launched on techniques for detritiation of solid waste, and on the feasibility of recycling, together with industrial partners.
- Extensive neutronic analysis to confirm the ability of the adopted design solutions to achieve adequate TBR, shielding and activation levels (e.g., see for example Ref. [14,28,29]).
- Preliminary studies to integrate auxiliary systems such as H&CD (EC, NBI, IC), fuelling and diagnostics systems. Aspects being analysed include: the opening in the breeding blankets and the impact on the breeding blanket segment design, remote maintainability, neutronics impact on the systems themselves and on other systems (e.g. shielding of the TF coils), safety [30].
- Global thermal-hydraulic analyses of the DEMO plant including th[redacted] blanket and Primary Heat Transfer System (PHTS) and provide a fa[redacted] design tool to optimize the thermal-hydraulic performances and [redacted] support accidental analyses and the dimensioning of the associa[redacted] systems (like the VVPSS) [31].
- Assessment of the plasma vertical stability and impact of ther[redacted] transients. In particular, it was found that the instability growth [redacted] strongly depends on the assumed plasma elongation (k_{95} = 1[redacted] and the distance of the plasma from passive structures, such as[redacted] vacuum vessel, which is the nearest toroidally continuous passi[redacted] conducting structure to the plasma [14]. The 3D effect of non[redacted] oidally continuous breeding blanket modules and ports, is also t[redacted] into account. The analysis of the vertical stability control indi[redacted] that for the current configuration the passive stabilization sa[redacted] controllability (m_s = 0.3, [32,33]). The active stabilization [redacted] evaluated on optimised equilibria, with reduced distance betw[redacted] the plasma centroid and the magnetic axis, which improved [redacted] decoupling between plasma perturbations and vertical moveme[redacted]
- Shorter dwell-times of around 10 min, achievable through q[redacted] recharge of the central solenoid and rapid vacuum pump-dow[redacted] the plasma chamber to 1 mPa prior to the initiation of the next p[redacted] and use of ECH assisted start-up, could have a beneficial impact [redacted] the minimization of the adverse effects of pulsing on the heat [redacted] changer and turbine. Initial results by modelling are encouragi[redacted] and the model used for the EC assisted breakdown is now bei[redacted] verified experimentally on the impurity conditions level relevant f[redacted] DEMO [14].
- As the heat loads in a fusion device are poorly characterized [34][redacted] and their impact to the design of the in-vessel components is very[redacted]

[redacted] a DN no additional Plasma Fa[redacted] would be needed on the top, [redacted] plasma stability control, a[redacted] wall contact areas. Howe[redacted] integration challenges [redacted] further investigated.

4.3. Preliminary plan[redacted]

A first DEMO[redacted] tion with AREV[redacted] needed to co[redacted] layout serve[redacted] a technical[redacted] sign. It e[redacted] technica[redacted] analys[redacted] kama[redacted] heli[redacted] lin[redacted] ch[redacted] p[redacted]

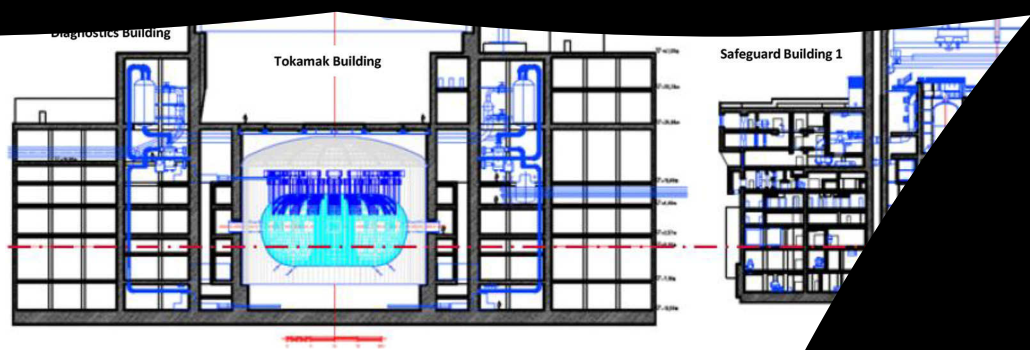


Fig. 4. DEMO Tokamak Building Complex (comp[redacted]

radius for different P_{sep}/R values for an SF divertor, taking into account achievable shaping and flux swing effects. The current baseline value is also plotted. It can be seen that $P_{sep}/R > 27$ MW/m—equivalent to radiating around 200 MW in the SOL and X-point, twice the conventional value—is required before the benefits of implementing an SF divertor become apparent. In addition, the increased X-point radiation implies a radiation load of up to 1.2 MW/m^2 on the first wall close to the divertor which must also be considered. In addition, plasma control to maintain the divertor configuration is also an underexplored area and almost certainly presents greater challenges than conventional (single- and double-null) short leg divertors.

A SN SX divertor has been found to only ameliorate the heat load at the outer target except using a DN SX configuration, which would substantially increase the magnetised volume of the machine. In the case of a SX configuration coils internal to the TF would be also re[redacted]quired, raising daunting feasibility and assembly issues of large super[redacted]conducting coils. Additional issues, include large divertor sizes an[redacted] larger TF coils, in addition to required positioning of PF coils in area[redacted] critical for RM of the divertor cassettes.

Albeit preliminary, the current work aims to provide a rapid [redacted]tegrated engineering assessment of the impacts of incorporating th[redacted] solutions into a DEMO design and provide targets for the performa[redacted] such configurations must achieve to be considered as viable and c[redacted]petitive for DEMO and future fusion power plants.

Considerations are also given to design a machine designed t[redacted]itially operate in a short pulse mode (e.g., 1 h), with conserva[redacted] physics assumptions, but that could move to steady-state operation [redacted] foreseeable improvements in physics and current drive, based on la[redacted]

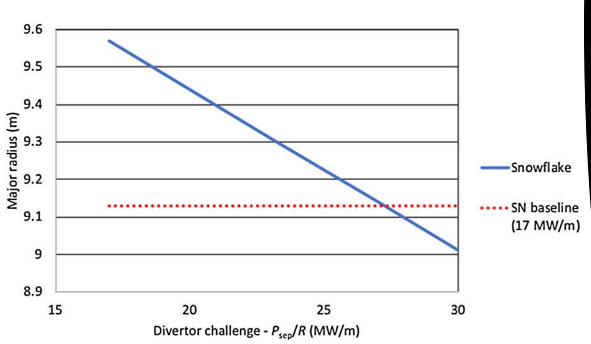


Fig. 5. Plot showing major radius as a function of divertor physics performan[redacted] (quantified as P_{sep}/R) for a snowflake divertor device targeting 500 MWe and[redacted] 2 h pulse length, taking magnet design, plasma performance, and additiona[redacted] space requirements into account. The dotted red line is the size of the ITER-lik[redacted] baseline design.

stage ITE[redacted] scope a[redacted] device[redacted] gain [redacted] cove[redacted]

du[redacted] s[redacted]

[redacted] nological extrapolation that can be considered for the DEMO breeding blanket. To minimize the risk to provide a system that cannot fulfil the goal to qualify a blanket to be used in a FPP, DEMO is envisaged to act as a “Component Test Facility” for the blanket. This means that while using a so-called ‘driver blanket concept’ (i.e., the near-full coverage blanket concept to be installed by day-1 to achieve tritium self-sufficiency and to extract the thermal power deposited mainly by the neutrons and convert this in electricity), it must be used to test and validate in properly designed and supported ports or segments more advanced breeding blanket concept(s) having the potential to be deployed in a FoaK FPP.

At the moment, four design options with different level of design and technology readiness are still considered as potential driver blankets within WPBB, utilizing helium, water, and LiPb as coolants and a solid or LiPb as tritium breeder/neutron multiplier [30,39]. The strategy is to arrive to the DEMO driver blanket down selection around the year 2024 [30] by taking into account design and R&D input obtained not only in the area of blanket, but safety, materials, BoP, remote maintenance, etc. This will enable a DEMO plant concept to be coherently designed for a design review by 2027. For both cases with helium and water as coolant, preliminary design layouts and performance analyses of the PHTSs, and Power Conversion Systems (PCS) are being studied taking into account realistic coolant pipes layout and the required mass flow rates (see below). This enables the estimation of the coolant inventory and the associated enthalpy, which together with the PHTS system segregation and layout are essential data for progressing safety analyses and for the design of key systems like the vacuum vessel pressure suppression system (VVPSS), which is an important safety-class component. An update of the progress on design and R&D is provided elsewhere [30].

ITER represents a first and unique opportunity to test [redacted] components and confirm/validate the choice of the breeding blanket [redacted] be installed in DEMO. However, to enable a consistent DEMO [redacted] struction decision in time, the TBM programme must include the [redacted] combination of design options regarding coolants, breeding [redacted] and technologies that could effectively minimize the technical [redacted] DEMO. To this extent, an assessment has been recently [redacted] Europe to review the choice of the TBM concepts to be tested in [redacted] particular, the possibility to replace one of the two He-cooled [redacted] water-cooled (WCLL) TBM is recommended in order to be able to [redacted] ITER both high temperature/high pressure coolants (helium and [redacted] and breeder materials (PbLi and ceramic/Be). Implementation [redacted] recommendation is still pending management approval. Currently, [redacted] is perceived to be the best strategy to minimize the remaining [redacted] risks and gaps to arrive to a consolidated design for the driver [redacted] blanket for DEMO. In parallel, vigorous materials irradiation [redacted] limited number of existing fission material research reactors and [redacted] mately in a DEMO-Oriented Neutron Source like IFMIF-DONES [redacted] quired together with the likely construction of a dedicated [redacted] blanket test facility for testing integrated multi-effect blanket [redacted] viour. A similar facility has been advocated in the US but has [redacted] been built [40]. A study is planned to determine the needs and [redacted] features of this facility and see whether existing facility used for [redacted] and qualifications of components in fission industry can be adapted [redacted] used.

5.2. Balance of plant (WPBOP)

Work is ongoing to assess the design, design integration and [redacted] nological problems posed by the PHTS for the breeding blanket [redacted]

[redacted] dimensions of main components [redacted] collectors); (ii) identify [redacted] commercial availability and [redacted] quirements and evaluate [redacted] addition, the pulsed [redacted] design problems on the [redacted] rently considered that [redacted] (burn time); the [redacted] for recharge.

An [redacted] Energy Storage [redacted] being [redacted] steam [redacted] the [redacted] work is [redacted] rect [redacted] power [redacted]

Table 5
Main issues of blanket coolants.

	Issue	HCPB	WCLL	Notes/assessment/optimization
PHTS	Circuit dimension	9 separated circuits	2 separated circuits (4 Loops)	The space required by HCPB is greater than for WC [redacted] number of loops, length of the pipes and turbomac [redacted] be deployed (e.g, circulators). Assumed circulator [redacted] construction Circulators of 5 MW).
PHTS Pumping power	Recirculating power requirements	130 MW	17.7 MW	HCPB has a huge pumping power and low level [redacted] blowers technology.
PHTS Length of Pipes	Dimension/layout integration/Inspection & Test/Cost	4 km (DN_max 1300)	1.7 km (DN_max 850)	High overall length of PHTS (especially for HCP [redacted] integration issue and leads to an increase of Tok [redacted] Impact also on inspection and testing requireme [redacted]
N_{16}, N_{17} in PHTS	Radiation doses in the area where the PHTS is localised	No issues	Relevant issue	WCLL needs shielding and accurate layout of P [redacted] equipment (e.g. I&C) to prevent significant radi [redacted] plasma operation.
[redacted]	[redacted]	[redacted]	Reasonable (≈ 500 m^3)	Analyses on going for HCPB to investigate the po [redacted] partially such volume through a wet EV; ii) use [redacted] Maintenance Facility area or some area of the to [redacted] expansion volume; and (iii) use of isolation val [redacted] inventory lost in the event of an accident is also [redacted] WCLL is expected to require larger EV for Ex-Ves [redacted] becomes reasonable if provision are adopted to [redacted] [redacted]sed in the containment as in NPPs. [redacted]CPB - The use of isolation valves to redu [redacted] [redacted]f an accident is also under investi [redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]rgy storage system (direc [redacted] [redacted]stry. Possible solution [redacted] [redacted] motorization of [redacted] [redacted] enthalpy.
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]mensions [redacted] [redacted]der [redacted]

[redacted]
during the concept design phase. The most significant risks remain those related to the control of the large, relatively flexible, in-vessel components and the challenging in-bore welding and inspection of service pipes.

As the RM system has developed, three different transfer strategies have been proposed [53]. In the first strategy separate casks are transferred to the vertical port to deploy and remove remote handling systems and components. In the second, a vertical transport cask remains docked to the vertical port throughout the maintenance process and smaller casks are docked to the transfer cask to deploy and remove remote handling systems and components. Currently, the remote handling systems and components are transferred through a hot-cell above the reactor. The conclusion of this work is that, by eliminating casks from the maintenance strategy, there was a significant reduction in the time taken to complete a DEMO maintenance campaign, because it eliminates the time taken to dock and undock the casks which is often on the critical path for the maintenance operations [54]. Development of the Active Maintenance Facility design to reflect the latest transfer strategy has also shown that the reduction in the number of transfer casks significantly reduces that storage space required in the facility.

The maintenance duration estimate was developed in conjunction with a Reliability Availability Maintainability Inspectability (RAMI) assessment based on the sequence and durations from the duration estimate. It considered the availability of the Blanket Handling RM System equipment and procedures to indicate the impact of reliability and down time on the time to perform the blanket exchange. It concluded that the availability of the 2015 design, implemented with high reliability equipment is ~94%, however, to achieve this a significant investment is required, with most of the downtime caused by the [redacted]
cutting and welding operation and the consequence of the long [redacted]
duration following drops, slipping and collisions of heavy loads. [redacted]
suitable RAMI IT codes were also identified; 'FlexSim' and [redacted]
Simulation'.

To achieve high availability the maintenance strategy in DEMO [redacted]
need to develop robotics and autonomous system to allow multiple [redacted]
multaneous operations that achieves state of the art assembly [redacted]
efficiencies. Early assessments for how this might be achieved [redacted]
into consideration such things as; nuclear safety, component design [redacted]
the impact on the plant layout are underway.

Three concepts for the Divertor Cassette Mover have been [redacted]
oped and compared along with designs for the fixation and [redacted]
bonding tooling and work is underway to integrate the pipes, [redacted]
mover and vacuum pumping systems in the divertor port. The [redacted]
sion of this work is that the current tokamak configuration [redacted]
allow practicable RM solutions, which are efficient and [redacted]
The work on the Adaptive Positional Control System has been [redacted]
with further research into state-of-the-art techniques for [redacted]
systems that deform significantly under load [55,56]. A first test [redacted]
system will be conducted in 2018 using the JET ex-vessel RM [redacted]
ment system: TARM (Telescopic Articulating Remote MAST), which [redacted]
been transferred to the Remote Application in Challenging [redacted]
ments (RACE) building and work is underway to recommission [redacted]
system with updated control hardware.

5.5. *Tritium fuelling and vacuum (WPTFV)*

The design of the DEMO Tritium Systems is developed [redacted]
the following guiding principles [57,58]: (i) full application of the [redacted]
rect Internal Recycling concept leading to two continuous re-cycle [redacted]
in addition to an outer loop with classical isotope separation and [redacted]

[redacted]
protection and dose minimization [redacted]
conditions.

As for the concept [redacted]
systems, the main [redacted]
chanical pump train at the [redacted]
for operation for the [redacted]
2018–2020. This [redacted]
bination of a vapour [redacted]
operated with a [redacted]
first complete [redacted]
acterization [redacted]

In the [redacted]
pellet [redacted]
much as [redacted]
system [redacted]
the [redacted]

The [redacted]
are [redacted]

[redacted] approach is that it allows for the [redacted] fabrication tolerances throughout the manufacturing process. The study resulted in the adaptation of the VV design concept to the fabrication including the requirement for full volumetric inspection. The developed DEMO VV design requires only 2D-formed sheets, which can be formed via the common forming processes rolling and bending, no expensive 3D-formed sheets are required. The developed fabrication concept for the inboard wall reduces significantly the amount of welds. These and other special solutions contribute to a fabrication- and examination-friendly design, which will eventually ease regulatory inspections, reduce cost and manufacturing risks and provide the basis for achieving precise manufacturing tolerances.

6. Concluding remarks

The demonstration of production of electricity around the middle of this century in a DEMO fusion plant that demonstrates a closed tritium fuel cycle represents the primary objective of the fusion development programme in Europe. The approach followed in Europe to achieve this goal is outlined in this paper together with a preliminary description of the design solutions being considered and results of the R&D programme. This includes:

- Modest extrapolations from the ITER physics and technology basis to minimize development risks.
- An integrated design approach to understand 1) the requirements and 2) the interactions of systems in context, and develop a coherent integrated DEMO concept design.
- Evaluation of multiple design options and parallel investigations fo[redacted] systems and/or technologies with high technical risk or novelt[redacted] (e.g., the choice of breeding blanket technology and coolants, powe[redacted] exhaust solution and configuration, etc.)
- Design Phase Gate Reviews to effectively assess Design Maturit[redacted] System Design Readiness
- Emphasis on plant performance, design integration risks and [redacted] gineering and operational challenges arising from power convers[redacted] aspects and feasibility/reliability of the BoP together with the [redacted] levant impact on the interfacing systems, safety and remote m[redacted] tenance.
- Targeted technology R&D and sub-system design studies drive[redacted] requirements of the DEMO system and respond to critical de[redacted] feasibility and integration risks.

This differs from past approaches and represents an impor[redacted] change in the EU fusion community culture. In addition, it is impor[redacted] to recognize the importance of the gradual increase of the involver[redacted] of industry in the design and monitoring process from the early stag[redacted] ensure that early attention is given to industrial feasibility, costs,[redacted] clear safety and licensing aspects, and the strengthening of inte[redacted] tional collaboration to better exploit synergies and minimize dupl[redacted] tions.

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